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Sizing of pressure aeration systems for stored grain

Abstract

Aeration is widely used to cool grain, preserving the physical conditions of the stored product and appearing as one of the most important practices of the postharvest sector in terms of food security. The proper sizing of the aeration system components is essential for guaranteeing the correct operation and management of this preventive technique. Either pressure or suction airflow could be used in most grain storage structures, with pressure systems being most popular. In this article, procedures required when sizing pressure aeration systems for stored grain are discussed. The main equations and recommendations for selecting the proper fan power and size are presented, aiming at allowing to deliver the adequate aeration airflow rate for grain storage during aeration. Technical information about how to calculate the dimensions of roof vents are also showed, in order to provide natural ventilation inside the storage and avoid under-roof condensation. Additionally, a methodology for calculating the dimensions of the aeration perforated ducts is proposed, aiming at suitable uniformity of airflow in the grain mass during this process. Technical and scientific information described in the literature were integrated with empirical rules and recommendations, resulting in a guideline capable of helping students and engineers that need to size pressure grain aeration systems for flat and cylindrical bins.

Keywords: grain aeration, post harvest, system design

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Introduction

Aeration can be defined as the forced movement of ambient or chilled air with suitable quality through a grain bulk for improving its storability.[1] This method is widely used to preserve the physical conditions of the stored grain, and is considered one of the most important practices of the postharvest sector in terms of food security.[2] The basic components of an aeration system are the storage unit with a fully or partially perforated false floor (or with perforated ducts), a fan and roof vents to intake or exhaust of the air.[3] Either pressure or suction airflow could be used in most grain storage structures, with pressure systems being most popular since they result in more uniform airflow distribution.[5] Pressure airflow is also required when loading warm grain on top of bulk already cooled, allowing the aeration even when air humidity is high, since ambient air is heated after passing through the fan, reducing the relative humidity of air entering the grain mass. Additionally, pressure aeration systems are recommended in regions where storage roof vents can become iced over because of freezing rain or heavy snow, minimizing the risk of roof collapse.[1] In the pressure aeration systems, fans are connected to the plenum or duct system, and air is blown upward through the grain at relatively low rates.[3]

Good design and well-defined control strategies of aeration systems are essential for efficient storage management and operation. Specifically, aeration system sizing consists in selecting the proper fan power and size (based on the static pressure of the system),[4] estimating the dimensions of roof vents in order to provide natural ventilation inside the facility,[1] as well as defining the perforated duct layout (dimensions and location) considering the grain bulk mass, direction of air movement through the grain and the required airflow rate.[5] Fans must be properly sized with the purpose of delivering the adequate aeration airflow rate for grain storage. The correct use of aeration fans can reduce temperature differences within the bin and optimize the grain cooling.[6] Storage facilities with sufficient roof vents tend to have enough natural ventilation to avoid under-roof condensation,[1] while the correct distribution and sizing of the duct system is important for obtaining a suitable uniformity of airflow in the grain mass.[7]

In this article, the main recommendations and equations for sizing pressure aeration systems for stored grain are presented. Technical and scientific information described in the literature were integrated with empirical rules, composing a guideline for helping students and engineers that need to size pressure grain aeration systems for flat and cylindrical bins.

Procedures for sizing aeration systems

The required data for sizing an aeration system are the grain type and its properties (bulk density and angle of repose), the specific airflow rate and the storage unit type (flat or cylindrical bins). Additionally, it is important to know if the storage unit is peak-filled or not, and its dimensions. These parameters are essential for the success of the aeration system sizing, since their variations can modify the design results considerably.

