

## **Study on in-store drying technology of paddy in China**

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DOI: 10.5073/jki.2010.425.144

### **Abstract**

In China, with accelerating growth of agriculture economy structure and rapid development of farming mechanization, the intensity and scale of grain planting has increased considerably. However, the drying of freshly harvested grain is a big problem needing to be resolved. In-store drying technology has good ability for large scale drying. Low energy consumption and successful application of this technology in Australia and America has attracted much attention by the Chinese government. Therefore, study of in-store drying started in China from the cooperative study of 'In-store drying of paddy in China' with Australia in 1997. This paper will introduce the main projects of in-store drying in China since 1997, different periods of the technology development, key problems solved, major achievements and the drying technology distribution within China. After about 13 years development, in-store drying of paddy in China includes technology and related equipment specifically for China, such as technology and equipment for mobile ventilation, mold prevention with ozone, heaters for drying grain moisture, and computerized cooling systems. The initial moisture content of paddy allowed for in-store drying increased from 16% to 25%, the bulk allowable depth of paddy increased from 1.8 m to 6 m, and was competitive with paddy drying throughout the world. The main tasks to advance in-store drying in China in the future will be integration of two stage drying technology for paddy and development of relevant equipment, wireless control ventilation technology and development of relevant equipment, study and application of in-store drying technology in new varieties such as wheat and rapeseed.

**Keywords:** China, In-store drying, Paddy, Moisture content

### *1. Introduction*

Grain is the basic food source for human survival. Grain is related to, not only national economy and people's livelihood, but also to global development and security. China is a major grain-producing country as well as a large grain-consuming country. Chinese traditional agriculture comprises mainly small-scale operations relying on individual farmers. After hand-cultivation and harvest, farmers will mainly dry their grain by exposing them on tarps on the ground directly in the sun. This drying method depends heavily on weather conditions, and requires adequate drying space. With China's urban and rural economic and social development and application of urban-rural integration strategy, arable land has been utilized by gradually increasing scale of farm size. "Grain bank", "order agriculture", "grain storage on behalf of farmers" and other services for "three rural issues" has been carried out gradually. In these situations, a bottleneck of grain drying has emerged with large-scale cultivation, and the problems about grain drying have become more pressing. How to handle high-moisture grain is not only the concerns of China's agricultural sector and farmers, but also seriously concerns the government at all levels, this is then focused back on grain administrations, grain storage companies, and grain research institutes.

For high-moisture grain drying, the main method is drying in the sun, or treating grain for emergency in grain-producing enterprises and storage companies equipped with large or small special external high temperature grain dryers. However, the existing drying equipment has some apparent shortcomings such as high investment, high operating costs, serious food quality losses after drying and low utilization, which will restrict its wide usage. In addition, China's grain production and consumption characteristics need a longer storage period. Nearly 90% of the grain storages are warehouses; the special type of flat horizontal storehouses and limitations of existing transporting equipment are the main reasons leading to high costs of external high temperature drying equipment.

In-store drying is a technical measure allowing treatment of large volumes of grains directly in storehouses (according to storehouse size, the quantity of grain is from 100 t to several thousand tonnes) by use of specially equipped high-air-volume ventilation facilities with in-line air heaters, and the dry air conditions (temperature and humidity) controlled by computers and drying engineers. This in-store drying technology reduces stored-grain moistures to safe water activity (grain moisture content) levels in storehouses.

Since the 1980s, China began to study in-store drying of grain, especially with cooperation of Australia experts supported by the Australian Centre for International Agricultural Research (ACIAR) who promoted the rapid development of in-store drying of grain in China in the mid-1990s.

## 2. Study history

Chengdu Grain Storage Research Institute, Sinograin (CSR), is the only national research institute specializing in grain-storage technology, including grain drying. Since undertaking the Sino-Australian cooperation project "in-store drying of grain in China" in 1997, China has carried out a comprehensive and systematic study of in-store drying of grain and has spread the technology. The main work and the major technological achievements obtained in in-store drying of grain in China at different periods are shown in Table 1; the technical application example is showed in Table 2.

