International Conference on Control, Engineering & Information Technology (CEIT'14)
Proceedings – Copyright IPCO-2014
ISSN 2356-5608

Modeling and Simulation of Heat Transfer in Cereal Storage System

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Abstract

This study focuses on the development of a mathematical model describing the phenomena of heat transfer in the grain mass during the storage period and the control of the airflow of the aerated cereal in the silo. Therefore, the improvement of air flow characteristics in the aeration of grain is extremely important for a long and safe storage. The model simulation was intended to control the air temperature as well as the grain temperature inside the grain silo by the variation of ventilation rate.

Keywords— Grain storage, Heat transfer, Modelling, Simulation

I. Introduction

Food-processing industry is the sector more affected by moisture, in particular the cereals. At harvest, the cereals will be stored in silos. This need for storage over a long period of time requires an accurate control of the temperature and the moisture content of the product [1]. The retention of grain quality requires understanding the role of two major factors: low temperature of storage and low moisture content grain. The hygroscopic property of forced air flowing through the silo will be controlled using dehumidifier for cooling and equalizing of air temperature notably that of cereals and moisture removal.

Thus, the objective of this study is to find out suitable model and to analyze the effect of the air temperature on the grain mass as well as the moisture content.

II. Materials and Methods

Fig.1 describes our system composed of a cylindrical silo filled with grain. The moist air at the silo outlet will be recycled by a dehumidifier to reduce its moisture content. To maintain humidity until a safe level and a constant desired temperature, the dry air at the outlet of dehumidifier will be blown into the silo through a ventilation system.

The cylindrical metal silo has 0.636 m of diameter with 1m of height was divided into 10 control volumes of 0.1m height as it shown in Fig.2 and was filled with around 210 kg of wheat grain. An air stream at constant temperature and relative humidity was blown through the mass of grain which will be aerated. In order, to maintain air properties constant a dehumidifier was proposed. The dry air at the exit of the dehumidifier is impelled by an axial fan (Automelec, Model AX015) to provide the forced ventilation through wheat grain.

Heat balance in the air

$$\rho_a V_a C_a \frac{dT_a}{dt} = \dot{m}_a C_a (T_{ain} - T_a) - h_{ca,g} A_g (T_a - T_g) - h_{ca,w} A_w (T_a - T_w) \quad (1)$$

Heat balance in the grain:

$$m_g C_g \frac{dT_g}{dt} = h_{ca,g} A_g (T_a - T_g) \quad (2)$$

Heat balance in the silo wall:

$$\rho_w V_w C_w \frac{dT_w}{dt} = h_{ca,w} A_w (T_a - T_w) - h_{dw} A_w (T_w - T_{am}) \quad (3)$$

The air-grain mass transfer is described with a kinetic equation. The moisture ratio is expressed as :

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (4)$$

$$MR = \exp(-Kt) \quad (5)$$

$$K = 635.1 \exp\left(\frac{3766.1}{Ta + 273.15}\right) \quad (6)$$

The equation of mass conservation is given by:

$$\rho_a V_a \frac{\partial Xa}{\partial x} = -(1-\varepsilon)\rho_g \frac{\partial M}{\partial t} \quad (7)$$

The equation of air mass conservation is written:

$$X_a(t) = \frac{\Delta x}{\rho_a V_a} \frac{(M_e - M_0)}{K} \rho_g (1-\varepsilon) e^{-Kt} + X_{a0} \quad (8)$$

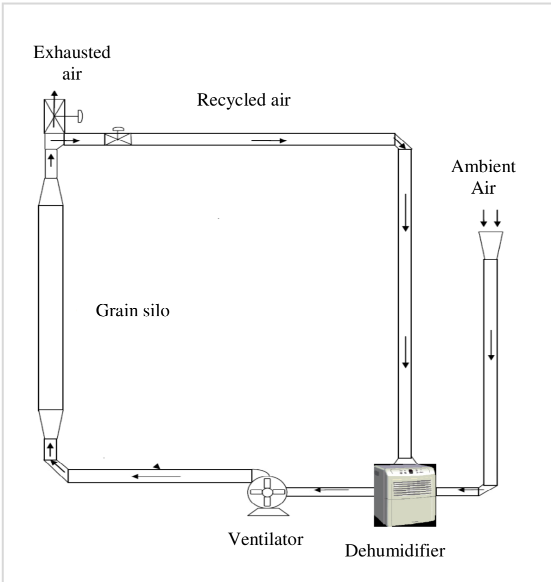

Fig. 1 Schematic Diagram of the Cereal Storage System

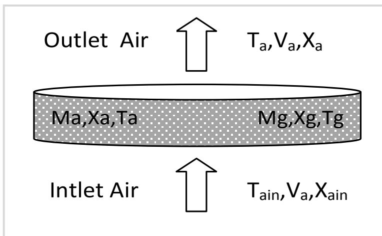

Fig. 2 Schematic Diagram of the Control Volume

The model equations were programmed using Simulink-Matlab.

