THE EFFECT OF AERATION RATE ON COOLING OF COTTONSEED IN THE MID-SOUTH

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Abstract

Cooling rates of cottonseed were studied utilizing instrumented chambers at five different aeration rates (0, 2.5, 5, 7.5 & 10cfm/ton). Seed, ambient and exhaust air temperatures, and exhaust relative humidity were measured and recorded during the study. Environmental conditions during the 1996 ginning season at Winona, MS did not result in an increase or decrease in the moisture content of seed when continuous aeration was performed. Temperature increases were observed at the upper levels of the chambers during the time when warmer weather conditions were moving through the area. Cooling front progression rates from about 2 ft/day for 2.5 cfm/ton to 5.4 ft/day for 10 cfm/ton were observed. A manager of a seed storage facility would be able to pass a cooling front through a 24 ft depth of seed in 12.5 days using the 2.5 cfm/ton aeration rate or 4.6 days using the 10 cfm/ton aeration rate. The difference between initial and final seed temperatures resulting from aeration was determined by the temperature of the ambient air and not by the aeration rate.

Introduction

Storage of cottonseed at gins has become more common in recent years. This is due primarily to a shift in the markets of cottonseed for cattle feed. The increase in seed storage at gins has brought about renewed interest in knowledge of the necessary aeration rate and in managing aeration systems economically. Lower aeration rates lend themselves to using wider duct spacings, smaller piping and fans which result in lower equipment and operating costs. Lower aeration-rate also means that the seed in storage will remain at higher temperatures for longer periods of time because it takes the cooling front longer to pass through the entire seed depth. Smith(1975) recommended that planting seed should be aerated at a minimum of 10 cfm per ton for safe storage. He recommended that aeration be conducted only during the periods when ambient relative humidity is below the equilibrium moisture content of the seed being aerated. Smith also found that cottonseed in storage decreased in germination and increased in free fatty acids when they were stored at high temperatures for longer periods of time. Despite this fact, cottonseed oil processing mills store seed with as little as 2 to 2.5 cfm per ton for extended periods of time. Due to the capacity of the oil mill storage buildings aeration is typically conducted continuously regardless of the ambient relative humidity. Shaw and Franks(1962) reported that high oil mill qualities were maintained when seed were dried at high temperatures and placed directly in storage without cooling. These seed remained at temperatures above 80 °F for one week as they lost heat in small piles by ambient cooling.

Cottonseed behave similarly to grains, perhaps with the exception of resistance to air flow properties, density and the wall forces generated by the seed (Willcutt, et al., 1996). Higher aeration rates are recommended for grain storage when the seed moisture content is expected to be higher (Gebhardt, 1990). The aeration rates for grains are usually much higher than for cottonseed. Thompson(1975) stated that 160 hours of fan operation would be required with an aeration rate of 0.1 cfm per bushel of corn in storage for winter conditions in Kentucky. The fan operating time would be reduced to 32 hours if aeration rate was increased to 0.5 cfm/bu. If these requirements hold true for cottonseed, it would translate to an aeration rate of 32 cfm/ton for an equivalent volume of cottonseed (one ton of cottonseed is equivalent to80 ft^3 or 64 bushels) or 18 cfm/ton for an equivalent weight.

The relationship between planting seed quality, storage temperatures, and the duration in storage is well documented in the literature. Sorensen and Wilkes (1973) and Curley, et al., (1988) found similar relationships for seed germination and free fatty acid contents from seed cotton stored in modules. Generally the higher the storage temperature and the longer the duration at that storage temperature the lower the germination and the higher the free fatty acid content of the seed.

The goals of this study were to measure the rate of cooling cottonseed with different aeration rates, and to develop recommendations about how to best manage aeration of cottonseed during storage. This study did not include an evaluation of the cottonseed quality resulting from the different aeration rates.

Materials and Methods

Five chambers measuring 4 ft wide by 8 ft long by 8 ft deep were constructed from 0.75 inch plywood reinforced with 2 by 6 inches pine girts, spaced approximately 18 inches apart around the horizontal perimeter of the chamber. No bottoms or tops were included in the chambers. The chambers were sealed using conventional caulking materials and tape in the corners and to the concrete floor in the seed storage building to prevent air from entering the chamber near the floor. Total volume of a chamber was 256 ft^3 and the capacity was approximately 6500 pounds of gin run cottonseed.

