SETTING UP AND EVALUATING AN AERATION SYSTEM WITH ARTIFICIALLY COOLED AIR

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ABSTRACT

The aeration system is used to preserve the quality of the stored grains, with the main objective of cooling the grain mass. Despite being the most widespread system for preserving stored grains, aeration has limitations such as dependence on local climatic conditions. Therefore, the cooling system can be an alternative technology to replace conventional aeration. The objective of this work was to design, construct and evaluate an artificially cooled grain aeration system. A prototype silo with dimensions of 0.9 m in diameter and 3 m in height, with a perforated bottom, was built, and an artificially cooled aeration system was adapted, in which the vortex tube coupled to the side of the plenum was used to blow the cold air. In the recording of temperature and interstitial moisture data of the grains; and the temperature and humidity of the environment, SHT75 sensors were used that were placed in the center of the prototype silo. The vortex tube was activated 15 minutes before turning on the fan, so that the temperature of the air blown by the fan in the silo was lower than the temperature of the ambient air. The artificially cooled system was activated daily at 7 pm and turned off at 8 am. In the evaluation period, the air temperature did not present major variations, ranging from 20.97 to 26.56ºC, on the other hand, the relative humidity of the air suffered large oscillations from 81.13 to 34.78%. The evaluation time was 26 days and the average temperature recorded at the end of the experiment was 24.02ºC. The artificially cooled aeration system worked correctly, reducing the temperature of the aeration air, but only with one compressor it showed low efficiency.

Keywords: Vortex tube. Arduino. Grain storage. Temperature. *Zea mays*.

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INTRODUCTION

Food production in Brazil, especially grains such as corn, wheat, soybeans, and barley, had high growth rates, resulting from modernization and agricultural technologies (BARONI et al., 2017).

The grains produced, after going through the cleaning and drying processes, are stored so that they can be used later. Storage is a process that is based on gathering and storing a certain volume of product for a prolonged period, in order to preserve the quality and primary characteristics of the grains, avoiding fungi, pests and excessive moisture (MOHAPATRA et al., 2017; NEME and MOHAMMED, 2017; MUTUNGI et al., 2019)

Temperature and relative humidity are the main factors that can interfere with grain quality during the storage period (BORÉM et al., 2019). The reduction in grain temperature slows down the speed of biochemical and metabolic reactions (PARAGINSKI et al., 2014). According to Ziegler et al. (2016), for grains stored at a temperature of 15 ºC, there is a purge effect, controlling insect infestation.

Aeration is the most widespread and used preventive control method in the preservation of stored grains. This method consists of the forced passage of ambient air through the grain mass, in such a way as to modify the intergranular microclimate, creating unfavorable conditions for the development of organisms that influence the preservation of grain quality (LOPES AND STEIDLE, 2019). Another technique used to maintain the quality of the stored grains is artificial cooling, which consists of reducing the temperature inside warehouses and/or vertical silos. Cooling allows air exchanges between the environment and the interior of the grain mass, and cold air is blown into the silo, which remains in operation until the desired temperature of the grain mass.

Reducing the temperature to refrigeration levels can be a promising technology in maintaining the quality of the grains, delaying the development of insects, pests and the microflora present, regardless of the climatic conditions of the region (Demito and Afonso, 2009). Rigueira et al. (2009) pointed out that storing production in systems where the temperature is reduced is an effective and economical technique for long periods.

In this context, the objective was to build an artificial cooling system for grains stored in metal silos.

MATERIAL AND METHODS

LOCATION AND DESCRIPTION OF THE STUDY AREA

The study was developed at the Laboratory of Drying and Storage of Plant Products, located at the Central Campus of Exact and Technological Sciences Henrique Santilo, of the State University of Goiás, in Anápolis-GO.

