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# DEVELOPMENT OF A NEW GENERATION OF TORNUM REX MINING GRAIN DRYERS AND THEIR DESIGN METHODS

***Abstract***

*The materials of the article analyze the problems and methods of drying grain in modern grain dryers. In recent years, the mixed-flow dryer has been the subject of many studies on drying efficiency, dryer control and productivity improvement. However, there is still a significant need for optimization in terms of energy efficiency and drying uniformity. In order to analyze the specific energy consumption and drying uniformity of the technological process, various thermodynamic conditions of the process were investigated, design solutions were investigated using numerical and experimental methods. Based on the results obtained and the aerodynamic analysis of air flows, the design of a new generation TORNUM REX series grain dryer was developed. Pressure losses, drying agent flow distribution and temperature distribution in the hot air chamber in a continuous grain dryer with mixed flow were investigated using CFD (Computational Fluid Dynamics). The flow in the dryer was considered as steady, laminar and turbulent. It is important that the grain is dried evenly, since uneven drying can lead to spoilage of the final product during storage. The graphic practical materials of the article provide the design of TORNUM REX shaft grain dryers, a general view of the movement of air flows in the REX series grain dryer, diagrams of air flow speeds in the grain shaft, a diagram of the distribution of air flows in the temperature spectrum in the REX series grain dryer, a diagram of the formation of the drying agent during mixing with recuperation air in the REX series grain dryer. It was found that different temperature distributions in the output sections can lead to improper drying or damage to the final product, which influenced the change in the design of the dryer. To reduce pressure loss and increase the uniformity of the flow entering the subchamber of the linear gas burner, a new design of the air mixing section and guide vanes in different designs of hot air chambers is proposed. This approach to modeling using CFD can be applied to new technological processes, as well as to evaluate and optimize already established conventional systems.*

**Keywords: grain drying, mixed flow dryer, CFD, air flow measurement, temperature distribution, technology.**

## Introduction

Usually, grain is harvested with a moisture content of 18-25% [1]. Therefore, post-harvest treatment in the form of drying is necessary to reduce the moisture content to 14%, as this ensures safe storage of grain. Typically, the amount of energy used to remove water by evaporation from the grain during drying exceeds 4.5 MJ/kg, while the amount of energy required to evaporate free water is only 2.3 MJ/kg, making the grain drying process energy-intensive [2]. Therefore, it is important to ensure that the drying process is as efficient as possible, while grain damage must be minimized.

In the current generation of continuous flow dryers, there has been an improper mixing of air currents in the hot air chamber. This causes significant fluctuations in temperature and flow distribution as air enters the grain drying column. Giner et.al. [3] A comprehensive mixed-flow grain drying model was developed that took into account two-dimensional air and grain flow patterns around the inlet and outlet ducts in the drying column. As a result, it was found that heating and drying of grain occur more intensively in the immediate vicinity of the air ducts located in the grain column. Thus, it is important to obtain an even temperature distribution to avoid overdrying of the grain near the air ducts.

Therefore, the design of the hot air chamber is desirable, which can ensure an even distribution of temperature in the grain column. Several studies have been conducted on airflow and temperature distribution in smaller drying systems, such as batch and chamber dryers [4, 5].

## Materials and methods

In the work, methods of mathematical modeling of the geometry of the grain dryer were used. A multipurpose calculation methodology has been formed, namely the area of solution, the method of the determining equation in which the fluid flow in this study is air in a stationary, compressed in a three-dimensional turbulent flow. The numerical calculation of the flow can be considered as mathematical formulations of the laws of conservation of fluid mechanics. Applying the laws of conservation of mass, momentum and energy, the basic equations of fluid dynamics; Navier–Stokes equation of mass and momentum [6]. To analyze the type of air flow, the method of modeling air turbulence was used [7], because the risk of turbulent air flows in the hot air chamber of the grain dryer is increased, which negatively affects the correct distribution of the drying agent in the volume and supply to the air ducts of the grain shaft of the grain dryer. To analyze the temperature front of air distribution, the formed expressions were solved numerically using the computer code ANSYS Fluent ver. 17.2. The accuracy of the numerical solution depends on how well the discrete equations reflect the initial partial differential of the equation. ANSYS Fluent applies the finite volume method to discretize partial differential equations and uses a non-checkerboard approach where variable values are calculated at the center of the cells [8]. To assess the consumption of thermal energy, drying uniformity and thermodynamic conditions of grain drying, a number of studies of the design of dryers were carried out using digital and experimental methods. A mathematical model based on CFD (Computational Fluid Dynamics) was developed, using the ANSYS® ICEM software product. [8]. The object of the study is the TORNUM REX grain dryer. The subject of the study was the process of drying grain.