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Aeration systems consisting of three 2-inch PVC well screens, spaced 1 ft apart, running the length of the chamber at the floor level were placed inside four of the chambers. These pipes were connected with a manifold system to a small regenerative blower (ring compressor) for each chamber. Each blower was capable of delivering an aeration rate equivalent to 2.5, 5, 7.5 or 10 cfm per ton through a 24-ft depth of seed. Air flow rates were adjusted by opening or closing a gate valve between the aeration pipes and the blower. The fifth chamber served as an non-aerated control chamber.

Eight thermocouples were spaced at 1 foot intervals in the center of each chamber; level 1 being at the bottom and level 8 being at the top of the chamber. Relative humidity sensors and thermocouples were placed in the exhaust manifold before the blower intake to measure exit air relative humidity and temperature from the seed. Relative humidity and temperature sensors were installed near the top of the chambers to measure ambient conditions. All sensors were connected to data logging equipment to continuously record data at three minute intervals. Data was transferred to a laptop computer at the end of each run.

The chambers were filled by blowing seed directly from the gin operating at 20 to 24 bales per hour. Each chamber was filled in approximately 25% increments before moving to the next chamber allowing samples to be taken for moisture determinations. Three samples were collected from each filling level for a total of 12 samples per chamber during filling. Moisture samples were processed using standard gravimetric moisture determination methods.

Air flow rates were measured with a hot-wire anemometer which was inserted in the exhaust of the blowers. Static pressure readings were made approximately 2 hours after aeration was initiated to allow the chamber to reach steady state conditions. The primary purpose of the static pressure readings was to verify the possibilities of air leakage into the chambers at the floor level. Each chamber was aerated for a 7 to 10 day period. Moisture samples were taken from each chamber immediately after aeration. A total of four runs of the chambers was accomplished throughout the harvest season beginning in late September and finishing in November of 1996; however, the data from one run was not used in this paper due to discontinuities in the instrumentation. This provided a range of seed and ambient air conditions over which to observe the cooling and drying rates of the seed.

Data analysis was accomplished by first taking a moving average to smooth the data after which every other data point was discarded. This process was repeated six times yielding a smaller data set with an equivalent time spacing of one data point every 192 minutes (3 hrs 12 min or 0.1333 days).

Results and Discussion

Moisture contents before and after 10 days of continuous aeration differed by less than 1% for any of the five aeration rates (Table 1). The non-aerated chamber exhibited a slight rise in moisture in some runs, probably due to respiration and microbial activity in the seed. Seed were near their equilibrium moisture content for the temperature and relative humidity conditions present during the study. Consequently, significant drying did not take place under continuous aeration in these tests. Perhaps some drying might have been accomplished by selectively aerating the seed only during periods of low relative humidity. Higher initial seed moisture contents probably would result in greater drying for the air conditions that were present during the study.
The temperature profiles of each chamber during the second test are presented in Figures 1 through 5. Other runs behaved similarly. The top temperature sensor, level 8, tracks the ambient temperature profile very closely for the aerated chambers. The temperature profile of the unaerated chamber (Figure 1) first increased slightly then decreased about 5 to 8 degrees over the entire 10-day storage period. This is due to respiration and heat loss through the sides of the chamber, but primarily through the top of the chamber. The sensors at the lower levels detected less cooling than at the top. The temperature at the top 3 or 4 feet of seed in a pile would be expected to naturally seek the ambient temperature over a long period of time. Seed below about 4 feet in the pile would not cool appreciably and may rise due to respiration and microbial activity.

The temperature profiles of the aerated chambers indicate faster cooling for higher aeration rates as one would expect. The temperature profiles at all depths followed the ambient temperature profile with offsets and with time lags ranging from two to seven days depending on seed depth and the rate of aeration. The figures show that most cooling took place during the first few days of aeration. This is intuitively true because the temperature difference between the freshly ginned warm seed and the ambient air were the largest at that time. It is also clear from the figures that the coolest seed temperature that one can reach with aeration is greater than or equal to the lowest ambient temperature.

In an attempt to gain insight on the rate of cooling, observations on the movements of cooling fronts were made. The cooling temperatures of levels 1, 2, 6, and ambient temperature were observed to determine the point in time when cooling and heating began (drop and rise in temperatures) with respect to the ambient temperature.

In order to simplify the explanation of cooling front observation, some new terms are introduced:

Onset-Cooling-Time (OCT) - The time when cooling begins for a given layer. This is defined as the time when the slope (direction of movement) of a temperature changes direction from positive to negative for the first time, or the starting time if the temperature slope is negative from the beginning to the end of the data set.

