Computer Aided Grain Aeration Management: An Antidote to Grain Deterioration in Metal Silo

1 B. J. Olorunfemi, 2A. A. Adekunle, and 2 S. B. Adejuyigbe
1Department of Mechanical Engineering, Federal University Oye-Ekiti
bayode.olorunfemi@fuoye.edu.ng
2Department of Mechatronics Engineering, Federal University Oye-Ekiti

Abstract—Aeration is very important for good grain storage as it helps to maintain uniform grain temperatures, minimizes moisture migration, and prevents quality loss of stored grain. The temperature of grain stock was monitored with the aid of temperature sensors installed inside the silo bins. Each silo contained twenty sensors located on five probes at different sections of the silo bin. Grain was received to experimented metal silos at 30°C. The parameters for grain before reception were 1% broken grain, 1% mould, 1% foreign matters, 68–75KG/HL weight and 12% moisture content. Grain temperature rose to 45°C within three weeks of storage. Temperature readings were taken in the morning and at evening times. Aeration system (fans) was operated several times, each time for long hours (>24hours) enough to equalize temperature throughout the entire grain mass. Aeration fans were used to rapidly cool grain to 25°C and then held it between 25 - 41°C for over a year. The power requirement increased as air flow rate and grain depth increased. Aeration fans were controlled automatically from the operating control room while dehumidifiers were installed on the aeration fans. Loss recorded at manually operated metal silo was compared with the one from the silo monitored with computer software developed. While aeration could be used to lower grain temperature, minor changes took place on the moisture content of the grain mass. Loss was reduced to < 1% as against 5% allowable level. Aeration can be better monitored economically with the use of a computer system.

Keywords—Aeration, Computer- aided, Grain, Silo and Management

1 INTRODUCTION

The predominance of grains in Nigeria in terms of seasonal production supply nature, large production potentials, and large dependency consumption demand capacity utilisation and make storage and preservation imperative (Igbeka, 2013). Resulting from poor storage and preservation of food crops at the time of plenty, post-harvest loss is such a great concern that farmers often feel discourage to invest in large-scale production (Olorunfemi, 2016). Aeration is the stored grain management technique of forcing cool air at low airflow rates through the grain mass in order to equalize the grain temperature and in the process effect cooling.

Grain aeration allows farmers and storage managers to maintain grain quality by regulating moisture and temperature. Grain is a living matter; it respires, producing heat and moisture. However, when grain is clean, sound and at moisture content of equal or less than 12%, where all the metabolic activities, such as respiration are extremely low and in this way the grain is dormant and stores very well (Warrick, 2010). Any deterioration in grain quality and development of "hot spots" due to condensation, rain leaks, or insect activity result in increased metabolic activity which produces heat that manifests itself in a temperature rise to the extent that the germ is destroyed. In addition, under a high moisture content condition, insect multiply rapidly, while at low moisture levels they remain dormant or die. The moisture content of the seed or grain is changed very little by aeration due to the low volume of air.

Aeration conditions grain by lowering the temperature of the material and equalizing the temperature within the storage structure. This prevents moisture migration and condensation. All organisms responsible for losses in quality and quantity of stored grain and are affected by the temperature and moisture of the material. Such organisms include bacteria, insects, molds and mites. Cool but dry grain and seed keep longer if these deteriorating elements are prevented. During aeration, exhaust air and grain surface are monitored to determine when cooling is complete. Grain at the top of the stack is the hottest as heat rises through the grain and it is exposed to the head space in the silo, which can get very hot during summer (Warrick, 2010). There are three phenomena that are related, namely; the climate, the response of micro organic life to environment and the response (equilibrium moisture) of grain to the environment. And when these three phenomena are described mathematically, proper levels of aeration can be computed and modified for grain storage in humid tropics like Nigeria (Igbeka, 1994).

Arthur et al (2001) asserted that Computers are an ideal platform to model grain storage management systems and that, this can be utilized to study the physical and biological parameters involved in the grain storage and established realistic operating parameters to implement monitoring practices. Computer Aided Design (CAD) and Computer Aided Management (CAM) is the integration of computers into the design and management process to improve productivity (Adejuyigbe, 2010 and Olorunfemi, 2014). In addition, Computer aided management would ensure timely registration of goods; enhance human efficiency and effective managerial decisions (Olorunfemi et al, 2015). The vision in the transformation strategy of the government of Nigeria since 2012 was to achieve a hunger- free Nigeria through agricultural sector that drives income growth, accelerates achievement of food and nutritional sector, generates employment and transforms Nigeria into a leading player in global food markets to wealth for millions of farmers (ATA, 2012).
1.1 Aeration Fan