## Literary review and formulation of the problem

### Design of continuous mixed flow grain dryers TORNUM REX

Engineering thought in the field of grain drying is constantly and dynamically moving forward. Recently, continuous dryers with mixed air flow have been highly rated for the most up-to-date performance and quality worldwide.

The secret of their popularity lies in the fact that the developed design of the grain column with special geometry allows the drying agent to penetrate through the grain layer evenly in different directions. This design allows you to achieve a uniform final grain moisture content with significant fuel savings, compared to grain dryers of other types.

The painstaking work of the development of grain dryers has led to significant results in improving the concept, which adds important new features that offer softer and more efficient drying, easier cleaning, lower energy consumption and excellent environmental performance. The next step in the development of grain drying technologies is the conceptually new grain dryer of the REX series (Fig. 1). It combines all the best created so far, and everything progressive offered by the market.

The grain dryers of the REX series embody a new concept of dryers - an improved design, the presence of new functions that provide softer and more efficient drying, ease of cleaning, less energy consumption and minimal emissions into the environment.

Today, continuous shaft dryers with mixed air flow are in the greatest demand. The secret of their popularity lies in the fact that the developed design of the grain column with special geometry allows the drying agent to penetrate through the grain layer evenly in different directions. This design makes it possible to achieve a uniform final grain moisture content with significant fuel savings, compared to other types of grain dryers. Such equipment allows you to effectively dry grain in any weather conditions.

An urgent issue in the operation of any grain dryer is energy consumption. Here it is important not only the problem of economic consumption of energy carriers, i.e. the consumption of a certain amount of them in order to reduce the moisture content of grain by 1 ton-percent, but also what type of fuel to use as an energy carrier.

The new generation grain dryers of the REX series are distinguished by the fact that they are adapted from the beginning to work with several different heat sources to choose from. REX series dryers are designed to work with each grain crop and are adapted for various energy carriers (natural gas, propane-butane, diesel fuel, biomass, etc.). In particular, wood chips or pellets (pel-

