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Numerical modeling of the horizontal flow and concentration distribution of nitrogen within a stored-paddy bulk in a large warehouse

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Abstract

The insect population in grain stores can be kept under control by maintaining a high concentration of N_2 gas throughout the grain bed. The development of controlled atmosphere storage technology for insect control requires an accurate prediction of the distribution of introduced gases in bulk grain. In this paper, based on the convective-diffusion model, the horizontal flow of N_2, which was introduced into the paddy bulk in a large warehouse by means of the horizontal ventilation system, are modeled as fluid flow in a porous medium. The experimental data for N_2 transfer and flow through ducts and bulk paddy were used to validate the model. The equations were solved using the finite difference method, and the predictions from the proposed model were in good agreement with the experimental results. The concentration distribution and flow uniformity of nitrogen in stored paddy were also analyzed during the nitrogen-filling procedure for CA storage. It was shown that it is feasible and practical to introduce nitrogen into stored bulk grain in a large warehouse by means of the horizontal ventilation system.

Keywords: numerical modeling, stored paddy, concentration distribution, nitrogen-filling procedure

1. Introduction

Chemical control methods such as fumigation with phosphine are effective against insect pests, but have disadvantages including residue problems and development of tolerance by insects (Banks et al.,1990). In the recent past, the use of controlled atmosphere (CA) as a safe residue-free alternative to chemical fumigants and protectants has gained popularity for controlling insects infesting stored grain. Controlled atmosphere with low oxygen (O_2) and high nitrogen (N_2) in storage by injecting nitrogen into the storage displacing the oxygen is just one of a number of methods that can be used for controlling pests in stored products.

Controlled atmosphere storage for insect control involves the alteration of the proportion of the normal atmospheric gases, i.e., N_2, carbon dioxide (CO_2) and O_2, to create an atmosphere that is lethal to the insects. The success of CA and fumigants in killing stored product pests depends on the movement of gas through and uniform distribution of the gas in the stored grain, and maintaining a lethal gas concentration level for the required exposure period.

Three-dimensional heat, mass and momentum transfer models with concentration species were developed by Singh et al. (1993), Lawrence et al. (2013a, 2013b) and Mat Isa et al. (2014) for predicting fumigant concentrations in a rectangular domain or cylindrical silo. These models need to be validated under a wider range of conditions, and can then be used to evaluate causes of fumigation failures and to develop best management practices to prevent the failures. Although the Lawrence et al. model was not validated, it included gas sorption and insect extinction models which were empirically based.

A mathematical model of the three-dimensional movement of CO_2 in stored wheat was solved using the finite-element method (Alagusundaram et al., 1996a, b). The model simulates the initial bulk flow of CO_2 as it sublimates and expands from a dry ice source. The mean relative errors between the predicted and measured CO_2 concentrations in a bin with an open top surface were 24% at 3 h and 16% at 21 h. The model developed by Alagusundaram et al. (1996c) handles the loss of CO_2 by modifying boundary conditions. It can predict the CO_2 concentrations at any point in a grain bulk stored in any shape or size structure and can be used by engineering designers to determine the best location for adding CO_2, the approximate amount of CO_2 needed, and the expected level of insect mortality. The boundary conditions for gas transfer models in stored grain can be quite variable (Jayas, 1995). The CO_2 leaving the grain surface will diffuse rapidly into the head space air. If the head space is not well ventilated by wind through openings in the roof and wall, the CO_2 concentration may rise above the atmospheric level. The top surface could be covered with a gas impermeable sheet, resulting in zero flow across the boundary.

Uniform and fast application of N_2 to all parts of the grain storage is fundamental to effective pest management. However, relatively few studies have been reported on the movement of N_2 through the stored grain and uniform distribution of N_2 in the stored grain. This study investigated the flow and concentration distribution of nitrogen inside a grain storage structure during the nitrogen-filling procedure. The specific objective was to model the flow uniformity of nitrogen within a stored-paddy bulk in a large warehouse using computational fluid dynamics. In this paper, the horizontal flow, concentration distribution and uniformity of nitrogen were evaluated and verified within a stored-paddy bulk in a large warehouse during the nitrogen-filling procedure by means of a ventilation system.

