ECONOMIC CONSIDERATIONS IN SEED HOUSE AERATION SYSTEMS DESIGN

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Abstract

Air-flow and power measurements of two cottonseed storage aeration systems were made during the summer of 2000. These measurements provide insight into the energy cost and static losses of concrete aeration ducts. Power consumption was measured for different flow rates in a rough concrete duct and energy costs computed for the different flow rates. An energy price of $0.06/KWH, 800 feet of the rough concrete duct needed to aerate 6400 tons of seed at 5 CFM/ton resulted in approximately $425 per year greater energy cost than conveying the same amount of air through smooth round metal pipe at the same velocity. Doubling or tripling the energy rates will double or triple the cost differential. Slower velocities within the ducts reduce static pressure losses and thus energy costs. Persons considering construction of cottonseed storage facilities should consider the lifetime energy cost of different duct designs before selecting a final design. Several alternative designs are discussed.

Introduction

Changes in the marketing of cottonseed and the oil crushing industry have resulted in many gins constructing seed storage facilities. Design criteria for a cottonseed house aeration duct systems was established by Smith [2] to accommodate two factors: to prevent seed transport in open sided ducts (above 1500 to 2000 ft/min), and to minimize static losses in the system itself. Smith established a maximum air velocity entering the surface of an aeration duct at 10 ft/min. Multiplying the total tons of seed to be placed in storage by the desired aeration rate (CFM/ton) then dividing by 10 ft/min yields the total duct surface area in the house for the desired aeration. While placement of ducts relative to the side and end walls and each other are important considerations, the total surface area should remain the same regardless of layout. There have been significant changes in construction techniques in recent years, which has lead to the need to reevaluate the cost and energy efficiency of aeration systems.

This is a study of aeration systems used in cottonseed houses for determining the economic impact of different duct designs. The seed houses included in the study had all their ducts embedded in the floor. The most energy efficient design is the one with ducts with the largest effective cross sectional area that produces the smallest amount of static pressure loss. Construction costs can often be a far greater consideration. Cost savings computations based on reduction of static pressure of different duct sizes were conducted and the cost associated with operating the different duct designs under different scenarios were tabulated.

Material and Method

Pneumatic mathematical models were used to give relationships of different fan capacity, duct diameter, static loss, and the associated cost of operating the aeration system. Data obtained from physical measurements of two seed houses were then included into the computation to give a more realistic case study.

Air flow measurements of aeration duct and current measurements of aeration fans were made at two gins: Swan Lake Gin and Due West Gin of Tallahatchie county, MS. Both gins had the air ducts embedded in the floor. Fans were connected to three or four ducts through a manifold with gate valves to each duct for control.

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The 80-ft long trenches of Swan Lake Gin (Figure 1) were of a shallow design with a depth and width measurements of 8.0 inches and 42 inches, respectively. One 8.0 inch I-beam positioned in the middle of the each trench was used as support members for the bar grating perforated metal cover plate. The I-beams were spaced evenly to the width of the trenches. The air system was arranged with a plenum such that each fan handled four ducts. The diameter of the plenum pipes was 26 inches.

The 60-ft long trenches of Due West Gin were similar in design to Swan Lake Gin with two I-beams inside the trenches. The perforated cover plates contained integrated metal grid, which functioned as the structural support of the cover plate. The plenum system were of similar arrangement in both seed houses with the exception that the gating of each duct was done with a sliding plate in Due West gin, while Swan Lake gin used a rotating shutter valve for controlling air flow in each duct.

Air measurements were made in the main branch of the plenum with only one valve opened, thus the airflow was from one duct only. Leakages that were found in the pipes were sealed. Current measurements of the fan motor were monitored using a digital current meter. The air parameters measured were velocity and static pressure using a digital differential pressure meter. The measurements were made at the center of the round duct on the duct side of the gate valve. The motor current, static and velocity pressures measurements were measured during three conditions: all valves closed (maximum static pressure of the fan), one valve half open, and one valve completely open.

Analysis and Discussion

The amount of pressure losses in an aeration duct system is the sum of friction loss and shock loss (dynamic losses). Friction losses are the losses in the pipes, while shock losses are the losses in the elbow, tee, and other places that involve changes in shape and size of the pipes.

