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A NEW METHOD TO DRY SOME GRANULAR MATERIALS

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Soluția prezentată în acest articol se referă la un nou procedeu de uscare a unor materiale granulare, aşa cum sunt boabele de grâu, porumb, secară, floarea soarelui, orz, soia etc, dar şi altor tipuri de granule. Procedeul propus permite o economie semnificativă de energie, fără a dăuna calității uscării, prin intensificarea transferului de căldură dintre agentul de uscare şi granulele tratate , asigurând uniformizarea avansată a principalilor parametri ai uscării– temperatura şi umiditatea - , în oricare strat al coloanei de granule. Randamentul uscării este de peste 70 % .

A great part of the grain harvests, each year, must be dried with heated air, in order to prevent spoilage. The drying processes now in use require more energy than is theoretically necessary to ensure long-term storage of the grain. The common dryer configurations on farms and at commercial elevators are the crossflow and in-bin counterflow processes.

The solution presented in this paper has a great potential to reduce the energy use, by the intensification of the heat transfer between the drying agent and the grain and by the advanced uniformization of the main parameters – temperature and humidity -, in any layer of the grain column. Moreover, the proposed method can be applied to many other types of granules. Regarding the features of the proposed solution, we underline the efficiency (over 70%) .

Keywords: corn grain drying, heat transfer, gaso-dynamical computations, temperature field uniformization

1. Introduction

The grain circulate gravitationally, continuously, with a constant and well controlled flow, through plane vertical channels (canals), limited by some plates of steel with perforations, through which the grains do not circulate but the gases. By these, all the grains are subjected to the most favourable drying regime. with a minimum duration, an optime drying quality, with competitive technico-economical indicators.

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The common dryer configurations are the crossflow and the in-bin counterflow processes. The crossflow configuration forces heated air horizontally through the vertical column of grain, causing significant temperature and moisture gradients across the grain. While grain at the air inlet is overdried and excessively heated, grain at the air-discharge side retains an elevated moisture level and a lower temperature. In addition, the high-temperature drying, followed by rapid cooling, is known to cause stress-cracking of the kernels, leading to kernel breakage and a marked loss in quality. This solution was improved by making use of parallel-flow drying sections separated by tempering zones, which would ensure that the drying stages proceed at a more rapid rate of energetical consumption and a better using of the heated air and the moisture-removal. This was better than the in-bin counterflow systems, assuring an increased energy efficiency and higher capacity. The most modern driers have some canals like a letter "V" upset, open at the inferior part, that larger, and put in "echiquier"; by some of these canals, the hot initial thermal agent is circulating and by others the degradated agent is going out, relatively cold and humid.

2. Experimental

2. 1 . Preliminaries regarding the proposed technology

The drier will dry grains – maize, corn, wheat, rice, soy, barley, sunflower seeds etc., after the preliminary passage through cleaning devices. In order to be more specific, we will present a drier for 40 t/h maize, which must be dried from the relative initial moisture of 30 % to that final of 14 % (respectively from the absolute initial moisture of $\frac{0.30}{1-0.30}$ = 42.86 % to that final of 16.28 %).

Those 40(1 – 0.30) = 28 t/h dried maize will give way in the drier 28(42.86 – 16.28)10^{-2} = 7.44 t/h water; from the drier will go out 40 – 7.44 = 32.44 = 32.56 t/h maize with X_f = 16.28 % and U_f = 14%. In the case when the drier will be applied to other grains, its thermal charge will be smaller.

The circulation in only one way (unique sense) of the drying thermal agent determines the following variation in the respective layer of grains, both for temperature and moisture: at the entrance of the gaseous agent in layer, the grain temperature is maximum (and the moisture minimum) and at the discharge, the grain are the most cold and humid. Such variations lead to average values which are not favourable, because the greatest admitted temperature is attained by a small part of the grains; the majority is subjected to a less intense thermal regime, prolonging thus the drying duration and reducing the drying quality.

