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CFD SIMULATION OF AN INNOVATIVE SYSTEM FOR HEMP SEEDS DRYING

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Abstract: Obtaining a temperature and humidity gradient as uniform as possible during drying is important in obtaining quality dried hemp seeds. To this end, active control equipment for drying hemp seeds has been designed. The article aims to simulate the flow of hot air in the equipment with active control for drying hemp seeds in order to obtain the distribution of the field of velocities, temperatures and relative humidity in the hemp layer that is subjected to drying. The present study proposes an innovative concept in the construction of a polygonal dryer for hemp seeds harvested from experimental plots. By simulating the CFD (Computational Fluid Dynamics) of the innovative dryer for hemp seeds, in this paper we obtain 3D representations of the flow field of the drying agent within the technological drying process. In case of drying the hemp seeds that will be used for sowing, by simulating the dryer, optimal values of the working parameters (velocity and temperature) are obtained, in order to preserve the superior germination quality of the hemp seeds.
Keywords: numerical simulation, drying process, hemp

INTRODUCTION

The equipment is used for drying hemp seeds harvested from experimental lots. The technological system includes a support with 3 elements of perforated sheet that distributes heat, a metal housing that includes the constructive elements of the system, two sliding systems with plates positioned with linear guides and driven by two mechanisms screw–nut with hand wheel that allows unloading seeds in the tubs of two conveyor belts with squeegees and which have a discharge hopper provided with an adjusting device.

Many mathematical models have been developed to simulate the heat and the moisture transfer in aerated bulk stored grains (Amini, G., et al, 2021). The models were obtained at relatively low temperatures and low humidity to grain (Cârlescu P., Arsenoaia V et al, 2018). The models simulated forced convective heat and moisture transfer in vertical direction (Cârlescu P., Tenu I.,2018; Cârlescu P., Arsenoaia V, et al,2017), but the model was not validated (Chang,C. et al., 1994) and (Sinicio,R. et al., 1997) developed a rigorous model to predict the temperature and moisture content of wheat during storage with aeration(Guaita, M., Panero, L, et al,2021) and found that prediction result is in reasonable agreement with observed data (Thorpe, 2008) calculated on CFD models to a software that simulates heat and moisture transfer in the bad grain. Based model and simulation of (Thorpe, G.R., 2008; Muscalu, A. et al., 2016) developed and validated by experimental measurements of temperature transducers introduction the theoretical model at different points in a grain silo (Inada, K., Ohanna, P, et al, 2020).

Obtaining a temperature and humidity gradient as uniform as possible during drying is important in obtaining quality dried hemp seeds (Kenenia, Y.G., Hvoslef–Eideb, A.K.et al, 2019). To this end, active control equipment for drying hemp seeds has been designed. The article aims to simulate the flow of hot air in the equipment with active control for drying hemp seeds in order to obtain the distribution of the field of velocities, temperatures and relative humidity in the hemp layer that is subjected to drying (Muscalu A., Cârlescu P., 2018)

Knowing the temperature distribution in the hemp layer indicates the uniformity of heating and drying, respectively. By knowing the humidity profile of the intergranular air in the hemp layer, it is possible to optimize the flow and temperature of the hot air at the entrance to the equipment with active control for the drying hemp (*Wen–Bo, M., Yan–Yan, N, et al, 2021*).

MATERIALS AND METHODS

The active control equipment for drying hemp seeds is designed to achieve a gentle drying of the seeds to keep their germination power active. The CFD (Computational Fluid Dynamics) simulation was performed to obtain high–performance equipment in the drying operation.

The geometry of the equipment with active control was conditioned by the shape of the dryer chamber, being made with four regions of layer drying of hemp seeds, provided with three perforated distributors introduced in the layer with the role of drying uniformity and which are coupled to a central distributor. warm air. The lateral introduction of hot air into the drying equipment was imposed by technological conditions. The active control equipment for drying hemp seeds is shown in Figure 1, and the simplified geometry of the equipment necessary for CFD simulation and its composition is presented in (Figure 2).

