1992

Comparison of Conventional and Chilled Aeration of Grains Under Texas Conditions

Dirk E. Maier, *Purdue University*
Rosana G. Moreira, *Texas A&M University*
Fred W. Bakker-Arkema, *Michigan State University*

Comparison of Conventional and Chilled Aeration of Grains Under Texas Conditions

D. E. Maier, R. G. Moreira, F. W. Bakker-Arkema
Member ASAE, Member ASAE, Member ASAE

Abstract

Conventional and chilled aeration of rice and corn were investigated for Texas conditions using the simulation model AERATE. Of four conventional aeration strategies, continuous aeration performed best since it results in the smallest moisture losses and moisture gradients in the commercial rice and corn silos investigated. Chilled aeration utilizes a refrigeration system to control the bin inlet air conditions. It is able to prevent moisture losses and to maintain the average grain temperatures 15° C (25° F) below that of conventionally-aerated rice and corn during the summer months. **Keywords.** Ambient aeration, Grain chilling, Grain quality.

Introduction

Grain quality has become an important issue in the grain trade worldwide due to increased export competition, more stringent food-safety demands, and more precise grain-buyer quality awareness. The application of grain chilling permits both short- and long-term storage of grain regardless of the ambient conditions. The chilled aeration of grain storages has been successfully practiced in over 50 countries for the past 30 years. Annually, over 25 million metric tonnes (1 billion bu) of grain are cooled with grain chilling systems (Brunner, 1990). Commonly, grain is cooled using conventional aeration systems which lower the grain temperature in the storage bin to several degrees above the minimum ambient temperature. Grain chilling is defined as the cooling of grain to below the minimum ambient temperature using a mechanical refrigeration system.

Figure 1 illustrates the grain chilling process. In a mobile grain chilling system, ambient air is ducted over a bank of refrigeration coils in order to decrease its temperature. In this process the relative humidity of the air is increased. The chilled air temperature is set by the operator. Since grain absorbs moisture at high humidity levels, the chilled air is slightly reheated in the condenser, and if necessary, by built-in electrical resistance heaters to the desired 60-75% relative humidity range. The ability to control the bin-inlet air temperature and humidity to the desired values, regardless of the ambient conditions, is a distinctive feature of a well-designed grain chilling unit. (The specifications of a typical grain chiller are given in Table 1.) After the initial cool-down, a rechilling cycle is run periodically in order to maintain the grain at the desired temperature.

This article explores the need of chilled aeration of grains in Texas and compares it to several conventional in-bin aeration strategies. The systems are investigated for the corn and rice crops harvested in late July for the years 1988-1990.

Literature Review

Commercial grain chilling units were manufactured in Western Europe as early as 1958 to help preserve wet grain after harvest in Germany (Escher Wyss, 1960). At the time, the increased utilization of combine harvesters necessitated an alternative method to preserve freshly harvested grain due to the limited capacity of the available drying equipment. McCune et al. (1963) were among the first to publish studies on grain chilling. They successfully stored sorghum grain at 19% w.b. moisture in Texas for six months at 10° C (50° F). Heidt and Bolling (1965) pursued the effective chilling and storage of harvest-wet wheat and

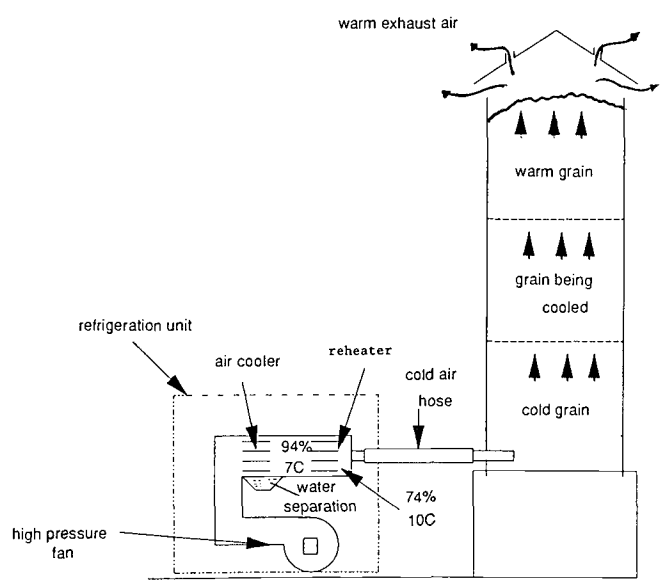

Figure 1–Grain chilling process which utilizes a refrigeration system to control the temperature and relative humidity of the air into the storage bin.

Article was submitted for publication in November 1991; reviewed and approved for publication by the Food and Process Engineering Inst. of ASAE in August 1992.

The authors are **Dirk E. Maier**, Assistant Professor and Extension Agricultural Engineer, Agricultural Engineering Dept., Purdue University, West Lafayette, IN; **Rosana G. Moreira**, Lecturer and Research Scientist, Agricultural Engineering Dept., Texas A&M University, College Station; and **Fred W. Bakker-Arkema**, Professor, Agricultural Engineering Dept., Michigan State University, East Lansing.

