Dynamic Modeling of Tower-Type Corn Grain Dryer in Vietnam

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Summary

The paper shows transfer function for a tower-type dryer. To find out these transfer function, it is necessary to study the transfer of heat and material in corn grain, and thermal transfer in the tower-type dryer. Results would be tested by experiment.

Keywords: *tower-type dryer; corn; dynamic model*

SYMBOL	PARTICULARS	UNIT
B	Air pressure	bar
D	Practical amount of drying agent	kg/h
d	Moisture content of drying agent	kg of moisture /kg of air
C	Thermal capacity of moist material	kJ/kg.^oC
C_a	Thermal capacity of moisture	kJ/kg.^oC
C_k	Thermal capacity of dry material	kJ/kg.^oC
W	Moisture amount in need of evaporation	kg/h
u	Relative moisture content of grain	%
φ	Relative moisture content of heated air	%
φ_0	Relative moisture content of ambient air	%
g	Capacity of grain	kg/h
Q_v	Thermal losses taken away by grains	kJ/h
Q_{mt}	Thermal losses vented out the environment	kJ/h
q_{mt}	Current of thermal losses vented out the environment	kJ/m^2.h
q	Current of calorie transferred through the wall	kJ/m^2.h
t_0	Environment temperature	^oC
tf_1	Temperature of hot air in drying zones	^oC
tf_2	Ambient temperature	^oC
K	Coefficient of thermal transfer through the wall	W/m^2. ^oC
α_1	Coefficient of thermal emission from hot air into the wall	W/m^2.^oC
α_2	Coefficient of thermal emission from the wall into the air	W/m^2.^oC
δ	Thickness of the wall	m
λ	Coefficient of thermal conduction of the wall	W/m.^oC
p_b	Saturated pressure of steam in the air	bar

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i	Name of drying zones
1	Set input
2	Set Output

Background

In recent years, the achievements in agricultural production have brought Vietnam, a country used to import food, to become the second largest rice exporter in the world. Following rice, corrn is the staple food for the ethnic minorities and material for feed processing.

However, for food production, esp. corrn, drying is a big problem, particularly when it is harvested in rainy season. Although drying technique has been studied by many authors [5, 6], it is still in need of research to find out the optimum drying model appropriate for corrn grain. One of the most notable techniques is tower-type drying technique.

In Vietnam, most of the researches on the control system for drying agent don’t meet the drying technology. Majority of the control system is manually done; therefore, many criteria are affected including dried grain quality. To improve the grain quality, it is necessary to design a controller's set for tower-type dryer to adjust the drying agents such as temperature, moisture content, etc.

Based on diagram in figure 1 [13], the dynamics of the tower-type dryer can be determined by linking channels of changes of parameters of corrn and thermal carrying matter (air drying) with the change of heat flow.

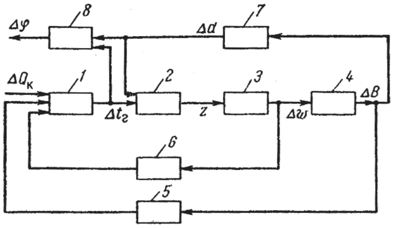


Fig. 1. Diagram structure of controlling system for drying process of tower-type dryer

Transfer function 1 characterizes inertia of heat exchange process in the dryer. It is calculated by the thermal balance equation of the dryer [13]:

$$Q_k=Q_1+Q_2+Q_3 \qquad (1)$$

in which Q_k – total thermal flow;

Q_1 – thermal loss to evaporate;

Q_2 – thermal loss to heat the air;

Q_3 – thermal loss into atmosphere.

Transfer function 2 characterizes influence of moisture content of the atmosphere to the temperature of the thermal carrying matter.

Transfer function 3 characterizes drying duration.

Transfer function 4 characterizes the speed to take moisture off corrn grains basing on relative humidity.

Transfer function 5 characterizes the thermal loss, depending on the change of speed, which takes moisture off corrn grains.

Transfer function 6 characterizes the thermal loss caused by moisture content of materials.

Transfer function 7 characterizes changes of moisture content of the atmosphere and changes of speed taking moisture off grain bulk.

Transfer function 8 characterizes the relative humidity of the atmosphere and its moisture content.

To define relations of the above-mentioned stages, the following should be developed:

- Studying heat and mass transfer in corrn grain.
- Studying thermal transfer of the tower-type dryer
- Practically testing the obtained results.