CHARACTERIZATION OF THE EQUIPMENT THAT MAKES UP THE ARTIFICIAL COOLING SYSTEM

Prototype Silo

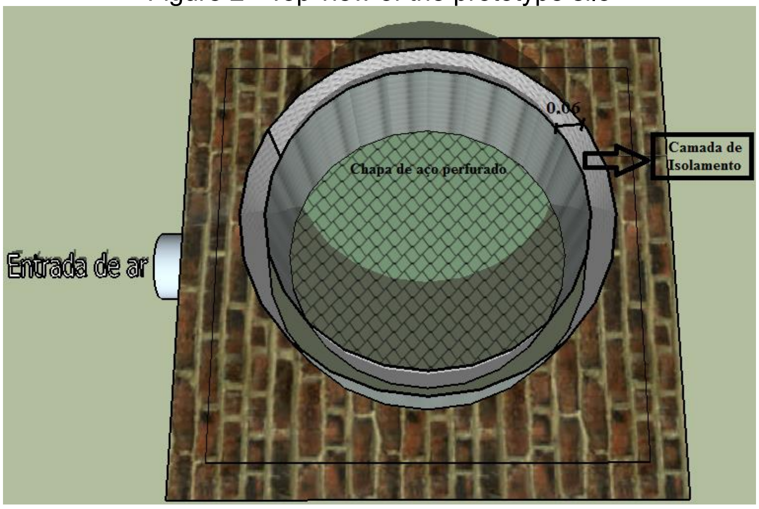
A cylindrical metal silo was used, with dimensions of 0.9 m in diameter and 3 m in height, with capacity to store 1500 kg of corn grains, with a specific weight of 750 kg $^{m-3}$. A masonry plannum was built to allow air to enter the silo, with dimensions of 1.2 m in diameter and 0.3 m in height, as illustrated in Figure 1**.**

On the external surface of the silo, thermal insulation was inserted, consisting of a layer of glass wool, 0.06 m thick (Figure 2), in order to minimize the heating of the grains from the conditions of the environment outside the silo. In the lower part of the silo, perforated steel plates with sieves with a diameter of 0.006 m were installed to allow the passage of air through the grain mass, Figure 2.

Figure 1 - Prototype silo used to evaluate the artificial cooling system

Source: AUTHOR

Figure 2 - Top view of the prototype silo



Source: ANTUNES (2016)

Fan

A radial blade centrifugal fan, built in sheet metal, was used, Figure 3. The air flow rate provided by the fan was 6 m^3 $^{min-1}$ and the static pressure was 35 mmCA $^{m-1}$. The high-speed 1 hp three-phase motor was used to drive the radial blades.

Figure 3 - Centrifugal fan with radial blades used to blow air into the silo

Source: AUTHOR

Frequency Inverter

The PowerFlex4 frequency inverter, Figure 4, was used to regulate the rotation of the fan rotor, aiming to achieve an aeration air flow of 0.15 m^3 $^{min-1}$, so the frequency used in the inverter was 7.2 hertz.

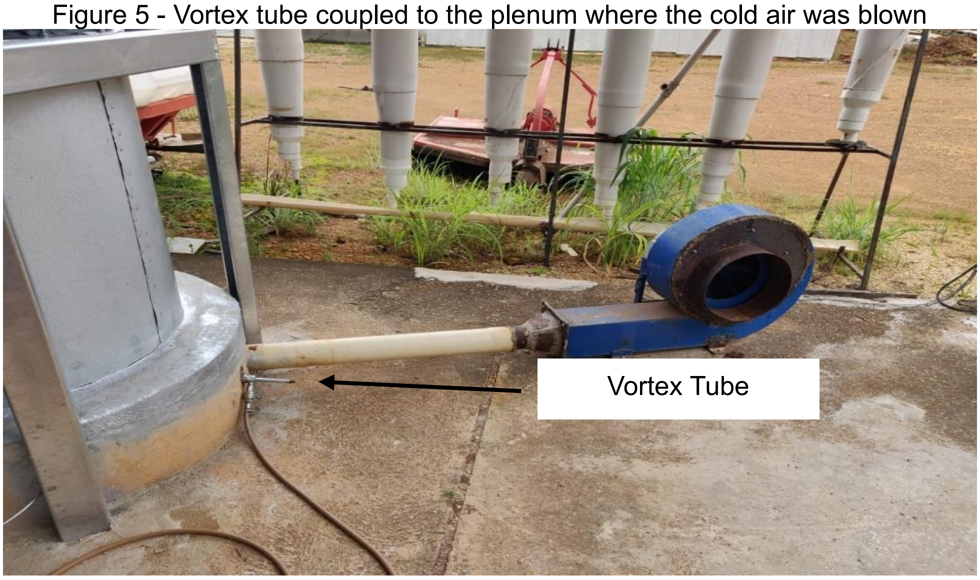
Figure 4 - Frequency inverter used to regulate the rotation of the fan rotor

Source: AUTHOR

Vortex Tube

The small vortex tube of the EXAIR brand, model 3230, was used to provide artificial cooling. The air temperatures generated by the vortex tube were from -1 to 56 ºC, and with a maximum flow rate of 0.6 m^{3min-1}. These temperature variations depend on the size of the pipe and the power of the compressor used. The vortex tube was coupled to the side of the silo plenum as shown in Figure 5, where the cold air was blown away.