TABLE 1. Typical design and operating specifications of a commercial* grain-chilling unit

Cooling capacity	tonnes / day	bu / day
maximum	500	17,700
average	330-340	11,600-12,000
Cold air flowrate		
at 100 mm W. G. (4 in.)	18 000 m^3 / h	10,600 cfm
at 300 mm W. G. (12 in.)	14 200 m^3 / h	8,400 cfm
Compressor cooling load at 30° C (86° F) condensing and 0° C (32° F) evaporating temperature	107.0 kW	365,200 Btu / h
Connected loads		
compressor	23.2 kW	17.3 Hp
cold air fan	22.0 kW	16.4 Hp
condenser fan	4 × 2.2 kW	4 × 1.6 Hp
total connected load	54.0 kW	40.3 Hp

* KK400 manufactured by Sulzer-Escher Wyss, Lindau, Germany.

corn. Wheat with a 20% moisture content was successfully chilled to 7° C (45° F) and stored for 20 days; corn at 30% moisture was chilled and stored for 10 days.

Burrell and Laundon (1967) were the first to publish an in-depth study of grain chilling; they cooled 17-24% moisture wheat rapidly to about 4° C (40° F) in a 10.5 m (34 ft) high metal bin, and successfully stored it under UK conditions for a period of three months with one rechilling treatment after two months. Chilling was employed to provide temporary storage until the grain could be dried; insect and mite development was prevented as long as the grain temperature remained below 5° C (41° F). Navarro et al. (1973) slowly chilled 12% moisture wheat in a 19.5 m (64 ft) high concrete silo under Israeli summer conditions; a reheater was incorporated in the chilling unit to prevent moisture adsorption by the grain near the cold air inlet.

Hunter and Taylor (1980) promoted grain chilling as a non-chemical preservation method in storing wheat under Australian conditions; insulating of the silo and recirculation of the headspace air was necessary for the process to be economical. Thorpe and Elder (1982) investigated a combination process of grain chilling and low-dosage pesticide treatment for non-insulated grain stores, also in Australia. Ben-Efrain et al. (1985) studied the intermittent use of a chilling unit in Israel at times when the ambient temperature was too high for conventional aeration of soybeans; with the combination of regular and chilled aeration, soybeans were stored for four years.

Sutherland (1986) reviewed the 10-year use of chilled grain storage in Australia. In the warmer regions of the country, chilling of the aeration air was found to be necessary because the ambient temperatures were too high for regular aeration. Three types of chilled grain storage were considered by Komba et al. (1987) for Central European conditions – i.e., low (14-15%) moisture grain at 10-12° C (50-54° F), intermediate (16-22%) moisture grain at 5-8° C (41-46° F), and high (> 22%) moisture grain at 4-5° C (40-41° F). In each moisture range, chilled storage required less energy than traditional storage technologies.

Bakker-Arkema et al. (1989) investigated the effect of airflow rate and of grain moisture content/temperature on the chilling rate and moisture loss during the initial cool-down of a bin of corn in a temperate climate; a simulation model was developed for the chilling process. Maier et al. (1989) stored 18% moisture maize for seven months at 4-6° C (40-43° F) in the midwestern United States using a commercial chilling unit. A capital budgeting analysis showed positive cashflows for several economic scenarios.

The chilling of rice has been used in the rice industries of Spain and Italy for several years (Brunner, 1989 and Finassi, 1987). Improvements in the milling quality of rice through a 20% increase in head yield have been reported (Rius, 1987). Combining chilled aeration with the drying of paddy in Malaysia increased dryer capacity by 40% (Chek, 1989). In the U. S. rice industry grain chilling technology is being considered in the handling of brown rice and the conditioning of parboiled rice (Brunner, 1990).

If ambient aeration is used in warm climates, the grain temperatures will remain at high temperatures for extended time periods, resulting in insect-infestation of the grains (Nour et al., 1988). Thus, grain storage in the climate of the southern United States requires chemical insect control even when aeration is practiced. Chilled aeration storage provides the opportunity to store grains safely in the southwest while potentially reducing the use of chemical protectants. Furthermore, the lower the temperatures in the storage, the longer the half-life of the chemical protectant (Thorpe and Elder, 1982).

AERATE

An in-depth analysis of in-store aeration can be made with a fixed-bed drying model (Bakker-Arkema, 1984). Although the partial differential equation model is considered to be more accurate than the heat and mass balance model (Parry, 1985), it requires excessive computer time when long time periods are simulated. Since the aeration of bulk grain is practiced at low airflows, the cool-down time is extensive, on the order of 100-250 hours. Therefore, the aeration simulation model chosen in this study is of the heat and mass balance type, with equilibrium assumed between the grain and air temperatures and humidities. The aeration model is called AERATE and was developed by Michl (1983); modifications to the Michl model have been made by Muhlbauer (1987) and Maier (1988). The Michl model is a modified version of the equilibrium-type fixed-bed grain drying model of Thompson (1972).