Onset-Heating-Time (OHT) **-** The time when heating begins for a given layer. This is defined as the time when the slope of temperature changes direction from negative to zero or to positive for the first time after a cooling period. For a slow aeration rate, there may be no heating time observable due to the fact that it takes a much longer time for the temperature to drop for cooling than the amount of data captured in the data set.

Front-Propagation-Time (FPT) **-** The time it takes for a temperature profile of a given slope, at a given layer, to another temperature profile of the same slope at another layer. Several view points in determining the FPT were used to gain insight in the rate of cooling in a given chamber. The first view point was observing the difference in time between two OHT of two different layers. The second view point was observing the difference in time between two OCT of two different layers. Due to the existence of hysteresis in the thermal properties of any biological material, the two view points may not necessarily yield the same result.

Front-Propagation-Rate (FPR) **-** The average speed at which the cooling front is moving. FPR is calculated by simply dividing the distance between two layers (depth of seed between two layers) by FPT (distance/FPT). This gives the "feet per minute" or "feet per day" quantity for the cooling front.

Figures 6 to 9 are simplified views showing temperatures from levels 1, 2, 6 and ambient of the first cooling phase for aeration rates of 2.5, 5, 7.5 and 10.0 cfm/ton, respectively. The end point of each curve was determined by using the definitions above. The rate of the front progression was determined by taking the difference in the time that the level six and level one sensor slopes changed from negative to positive and dividing that time by the vertical distance (5 ft) between the fronts. The 2.5 cfm/ton curves (Figure 6) show level six turned positive after about 3.4 days and level one turned positive after about 5.8 days. The difference of cooling 5 ft in 2.4 days amounts to a front progression rate of approximately 2ft per day. Some figures show the ambient air being warmer than the seed being cooled at a given level. This is possible since the seed above a given level was cooled when the ambient temperature was cooler. Seed at the cooler temperatures absorb heat from the warmer air, thus the net air temperature is sufficiently cool enough to produce continued cooling at lower levels.

The front propagation rates (FPR) for different aeration rates are shown in Figure 10. The values indicate that the rate of movement of the cooling front is not linearly dependent on the aeration rate.

Conclusions

Significant drying of cottonseed is unlikely using continuous aeration under ambient conditions in the mid south. In other parts of the cotton belt where cooler and dryer ambient air conditions can be found, aeration in higher rates can be managed and used to lower the moisture content of seed with higher initial moisture contents. Cooling rates of about 2 ft/day using 2.5 cfm/ton to 5.4 ft/day using 10 cfm/ton of aeration rates were observed during this experiment. A manager of a seed storage facility would be able to pass a cooling front through a 25 ft depth of seed in 12.5 days using a 2.5 cfm/ton aeration rate or 4.6 days using a 10 cfm/ton aeration rate. The difference in the initial seed temperature and the temperature of the ambient air used in the cooling process will determine the amount of cooling that can be achieved in one pass of the aeration front through the seed. When using slower aeration rates it is important to use continuous aeration in order to achieve maximum cooling. Higher aeration rates should be managed to maximize cooling and drying without reheating the seed mass when the ambient temperature increases. Selective aeration can be used in the mid-south, in the fall, in intervals of three to five days, when the temperature and humidity of ambient air were low.

When designing aeration systems for cottonseed storage facilities the designer should not overlook the factors that work to the facilities' advantage. Namely, greater aeration capabilities must exist to facilitate selective aeration. Seed from the early part of harvest that may be higher in moisture content and higher in temperature can be cooled faster by spreading in the storage facility. Cotton harvested with dryer seed, as fall temperatures cool and humidity declines, may be placed on top of the previously conditioned seed and will require less aeration. Selecting seed from dryer seed cotton that requires/generates less heat, for storage, in the ginning process will reduce the demands on cooling and drying in the storage facility.