2. Materials and Methods

2.1. Controlled atmosphere (CA) grain storage model

The simulation used a 3-dimensional model of a stored paddy warehouse with dimensions of 18 m wide, 50 m long and 5.0 m flat height. The flat top surface of the stored paddy was covered by a gas impermeable sheet of polythene (Fig. 1). The stored grain was represented by a porous zone. Nitrogen from a nitrogen generator was introduced into the stored paddy at the main horizontal and branch vertical perforated ducts on the north side, then cross-flowed the stored paddy to the main and branch perforated ducts on the south side using suction fans which exhausted the gas to the outside of the warehouse.

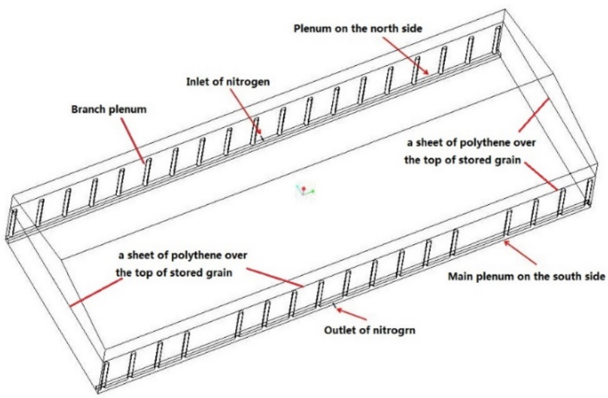

Fig. 1 Schematic diagram of the horizontal ventilation system.

2.2. Mathematical Model and CFD Model Parameters

2.2.1 Mathematical model of nitrogen flow and convection-diffusion in stored grain mass

The physical processes that occur in bulks of stored grain obey conservation laws. These phenomena were captured mathematically by a partial differential equation of the form:

$$\varphi \frac{\partial C}{\partial t} + u_j \frac{\partial C}{\partial x_j} = \frac{\partial}{\partial x_j}\left[D_{eff} \frac{\partial C}{\partial x_j} \right] \tag{1}$$

where φ is the grain bulk porosity (φ =0.55), u_j is the component of velocity in the jth direction (m/s), t is the time (s), C is the nitrogen concentration (species fraction) in stored grain, D_{eff} is the nitrogen effective diffusion coefficient in stored grain (D_{eff} =2.46 * 10^{-5} m^2/s) (Thorpe, 2008).

2.2.2 CFD model parameters

ANSYS Fluent was used to solve the transient species transport model. For the porous zone, a porosity of 0.55 for paddy and a computed viscous loss coefficient of 2.037 x 10^8 /m^2 were used as inputs; the inertial loss coefficient was 26767 (Pa•s^2/kg) (Thorpe, 2008). Nitrogen inlet was given a fixed velocity of 5.0 m/s, i.e., the volume flow rate of nitrogen at the inlet was 60 m^3/h. The concentration of nitrogen at the entrance was 0.998 (species fraction). The initial temperature was assumed 25°C. The walls were considered no-slip wall boundary conditions. The initial species mass fractions were assumed 0.78 for N_2 and 0.22 for O_2.

3. Results

3.1 Numerical simulation results and analysis

Fig. 2 shows the streamlines of nitrogen flow in the stored paddy. It can be seen that the nitrogen uniformly entered from the ducts on the north side, then cross-flowed through the stored paddy with a superficial velocity of 6.67×10^{-5} m/s to the ducts on the south side. Fig. 3 shows nitrogen continues to move forward horizontally in the grain mass covered by a sheet of polythene. The average concentration of nitrogen in the grain mass was above 0.99 (species fraction) when the time of the nitrogen-filling procedure was about 61 hours (above 2.5 days) (Fig. 4), while nitrogen concentration of the outlet reached 0.978 (species fraction). According to the standard of CA with nitrogen in China (more than 0.97), the nitrogen-filling process can be stopped at this time.

