Research on the space temperature control of grain bins with groundwater and heat exchanger

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Abstract

As the grain temperature in a grain depot increases in spring and summer, deterioration of stored grain by mildew and pests can become serious. To solve these problems, a temperature control technique for the storage bin using a heat exchanger, fan coil units (FCU) and the abundant groundwater resources in Hangjiahu Lake in southern China was studied. The results indicated that the head-space temperature (HST) of the treated bin was controlled effectively; the maximum HST was less than 26°C. The maximum grain temperature of the surface layer (GT-SL) of the grain mass was less than 25°C in the treated bin, the increasing rate of GT-SL was stabilized. The average grain temperature (AGT) in the whole grain mass was less than 18.3°C. In the control bin, maximum HST was about 36°C, maximum GT-SL reached 28.7°C peak temperature, meanwhile, the rate of temperature increase in grain layers was rapid, with the AGT of 21.0°C. Using heat exchanger technology for 11 wks, the electricity cost was 1.175 RMB/t of grain. Therefore, a quasi low temperature grain storage (QLTGS) has been achieved in the experimental bin with this new method in Zhengjiang Province, China. It will have an important significance for safe grain storage.

Keywords: Grain storage; Low-temperature Grain storage; Groundwater; Heat exchanger; Fan coil unit

1. Introduction

The State Grain Depot (SGDD) of Deqing, Zhejiang is a mesothermal grain storage area of high humidity, which is located in the north of Hangjiahu Plain in Zhengjiang Province, China, and was the fifth of seven grain storage eco-regions of China. Under such conditions, it is easy to cause deterioration of stored-grain quality and serious insect damage during more than two years of storage, which makes it difficult to store grain safely. Therefore, the focus of this storage work is to develop a system to prevent deterioration and insect damage to the grain in this region.

An effective solution to the above problems is to reduce or delay the rise of grain temperature within the bin as much as possible. The SGDD commonly uses the low temperature of autumn and winter for natural ventilation of stored grain, which can drop the average grain temperature (AGT) to 5°C. The grain surface is then covered with a layer of bags filled with rice hulls to insulate the grain surface and delay the effect of outside and storage head space temperature (HST). This can keep the grain bulk in a low temperature state for an extended period of time. In practical application, it is found that though the grain surface is insulated with rice hull bags, the temperature of the bins ascends slowly due to the high outside temperature in the spring and summer. After the summer in SGDD, the AGT rises from 5 to about 25°C; the grain temperature of surface layer (GT-SL) was about 30°C, and the bin HST average was about 36°C. This leads to a c real problem of year-round grain storage of "cooling down is easy, keeping it cool is difficult". Without grain cooling and maintenance technology, depot managers can not achieve the standard requirement of Zhengjiang Province on the low temperature grain storage (LTGS), which allows accelerated deterioration and insect damage of grain.

In grain depots in southern China, a variety of grain storage technologies are studied, such as mechanical refrigeration cooling (Yun, 1998), air-conditioning cooling (Meng et al., 1994; Hu et al., 1997), grain-chiller cooling (Li, 2002) and so on, to focus on resolving the problems of LTGS in summer, or achieving quasi low temperature grain storage (QLTGS). As a result of large investment cost in equipment and high operating costs, the promotion and application of these technologies are limited.

In a large flat bin filled with 1890 t of late paddy in the Central Grain Depot of Huzhou. An improved cold water and heat exchanger within the circulation plumbing was used to achieve a balanced temperature and humidity in the grain mass. During August to September 2006, the average of GT-SL was 25.8-28.1°C, so the system failed to meet the standard of QLTGS (Lu and Zhang, 2007) But, by using the abundant groundwater resources in Hangjiahu Lake and the selecting of a highly efficient heat exchanger, SGDD could develop a temperature control technique with groundwater and fan coil units (FCU). This new technique, with low capital investment, low operating cost and high efficiency, aimed to achieve the QLTGS in bins of SGDD is described.

2. Materials and methods

2.1. Principle

According to the heat exchange principle of fan coil units, deep groundwater of 45 m in SGDD was used moved by water pumps through FCUs placed in the bin head space. The warm air of the head space was ventilated through the fan coil units to reduce air temperature in the test bin. Reducing the head space air temperature reduced the heat conduction into the grain surface and, thus, the grain mass. Thus, AGT rise was slower in the test bin than the control bin.

2.2. Materials

2.2.1. Shape of the experimental bins

The No. 2 and No. 12 bins located in the northern part of SGDD were chosen to be the depot test sites; No. 2 was the test bin, and No. 12 was the control bin. Both bins were horizontal warehouses, with a length of 42.95 m, width of 18 m, eave height of 6.5 m, roof height of 12 m, grain depth of 3.5 m, designed capacity of 2000 t with a volume of 3286 m^3.