I. STUDY ON HEAT AND MASS TRANSFER

Due to the exchange of moisture of corrn with the ambient atmosphere occurs mainly through the embryo; thus, it can be seen the flow of moisture travelling in corrn kernels is only in one direction (e.g. towards direction x), then the model description equation will be [1, 2]

$$\frac{\partial u}{\partial \tau} = a_m \frac{\partial^2 u}{\partial x^2} \qquad (2)$$

Boundary conditions:

$$u(0,\tau)=u_0=const \qquad (3)$$
$$u(\delta,\tau)=u_{cb}=const$$
$$0\le x\le \delta;\ 0\le \tau$$

In which δ - Thickness of grain bulk, mm; for corrn δ = 4mm;

τ - time, hours;

u_{cb}- Balanced moisture of grains.

The balanced moisture of grains is a dependent quantity on the grain property, ambient temperature and humidity of the grain and is determined by the following formula [2]:

$$u_{cb} = \left[-\frac{ln(1-\varphi)}{5{,}876.10^{-5}(t+45{,}5)} \right]^{0{,}5} \tag{4}$$

In which φ - Relative humidity of the atmosphere,%;

t – Temperature of the atmosphere, °C.

Initial conditions:

$$u(x,0)=f(x)$$
$$F(x):= Ax+B.$$

Coefficients A, B are defined by the boundary and initial conditions. With the selected conditions, function f(x) has a form as below [2]

$$F(x) = -\frac{u_0 - u_{cb}}{\delta} x + u_0 \tag{5}$$

Quadratic equation of 3 unknowns which describes moisture exchange process between corrn grain and the ambient atmosphere with the above-mentioned boundary and initial conditions can be solved by grid method [2] and analytic procedure. By reference [3], the root of the equation is:

$$u(x,\tau) = \frac{1}{\sqrt{\tau}}.e^{-\frac{x^2}{4a_m{}^2\tau}} \tag{6}$$

By applying the algorithm to solve equation of thermal exchange and diffusion into equation (2), a block diagram to calculate the coefficient of moisture transfer based on temperature and moisture content can be set up as follows (see Fig.2)

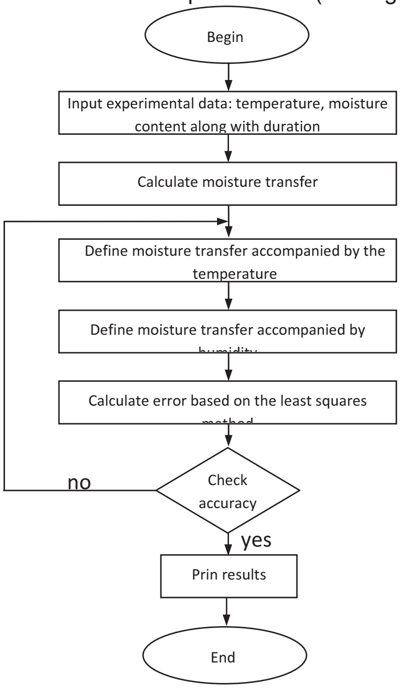


Fig. 2. Block diagram to calculate the coefficient of moisture transfer based on temperature and moisture content of grains

II. STUDY ON THERMAL TRANSFER IN THE TOWER-TYPE DRYER

Structure of the tower-type dryer is composed of drying tower, exhausted drying agent vent-canal, calorifer and fan. The material to be dried is supplied by an elevator and conveyer from the tower top and it travels down. The drying agent goes through the grain bulk (material to be dried), then into the canals and finally is vented in to the atmosphere. The tower-type dryer acts as convection drying process. The thermal exchange process takes place in the two currents: grain current (the material to be dried) and hot air current (drying agent). The two currents move in the opposite direction (see Fig.3).

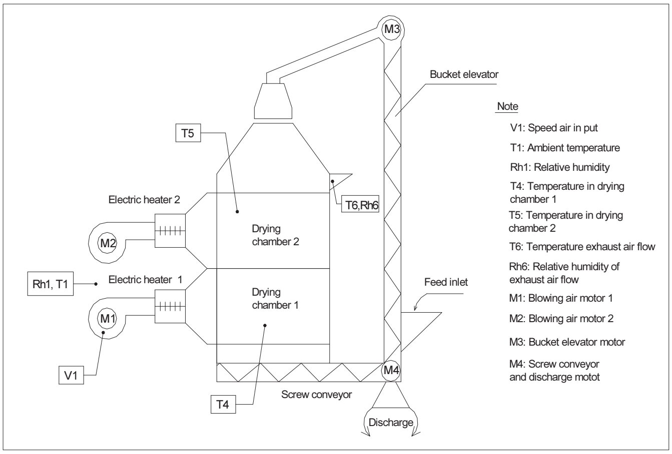


Fig. 3. Structural outline of a tower-type dryer

The drying tower can be divided into several zones. In the paper the two drying zones are mentioned accordingly i = 1 and I = 2. Hence, in calculation for drying the thermal equilibrium equation for each zone is considered. According to [1, 5] the equation can be seen:

$$D_i(I_{1i}-I_o) = (2500+1,842.t_{2i} - c_a.t_{1i}) + D_i\,(1,004+1,84\,d_{1i})(t_{2i}-t_o) + Q_{vi} + Q_{mti} \quad (7)$$

