PNEUMATIC CONVEYING FOR INCINERATION OF PAPER TRIM

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ABSTRACT

The design parameters were developed for a system of pneumatic conveying of paper trimmings and shredded resins from multiple sources to boiler firing 1400 ft away. The necessary air velocity in the piping, blower sizes and horsepower, air-to-paper ratio and other practical data were determined. The system has been in use 3 years. A system of scrap paper transport to balers is also described.

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF</td>
<td>centrifugal forces, equal to ( W_m + \frac{V_m^2}{2g} )</td>
</tr>
<tr>
<td>d</td>
<td>distance around bend, equal to ( \pi r / 2 )</td>
</tr>
<tr>
<td>D</td>
<td>diameter of pipe, feet</td>
</tr>
<tr>
<td>f</td>
<td>coefficient of friction in galvanized steel duct; 0.5</td>
</tr>
<tr>
<td>f_c</td>
<td>correction factor for pipe roughness, used in Fig. 42, “Fan Engineering”</td>
</tr>
<tr>
<td>f_d</td>
<td>coefficient of drag</td>
</tr>
<tr>
<td>g</td>
<td>acceleration due to gravity; 32 ft per sec/per sec</td>
</tr>
<tr>
<td>H</td>
<td>horizontal length of duct; feet</td>
</tr>
<tr>
<td>L</td>
<td>length of pipe, feet</td>
</tr>
<tr>
<td>R</td>
<td>material loading = ( \frac{W_m}{W_a} ); lb material/lb air</td>
</tr>
<tr>
<td>r</td>
<td>radius of elbow, feet</td>
</tr>
<tr>
<td>( TP_a )</td>
<td>friction loss due to acceleration of trim; inches water</td>
</tr>
<tr>
<td>( TP_h )</td>
<td>friction loss due to trim moving in horizontal duct; inches water</td>
</tr>
<tr>
<td>( TP_L )</td>
<td>total pressure lost by air in lifting material vertically; inches water</td>
</tr>
<tr>
<td>( \Delta TP_d )</td>
<td>friction loss due to air in straight pipe sections, inches water</td>
</tr>
<tr>
<td>( TP_{90} )</td>
<td>friction loss due to trim moving through elbows; inches water</td>
</tr>
<tr>
<td>( V_a )</td>
<td>air transport velocity; ft per minute</td>
</tr>
<tr>
<td>( V_f )</td>
<td>floating velocity; ft per sec (or ft per min)</td>
</tr>
<tr>
<td>( V_m )</td>
<td>material velocity; ft per min</td>
</tr>
<tr>
<td>( V_r )</td>
<td>relative velocity; ft per min</td>
</tr>
<tr>
<td>( VP )</td>
<td>velocity pressure of air, inches water</td>
</tr>
<tr>
<td>( W_a )</td>
<td>lb of air per min</td>
</tr>
<tr>
<td>( W_m )</td>
<td>lb material per min</td>
</tr>
<tr>
<td>( \rho_a )</td>
<td>density of air; lb per cu ft</td>
</tr>
<tr>
<td>( \rho_p )</td>
<td>trim particle density; lb per cu ft</td>
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</table>

INTRODUCTION

In the summer of 1963, the Eastman Kodak Company found that disposal of slitter edge trim at the winders, in one of its paper-coating divisions, had become a major problem. The coated paper thickness is 0.020 in. and it weighs up to 55 lbs per 1000 sq ft. Each day 3,000 lbs of trim were being collected and baled for trucking to and burning at the plant incinerator, about two miles away.
WASTE PAPER
TRIM DISPOSAL SYSTEM

FIG. 1 DISPOSAL SYSTEM FOR WASTE PAPER TRIM
This chore was not only laborious and costly, but it was presenting a difficult housekeeping problem. Furthermore, the resin-coated paper had 10,760 Btu per lb and 3.6 percent ash. We solved the problem by conveying the trim pneumatically through a 6-in. pipeline 1,400 ft long to the plant powerhouse, for burning in either of two boilers.