Figure 5 - Vortex tube coupled to the plenum where the cold air was blown



Source: AUTHOR.

Compressor

A Pressure compressor, Figure 6, was used, with the following characteristics: operating pressure: Maximum 175 lbf $^{in-2}$ (12.07 bar); reservoir volume: 250 L; flow rate: 20 pcm (0.6 $m^3/^{min-1}$); and motor power: 5 hp three-phase.

Figure 6 - Compressor used to supply compressed air to the vortex tube

Source: AUTHOR.

PRELIMINARY PROCEDURE FOR ARTIFICIALLY COOLED AERATION

In the artificially cooled aeration system, the vortex tube was activated 15 minutes before turning on the fan, so that the temperature of the air blown by the fan in the silo was lower than the temperature of the ambient air. After the plenum cooling period, the artificially cooled aeration system fan was activated. The system was turned on daily at 7 p.m., and turned off at 8 a.m

HEATING SYSTEM

An air heating device was developed to heat the stored grains to a temperature of 30 ºC. Grain heating is necessary to simulate the real condition of the grain outlet temperature of a commercial dryer (LAWRENCE and MAIER, 2011).

The device for heating the grain mass was built with metallic material, with dimensions of 0.5 x 0.16 x 0.15 m. Inside the device, two resistors (type U) were placed, with dimensions of 0.45 x 0.06 m and powers of 2 and 1 Kw.

The heating system was coupled to the fan and the planum of the silo, Figure 7. The tests with artificially cooled aeration began when the entire grain mass had reached 30 ºC. To monitor the heating process, a temperature sensor was installed inside the planum.

Figure 7 - Heating system coupled to the fan and plenum

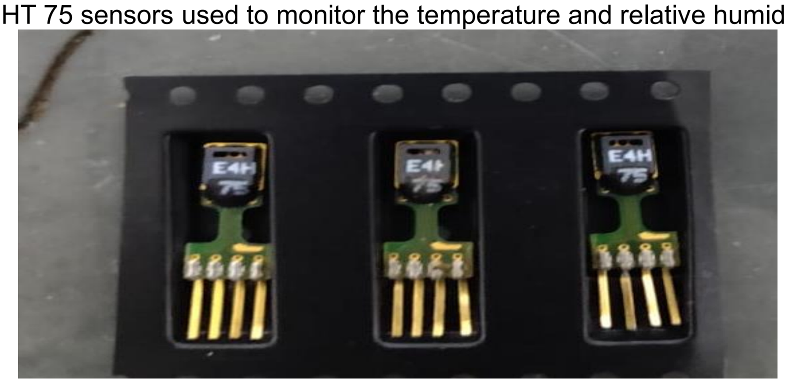
Source: AUTHOR

CHARACTERIZATION OF THE CONTROL OF THE AERATION SYSTEM

Sensors

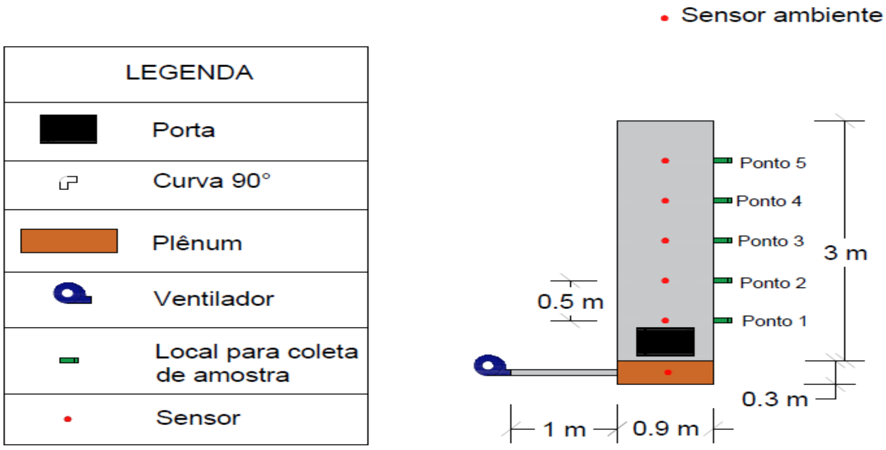
The sensor selected to monitor interstitial air temperature and humidity was the SHT 75 model, Figure 8, of the Sensirion family. The temperature reading range is from -40 to 123.8 ºC with an accuracy of 0.4 ºC. Relative humidity can vary from 0 to 100% with an accuracy of 1.8%. A total of 7 sensors were used, which were distributed: 5 sensors in the silo, spaced 0.5m apart in the grain mass; 1 sensor on the plenum; and 1 for environmental parameters, positioned in a place outside the grain mass, Figure 9.