The practical drying amount is [2]:

$$D_i\,(d_{2i}-d_{1i}) = w_i \quad (8)$$

The relative humidity of the air is defined by the mass equilibrium equation [1, 5]:

$$0,621.\varphi_{2i}.p_{bi} + \varphi_{2i}.p_{2i} + d_{2i} = B.d_{2i} \quad (9)$$

Here

$$p_{bi} = Exp[12,031-4026,42/(235+t)]$$

$$d_{2i}.i_{2i} = d_{2i}[c_a.t_o-(q_{vi} + q_{mti})] + d_{1i}\,(1,004+1,84\,d_{1i})\,(t_{1i}-t_{2i}) \quad (10)$$

The thermal losses into the atmosphere are [1, 5]:

$$q_{mti}w_i = q_iF_i \quad (11)$$

The thermal losses into the atmosphere can be calculated as losses in side walls with an increase of the coefficient of the thermal convection exchange of 30 %. This problem becomes calculation of the thermal transfer coefficient as the following formula [3, 4]:

$$q_i = \sum K.\Delta t \quad (12)$$

The thermal transfer coefficient through walls of zones is calculated by:

$$K = \frac{1}{\frac{1}{\alpha_1} + \sum \frac{\delta_n}{\lambda_n} + \frac{1}{\alpha_2}} \quad (13)$$

Based on thermodynamics of the non-reversible process the following formulas are drawn:

- For the forced hot air-flow inside :

$$\alpha_1 = 1{,}715\Delta t^{0{,}033} \tag{14}$$

For the forced hot air-flow outside:

$$\alpha_2 = 1{,}416 l^{-0{,}253}\Delta t^{0{,}249} \tag{15}$$

$$\Delta t = t_{f1} - t_{f2}$$

in which t_{f1} – temperature of hot air-flow in drying zones cab be defined by [1]:

$$t_{f1} = 0{,}5(t_{1i} - t_{2i})$$

t_{f2} - temperature of hot air-flow outside; thus, $t_{f2} = t_0$

Thermal losses taken away by grain (moist material) can be defined by [3]:

$$Q_{vi} = g_{2i}.C_{vi}(t_{v2i} - t_0) \tag{16}$$

$$q_{vi}w_i = Q_{wi} \tag{17}$$

Specific thermal capacity of grains studied by experiment is defined by [2]:

$$100(c - c_k) = (c_a - c_k)w \tag{18}$$

Amount of moisture content which needs evaporating is defined by the formula below [1]:

$$W_i(1-\omega_{2i}) = g_1^i u_1^i - u_2^i \tag{19}$$

$$g_{2i} = g_{1i} - w_i \tag{20}$$

With a system of two equations from (7) to (20), based on Gauxo method the thermodynamic parameters appear in the system of equations can be calculated, and Fig.4 shows a block diagram of thermal transfer for a tower-type dryer.

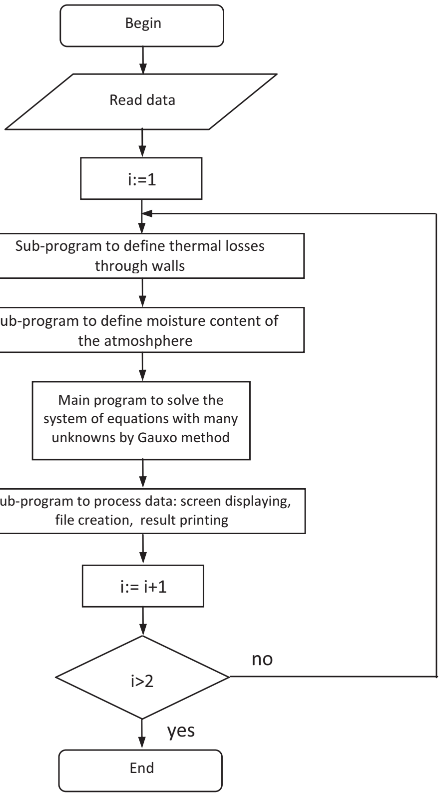


Fig.4. Block diagram to study thermal transfer of the tower-type dryer
i=1 – for drying chamber 1; i=2 – for drying chamber 2

III. EXPERIMENT STUDY

Structure of the tower-type dryer (see Figs. 3 and 5) is composed of drying tower, exhausted drying agent vent-canal, calorifer and fan. The material to be dried is supplied by an elevator and conveyer from the tower top and it travels down. The drying agent goes through the grain bulk (material to be dried), then into the canals and finally is vented into the atmosphere. The tower-type dryer acts as convection drying process. The thermal exchange process takes place in the two currents: grain current (the material to be dried) and hot air current (drying agent). The two currents move in the opposite direction.

