DEVELOPMENT OF THE AERODYNAMIC DRYING METHOD FOR THE CHOPPED VEGETAL MASS / *ELABORAREA METODEI DE USCARE AERODINAMICĂ A MASEI VEGETALĂ TOCATĂ*

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ABSTRACT
The article presents the theoretical study and elaborates the calculation methodology of the technological and constructive parameters of the aerodynamic dryers: the saltation speed of the vegetal mass particles, the speed of the thermal agent flow, the length of the dryer pipes and the duration of the moist particles contact with the thermal agent. The comparative analysis of the aerodynamic dryers was performed: with direct and vortex flow. The advantages of vortex dryers, recommended for implementation in production, are theoretically argued. In the research of the developed conical shape dryer, it has been identified a phenomenon of vortex flow parameters self-regulation to the material to be dried inside the dryer, under the condition of varying the amount of material feeding the dryer, allowing automatic creation of optimal drying conditions, when the supply of raw material and/or its humidity were changed within the studied limits. It has been demonstrated the possibility to increase up to 12-15 times the duration of contact of the raw material particles with the thermal agent and, respectively, to reduce the overall dimensions of the developed vortex dryer, compared to the known ones, which have direct air flow.

REZUMAT
In acest articol este prezentat studiul teoretic și elaborată metodica de calcul a parametrilor tehnologici și constructivi ai uscătoarelor aerodinamice: viteza de flotație a particulelor masei vegetale, viteza fluxului agentului termic, lungimea conductelor uscătoarelor, durata contactului particulelor umede cu agentul termic. A fost efectuată analiza comparativă a uscătoarelor aerodinamice: cu curentul direct și turbionar. Sunt argumentate teoretic avantajele uscătoarelor turbionare, recomandate pentru implementare în producție. În procesul cercetărilor uscătorului de forma conică elaborat, a fost identificat un fenomen de autoreglare a parametrilor fluxului turbionar cu materialul supus uscării în spațiul interior al uscătorului, în condițiile varierii cantității de materie primă care alimentează uscătorul, ceea ce a permis crearea automată a condițiilor optime de uscare, atunci când a avut loc schimbarea dozei de alimentare a materiei prime și/sau a umidității acesteia în limitele studiate. S-a demonstrat posibilitatea majorării de până la 12-15 ori a duratei contactului particulelor de materia primă cu agentul termic și respectiv, micșorării dimensiunilor de gabarit ale uscătorului turbionar elaborat, în raport cu cele cunoscute, care au curentul de aer direct.

INTRODUCTION
Specialists in the world economy pay increased attention to biomass drying technologies, with the aim of conditioning the raw material, which in most cases consists in reducing humidity by up to 8-12% (in this case and further on considered relative humidity). It should be noted that the humidity of the raw material in the initial phase can far exceed the required level. For example, tree branches after cutting have a humidity of up to 50%. For economic reasons, reducing the high humidity of the vegetal mass is most rational to be achieved under natural conditions, using solar energy, removing most or all of the excess moisture (*Ericsson and Werner, 2014; Iftekhar et al., 2017*).

The final value of the moisture of the dried vegetal mass under natural conditions depends a lot on the humidity of the surrounding air. The porous material of the vegetal mass has the property of removing or absorbing water vapour from the surrounding air, obtaining the so-called equilibrium humidity. The dependence of the equilibrium humidity values of the wood material (fig.1) (*Ivanov, 1956*) demonstrates that, for example, at the ambient air temperature t_a = 25ºC and its humidity φ_a = 85% (real values for the climate of Moldova) wood can be dried under natural conditions up to a minimum humidity of 18% (point A in fig.1). Therefore, in order to obtain the raw material in accordance with the technological requirements, it must be further dried under artificial conditions.

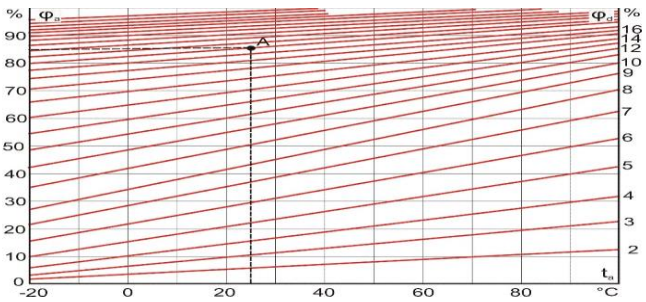


Fig. 1 - Humidity of wood particles φ_d as a function of temperature t_a and humidity φ_a of the atmospheric air
(*Ivanov V., 1956*)

Of all the variety of artificial drying methods and installations (*Gavrilencov et al., 2014)* the most promising, in our view, is convective aerodynamic drying, in which the thermal agent (air or an air mixture with flue gas), in addition to performing the base function, it also performs the transportation of raw material particles, simplifying the construction of the dryer. At the same time, the use of flue gas as a thermal agent increases the efficiency of the dryer.