Aeration is introduced into silo construction for the purpose of temperature management, to control mould proliferation, insect and moisture migration. Grain is often aerated with ambient air by means of simple fans in tropical countries. Grain is hygroscopic, if relatively humid air is brought into contact with dry grains a dangerous uptake of moisture content of 16%, the relative humidity of the air between the kernels is about 74%. If on the other hand, air with 90% relative humidity is brought into contact with dry grain, a dangerous moisture increase to 22-25% as the air inlet temperature is higher than the grain temperature (McNeil, 2010). Aeration fan can either be a centrifugal or axial type. Centrifugal fans are either low speed- 1750 rpm/60Hz; 1460 rpm/50HP or high speed and in-line centrifugal of 3500 rpm/60 or 2900rpm/50Hz. Axial- flow fan is a vane- axial (fixed or adjustable pitch blade). It can also be a tube- axial (small fans- 2HP or less). Fan should be selected based on optimum performance, efficiency in terms of airflow per unit of energy (CFM/hp or m3/min/kW), noise, cost, reliability, mounting factors, and so on. Fig. 1 was a picture of a typical axial fan. Fig. 2 shows a clusters of metal silo. Aeration cooling requires airflows of at least 2-3 litres of air, per second, per ton. For example, a 100t silo will require 200-300 litres per second (l/s) of air to cool the grain effectively (GRDC).

1.2 Temperature Sensor Probes

The temperature monitoring system is a remote monitoring system that detects temperatures at various levels within the bin. If it is found that any silo shows increase in the temperature of +2°C, then aeration is indicated. However, should the temperature increases rapidly by more than 1°C or 2°C, emergency procedures must be initiated. The thermocouple sensor cables monitor temperatures at the remote area of the bulk grain. The cables are suspended in between the grain with a lead-wire extension and each cable contains sensor points and it is connected to a display instrument through a readout plug to the control panel. Fig. 3 is a sketched metal silo showing sensor cables.

1.3 Air Flow Rate

It is the quantity of air that is moved through a quantity of grain in a given amount of time. Adequate air must reach all areas of the stored grain to cool it before condensation begins. Satisfactory aeration depends primarily upon air flow rate. The air flow rate through the grain will not be uniform where ducts are used. Thus, the air flow rate is an average value and must be high enough for adequate air supply to reach the grain in all areas of storage. For grain aeration purpose, airflow rate is usually described in units of cubic feet of air per minute (CFM) per bushel of grain, or CFM/bu. Typical air flow rate for full bin aeration systems range between 0.1-1.0 CFM/bu (McNeil et al, 2010). Vertical aerators is effective in circular metal bins, it can be used with sweep augers as installed at Government Silo Complex in Nigeria (Fig.4a) while Fig. 4b shows aeration ducts for the distribution air for aeration. Ducts that are shorter) should have openings or perforations equally spaced over their surface area for air passage into the grain.

1.4 Fan Performance

The air performance is the air flow volume a fan delivers across its static pressure range. Air performance data are indicated by fan manufacturers. Hence, selection of fan should be based on their optimum performance, its efficiency in terms of airflow per unit of energy (CFM/hp or m3/min/kW) and other factors. Example of work done by McNeill (2010) is shown in Fig. 5.

1.5 Relative Humidity

Relative humidity is very important for many Agricultural environments, such as grain storage facilities.
and their handling equipment. Ileleji (2010) asserted that the conditions for the optimum growth of storage moulds must be controlled by ensuring that the grain moisture content (interstitial water activity, aw) be low at low RH (<65%), temperature (100°C), and that the kernel should be intact with less damage and dusts. Hygrometer, which contains a wet and dry bulb thermometer, can be used to determine the relative humidity of the air.

1.6 Control Panel

Automatic controls that take full advantage of favorable weather are normally used for larger amounts of stored grain; manual controls may be practical for relatively small amounts of grain. Manual controls require a close check of temperature and humidity to determine when to aerate. A humidistat and a thermostat provide automatic control. Both the humidistat and thermostat are adjustable. The humidistat prevents aeration when the air temperature is too high to cool the grain. With these controls, the fan will not operate unless both the humidity and temperature are below the control settings. Fig. 6 shows the mechanism of an installed humidistat and thermostat to provide automatic control.

1.7 Frig-O-Dry Storage and Preservation System

The Frig-O-Dry storage and system is an update or improved version of modern metal silo system. It uses a computerized regulatory control cooling mechanism. It was installed at the National Silo Complexes at Okuku-Ogoja, and Lafiagi both in Nigeria (SGR Bulletin). Conditioned air-cold and relatively dried-air is passed through stored grain in the silos. Cooling could be sustained for several months of storage. Cold preservation of grains also offers excellent protection against insect activity.