The discretization of the geometry of the equipment with active control for drying hemp seeds is unstructured being performed with the Ansys–Gambit program (Figure 3). In the region of those distributors and the layer of hemp seeds subjected to drying, the discretization was performed with a larger number of knots. Discretization was performed with a sufficiently large number of volumes so that the accuracy of the results was not affected and the computation time was reasonable. The average number of nodes resulting from the discretization was 1,594,075, and the quality of the discretization was 0.7.

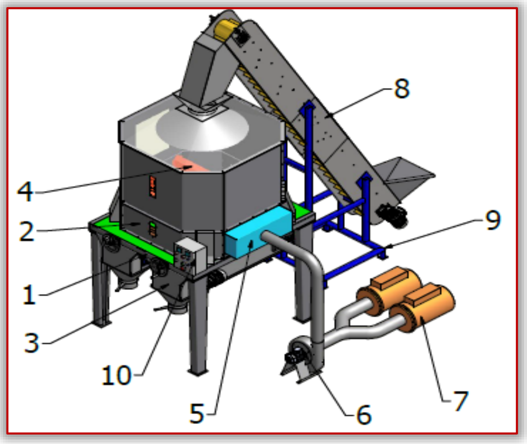

Figure 1 – Equipment with active control for drying hemp seeds:
1–support; 2–housing; 3–lane unloading; – drying cap; 5– hot air distributor; 6 – hot air fan; 7–hot air generator; 8–band seed transport; 9–support conveyor belt; 10–electrical panel for command and control

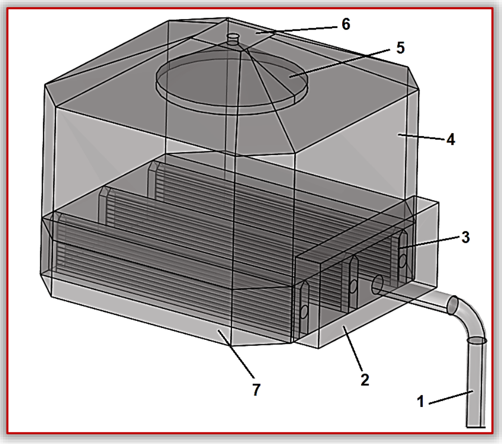

Figure 2 – Geometry of the equipment in CFD simulation:
1–hot air inlet duct; 2– central hot air distributor in the equipment; 3– perforated hot air distributor; 4– wall dryer; 5– cone distribution of hemp seeds; 6– used drying agent outlet; 7– layer of hemp seeds subjected to drying

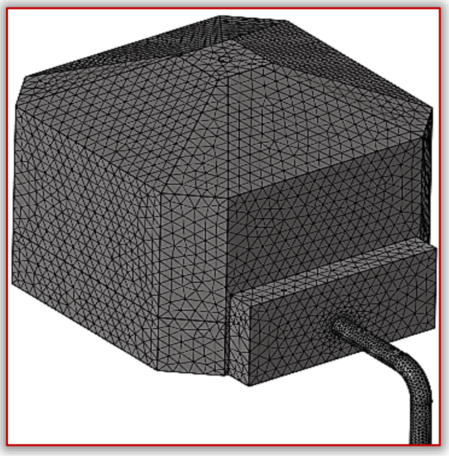

Figure 3 – Grid for geometry of the drying equipment

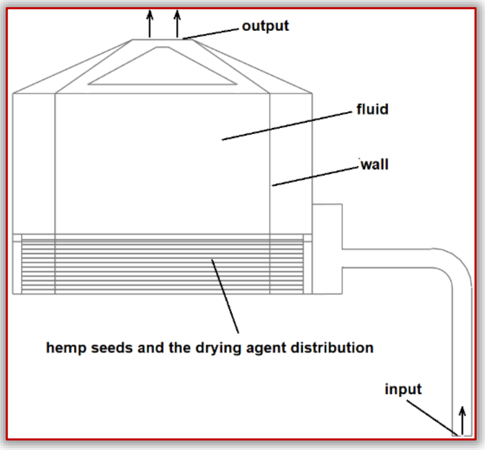

Figure 4 – Boundary condition for the CFD simulation

The discretization of the geometry of the equipment with active control for drying hemp seeds is unstructured being performed with the Ansys–Gambit program (Figure 3). In the region of those distributors and the layer of hemp seeds subjected to drying, the discretization was performed with a larger number of knots. Discretization was performed with a sufficiently large number of volumes so that the accuracy of the results was not affected and the computation time was reasonable. The average number of nodes resulting from the discretization was 1,594,075, and the quality of the discretization was 0. 7.