The AERATE program requires information about the desired aeration strategy, the ambient conditions, the bin configuration, and the grain being dried/cooled. The simulation of conventional aeration is accomplished by using historic weather data. The hourly temperature and relative humidity values are needed along with the local barometric pressure. The other moist air parameters are calculated with the help of the built-in psychrometric subroutines. In this study, actual weather data for the coastal region of Texas (where most rice and corn are produced) was used.

In the chilled aeration operation, it is assumed that the inlet air temperature and relative humidity are supplied by a grain chilling unit independent of the ambient conditions.

The cooling air flow rate, temperature, and relative humidity to the grain pile are fixed at the bin inlet.

The typical operation of a commercial grain chiller is shown in figure 2 during a five-day early summer period in the midwestern United States. The ambient temperature varied between 10° (50° F) and 28° C (82° F) but the chilled-air temperature remained between 6° (43° F) and 7° C (45° F). Likewise, the relative humidity of the chilled air remained practically constant at 90 ± 2%, although the ambient air humidity ranged from 25 to 98%. The curves show that a grain chiller is able to maintain constant air conditions into a storage bin regardless of the ambient temperature and relative humidity.

Procedure

In order to assess the advantage of the use of grain chillers in Texas, the storage of rough rice and food corn in the Corpus Christi area was considered. Simulation was employed to analyze conventional and chilled aeration at two commercial food-grain elevators. One company stores rice, the other corn. The rice is stored in 60 concrete silos with a holding capacity of 91 tonnes [2,000 hundredweights (cwt)] each; the silo diameter is 3.7 m (12.2 ft) and the fill depth is 15.3 m (50.3 ft). The corn is stored in 36 concrete silos with a holding capacity of 1200 tonnes (45,000 bu) each; the silo diameter is 9.1 m (30 ft) and the fill depth is 23.8 m (78.3 ft). The rice and corn are harvested in late July, dried (if needed) to about 13% (w.b.), and reach the silos at approximately 38° C (100° F). In order to cool the rice and corn, the bins are aerated. Different aeration schedules are used by Texas grain-storage managers. Their principle aim is to cool the grain to below 15° C (60° F) as rapidly as possible without excessive overdrying or absorption of excessive moisture by the bottom grain layers in the silo. In addition, it is undesirable to develop a large moisture gradient in the silo.

Four aeration strategies are investigated using ambient air at a flow rate of 0.1 m^3 of air per minute per tonne (0.1 cfm/bu): (1) continuous aeration, (2) aeration whenever the relative humidity of the ambient air is below 75%, (3) aeration between 10 A.M. and 4 P.M., and (4) aeration between 10 P.M. and 4 A.M. For each of the two elevators (i.e., corn and rice), the grain temperatures and moisture contents in the silos are calculated during the warmest storage months (i.e., August, September, and October) over a three-year period (i.e., 1988-1990). AERATE is employed in the calculations using actual weather conditions recorded every three hours (NOAA, 1988, 1989, 1990).

The chilling of the grain is also simulated with AERATE. The aeration simulation program utilizes the weather data in conjunction with a commercial chilling unit (see Table 1) in which the ambient air is cooled and dehumidified to a temperature of 15° C (60° F) with a relative humidity of 58% for corn and 63% for rice. The airflow rate during chilled aeration is also 0.1 m^3/min/tonne (0.1 cfm/bu). The grains are assumed to be rechilled intermittently to maintain the chilled storage conditions.

Results and Discussion

Regular Aeration

The weather conditions for August-October 1988 in Corpus Christi, Texas, are plotted in figure 3. The average temperature is 26.3° C (79.3° F) with a range from 13.3 to 38.9° C (55.9 to 102° F). The average relative humidity is 75.5% with a range from 27.0 to 100%. The 28-year average temperatures (i.e., 1962-1989) for August are 28.6° C (83.5° F), for September 27.0° C (80.6° F), and for October 23.3° C (73.9° F).

The optimum moisture content for storing rice and corn in Texas is 12.5-13.0% (w.b.) and 13.0-14.0% (w.b.), respectively. In figure 4, the equilibrium moisture content (EMC) curves of rice and corn are drawn at 26.3° C (79.3° F), the 28-year average summer temperature in Corpus Christi. At 26.3° C (79.3° F) and 13.0% moisture, the equilibrium relative humidity (ERH) for rice is about

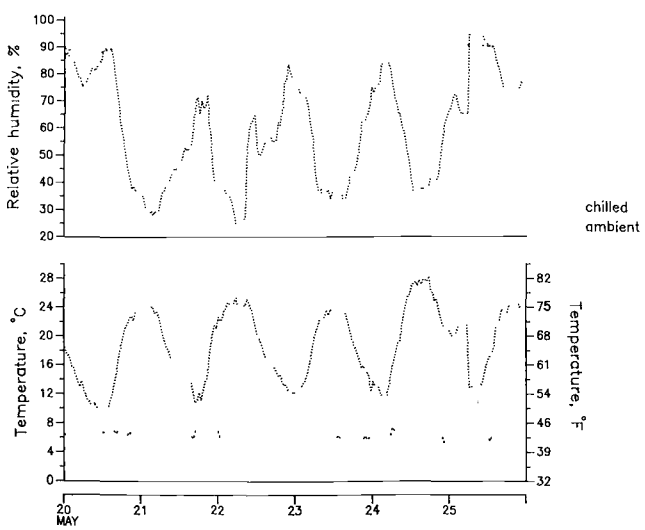

Figure 2–Temperature and relative humidity of the ambient and chilled air in May 1989 under midwestern U. S. conditions.