Figure 8 - SHT 75 sensors used to monitor the temperature and relative humidity of the silo



Source: AUTHOR

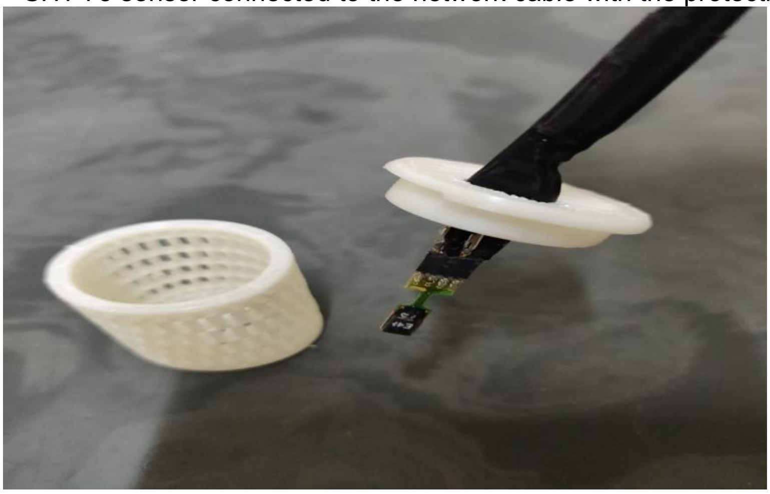
Figure 9 - Schematic of the prototype silo with the sensors arranged in the center



Source: AUTHOR

All sensors were connected to a Cat5 network cable, eight ways and shielded to prevent electromagnetic interference. In order for the sensors not to be in direct contact with the corn, a protection device, Figure 10, was plotted on a 3D printer. The device had the following dimensions: 0.035 m high and 0.03 m in diameter, with rectangular screens 0.001 m high and 0.0005 m wide, and with a lid of 0.03 m in diameter.

Figure 10 - SHT 75 sensor connected to the network cable with the protective device



Source: AUTHOR

Arduino Microcontroller

The Arduino microcontroller was used, because its programming is simple, easy to acquire and met the hardware requirements for the execution of the project. The microcontroller is responsible for intermediating in the system, where it receives information on the temperature and relative humidity parameters and sends it to a microcomputer that presents the information to the user

The Arduino model chosen was the UNO, Figure 11 which has a serial communication channel, 13 digital input and output ports, 6 analog ports and an ATMEGA 328P processor. 1 Arduino board was used for the silo and one for the environmental parameters.

Figure 11 - Arduino Uno used in data acquisition

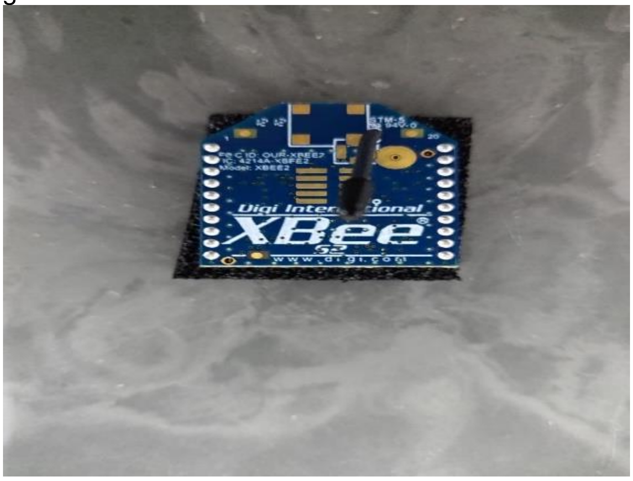
Source: AUTHOR

Xbee Modules

The Xbee modules were used for wireless communication with the Arduino board installed in the silo. The Xbee module model chosen was S2,

Figure 12, with a communication frequency of 2.4GHZ. Two modules were used, one connected to the Arduino and the other in the microcomputer used to store the data.