A maxime uniformization of the fields of temperatures and moistures is below proposed, by the alternance of the sense of running of the gases through the grain layers, by assuring at least 10 changes of sense during the grain drying.

Our solution has great advantages; e.g. the steam lines have equal lengths and the grain layers have an absolutely uniform thickness. Moreover, the alternating sense avoids the grain near the air inlet to be overdried and excessively heated and in the same time, the air-discharge side to retain an elevated moisture level and a lower temperatures.

Our solution answers very well to the requirement of energy saving, as we will prove in the following.

2. 2 .Thermal and Gasodynamical computations

The grain is heated from the initial temperature (15^oC) to the average temperature in the zone which has the wormest admitted temperature (45^oC, with a local maximum of 50^oC) ; then, the grain is cooled at 20^oC and the maize is so evacuated from the drier. The global thermal evolution of the dried grain needs

$Q = 40 \times 10^3(1 - 0.30)\times 0.27(20 - 15) = 37{,}800$ kcal/h = 158.3 MJ/h,

where 0.27 means the massic specific heat of the dried substance. By weighting the temperatures and the thermal charges, one gets a mean value of about 42^oC, keeping into account that a part of water is vaporized al smaller temperatures, while the grains are heated from 15 to 45^oC.

The bound energy being evaluated at 3 kcal/kg water, the vaporization heat of water will be about 574 kcal/kg. The consumption of thermal energy afferent to the water heating , vaporization and then to the overheating of water steam at 50^oC will result to be

$m_w(1.0(42 - 15) + 577 + 0.45(50 - 42)) = 607.6\ m_w$,

(m_w = water mass).

In the cooling zone, from 45 to 20^oC , of the grains with the final absolute humidity of 16.28 % (the relative value being 14 %), the mass of dried air $m_{d.\,a.}$, heated from 10 to 30^oC (with φ = 80 % and x_{in} = 6.4 g/kg d. a.), consumes $m_{d.\,a.}\times 0.24(30 - 20) = 2.4\ m_{d.\,a.}$ kcal/h.

The water quantity m_w which is vaporized will consume $m_w \times 585$ kcal/kg. Under the equilibrium conditions, air at 30^oC would arrive to φ = 82 %, but in kinetical conditions, one accepts φ = 75 %, with x_f = 20.2 g/kg d.a. The vaporized water is refound in the drying air, hence

$$m_{d.\,a.}(20.2 - 6.4) \times 10^{-3} = m_w \ . \qquad (1)$$

On the other hand, we have

$$28\times 10^3(0.27 + 0.1628\times 1)(45 - 20) = 302{,}960 \text{ kcal/h}$$

and the following thermal balance equation:

$$2.4\ m_{d.\,a.} + 585\ m_w = 302{,}960\ . \qquad (2)$$

From this algebraic system with two unknowns, it will result the following values:

$$m_{d.\,a.} = 28{,}927.8;\ \ m_w = 399.2 \text{ kg/h}\ . \qquad (3)$$

The mass of hourly vaporized water in the zone of the grain heating, practically isothermic, is 7.44 – 0.40 = 7.04 t/h.

The flows of dried air (respectively steam) result to be 28,927.8/1.293 = 22,373 (respectively 399.2/0.8 = 499 m^3_n/h),and that total will be of 22,373 + 499 = 22,872 m^3_n/h. The thermal charge will be:

$7.04\times[1.0(42 - 15) + 577 + 0.45(50 - 42)]\times10^3 + 40\times10^3(1 - 0.30)\times0.27(42 - 15) =$

4,481,624 kcal/h = 18.76 GJ/h.