The fundamental mathematical equation governing friction losses is the turbulent flow equation as follows:

$$P = f * L * \rho * \frac{V^2}{8 * m * g}$$

Where P is pressure drop (inches of water), f is friction factor (unit-less), L is the length of pipe (feet), ρ is the density of air (lb/ft^3), V is velocity of air (ft/sec), m is the hydraulic radius (ft); which is the cross-sectional area of the duct divided by the wetted perimeter, g is gravitational constant (32.17 ft/sec^2) [1]

The above equation clearly shows that friction losses increase with increasing velocity, length of pipe, and the material by which the pipe is made (friction factor). Velocity plays the most significant role and friction losses can be reduced by using larger ducts (increasing the value of m).

The velocity of air is normally determined by a desired flow for a given seed house, the size and length of pipe can be controlled to a limited extent, the material by which the duct is made (how smooth it is) can be selected at construction time. Although smooth drawn tubing such as glass or PVC has the smallest friction factor, most ducts in cotton-seed houses are either made of galvanized metal or concrete. Minimizing friction losses is an effort that must be done at design or construction time of the seed house.

Shock losses in an aeration system are those losses caused by cross sectional areas in the duct and by the changes in the duct such as elbows and tees. It is the pressure differential between the inlet and the outlet of the change in the duct, and it is governed by the following mathematical equation:

$$P=\left(\frac{V}{4005}\right)^2 * C$$

where, P is shock loss (inches of water), V is the air velocity, C is loss coefficient (dictated by the type of bends and tees used). Again, the amount of shock losses is highly influenced by the velocity of the air, the loss coefficient in general increases if the changes in the duct are abrupt. It should also be noted that the air velocity changes every time there is a change in pipe size for a fixed amount of air or additional air is added from another duct (i.e. a manifold system) For a given duct, the shock loss is computed with the same equation mentioned above, with the velocity variable replaced with the difference of upstream and downstream velocities.

The power consumption of a fan is reflected in its air horsepower value (ahp) and the mathematical expression of ahp is given as follows:

$$ahp = \frac{Q * P_t}{6356}$$

where: Q is the flow rate (CFM) and P_t is the total pressure produced by the fan (inches of water). The total pressure of the fan includes the pressure used to aerate plus the pressure losses. The costs of electricity can therefore be computed using the equations above, for any given Kilowatt Hour (KWH) charge. Table 1 shows static pressure losses as velocity increases and the resulting cost of electricity for smooth metal pipe, assuming that electric energy is $0.06 / KWH and annual operation is 240 hours (10 days, 24 hours/day which is typical aeration time for a mid south cottonseed storage facility). Conveying 2000CFM at 2000 ft/min through 800 feet of 14 inch round pipe would have an annual cost of $9.46. Decreasing pipe size to 9 inches would require a 5000ft/min velocity and would cost $86.53 for the same distance. When sizing pipe for this facility, the annual electric cost over the life of the system (include expected increases in electric rates) plus any interest on these costs should be weighed against the difference in the lifetime cost of the different pipe sizes.

Table 2 shows the results of the computations based on measured data at Due West and Swan Lake gins. Comparing equivalent flow rates for metal pipe in Table 1 to the concrete ducts in Table 2 demonstrates the importance of finishing the duct as smoothly as possible. A 14inch metal pipe conveying 4000CFM at 4000 ft/min would cost $75.71 (Table 1) compared to the same conditions in rough concrete that would cost $502.95 (Table 2) annually.

Table 3 shows the cost differences for a sample of different of KWH rates under the same constraints of Table 2. It also shows a sample of results computed for three different air rates with a fixed aeration time of 240 hours, which is probably typical for seed aeration in the mid south .

The different Velocity and static losses measurements were obtained by controlling the gating valves of the different sections of the seed house.

Aeration Duct Design of Different Seed Houses

The majority of newly built seed houses are of the type outlined in Figure 2 and the aeration ducts are in the floor (concrete trenches Figure 1). The arrangement of ducts in the floor varies widely. The following paragraphs describe a few of the variations and discus some of the cost issues that are pertinent for consideration.

Most existing aeration systems for cottonseed houses are arranged with a fan serving four or more ducts using a plenum system with a gating valve incorporated in each branch of the duct. The length of each duct (trench) in a branch can span the width of the seed house or it can span a half of the width of the seed house (see Figures 2 and 3). The spacing between ducts, width and depth of each trench also varies from design to design (see Figure 4). There is no established standard of how the in-floor duct should be arranged or constructed. It is therefore pertinent that an analysis of different duct design be done to help in the decision of building a seed house.