Table 1. Boundary conditions for drying equipment

Boundary sections	Boundary conditions
Inlet	velocity v=ct.; temperature T_a=ct; moisture X_a= f(τ)
Outlet	p=0
Wall	$\partial v/\partial n = 0$ (n – normal to the surface)
Volums	fluid (air)/solid bed (hemp)

Through the drying equipment, hot air flows from the central distributor to the three perforated distributors positioned in the hemp seed layer with the role of uniformizing the drying agent in the seed layer. In the CFD simulation processing stage, the conditions necessary for the calculation to determine the speed, temperature and relative humidity field inside the drying equipment were introduced. The conditions introduced are presented in Table 2.

Table 2. Processing conditions

v (m/s)	T_a(K)		X_a (Kg water/Kg dry air)	ρ_a (kg/m^3)	η (kg/ms)	C_{pa} (J/kgK)
	input	wall				
20	303.15	293.15	X_a= (τ)	1.225	$1.9\cdot10^{-5}$	1006

where: ρ_a density of air, η dynamic viscosity of air; C_{pa} specific heat of air, τ time for drying.
The absolute humidity of the air entering the drying equipment varies over time according to the function presented in Table 3.

Table 3. Function of entry into the drying equipment

X_a (Kg water/Kg dry air)	$X_a = -2\cdot10^{-12}\cdot\tau^2 + 6\cdot10^{-7}\cdot\tau + 0{,}0094$

The flow regime at the inlet of hot air into the drying equipment is laminar, being determined according to the

Reynolds criterion. The thickness of the layer of hemp seeds in the dryer is 400 mm, and the initial humidity of the seeds is 30%. The thermophysical characteristics of wet hemp seeds are introduced in the simulation as average values (ρp = 725 kg/m^3, Cpp = 1985 J / kgK, product conductivity K = 0.117 W / mK). The porosity index of the hemp seed layer is introduced in the simulation with the value of 0.3, considering the seed layer as homogeneous and isotropic. CFD simulations were performed in a non–stationary regime with a drying time duration of 7 hours. Drying simulation was performed with the DELL workstation (2XCPU–Intel Xeon 22 core 3.33GHz; 128 GB RAM DDR4ECC).

RESULTS AND DISCUSSION

The results of the simulation are presented in the form of the fields of speed, temperature, humidity and respectively the trajectory of the power lines in the simulation field of the drying equipment. The CFD simulation was performed both for the drying equipment without hemp seeds and with hemp seeds distributed in a uniform layer of constant thickness. The three–dimensional simulation of the hot air flow in the drying equipment without hemp seeds shows the field of the power lines with the variable temperature (Figure 5).

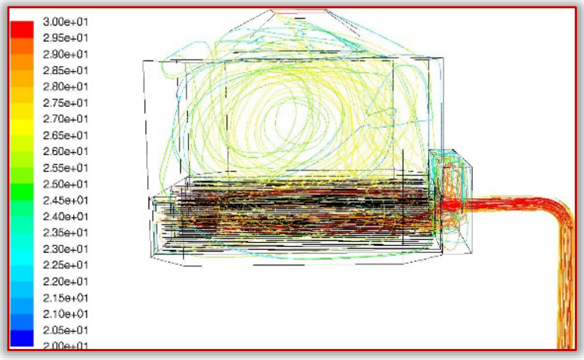

Figure 5 – The temperature pathlines of the warm air inside the drying equipment without hemp seeds

