Applied Industrial Hygiene

ISSN: 0882-8032 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/uaph20

Pressure Drop in Flexible Ducts

Deborah E. Durr , Nurtan A. Esmen , Clarence Stanley Jr. & Dietrich A. Weyel

To cite this article: Deborah E. Durr , Nurtan A. Esmen , Clarence Stanley Jr. & Dietrich A. Weyel (1987) Pressure Drop in Flexible Ducts, Applied Industrial Hygiene, 2:3, 99-102, DOI: 10.1080/08828032.1987.10389815

To link to this article: https://doi.org/10.1080/08828032.1987.10389815

Pressure drop in flexible ducts

DEBORAH E. DURR,[A] NURTAN A. ESMEN,[A] CLARENCE STANLEY, Jr.[B] and DIETRICH A. WEYEL[A]
[A]Department of Industrial Environmental Health Sciences, Graduate School of Public Health, University of Pittsburgh, 130 DeSoto Street, Pittsburgh, Pennsylvania 15261; [B]U.S. Army, Edgewood Arsenal, Maryland 21005

In many ventilation system design requirements, a hood of one kind or another is required to be movable. This requirement calls for the use of flexible ducts. Although the availability of flexible ducts presents no problems, the designers have had to depend on rather scanty data in the estimation of pressure drop for air flow through flexible ducts. In general, data availability are limited to manufacturers' data sheets, and the information presented is not uniform. Experiments using two makes of flexible ducts and various sizes suggest a uniform method of pressure loss estimation for flexible ducts. The experimental results and the resulting equations suggest a direct and relatively simple estimation process. **Durr, D.E.; Esmen, N.A.; Stanley, Jr., C.; Weyel, D.A.**: Pressure drop in flexible ducts. *Appl. Ind. Hyg. 2:*99-102; 1987.

Introduction

Flexible ducts are used in many ventilation systems where the system must follow the process to be controlled. Thus, the use of flexible ducts in ventilation systems is a common occurrence. These ducts are constructed from a variety of materials such as galvanized metal, stainless steel, plastic and others. Each material gives the duct different skin properties which not only define its possible uses, but also specify its fluid mechanical properties. Although the availability of flexible ducts presents no problems, the ventilation system designers have had to rely upon rather scanty data in the estimation of pressure drop for air flow through flexible duct systems. In general, the data availability is limited to manufacturer data sheets, and under many circumstances this information may not be readily applicable to the design problem at hand.

The studies which report on the flexible ducts(1,2) treat a few specific types. The information provided is not sufficient to generalize the reported findings so that they can be used to adjust the design parameters to take any variations from the reported values into consideration. In order to alleviate this important lack of information, the study reported here attempts to express the pressure losses in a flexible duct using the fundamental parameters of flow through pipes.

In any straight constant diameter duct, the pressure loss may be expressed by the Darcy-Weisbach pipe friction equation:

$$p_1/p_v = f \bullet (L_o/D) \qquad (1)$$

where:

p_1 = friction head loss for the duct run
p_v = velocity head
f = Darcy friction factor
L_o = length of duct
D = diameter of duct

So long as the numerator and the denominator have the same units in each of the pressure and length terms, the dimensionless friction factor is independent of the units used in the calculation of the losses. The friction factor depends upon the relative roughness of the duct and the Reynolds number of the flow. However, there is no theoretical formulation for this factor, and its experimental determination is required for each type of duct. As the friction factor is a function of a duct parameter (relative roughness-k) and a flow parameter (Reynolds number-Re), the logical parameter to specify for a duct is the relative roughness. If the relative roughness is known, then the friction factor can be calculated from the Colebrook equation(3) with x as a parameter for computation:

$$x = -0.86 \ln[k/3.7 + 2.51\, x/Re]; \qquad (2)$$
$$f = 1/x^2$$

or from a Moody Diagram, which is the graphical representation of the Colebrook equation.

In a flexible duct system, the frictional head loss for a straight duct has relatively small merit because, in most cases, the flexible duct is not uniformly supported and contains a number of "drooping sections" and, in addition, by the definition of its function contains a number of curves of non-standard radii of curvature. This paper reports on an experimental study which provides generalized semi-empirical formulae for the drooping sections and also applies the results of another study which generalizes the calculation of pressure drop due to 90 degree bends.