The bulk density is defined as the mass over the bulk volume, including air voids, and is generally expressed in kg m^{-3}. This is a critical parameter for predicting grain pressures in storage facilities, varying among the grain types and moisture contents.[8] On the other hand, the angle of repose is the angle, generally expressed in degree, between the upper surface of a peak of grain and the horizontal, presenting larger values in grain bulks with higher moisture contents, also varying with the grain type.[9]

The specific airflow rate in an aeration system depends basically of the grain type, the grain depth and the storage unit type. In temperate climates, for concrete silos and tall steel bins storing small grains, airflow rates from 0.05 to 0.1 m^3 min^{-1} t^{-1} are typically used. For horizontal storages and big grains, airflow rates between 0.1 and 0.2 m^3 min^{-1} t^{-1} are recommended[1]. When the grain depth exceeds 30 m, the power requirements could become excessive, requiring airflow rates from 0.03 to 0.05 m^3 min^{-1} t^{-1}. Finally, for regions with limited cooling time, the airflow rates from 0.2 to 0.25 m^3 min^{-1} t^{-1} should be considered.[7] It's important to observe that doubling the airflow rate, triples the required static pressure, while fan power is increased by over four times.[5]

Auxiliary sizing equations

The storage floor surface area and volume are required for calculating the grain mass and the static pressure during the selection of the proper aeration fan, depending on the dimensions and type of storage facility. The storage floor surface areas for cylindrical and flat bins are calculated by using equations 1 and 2, respectively.[10]

$$S = \pi R^2 \tag{1}$$

$$S = L W \tag{2}$$

Where S is the storage floor surface area (m^2), R is the bin radius (m), L is the storage length (m) and W is the storage width (m).

The storage volume of not peak-filled facilities with flat bottom (rectangular or cylindrical) is calculated by equation 3. On the other hand, equations 4 and 5 are used for peak-filled cylindrical bins with flat bottom and peak-filled hopper-bottom bins, respectively.[10]

$$V = H S \tag{3}$$

$$V = S \left(R \, tg \left(\alpha\right) / 3 + H_c\right) \tag{4}$$

$$V = \pi H_B / 3 \left(R^2 + \left(R - H_B / tg \left(\beta\right)\right)^2 + R \left(R - H_B / tg \left(\beta\right)\right) + S H + S R \, tg \left(\alpha\right) / 3 \tag{5}$$

Where V is the storage volume (m^3), H is the total grain depth (m), H_c is the height of the cylindrical section (m), H_B is the height of the conical base (m), α is the angle of repose (º) and β is the angle between the sloping conical floor and the horizontal.

The storage volumes of not and peaked-filled semi-V bottom flat facilities are determined by equations 6 and 7, respectively.[10] The same equations can be adapted for V and W-bottom flat storages.

$$V = S H + \left(\left(L - W\right) W^2 tg \left(\alpha\right) / 4\right) + \left(W^3 tg \left(\alpha\right) / 6\right) \tag{6}$$

$$V = S H + \left(\left(L - W\right) W^2 tg \left(\alpha\right) / 4\right) + \left(W^3 tg \left(\alpha\right) / 6\right) + L \, tg \left(\beta\right) \left(\left(W - 1\right) / 2\right) + L \, tg \left(\beta\right) \left(\left(W - 1\right) / 2\right)^2 \tag{7}$$

The grain mass represents the amount of grain to be aerated (equation 8), while the total airflow rate is the quantity of air passing through the grain bulk in a given amount of time (equation 9).[5]

$$M = V \rho / 1000 \tag{8}$$

$$Q_t = Q M \tag{9}$$

Where M is the grain mass (t), ρ is the bulk density (kg m^{-3}), Q_t is the total airflow rate (m^3 min^{-1}) and Q is the specific airflow rate (m^3 min^{-1} t-^{1}).

Roof-vent sizing and fan selection

The sizing of the roof vents (equation 10) must provide an adequate cross-sectional area to minimize outlet pressure losses and prevent humid air condensation in the storage head space.[7] The cross-sectional area must maintain vent throughput velocities from 300 to 400 m min^{-1}, allowing adequate exhaust of inlet air volume.[1] As shown in Figure 1, multiple roof vents are recommended in an aeration system, which must be divided into several equally spaced units around the circumference of the roof at about half the distance up the slope from the lower edge and near the roof peak[5].

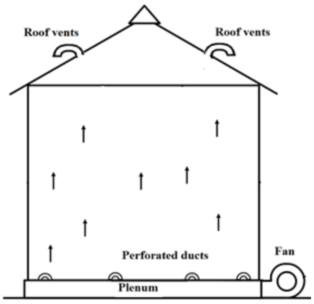

Figure 1 Components of an aeration system.

$$S_R = Q_t / V_R \tag{10}$$

Where S_R is the total cross-sectional area of the roof vents (m^2) and V_R is the vent throughput velocity (from 300 to 400 m min^{-1}).