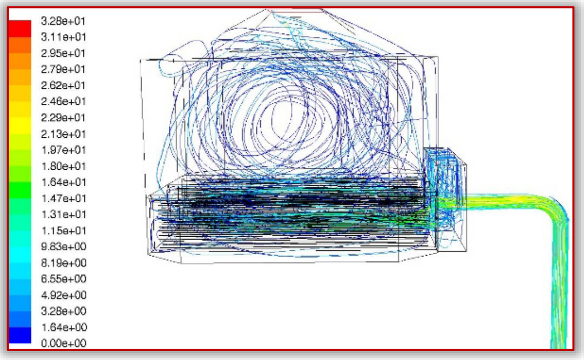

Figure 6 – The velocity pathlines of the warm air inside the drying equipment without hemp seeds

This distribution of the power lines shows the flow of hot air at the level of the seed layer, but without them existing in the layer, showing the speed distribution (Figure 6). The profile of the temperature and speed field in a YOZ plane in the middle of the seed drying equipment, without hemp seeds is shown in Figure 7 and Figure 8.

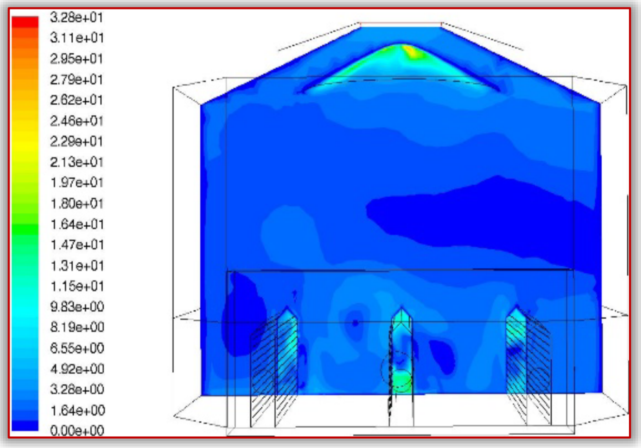

Figure 7 – Air velocity field in the transverse plane of the drying equipment (m / s)

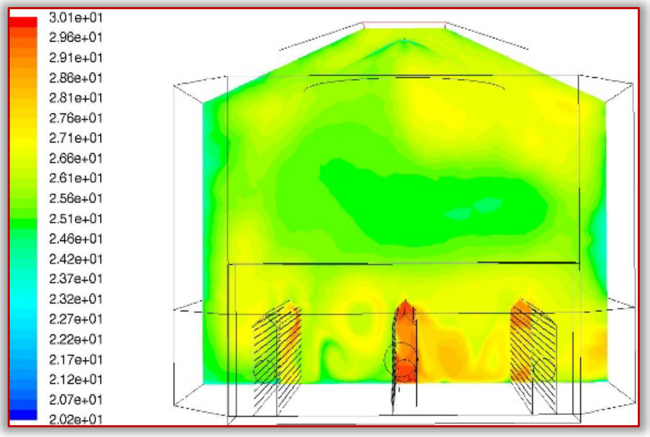

Figure 8 – Air temperature field in the transverse plane of the drying equipment (ºC)

From the figures of the distribution of the speed and temperature of the hot air in the equipment without seed layer, the non–uniformity of the distribution at the level of the seed layer region can be observed.

In order to verify the distributions of the temperature and relative humidity fields of the thermal agent inside the drying equipment, when a layer of wet hemp seeds was introduced inside, a new CFD simulation was performed.

By introducing a layer of hemp seed evenly distributed in height in the drying equipment, it is expected that the degree of uniformity of the drying agent temperature in the layer will increase due to the aerodynamic resistances of the seed layer with uniform porosity of 0.3, according to Figure 9, Figure 10, Figure 11, and Figure 12.