2 MATERIALS AND METHODS

National Strategic Grain Reserve Silo Complex, Akure was the location for this study, being one of the oldest silo complexes in Nigeria. Five silo cells of 2,500m³ capacity each were selected. Standard parameters for grain storage were used; ≤ 1% foreign matter inclusion, ≤12% moisture content, ≤1% mould inclusion, 68-75KG/HL weight, ≤1% broken grain and age of not more than one year. These parameters were utilised in the designing of the software for grain aeration management. Grain temperature and moisture content were monitored on daily basis. Samples were taken monthly for analyses. Moulds and caked grains were measured to quantify level of losses. There was also proper maintenance of handling equipment for better performance and avoidance of losses through them.

2.1 Determination of the Deterioration of the Grain

The process of grain deterioration is majorly determined by aerobic respiration of fungi as they consume carbohydrates in the grain kernel. This is represented mathematically by Ileleji (2010) as:

\[ \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Heat (677.2kCal)} \]  

This translates into 1.47g of CO2, 0.6g of H2O and 677.2kCal of heat are produced for each gram of carbohydrate that is consumed or decomposed (Ileleji, 2010). Mathematically, the CO2 production is defined as:

\[ \log(\text{CO}_2) = AN - B \]  

Where CO2 = CO2 per 100gm dry matter loss

M = Moisture Content percentage, wet basis

A&B = grain constants

According to Igbeka (1994), Equation (2) could be related to dry matter loss, which in turn has been correlated “acceptability” of grain in the following equation where the Dry Matter Loss (DML)

\[ \text{DML/day} = (\text{CO}_2)10^4(0.682) \]
2.2 Determination of Equilibrium Moisture Content of Grain

The air surrounding stored grain has an equilibrium moisture content (EMC) which is the point at which atmospheric air and grain does not exchange moisture. The relationship between relative humidity and product moisture content at equilibrium is represented mathematically as shown in equation 4 below;

\[ 1 - \frac{RH}{EXP (-kTM)} \]

Where, \( RH \) = equilibrium relative humidity expressed as a decimal  
\( EXP \) = natural (Naperian) base of logarithms  
\( T \) = absolute temperature  
\( c \) & \( n \) = empirical constant  

The values of the constants \( c \) and \( n \) for maize were given as: \( c = 1.10 \times 10^3 \) and \( n = 1.90 \) (Igbeka, 1994).

American Society for Agricultural Engineering (ASAE) recommended a standard relationship between moisture content of grain and their storage temperature (Appendix A- C).

2.3 Determination of Moisture Removed from Grain during Aeration

Moisture removal by air at various drying temperatures and humidity have been worked upon by several authors (McNeill (2010), Igbeka (2013), and Worley (2009). The chart is presented as Appendix 4 with the initial condition of air as 15.6°C temperature and 65% relative humidity.

Air flowing at a rate of 1000 CFM/bu and heated from an average design temperature of 60°C and 65 percent humidity heated to 43°C would remove 17.24kg of moisture per hour (Table 2). The air flow rate required to dry a given quantity of grain is given by the expression below,

\[ CFM = \frac{(Q X 1000)}{(E X R)} \]

Where, \( CFM \) = Cubic Feet of air per Minute, capacity of drying fan  
\( Q \) = Quantity of moisture to be removed from wet grain in 1 hour  
\( H \) = wt of moisture removed each Hour by 1000 CFM of drying air, Table 7  
\( E \) = Efficiency of drying air in removing moisture (0.75 for average fall condition)

2.4 Determination of Deterioration Index of the Climate

This is given as a function of the relative humidity and the effect of temperature on rates of deterioration

\[ DI = (RH\% - 65) P_a 10^4 \]

Where DI = Deterioration index  
\( RH \) = Relative humidity  
\( P_a \) = Saturation vapour pressure at the temperature under consideration in Pascal  

In tropical climates, simple linear equations have been developed which can be used to adequately estimate the saturated vapour pressure. They are applicable to Nigeria (Igbeka, 1994). They are;

\[ P_a = 151 (\degree C) – 641 \text{ temperatures of 20-25°C} \]  
\[ P_a = 214 (\degree C) – 2240 \text{ temperatures of 25-30°C} \]  
\[ P_a = 283 (\degree C) – 4310 \text{ temperatures of 30-35°C} \]

2.5 Computer-aided Software Development

The software developed have three major sections: the front-End (Graphical/user interface) which the user interact with, this section was developed using Dreamweaver 8, the middle-end (coding section) was developed using Pre-processor Hypertext Programme (PHP) code, and the back-End (Database) was developed using MySQL. The software built to manage the day to day aeration activities would records daily temperature readings, grains in stock, moisture content, releases and losses, acceptable storage parameters. All these are captured in real-time and the data centrally stored. This application could be used with the aid of computer networking and internet service to enhance proper connection between different offices at the silo location.