The fan is the device used to move air through the grain bulk, overcoming a certain pressure and operating at a certain nominal speed.[11] This process allows that the cooling front moves through the bulk within a satisfactory time. Thus, one of the main criteria for the aeration system sizing is the selection of the proper fan for a given storage unit.[5] One or several fans could be used to deliver air to an aeration system. When more than one fan is employed, they can be connected in series or in parallel. Fans coupled end-to-end are connected in series and fans coupled side-by-side (delivering air from different inlet locations to the same system) are connected in parallel.[7] The most common is to find identical fans operating in parallel, making that each fan overcomes the same static pressure, with the sum of the individual airflow rates delivered by the fans composing the total airflow rate of the system.[12] The two main types of fans used for aerating stored grain are the axial and the centrifugal.[11] Axial fans are often used in systems that operate with high airflows and small static pressures, being less expensive but, noisier and less efficient. Centrifugal fans are most popular in systems operating with moderate airflow and high pressures, or when it is necessary to deliver air to different types of grain and bulk depths. This type of fan tends to be quieter and more efficient than the axial fan, but is usually more expensive.[5] When selecting a fan for aerating grain, primary considerations are the airflow and the static pressure required to provide this quantity of air. With these parameters it is also possible to calculate the power required to the fan motor.

The static pressure could be defined as the resistance of grain to airflow, being represented by equation 11, which has been adopted as a standard to calculate the static pressure of grains at various airflow rates.[13] A packing factor of 1.5 is applied to equation 11 to compensate the system losses, assuming a 50% increase in airflow resistance caused by other effects such as moisture content variation, fines and filling method.[14]

$$\Delta P = 1.5 \, H \, a \left(Q_t / \left(60 \, S\right)\right)^2 / \ln \left(1 + b \left(Q_t / \left(60 \, S\right)\right)\right) \tag{11}$$

Where a (Pa s^2 m^{-3}) and b (m^2 s m^{-3}) are constants for a particular grain type and ΔP is the static pressure (Pa).

Fans for grain aeration must be selected from the manufacturer rating tables or curves, to deliver the required air volume at an expected static pressure.[11] This is performed verifying, among the available fans, the one that presents the best performance for the required system design point (ΔP versus Q_t). Usually, fan efficiencies range from 0% (when there is no airflow) to 85% (when airflow is maximum), decreasing for fans that operate with higher static pressures and lower airflows.[10] At high altitudes, the air density is smaller and the fan must operate with greater speeds to provide the same weight of dry air compared to sea level.[5] Usually, the fan curves are supplied to sea level and temperatures of 20ºC. Equation 12 should be used to compensate the altitude and temperature effects on fan operation when selecting these devices from the manufacturer rating tables or curves.[12]

$$\Delta P_c = 101.325 \, T \, \Delta P / \left(293.15 \, P_{atm}\right) \tag{12}$$

Where ΔP_c is the adjusted static pressure (Pa), T is the local temperature (K) and P_{atm} is the local atmospheric pressure (kPa).

The fan power requirements can be estimated by equation 13, using the static efficiency of 60% when fan curves are not available.[5]

$$P = Q_t \Delta P \; / \; (44129.925 \; \eta) \tag{13}$$

Where P is the fan power (hp) and η is the fan static efficiency (decimal).

Sizing the perforated duct system

Generally, aeration systems equipped with a fully or partially perforated false floor result in high costs. On the other hand, this layout leads to more efficient and uniform air distribution into the grain bulk, since it provides total contact area between the grains and the incoming air.[7] Due to the more accessible costs, the use of a duct system is most common when installing aeration systems. In this case, perforated ducts can be built either into the storage floor, or placed on the top of it.[10] Despite make emptying of the storage more complex, above-floor ducts are less costly and more practical, usually made from corrugated perforated steel sheet, which is rolled into semi-circular shape, being fitted to the floor of the facility.[7]

Different layouts can be used when installing the ducts of an aeration system. Aeration ducts in flat storages are usually aligned across the facility, allowing easier control of airflow into the grain[5,7] (Figure 2). For flat-bottom bins there are several options for air distribution systems (Figure 3), with parallel ducts (Figure 3A, 3B and 3C) appearing as the most common and differing only in their size and spacing.[1,7] Hopper-bottom bins, semi-V, V and W-bottom flat facilities normally use perforated ducts running up and down the sloped surface (Figure 4A), but it is also possible to employ radial-type ducts (Figure 4B).