An improvement of the uniformity of the speed field of the drying agent in the seed layer also attracts an improvement of the uniformity of the temperature field with values between 24.8^{0}C and 27.1^{0}C. The decrease in the air temperature in the layer compared to the air temperature used as a drying agent (30^{0}C) occurs as a result of the drying process by removing moisture from the hemp seeds. Also, at the walls of the dryer was considered in the simulation a temperature of 20^{0}C. In practice, towards the end of drying the hemp seeds the temperature reaches approximately equal to the temperature of the drying agent.

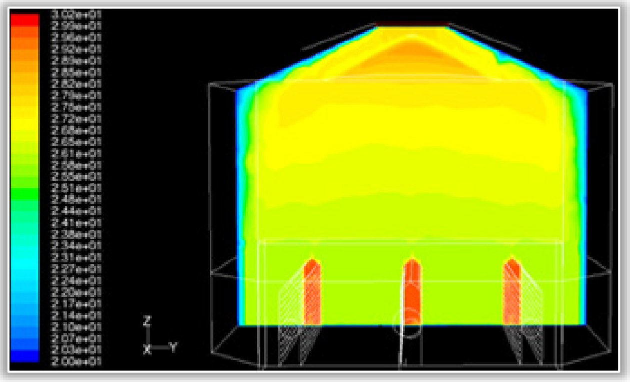

Figure 9 – Transverse plane (YOZ) air temperature field of hemp seed drying equipment (ºC)

The temperature field also varies on the vertical of the seed layer (Figure 10, 11, 12) so at the base of the layer the temperature has an average value of 25.8^{0}C, in the middle of the layer the temperature increases with the value of 27.1^{0}C, reaching as in the upper plane of the layer the temperature should drop to 24.8^{0}C. This temperature stratification is explained by the migration of moisture to the top of the seed layer which is finally removed by air to the top of the drying equipment.

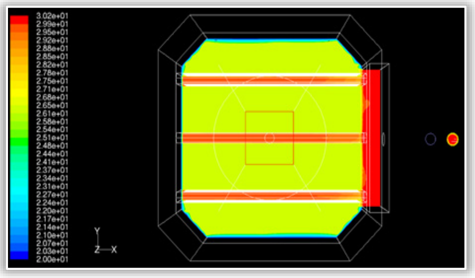

Figure 10 – Temperature field in the plane at the base of the hemp seed layer (ºC)

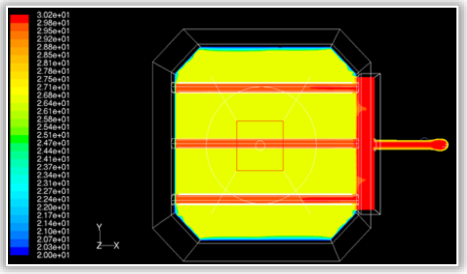

Figure 11 – Temperature field in the plane in the middle of the hemp seed layer (ºC)

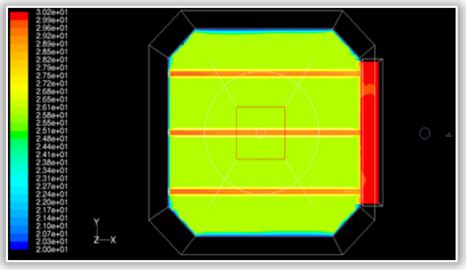

Figure 12 – Temperature field in the upper plane of the hemp seed layer (ºC)

In order to verify the air humidity gradient in the hemp seed state of the drying equipment, a new simulation was performed in which the technological parameters previously used to simulate the flow of hot air used as a drying agent were introduced. The results of the CFD simulation regarding the humidity field are presented in the XOY and YOZ planes, respectively, inside the drying equipment with hemp seeds according to Figure13 and Figure 14.