An important heat consumer is the drying air which, heated from 10 to 50°C (the average value), must transport in atmosphere 7.04 t/h water. With 3 % heat dissipations (because of the drier construction), the air aspired from exterior, mixed up with the cooling air, is heated to about 160°C; thanks to the alternating sense of circulation through the grain layers, the average value is about 83°C, as confirmed later. By cooling from 160 to 50°C, the drying air will cede

$$1.03\times18.76 = 19.32 \text{ GJ/h} = 4.61 \text{ Gcal/h}. \quad (4)$$

The gaseous mixture introduced in the drier has x_{in} = 9.32 g/kg d. a. (dried air) and a flow of:

$4.61\times10^6 / [0.241\times160 - 0.240\times50 + 0.00946\times(0.450\times160 - 0.446\times50)] =$

$4.61\times10^6 / 27.03 = 170{,}550$ kg/h = 131,901 m^3_n/h d. a. ,

at which one adds 0.00946×170,550 = 1,613 kg/h = 2,016 m^3_n/h steam. The total gaseous flow will be 131,901 + 2,016 = 133,917 m^3_n/h=37.2 m^3_n/s. (5)

The steam comes from atmosphere ($170{,}550\times10^{-3}\times6.4$ = 1,091.5 kg/h), from the maize drying during its cooling (399.2 kg/h by (3)) and from the diesel oil burning (99 kg/h). One gets (1,091.5 + 399.2 + 99)/170,550 = 9.32×10^{-3} kg water/kg d. u.

Globally, for the whole drier, one vaporizes 7.44 t/h water, which consumes $1.03\times7.44[1.0(41 - 15) + 578 + 0.45(50 - 41)]\times10^{-3}$ = 4.66 Gcal/h = 19.51 GJ/h .

We have kept into account the increase of bound energy of water in the final period of drying and also the reduction of the average grains temperature from 42 to 41°C. One also consumes energy to heat the quantity of 170,550 kg/h air with 1,091.5 + 99 = 1189.5 kg/h steam from 10 to 50°C (steam from atmosphere and the diesel oil complete burning); namely:

$1.03\times170{,}550(0.240\times50 - 0.239\times10) + 1.03\times1{,}189.5(0.446\times50 - 0.445\times10) =$

1.71 Gcal/h = 7.16 GJ/h .

To conclude with, the total consumption of heat is 4.66 + 1.71 = 6.37 Gcal/h = 26.67 GJ/h and the global efficiency, as consequence of the alternance in the sense of displacement of the drying agent through the grain layers subjected to drying, is

$$\eta = \frac{19.51}{1.03 \times 26.67} \approx 0.71 .$$

The consumption of diesel oil, with the inferior burning heat (≡ calorific value) of 10,680 kcal/kg = 9,291.6 kcal/l (the density of diesel oil being 0.87 kg/l), results to be $6.37.10^6$/9,291.6 = 685.6 l/h . We can summarize and state the following

For a drier of 40 t/h, the global efficiency of the technology is η = 71 % and specific consumption is γ_s = 0.922 l diesel oil per any t. p. (tone and percent of humidity).

Indeed, γ_s = 685.6 / 7,440 = 0.0922 l diesel oil per 1 l water, hence γ_s = 0.922 l/t. p.

2.3. The proposed technology

The grains descend continuously, gravitationally, by vertical canals, limited by plates of steel with perforations which can be crossed by gases (in alternating sense) and not by grains. Each metallic plate will be in contact with gases at 160 and then at 50°C, again 160 and 50°C etc. If the alternance is made per 1 minute (the period being of two minutes), the plates temperature will vary with max. 5 K around the average (Fig. 1).

The flow, established previously in (5), for the heating zone (and isothermic evolution of maize), completed with the steam from diesel oil burning, was of 133,917 $m^3{}_n$/h = 37.2 $m^3{}_n$/s; one adds the average flow of steam resulted from the grain drying in this superior zone of the drier (7,440/2 = 3,720 kg/h = 4,651 $m^3{}_n$/h steam). One gets 138,568 $m^3{}_n$/h = 38.5 $m^3{}_n$/s.