Experimental Methods

The air flow and resistance measurements were carried out using 3-, 4-, 6-inch nominal, internal-diameter, industrial grade corrugated and smooth rubberized flexible ducts. The actual internal diameters of the ducts did not differ from the nominal diameters. The throughput velocities ranged from less than 1200 to more than 8000 feet per minute. The flexible ducts used were purchased from local dealers. In the experimental set up, all ducts were 10 feet 6 inches in length. The air flow and

---

This research was supported in part by the National Institute for Occupational Safety and Health under Grant Number 1-R01-OHO2132-01. One of the authors (Clarence Stanley, Jr.) gratefully acknowledges the United States Army Medical Department for the long-term graduate study support.

0882-8032/87/03099-04$2.00

the resistance measurements were carried out using a calibrated wind tunnel with a 6-inch ID outlet. The wind tunnel had a 6-foot flow straightener between the fan and the test and measurement section, and the air flow at the entrance of the flexible duct was fully developed turbulent flow. For the smaller flexible ducts, 18-inch-long transition sections were used. The velocity distribution at the exit of the transition was not distorted, as verified by pitot static traverses. The wind tunnel calibration and calibration of the transition pieces were carried out by 10-point vertical and horizontal traverses. The pressure measurements were made by calibrated magnehelic gages of appropriate capacity connected to the test section by means of piezometric rings.

The roughness characteristics of each duct were determined when the ducts were fully expanded. The alignment of the duct in the horizontal plane was assured by supporting the duct throughout its length in a metal trough whose width was fixed to that of the duct diameter. In addition, sufficient wire ties were securely positioned along the trough to keep the duct straight and level. The drooping sections were arranged at the middle of the duct, while the entry and exit lengths were kept straight and level as above (Figure 1).

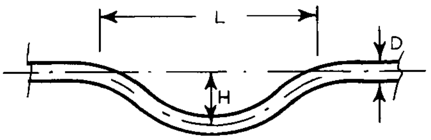

Figure 1—Schematic representation of a drooping section.

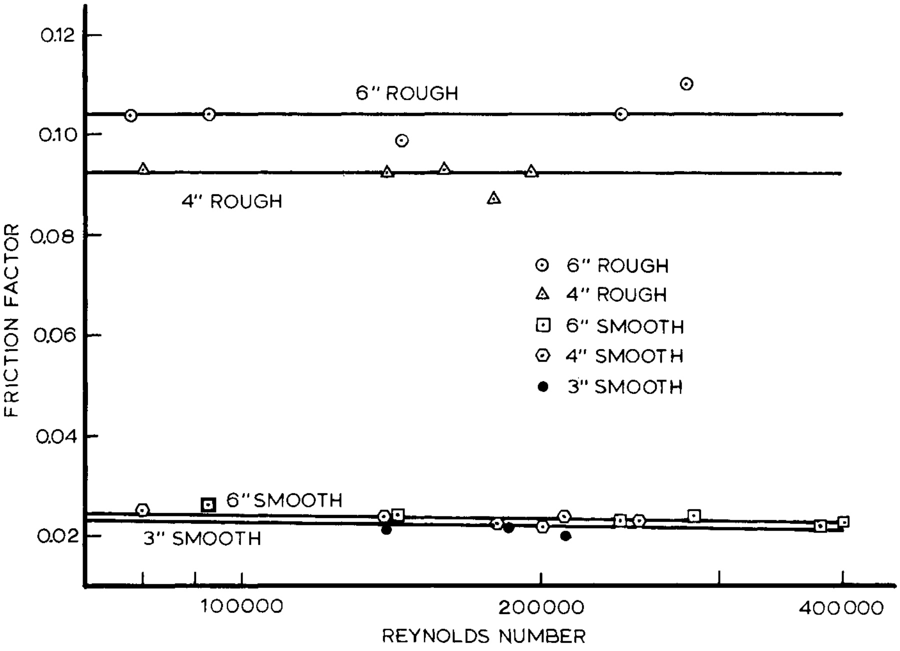

Figure 2—Measured and calculated friction factors as a function of Reynolds Number.