Following the simulation analysis in the drying process, the relative humidity distribution in the XOY plane in the middle of the hemp layer has higher values near the perforated distributors due to the more pronounced moisture loss of the seeds, the intergranular air reaching a relative humidity of up to 81.9%, in the center of the layer the air reaches a relative humidity of 67.1%, and in the wall area the humidity reaches 58.2% (Figure 13). Analyzing the relative humidity profile of the YOZ cross–sectional plane, it is observed that the distribution is kept high near the perforated distributors through which the hot air passes with a relative humidity of 37%, therefore the highest moisture loss of hemp seeds is near distributors and a lower loss in the center of the layer and near the walls of the dryer (Figure 14). During the drying of hemp seeds, this uneven distribution of the relative humidity of the air is directly reflected in the uneven moisture of the seeds in the layer, showing that in the middle of the layer and near the walls of the dryer the seeds lose moisture more difficult. As a result of the uniformization of the temperature in the layer (Figure 11) towards the end of drying, the humidity of the seeds in the layer becomes uniform at an average value of preservability.

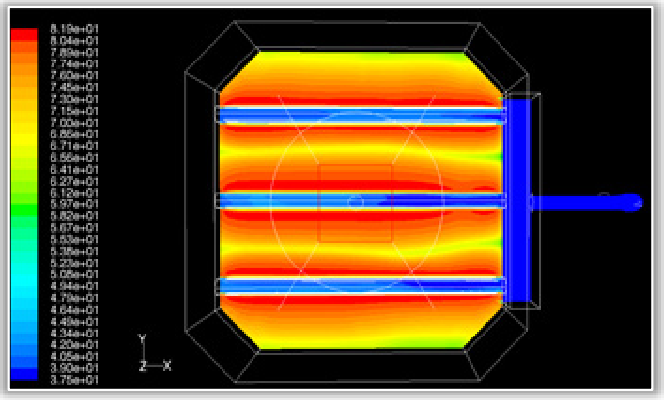

Figure 13 – The relative humidity of the warm air inside the drying equipment with hemp seeds in XOY plane (%)

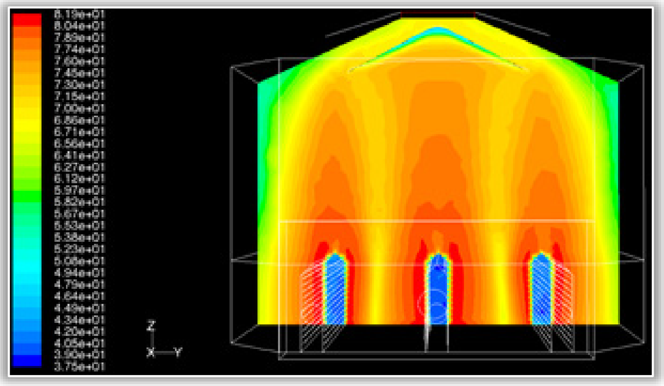

Figure 14 – The relative humidity of the warm air inside the drying equipment with hemp seeds in YOZ plane (%)

The CFD simulation of the active control equipment for drying hemp seeds requires a calibration by taking the experimental data from the drying equipment for the parameters of speed, temperature and relative humidity of the hot air at the equipment inlet, as well as by repeated determinations of temperature and humidity. on three different heights and between distributors in at least three points in the state region, both without and with a layer of seeds.

Also, in order to increase the accuracy of the simulated model, it is necessary to take samples at the end of drying the hemp seeds and to determine the humidity from different points of the seed layer by three repetitions.

The technological system includes a support with 4 elements of perforated sheet that distributes heat, a metal housing that includes the constructive elements of the system, two sliding systems with plates positioned with linear guides and driven by two mechanisms screw–nut with hand wheel that allows the unloading of seeds in the tubs of two conveyor belts with squeegees and which have a discharge mouth provided with a syringe. during the drying of the seeds then it opens to remove moisture and supply the seeds for a new drying cycle. The heat source is made with the help of two electric air heaters that ensure the optimum temperature of 28–30^{0}C and a flow of 2500 m^3 / time required for the drying process.

The seed supply is made with a scraper conveyor belt that is positioned and placed on a metal support. The electrical panel includes the controls for the feed conveyor belt, the unloading conveyor belts, the control of the high pressure centrifugal fan that ensures the necessary flow and control of the two electric air heaters. The fan speed is regulated with a frequency converter. For the temperature control inside the dryer is mounted a thermometer with electronic display. The humidity check is done with a special equipment for humidity control for cereal seeds. The entire technological process can be monitored and adjusted automatically with a process computer.

