

FRICION AND SHOCK LOSSES IN SOME AIR-CONVEYING SYSTEMS USED IN AGRICULTURAL APPLICATIONS*

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In the design of air-conveying systems, such as those employed in many batch-type agricultural product dryers and in some livestock shelter ventilation systems, the need to minimize pressure losses is of critical importance. Any increase in pressure requirement of a system results in a decrease in air flow rate or an increase in power required to maintain a given rate of flow (1) (2). A careful analysis of the component parts of a system reveals its weaknesses and quickly permits improvement of the aerodynamic design.

The general subject of pressure losses in fluid-conveying systems is of wide interest, and procedures that have been well established can be profitably used in the design of the systems mentioned above. The results of extensive investigations carried out in the field of heating and air conditioning to evaluate pressure losses in ducts, are likely to be of particular interest. In addition, numerous studies have been made by agricultural engineers of the resistance of grains and forage to air flow, the results of which are of value in dryer design.

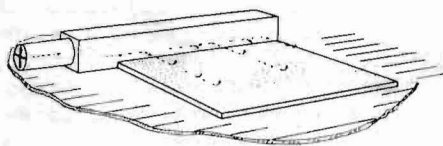


Fig. 1 Air flow in a perforated floor dryer.



Fig. 2 Air flow in a ventilation system having an extended plenum supply duct.

There is a wide variety of applications of air-conveying systems to agricultural problems and different layouts can be employed in each application. For example, farm constructed batch dryers may be of a perforated floor type (Fig. 1) or of some other type; the ventilation system shown in Fig. 2 is only one of many possible types. Despite the numerous variations the same basic components are employed in most systems and as a result there are only a few different

sources of loss. The loss in each component of a system can generally be evaluated separately and used in computing the total loss.

Sources of pressure loss, some of which will exist in all air-conveying systems are:

- (a) Changes in duct cross-section.
- (b) Duct friction.
- (c) Change in air velocity at takeoffs.
- (d) Constrictions in the path of air flow.
- (e) Resistance of a bed of material to air flow.

Changes in Duct Cross-Section

An increase in duct cross-section, such as is shown in Fig. 1, results in a shock loss due to change in air velocity. If the expansion is abrupt and symmetrical (Fig. 3), the loss, H , in inches of water, is given by Eq. 1. This value is sometimes referred to as the Borda loss.

$$H = p \left(\frac{V_1 - V_2}{1096.5} \right)^2 \quad (1)$$

If p , the air density, is 0.075 pounds/cubic foot,

$$H = \left(\frac{4005}{V_1 - V_2} \right)^2 \quad (2)$$

V_1, V_2 = inlet and outlet velocity respectively - feet/min.

Water density is assumed to be 62.3 pounds/cubic foot.

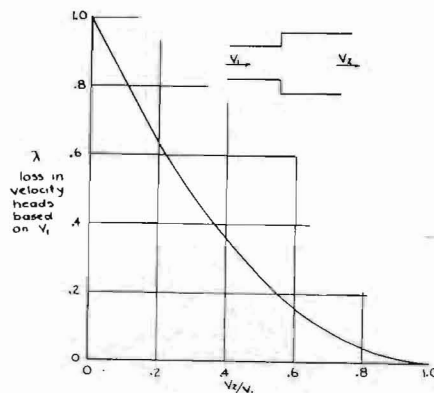


Fig. 3 Pressure loss due to abrupt expansion. Head loss in inches of water is equal to

$$\left(\frac{V_1}{4005} \right)^2$$

If the transition piece is tapered to allow gradual expansion, the pres-

sure loss is less than for an abrupt transition. For example, the minimum loss for a rectangular taper, with two sides parallel, having an outlet to inlet area ratio of 2.25:1, occurs when the angle of divergence is 11° (3). For this case the loss is approximately 16% of the Borda loss.

Another method of reducing pressure loss is to use a Gibson enlargement (3) in which case the transition section is tapered for a portion of its length and the taper is followed by an abrupt expansion (Fig. 4). For a rectangular section, the loss in a well designed Gibson enlargement is about 90% of that for an ideally tapered section. The tapered section has to be much longer to give minimum loss and friction loss becomes important (4)

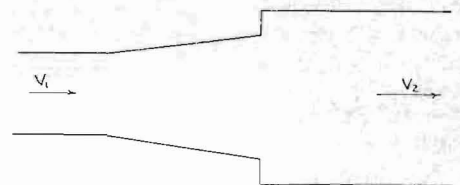


Fig. 4 A Gibson enlargement.

A third method, described by Berry (3), of the reducing loss due to duct area change, is to employ a number of small, abrupt expansions in series. The loss occurring in each of these is given by Eq. 1 and the total of these losses is less than that for one abrupt area change.

Head loss occurs if the duct cross-section is reduced (5) and can be expressed as follows:

$$H = C \left(\frac{V_2}{4005} \right)^2 \quad (3)$$

V_2 = velocity following the area reduction - feet/min.

C = a constant that depends on the type of entry.