III. Results and Discussion

Fig.3 shows the evolution of the air temperature initially at 25°C. The exit air temperature was raised to 26.4°C, it is explained by the heat gains from grain mass during the cooling process. The increase of air temperature describes the evaporative power of the interstitial air which makes the time of rise shorter. It is important to notice that the air velocity and the inlet temperature affect the variation of the interstitial air temperature. Fig.4 shows the evolution of the grain temperature subjected to forced-air ventilation with air at a temperature of 25°C and a velocity of $1 m.s^{-1}$.The initial grain temperature was about 30°C. When this grain was subjected to forced-air ventilation the temperature dropped to around 29,9°C. Grain located far away the air inlet, took more time to cool than grain located near from the air inlet.

The air temperature has an effect on the variation of the grain moisture content as shown in Fig.5, this result was also demonstrated in other research publications [12-13]. The variation of grain moisture ratio with time is shown in Fig.6. The moisture ratio decreases quickly in the first few hours and indicates an insignificant effect on wheat moisture ratio later. The changes of the air temperature effect considerably in the drying kinetic.

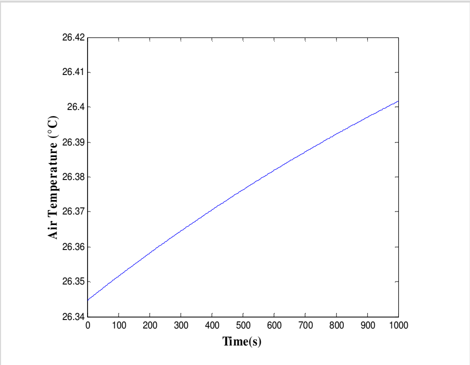

Fig. 3 Variation of air temperature for T_{ai}=21°C et V=1m/s

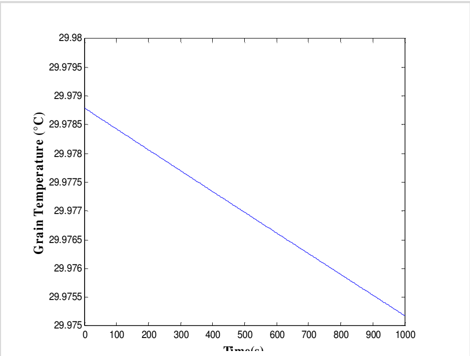

Fig. 4 Variation of grain temperature during the aeration

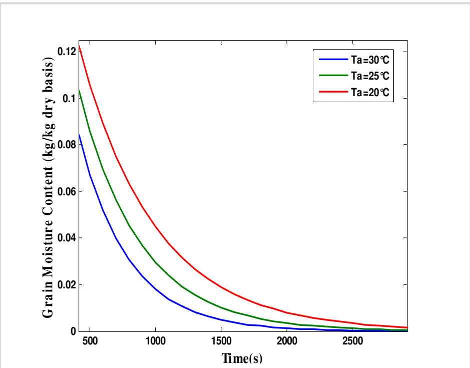

Fig. 5 Grain moisture content variation for different temperatures

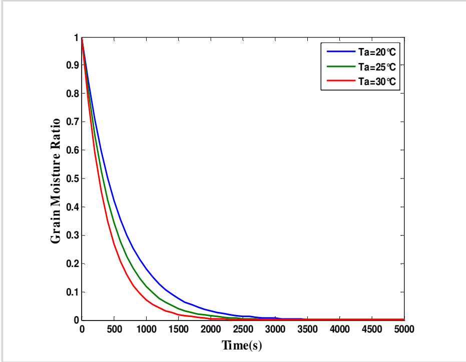

Fig. 6 Moisture ratio variation for different temperatures

IV. CONCLUSION

A mathematical model based on heat and mass balances was developed to simulate the evolution of grain and air temperature in wheat storage silo with forced air ventilation. The results of simulation summarize the effect of the airflow characteristics on the grain temperature and its moisture content. The model parameters used allow to predict the variation of the grain temperature and the properties of air to cool the stored grain under different ventilation conditions.

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