In the typical technological process (fig.2) the aerodynamic drying of the chopped vegetable raw material is performed with the use of flue gas, produced by the thermal generator *1*, in which different fuels can be used for combustion. To decrease the flue gas temperature from 500-700ºC to 150-300ºC, they are diluted with fresh air using the temperature regulator *2* (*Gavrilencov et al., 2014; Hăbășescu et al., 2015; Hăbășescu et al., 2016b*). Moist raw material is further introduced into the mixture of fresh air and flue gas using the mixer *3*, which moves in the direction of the aerodynamic dryer *4*. From the moment of contact with the thermal agent, water vapour is extracted from the raw material due to heat convection. The dried particles of the raw material (φ_d = 8...12%) are conveyed by the thermal agent into the cyclone *5,* where they separate from the thermal agent with high humidity and are transported for further processing. The thermal agent used is discharged into the atmosphere by means of the suction fan *6*, which at the same time ensures the required amount of fresh air in the burner (heat generator) *1*.

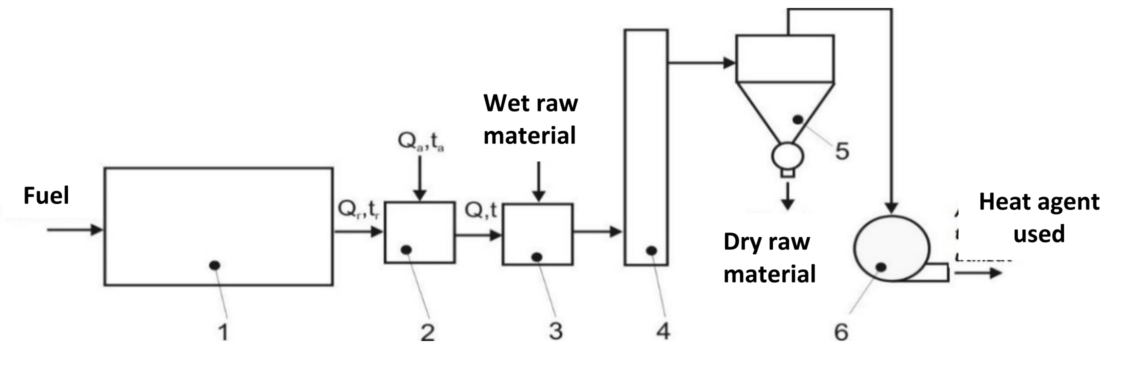


Fig. 2 - Scheme of the technological process of the chopped vegetable mass aerodynamic drying using flue gas
1- thermal generator; 2- device for regulating the temperature of the flue gases; 3- mixer;
4- vertical aerodynamic drying pipe (dryer); 5- cyclone; 6- fan

In some versions of placing the components of the drying equipment, the fan *6* is installed between the dryer *4* and cyclone *5*. In this case, two phenomena occur simultaneously: the positive one (increased pressure in the cyclone, which improves the operating conditions of the shutter) and the negative one (intense abrasive wear of the fan blades).

The incontestable advantages of the aerodynamic dryers contribute to their widening spread in various branches of industry and agriculture (*Konovalov et al., 2002*; *http://www.ecomihis.ro/)*, but, in our view, some useful properties of the vortex flows in the aforementioned dryers, are not given deserved importance. This refers, first of all, to the Ranque-Hilsch vortex effect, which consists in the separation of fluids into two phases during their vortex motion in a cylindrical pipe (*Guțol, 1997; Koleadin & Vinogradov, 2004*). As a result, the helical flow with a higher temperature is formed at the periphery, and in the centre, the helical flow with a lower temperature (fig. 3). It should be noted that the rotation of the central flow takes place in the opposite direction to that of the periphery. Unfortunately, with the vortex flows speed that are used in the drying processes, the thermal phenomena of the Ranque-Hilsch effect practically do not occur, but the flow configuration is maintained even at relatively low speeds, which is important for our subsequent observations.

The configuration of the vortex flows of the fluids in pipes with different shapes, which can be assimilated with the vertical aerodynamic dryers, is presented in fig. 3.