It may be as high as 0.4 for a sharp cornered entry and as low as 0.0001 for a long radius corner.

Static Regain and Duct Friction

As air flows along a supply duct part of it may be drawn off through perforations in the wall or through takeoff ducts (Fig. 5). If the cross-sectional area of the duct is constant throughout its length (an extended plenum) the air velocity will decrease

and the phenomenon of static pressure regain will occur.

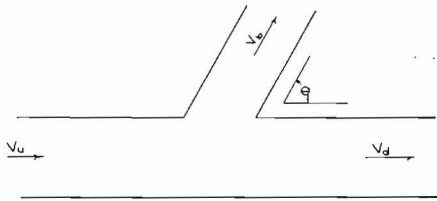


Fig. 5 Supply duct and branch takeoff.

The importance of static regain in ducts lies partly in its effect on local static pressure and therefore on the local rate of efflux. A variation in static pressure along a supply duct, to which static regain contributes, may have a significant effect on the local rate of efflux for a ventilation system but the effect is likely to be small for a dryer, which, because of its higher operating pressure, the effect of the variation due to regain will be relatively small.

Lack of space does not permit a discussion of regain effects. Information relating to regain across lateral takeoffs is given by Nelson (6) and Ashley (7), also an investigation of air flow through a tiny slot parallel to the duct axis, and therefore similar in nature to the perforated wall case, was carried out by Koestel and Tuve (8).

Friction loss, in inches of water, in air ducts can generally be expressed as follows:

$$H = f \frac{L}{D} \rho \left(\frac{V}{1096.5} \right)^2 \quad (4)$$

- f=friction factor
- L=duct length - feet
- ρ =air density - pounds/cubic foot
- V=air velocity - feet/min
- D=duct diameter - feet

For rectangular ducts with dimensions "a" and "b" the head loss is the same as for a circular duct, of equivalent length, of diameter $D = \frac{2ab}{a+b}$ and carrying air at the same velocity V. If ρ equals 0.075 pounds/cubic ft.,

$$H = f \frac{L}{D} \rho \left(\frac{V}{4005} \right)^2 \quad (5)$$

Head loss charts are available for sheet metal ducts, but for other materials the evaluation of the friction factor f and the use of Eq. 4 or 5 is usually necessary to find the head loss.

Eq. 5 gives the head loss where the fluid velocity is the same throughout a length of duct but if the velocity varies along the duct, as is the case for extended plenum ducts with takeoffs, the loss, if computed using Eq. 4, must be calculated separately for

each section in which the velocity is different. Christiansen (9) presented a relationship which consists of a modification of the Darcy equation multiplied by a correction factor F to give friction head loss in irrigation header pipes, when the volume rate of efflux is the same at all takeoffs, and the same distance separates successive takeoffs. The same factor F can be used with Eq. 4 or 5 to obtain the friction head loss between the first and last takeoff of an extended plenum air duct.

V is the air velocity before the first takeoff.

$$H = F f \frac{L}{D} \rho \left(\frac{V}{1096.5} \right)^2 \quad (6)$$

$$F = \frac{1}{m+1} + \frac{1}{2N} + \frac{m+1}{6N}$$

N=number of spaces between outlets.

m commonly assumed equal to 2.

For the case of a perforated duct the number of takeoffs N would be very large and F would be approximately 0.333, corresponding to N equal to infinity.

Alternatively, using Eq. 4, step by step calculations lead to an approximate evaluation of friction head loss in the duct if the rate of efflux at each takeoff is estimated first and used to calculate local duct velocities. This value can be improved by estimating the amount of static regain based on the assumed takeoff rates and making a second estimate of the rate of efflux at each takeoff.

Shock Loss Due to Entering Takeoffs

The pressure loss due to entering a branch takeoff is caused by turbulence and stream contraction resulting from the change in direction of flow. It is usually given on a no-length basis, the normal friction loss being subtracted from the total loss measured between the points of observation.

$$HT = T.P.u - T.P.b - Lf \quad (7)$$

HT = takeoff loss

TPu, TPb = respectively total pressure at the observation points in the supply duct upstream from the takeoff, and in the branch takeoff.

Lf = normal friction loss between the observation points.

A dimensionless loss coefficient for takeoffs is

$$Xb = \frac{HT}{V.P.b} \quad (8)$$

V.P.b=velocity pressure in the branch

Data on butt connected, circular fittings attached to extended plenums

are presented by Korst et al (10) Holl et al (11) Gilman (12) and for rectangular divided flow fittings by Miller et al (13).

It is demonstrated that the takeoff coefficient (Eq. 8) for circular, butt fittings is effectively independent of the Reynolds number at high Reynolds numbers but increases at low values of this parameter. The takeoff coefficient depends on the ratio Vb/Vu , and on the duct to branch area ratio.

For a takeoff angle, α , (Fig. 5) of 90° the branch takeoff loss (9) predicted by

$$Xb = 0.5 + \frac{Vb^2}{Vu} \quad (9)$$

is shown (7) to agree well with experimental results for a takeoff to duct area ratio of 0.14 and for takeoff to duct velocity ratios above 0.4. Xb , for a takeoff to duct area ratio of 0.49, however, falls considerably below the value predicted by Eq. 9. It seems that Eq. 9 should generally apply for small take off to duct area ratios.

