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THE COMBINED ACTION OF LOW-TEMPERATURE, LOW-OXYGEN AND LOW-PHOSPHINE CONCENTRATIONS IN THE "TRIPLE-LOW" GRAIN STORAGE TECHNIQUE

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ABSTRACT

To determine the mechanism of the "Triple-Low" grain storage technique and eventually enable the formulation of comprehensive mathematical models describing the mechanism, we must not only measure the internal heat source (grain respiration) but more importantly, must determine the interactions among phosphine concentration, oxygen concentration, and temperature. A container 1.5m high and 1m in diameter situated in a room with controlled temperature, was used in this study. Distribution of oxygen and carbon dioxide was measured under these conditions when the container was either sealed or not sealed. Temperature distribution was determined either without the release of phosphine or with a low concentration of 0.213g AlP/m^3. Findings revealed that the oxygen concentrations in the upper half of the container decreased and carbon dioxide increased when the container was sealed with a plastic sheet, and that the level of highest oxygen concentration moved downward. Average grain temperature decreased when a low concentration of phosphine was released. Peak temperature decreased by about 1.8°C.

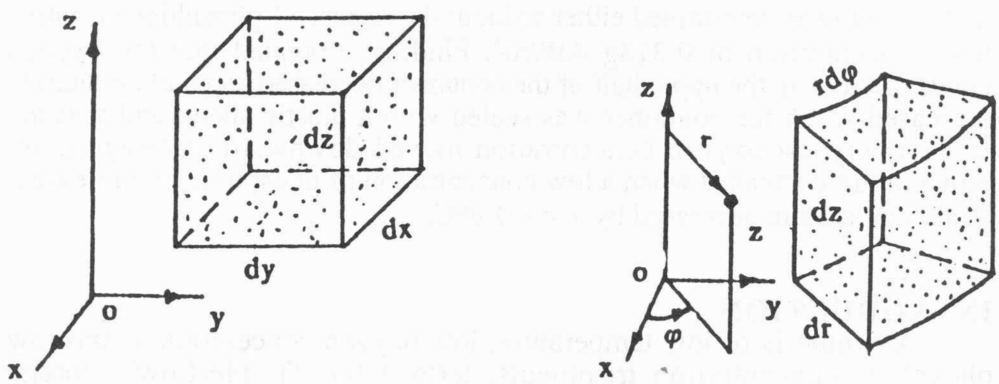
INTRODUCTION

A synthesis of low temperature, low oxygen concentration, and low phosphine concentration treatments, termed the "Triple-Low" storage technique is used extensively in China, especially in Jiangsu province. The quantities of grain stored using this technique amount to 20 million tonnes. By means of this technique, insect damage and quality deterioration of stored grain are controlled effectively and the cost of storage reduced. This technique has been endorsed in the P.R. of China, and is also applicable in other developing countries of South East Asia.

The "Triple-Low" grain storage technique incorporates several storage approaches such as mechanical aeration to reduce temperature, the use of plastic sheeting to seal the grain bulk, and the use of chemical fumigation. These treatments are undertaken according to the grain species, the moisture content (m.c.) of the stored grain, and the season in which the grain is placed in storage. The three treatments - low-temperature, low-oxygen and low-phosphine - constitute the "Triple-Low" technique. In order to investigate this technique in detail, mathematical-physical models can be formulated to describe the fields of grain temperature and gas concentration, and find a solution method. This study is essential in order to predict temperature changes, and gas concentrations, and relate these to the stored grain condition.

HEAT CONDUCTION DIFFERENTIAL EQUATION

Stored grain is a mixture of grain and gas which, if considered as a quasi-continuous medium, can be written as the heat conduction differential equation for an element (Fig.1).



a. Rectangular coordinates b. Cylindrical coordinates

Fig.1: Element of grain-gas mixture.

In rectangular coordinates:

$$\rho C_P \frac{\partial T}{\partial t} = k\frac{\partial^2}{\partial x^2}T + k\frac{\partial^2 T}{\partial y^2} + k\frac{\partial^2 T}{\partial z^2} + q \qquad \text{[Eq. 1]}$$

In cylindrical coordinates:

$$\rho C_P \frac{\partial T}{\partial t} = \frac{k}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{k}{r^2}\frac{\partial^2 T}{\partial \varphi^2} + k\frac{\partial^2 T}{\partial z^2} + q \qquad \text{[Eq. 2]}$$

and where ρ is the bulk mass density of grain, C_P is the specific heat of grain, and k is the apparent heat conductivity of grain. Equations [1] and [2] may be written also as :

$$\rho C_p \frac{\partial T}{\partial t} = k\nabla^2 T + q$$

where q is the internal heat source of grain (respiration heat), caused by physiological reaction of grain, insects and microorganisms. It is mainly a function of the grain species, grain moisture content, temperature, oxygen concentration and chemicals concentration released.

