Grain aeration system controlled by computer

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Abstract

A mathematical model based on experiment work was constructed to predict the effect on grain aeration of changing physical parameters. The variation of these parameters was observed in order to define the most effective way to control aeration. With this information, computer controlled aeration systems have been possible.

Introduction

In China, grain aeration is one grain storage technology which has been extensively applied in recent years. How to control the aeration process scientifically and efficiently is a very important subject. In the past, setting temperature, humidity or time alone was often used for aeration control. However, this is not very efficient or suitable in many areas in China where there are great changes in air temperature, high humidity and different grain types.

Over the past few years, we have been researching and experimenting with using computers to control aeration. By building a mathematical simulation to imitate the changes of each parameter in the aeration process, the best time for aeration can be calculated and selected by computer. Equipment for grain aeration control by computer manufactured in Tianjin city in 1990 has been been put into use extensively in China. This paper will discuss some theoretical and practical problems associated with this research.

Grain Equilibrium Absolute Humidity and the Conditions of Aeration Control

In controlling the grain aeration process, the main problem is to correctly select a group of atmosphere parameters, such as the upper and lower limits of temperature, humidity and conditions of dew point, etc. This group of parameters must satisfy the following requirements:

First, it must satisfy the specific aim of aeration, for example, it must select completely opposite conditions of humidity in two different kinds of aeration: reducing moisture content or regulating grain quality (increasing moisture content of grain slightly in order to improve grain milling quality).

Second, it must satisfy not only the efficiency of aeration, but also the time required for aeration, which is the key to reducing energy use and costs.

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Third, it must avoid adverse effects, for example, if you want to lower temperature, you must protect the grain from gaining moisture.

Fourth, it must ensure the security of aeration, in particular, protecting the grain from dewing.

For all of these conditions to be satisfied at once, it is necessary to find the best equilibrium point for many factors.

The first part of this process concerns the relationship between the moisture content of the grain and the humidity of the air. Figure 1 is an equal temperature curve of the moisture content of grain and the relative equilibrium humidity. It is a 'S' curve which is composed of an absorption curve and an opposite absorption curve. Its shape and location is dependent on the temperature and species of the grain. Because in most cases of aeration, the grain is in a state of opposite absorption, and in reality the r.h. of the atmosphere is not less than 20%, the mathematical simulations use the curve of opposite absorption and only similate the part of the curve where r.h. exceeds 20%. Regression analysis of the relation between the moisture content and the equilibrium humidity was determined for five grain species: wheat, maize, paddy, rice and soya bean.

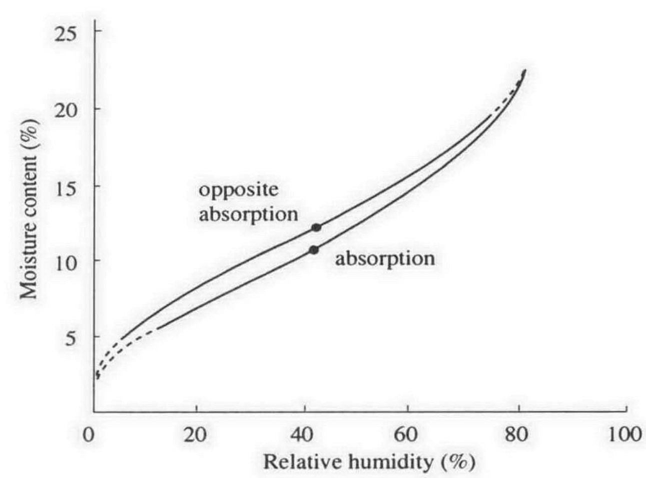

Fig. 1. The equal temperature curve of the moisture content of grain and the relative equilibrium humidity.

These were then incorporated in a mathematical simulation (MS) which represents the relation between grain moisture content and the equilibrium humidity. It is:

The equilibrium relative humidity (r.h.);

r.h.(%) = e(K1X+Y+A)/B1

The equilibrium absolute humidity (AH);

Ps2(mmHg) = e(K2X+Y+A)/B2

The absolute humidity of atmosphere;

Ps1(mmHg) = e(K3X+Z+C)/B2

The temperature of dew point;

T(°C) = D/p+E

Where:

A, B1, B2, C, D, E are constants;

K1, K2, K3 is relevant to grain species;
X is relevant to grain temperature;
Y is relevant to grain moisture;
Z is relevant to r.h.;
p is relevant to the equilibrium absolute humidity.

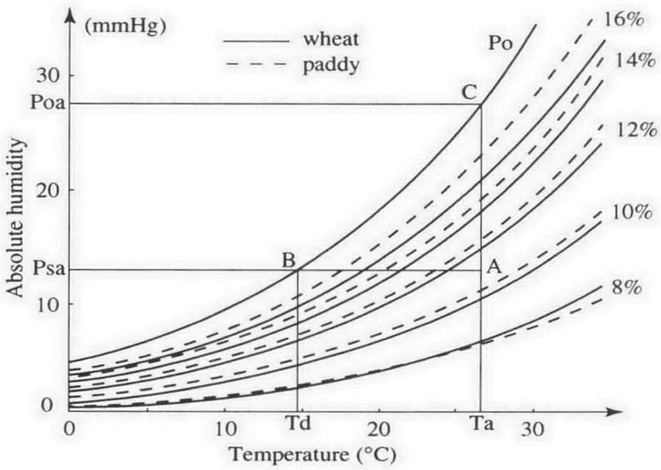

Fig. 2. The curve graph of grain equilibrium absolute humidity.