2.2.2. The storage conditions of the grain

The basic design factors of the test and control bins and grain being stored are shown in Table 1.

Table 1 Basic instance of test and control bins and the grain

Storage case of grain		North part No.2 (control bins)	North part No.12 (test bins)
Variety		wheat	wheat
Origin		Henan	Shandong
Quantity (T)		2024	2063
Density (kg/m^3)		792	781
Impurity (%)		0.7	1.0
Moisture (%)		11.5	11.6
Store mode		bulk storage with circuit bags	
Join time (year)		2007	2007
June 22	Maximum grain surface temperature (°C)	24.4	23.4
	Average grain surface temperature (°C)	19.5	18.1
	Average grain temperature (°C)	15.5	15.1

2.2.3. The experimental equipments

Acetone	0.97	—	—	—
4-hydroxy-4-methyl-2-pentanone	0.01	—	—	—
2-heptanone	—	0.95	—	—
6-methyl-2-heptanone	0.16	0.48	—	—
heptene-dione	—	0.286	—	—
6-methyl-5-ene-2-heptanone	1.28	—	—	—
3,5-heptadiene-2-one	0.21	0.15	—	—
2-octanone	—	0.35	0.91	0.71
2,3- octandione	—	—	0.32	0.88
3-octene-2-one	—	0.46	0.45	—
3-octdiene-2-one	—	—	—	0.06

6-methyl-5-heptanone	—	—	0.691	1.83
5-ethyl-6-methyl-2- heptanone	—	—	0.08	0.39
6-methyl-3,5-heptadiene-2-one	—	—	0.39	0.76
2-nonanone	—	0.169	—	—
3-nonene-2-one	—	—	0.25	—
2-undecanone	—	0.32	0.24	—
6,10 -dimethyl-2-undecanone	0.67	—	0.51	0.72
6,10-dimethyl-5,9-undecandione	0.291	—	—	—
2-dodecanone	—	0.56	0.55	0.12
2-tridecanone	—	—	0.17	0.19
2-pentadecanone	0.26	—	—	0.11
6,10,14-trimethyl-2-pentadecanone	2.60	0.41	0.79	1.99

1. FCU was produced by Yuli Air Conditioning Equipment Corporation in Jingjing, Jiangsu with a size of 140 cm x 45 cm
2. 23 cm, air volume of 350 m^3/h-2000 m^3/h and power of 60 W/h;
3. A well with a depth of 45 m was used for groundwater;
4. The deep well water pump was supplied by Minyi Pump Corporation, Shanghai, with a power of 1100 W/h, flow capacity of 5.5 t/h.
5. In/out pipes and accessories.

2.3. Methods

2.3.1. The control method of space temperature in grain bins

Twelve FCUs were connected in series, and installed along the center of the test bins at a height of 2 m above the grain surface; The groundwater deep well pipe was connected with the 12 FCUs in a series flow loop; the detailed connection process is shown in Figure 1. The groundwater of 18°C was pushed into the FCU by the deep well water pump. The water temperature pumped into the first FCU was 19.5°C, then after cooling water passed through the heat exchangers, the temperature of the effluent from the last FCU was 24°C. The cooling water flow was 5.5 m^3/h.