Fig.5. Tower-type corn grain dryer designed by author

IV. RESULTS AND DISCUSSION

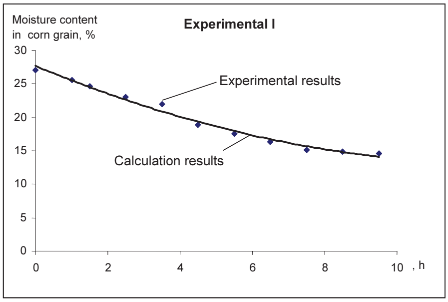


Fig. 6. Comparison of experimental results and calculated results with a_m=0.011 + 0.378u + 5.67u^3 + 0.015ut + 0.232u^{3}t - (1.512 + 0.062t)u^2 in experiment I

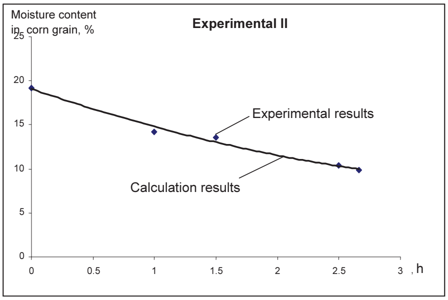


Fig.7.Comparision of experimental results and calculated results with a_m=0.011 + 0.378u + 5.67u^3 + 0.015ut + 0.232u^{3}t - (1.512 + 0.062t)u^2 in experiment II

Figures 6 and 7 show that theoretical study results match the experimental results; hence, the following conclusion can be drawn:

The exchange of heat and material of corrn grain moisture with the ambient atmosphere is mainly through germ layer; therefore, the moisture transfer in the grain can be defined by Li and Morey (1984):

$$MR = (u-u_e)/(u_i-u_e) = exp(-K.t^N)$$

where MR - moisture ratio;

u - moisture content, decimal d.b.;

u_i - initial moisture content, decimal d.b.;

u_e - equihbrium moisture content, decimal d.b.;

K, N - product constants;

t - time, min.

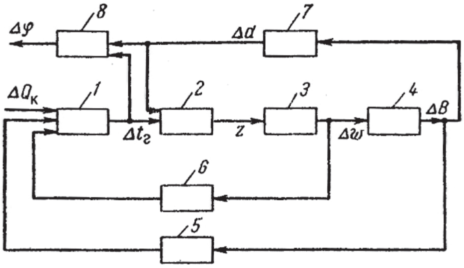
with the experimental rusults, coefficients of the above equation, as follows:

$$\mathbf{K= -0,096914101 - 1,979960571.10^{-4}.t + 0,037766202.t.u}$$
$$\mathbf{N = 1,426585003 - 2,279949923.\ u_i^2 + 6,606504798.10^{-5}.t^2}$$

and the coefficient of moisture decrease:

$$\mathbf{a_m=0.011 + 0.378u + 5.67u^3 + 0.015ut + 0.232u^3t - (1.512 + 0.062t)u^2}$$

With the calculation of moisture conduction coefficients and of heat for the tower-type dryer based on the balance equations of moisture and heat, a controlling diagram for the tower-type dryer is set up as below:



Transfer function 1 – Demonstrating the total heat current in the drying process [1]:

$$Q_k = \frac{1,004t_1 + d_1(2500 + 1,842t_1) - 1,004t_0 - d_0(2500 + 1,842t_0)}{d_1 - d_0}$$