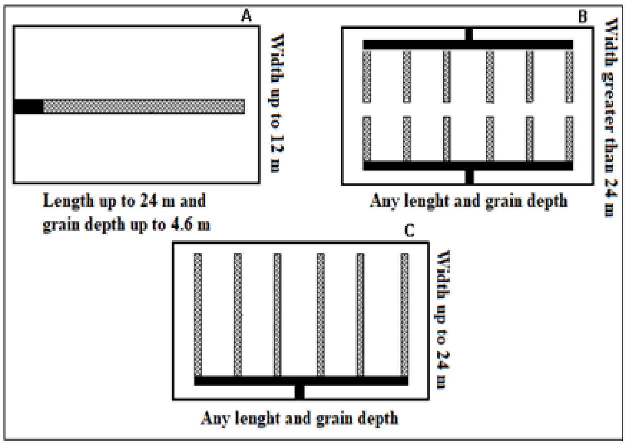

Figure 2 Most used aeration duct arrangement for flat storages.

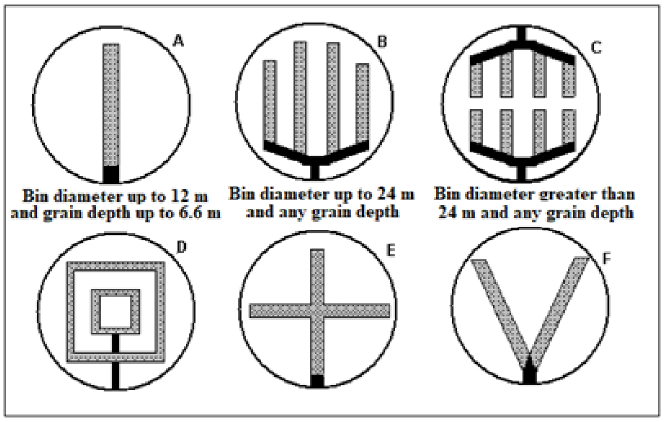

Figure 3 Most used aeration duct arrangement for flat-bottom bins.

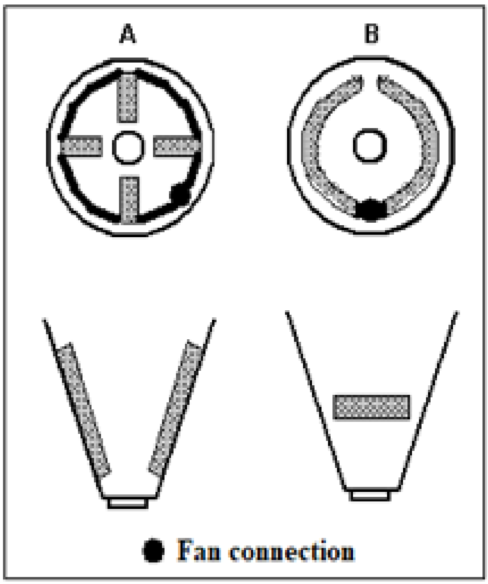

Figure 4 Most used aeration duct arrangement for hopper-bottom bins.

When a perforated duct system is applied, the aim is to keep the air paths through the grain as nearly equal in length as possible, avoiding that a section of the grain bulk does not cool as well as other.[5] Many of the recommendations on design and operation of perforated ducts for grain aeration are empirical rules.[1] The number of ducts will be determined according to a combination of duct length and diameter that generate an area equal to or greater than the total required perforated area, preserving the airflow path ratio design, and the recommended distances between ducts and storage walls.[10]

The air velocities in ducts must be from 6 to 9 m min^{-1}, which allows to calculate the total required perforated area (equation 14). The velocity of 9 m min^{-1} is indicated for vertical bins (height greater than diameter), while 6 m min^{-1} is recommended for horizontal facilities (flat storages or silos with diameter greater than the height).[5]

$$S_P = Q_t \; / \; V_P \tag{14}$$

Where S_P is the required perforated area (m^2) and V_P is the air velocity (from 6 to 9 m min^{-1}).