$q = f_1(\text{species}, \phi, T, C_{O_2}, \text{amount of chemicals})$ [Eq. 3]

where ϕ is grain moisture content (%), C_{O_2} is mole concentration of oxygen in gases.

MASS DIFFUSION DIFFERENTIAL EQUATION

There are two equations of mass diffusion which correspond to O_2 and CO_2 respectively:

$$\frac{\partial C_{O_2}}{\partial t} = D_{O_2, CO_2 - N_2} \nabla^2 C_{O_2} + R_{O_2} \qquad \text{[Eq. 4]}$$

$$\frac{\partial C_{CO_2}}{\partial t} = D_{CO_2, O_2 - N_2} \nabla C_{CO_2} + R_{CO_2} \qquad \text{[Eq. 5]}$$

where C_{O_2} and C_{CO_2} are mole concentrations of O_2 and CO_2, respectively; D_{O_2, CO_2-N_2} and D_{CO_2, O_2-N_2} are diffusion coefficients of oxygen in mixture of CO_2-N_2 and that of CO_2 in mixture of O_2-N_2, respectively; R_{O_2} and R_{CO_2} are production terms of mole concentration of O_2 and CO_2, respectively, due to grain respiration (including insect and microfloral respiration). R_{O_2} and R_{CO_2} should be with opposite sign. The definition of ∇^2 is the same as that in Eqs.[1] and [2].

$$R_{O_2} = f_2 \text{ (species, } \phi, T, C_{O_2}, \text{ amount of chemicals)} \qquad \text{[Eq. 6]}$$

$$R_{CO_2} = f_3 \text{ (species, } \phi, T, C_{CO_2}, \text{ amount of chemicals)} \qquad \text{[Eq. 7]}$$

If the grain only takes respiration with oxygen, it is apparent to have

$$R_{O_2} = -R_{CO_2} \qquad \text{[Eq. 8]}$$

EXPERIMENTS

Determination of the term of internal heat source in Eq.[3] relies on experiments. Wang and Di (1989) and Wang (1991) offer measurement methods to determine the heat of grain respiration. The calculation methods and value tables for the two diffusion coefficients in Eqs.[4] and [5] may be found in Welty *et al.*(1976).

Equations [6] and [7] both need experiments for determination. Apparently, it is practical to take single-effect experiments under conditions of constant temperature in the laboratory.

The test container was a cylinder 1.5 m high and 1.0 m in diameter. It contained 600 kg grain and was equipped for measurement of the distribution of temperature, O_2 concentration and CO_2 concentration. Two conditions are possible at the surface layer of the grain: one that the surface is sealed with a plastic sheet, and the other that it is exposed to the atmosphere. Following this, two different boundary conditions are presented for Eqs. [4] and [5]. At the upper grain surface sealed with a plastic sheet:

$$\frac{\partial C_{O_2}}{\partial z} = 0 \qquad \text{[Eq. 9]}$$

$$\frac{\partial C_{CO_2}}{\partial z} = 0 \qquad \text{[Eq. 10]}$$

or for the upper surface exposed to the atmosphere:

$$C_{O_2} = 0.21 \cdot C_{AIR} \qquad \text{[Eq. 11]}$$

$$C_{CO_2} = 0 \qquad \text{[Eq. 12]}$$

Therefore, the condition of the surface layer, whether sealed or without the plastic sheet, should produce a different distribution of gas components. From Eq.[3], we know that a different distribution of the gas component will lead to a different distribution in internal heat source q, thus Eqs. [1] and [2] will determine the different distribution of temperature.

Table 1 (a) and (b) gives the mole fractions of O_2 and CO_2 at different depths within the grain, with or without the sealed plastic sheet. Mole fractions of O_2 at the upper levels of the grain were reduced from 18.8-16.0 % and 16.6 - 14.4% due to the plastic sheet seal.

Table 1 (a): Distribution of gas fractions when grain was sealed with plastic sheet.

Distance from top (cm)		20	30	40	50	60	70	80	90	100
mole fraction	CO_2	4.4	4.4	4.6	5.8	6.2	6.0	6.6	7.0	7.4
(%)	O_2	16.0	16.0	15.8	14.4	14.6	14.8	13.6	13.0	12.6

Table 1 (b): Distribution of gas fractions without plastic sheet to seal the grain.