Using experimental data, the MS then produced the curves for grain equilibrium absolute humidity (Fig. 2). In Figure 2 the ordinate is the absolute humidity (unit: mmHg), the curve Po is the curve of saturation absolute humidity of atmosphere under one atmospheric pressure, the rest are curves of the equilibrium absolute humidity of grain, showing the variation of the equilibrium absolute humidity of grain under different conditions of temperature and moisture content. The project of point A on the ordinate and abscissa presents the absolute humidity, Psa, and temperature, Ta, of this point. The projection of points B and C on the ordinate and abscissa of the curve, represents the temperature of dew point Td and the saturation absolute humidity Poa of point A; the radio of Psa/Poa is r.h.(%) of point A. If the moisture content which is on the curve of grain equilibrium absolute humidity across point A is W%, the Psa, r.h.a and Td respectively represent the grain equilibrium absolute humidity, the equilibrium r.h. and grain temperature of dew point of point A.

If the equilibrium absolute humidity of the different grain species is different under the condition of same temperature and moisture content, then from Figure 2, it can be seen that the homologous points of dew and equilibrium r.h. are also different. Therefore the difference in grain species must be considered in the aeration process.

The following examples illustrate the relationship between these different parameters and the condition of aeration control.

Example 1. Judging whether a grain depot can be ventilated for cooling given the following conditions: the wheat temperature is 30°C, the moisture content is 11.5%, the atmosphere temperature is 20°C, r.h. is 80%.

When the moisture content of the wheat is 11.5%, temperature (Ta) is 30°C, its homologous point is A, then from Figure 3:

the equilibrium absolute humidity: Pa = 16.4 mmHg
the saturation absolute humidity: Poa = 31.6 mmHg
the equilibrium r.h.: r.h.a = Pa/Poa = 51.9%
When atmosphere temperature Tb = 20°C,
the saturation absolute humidity of atmosphere:
Pbb = 17.3 mmHg,
the absolute humidity of atmosphere:
Psb=17.3 × 80% = 13.9 mmHg.

Comparing point A with B: the r.h. of point B is higher than point A, but its absolute humidity is lower than point A, showing that the moisture of grain will not increase during aeration, so the condition of humidity in aeration can be fulfilled. Technology Regulations of Grain Aeration (Commercial Ministry, PRC) state that the difference in temperature between the grain and atmosphere in the beginning of ventilation cannot be less than 8°C, which means that in this case, the upper limit of atmosphere temperature is 30°C–8°C = 22°C (line CD). In this example then, the air temperature is lowered to 22°C, and this satisfied the requirements of the conditions concerning temperature and so the grain depot may be ventilated.

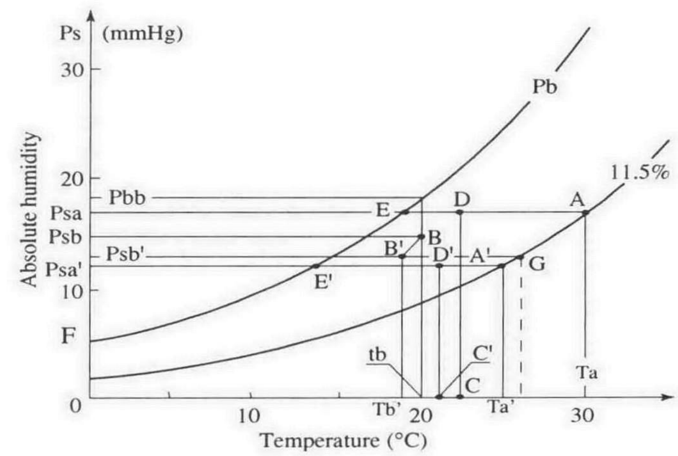

Fig. 3. The analysis of the wheat aeration for reducing temperature. The fold line CDEF gives a border conditions of ventilation, which looks like a 'window'. If the state of atmosphere is within the 'window', the ventilation is permitted, otherwise, it is not.

Example 2. If the temperature of wheat in example 1 after ventilation is lowered to 25°C, the moisture has not changed, the atmosphere temperature is lowered to 19°C, and the r.h. of atmosphere is lowered to 77%, should aeration be continued or not?

The Technology Regulations of Grain Aeration further state that the difference in temperature required to stop ventilation is 4°C. That is to say, the upper limit of atmosphere temperature is 21°C (line C'D', Fig. 3), thus the temperature of atmosphere is still suitable for aeration.