A schematic diagram of our system from winders to the boilers is shown in Fig. 1. The trim is chopped in trim cutters after leaving the winders, (Fig. 2) prior to entry to the winder trim blowers (Fig. 3). The trim varies in width from \( \frac{3}{4} \) in. to 2 in. The trim cutters chop it into lengths of about 3 in. to 4 in. Trim is collected at numerous winders, and several submain ducts carry it to a large booster fan (Fig. 4) prior to delivery to a cyclone separator for initial collection. The cyclone exit air is withdrawn and washed by a wet centrifugal blower-scrubber. Meanwhile the paper stream from the bottom of the cyclone is withdrawn by two high pressure blowers, in series, (Fig. 5) and delivered through the 6-in. pipeline which runs through, along, and over buildings to the powerhouse (Fig. 6). A diverting valve in the powerhouse permits a choice of boilers. Note the flexible metallic hose at the boiler entry (Fig. 7) required by the movement of flange opening of about 2 in. on heat-up of the boiler.

Transporting pieces of paper trim with high tensile strength, of width up to 2 in. and random lengths up to 24 in., through two blowers, in an outdoor pipeline, and through the tube wall of a boiler is a formidable problem. Some trim is as long as 24 in. because all winders do not have trim cutters. We shall present some of our design details which resulted in a successful system, operating without labor.
DESIGN PARAMETERS

Our thoughts were immediately directed toward assurance of no plugs in this long outdoor pipeline, the blowers, and the boiler entry. We conducted trim conveying tests through a clear Tenite pipeline in our engineering test laboratories. We were able to determine conveying velocities and actually see the travel of the paper trim through elbows, as well as straight sections of pipe. We found that the minimum conveying velocity was 1800 ft per minute and that the paper moved very well at 3000 ft per minute. We decided to design our system for a velocity of 4500 ft per minute because of our determination that there should be no plugs. Bends were fabricated with a radius ratio of 6/1 to provide long sweeping turns.

Since our pipe would be under the relatively high pressure of 90 in. of water (gage pressure) at the exit of the blowers, commercial pipe or tubing rather than air ductwork appeared necessary. We were fortunate in finding a spirally wound lightweight galvanized steel duct, capable of withstanding an internal pressure of at least 25 psi, practically free of air leakage and very economical in price. We then tested the spiral duct in our engineering laboratories and found no snags, plugs, or excessive leakage. We learned that the manufacturer could supply this material in double duct form, prefabricated with 1 in. of fiberglass insulation. We believed this desirable to assure no condensation or freezing of humidified air within the pipe when operating with sub-zero outdoor temperatures. At our request, because of the different temperature within the interior pipe and outside the exterior protective pipe, the manufacturer built a slip joint into the exterior pipe to allow for differential expansion of the interior and exterior pipes.
We believed the humidity of the air in our paper winding department too high to permit its use in the outdoor pipeline without condensation and icing, so we initially introduced less humid outdoor air heated to 105°F into the system at the bottom of the cyclone separator. However, we later found that we did not need the outdoor dry air. Air moves through the pipeline at all times, even though the blowers may be shut down, because of the negative pressure at the boilers.

The manufacturer of the blowers assured us that cone-shaped cutting wheels would chop the trim, and that plugging would not occur at the blowers. This has been the case. Additionally, the blowers were built with extra large inlets, to assure freedom of plugs at this point.

We designed a long narrow nozzle of high nickel stainless steel for entry into the firebox of the boiler through a free space of 2-in. width between boiler tubes. The alloy withstands the furnace temperature above 1000°F. We made a model of this nozzle and tested it for plugging with trim in our lab before installation in the boiler.

Our needs in 1963 were for a system to handle 3000 lb per day of trim, but we designed for growth, and 9000 lb per day became the design basis. Technical literature covering the pneumatic conveying of grains and chemicals indicated that our maximum loading should be about 1/2 lb trim per lb of air. With the 4500 ft per minute velocity and the 6-in. diameter tube, we had an air volume of 900 cu ft per minute, and this resulted in the very conservative material loading of 0.095 lb trim per lb of air. We could have selected a smaller diameter and a higher material loading, but this would have resulted in too high a pressure drop for our long pipeline. Our calculations indicated a system pressure drop of 67 in. water.

**OPERATING RESULTS**

This trim disposal system has been operating successfully for three years. When the system was put into operation, we measured air flow at 885 cu ft per minute and static pressure at 81 in. water. This is reasonably close to predicted performance. There have been no major operating difficulties.