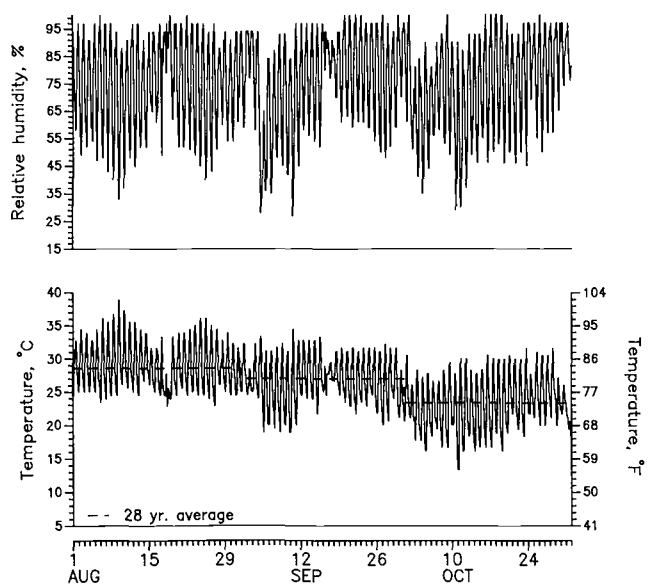

Figure 3–Ambient temperature and relative humidity in Corpus Christi, Texas, between August 1988 and October 1988.

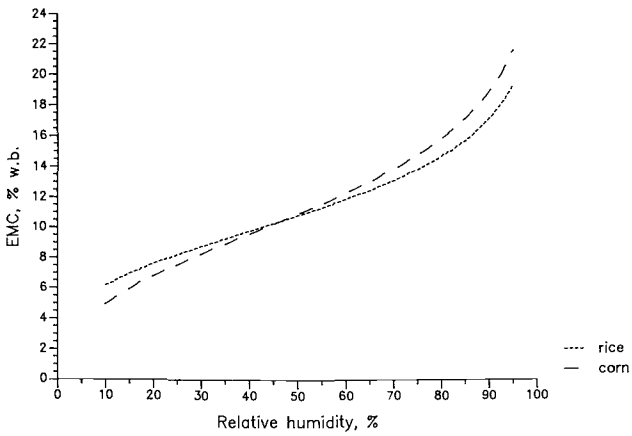

Figure 4–Equilibrium moisture content of rice and corn at 26.3° C (79.3° F).

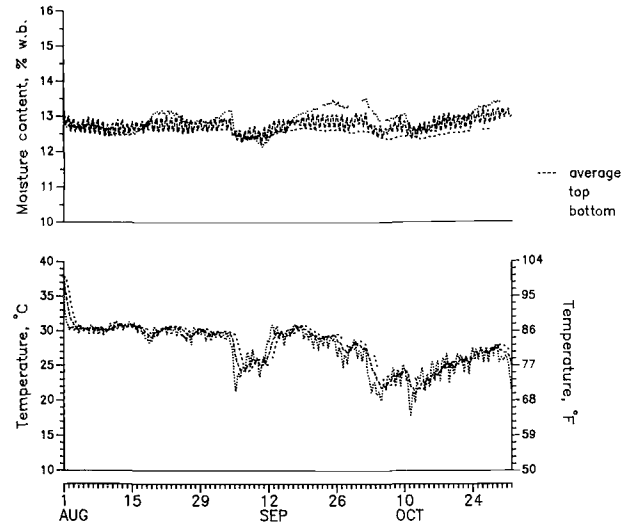

Figure 6–Temperature and moisture content of rice aerated continuously under Texas conditions between August 1988 and October 1988.

70%; and for corn at the same temperature and 14.0% moisture the ERH-value is about the same. At 15° C (59° F), the ERH-values for rice and corn are approximately 65% for moisture contents of 13 and 14%, respectively.

There is little difference in the stored grain temperatures, at least not in the 1988-1990 period. This is shown in figures 5 and 6 for the case of continuous aeration of rice. In 1990 the rice remained above 30° C (86° F) for a longer period of time early in the storage season, but cooled off quicker in October. The average rice temperatures and moistures in the silos were similar, ranging in average temperature from 27 to 28° C (80 to 82° F) and in average moisture from 12.6 to 12.8% w.b. Since there is little variation from year to year, the rest of the results will be presented only for 1988.