The use of a conical takeoff materially reduces the takeoff loss (9).

A reduction in the takeoff angle below 90° generally reduces the takeoff loss. The loss coefficient for one system (9) with a takeoff angle of 45° was found to be between 20% and 30% of that for a 90° takeoff angle, for branch duct velocity ratios between 0.4 and 3.0. It is also demonstrated (12) that a natural angle of efflux, which is approximately predicted by

$$\frac{Vb}{Vu} = \frac{1}{\cos \alpha} \quad (10)$$

gives the minimum takeoff loss for the particular velocity ratio.

Constrictions

A perforated wall of a ventilation system or dryer imposes resistance to the passage of air through it. Henderson (14) (15) correlated pressure loss through perforated sheets supporting grain in terms of the depth of clean grain "D" in feet which would have caused the same loss, and the percentage of sheet area "p" occupied by openings. When shelled corn covered the perforated plate he found

$$Dp = 1.55 = 7.40 \quad (11)$$

$$\text{For soybeans} \\ Dp = 1.27 = 7.30 \quad (12)$$

$$\text{For oats} \\ Dp = 1.62 = 5.25 \quad (13)$$

The calculated value of "D", when used in conjunction with the resistance value for the grain (27), gives the pressure drop through the plate. *Resistance of Beds of Material to*

Air Flow

Since it causes a major part of the resistance to air flow in dryers, the resistance of beds of grain and forage to air flow has been the subject of a considerable amount of research. The results can readily be used to calculate pressure drops for one-dimensional flow problems, but with difficulty in problems involving two or three-dimensional flow patterns (16) (17) (18).

The resistance of hay to air flow has been studied by a number of investigators (19) (20) (21) (22) (23) (24) (25) (26). Gillou (27) presented a relationship for pressure drop through vertical columns of hay.

Data for resistance of a number of grains to air flow are given by Shedd (28), and the Agricultural Engineers Yearbook (1958).

Since the resistance is proportional to the thickness of the bed, and the rate of air flow, it is desirable to keep the thickness at as low a value as is consistent with efficient use of drying air.

Closure

It appears that an insufficient amount of work has been done to formulate accurate, generalized equations, for some of the foregoing sources of loss. However, an estimate based on the information obtained from research with a limited number of geometrical designs, a limited range or number of air flow rates, or with substances whose physical properties may not be completely specified is likely to be materially better than an unaided guess.

Frequently it is not necessary or practical to design livestock ventilation systems or agricultural dryers with extreme care regarding pressure losses. It is likely, however, that a general appreciation by the designer, of the causes of pressure loss will permit him to incorporate, with little or no cost in money or time, features which will reduce the pressure against which the fan must work with consequent improvement in system performance.

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(Continued from page 14)

too distant future a saturation point may be reached in terms of locations where these plants can operate economically, but it is felt they should be promoted with full impetus until that point is reached. With the interest in late years in better seed cleaning facilities, much interest is developing in scaled down versions of these stationary plants—in other words a plant capitalized at \$10,000 to \$15,000 cleaning 75,000 to 125,000 bushels annually. Many small mixed farming areas which could not economically operate the larger plants could well afford the latter.

It is up to Agrologists to promote better seed through improved seed cleaning facilities. Improved cultural practice and use of chemicals is continually being stressed. Why not then, stress proper seed cleaning and seed grading to lessen the competition of weeds and to grow cleaner, more healthy crops? This will result in greater yield and returns, which is the same basis as for the use of cultural and chemical control practices.

CORRECTIONS

MacQueen, DOSIMETRY AND RADIATION FACILITIES, P. 6

P. 6 Column 1, - Line 12 should be deleted.

P. 8 Column 1, - Illustration at bottom of page should be inverted.

Hedlin, FRICTION AND SHOCK LOSSES IN SOME AIR-CONVEYING SYSTEMS
USED IN AGRICULTURAL APPLICATIONS, P. 15

Eq. 2 should read $\left(\frac{V_1 - V_2}{4005}\right)^2$

Fig. 3 "Head loss, in inches of water, is equal to $\left(\frac{V_1}{4005}\right)^2$ " - should be deleted.

Eq. 5 - delete "p"

Eq. 6 - The expression following Eq. 6 should read:

$$F = \frac{1}{m \cdot l} \cdot \frac{1}{2N} \cdot \frac{m - 2l}{6N^2}$$

Eq. 8 should read

$$X_b = \frac{HT}{V.P.b}$$

P. 16, Column 3, Line 11 - "ration" should read "ratio"

P. 16, Column 3, Line 20 should read

--"duct velocity ratios above 0.4. The loss X_b for a takeoff to-----"

The angle theta in Fig. 5 is the same as inverted e used in the text.

P. 17 Reference 2 - Kramer instead of Framer

" 8 - Tuve instead of Tauve

" 9 - Christiansen instead of Chrisiansen