As a consequence of the successful operation of the trim pipeline from the coating division, one of our product finishing departments installed a similar pneumatic system conveying trim from packaging operations to the same boilers, a distance of about 700 ft. In this case, edge trim was cut at skiving machines and conveyed in a humid air stream to a bag-type dust collector outdoors for primary collection. However, in the winter chunks of ice and paper trim formed in this collector and they subsequently plugged the pipeline and/or the boiler entry point. A cyclone separator was installed and no further difficulty occurred. This pipeline is 6 in. in diameter and has an air volume of 900 cu ft per minute. The material loading is less than that in the previously mentioned pipeline.

At present, we have an approved program for the expansion of waste paper disposal through pipelines to the boilers. Our waste paper includes drying alley drops, scrap butt rolls and roll cores. This waste paper is now trucked to our plant incinerator for burning in the primary furnace. We also have an appreciable quantity of resin waste "logs" which are trucked to the plant incinerator, where they simmer and burn slowly in the secondary combustion chamber. "Logs" are chunks of resin waste generated by plastic extrusion machines. They are cast in metal boxes filled with water. They measure about 45 in. x 15 in. x 6 in. They are very tough and burn slowly.

We plan on cutting the waste paper initially in a 20 HP rotary cutter to strips full width by about 1/4 in. The resin "logs", roll cores, and butt rolls will be fed to a 200 HP disintegrator ("hog"), fitted with a 1-in. screen, to shred the wastes to small chips suitable for pneumatic conveying. The paper will be fed to the same "hog", by means of a cleated inclined belt conveyor, for further size reduction. We will install a 12-in. diameter pipeline (1400 ft long) from the coating division to the powerhouse. Our blower will deliver 3400 cu ft per minute against a static pressure of 35 in. of water. This will require a 40 HP motor. Our pipeline velocity again will be 4500 ft per minute. The chips of paper and resin "logs" to be conveyed will be about the size of a nickel. We are designing for a material loading of 0.2 lb waste per lb of air, and we expect surges to 0.5 lb/lb air when "logs" or butt rolls are consumed by the hog in about 20 seconds.

We conducted tests of the shredding of resin "logs", butt rolls, and roll cores at the plant of a shredding machinery manufacturer. These tests enabled us to learn whether or not the "hog" could shred these materials, the capacity of their machines, horsepower requirements, and noise generated.

**BALING SYSTEM FOR SCRAP PAPER**

In another project, we have just completed installation of a large multi-pipe conveyance system to handle scrap from the various photographic finishing operations (Fig. 8). A vertical type shredder has been installed below a shaftway extending up through the building to receive roll ends and other scrap thrown down the shaft. The shredded
2 BALER PAPER SCRAP SYSTEM
APPROX. 20 TONS PER DAY TOTAL

FIG. 8 SCRAP PAPER DISPOSAL SYSTEM WITH BALERS
material is then conveyed to a horizontal type automatic baler. Another part of the system involves a 1000-foot conveyor line from the production area to the plant boilers. Both of the above systems have been designed to handle 200 lb of paper per minute. Other systems involve scrap pick-up at points of generation and pneumatic conveyance to one or the other of a dual baling assembly. With the exception of air in the 1000-foot pipe system, all conveyance air is filtered and returned to the building air-conditioning system. Total conveyance air amounts to approximately 40,000 cfm.

**DESIGN PROCEDURE**

We believe our design procedure will of interest. We followed the outline recommended by Buffalo Forge Company in *Fan Engineering*, sixth edition, Chapter 18.

It is first necessary to determine from the literature, or by test, the necessary transport velocity for the trim. Then a layout of the proposed system should be prepared to determine length of runs and number of fittings. It is necessary to determine or estimate paper density, frontal area and volume for a typical piece of trim, coefficient of drag for the trim, and coefficient of friction for the pipe or tube material. Initial calculations are made of particle floating velocity, relative velocity, and material velocity. Material rate, air velocity, material loading, and air volume are then determined. At this point calculations are made of system pressure losses due to material flow, including:

1. Lift losses
2. Acceleration losses
3. Horizontal losses
4. Elbow losses

Friction losses due to air flow are then calculated. System entrance and exit losses are determined by calculation or test. Then the losses are summed up.

Fan power is determined using normal formulae for air horsepower, but a correction factor is applied for the presence of solid material in the air system. This factor equals the ratio of effective density to air density. Effective density in turn equals weight of material and air divided by volume of the mixture.