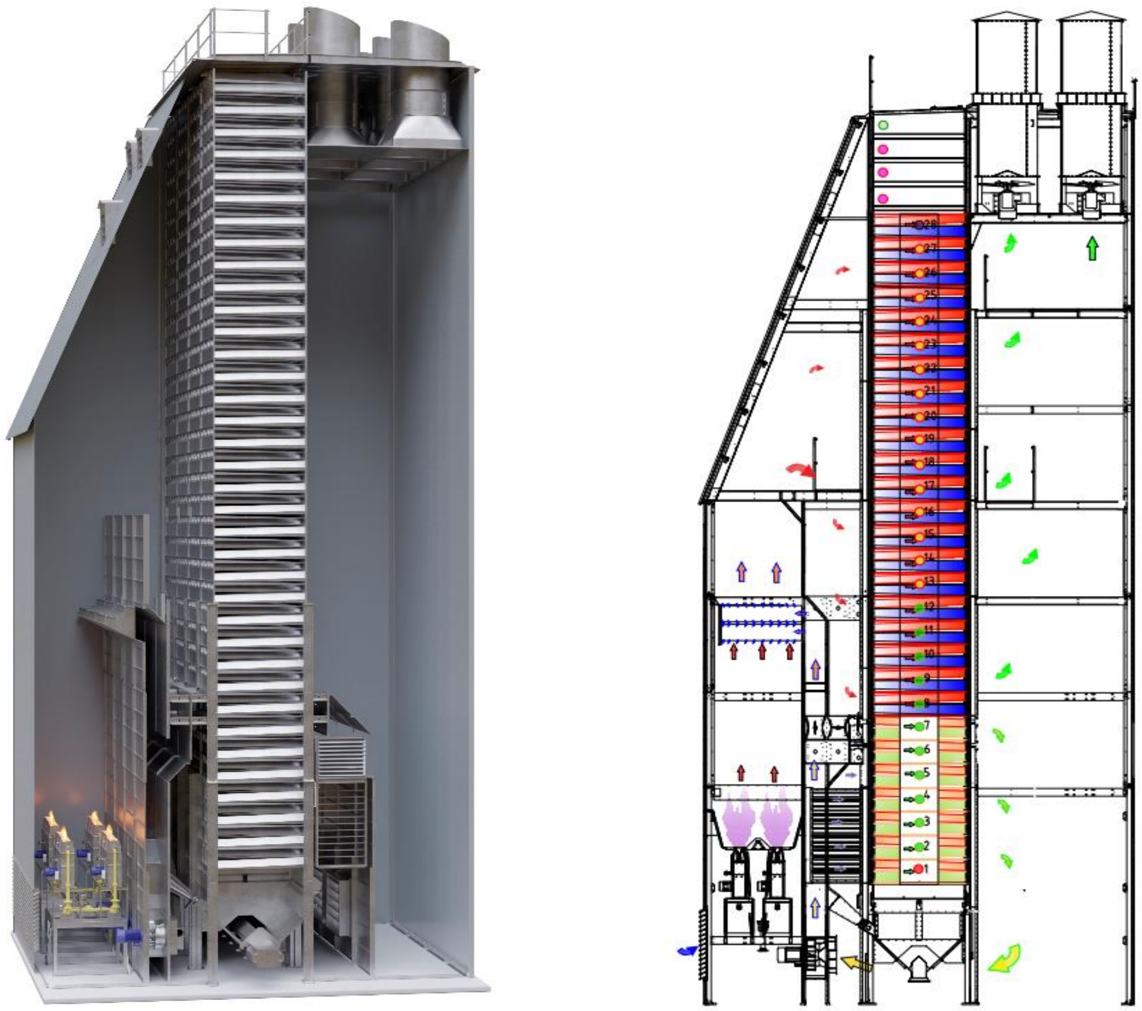

**Fig. 1. General view of air flows in the REX series grain dryer**

lets), which are a neutral source of carbon dioxide, can be used as biofuel in these machines. For those enterprises where there is hot water or steam, a heat exchanger for this heat source will be optimal. The equipment also minimizes grain dust emissions into the atmosphere. Additional functions are also provided to ensure higher efficiency of grain drying.

## Results of the study and their discussion

The dryers of the new REX series are the best solution for farms that are geographically located in regions with a cold climate. It uses the technology of economical drying of grain with preheating to avoid cracking, especially on corn. In the upper zone of the dryers there is a grain preheating chamber, passing through which improves drying and saves heat consumption in the main working area of the machine. Outside, the dryer is sheathed with sandwich panels with polyurethane (it has advantages over mineral wool), which perform the functions of thermal insulation, so it is possible to avoid heat loss. It also prevents condensation from forming on the inner walls of the equipment. The smooth, non-corrugated design of the inner walls does not allow dirt to accumulate on them, and this simplifies the maintenance of the dryer, because there is no need to clean them regularly.

The passage of grain through the preheating chamber improves drying and saves heat consumption in the main working area. The heat recovery function (rereturn of already heated air to work from the grain drying and cooling zone after drying) allows you to save enough thermal energy, and this reduces energy costs. More than 20% of the heat that is simply dissipated in a traditional grain dryer is returned to the system here.

One of the most important design tasks is the calculation of the differential pressure and air distribution in the hot and cold air chambers, as well as in the air duct systems of the grain column. This means that it is necessary to ensure an even distribution of the air flow over the entire width of the grain shaft of the dryer. This is especially true for high-performance dryers with a grain shaft width of 8, 9, 12 meters.

The use of the software product significantly improves the quality of system engineering, which leads to optimal, more efficient and reliable solutions in the design of grain drying equipment. For the user, this means that he receives a high-quality energy-efficient dryer that provides the declared drying performance, has low energy consumption, is safe and easy to use.

The principle of operation of this design is as follows: hot humid air from the dryer passes through the recirculation zone, and then mixes with heated air for cooling, Fig.1. After recirculation, it has a higher temperature (compared to using only fresh air), so it is possible to reduce the supply of energy to the gas burner. The exhaust fans at the top of the dryer also require less energy.