The full-length aeration duct arrangement uses the least number of fans, thus the size of fans required has to be large enough to handle air for a full length of the ducts. To reduce friction losses in large houses, the length of ducts can be cut in half, partitioning the seed house into two sides (Figure 3) with each side having its own air handling system. The arrangement will result in lower air velocities down the duct, thus lower static losses.

The two commonly used trench designs shown in Figure 4 are very similar in shape, both have approximately the same effective cross sectional area, the difference is in the requirement of bar grating cover for the trench. The two I-beams design requires lighter bar grating and lighter I-beams, normally one-inch grating is used for this design. The construction cost difference between the two-trench design is slight: approximately $6.69/ft^2 for the two I-beam design and $8.00/ft^2 for the one I-beam design. For a 6,000 tons seed house, which requires approximately 3,000 ft^2 of ducts, the construction cost difference is about $930. An example of bar grating is shown in Figure 5.

In an effort to reduce friction losses further, one can visualize the use of a half-length configuration, but with the branch pipe brought to the mid point of the half-length duct, thus cutting the half-length further in half (Figure 3). The advantage of this scheme is that the velocity down the duct and thus friction losses due to the length of the duct is reduced. Using metal pipe (or other smoother material) from the center of the duct to the fan and conveying at higher velocities than are efficient with a concrete duct will further reduce static loss (Figures 6 and 7). The drawback of this scheme is that the piping must be extended to the middle of the half-length duct, thus increasing the cost of pipe and the installation of the piping system is more complex.

A possible way of constructing a highly efficient in-floor aeration duct for cottonseed houses is to use pre-fabricated materials (pre fabricated trenches) (Figure 8). The use of pre-fabricated design has many advantages and some disadvantages. The advantages include: the material used can be "factory smooth" and identical, the bar grating covers can be uniformly manufactured, the entire aeration system can be made in KIT form thus installation is much simplified. The disadvantages of pre-fabricated trenches include the quantity requirement and the shipping expense when concrete is the chosen material. In order to reduce production cost, the form must be used on greater numbers of duct sections. Since the number of new seed houses is not very large, the cost of manufacturing and installing pre-fabricated ducts may be higher than the cost forming and pouring in place. Additionally, placement may become intensive if any grading and mudding must be performed.

Another option that appears to have merit is the use of shallow duct trenches as described above with the depth of the trench equal to the height of the bar grating (Figures 6 and 7). This requires the airflow to be parallel to the bars in the grating (and bar grating to be open throughout it's length) (Figure 5) This provides maximum smoothness of the trench, best concrete continuity and reinforcement and support for the bar grating while making use of reusable forms. However, even with support of the concrete under the total bar grating area, manufacturers do not specify a lighter weight bar grating than they use for bridging an 18 to 22 inch span over "I" beams.

Conclusion

The criteria for implementing an aeration system should be that the system is capable of carrying the amount of air flow (CFM) in the most efficient manner. This normally translates to the minimization of energy losses in the air system. Friction losses are related to velocity, the "smoothness", the length, and the effective cross sectional area of the air duct. These parameters must be judicially chosen at the time when the seed house is being designed. Also to minimize losses, the number of branches (elbow and tees), and the amount of changes in cross-sectional area should be reduced as much as is practical. This suggests that the number of ducts served by one fan must be kept to the minimum at the same time not eliminating the capability to provide a larger than normal flow for a given duct in the event that a "hot spot" occurs in a particular area of the house.

The cost savings from a properly designed aeration system pay long term dividends once the seed house is built and the fans are installed. The amount of cost savings from minimizing friction losses is minimal relative to the total cost of the seed house construction. But given the increasing cost of energy per unit of usage, having the most efficient aeration system at the front end of a seed house investment can make good economic sense for the long run. The most significant cost savings however can be obtained from the operational aspects of the seed house. This includes proper maintenance of the air handling system, i.e. making sure leakages are minimized. Fans should be well maintained. Those constructing seed storage should also consider the use of automated systems to precisely control the turning on and off of aeration in an optimal manner.

References

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Table 1. Annual Electricity Cost of Static Pressure Losses at Three Different CFM.