Figures 6 through 9 show the moisture content and temperature of the rice at the bottom and at the top of the silo, along with the average values during the 1 August - 31 October 1988 storage period for the four aeration strategies. Since similar information was obtained for corn as for rice (Tables 2 and 3), only the case for continuous aeration of corn is illustrated (fig. 10).

The following observations are made from figures 6 through 10 for the aeration of rice and corn during summer conditions in Texas:

- Rice and corn react similarly to aeration – the average grain moistures in the silo remain at 12.5 ± 0.5% w.b., and the average grain temperatures for the summer are at 28 ± 2° C (82 ± 3° F).
- Continuous aeration results in less overdrying of the rice and corn in the bottom layers of the silos, in the lowest average grain temperatures (except for the 10 P.M. - 4 A.M. case), and has the smallest differentials in moisture content. Thus, it is the recommended strategy of aeration among the four

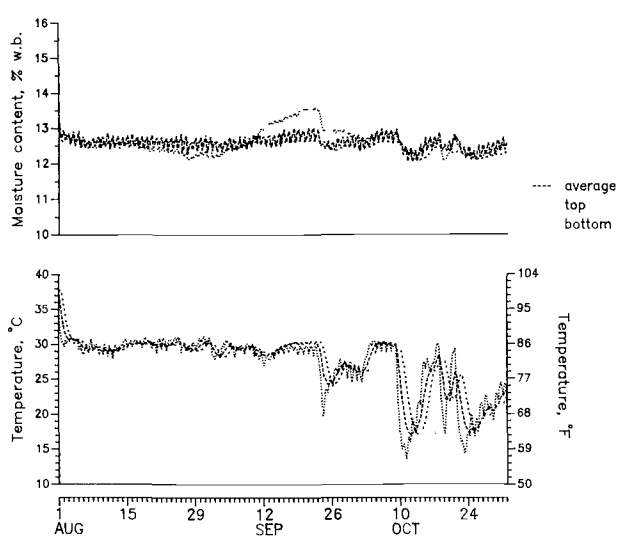

Figure 5–Temperature and moisture content of rice aerated continuously under Texas conditions between August 1990 and October 1990.

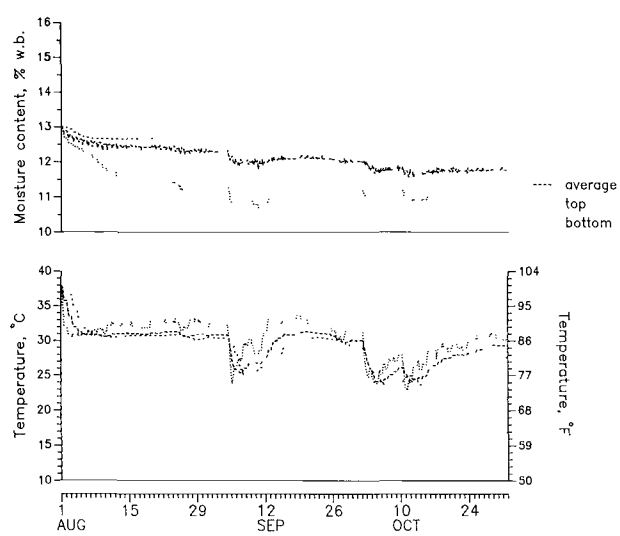

Figure 7–Temperature and moisture content of rice aerated when RH < 75% under Texas conditions between August 1988 and October 1988.

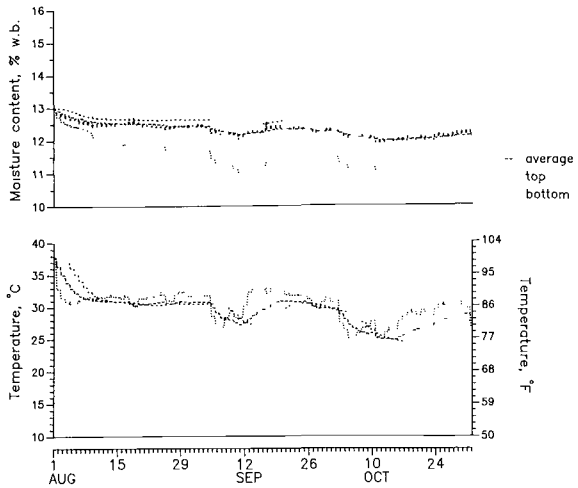

Figure 8–Temperature and moisture content of rice aerated daily from 10 A.M. until 4 P.M. under Texas conditions between August 1988 and October 1988.

investigated for food corn and rough rice in the coastal area of Texas.

- Aeration from 10 P.M. to 4 A.M. results in the lowest average rice and corn temperatures in the silos, i.e., about 21° C (70° F) in 1988. However, an excessively large variation in the moisture contents develops in the silos. The bottom rice and corn layers absorb up to 1.5 points of moisture over the three-month storage season.
- Aeration from 10 A.M. to 4 P.M., and under conditions of less than 75 percent relative humidity, result in excessive overdrying of the bottom layers of the rice and corn in the silos, i.e., by as much as two points of moisture.