**TYPICAL EXAMPLE**

Assume that we are to pneumatically convey 4000 lb per day of paper trim through a pipeline 800 ft long. There will be six 90 degree elbows with radius ratio of 5 to 1. There will be a system elevation change of 30 ft upward. The tube will be galvanized steel. A typical piece of trim will be 3/8 in. wide by 6 in. long. It will enter the system from a cyclone separator and be discharged into a furnace.

- **Transport velocity** = 4500 ft per min (Based on experience)
  - **Density of paper** = 58 lb per cu ft
  - **Frontal area of piece of trim** = 3/8 in x 6 in. = 2.25 sq in.
  - **Average particle volume**, for paper 0.008 in thick = 2.25 sq in. x 0.008 in. = 0.018 cu in.
  - **Coefficient of drag for paper trim**; assume $f_d = 1.0$ (*“Fan Engineering,” p. 470*)
  - **Coefficient of friction on galvanized steel**; assume 0.5 based on data for rolled oats

1. **Particle floating velocity**

   \[ V_f = \sqrt{\frac{2g}{f_d \times \rho_p} \times \frac{\text{Volume}}{\text{Frontal Area}}} \]

2. **Relative velocity**

   \[ V_r = V_f \] for vertical runs

3. **Material velocity**

   \[ V_m = V_a - V_r = 4500 - 165 = 4335 \text{ ft per min. for horizontal ducts} \]

4. **Material rate**

   \[ \text{Material rate} = \frac{4000 \text{ lb}}{24 \text{ hr}} = 167 \text{ lb per hr;} \text{ or } 2.78 \text{ lb per min.} \]

5. **Material loading**

   Based on experience, initially select 0.1 lb paper per lb air,

   \[ \text{Air Quantity} = \frac{2.78 \text{ lb paper}}{\text{min.}} \times \frac{\text{lb air}}{0.1 \text{ lb paper}} = 27.8 \text{ lb air per min.} \]

   \[ \text{Air Density at 70 F, 1 atm} = 0.075 \text{ lb per cu ft} \]
Tentative Air Volume = \( \left( \frac{27.8 \text{ lb}}{\text{min.}} \right) \left( \frac{\text{cu ft}}{0.075 \text{ lb/cu ft}} \right) = 370 \text{ cu ft per min.} \)

Determine duct size for 4500 ft per min. transport velocity

Duct diam = \( \sqrt{\frac{370 \text{ cu ft}}{\text{min.}} \times \frac{144 \text{ sq in}}{4500 \text{ ft}}} = 3.88 \text{ in.} \)

Therefore, select 4 in. diam duct, and recalculate air volume and material loading.

Final Air Volume = \( \pi \left( \frac{4 \text{ in.}}{2} \right)^2 \left( \frac{4500 \text{ ft}}{\text{min.}} \right) = 392 \text{ cu ft} \)

\[ R = \text{Material Loading} = \frac{2.78 \text{ lb per minute}}{400 \text{ cu ft per min.} \times 0.075 \text{ lb/cu ft}} = 0.093 \text{ lb/lb air} \]

6. Length of duct system

Horizontal and vertical duct = 800 ft

\[ H = \text{horizontal length of duct} = 770 \text{ ft} \]

7. Friction losses due to material

\[ a. \text{ Acceleration loss; horizontal entry to system} \]

\[ TP_a = \frac{W_m V_m^2}{694 W_a} \times \frac{2}{g} = R \left( VP \right) \]

\[ 69.4 \text{ is a conversion factor, converting feet of air to inches of water;} \]

\[ \left( \frac{1}{69.4} = 1 \text{ ft x 12 in.} \times \frac{0.075 \text{ lb/cu ft}}{62.4 \text{ lb/cu ft}} \right) \]

\[ VP \text{ of air at 4335 ft per min.} = 1.18 \text{ inches water.} \]

\[ TP_a = 0.093 \times (1.18) = 0.110 \text{ inches water} \]

There are other acceleration losses because the material is slowed down as it moves around bands, and there is a need for re-acceleration. However, in this problem with low material loading these losses are insignificant and are omitted.