The flow of 37.2 $m^3{}_n$/s (= 59.1 m^3/s at 160°C) enters in the layer at 160°C and increases to the average value 38.5 $m^3{}_n$/s (= 50.2 m^3/s at 83°C), reaching the value 37.2 + 7,440/(0.8×3,600) = 39.8 $m^3{}_n$/s = 47.1 m^3/s at 50°C, at the exit from the layer. With the mean temperature of maize of 42°C, the logarithmic average difference between the temperatures of the thermal agents − gases and grains − results to be $\dfrac{(160-42)-(50-42)}{\ln\dfrac{160-42}{50-42}}$ = 41 K;

thus, the average temperature in the granular layer will be of 42 + 41 = 83°C.

At this temperature and at 755 mm Hg (the drier will operate in depression), the average volumic flow of gas is $38.5 \times \dfrac{760}{755} \times \left(1 + \dfrac{83}{273}\right)$ = 50.6 m^3/s.

By considering the apparent average velocity of the gases through the grain layer w = 0.6 m/s, the total section of running in the drier (without the cooling zone) results to be 50.6/0.6 = 84.3 m^2. At 83°C, from the tables:
$\lambda = 25.3\times10^{-3}$ kcal/m K h (the thermal conductivity);
$\nu = 21.8\times10^{-6}$ m^2/s (the kinematic viscousity).

Moreover, from the literature, the porosity m of the bulk and the equivalent diameter d of the grain are
m = 0.39 (39 %) ; d = 6.6 mm.

With these values, the Reynolds criterion is $Re = wd/\nu = 0.6\times6.6.10^{-3} / 21.8\times10^{-6} = 181.7$;

The Reynolds criterion particularized to the grains filling is $Re_f = \frac{0.45}{(1-m)m^{0.5}} Re = 214.6$.

The Nusselt criterion is $Nu = \alpha.d/\lambda$, where α is the coefficient of convective heat transfer between gases and grains. Since Re < 200, Nu = 0.106 Re = 0.106×181.7 = 19.26 , whence $\alpha = \lambda.Nu/d = 25.3\times19.26/6.6 = 73.8$ kcal/m^2K h.

On the other hand, the global coefficient of heat transfer between the drying agent and grains is about 48.7 kcal/m^2K h and the specific surface of the maize bulk is 6(1 – m)/d = 6×0.61/0.0066 = 554 m^2/m^3 bulk. The grains volume is, by (4):$4.61\times10^{6}/(554\times48.7\times41) = 4.17$ m^3. The thickness of the grain layer is 4.17/84.3 ≈ 0,049 m ≈ 50 mm.

In order to assure the continuous running of the grains, avoiding the risk of forming nonstationary microvaults (hindering the uniform running of gases through layer), it is necessary an equivalent diameter of the layer at least equal to 20 diameters of the grains, hence 132 mm. Adopting a breadth δ of the vertical canals of 66 mm, the drop of pressure through the layer is

$$\Delta p = \frac{1}{m^{4.2}}(1.5 + 23/Re_f + 120/Re_f).\frac{\delta}{d}.\frac{w^2}{2g}.\rho =$$

$$= \frac{1}{0.39^{4.2}}(1.5 + 23/214^{0.5} + 120/214.6)\times\frac{66}{6.6}\times\frac{0,6^2}{19.62}\times0.965 = 33.53 \text{ mm water column.}$$

The flow of 39.8 m^3_n/s = 47.1 m^3/s at 50°C, previously established, at 755 mm Hg, will be displaced by two ventilators (24 m^3/s each, with about 70 mm water column, consumming 25 kW).

3. Conclusions

With all this data, one can design the drier in all the details, including the focus and the preparation of the drying agent.

The total area of the vertical canals with performations is about 96 m^2; accepting 9 parallel canals of 2000×66 mm, the height of the zone of heating and isothermic drying of the grain results of about 5 m. There also is a zone of grain cooling of about 0.7 m, so the total height of the drier is at most 6 m. One foresees a system of uniform extraction on all the length of 2 m of the canals, evacuating from each canal about 4.5 t/h dried grains.

The drier can be mounted in free air, without special protection, since it operates only short periods of time (the burner and the motors being dismantled in extraseason).

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