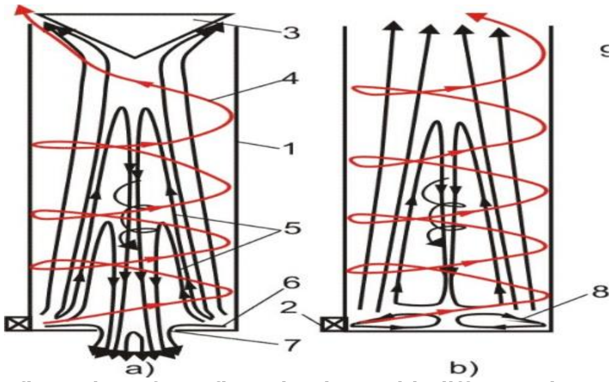


Fig. 3 - Configuration of gas flows in pipes with different shapes *(Guțol, 1997)*
a) cylindrical pipe with rolling valve and bottom diaphragm;
b) cylindrical pipe with free flow discharge and compact bottom

The first configuration (fig. 3a) illustrates the classical distribution of flows with currents in opposite directions in Ranque pipe. The peripheral vortex flow is formed by a vortex device *2*, which has a tangential or snail shape and is located at the bottom of the pipe together with the bottom diaphragm *7*. At the top of the pipe there is a metering valve *3*, which together with the cylindrical housing *1* forms an annular outlet. As a consequence of the movement of the peripheral vortex flow from the vortex device to the upper annular outlet is the formation of a vortex flow in the opposite direction which is discharged through the bottom diaphragm (Fig. 3a). An explanation of the cause of the flow in the opposite direction is given by *Guțol A., (1997)*: "with the movement of the flow that rotates intensely along the pipe, its circular (tangential) speed decreases because of the braking in contact with the chamber walls, the radial pressure difference decreases, respectively. If the speed of the translational movement of the gas along the pipe, which simultaneously rotates, is relatively low, i.e. the gradient of the longitudinal pressure drop at the periphery of the pipe is insignificant, then the rapid decrease of the radial pressure difference along the pipe leads to a negative pressure gradient along the axis of the pipe which is also the cause of the gas flow in the opposite direction". Although currently there is a large number of explanations and mathematical equations which describe vortex flows, a viable theory that fully describes the dynamics of such flows is still missing. However, existing knowledge allows the practical application of vortex flows.

If the bottom diaphragm and the metering valve are missing in the vortex pipe, then the configuration of the vortex flows is different: a new vortex area appears with the frontal flow *8*, which is formed by the interaction of the ascending peripheral flow and the descending central flow. In both cases (fig. 3a, 3b) the downward flow takes the form of a cone, which is caused, in our opinion, by the displacement of the peripheral vortex flow from the inlet to the outlet and the decrease of its tangential velocity due to friction with the inner walls of the pipe. As a result, the diameter of the vortex path increases and more and more "pushes" on the central region, compressing the newly formed downward vortex flow.

Technologies and installations for drying vegetal plant mass for energy needs, as well as feed and food needs, have been researched for several years. The result of this research is the development and assimilation in production of aerodynamic dryers, but there remain a number of problems that need to be solved: increasing energy efficiency and reducing the specific cost of dry raw material. Therefore, the purpose of our work is to conduct research on technological and constructive parameters of aerodynamic dryers and to develop the improved method and installation for drying vegetal mass.

MATERIALS AND METHODS

Carrying out the research requires development and exploitation of activities of aerodynamic dryers which have improved functional parameters to dry the vegetal mass. The first stage of this research is the theoretical study of the mentioned dryers.

In order to achieve the established goal, the following objectives were met:

- developing a concept of research and a study protocol;
- carrying out the analysis of the bibliographical references regarding the patterns of the aerodynamic dryers' construction and also the mathematical dependencies of the vegetal particles saltation speed and the working speed of the flow of the thermal agent as a function of the particles' as well as thermal agent's properties;
- determining, on this basis, of the theoretical postulates;
- developing the methodology for calculation of constructive and technological parameters;
- developing the method and improved construction of the aerodynamic dryer;
- physical modelling and studying of the working process inside the aerodynamic dryers.

In order to be able to transport the moist particles, it is necessary that the speed of the thermal agent exceeds the saltation speed of the particles at the given temperature. For the vertical pipe, which is also the case of the aerodynamic dryer, the particles' saltation speed can be calculated according to the equation given by *Boico V., (2008).*

$$V_f = Re\frac{v}{d}, \text{ [m/s]} \tag{1}$$

where:

Re- is the Reynolds criterion number;

v - kinematic viscosity of the air at the maximum temperature of the working process, [m²/s];

d - equivalent diameter of the particles, [m].