3 RESULT AND DISCUSSION

Temperature cables provides valuable information for isolated spots inside grain bins, especially where handheld grain sampling probe cannot collect samples and temperature probes could not penetrate the grain bulk, this was also reported by Maier (2002). Daily record of temperature reading makes the users to be on their toes whenever the readings fluctuate sharply from the expected range. Olorunfemi (2014) reported that though, thorough manual inspections provide valuable information about the quality of stored grain near the surface but have severe limitations in deeper regions of the bin unless a vacuum probe is used. The officer assigned must daily read and record the temperatures on this prescribed page so that management could be kept abreast of the temperature-condition of the stored grain.

If it is found that any silo shows increase in the temperature of 1-2°C, that is, any temperature beyond 42°C aeration is indicated. Mushira (2005) recommended that should the temperature increase rapidly by more than 2°C, the entire stock in the silo must be re-cycled. Sufficient exposure to different temperature and relative humidity would dry grain to the moisture as indicated. Experience has showed that stored grain moisture decreases with increase air temperature.
3.1 Samples of Manually Recorded Temperature Readings

The results of data recorded manually before the introduction of software are presented below as Table 1.

| POINT | T6°C  | T7°C  | T8°C  | T9°C  | T10°C |
|-------|-------|-------|-------|-------|-------|
| 1.    | 19.0  | 21.2  | 21.2  | 21.2  | 21.1  |
| 2.    | 19.2  | 21.3  | 21.3  | 21.3  | 21.2  |
| 3.    | 19.3  | 21.4  | 21.4  | 21.4  | 21.3  |
| 4.    | 19.4  | 21.5  | 21.5  | 21.5  | 21.1  |
| 5.    | 19.5  | 21.1  | 21.1  | 21.1  | 21.2  |
| Total | 96.4°C| 106.5°C| 106.5°C| 106.5°C| 105.8°C|
| average| 19.28°C| 21.3°C| 21.3°C| 21.3°C| 21.16°C|

3.2 Computer-aided Interface Developed for Monitoring Grain Parameters

The software built to manage the day to day aeration activities would record daily temperature readings, grains in stock, releases and losses based on shrinkages, monitoring parameters, and other events capable of reducing the stock level. All these are captured in real-time and the data are centrally stored. This application could be used with the aid of computer networking and internet service to enhance proper connection between different offices at the silo location. Figure 6 shows the home page. This is the landing page for the software. Password and name of user would be entered before accessing other pages.

Figure 7 is the Graphical user interface (GUI) showing the Temperature reading page. It has links with storage, silo management, stock management interfaces. The silo number would be entered as well as the month of the year. When submitted for processing, the result would show all the temperature readings taken for the month under review. Figure 8 is the interface for temperature data.
4 CONCLUSION

In order to achieve great result of aeration of stored grains, uniform temperature must be maintained to ensure no moisture accumulation and condensation. Stored grain insects thrive at 75 F to 85 F. Aeration should be operated immediately after binning when nighttime temperatures allow to lower temperature to unfavorable levels. Later in September aeration systems should be used to lower temperatures to the lower 60 seconds. If the grain will remain in storage through the winter into summer, another cooling cycle is needed in Light aeration systems, 0.1 CFM/bu or less, require long mid-winter to lower the grain mass to 30 F to 35 F to reduce operation times to lower grain temperatures and are best insect activity and equalize grain mass temperatures suited to cooler climates. The bin’s doors, unloading auger, under floor spaces, Medium and Fast aeration systems, 0.2 CFM/bu through and aeration fan openings should be cleaned and sprayed with a residual insecticide. Openings should be sealed before temperatures in stored grain. Just a few nights of operation will lower grain temperature to nighttime air temperature, Keep the open gings sealed year round, except when aeration fans are operating. As the range of chemical control options are been discouraged globally, due to chemical residual, grain aeration provides a powerful alternative non- chemical grain storage economic management instrument.

REFERENCES

Adejuyigbe, S. B. (2002). Computer Aided Design and Drafting, (CAD/ CAM) for Manufacturing, Akure, Ondo State. Topfun Science and Engineering books. pp 20-53.