**Table 1** The main research periods of In-store drying for grain in China

No.	Project name	Time	Main works	Major technological achievements
1	Sino-Australian cooperation project "In-store drying of grain in China"	1997 — 2001	1, personnel training; 2, data collection; 3, the drying tests of ground cage; 4, the in-store drying equipment research and development;	1, automatic control system for in-store drying; 2, rice ergosterol rapid detection method; 3, finished the tests of in-store drying for rice and maize;
2	Research and Development Project supported by Ministry of Science and Technology: research and development on upgraded in-store drying technology and equipment;	2002 — 2004	1, Basic technical conditions research on in-store drying for high-moisture grain; 2, Design and develop the movable combined vertical ventilation system; 3, Research and develop intelligent automatic detection and control systems; 4, Develop mobile dry air source equipment; 5, drying test in field;	1, obtain the safe storage period of high-moisture paddy and maize under different storage conditions; 2, developed the movable combined vertical ventilation system; 3, realize intelligent control system for in-store drying of paddy; 4, Technology Regulation of Application of in-store drying" (Draft)
3	Subproject of Science and Technology Project of Grain Production supported by Ministry of Science and Technology: the new technology development and demonstration on in-store drying of paddy in the Yangtze River middle and lower reaches;	2004 — 2006	1, to develop the complete sets of equipment for in-store drying of paddy; 2, to do process optimization and technology integration on in-store drying of paddy; 3, to carry out application demonstration of in-store drying of paddy in field; 4, to research and develop in-store drying for farmer storage;	1, Improved the movable combined vertical ventilation system and operation mode; 2, Efficient energy-saving auxiliary heating equipment; 3, ozone anti-mold equipment; 4, optimized the intelligent control system of in-store drying; 5, technology and equipment of in-store drying for farmer storage; 6, "technical regulation on the in-store drying of high-moisture paddy for farmer storage" (Draft)

**Table 2** The technical application examples of in-store drying of grain in China

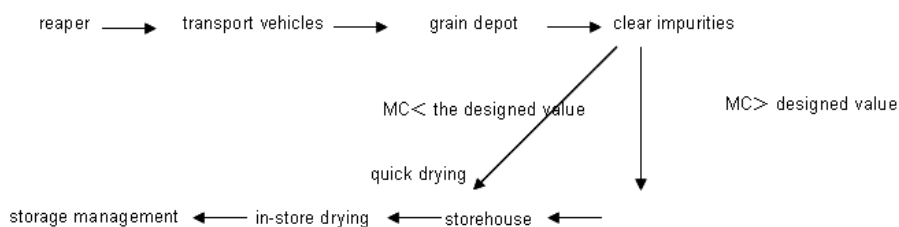
Place	Time	Grain	Initial moisture (%)	Termination moisture (%)	Depth of grain (m)	Amount (ton)	Energy consuming kW.h/1%.t
Jiangxi Nanchang	2003-1-25 to 2003-8	paddy	17.4	14.5	4.8	1533	4.30
Henan Anyang	2004-4-14 to 2004-6-20	maize	17.5	13.7	3.8	2830	2.32
Sichuan Deyang	2006-9-25 to 2006-11-7	paddy	16.1	13.5	5.0	1500	3.71
Shang hai	2007-4-23 to 2007-5-19	maize	15.6	13.8	5.0	5422	3.82
Shanxi Shangluo	2008-6-9 to 2008-7-20	maize	16.3	14.2	6.0	5280	3.72
Sichuan Chongzho u	2008-9-3 to 2008-11-10	paddy	23.1	13.1	2.5	963	4.18
Shanxi Weinan	2009-4-20 to 2009-6-12	maize	16.8	14.2	3.4	6280	3.36

### 3. Present situation

Through the above three national research projects, in-store drying of grain in China has developed technical systems and supporting equipment with its own characteristics, solved the problem of grain moisture content (m.c.) difference in different layers of grain and uneven drying throughout the grain bulk. These projects have promoted the use of in-store drying for about 10 million t of grain in many provinces such as Jiangxi, Shanxi, Ningxia, Hubei, Hunan, Sichuan, Shanghai, Henan, Yunnan and other provinces and cities. The bulk grain depth treated has exceeded 3 m, which is an internationally recognized depth limit. Particularly after the serious earthquake of 12 May 2008 ("5.12"), in-store drying technology has been used for paddy with from 18% to 23.5% m.c., with grain bulk depth from 2.5 m to 3.5 m in three earthquake-damaged locations (Qionglai, Chongzhou, Dujiangyan). This was undertaken with strong support of the local government, which had made important contributions to safe storage of grain after the disaster.

#### 3.1. Technical procedure

The integrated procedure from purchasing to storage of new harvested paddy is shown in Figure 1. Depending on the actual situation of each storehouse, different drying methods such as external drying machines, flexible containers for drying (Figure 7) and other quick drying methods can be adopted to handle moist grain at harvest. This integrated procedure enables the whole process for paddy harvest, transport, drying and storage to operate continuously in which paddy needn't touch the ground, which reduces contamination to grain and saves the cost of purchasing additional storage.