Velocity ft/sec	CFM Total	Diameter inches	Static Loss Inches water	AHP Horse Power	Total KWH	Cost/ 100ft	cost/ 800ft
1000	2000	19	0.09	0.03	5.07	0.30	2.43
2000		14	0.35	0.11	19.72	1.18	9.46
3000		11	1.2	0.38	67.60	4.06	32.45
4000		10	1.9	0.60	107.04	6.42	51.38
5000		9	3.2	1.01	180.27	10.82	86.53
1000	3000	23	0.06	0.03	5.07	0.30	2.43
2000		17	0.29	0.14	24.51	1.47	11.76
3000		14	0.7	0.33	59.15	3.55	28.39
4000		12	1.6	0.76	135.20	8.11	64.90
5000		10	4	1.89	338.01	20.28	162.24
1000	4000	27	0.05	0.03	5.63	0.34	2.70
2000		19	0.3	0.19	33.80	2.03	16.22
3000		16	0.7	0.44	78.87	4.73	37.86
4000		14	1.4	0.88	157.74	9.46	75.71
5000		12	2.8	1.76	315.47	18.93	151.43

Note: Assume 24 hours per day, 10 days per year @ $0.06/KWH

Table 2. Annual Electricity Cost of Static Pressure Losses at Due West and Swan Lake Gins.

Equivalent Diameter inches	Static Loss Inches water	Velocity Ft/sec	CFM Total	AHP	Total KWH	Cost/ 100ft	Cost/ house
21*	9.3	3963	9247.00	13.53	2422.29	145.34	1162.70
21*	9.2	3807	8883.00	12.86	2301.92	138.12	1104.92
21*	5.2	3109	7254.33	5.93	1062.54	63.75	510.02
21*	1.2	2085	4865.00	0.92	164.44	9.87	78.93
21*	0.2	1554	3626.00	0.11	20.43	1.23	9.80
21*	0.1	1390	3243.33	0.05	9.14	0.55	4.39
14**	9.3	3963	4000.00	5.85	1047.82	62.87	502.95

Note: Assume 24 hr/day, 10 days/year at $0.06/KWH
* concrete duct, ** metal duct

Table 3. Annual Cost of Static Pressure Losses at Three different Rates of KWH.

Cost/house at $0.06/KWH	Cost/house at $0.12/KWH	Cost/house at $0.18/KWH
$ 1,162.70	$2,325.40	$ 3,488.10
$ 1,104.92	$2,209.84	$ 3,314.77
$ 510.02	$1,020.03	$ 1,530.05
$ 78.93	$ 157.86	$ 236.79
$ 9.80	$ 19.61	$ 29.41
$ 4.39	$ 8.77	$ 13.16
$ 502.95	$1,005.91	$ 1,508.86

Figure 1. Swan Lake Cottonseed House Duct.

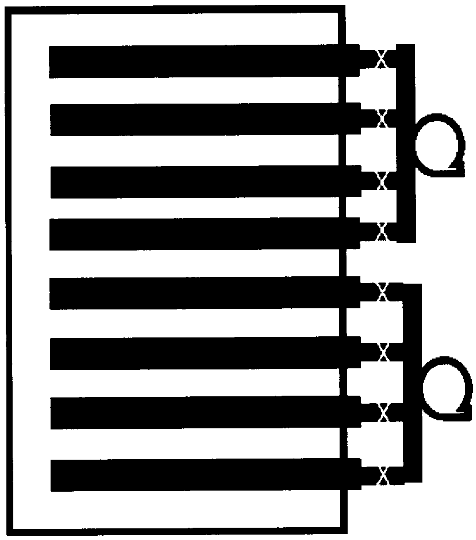

Figure 2. Full-length Aeration Ducts.

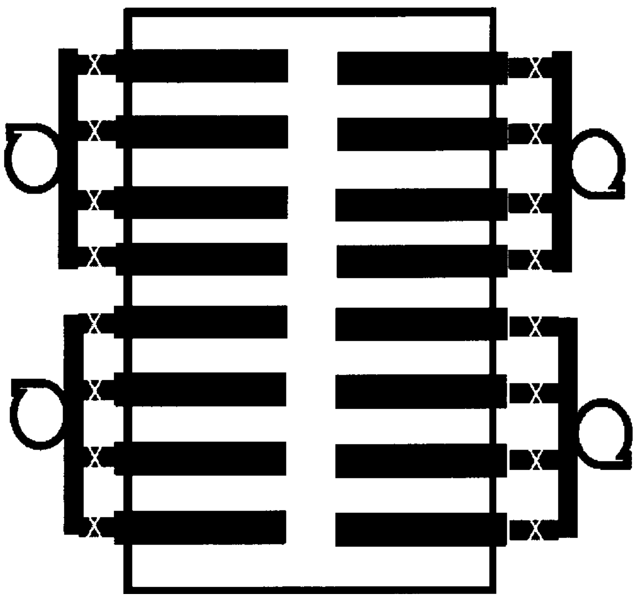

Figure 3. Half-Length Aeration Ducts.