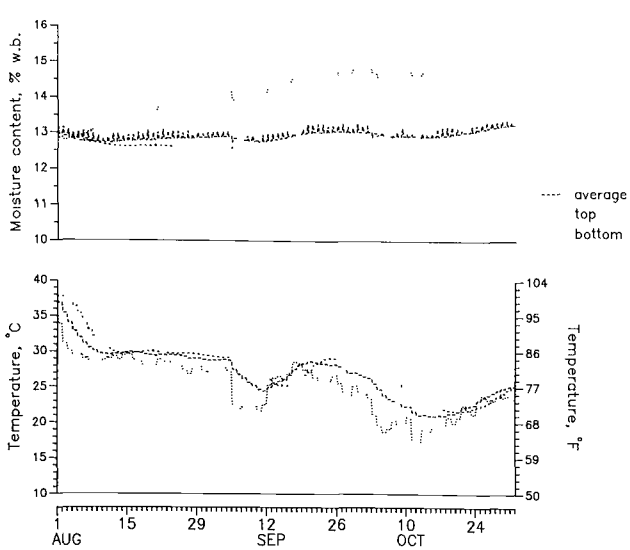

Figure 9–Temperature and moisture content of rice aerated daily from 10 P.M. until 4 A.M. under Texas conditions between August 1988 and October 1988.

TABLE 2. Average grain temperatures, moisture contents, and ranges for the regular and chilled aeration of rice in Texas between August and October 1988

	Temperature (°C)		Moisture (% w. b.)	
Strategy	Average	Range	Average	Range
Continuous	27.8	21.1 - 37.8	12.8	12.2 - 13.2
Less than 75% RH	29.3	24 0 - 37.8	12.1	11.6 - 13.0
10 A.M. - 4 P.M	29.3	24.7 - 37.8	12.3	11.9 - 13.0
10 P.M. - 4 A.M.	26 9	21.0 - 37.8	12.9	12.7 - 13.3
Chilled*	15.2	15.0 - 15.5	12.9	12.8 - 12.9

* After 124 hours of chilling.

Chilled Aeration

The results in figures 6 through 10 contrast sharply with those in figures 11 and 12, in which chilled aeration with constant air-inlet conditions for rice and corn are used, respectively.

The rice in the silo is cooled to below 25° C (77° F) within 54 hours, and below 15.5° C (60° F) within 124 hours (fig. 11). Due to the evaporative cooling effect, the initial rice moisture content can be as high as 13.8% w.b. to achieve a final average moisture content of about 13.0% at the end of the cool-down period. The moisture content of the entire pile is within 0.1 percentage points. The final temperature gradient between the bottom and top layers is less than 0.5 C (1° F).

The cool-down of the larger-sized corn silo to below 15.5° C (60° F) is completed in 154 hours, the corn temperature drops below 25° C within 66 hours of chilling. The moisture content of the corn is about 13.0% at the end of the cool-down period. The moisture content differential between the bottom and top layers is less than 0.1 percentage points and the final temperature gradient less than 0.5 K (1° F).

It is noted that depending on the capacity of the commercial grain chilling unit, multiple silos can be chilled at the same time when appropriate aeration ducting is used. Most importantly, at 15.5° C (60° F) and 12.5-13.0% moisture, the rice and corn can be stored indefinitely in Texas with a significant reduction in the risk of insect infestation (Baur, 1984).

A question still to be considered in the analysis of chilled grain aeration and storage is the need and frequency of rechilling. Bulk-stored grain is subject to rewarming due to the effects of ambient weather conditions which are severe in Texas. The recent development of a systems

TABLE 3. Average grain temperatures, moisture contents, and ranges for the regular and chilled aeration of corn in Texas between August and October 1988

	Temperature (°C)		Moisture (% w b.)	
Strategy	Average	Range	Average	Range
Continuous	28.3	21.9 - 37.8	13.0	12.4 - 13.6
Less than 75% RH	29.6	24.5 - 37.8	12.3	11.8 - 13.0
10 A.M. - 4 P.M.	29.8	25.2 - 37.8	12.5	12.0 - 13 0
10 P.M. - 4 A.M.	27.6	21.8 - 37.8	13.0	12.8 - 13.4
Chilled*	15.2	15.1 - 15.5	12.9	12.9 - 13.0

* After 154 hours of chilling.