The equivalent diameter d of the particle is the diameter of the sphere, calculated based on the formula:

$$d = 1{,}24\sqrt[3]{\frac{M}{\rho_t}}, \tag{2}$$

where:

M - is the mass of a particle, [kg];

ρ_t - density of the transported particulate material, [kg/m³]

In this case (Equation 1) the Reynolds criterion does not indicate the character of the movement of the whole flow in relation to the dryer pipe, but characterizes the movement of the vegetal particles in relation to the heating agent:

$$\mathrm{Re} = \frac{\mathrm{Ar}(1-\beta)^{4,75}}{18+0{,}61\sqrt{\mathrm{Ar}(1-\beta)^{4,75}}} \tag{3}$$

where β is the volume ratio of the solid phase in the air flow ($0<\beta<1$):

$$\beta = \frac{1}{1+\dfrac{\rho_t}{\mu\rho_a}} \tag{4}$$

Where:

ρ_a is the air density at the maximum temperature of the process [kg/m³];

μ – ratio of particles in the heat flow: $\mu = \frac{m_t}{m_a}$ (when $m_t \to 0$, then $\mu \to 0$ and $\beta \to 0$);

m_t- mass of transported particles, [kg];

m_a- mass of air used for transport, [kg];

Ar - Archimedes' criterion (number).

$$Ar = \frac{d^3 g(\rho_t-\rho_a)}{\rho_a v^2} \tag{5}$$

Archimedes number Ar presents a similarity criterion that characterizes the ratio between Archimedes' force (caused by the difference in densities at various locations in the studied system) and the viscosity forces in the base flow. The mentioned number is used in the calculations in which the movement of bodies in the fluid environment is studied, caused by the inhomogeneous density in the "body - external environment" system (*Chemist's Guide, 1968; Önsan Zeynep Ilsen and Avci Ahmet Kerim, 2016)*.

According to the research conducted by *Boico, (2008),* the reliable transport of the particles will occur when the actual speed of the air will exceed the value calculated by equation (1).

In vertical pipes, the real value of the air speed is calculated based on the equation:

$$V = 2V_f, \text{ [m/s]} \tag{6}$$

For horizontal pipes this value will be:

$$V_o = 2V = 4V_f \text{ [m/s]} \tag{7}$$

It is easy to show that, subject to the conditions from equations (6) and (7), the diameter of the vertical drying column can be greater than at least 1.4 times that of the horizontal pipe. The above condition is used in practice (fig.2) to maximize the time of maintaining the material subjected to the drying process in the flow of the thermal agent.

Using Sveatcov's empirical equation (*Zakirov and Zakirova, 2016; Teterin, 1972*), the saltation speed, V_f, can be calculated with the necessary precision, for particles with an equivalent diameter d> 0.4 mm:

$$V_f = 0.14\sqrt{\frac{\rho_t}{\left(0{,}02+\frac{\varepsilon}{d}\right)\rho_a}} \text{ [m/s]} \tag{8}$$

where ε is the coefficient taking into account the shape of the particles.

For particles with a square or semi-round cross section, ε = 1.1;

For particles with a rectangular section or of a similar shape, ε= 0.9.

If d<0.4 mm, it is recommended using the empirical equation from Arhangheliskii V. (*Zakirov and Zakirov, 2016*):

$$V_f = 0.135{\rho_t}^{0{,}5} \cdot d^{0{,}25}, \text{ [m/s]} \tag{9}$$

According to the authors *Orehova and Uvarov, (2013)*, *Romancov and Rașcovscaia, (1968),* the velocity of the transported particles V_t is lower than that of the air flow V, the difference is equal to the saltation velocity V_f:

$$V_t = V - V_f \text{ [m/s]} \tag{10}$$

Where:

V is the velocity of the thermal agent in a particular sector of the aerodynamic dryer [m/s].

To achieve the purpose, at the initial stage, the Institute for Agricultural Technology MECAGRO - Chisinau, Republic of Moldova (*Hăbăşescu et al., 2016a*), using the ANSYS software, developed computer simulations of the vortex flow in the dryer column. Subsequently, the experimental research was performed on the same model of the dryer, installed in the technological line as shown in fig.2.

As raw material there have been used tree branches and straw, which have been chopped, with the following fractional distribution (% mas.): particle size>5 mm - 3%; 3...5mm - 33%; 2...3 mm - 30.2%; 1...2 mm - 19.3%; <1mm -14.5%.