Acknowledgements

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Table 1: Moisture Contents of Cottonseed Before and After Aeration

Cfm/ton	Run 1	Run 2	Run 3	Run 4
0.0	10.13	13.42	11.28	12.63
2.5	9.81	12.96	10.96	13.99
5.0	9.47	13.34	10.90	11.60
7.5	9.75	12.88	11.26	13.58
10.0	9.71	13.36	11.32	12.69
Initial	10.45	13.49	11.53	12.25

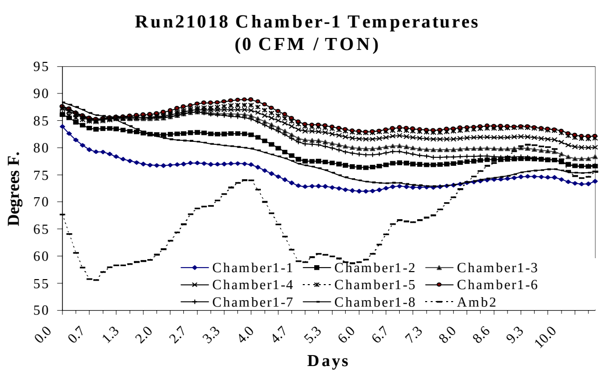

Figure 1. Seed Temperature Profile for 0 cfm/ton Aeration

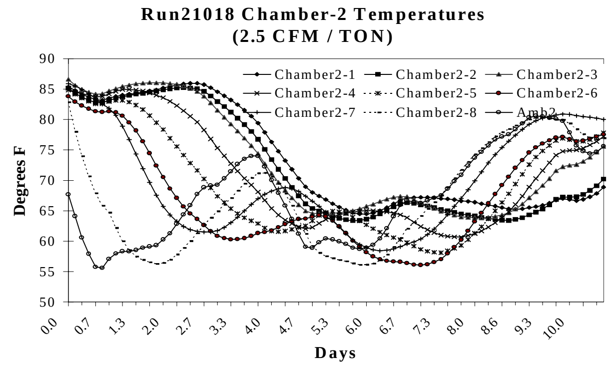

Figure 2. Seed Temperature Profile for 2.5 cfm/ton Aeration.

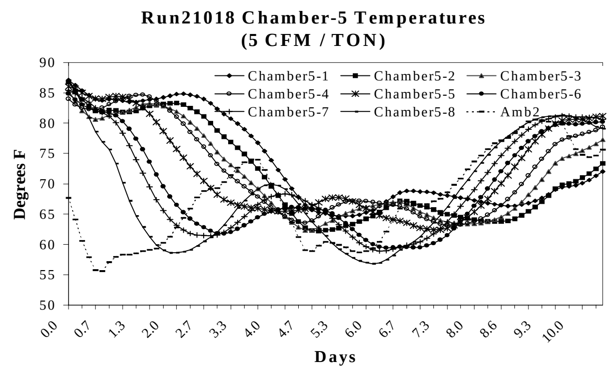

Figure 3. Seed Temperature profile for 5 cfm/ton Aeration.

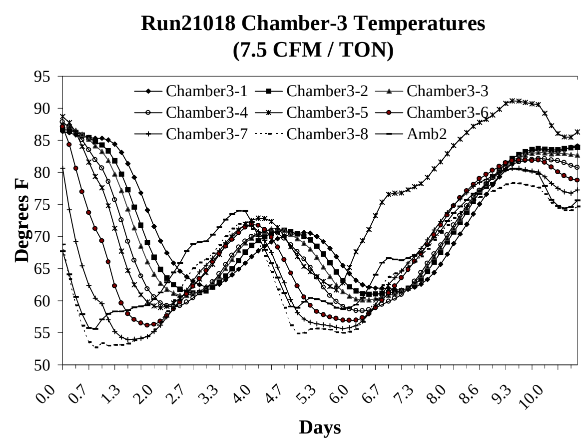

Figure 4. Seed Temperature profile for 7.5 cfm/ton Aeration.