Because of the reduction of grain temperature, the state of the grain moved from point A to A' (Fig. 3), equilibrium AH reduced to 11.7 mmHg; and the state of atmosphere moved from B to B', AH reduced from 13.9 mmHg to 12.5 mmHg. Now the 'window' is C'D'E'F, point B' has already moved away from the 'window'. So if the aeration is continued, the humidity of the grain will increase. This means that the aeration cannot be continued.

From the examples above mentioned it is clear to see the dynamic interation of the parameters in aeration. Now, we can conclude that aeration control is not reliable if constant temperature and humidity set points for the atmosphere condition are used to control ventilation. This is because even though the temperature and humidity set points of the atmosphere condition are suitable for ventilation at the beginning, they may not be satisfactory through the whole process of ventilation.

Table 1. The criteria for determining the possibility of ventilation.

The aim of aeration	The condition of aeration control
Reduce temperature	Ps1<Ps2
	Beginning: t2 – t1 > 8°C
	In sub-tropic areas: t2 – t1 > 6°C)
	During process: t2 – t1 > 4°C
	In sub-tropic areas: t2 – t1> 3°C)
Reduce moisture	Ps1 < Ps21
	t2 > td1
Regulate grain quality	Ps1 > Ps22
	t2 > td1

Where:

t1 — atmosphere temperature;
t2 — grain temperature;
td1 — the temperature of atmosphere dew point;
Ps1 — the AH of atmosphere;
Ps2 — the grain AH where grain temperature is t2;
Ps21 — the grain AH which reduces the moisture of grain by one percent, and the temperature of grain is equal to that of the atmosphere t1;
Ps22 — the grain AH which increases the moisture of the grain by 2.5%, and the temperature of grain is equal to that of atmosphere t1.

Definition of Conditions of Aeration Control

Table 1 outlines the main conditions for control of aeration.

Definition of the temperature limits for cooling aeration

Considering the efficiency of aeration and the opportunity of ventilation, the difference in temperature between the atmosphere and grain must not be less than 8°C at the beginning of ventilation and 4°C during ventilation in all areas except the sub-tropics in China. Because the annual differences in temperature are less in the sub–tropical areas of China, efficiency of ventilation must be partly sacrificed for the sake of ensuring enough opportunity to ventilate. So the differences in temperature should be 6°C in the beginning and 3°C during ventilation.

Definition of the humidity limits for aeration concerned with reducing moisture and regulating grain quality

For reducing moisture, the humidity condition for aeration is the grain equilibrium absolute humidity that reduces the moisture of the grain by 1%, while the temperature of the grain is equal to that of the atmosphere. For regulating grain quality, the humidity condition is the equilibrium absolute humidity that increases the moisture content of the grain by 2%, while the temperature of grain is equal to that of atmosphere. The equilibrium absolute humidity used here is an opposite absorption curve graph, and the homologous moisture value on the absorption curve is generally 2–2.5% higher than that on the opposite absorption curve under the same humidity level. Therefore, we need to add 2.5% moisture to grain moisture as the difference in moisture to compensate the difference between two curves and ensure that the humidity is increased effectively in the process of aeration for regulating grain quality.

Concerning the condition of dewpoint

There are two types of condensation in commodity ventilation: One is called ‘internal dew’, formed from water vapour in the stack, internally condensed on cool air when the temperature of the atmosphere is lower than the dewpoint of the stack. The other is ‘exterior dew’, formed from water vapour in the air condensed onto cool grain when the temperature of the grain is lower than the dewpoint temperature. The ‘internal dew’ has slight effect on ventilation in practice, because the dewing will stop immediately once the hot humid air inside the stack is displaced by large amounts of cool dry air from the outside. Because the moisture content of the grain can be changed by the air drawn into the stack, the ‘exterior dew’ is important. In order to avoid the occurrence of ‘exterior dew’, ventilation should not proceed when the temperature of the grain is lower than the dewpoint of the atmosphere.

The Principle and Practice of Automatic Computer Monitoring of Grain Ventilation

An automatic computer monitor for ventilation of crops has been produced in TianJin. Its characteristics are as follows:

1. Using the mathematic model similar to the equilibrium AH curve of commodities, it can simulate all the variations of equilibrium AH of different species or moisture content of crops which change with grain temperature. Moreover, it can convert the r.h. and AH of atmosphere, dewpoint of grain and that of atmosphere at the same time.
2. According to different purposes of ventilation, it can open a ‘window’ for ventilation with the ideal border conditions. That is, by a decision control procedure, it can define the reasonable ventilating temperature and humidity conditions automatically, then can judge whether the ventilation is permitted or not. Moreover, by using the data concerning atmosphere and grain conditions collected by its sensors, it can rectify the ‘window’ conditions automatically and constantly, so the efficiency and security in the whole process of ventilation is ensured.

The automatic control installation can be used conveniently. Once you install the basic parameters of ventilation purpose, commodity type and moisture content on the keyboard, the equipment can substitute for skilled staff to control the process of ventilation automatically. Moreover, it can forecast and limit the possibility of forming dew. In terms of energy efficiency, it is generally 20–50% better than that of personal control.