The built-in cyclone dust collector minimizes dust emissions, making it easier to comply with environmental regulations. In addition, upward-pointing axial fans reduce operating noise.

In recent years, the mixed-flow continuous grain dryer has been investigated many times by TORNUM engineers for drying efficiency, process control and productivity improvement. Also, considerable attention was paid to the optimization of the design in terms of energy efficiency and uniformity of drying of different grain crops.

In order to analyze the thermal energy consumption and drying uniformity, as well as the different thermodynamic conditions of this process, a number of design studies were carried out using digital and experimental methods. A mathematical model based on CFDs was developed, using the ANSYS® ICEM software product. [8]. The resulting model was used to calculate the distribution of air flow in the dryer when determining the geometry of the shaft air duct, hot and cold air chambers, Fig.2. The pressure drop in the grain volume and the distribution of airflow were simulated using mass, energy and pulse balance, taking into account the characteristics of the material layer, grain column geometry and drying kinetics. Using the ANSYS® CFX software, the airflow distribution was analyzed.

The main goal is to ensure uniform distribution of the drying agent in the grain layer to supply energy and take moisture from the grain surface, Fig.2. When designing the correct geometry of the box, namely the opening angle, the angle of change of geometry along the length, allows you to obtain the maximum effect of energy efficiency, the maximum percentage of saturation of the drying agent with moisture.