\[ b. \text{ Horizontal friction losses} \]

\[ TP_h = \frac{f W_m H}{694 W_a} \times \frac{f R H}{69.4} = 0.5 \times 0.93 \times (770 \text{ ft}) = 0.52 \text{ in. water} \]

\[ c. \text{ Vertical (upward) lift loss} \]

\[ TP_L = \frac{W_m L}{694 W_a} = \frac{R L}{69.4} = 0.093 \times (30 \text{ ft}) = 0.042 \text{ in. water} \]

\[ d. \text{ Elbow losses} \]

\[ TP_{90} = \frac{f (CF)d}{694 W_a} = \frac{f W_m V_m^2}{694 W_a} \times \frac{2 g \pi r}{2} \times \pi f R \left( VP \right) \]

8. Friction losses due to air flow

\[ a. \text{ For galvanized steel pipe, horizontal and vertical runs, use Figs. 42 and 45; pages 96-100; Fan Engineering} \]

\[ \Delta TP = f_c \left( \frac{L}{D} \right) \times \left( VP \right) \text{ Fan Engineering, page 97, is the basis for Fig. 45.} \]

From Fig. 45; for 4 in. duct, 4500 ft per min., \[ \Delta P/100 \text{ ft} = 9.0 \text{ in. water} \]

From Fig. 42; for medium smooth 4 in. pipe, \( f_c = 0.84 \)

\[ \Delta TP_d = 0.84 \times (9.0 \text{ in. water}/100 \text{ ft}) \times (800 \text{ ft}) = 60.4 \text{ inches water} \]

\[ b. \text{ Friction losses in elbows} \]

From Fig. 48, page 104, \textit{Fan Engineering}

For radius ratio of 6 to 1, loss in velocity pressure = 0.24 \( VP \)

\[ \text{Velocity pressure of air at 4500 ft per min.} = 1.26 \text{ in. water} \]

For 6 elbows; \( 6 \times 0.24 \times 1.26 = 1.82 \text{ in. water} \]

\[ c. \text{ Friction loss for air entering system} \]

From \textit{Fan Engineering}, page 113, for square-edged entry loss in velocity pressure = 0.50 \( VP \)

\[ \text{Velocity pressure of air at 4500 ft per min.} = 0.50 \text{ in. water} \]

For 6 elbows; \( 6 \times 0.50 \times 1.26 = 3.78 \text{ in. water} \]

\[ d. \text{ Friction loss for air entering furnace} \]

For abrupt enlargement, allow 1 \( VP = 1.26 \text{ inches water} \]

9. Summation of Pressure Losses

<table>
<thead>
<tr>
<th>Material</th>
<th>Inches Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>0.11</td>
</tr>
<tr>
<td>Horizontal Friction</td>
<td>0.52</td>
</tr>
<tr>
<td>Vertical lift</td>
<td>0.04</td>
</tr>
<tr>
<td>Elbow losses</td>
<td>1.03</td>
</tr>
</tbody>
</table>

\[ 65.81 \text{ inches water} \]

\[ 60.40 \text{ inches water} \]

\[ 1.82 \text{ inches water} \]

\[ 0.63 \text{ inches water} \]

\[ 1.26 \text{ inches water} \]

\[ 65.81 \text{ inches water} \]

\[ 72.99 \text{ inches water} \]

Have fan deliver 400 cfm versus 72 inches water.
10. Fan Horsepower

Air horsepower = \( \left( \frac{\text{min HP}}{33,000 \text{ ft lb}} \right) \left( \frac{\text{cu ft per min}}{\text{lb per cu ft}} \right) \)

\( \left( \frac{\text{ft}}{12 \text{ in.}} \right) \left( \frac{\text{cu ft}}{0.075 \text{ lb air}} \right) \left( \frac{62.4 \text{ lb}}{\text{cu ft water}} \right) \)

Air horsepower = (400) (0.075) (72) (69.4) (1/33,000) = 4.53

Assume a fan efficiency of 60 percent for a material handling unit.
Correct for trim in the air stream

Factor = \( \frac{\text{Effective density}}{\text{Air density}} \), \text{Fan Engineering, p. 475}

Effective density = \( \frac{\text{lb material/lb air} + 1 \text{ lb air}}{13.35 \text{ cu ft/lb air}} \)

\( = \frac{0.093 + 1}{13.35} = 0.082 \)

Factor = \( \frac{0.082 \text{ lb/cu ft}}{0.075 \text{ lb/cu ft}} = 1.09 \)

Predicted fan horsepower = \( \frac{1.09 (4.53)}{0.60} = 8.2 \)