Agricultural Transformation Agenda (Ed.) (2012). New Agricultural Policy Thrust, Abuja, Nigeria. Federal Ministry of Agriculture and Rural Development. p 4.

America Society of Agricultural Engineers (ASAE) (2002). Moisture relationship of grains. American Society of Agricultural Engineers. ASAE Standards (D254.4). St. Joseph, Michigan.

Arthur, F. H., Throne, J. E., Maier, D. E. and Montross, M. D. (2001). Impact of aeration on maize weevil (Coleoptera curculionidae) populations in corn stored in the Northern United States: simulation studies. American Entomol. 47: 104-110.

Grain Research Development Corporation (GRDC) (2014). Grain Storage Facilities: Planning for Efficincy and Quality. www.storedgrain.com.au. P.O. Box 5367, Kingston ACT 2604.

Igbeaka, J. C. (1994). Quality Control Operation (Aeration) in the Management of a Grain Silo Complex. Paper presented at the training workshop for Strategic Grain Reserve Staff, Federal Ministry of Agriculture, Ibadan, Nigeria. December, 1994.

Igbeaka, J. C. (2013). Agricultural processing and storage Engineering. Ibadan University Press, pp 99-140.

Ileleji, K. E. (2010, March). Sanitation, loading, aeration and monitoring. Paper presented at the US-Nigerian commodity storage workshop, Akure, Nigeria. Federal Ministry of Agriculture and Rural Development, Nigeria.

Mushira M’ Avung’ana (2005). Manual on grain management and equipment maintenance in metal silos. FAO project UJT/NIR: SPF- Output 5. Training manual for grain storage managers. Federal Ministry of Agriculture and Rural Development, Nigeria.

McNeill, S. (2010, March). Moisture and temperature management of grain and grain aeration. Paper presented at the US-Nigerian commodity storage workshop, Akure, Nigeria. Federal Ministry of Agriculture and Rural Development, Nigeria.

McNeill, S. G. and Montross, D. (2010). Harvesting, drying and storing of grain Sorghum. University of Kentucky Cooperative Extension service. AEN-17.

Novarro, S. (Ed). (2000). The Volcani- cube for safe storage. Postharvest bulletin. Israel. The Volcani centre, Agricultural Research Organization.

Olorunfemi, B. J. (2014). Computer aided management for grain storage in Nigeria. Unpublished doctoral dissertation. Federal University of Agriculture, Abeokuta. pp 101-108.

Olorunfemi, B. J., Adejuyigbe, S. B. and Adekunle, A. A. (2015). Development of computer aided management for grain reception at grain storage silos in Nigeria. International Journal of Engineering and Applied Sciences (IJIAS). ISSN: 2394-3661, vol.-2, issue 7, pp 1-2.

Olorunfemi, B. J., Adejuyigbe, S. B., Adekunle, A. A. and Aseyemi, O. H. (2016). Computer- aided Maintenance of Grain Storage Equipment. Proceedings of 2016 SEET Annual Conference. School of Engineering and Engineering Technology, Federal University of Technology, Akure, Nigeria. 16th- 18th, Aug. 2016.

Warrick, C. (2010). Grain aeration controllers.
Appendix A: Equilibrium Moisture Content for Grain Storage %wb

| Temperature (°C) | Relative Humidity (%) |
|------------------|-----------------------|
| 21               | 9.9 11.3 12.8 13.6 14.4 16.4 19.4 |
| 27               | 9.4 10.8 12.3 13.1 14.0 16.0 18.8 |
| 32               | 9.1 10.5 11.9 12.7 13.5 15.5 18.4 |
| 38               | 8.7 10.1 11.5 12.3 13.1 15.1 17.9 |

(Source: ASAE, 2002)

Appendix B: Equilibrium Moisture Content for Maize Grain

(Source: McNeill, 2010)

Appendix C: Equilibrium Moisture Content for Soy-bean

(Source: McNeill, 2010)

Appendix D: Moisture Removal by Air at various Temperatures and Humidity.

| Temperature of Air (°C) | Humidity of Air (Percent) | Kg of Water Removed per 1,000 CFM in 1 hr. |
|-------------------------|---------------------------|------------------------------------------|
| 15.6                    | 65                        | 3.17                                     |
| 21.1                    | 45                        | 5.40                                     |
| 26.7                    | 32                        | 8.16                                     |
| 37.8                    | 18                        | 14.06                                    |
| 43.3                    | 11                        | 17.24                                    |
| 60.0                    | 5.8                       | 27.22                                    |
| 82.2                    | 2.2                       | 35.38                                    |

(Source: Worley, 2009)