Distance from top (cm)		20	30	40	50	60	70	80	90	100
mole fraction	CO_2	1.8	2.6	3.2	4.8	5.0	6.4	7.4	8.4	9.8
(%)	O_2	18.8	17.8	18.6	16.6	15.8	14.8	13.8	13.2	12.2

Release of phosphine under sealed plastic sheeting will restrain insect, microfloral and grain respiration, and consequently the distribution of temperature inside the cylinder will change. A comparison of changes in temperature distribution is given in Fig. 2 (a) and (b). The amount of phosphine released was 0.213 g/m^3, - much lower than the standard recommended dosage. From Fig. 2 it can be seen that the highest temperature point was reduced by about 1.8^{o}C and the peak of the curve of temperature distribution shifted about 20 cm downward. This was due to the reduced oxygen fraction leading to a reduction in the heat of respiration.

Based on work carried out by Wang and Di (1989) and Wang (1991), the respiration heat, which is the heat source term in Eq.[3] can be treated as follows:

$$q = a \bullet EXP\left(-\frac{b}{T}\right) \cdot \quad (W/m^3) \qquad \text{[Eq. 13]}$$

where constant a is a function of humidity ϕ(%) and T temperature (K), for a given grain species,

$$a = \alpha_1 + \alpha_2 \phi \qquad \text{[Eq. 14]}$$

and constant b is also treated as a function of humidity ϕ, T, (%), for a given grain species,

$$b = \beta_1 + \beta_2 \phi, \qquad \text{[Eq. 15]}$$

where a_1 and a_2, and b_1 and b_2 are constants given in Table 2.

Table 2: Constant values of α_1 and α_2 and β_1 and β_2 for the calculation of heat of respiration in different types of grain.

Grain Species	Round Rice	Long Rice	Wheat
α_1	-2.2417×10^{20}	9.0162×10^{13}	3.0042×10^{16}
α_2	1.6012×10^{21}	-6.3590×10^{14}	-2.1939×10^{7}
β_1	-5.5036×10^{4}	1.5167×10^{4}	1.2820×10^{4}
β_2	4.1742×10^{5}	-4.4673×10^{4}	-6.7577×10^{4}

The comparison of Eq.[13] with the experimental data from Wang and Di (1989) and Wang (1991), is shown in Fig. 3. The maximum relative error value is within 8.346%.

CONCLUSIONS

From the above analyses and experiments, the following general conclusions can be drawn:

1) The formulation of a set of differential equations of heat and mass diffusion, to investigate a numerical solution, is an essential step in the study the "Triple-Low" grain storage technique.

2) "Triple-low" does not involve the use of three isolated conservation techniques, but of combined factors. This must be considered comprehensively with clarification by the approach of numerical calculation.

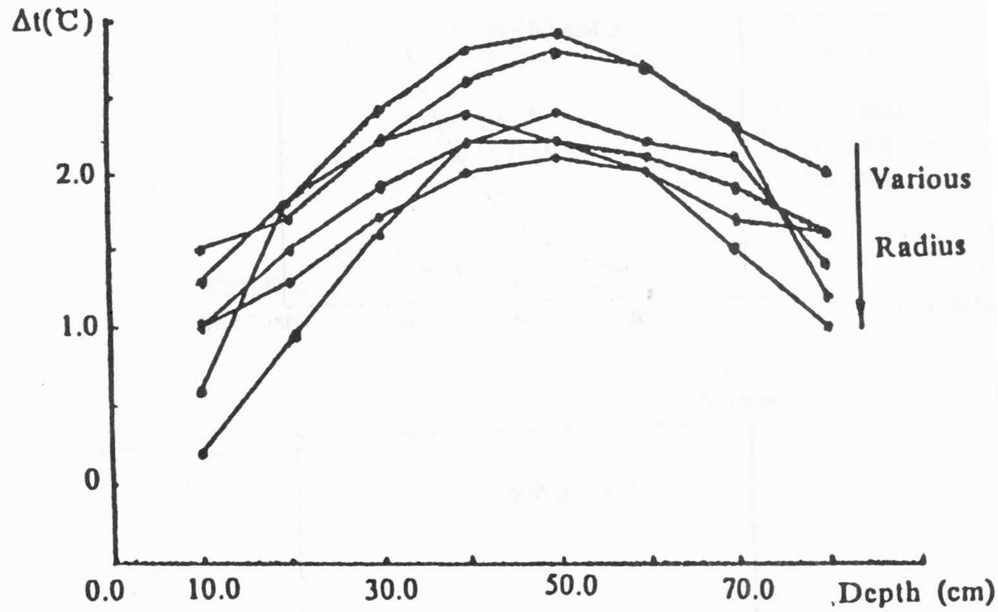


Fig. 2 (a): Distribution of temperature in container after phosphine release at 0.213g/m³.