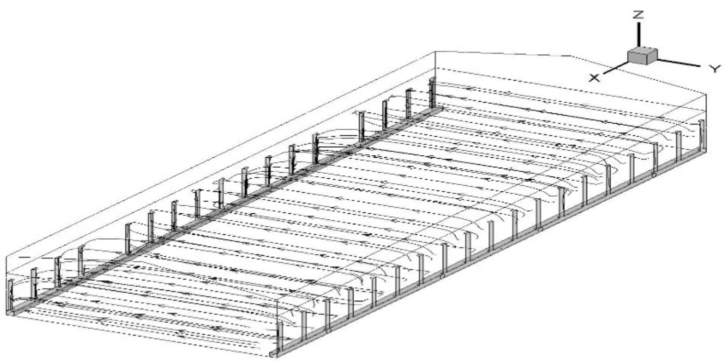

Fig. 2 The streamlines of nitrogen in the stored paddy inside the storage warehouse.

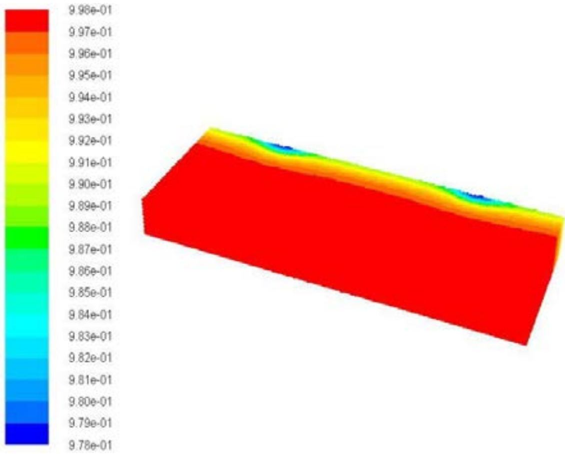

Fig. 3 Distribution of nitrogen concentration at 61 hours during the nitrogen-filling procedure in stored paddy.

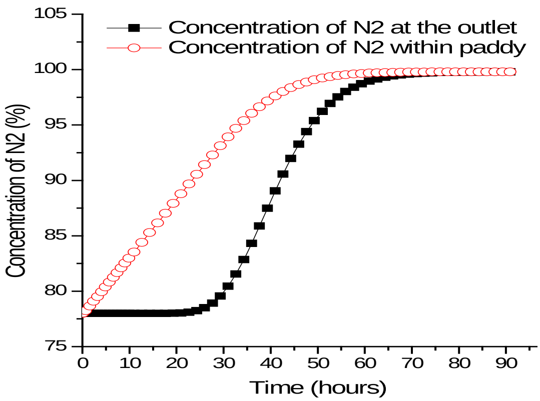

Fig. 4 Variation of nitrogen concentration in stored paddy with the time of nitrogen-filling.

3.2 Evaluation of uniformity of nitrogen concentration in the grain mass

The uniformity index was used to evaluate the uniformity of nitrogen concentration distribution in the stored paddy during nitrogen-filling. The formula of uniformity presented by Weltens (1993) was used to calculate the value of uniformity of nitrogen concentration inside stored paddy. Fig. 5 is a layout of the monitoring points of nitrogen concentration at each level in the stored paddy. For monitoring of the nitrogen concentration, 27 monitoring points at three levels were placed inside the stored paddy, and each layer had nine points. The heights of the monitoring points for the upper, middle and bottom layers were 1, 2.5 and 4 m, respectively, away from the warehouse floor. Each monitoring point was 1 m away from the inner wall of the warehouse. The evaluation of observed and simulated uniformity values of nitrogen concentration distribution inside the stored paddy is summarized in Tab. 1. It was found that the nitrogen gas was distributed uniformly in the stored paddy after 61 hours of nitrogen-filling. A good agreement between the observed and simulated nitrogen concentrations indicated that the model and the parameter values used in the model are applicable for predicting nitrogen gas concentration in stored grains.

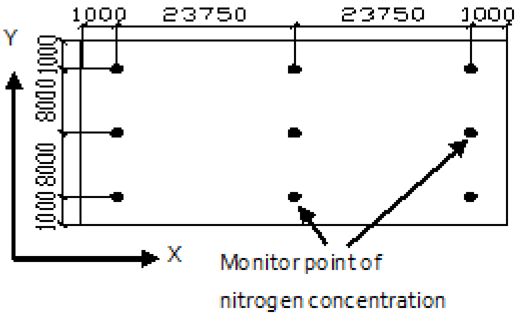

Fig. 5 Layout of monitoring points of nitrogen concentration at each layer in stored paddy.