**Figure 1** Integrated line of purchasing and storage of paddy

The initial moisture content of paddy treated by in-store drying is different according to style of the storehouse and the specific condition during ventilating. At present, the storehouse suitable for in-store drying of grain is mostly flat storehouse in China, and the depth of grain bulk includes 2.5, 4.5 and 6 m,

based on the initial storage moisture content of the paddy. The initial moisture designed for in-store drying of paddy with different height is showed in Table 3.

**Table 3** The designed initial moisture of paddy for in-store drying.

Height of grain bulk (m)	2.5	4.5	6
Designed moisture (%)	≤25	≤21	≤18

### 3.2. Grain quality security system

The security system to maintain high grain quality includes six major sections: 1) in-floor aeration duct and pressure fan up-flow cooling ventilation system, 2) movable combined vertical ventilation system, 3) heat pump heating or dehumidification system, 4) intelligent (computerized) ventilation control system 5) ozone anti-mold system, and 6) professional design and service team.

#### 3.2.1. In-floor aeration duct and pressure fan up-flow cooling ventilation system

Generally, grain storehouses are equipped with this system in China. The amount of grain treated by in-store drying commonly reaches 1000 t and it often takes about 2 wk to load grain into the warehouse. The pressure fan grain cooling ventilation system is mainly used to control the temperature of grain in the process of loading, thereby prolong the safe storage term of high moisture grain, which keeps fresh air flowing through the moist grain and will provide enough preparation time for in-store drying.

#### 3.2.2. Movable combined vertical ventilation system

This system is mainly composed of stainless steel vent-pipe, special UPVC vent-pipe, circle vent-pipe, flexible vent-pipe with branches, which is easy to install and allows grain managers to use the system multiple times among several storehouses during the storage season. The vertical vent-pipes can be pulled part way out after finishing drying of that layer, which can effectively solve the moisture stratification problem during in-store drying for deep grain bulk. The system had been shown in Figures 3, 4, 5 and 6.

#### 3.2.3. Heat pump heating or dehumidification system

Natural air drying with supplemental heating is the major measure to increase drying speed and overcome adverse weather conditions. The COP showing the energy-efficiency of the heat pump developed and produced by CSR is over four. The heat pump uses energy efficiently; it has a dual function to provide heat to grain drying in the fall and spring or provides cooling to reduce the grain temperature in summer, which provides highly efficient utilization of the machine.

#### 3.2.4. Intelligent ventilation control system

Intelligent ventilation control systems consist of computer hardware and software systems. The system can automatically estimate the ventilation condition, automatically control the cooling fan and heat pump based on collected real-time data about temperature and humidity in the grain by an acquisition module. The system is multifunctional because it predicts ventilation requirements, controlling temperature and humidity, provides warnings and other features.

#### 3.2.5. Ozone anti-mold system

The system effectively prevents the mould from rapidly growing and reproducing under hot and humid environment, thereby it prolongs the safe storage term of grain and protects the quality of high-moisture grain during in-store drying.

#### 3.2.6. Professional design and service team

As the leading role in in-store drying technology research, CSR has formed a professional technical service team after 10 years of continuous research and development. This team visits every site with in-store drying application projects to learn more about the situation and formulate the best program. They conduct technical training for the local technical staff in technology application sites to help them master key technology of in-store drying. Their meticulous support services guarantee grain quality security during in -store drying.

### *3.3 Technical features*

In-store drying technology has the following characteristics:

1. Low investment: the one-time investment reduces one-third to one-half compared with the equipment required for low-temperature drying for paddy with the same moisture removal.
2. Low operation cost: the operation cost is reduced at least one-third compared with equipment required for low-temperature drying of paddy.
3. Large drying capacity - the amount of grain treated is based on capacity of storehouse.
4. Maintains the grain quality well: the drying process is low-temperature low-humidity natural air ventilation drying, and utilizes ozone with high concentration to restrain mold, which effectively protects grain from damage of mycotoxin in the process of in-store drying while maintaining high grain quality.
5. Low grain loss: the newly harvested grain is directly transported into storehouses from harvest fields so the whole drying process has no grain transport delivery expense.
6. A high degree of automation: the operation process is controlled intelligently by a computer software cooling and drying algorithm;
7. energy-saving and environmental protection: high efficiency heat pumps, heating combined with cooling function, with no emissions of waste liquid or gas in drying makes this process efficient and environmentally friendly.