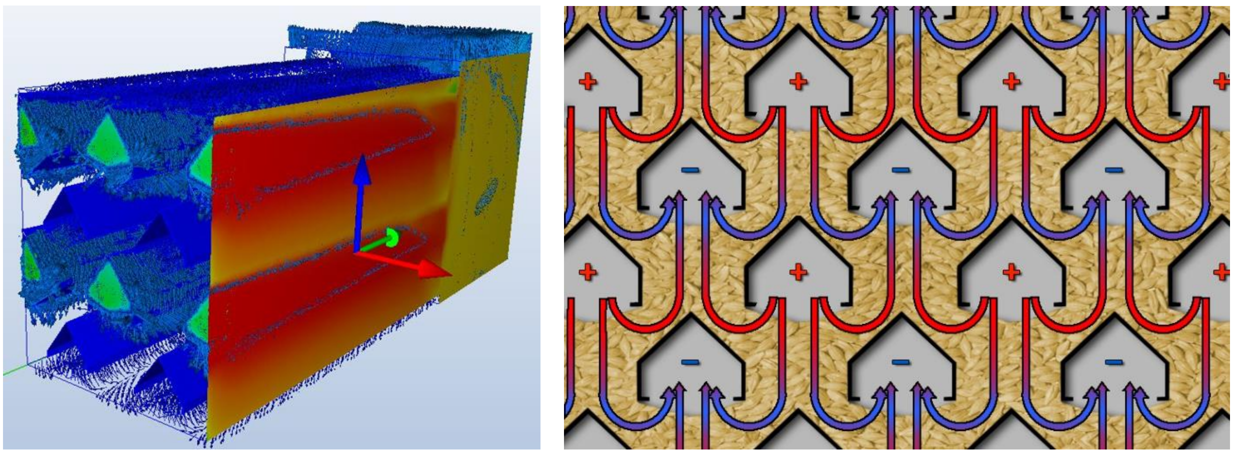

**Fig. 2. Diagram of the velocity of air flows in a grain column**

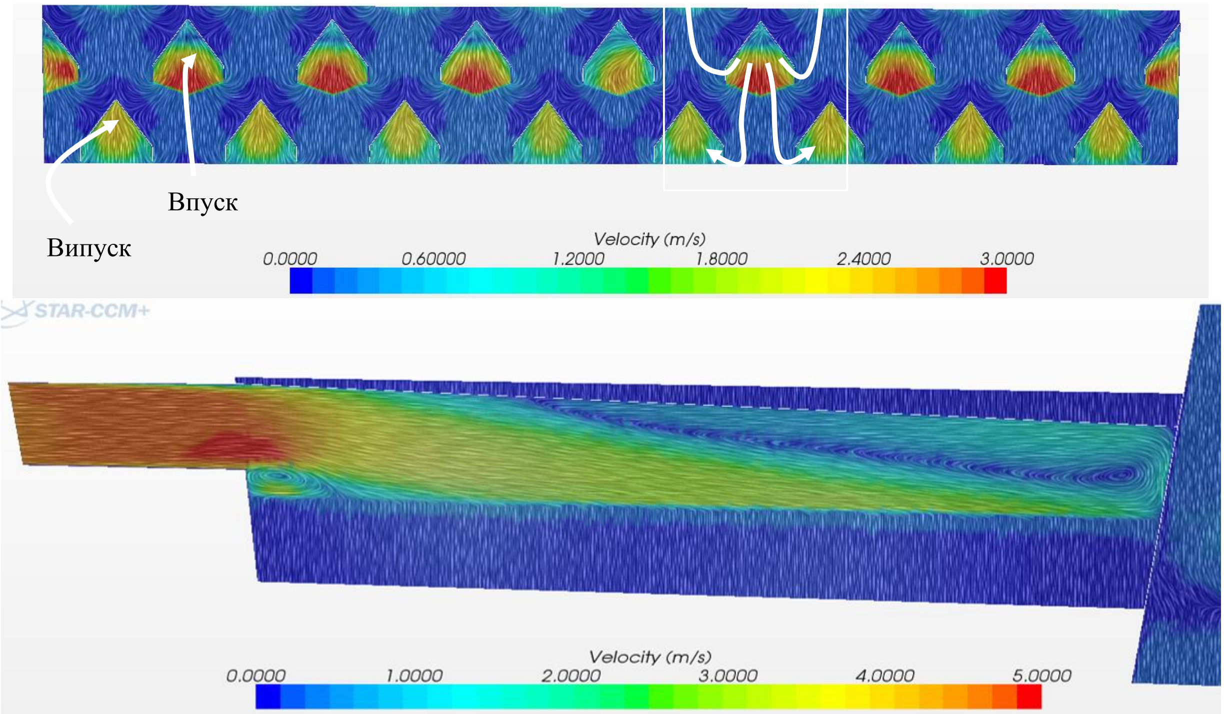


**Fig. 3. Diagram of the velocity of air flows in a grain column**

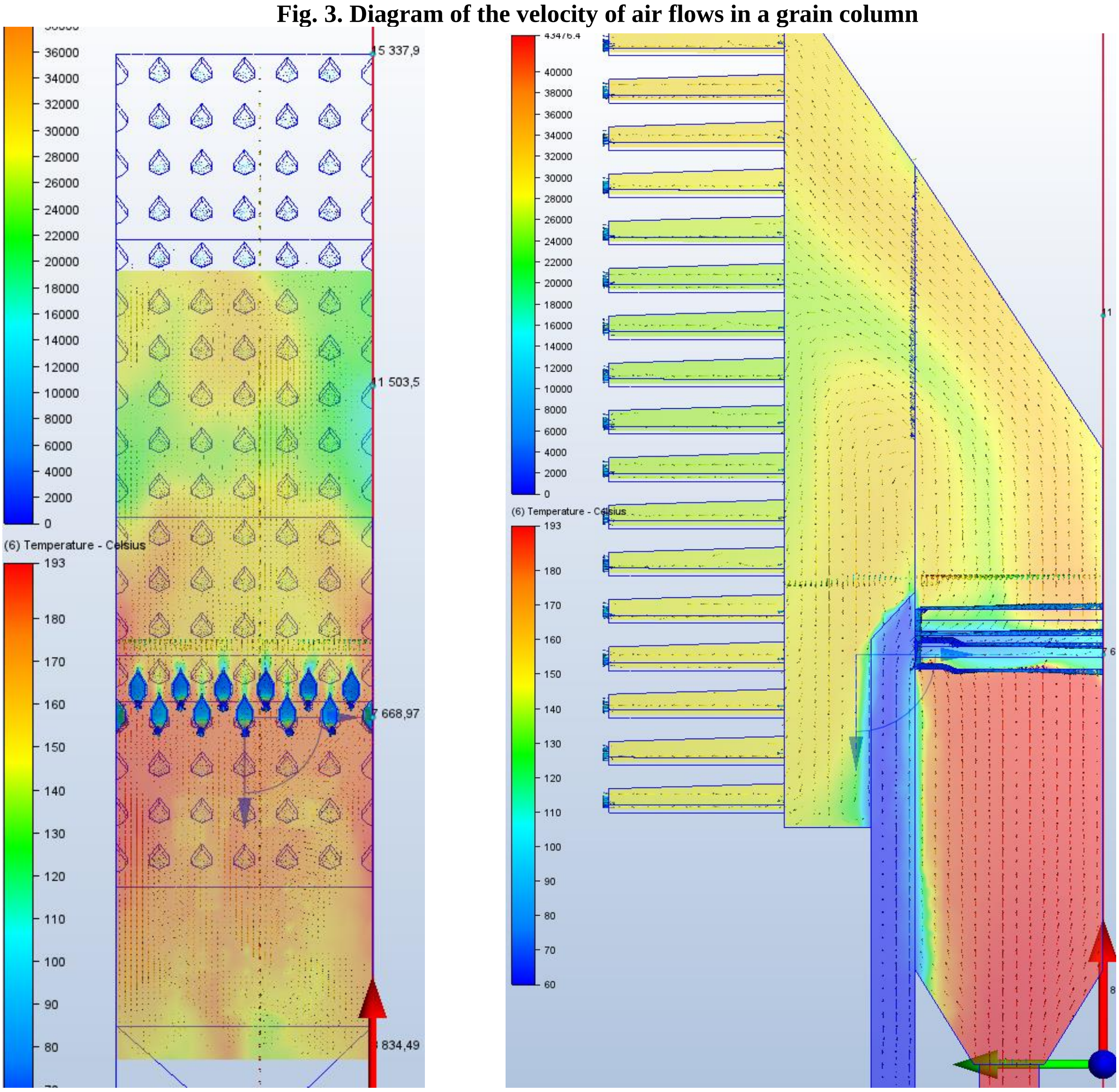


**Fig. 4. Diagram of the distribution of air flows in the temperature spectrum in the grain dryer of the REX series**

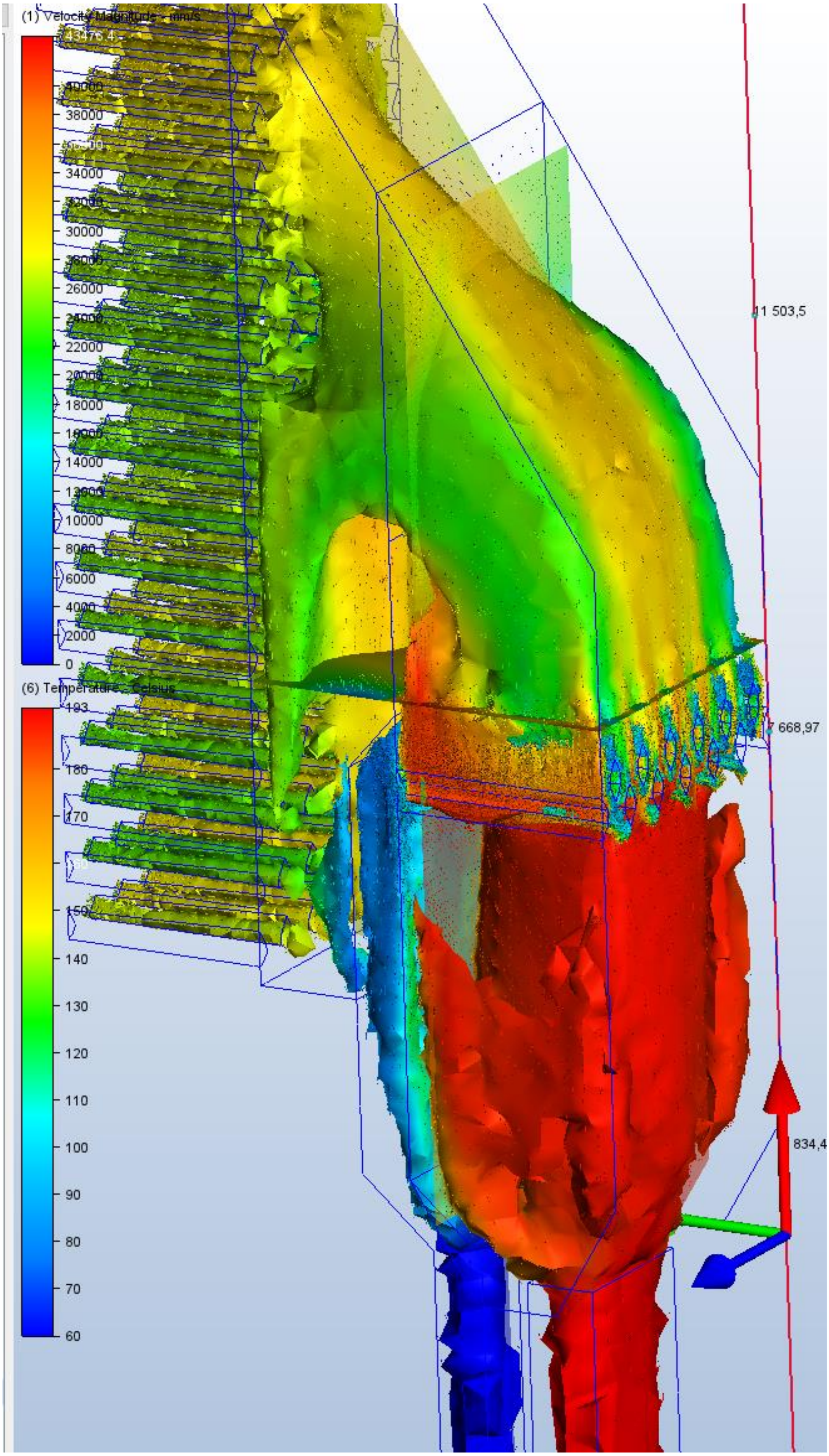


**Fig. 5. Diagram of the formation of a drying agent when mixed with recovery air in the REX series grain dryer**

When studying the longitudinal section of the grain dryer box for the value of the agent's velocity, values were obtained regarding the maximum speeds of entry and exit of the drying agent into the grain column. So from the diagram it can be noted that the speed is in the range of 1.5 -3 m/s ( Fig.3).

Accordingly, hot air passes through a thin layer of grain, which ensures uniform drying of the grain. When organizing the drying process of different crops, accordingly, there is a need to provide a different amount of air per 1 m3 of product, therefore, to implement this task, frequency control devices for the main fans of the grain dryer are used. At the same time, the level of rotation of the