Figure 12 - Xbee communication module used in Arduino



Source: AUTHOR

DATA ACQUISITION SYSTEM

In the data acquisition system, the algorithm was developed using the standard libraries, made available by the Arduino software (MCROBERTS, 2011). To present in real time the values of temperature, relative humidity, another system was developed based on the PHP programming language, where the data was collected and stored every ten minutes.

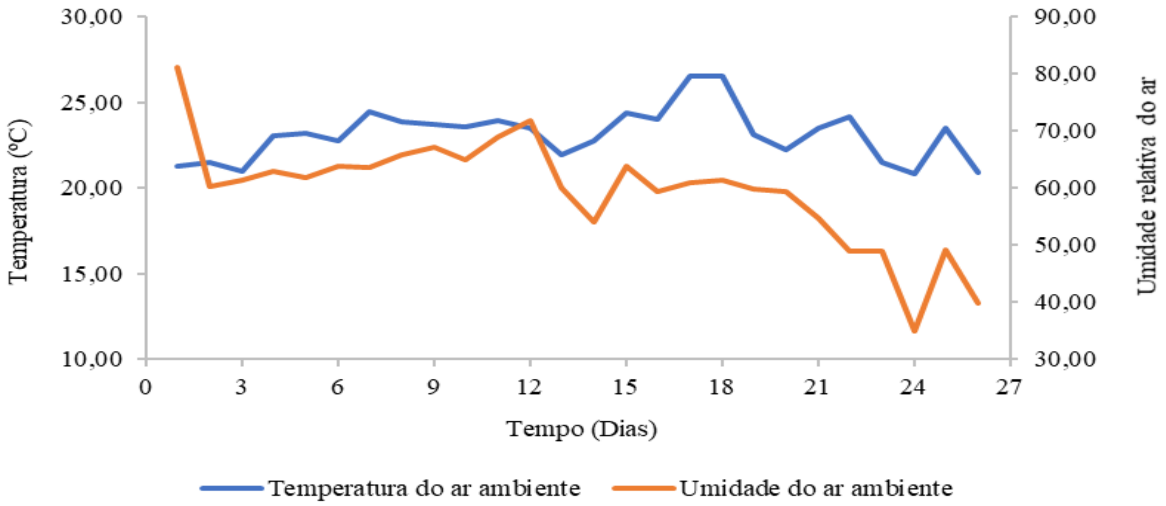
RESULTS AND DISCUSSION

AMBIENT TEMPERATURE AND AIR CONDITIONS DURING ASSESSMENTS

The temperature and relative humidity conditions during the evaluation period (January 14 to February 9, 2021) of the artificially cooled aeration system portray the transition from the rainy season to the dry season, characteristic of the city of Anápolis-GO.

It was noted that during the period of evaluation of the system the air temperature did not suffer major variations, Figure 13, ranging from 20.97 to 26.56 ºC. On the other hand, the data collected on the relative humidity of the air during the 26 days of evaluation varied from 81.13 to 34.78 %, following the characteristic period of the region. According to Lopes et al. (2015), these oscillations in the relative humidity of the air show that the stored grains need efficient control in the aeration process.