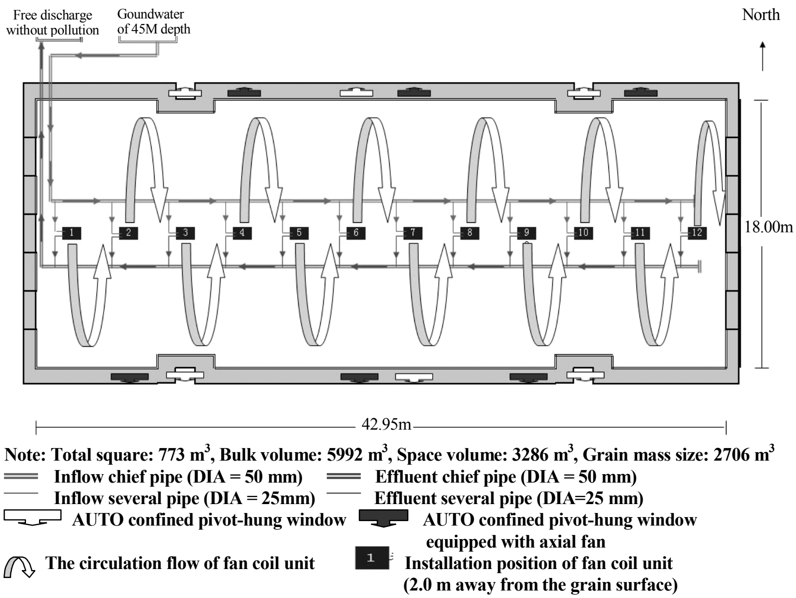

Figure 1 Plan sketch on design and installation of fan coil unit in test bins

2.3.2. The testing methods

1. Measurement of the space temperature: a psychrometer was placed in the centre of headroom above the grain surface; temperature was measured at 8:00, 13:00 and 15:00 daily;
2. Measurement of the grain temperature: the measuring and controlling system of Beibo Electronics Corporation, Zhengzhou, Henan was used. Fifty temperature measurement points were installed for each floor, 0.3 m from the grain surface, the bottom and walls of the bins. It was three-tier with upper, middle and lower layers having a point-to-point horizontal distance of 4.71 m, a column and vertical distance of 4.35 and 1.45 m, respecitively;
3. Measurement of electric energy consumption: a three-phase, four-wire watt-hour meter installed with the device to record data from beginning to end of the test period.

3. Results

3.1. The AGT in treated bin changed slowly with air temperature (AT)

The weekly variation of AGT in the test bin was significantly less than the control (Fig. 2). During the period of HST controlled by water cycle, the daily AGT in the test bin was maintained close to 24.0°C. The test bin AGT changed slower than the control bin, and the daily average AT. During the period of 15-29 d and 57-69 d, when the daily mean AT was about 35.0°C and similar to the control bin, daily AGT in the test bin only reached 25.0°C. The daily AGT in the control bin varied with the change of the daily mean AT.

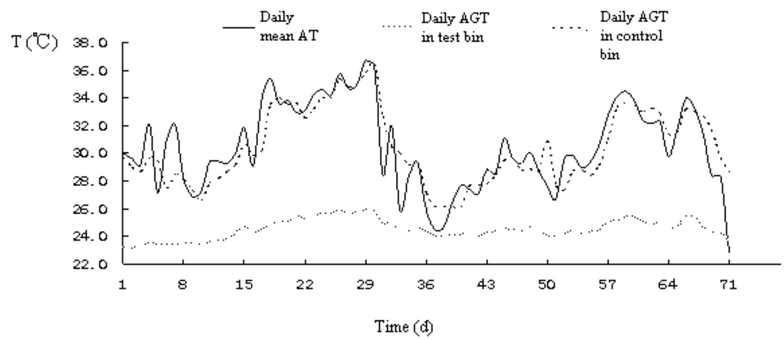

Figure 2 Changes of the average grain temperature (AGT) of the test and control bin, and daily mean air temperature (AT)

From the 29 to 38 d, AT dropped sharply to 26 and 24.3°C, respectively, due to continuous rain; the daily AGT in the control bin quickly dropped to 26°C during the same time. When the AT rose again, the control bin AGT also increased rapidly, and at 45 d, the AT and AGT both reached 29°C. However, the temperature change in the test bin was distinct from that of the control bin. When the AT dropped sharply to 24.0°C, the daily AGT in the test bin dropped slightly from 26 to 24.0°C. When the AT rose again, there is little change in the test bin, and until the 45 d, the daily AGT was still maintained at about 24.3°C.

3.2. The AGT in test bin rose slowly to achieve a QLTGS

The grain temperature in the test bin and control bins were compared continuously for 11 wks, from 22 June 2009 to 31 August 2009 (Table 2). There was a slight variation of the GT-SL and AGT in the test bin. From beginning to end of the test, maximum and mean GT-SL increased from 24.4 and 19.5°C to 24.9 and 21.8°C, an increase of 0.5 and 2.3°C, respectively.

The AGT increased 2.8°C from 15.5 to 18.3°C. However, temperature in the control bin was influenced largely by AT. From beginning to end, the maximum and mean GT-SL increased from 23.4 and 18.1°C to 28.7 and 24.3°C, a growth of 5.3 and 6.2°C, respectively. The AGT increased 6°C from 15.1 to 21°C. Over the whole storage period, AGT in the test bin did not exceed 20°C, and the maximum grain temperature did not exceed 25°C.

Thus, the QLTGS had been achieved in the test bin but failed to meet the standard of the LTGS (Grain and Oil Storage Technical Specifications, LS/T 1211-2008).

Table 2 Comparison of grain temperature surface layers (GT-SL) and average grain temperature (AGT) of the test and control bin.