axial fans of the grain dryer is established by the calculated and practical method in accordance with the type of crops. The differential distribution of the amount of drying agent along the height of the grain shaft also plays a fundamental role in relation to the energy efficiency of the grain drying process, Fig.4

For example, corn grain, by its physical and chemical properties, is most sensitive to rapid heating, respectively, during drying at temperatures above +105°C, the greatest risk is temperature damage, during which there is darkening of the germ, damage to the outer shell, accompanied by grain quality, weight, and the percentage of combat during its transportation after drying. Under these conditions, a number of calculations and simulations were carried out during the creation of a series of REX grain dryers. The geometry of the air chambers of REX grain dryers allows the most correct distribution of air flows inside the equipment, creating directly favorable drying conditions, Fig.5

From the diagram, one can also note a very good mixing of air flows from the heat recovery zone and the main heated flow. The coldest air is in the middle of the dryer, the warmest is at the beginning and end of the drying zone.

Such studies make it possible to develop a perfect geometry of the structure, as well as to evaluate and optimize existing models of grain dryers from the point of view of the technological process. Based on the results obtained and the aerodynamic analysis of air flows, a new generation of the TORNUM grain dryer of the REX series was developed, which was presented to the world market at the specialized exhibition Agritechnica 2019 in Germany.

## Conclusion

The CFD (Computational Fluid Dynamics) model was developed to investigate the airflow in the hot air chamber of a newly designed mixed-flow continuous grain dryer. The main objective of the study was to simulate airflow and improve the mixing of recuperation and heated ambient air flows.

Given that different temperature distributions in the output sections can lead to improper drying or damage to the final product, various design changes have been analyzed to improve these parameters. The new design of the air mixing section has been developed to reduce pressure loss and increase the uniformity of the flow entering the sub-chamber of the linear gas burner. After successfully reducing the pressure loss, the new guide blades were implemented in various hot air chamber designs.