Raw material moisture is within 25 and 30%, which represents the maximum level for practical cases. The mass of the samples was determined by weighing with the electronic scale Alex Kern with a ± 1% margin of error, and the duration was recorded with the SOP timer pr-2a-2-010. The temperature was measured with a thermocouple and an electronic device (Vento Company), the pressure and the speed of the workflow, respectively, were measured, using an anemometer equipped with a Pitot TA 400 tube (Trotec Company).

RESULTS

The results of the experimental research performed by the authors show that the required saltation speed of the particles in the drying process depends on the density of the air, especially at high temperature, ($\rho_a = f(t)$), so we have modified equation (9) as follows:

$$V_f = 0.135 \cdot \left(\frac{\rho_t}{\rho_a}\right)^{0.5} d^{0{,}25} \quad \text{[m/s]} \tag{11}$$

The correction carried out allows, at high drying temperature (t > 150°C), when in some cases problems arise in transporting the particles, obtaining higher values of the speed V_f than that from the original equation (9), and therefore, it will increase the reliability of transporting chopped particles by means of heated air.

The values calculated based on equations (8, 9, 11) of the saltation velocities V_f of the wood particles (ρ_t = 600 kg/m^3) are shown in fig. 4.

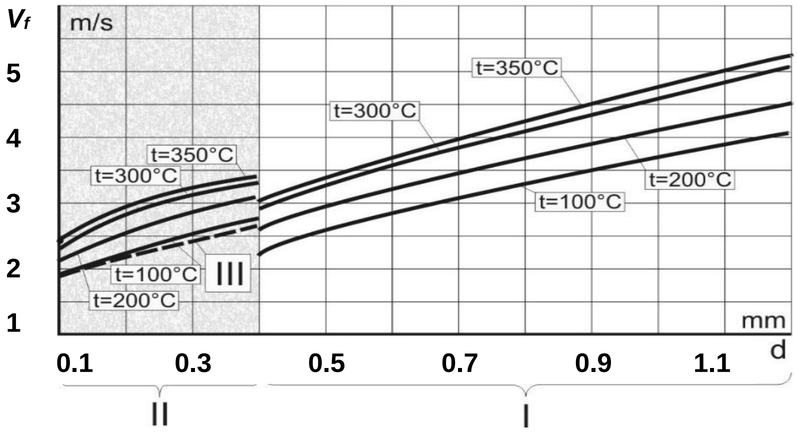


Fig. 4 - Calculated values of the saltation velocity V_f of wood particles depending on the temperature of the thermal agent t and the equivalent diameter d of the particles

(Note: values are obtained based on empirical formulas)

Thus, knowing the working size of the drying machine, it is possible to evaluate the duration of the contact τ with heating agent of the particles subjected to drying, i.e. the duration of the drying process:

$$\tau = \sum_{i=1}^{n} \frac{L_i}{V_{ti}}, \text{ [s]} \tag{12}$$

where:

Li is the length of the segment i of the drying installation, [m];

V_{ti} - the particle velocity in the segment i, [m/s]. (See equation (10)).

Using equation (12) the particles' drying time was calculated for the dryer ST-300 (China) (horizontal pipe diameter - 200 mm) (fig.3): τ~2-3 s.

Even at the initial temperature of the thermal agent of 300-350^{o}C, the calculated value of the duration τ may be insufficient to obtain the raw material with the required humidity. At the same time, it is necessary to take into account that the speed of the heating agent, in any segment of the dryer, may be less than that calculated by the equations (6), (7), which is based on the actual situation $V = (2- 4)V_f$, and thus essentially limiting the measures to increase the duration of the drying process.

To increase the duration τ, in many cases consecutive coupling of several drying columns (fig.2) or other procedures are used, which lengthen the trajectory of the drying flow.

Such measures have the consequence of increasing metal consumption for manufacturing the added columns and/or the energy at the intake fan, and therefore a reduced economic efficiency of the process.

In the world practice there are used aerodynamic dryers equipped with drying columns (pipes), in which the flow moves on paths parallel to the longitudinal axis of the column (fig.5a,c) or a helical path along the column (fig.3; fig.5b,d).

The computer modelling of the flow in the dryer performed by the authors showed that, in the case of its tangential entry in the inner space of the column with certain ratios of geometric parameters (fig.5b), a vortex flow is formed (fig.5d), which increases the trajectory length of the particles subjected to drying and respectively the duration of the contact between the moist material and the thermal agent.

Calculations based on the developed models (gauge geometric parameters in both dryers are identical, fig. 5a, b) have shown that the movement of the vortex flow in the column (fig. 5d) exhibit a 3-4 fold increase in trajectory length of the particles, (i.e. τ~5...12 s) compared to the direct current dryer (τ~2...3s, fig.5c).