Figure 13 - Daily average temperature and relative humidity

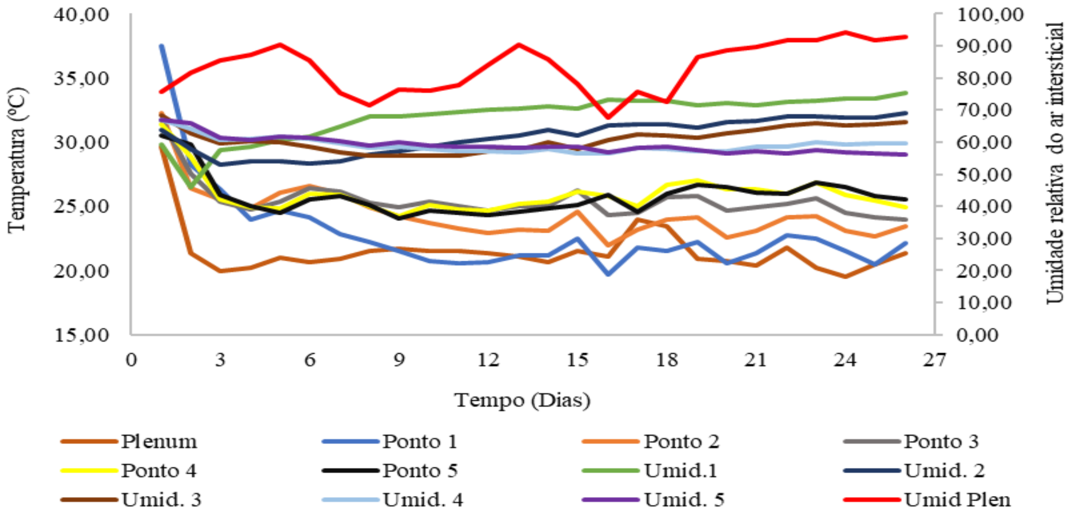


Source: AUTHOR

COOLING FRONT

The temperature variation of the grains stored during the evaluation period of the artificially cooled aeration system, at the 5 points of the silo, is represented in Figure 14.

Figure 14 - Variation in temperature and humidity of the interstitial air of the grain mass at points (1, 2, 3, 4, 5 and Plenum)



Source: AUTHOR.

The average temperature of the grain mass was higher than expected, and was due to the action of insects. According to Antunes et al. (2011), insects provide a warmth in the grain mass, by increasing the metabolic activity and respiration rate of the stored grains.

When there is a reduction in temperature in the grain mass, it can be said that the aeration was satisfactory; And when the temperature of the whole silo is reduced, it can be inferred that the cooling front has reached the top silo. According to Figure 14, it is possible to notice the cooling front, the temperature reduction in the grain mass occurred in the vertical direction, in the upward direction in the silo. The cooling in the grain mass was more intense at points 1 and 2. From point 3 onwards, the process of temperature reduction was slower. It was noted that during the evaluation process of the artificially cooled aeration system, the lowest temperatures recorded were at points 1 and 2, of 19.66 and 21.92 ºC respectively.

It was found that in points 3, 4 and 5 the lowest temperatures were recorded on the last day of evaluation, 23.98; 24.94 and 25.54 ºC, respectively. According to Quirino et al. (2013), the upper layers of the silos are more influenced by the storage environment than the lower layers, thus taking longer for their cooling.

Regarding the temperature of the plenum, it was noted that when activating the vortex tube, the temperature difference between the plenum and the ambient air temperature was 4 ºC, and when turning on the fan, this difference reduced to 2 ºC. This increase in temperature was generated due to the higher temperature of the ambient air, which was inflated in the plenum.

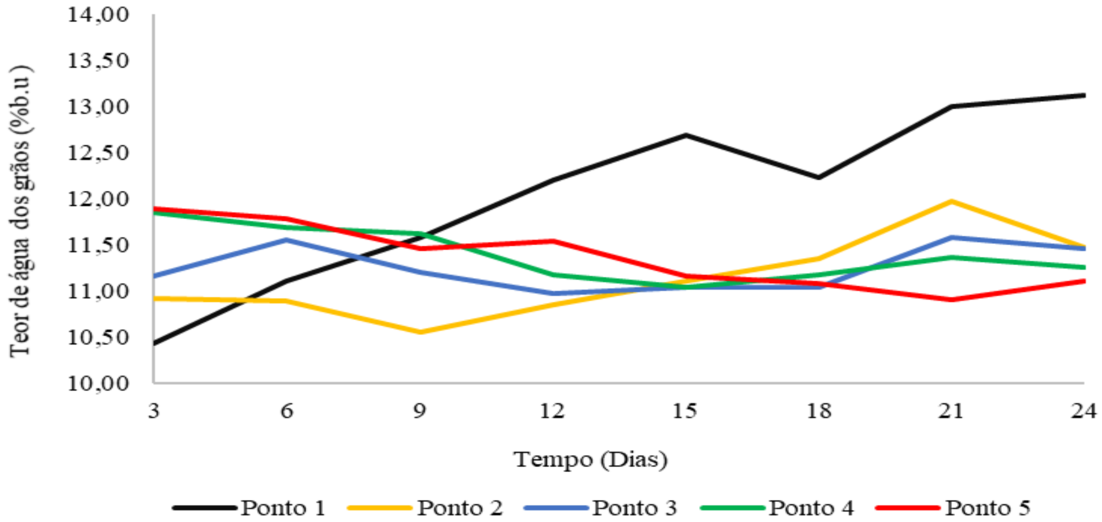
In order for the vortex tube to work efficiently, the air inlet pressure must be 7 bar constantly. Whang et al (2009) used the inlet pressure of 7 bar and obtained the best cooling effect. In the tests to start the evaluations of the systems, two compressors were used, connected in parallel, which maintained the inlet pressure at 7 bar. But on the first day of the experiment, one of the compressors broke down. Thus, during the remaining days of the experiment, the artificially cooled aeration system worked only with a compressor, which maintained the inlet pressure of 4 bar, reducing the efficiency of the system.