Technical data: inlet humidity: 25–30%; output humidity: 10–12%; warm air temperature: 28–30^{0}C; hot air flow: 2400 m^3 / hour–productivity: 500 Kg / batch; the system works in semi–automatic mode with a technological process computer for adjusting temperatures and air flow.

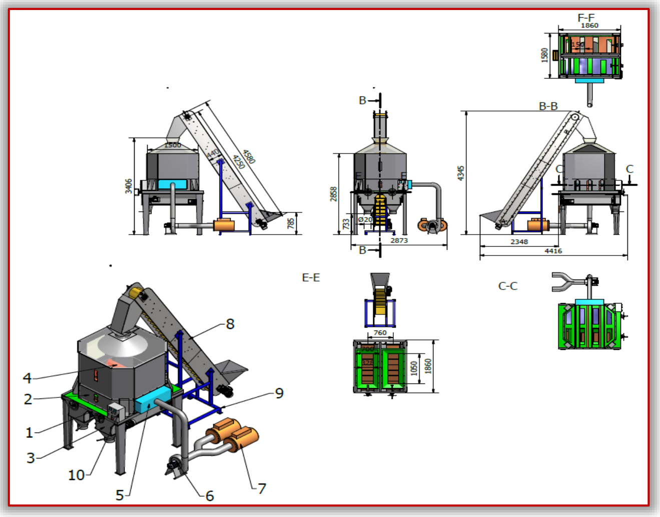

Figure 15 – Constructive diagram of the equipment

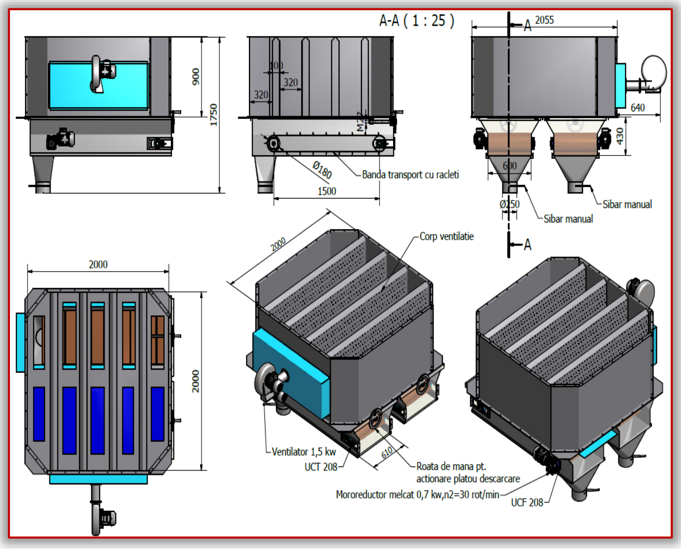

Figure16 – Dryer body

1 – Support; 2 – Housing; 3 – Unloading belts; 4 – Dryer cover; 5 – Hot air distributor; 6 – Hot air fan; 7 – Hot air generator; 8 – Seed transport belt; 9 – Conveyor belt support; 10 – Electrical panel for command and control

Technical advantages over known solutions:

- Compact construction that ensures uniform heat distribution in the entire number of seeds;
- Low electricity consumption due to the adjusting device closing system at the top of the dryer;
- Active control and automatic reclassification of the parameters during the technological drying process

CONCLUSION

The CFD simulation of the hot air flow through the active control equipment for drying hemp seeds can lead to the optimization of its constructive form.

By the constructive optimization, both the constructive shape of the box and the thickness of the layer of hemp seeds subjected to drying are obtained by following the temperature gradient correlated with the movement of the air inside the dryer.

The temperature difference obtained by CFD simulation in the hemp seed layer is 2.3 ºC, and the differences in relative humidity of the intergranular air in the seed layer is 23.7%.

By calibrating the CFD simulation with experimental predetermination, a drying equipment with optimal technological performance for drying hemp seeds is obtained.

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