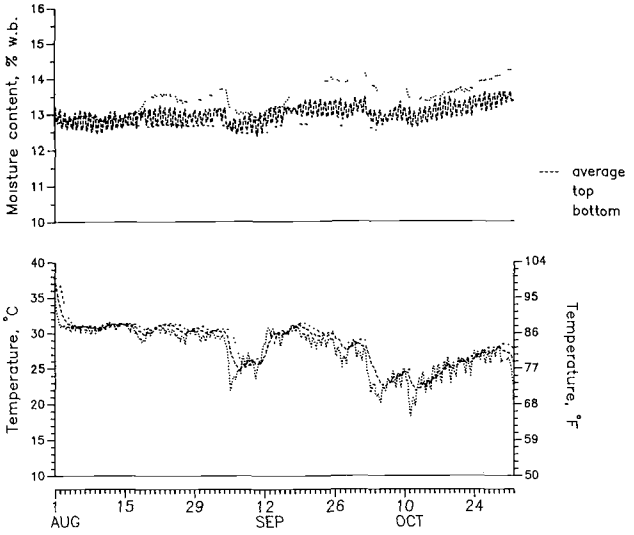

Figure 10–Temperature and moisture content of corn aerated continuously under Texas conditions between August 1988 and October 1988.

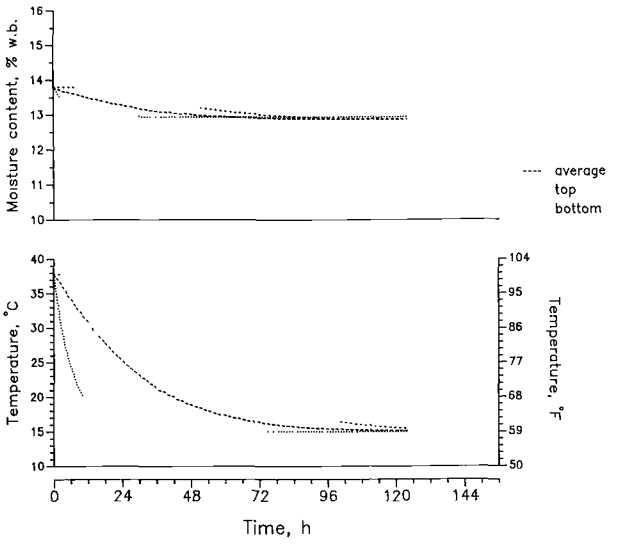

Figure 12–Temperature and moisture content of corn using chilled aeration under Texas conditions.

model for the chilled aeration and storage of cereal grains will allow analysis of this question (Maier, 1992).

The economic benefits of grain chilling should surpass the costs. Thus, the income derived from the improved quality of chill-stored grain should offset the investment cost of a grain chilling system. Maier et al. (1989) made a capital-budgeting analysis of the application of grain chilling in the United States. Savings accrued due to savings in (a) drying costs, (b) weightloss shrinkage, and (c) quality-deterioration discount. Under current U. S. economic conditions, the installation of a grain chiller appeared economical (i.e., the cashflows were positive). In Texas additional savings can accrue due to a reduction in the need for insecticides and fumigants. Due to the increased interest in grains grown organically, the only effective chemical-free storage technology is chilled aeration. Furthermore, at food-grade quality premiums of up to 75¢ for yellow and $1 for white corn above market prices, chilled aeration is an economic incentive for growers in Texas, especially considering the potential of up to 10% in estimated losses during food-corn storage. Rice is very sensitive to a reduction in head yield due to over- and underdrying. A market price of $16/cwt for milled parboiled rice makes chilled-aeration storage an attractive technology for both the quality preservation of stored rough rice and the conditioning of parboiled rice.

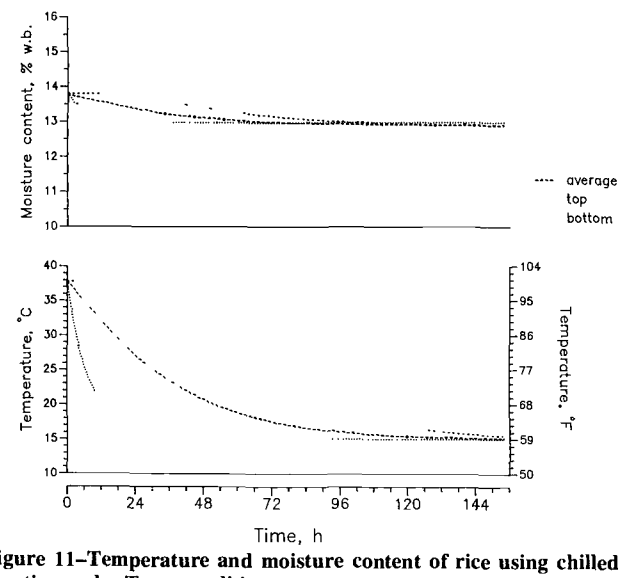

Figure 11–Temperature and moisture content of rice using chilled aeration under Texas conditions.

Conclusions

Based on the results of this study, the following conclusions are drawn for the conventional and chilled aeration of grains under Texas conditions:

Aeration of rough rice and food corn during the summer months (August-October) cannot lower the average grain temperature below 28° C (82° F).

Continuous aeration results in minimum overdrying of rice and corn in the bottom layers of a silo.

Time-clock and upper-limit relative humidity control of regular aeration leads to the partial overdrying or underdrying of grain in a silo.