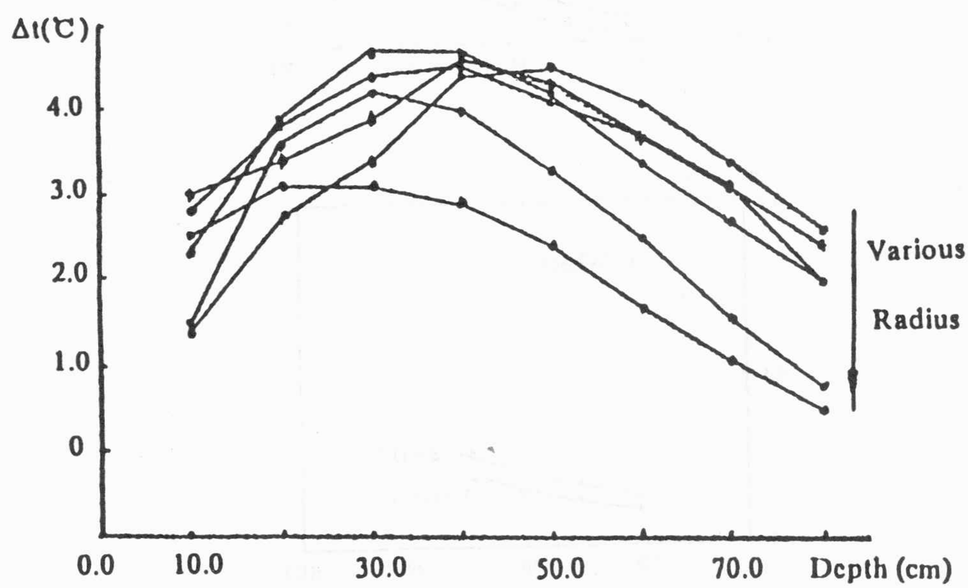


Fig. 2 (b): Distribution of temperature in container without phosphine.

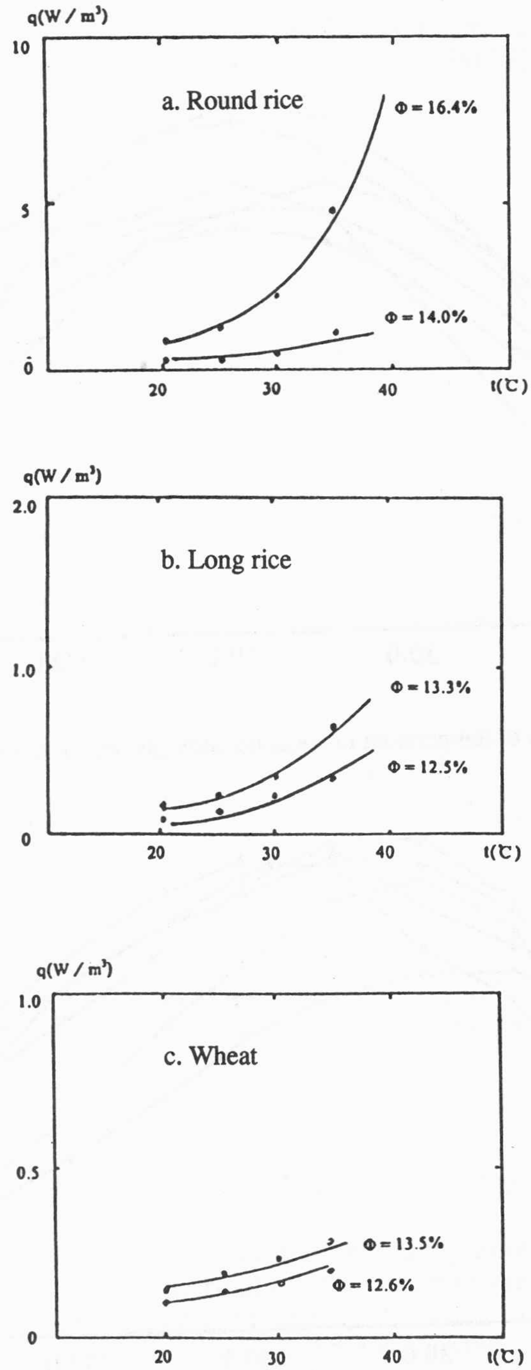


Fig. 3: Experimental and calculated values of heat of respiration in different types of grain. (curves obtained from Eq. 13).

3) The sealed plastic sheet over the grain surface changes the boundary conditions of oxygen diffusion that reduces mole fraction oxygen and restrains the heat source of grain. It is one aspect of the contributing factors.

4) After a low-concentration of phosphine is released, respiration of the grain, insects and microorganisms is restrained, and maximum temperature is reduced by 1.8°C. This is another aspect of the contributing factors.

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