Tab. 1 Comparison of uniformity values of nitrogen concentration distribution from a field observation and simulation.

	Uniformity of nitrogen concentration in X direction			**Uniformity of nitrogen concentration in Y direction**			**Uniformity of nitrogen concentration in Z direction**		
Location (m)	X=1.00	X=24.75	X=48.50	Y=1.00	Y=9.00	Y=17.00	Z=1.00	Z=2.50	Z=4.00
Value of monitoring (species fraction)	0.9911	0.9897	0.9916	0.9890	0.9997	0.9882	0.9948	0.9936	0.9987
Value of simulation (species fraction)	0.9997	0.9997	0.9997	0.9999	0.9999	10.000	0.9997	0.9997	0.9996

4. Conclusions

Application of controlled atmosphere technology in grain storage using nitrogen is highly efficient, environmentally friendly and safe. It is essential to investigate the movement of gas through the grain mass and the uniformity of gas distribution in the stored grain in order to maintain a lethal concentration level for the required exposure period. In this paper, numerical simulation of the horizontal flow and concentration distribution of nitrogen within a stored-paddy bulk in a large warehouse was conducted. The concentration distribution and flow uniformity of nitrogen were also analyzed during the nitrogen-filling process for CA storage. The following specific conclusions were drawn from this study:

(1) Numerical modeling can accurately predict the flow and concentration of nitrogen inside a stored grain mass during the nitrogen-filling process.

(2) It is feasible and practical to introduce and distribute nitrogen gas into a stored grain bulk in a large warehouse by means of the horizontal ventilation system of the warehouse.

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Study on Rapid Detection of Degree of Freshness of Paddy Rice in China

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Abstract

This paper describes research results and progress of rapid detection of the degree of freshness of paddy. We studied the changes of degree of freshness, fat acidity value and taste evaluated value of paddy under different storage conditions in the laboratory. The correlations between the degree of freshness, fat acidity value and taste evaluated value were analyzed. The results showed that there was a significant negative correlation ($p < 0.01$) between the degree of freshnessand fat acidity value. The correlation coefficient was -0.845. The degree of freshness was significantly positively correlated with the taste evaluated value, and most of the correlation coefficients were above 0.9. The nationwide investigation result of paddy's degree of freshness showed that there was an obvious distinction in the degree of freshness between newly harvested rice and rice harvested in previous years. The degree of distinction of indica rice achieved 85%. Due to its special reasons, japonica rice had a lower degree of distinction, but it also reached 75%.

Keywords: paddy, degree of freshness, fat acidity value, taste evaluated value.

1. Introduction

Rice is a staple food for more than 60% of the world's population, especially in China (Wei et al., 2007). As a primary dietary source of carbohydrates, rice plays an important role in meeting caloric requirements and nutrient intakes (Yang et al., 2006). Aging during storage results in numerous changes in the chemical and physical properties of rice (Patindol et al., 2005; Singh et al., 2006; Sodhi et al., 2003). These changes in pasting properties, color, flavor, and composition affect rice cooking and eating quality (Srikaeo K et al., 2013; Park C E et al., 2012). The fresh rice is prefered in the market in China. So it is particularly important to detect the degree of freshness rapidly during acquisitions, and during daily or long-term storage of paddy rice.

Since 2013, we have developed an instrument which could detect the paddy freshness rapidly for the degree of freshness. The higher the degree of freshness of paddy is, the fresher it is. The detection principle of the degree of freshness of paddy is that milled rice is mixed with special reagent, according to the different contents of ketones and aldehydes, the solution reveals different color. Analysing the spectrum of these colors, we can quantify the degree of freshness of paddy. The instrument is easy to use, and the results are objective and accurate.

In nearly two years, the research on rapid detection of degree of freshness has made new progress. We studied the changes of paddy freshness qualities during different conditions of storage in a