Time	**Temperature (°C)**							
	Control bin				**Test bin**			
	GT-SL				**GT-SL**			**AGT**
	MAX	**MIN**	**MEAN**	**AGT**	**MAX**	**MIN**	**MEAN**	
The 1st week	23.4	14.3	18.1	15.1	24.4	15.4	19.5	15.5
The 2nd week	24.4	14.7	18.7	15.5	24.2	16.6	20.1	16.0
The 3rd week	24.5	15.6	19.5	16.2	24.5	17.1	20.4	16.5
The 4th week	26.9	16.7	20.6	17.2	24.8	17.1	20.8	16.7
The 5th week	28.2	17.6	21.7	18.0	25.2	17.7	21.2	16.7
The 6th week	27.3	18	22.3	18.5	24.9	17.8	20.7	16.8
The 7th week	26.8	19.2	22.7	19.2	24.7	18.4	21.6	17.5
The 8th week	27.2	18.2	22.8	19.5	24.8	18.6	21.7	17.7
The 9th week	26.7	19	23	19.8	24.9	19.2	21.7	17.9
The 10th week	28	20.5	23.7	20.4	24.6	19.2	21.8	18.1
The 11th week	28.7	21.2	24.3	21.0	24.9	19	21.8	18.3

The objective of the LTGS is that AGT not exceed 15°C, and maximum grain temperature does not exceed 20°C; the objective of the QLTGS is that AGT not exceed 20°C, and maximum grain temperature does not exceed 25°C.

Both of the weekly AGT of the test and control bin kept increasing throughout the experiment, but that of the test group was slower than that of the control (Fig. 3). Growth of the AGT in every layer of the test bin was significantly slower than in the control (Fig. 4).

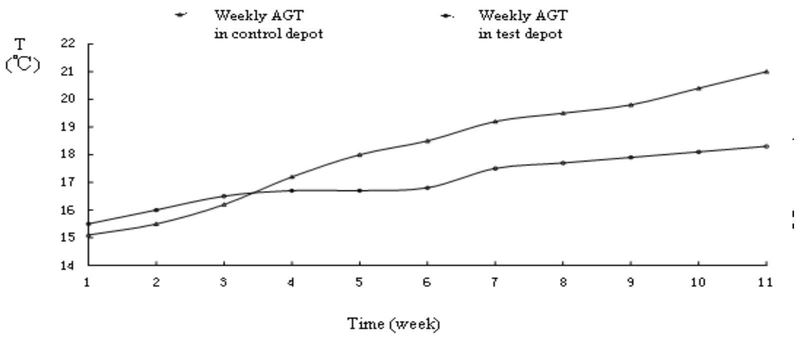

Figure 3 Changes of weekly average grain temperature (AGT) in the test and control bin

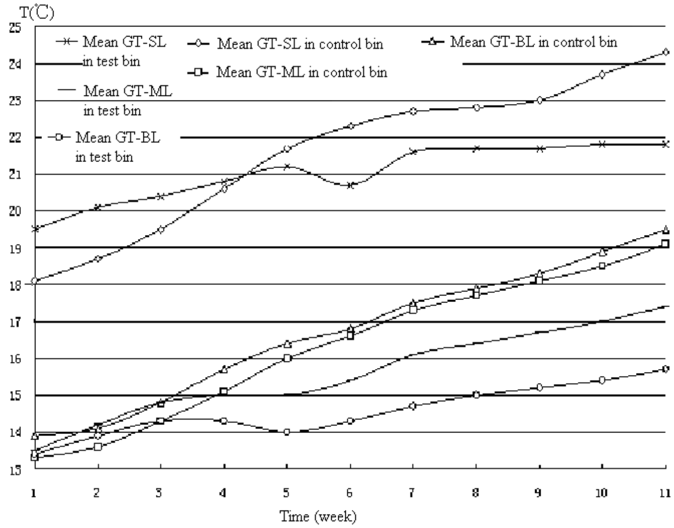

Figure 4 Changes of weekly average grain temperature (AGT) of different layer in test bin

3.3. Energy consumption of temperature control groundwater and fan coil cooling units

The experiment was conducted for 71 d, 24 h/d. The daily energy consumption was computed as (1.1 kW + 0.72 kW)/h × 24 h = 43.68 kW, and the average daily consumption for each tonne of grain was 0.021 kW. According to the price calculation, operating costs of equipment every day was 34.14 RMB. During the experimental period, the total operation cost was 34.14 RMB/d x 71 d = 2423.94 RMB; cost per tonne of grain was 2423.94 RMB/2063 t = 1.175 RMB/t.

4. Conclusions

It was effective to control the HST of the bin with a temperature control technique using groundwater and fan coil head space cooling units. By using this technique, the temperature transmission of the head space air heat was reduced, and the increase of grain temperature in each layer was delayed. The GT-SL was controlled to 22°C, and the AGT of the whole bin was controlled to 18.3°C. Therefore, the QLTGS has been achieved in the experiment bin with the new method. It will have an important significance for safe grain storage in Hangzhou.

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