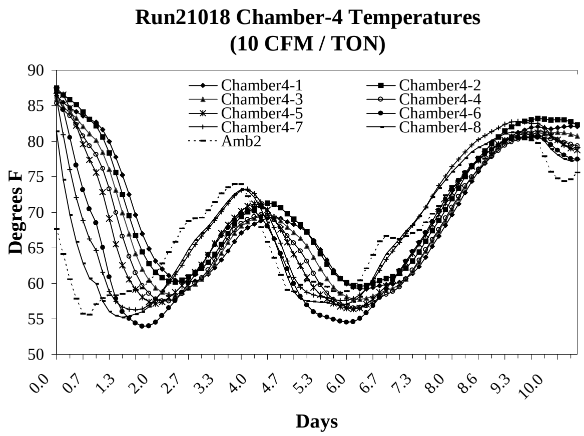

Figure 5. Seed Temperature profile for 10 cfm/ton Aeration

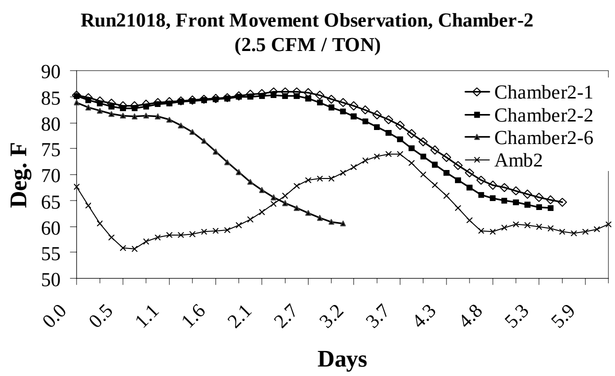

Figure 6. Cooling Front Progression for 2.5 cfm/ton

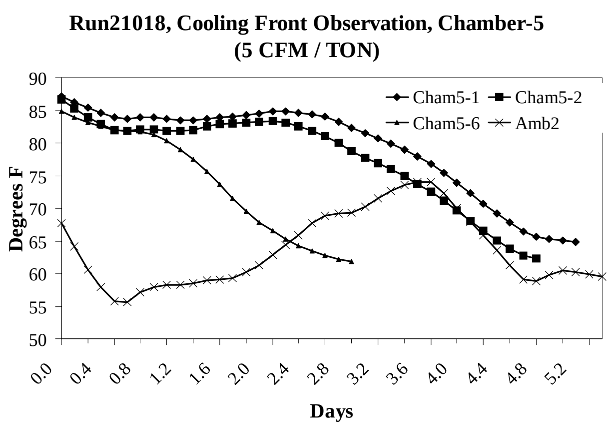

Figure 7. Cooling Front Progression for 5 cfm/ton

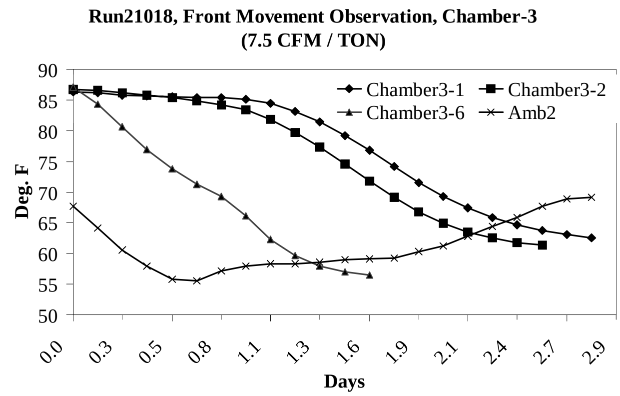

Figure 8. Cooling Front Progression for 7.5 cfm/ton

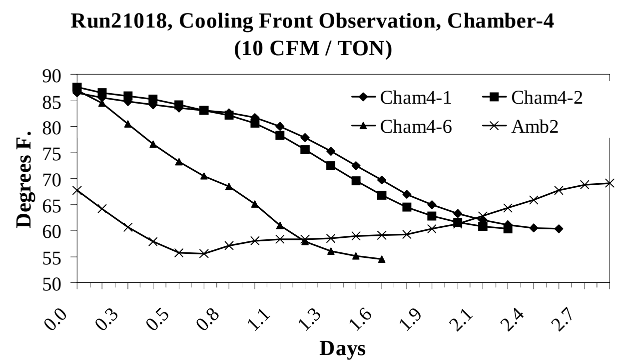

Figure 9. Cooling Front Progression for 10 cfm/ton

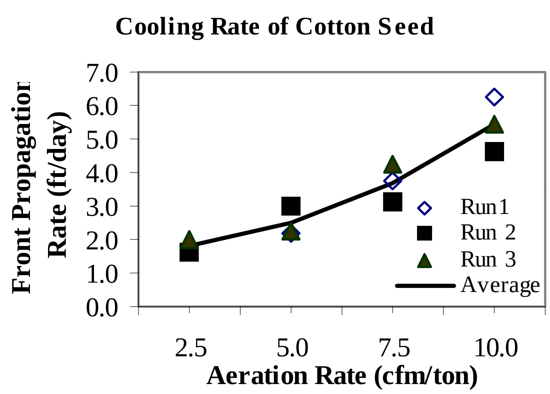

Figure 10. Cooling Front Progression Vs. Aeration Rate