Chilled aeration with properly-sized equipment is able to lower the rice and corn temperatures in commercial silos filled during the summer time to below 15.5° C (60° F) within a 120-160 h period.

Chilled aeration is able to permanently maintain the moisture content of silo-stored rice and corn uniformly at 13% (w.b.).

References

Bakker-Arkema, F. W. 1984. Selected topics of crop processing and storage. *J. Agric. Eng. Res.* 30:1-22.

Bakker-Arkema, F. W., D. E. Maier, W. Muhlbauer and H. Brunner. 1989. Initial cool-down in chilled maize storage. In *Agricultural Engineering*, eds. V. A. Dodd and P. A. Grace. Vol. 4:2261-2266. Rotterdam, Netherlands: Balkema, Inc.

Baur, F. J. 1984. Insect Management for Food Storage and Processing. St. Paul, MN: AACC.

Ben-Efrain, A., N. Lisker and Y. Henis. 1985. Spontaneous heating and the damage it causes to commercially stored soybeans in Israel. *J. Stored Prod. Res.* 21:179-187.

Brunner, H. 1989. Grain preservation by means of refrigeration in tropical countries. *Sulzer Technical Review 4/1989.* Winterthur, Switzerland: Sulzer Brothers.

———. 1990. Personal Communication. Sulzer-Escher Wyss, Lindau, Germany.

Burrell, N. J. and J. H. J. Laundon. 1967. Grain cooling studies. I. Observations during a large scale refrigeration test of damp grain. *J. Stored Prod. Res.* 1:125-144.

Chek, T. I. 1989. Application of paddy cooling technique in Malaysian rice industry. Workshop on Grain Drying, Bulk Handling, Storage Systems in ASEAN. Pitsanuloke, Thailand.

Escher Wyss. 1960. User Notice (In German). Escher Wyss GmbH, Lindau, Germany.

Finassi, A. 1987. Recent progress in rice cultivation in Italy. *International Rice Commission Newsletter.*

Heidt, H. and Bolling, H. 1965. *Grain Cooling* (In German). *Die Muhle.* 102:(10, 11, 12).

Hunter, A. J. and P. A. Taylor. 1980. Refrigerated aeration for the preservation of bulk grain. *J. Stored Prod. Res.* 16:123-131.

Komba, G., Z. Bellus and J. Csermely. 1987. Findings concerning the cooled storage of grain in Hungary. *Riv. di Ing. Agr.* 3:150-156.

Maier, D. E. 1988. User guide to AERATE - A grain drying and cooling simulation program. Unpublished. Michigan State University, East Lansing, MI.

———. 1992. The chilled aeration and storage of cereal grains. Unpublished Ph.D. thesis. Michigan State University, East Lansing, MI.

Maier, D. E., R. E. Kelley, F. W. Bakker-Arkema and H. Brunner. 1989. Long-term chilled grain storage. ASAE Paper No. 89-6541. St. Joseph, MI: ASAE.

McCune, W. E., N. K. Person, Jr. and J. W. Sorenson, Jr. 1963. Conditioned air storage of grain. *Transactions of the ASAE* 6(3):186-189.

Michl, J. 1983. Development of a method for the calculations of the drying time required for a number of grain-aeration systems with the aid of a microcomputer (In German). Unpublished M.S. thesis. University of Hohenheim, Stuttgart, Germany.

Muhlbauer, W. 1987. Personal Communications. University of Hohenheim, Stuttgart, Germany.

Navarro, S., E. Donahaye and M. Calderon. 1973. Studies on aeration with refrigerated air. I. Chilling of wheat in a concrete elevator. *J. Stored Prod. Res.* 9:253-259.

NOAA. 1988, 1989, 1990. National Oceanic and Atmospheric Administration Climatological Data. U.S. Department of Commerce, Washington, DC.

Nour, D. M., T. N. Chek and R. Abdullah. 1988. Bulk storage paddy aeration in concrete silos: A Malaysian experience. In *Bulk Handling And Storage of Grain in the Humid Tropics.* eds. E. E. Champ and E. Highley. ACIAR Proceedings No. 22. Canberra, Australia.

Parry, J. L. 1985. Mathematical, modelling and computer simulation of heat and mass transfer in agricultural grain drying: A review. *J. Agric. Eng. Res.* 32:1-29.

Rius, J. 1987. Experiences with storage of paddy using Granifrigors. Messr. Conserga, Spain.

Sutherland, J. W. 1986. Grain aeration in Australia. In *Preserving Grain Quality by Aeration and In-Store Drying,* eds. B. R. Champ and E. Highley. ACIAR Proceedings No. 15. Canberra, Australia.

Thompson, T. L. 1972. Temporary storage of high-moisture shelled corn using continuous aeration. *Transactions of the ASAE* 15:(2)333-337.

Thorpe, G. R. and W. B. Elder. 1982. Modelling the effects of aeration on the persistence of chemical pesticides applied to stored bulk grain. *J. Stored Prod. Res.* 18:103-104.