In the relative humidity of the interstitial air, it is noted that in point 1, there was a reduction from 59.28% to 45.95% from the first to the second day of evaluation. The reduction in the relative humidity of the interstitial air was promoted by heating the grain mass before starting the evaluation of the system. It is observed that the temperature on the first day of evaluation at point 1 of the silo is higher than the other points, causing air drying.

WATER CONTENT OF GRAINS

The evolution of the water content in % b.u in the grain mass is shown in Figure 15 for the five monitored points. The variation of the water content in the grain mass occurred throughout the evaluation period due to the hygroscopicity of the grains. The variation occurred until the grains reached the water content of equilibrium with the environment. It was observed that this variation occurred both by the interference of external factors, such as the relative humidity of the air and temperature of the aeration air and by the humidity of the interstitial air of the plenum.

Figure 15 - Variation of the water content in % b.u of the grain mass at points (1, 2, 3, 4, 5) in the silo



Source: AUTHOR

The initial average water content of the grain mass was 11.25±0.63 % b.u. It was verified that at all points, the water content of the grains remained below 12% b.u., ensuring good storage. According to Coradi and Lemes (2019), the physicochemical and microbiological qualities are directly linked to the water content of the grains, so the lower the quality of the stored grains. In addition, Bessa et al. (2015) concluded that grains stored for six and eight months should be kept with a water content of 10 to 12 % b.u.

It was noted that in the grain layer of point 1, there was greater drying in relation to the others, which can be explained by the heating done before starting the evaluation of the aeration systems.

It was also found that the grains in point 1 suffered an increase in water content that exceeded the recommended limit for safe storage, which according to Chigoverah and Mvumi (2016) is up to 12.5% b.u for corn grains in non-hermetic storage. The final water content of the grains at point 1 was 13.12±0.02 % b.u. It is verified that this variation in the water content of the grains at point 1 occurred due to the migration of moisture from the interstitial air from the plenum to the grain mass and by the infestation of insects that were in higher concentration at this point. Authors such as Antunes et al. (2011) and Pinto et al. (2002) observed that insect infestation results in an increase in the water content of stored grains by 3.6 percentage points in 90 days of storage; This increase is due to the metabolism of the insects and the respiration of the grains.

In point 2, it was noted that from the sixth day to the ninth day of the experiment the water content of the grains decreased. On the twelfth day, the grains reached hygroscopic equilibrium. However, on the last day of evaluation, the moisture content of the grains rose to 11.47±0.14 % b.u.

In points 3 and 4, it was observed that the water content of the grains entered equilibrium on the twelfth day and increased on the twenty-first day. In the last evaluation, the water content was 11.45±0.11 for point 3 and 11.26±0.26 % b.u for point 4. However, for point 5, the grains had a water content close to 12% b.u and ended the experiment with 11.72 % b.u.

It was found that the grain mass at points 2, 3, 4 and 5 remained with water content below 12.5 % b.u., which is the safe moisture for the storage of corn grains.

CONCLUSION

According to the results obtained and the conditions in which this work was developed, it can be concluded that:

1. The average temperature at the end of the silo evaluation was 24.02 ºC.

2. The artificially cooled aeration system using the vortex tube as a tool for cooling the air worked correctly, lowering the temperature of the aeration air, but only with a compressor it proved to have low efficiency.
3. The computer system for the acquisition of temperature and relative humidity data in grain storage, using Arduino, collected the data efficiently.
4. As future works, it is proposed to use two compressors that could maintain an air inlet pressure of 7 bar constantly, so that the proposed system is efficient. Investigate the use of a screw compressor in the efficiency of the cooling system. Another point to be improved would be automation in the activation of the aeration system.

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