With the help of research and simulation data using CFD (Computational Fluid Dynamics), it is possible to develop new processes as well as evaluate and optimize already established conventional systems from a technological point of view.

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# РОЗРОБКА НОВОГО ПОКОЛІННЯ ШАХТНИХ ЗЕРНОСУШАРОК TORNUM REX ТА МЕТОДИ ЇХ КОНСТРУЮВАННЯ

***Анотація***

*В матеріалах статті проаналізовані проблеми та способи сушіння зерна в сучасних зерносушарках. Протягом останніх років сушарка зі змішаним потоком багато разів була предметом дослідження щодо ефективності сушіння, керування сушаркою та підвищення продуктивності. Проте все ще є значна потреба в оптимізації з точки зору енергоефективності та однорідності сушіння. З метою аналізу питомої енерговитрати та однорідності сушіння технологічного процесу, різні термодинамічні умови процесу були досліджені*

*конструктивні рішення за допомогою чисельних та експериментальних методів. На основі отриманих результатів та проведеного аеродинамічного аналізу повітряних потоків була розроблена конструкція зерносушарки нового покоління TORNUM серії REX. Втрати тиску, розподіл потоку агента сушіння та розподіл температури в камері гарячого повітря в зерносушарці безперервної дії зі змішаним потоком були досліджені за допомогою CFD (Computational Fluid Dynamics). Потік у сушарці розглядався як усталений, ламінарний і турбулентний. Важливо, щоб зерно було рівномірно висушене, оскільки нерівномірне сушіння може призвести до псування кінцевого продукту під час зберігання. В графічних практичних матеріалах статті наведено проектування шахтних зерносушарок TORNUM REX, загальний вигляд руху повітряних потоків в зерносушарці серії REX, епюри швидкості повітряних потоків в зерновій шахті, епюра розподілення повітряних потоків в спектрі температур в зерносушарці серії REX, епюра утворення агенту сушіння під час змішування з рекупераційним повітрям в зерносушарці серії REX. Встановлено, що різний розподіл температури на вихідних секціях може призвести до неправильного сушіння або пошкодження кінцевого продукту, що вплинуло на зміну конструкції сушарки. Для зменшення втрати тиску та підвищення рівномірності потоку, що надходить у підкамеру лінійного газового пальника запропоновано новий дизайн секції змішування повітря та направляючі лопатки в різні конструкції камер гарячого повітря. Такий підхід в моделювання з використанням CFD можна застосовувати у нових технологічних процесах, а також оцінювати й оптимізувати вже створені звичайні системи.*

**Ключові слова: сушіння зерна, сушарка зі змішаним потоком, CFD, вимірювання витрати повітря, розподіл температур, технологія.**

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# DEVICE FOR CALIBRATION OF THE PRESSURE SENSOR OF GRANULAR BULK MATERIALS

***Abstract***
*According to the plan for the implementation of the scientific and technical work "Experimental and theoretical studies of the influence of the roll of a vertical deep container on the distribution of horizontal pressure of granular bulk material on the walls of the container" (DR No. 0121U112518), which is being carried out at the Department of Mechanical Engineering of ODABA, for further research on the pressure distribution of bulk material, a pneumatic measuring system for measuring pressure of granular material on the vertical walls of storage models was developed. Pressure measurements are indirect – based on the absolute value of the movement of the sensor platform, which perceives the pressure of the bulk material, relative to the sensor body, the amount of pressure of the bulk material on the sensor was estimated. The system is multi-channel, each measuring channel consists of a bulk material pressure sensor, a channel for measuring movement of the pressure sensor platform and a recorder of this movement. The device for calibrating the pressure sensor is designed to obtain the calibration dependence of the output signal (the air pressure in the measurement chamber with pneumatic sieves) from the input signal (the value of the uniformly distributed pressure on the sensor). The device is two connected hydraulic systems filled with water. One of them consists of a pressure chamber with a flexible membrane through which the water pressure is transmitted to the sensor, and a measuring tube with a ruler to measure the water level above the membrane. The second one is a buffer tank*

TECHNOLOGICAL PROCE SSES, EQUIPMENT