But, although a complex movement inside the vortex flow is quite convincingly demonstrated by the authors *Ahmetov et al., (2014),* because of a lack of convincing theoretical base to be used in the calculation algorithm, the rotation of the external layers of the flow were no taken into consideration.

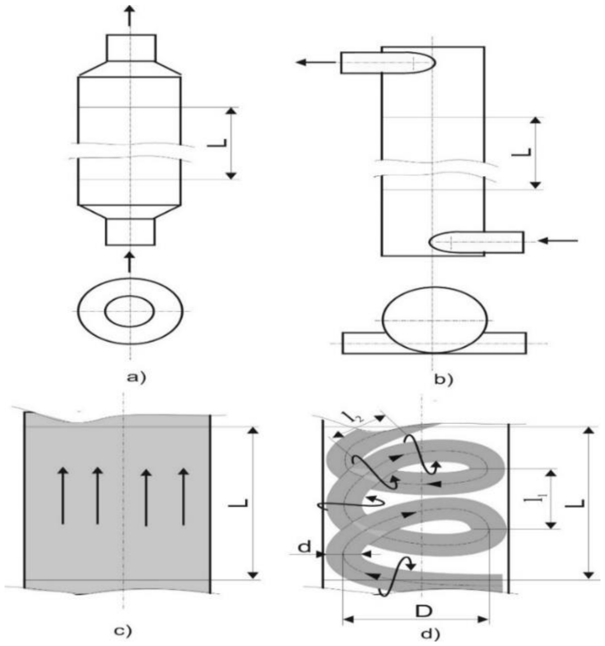


Fig. 5 - Configuration of the flow of thermal agent mixture + ground raw material in dryers: with direct current (a, c) and vortex (b, d)

l_1 – the step of the helical trajectory of the complete flow; l_2 - the step of the helical trajectory of the outer layers of the flow; d- the diameter of the flow cord; D- vortex flow diameter

Taking into account the existence of two trajectories of particles' motion in the vortex flow (fig.5d), their total path L_t in the segment of length L of the vortex dryer will be equal to:

$$L_t = n_1\sqrt{(\pi D)^2 + {l_1}^2} + n_2\sqrt{(\pi d)^2 + l_2^2} \quad [\text{m}] \tag{13}$$

where :

D - is the diameter of the peripheral vortex flow, [m];

l_1- step of the helical trajectory of the complete flow, [m];

n_1 - the number of turns of the vortex flow in the sector of the column with length L;

d - diameter of the flow cord, [m];

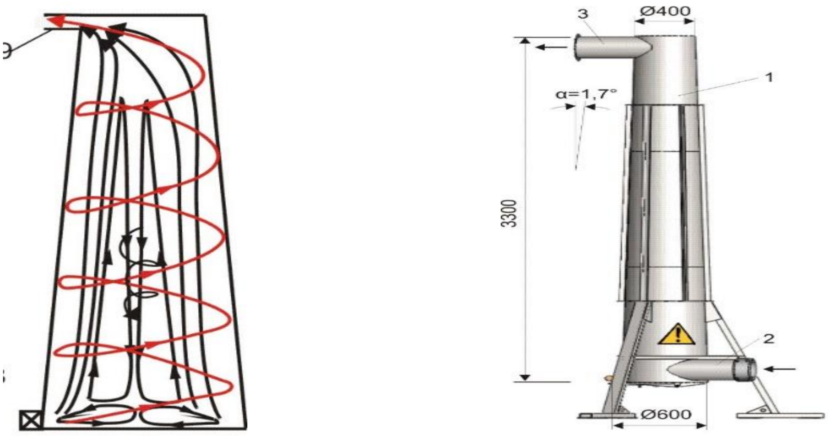
l_2 - the step of the helical trajectory of the outer layers of the flow, [m];

n_2- the number of turns in the helical path around the axis of the outer layers of the cord in the length L.

Based on the formulas (12), (13) and on the aerodynamic model created (fig. 5d) the value of the contact duration of the moist particles with the heating agent was specified: τ*~13...24 s*. The last value includes all the movements of the particles inside the vortex column, including the rotation of the outer layers of the flow in relation to its axis (fig. 5d). The known aerodynamic models (fig. 3) and the ones we elaborated (fig. 5) for vortex flows, made it possible to make a hypothesis.