### *4. The trend of research and development*

The existing in-store drying technology still has deficiencies such as drying moisture removal restricted by the grain bulk depth, high one-time investment of automatic control with cable, and technical requirements for automatic installation and debugging. With the acceleration of agricultural industrialization and intensification, China will carry out the following studies to solve the growing demand for paddy drying.

#### *4.1. Application test and demonstration of in-store drying with stratified ventilation*

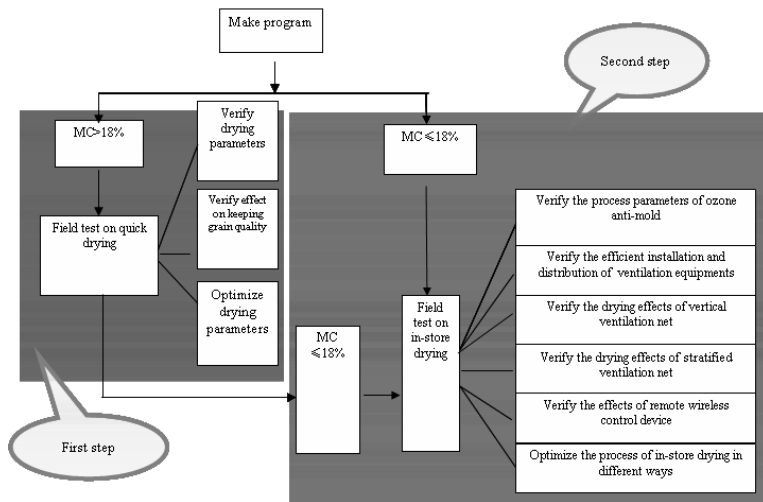
The movable combined vertical ventilation system (Figures 3, 4, 5 and 6) effectively solves the moisture stratification problem of in-store drying of deep grain bulks. However, labor intensity of pushing in or pulling out the vertical ventilation pipes increases with increased grain depth. So a new procedure has been proposed to solve grain moisture stratification by establishing a stratified ventilation piping network. Main research includes carrying out the application test on in-store drying with stratified ventilation network, determining the ventilation conditions, researching and validating the characteristic index that can reasonably reflect the uniformity of mechanical ventilation, establishing the uniformity evaluation methods of ventilation and developing the protocol of technical operating guidelines on paddy in-store drying with the stratified ventilation.

#### *4.2. Research and development on new technologies and equipment for in-store drying*

The research and development on new technologies and equipment for in-store drying mainly includes new ozone anti-mold technology and parameter studies, research and development of efficient installation and distribution on movable combined vertical ventilation system technology, and research and development on remote wireless control technology and equipment.

#### *4.3. Integrated application test and demonstration of two-step drying technology*

Taking the internationally common technology of drying by several steps as reference, it's proposed to integrate the advantages of drying by steps and traditional in-store drying to develop new technologies and equipments on intensive drying of paddy. The main research and implementation program is showed in Figure 2.



**Figure 2** Integrated application test and demonstration of two-step drying technology



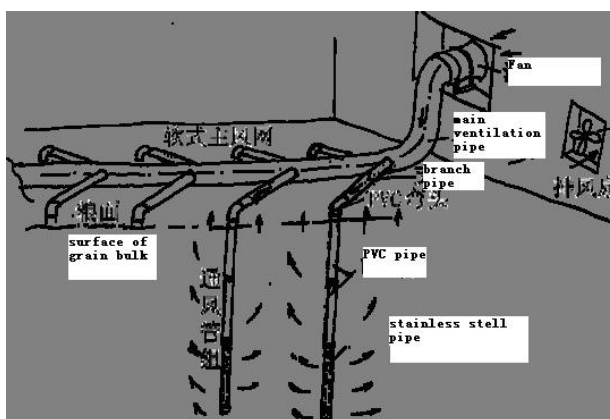
**Figure 3** Combined vertical ventilation system blowers and air supply hoses



**Figure 4** Ventilation system vertical aerator pipes spaced in grain



**Figure 5** Solid and perforated piping components for one vertical aerator assembly.



**Figure 6** Drawing of combined vertical aerator pipe ventilation drying



**Figure 7** Flexible container attached to fan and duct assembly for drying.

#### *4.4. Research on in-store drying of wheat, rapeseed and other kinds of grains*

In recent years, the research of in-store drying technology in China mostly focused on high moisture paddy and maize. However, wheat in-store drying technology applications are very few and the initial moisture content of wheat treated is below 16%. There are no research reports about rapeseed in-store drying technology applications. Therefore, application research on in-store drying of wheat, rapeseed and other kinds of grains will be carried out in future.