Results and discussion

The experiments carried out with straight ducts gave the results in terms of a pressure drop for the entire length of the duct for each velocity. The roughness for each duct was obtained by solving the Colebrook equation for the specific roughness k. The results of these experiments are shown in Table I. These values are best fit values to the equation, thus they do not indicate the scatter of the values. In order to show ^R, the data scatter, the friction factor for ducts with the obtained roughnesses is calculated as a function of Reynolds number and plotted in conjunction with the data points (Figure 2). It is important to know that the magnitude of error in the estimation of pressure drop would be expected as a function of the error in the estimation of the relative roughness. It may be readily shown that for the changes in geometry (e.g., droops, bends or straight ducts), the magnitude of pressure drop error is related to the relative roughness error as a function of the friction factor. It is apparent from Figure 2 that the relative error (i.e., the ratio of pressure drop error to relative roughness error) is a strong function of relative roughness and a weak function of the Reynolds number. In general, the reduction of Reynolds number from 300,000 to 40,000 will change the error ratio by about 0.5 percent. Figure 3 shows the ratio of percent error in the final calculation to the percent error in the estimation of the relative roughness. This figure indicates that if the estimation of the relative roughness is within 15 percent of the correct value, then the resulting error in pressure loss estimation will be within about 10 percent.

The results of the pressure drop due to drooping was analyzed by fitting a parametric curve to about one-half of the data points randomly selected from the complete data set and comparing the predicted pressure drop with the measured values for the entire data set. The predictive equation developed is:

$$p_1 = (f p_v L_o /D) + 31.7\, p_v\, f\, (H/D)\exp(-3L/8D) \qquad (3)$$

where:

L_o = total length of the duct

The results of these calculations are shown in Figure 4. These results indicate that the pressure drop may be estimated with an accuracy of about 10 percent for each droop. The pressure drop solely because of the drooping section is simply the second term of equation 3, and in practical calculations, this expression would be more useful.

$$p_d = 31.7\, p_v\, f\, (H/D)\exp(-3L/8D) \qquad (4)$$

where:

p_d = pressure drop due to drooping section
H = depth of drooping section
L = length of drooping section
D = duct internal diameter
P_d = p_v, H, L and D carry consistent units

In addition to one or more drooping sections, the flexible ducts also carry a

TABLE I

Relative roughnesses of the flexible ducts investigated

Type	Diameter inches	Relative roughness	Absolute roughness inches
Wide pitched wire enforced plastic (WPP)	6	0.102	0.612
WPP	4	0.080	0.320
Close pitched wire enforced heavy plastic (CPP)	6	0.00145	0.00870
CPP	4	0.00122	0.00488
CPP	3	0.00085	0.00255

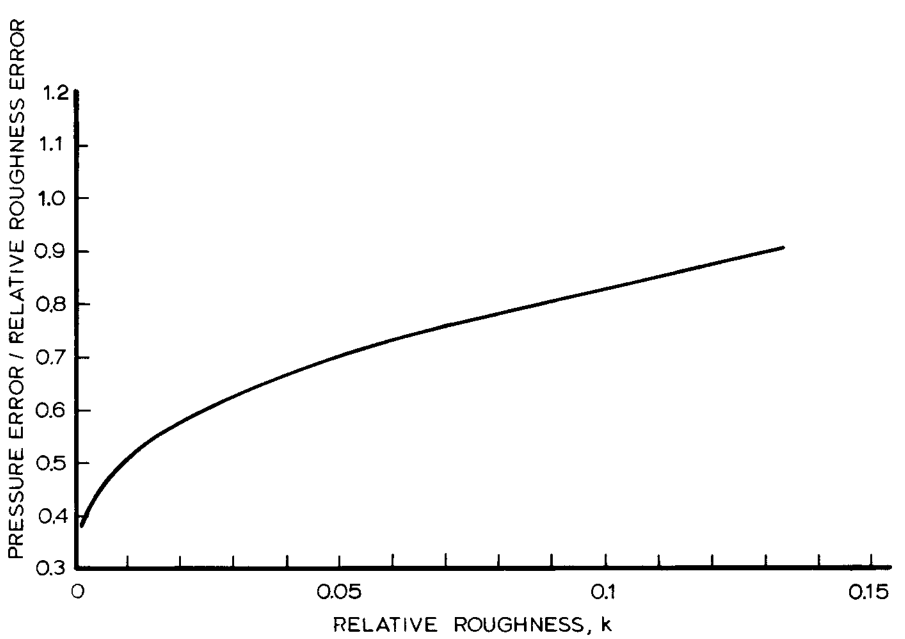

Figure 3—The ratio of final error to roughness estimation error as a function of the estimated roughness.

number of bends and turns. The pressure drop due to a bend or turn may be given as:[(4)]

$$p_e = 1.808\, p_v\, (c/360)\, [\exp(-3tr/4) + 9.956\, f \exp(-tr/100)] \qquad (5)$$

where:

p_e = pressure drop due to elbow

c = angle of turn – degrees

tr = turning ratio – turning radius/duct diameter

The total drop is calculated by the sum of all drooping sections with their parameters, the sum of all bends (irrespective of direction) with their parameters, and the drop for the length of the duct as calculated by equation 1. Depending upon the lay-out of the ventilation system and the reasonably assumable geometric configurations of the flexible duct, the designer can estimate a maximum expected pressure drop for the duct and utilize this value with an appropriate design safety factor.