Transfer function 2 – Demonstrating temperature of drying agent t_1 (^oC) depending on the ambient atmosphere d_0 (g moisture/kg air)

$$t_1 = - 0.01d_0^4 + 0.4725d_0^3 - 8.0301d_0^2 + 63.893d_0 - 142.96$$

Transfer function 3 – Demonstrating drying duration related to moisture content and coefficient of moisture transfer

$$MR = (u-u_e)/(u_i-u_e) = exp(-K.t^N)$$

with experimental coefficients of the above-mentioned equations:

$$K= - 0,096914101 - 1,979960571.10^{-4}.t + 0,037766202.t.u$$
$$N = 1,426585003 - 2,279949923.\ u_i^2 + 6,606504798.10^{-5}.t^2$$

and coefficient of moisture decrease

$$a_m= 0.011 + 0.378u + 5.67u^3 + 0.015ut + 0.232u^3t - (1.512 + 0.062t)u^2$$

Transfer function 4- Demonstrating intensity of moisture detachment W (kg moisture/h) depending on moisture content of grains u (%)

$$W = - 6E^{-11}u^2 + 122u – 2196$$

Transfer function 5- Demonstrating thermal losses Q (MJ/h) related to the intensity of moisture detachment W (kg moisture/h)

$$Q = - 1E^{-06}W^4 + 0,0027W^3 – 1,9926W^2 + 648,87W – 78350$$

Transfer function 6 - Demonstrating thermal losses Q (MJ/h) related to on moisture content of grains u (%)

$$Q = 0,4167u^4 – 36,667u^3 + 1209,6u^2 - 17436u + 92463$$

Transfer function 7- Demonstrating intensity of moisture detachment W (kg moisture/h) related to moisture content of the ambient atmosphere d_0 (g moisture/kg air)

$$W= 488$$

Transfer function 8 – Demonstrating the relative humidity depend on and moisture content of the drying agent [1]:

$$\varphi = \frac{0,98d}{(0,621 + d)e^{\left(12 - \frac{4026,42}{235,5t}\right)}}$$

V. CONCLUSION

All experiments in the tower-type dryer model help to build its kinetic model in the process of corn drying in the condition of Vietnam.

From the established experiments, transfer functions show a structure of indirect drying when input temperatures are changed.

Obtained results uncover a research direction in building control systems for tower-type dryers in the condition of Vietnam.

VI. REFERENCES

[1] Tran Van Phu. Calculation and design of drying system, Education Publishing House, 2002.

[2] Tran Van Phu. Movement of many constituents in processes of technology and the method to define properties of thermal transfer and matter transfer in moist materials, PhD dissertation, Riga 1988.

[3] Dang Quoc Phu, Tran The Son, Tran Van Phu. Thermal transfer, Education Publishing House, 1999.

[4] Tran Hong Thao, Nguyen Van Lien, Truong Ngoc Tuan. Building mathematic model for tower-type dryer to dry bulk agro-products, Journal of thermal energy, No. 95-9/2010.

[5] Tran Hong Thao, Nguyen Van Lien. Making survey on moisture transfer in corrn grain, Journal of thermal energy, No. 96-11/2010.

[6] Tran Hong Thao, Truong Ngoc Tuan, Le Tien Muoi. Determination of coefficient of moisture transfer in corrn grain. Journal of military scientific and technological studies, No. 16-12/2011

[7] Pham Cong Dung. Study on fluidized process and equipment, applied in grain drying and storage, PhD dissertation, Hanoi 2000.

[8] Tran Hong Thao. Applied research on adaptable control in drying equipment for agricultural grains with capacity below 10 tonnes per batch, Research project at ministerial level, 2005

[9] G. A. Korn and T. M. Korn. Mathematical Handbook for Scientists and Engineers, 2nd ed. (McGraw Hill, New York, 1973).

[10] Holman J., Heat transfer, Mc Graw-Hill, New York 1992.

[11] Courtois F., Dynamic modelling of Drying to improve Processing Quality of Corn, ENSIA, France, 1997.

[12] Johnner P. Sitompul, Istadi and I. N. Widiasa, Modelling and simulation of deep-bed grain dryer, Drying Technology 19 (2) – 269 – 280, 2001.

[13] Maier E. D and F.W. Bakker-Arkema, Grain Drying System, GEAPS FDC, 2002

[14] E. Mirzahoseinkashani and N. Kasiri, Mathematical Modelling of a cross flow conveyor Belt Dryer, Scientia Iranica, Vol. 15, No. 4, 2008.

[15] Г. Н. Положий, Н. А. Пахарева, И. З. Степаненко и др. Математический практикум. Государственное издательство физико-математической литературы. Хорошая, 1960 г.

[16] Гержой А.П., Самочетов В.Ф. Зерносушение и зерносушилки. Колос, Москва, 1967 г.

[17] И. П. Баумштейн, Ю. А. Майзель. Автоматизация процессов сушки в химической промышленностию. Издательство "Химия", 1970 г.

[18] М.В. Лыков. Сушка в химической промышлености. Издательство Химия, Москва, 1974 г.