Sometimes it is necessary to test some possibilities until to obtain the proper duct arrangement. Normally, attempts are made, starting with the minimum number of ducts that meet the distance requirements. That is, the distance between adjacent perforated ducts should be less than the grain depth, while the distance between perforated ducts and storage walls should be less than one half grain depth.[10] Additionally, the longest air path must be less than 1.5 times the length of the shortest air path for each perforated duct, so that static pressure on a duct will not be greater than 50% of the static pressure on each other.[7] The air paths are calculated according to geometry laws, considering a radial distribution of air as shown in the example of Figure 5.

Each duct area will be equal to its length multiplied by its diameter, with the total perforated area comprising the sum of the areas of all ducts of the aeration system. The length of each perforated duct is also determined according to the geometry laws, varying for different arrangements. For example, for a flat-bottom bin with two parallel ducts, the duct lengths can be calculated based on the triangle rules (Figure 6).

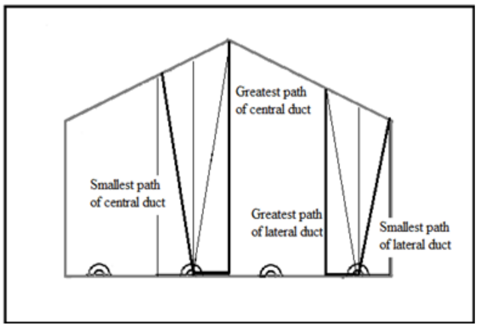

Figure 5 Example of air distribution and paths during the aeration process using parallel ducts.

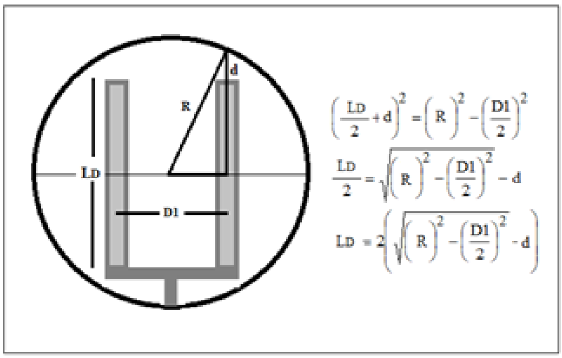

Figure 6 Example of mathematical deduction for calculating the length of a perforated duct in a flat-bottom bin.

The diameter of the ducts can be calculated by dividing the total required perforated area by the total duct length (sum of all duct lengths). Diameters from 0.3 to 0.8 m are preferable to avoid additional supporting structures when installing the ducts.[10] Thus, if diameters out of this range are obtained, it is recommended to try another configuration, for example increasing the number of parallel ducts.

The height of the duct, after rolling the steel sheet into a semi-circular shape, is dependent on the airflow and its velocity, as shown by equation 15. Ducts with different lengths will require different heights, with a maximum air velocity in ducts of 450 m min^{-1} indicated.[5]

$$H_D = L_D Q_t \,/\, \left(450\ L_T \phi\right) \tag{15}$$

Where H_D is the duct height (m), L_T is the total duct length or duct lengths sum (m), L_D is the individual duct length (m) and ϕ is the duct diameter (m).