Because the particles of the raw material subjected to drying are not at homogeneous moisture levels inside the vortex column, they are classified as follows: particles with relatively low humidity move only in the ascending peripheral flow, and particles with higher humidity in the peripheral flow reach the central descending flow, and after their humidity is reduced return to the peripheral flow, being discharged from the column. This phenomenon allows the homogenization of the particulate moisture at the exit of the dryer and the optimal use of thermal energy and reduced consumption. Simultaneously, this hypothesis demonstrates the importance of the trajectories' form, both peripheral as well as the central ones.

To achieve the hypothesis described above, it was proposed the construction of the conical-shaped vortex dryer (*Hăbășescu et al., 2016a)*. The computer simulations of the proposed dryer operation (fig. 6a) showed that, the tangential speed of the peripheral flow can be equalized (stabilized) vertically to a certain limit, which decreases the diameter of the peripheral flow D (i.e., the cross section of the internal space), proportional to the energy loss caused by friction with the inside walls of the dryer and obtaining its conical shape. The stability of the flow may be further increased, by using a tangential outlet nozzle (*Hăbăşescu et al., 2016a)*.



a) b)

Fig. 6 a) The configuration of the gas flows in the conical pipe with the compact bottom and the tangential outlet channel ; b) General view of the vortex dryer *(Hăbăşescu et al ., 2016a)*

1– conical housing; 2–power supply connection; 3–exhaust connection

In the conical vortex pipe (fig.6a) the conical trajectory of the descending flow becomes more extended vertically compared to the previous shapes of the pipes (fig.3). From the analysis, it is expected that the conical dryer (fig.6) would, first of all, provide better conditions for the drying of the ground vegetal mass, and simultaneously reduce the power consumption as well as the manufacturing materials for the column.

Research performed on an experimental model of the conical vortex dryer (fig.6b) with a height of 3.3m (diameter of horizontal pipes - 200 mm, suction fan flow - approx. 1500 m^3/h) has demonstrated that the duration of the movement of the raw material particles from the place of loading (mixer 3, fig.2) to the place of unloading (cyclone 5, fig.2) was τ = *30-35s*. This duration is 10-15 times longer than that obtained in the direct current aerodynamic dryer (ST-300).

In the research process, an interesting phenomenon was identified, namely: self-regulation of vortex flow parameters with the material subjected to drying in the interior of the dryer when varying the amount of raw material added to the dryer. The phenomenon discovered allowed automatic creation of optimal conditions for drying, when the supply of raw materials and/or the humidity has changed within the studied limits.

The identified phenomenon was presented as follows. When the working space of the dryer was empty and the fan was running, a stable vortex flow was formed inside the dryer (fig.7a). The temperature of the thermal agent at the entrance to the dryer had a value of 300ºC, and the flow rate was maximum. It should be mentioned that the vortex flow of air resulted in increased air resistance, therefore the fan flow decreased to 3500 m^3/h (exhibited before mounting on the machine) to 2300- 2500 m^3/h.

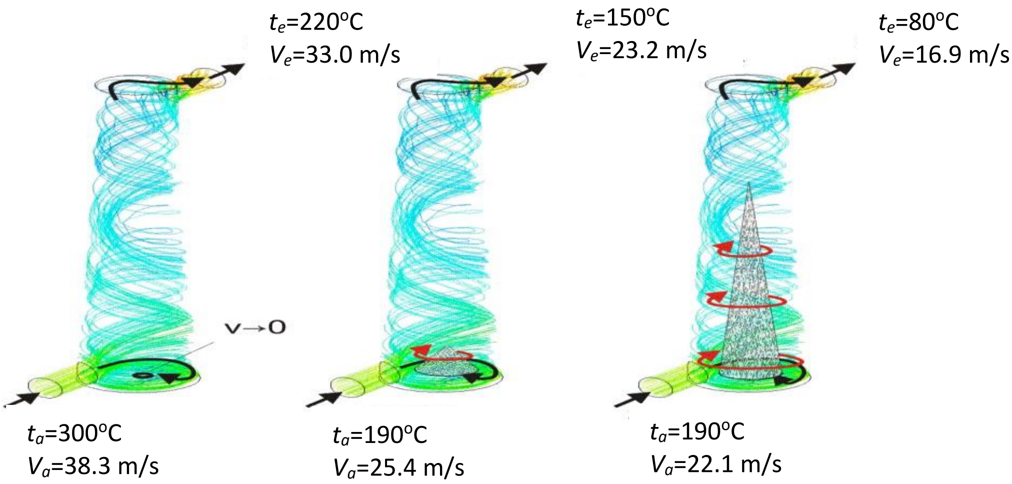


Fig. 7 - Steps for forming the cone of the material subjected to drying inside the aerodynamic dryer

t_a= heating agent temperature at the inlet; t_a= heating agent temperature at the outlet;
V_a=heating agent speed at the inlet; V_e= heating agent speed at the outlet;

Continuously adding the raw material to the flow of the thermal agent, at a humidity of 18-20% and an hourly rate of 350- 400 kg/h, the temperature at the dryer inlet fell from 300°C to 190°C and the flow rate from 38.3 m/s to 25.4 m/s (fig.7 a, b). The intensity of the vortex flow inside the dryer also decreased, simultaneously increasing the diameter of the helical path. The flow rate on the axis of this path was high, and at the peripheral layers it decreased, reducing the transport capability of moist particles.