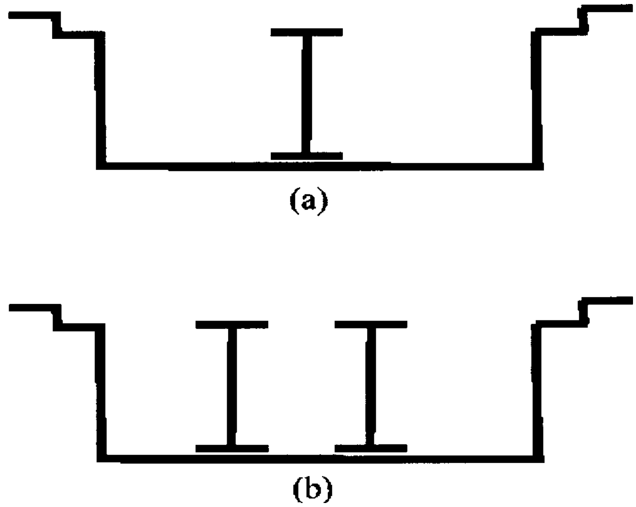

Figure 4. Trench Design, (a) one I-beam, two inch bar grating, (b) two I-beam, one inch bar.

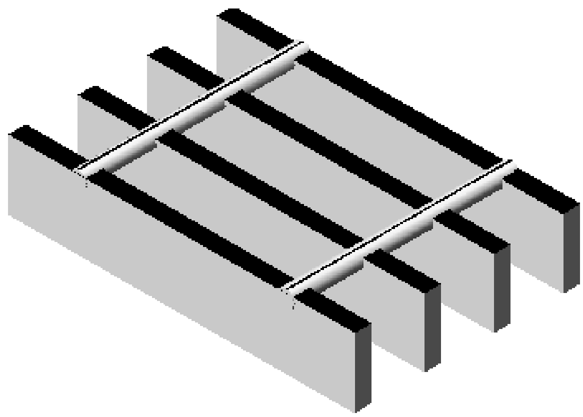

Figure 5. Example of Bar Grating for Shallow Aeration.

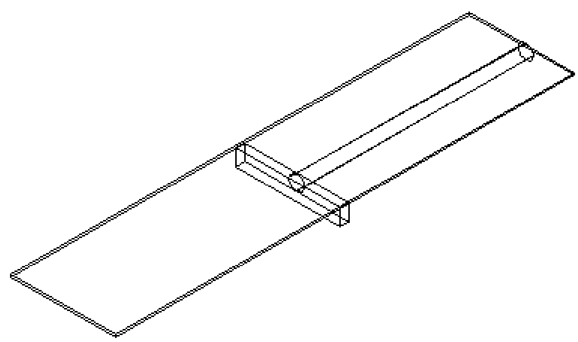

Figure 6. Top view of Shallow Aeration Duct with Pipe from Center.

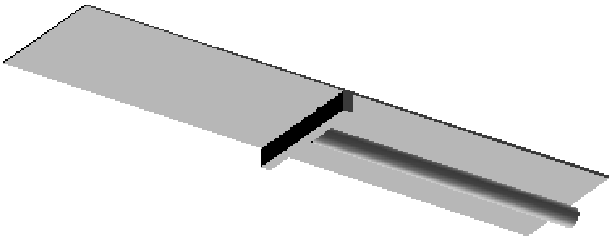

Figure 7. Bottom View of Shallow Aeration Pad with Pipe to Side.

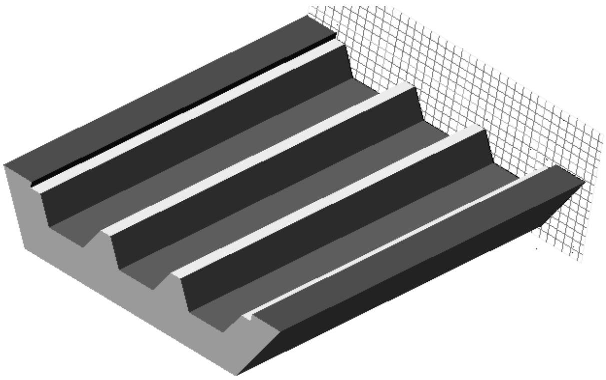

Figure 8. Prefab Concrete Duct Section.