Non-perforated supply ducts convey air to perforated ducts with a maximum velocity of 450 m min^{-1}. Usually, to avoid errors during construction the supply duct diameters are sized with the same values of the perforated ducts. The number of supply ducts, their depths and lengths are determined according to geometry laws, varying for different arrangements, as occurs with perforated floors. When sizing aeration systems for hopper-bottom bins it is also recommended to verify if the duct location is not restricting the flow of grain out the bin.[1,5]

Final considerations

Some parameters are not specified during the aeration sizing, but should be observed when installing the system. The connections between supply and perforated ducts must be smooth, as well as the transition ducts must be design to minimize friction losses. That is, the entrances of the transition ducts must match the size and shape of the fan outlet, changing gradually.[5] Furthermore, the angle between the beginning of the duct and the transition must be less than 20º, considering the center line of the transition.[10] Perforated ducts should have from 10 to 25% of the surface area open to prevent excessive pressure drop in the ducts. Perforations cannot allow whole grain kernels to pass through it. Thus, perforations need to be smaller than grain kernels or it should be used a cloth screen over ducts.[10]

Aeration fan noise is generated by its constructive characteristics, operation speed and diameter.[5] Fans that operate with slower speed and have small diameters tend to be quieter. The adequate fan position could reduce its noise. A simple solution is to locate the fans so that their inlets or outlets are directed away from or in opposite direction from residential, business or commercial areas.[1] Roof vents must be designed to minimize rain or snow blown into the storage, also being screened to keep birds and rodents from entering the storage head-space.[5] In some cases, more than one duct system arrangement is proper to an aeration system. The choice of the best one will depend on the costs, building limitations and the specific aeration requirements.

Conclusion

In this study, empirical rules and recommendations were integrated with equations, technical and scientific information, resulting in a guideline for helping students and engineers that need to size pressure grain aeration systems for flat and cylindrical bins. Many different aeration systems are used in practice, making that the choice of the proper fan, as well as the sizing of roof vents and perforated ducts also vary widely. Furthermore, the designs of aeration systems involve many variables, and even when well sized they may perform less efficiently than originally planned. Thus, when installing the aeration system, an efficient control strategy must be applied, faulty equipment and air leaking must be monitored, and molded grain layers or excessive foreign material must be avoided.

Acknowledgments

None.

Conflicts of interest

There were no conflicts of interest.

References

1. Navarro S, Noyes RT, Casada M, et al. In: Hagstrum, DW et al., editors. *Stored Product Protection*. Kansas State University, Kansas, 2020. p. 121–134.
2. Serna-Saldivar SO, García-Lara S. *Cereals: Storage*. Encyclopedia of Food and Health, 2016. p. 712–717.
3. Lopes DC, Steidle Neto AJ. Zephyrus: Grain aeration strategy based on the prediction of temperature and moisture fronts (Chapter 9). In: Bochtis DD, et al. editor. Information and Communication Technologies for Agriculture - Theme III: Decision. Springer, Berlim, 2022. p. 181–198.
4. Bartosik R, Rodriguez J, la Torre D. *AireAr: A new software for sizing aeration fans. International Commission of Agricultural and Biological Engineers, Section V*. Conference Technology and Management to Increase the Efficiency in Sustainable Agricultural Systems, Rosario, Argentina, 2009.
5. Navarro S, Noyes RT. *The mechanics and physics of modern grain aeration management*. 2001. CRC Press, Boca Raton. 2001.

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6. Maier DE. *Preservation of grain with aeration*. In: Aciar Proceedings, 1996. p. 379–398.
7. Newman CJE. Design parameters for aeration and in-store drying systems. In: Aciar Proceedings, 1996, p. 143–157.
8. Gao M, Cheng X, Du X. Simulation of bulk density distribution of wheat in silos by finite element analysis. *J Stored Prod Res*. 2018;77:1–8.
9. Bhadra R, Casada ME, Thompson SA, et al. Field-observed angles of repose for stored grain in the United States. *Appl Eng Agric*. 2017;33(1):131–137.
10. Pereira JAM, Pereira ALRM. *Grain aeration: air movement and systems sizing*. Centreinar: Viçosa, 1982.
11. Jones C, Hardin J. *Aeration and cooling of stored grain*. Oklahoma Cooperative Extension Service, 2010.
12. Alé JF. *Industrial ventilation systems - Fans*. PUCRS: Brazil, 2001.
13. ASAE. *Resistance to airflow of grains, seeds, other agricultural products and perforated metal sheets*. ASAE Standards, American Society of Agricultural Engineers, St. Joseph, MI, 1997.
14. Lower OJ, Bridges TC, Bucklin RA. *On-farm drying and storage systems*. ASAE, USA, 1994.

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