This phenomenon, along with the speed close to 0 m/s along the longitudinal axis of the dryer, leads to the formation on the bottom of the dryer of a conically shaped pile of the moister particles, which rotated the same direction as the base flow, but at a lower angular velocity. Adding raw materials, the cone in the centre of the dryer increased in height until the space between the inner walls of the dryer and the surface of the cone became optimal for the concrete values of the aerodynamic properties of the flow of the mixture heat-raw material on one hand, and of the real temperature of the thermal agent (fig.7c), on the other hand.

In this case, the stabilization of the flow velocity in the supply pipe also took place (V_a = 22.1 m/s), the flow rate having a value of 1500 m^3/h. As they dried, particles from the outer layers of the cone were discharged from the flow, and their place was taken up by new particles. In the case of an increase of the initial humidity of the raw material, the diameter of the base of the cone also increased and vice versa. In the first case, the flow rate increased, and in the second, it decreased. This is how the self-regulation of the drying process took place. Due to the conical shape of the dryer, it was also possible to compensate for the loss of flow velocity, caused by its friction with the walls of the dryer and thus stabilize the value of the diameter of the flow path formed in the space between the dryer walls and the inner cone. At the top of the dryer, the diameter of the outlet was almost equal to twice the diameter of the helical flow path. As a result, swirling turns began to touch each other, forming complex turbulences which limited the increase in cone height. After this, the mixed flow of thermal agent-dry material is discharged into the cyclone (fig.2). After stopping the supply of raw material, the intensity of the vortex flow increased, completing the evacuation of the dry particles in 5-10 minutes (depending on the initial humidity of the raw material).

The increase of the duration of the vegetal mass particles contact with the heating agent obtained in the experimental investigations (τ = *30-35 s*) compared to the calculated value of the duration (τ *~13...24 s*) can be justified by the fact that, under real conditions, the tangential velocity of the outer vortex flow decreases. At the same time, the phenomenon of separation of dry and moist particles of the vegetal mass inside the vortex dryer also serves to increase the duration of contact τ of the particles subjected to drying with the thermal agent. It is expected that the increase of the duration τ will have positive effects, namely: a) increasing the homogeneity of humidity in the dry raw material; b) the extension of the options for managing possibilities of the technological process of drying the raw material.

CONCLUSIONS

1) The bibliographic study demonstrates that for drying the chopped vegetal mass, which is intended for producing densified solid biofuels, a promising method is the convective aerodynamic dryer in which the thermal agent executes the base function i.e. drying, and the auxiliary one i.e. the transportation of the biomass particles, which essentially simplifies the construction of the drying machine, and the use as a thermal agent of the flue gases increases the efficiency of the process. In the category of aerodynamic dryers the vortex type dryers are also included, which show higher performances: the calculated value of the contact time of the particles with the thermal agent is 6-8 times higher than in the case of aerodynamic dryers with direct contact. For both dryers, the geometric and technological parameters were identical.

2) The theoretical and empirical equations that allow the calculation of the aerodynamic and technological parameters of the drying process were determined: the saltation speed of the biomass particles, the working speed of the vortex flow and the duration of contact of the particles with the thermal agent. The vortex effect was analysed: we analysed the Ranque-Hilsch vortex effect under working drying conditions, and we developed configurations of the gas flow for dryers of various shapes, which demonstrated the advantages of the improved conical form dryer.

3) The research carried out on an experimental model of an improved aerodynamic dryer, with a conical shape of the pipe, confirmed the results of theoretical research, the actual real value of the duration of the particle contact with the thermal agent was increased by 12-15 fold compared with the dryer with direct contact. During the research, while varying the quantity of material fed to the dryer, we identified a self-regulation phenomenon of the parameters of the vortex flow of material to be dried in the interior of the dryer.

This allowed for automatic generation of the optimum drying conditions when there was a change in the quantity of supplied material and/or in its humidity within the studied limits.

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