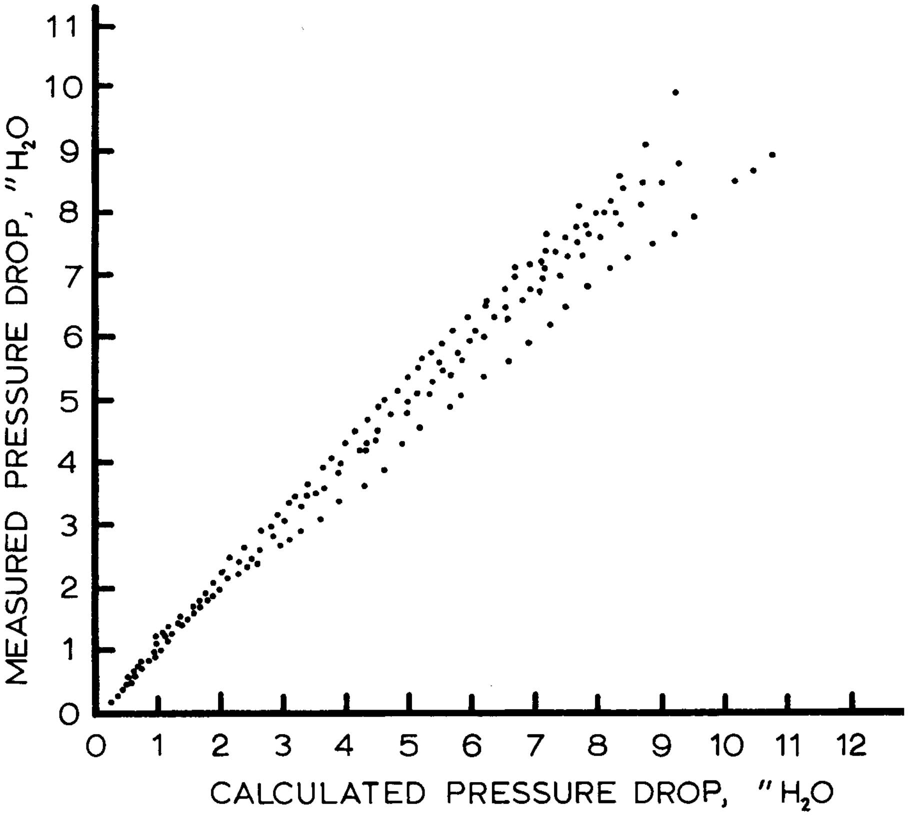

Figure 4—Comparison of calculated and measured results. Large number of points, especially at the lower end are omitted due to extensive overlap.

In order to facilitate such calculations, equations 4 and 5 may be written as:

$$p_d = p_v f \bullet fd \qquad (6)$$

and

$$p_e = p_v c \bullet fe \qquad (7)$$

The factors fd and fe are shown in Tables II and III, respectively. The total pressure drop for the flexible duct may be calculated by the summation of pressure drop for each droop and elbow and by adding this sum to the pressure drop calculated for the length of the duct from equation 1.

Conclusions

The results obtained and the equations and tables developed in this study suggest that the knowledge of relative roughness of flexible ducts makes it possible to estimate pressure drop for the use of that duct under all reasonable conditions. The designers of ventilation systems can experimentally determine the needed values, but such an endeavor will require access to a large laboratory with specialized flow measurement devices and may not be feasible. In this respect, the authors encourage the manufacturers of flexible ducts to provide this information to the users.

If there is no information available on the relative roughness of the flexible duct to be used, for metal and for close pitched wire enforced heavy duty plastic ducts an absolute roughness of about 0.002-0.009 inches (0.005-0.023 cm) and for lighter weight wide pitched wire enforced impregnated or plastic fabric ducts an absolute roughness of about 0.2 to 0.7 inches (0.5 to 1.8 cm) may be assumed. It must be recognized that these assumptions may be in considerable error.

Recommendations

Based on the results reported above, the following recommendations to the practicing industrial hygienist may be made:

1. Manufacturers of flexible ducts should be encouraged to provide the relative roughness values for their products.

TABLE II
The values of droop loss function Fd

L/D	H/D								
	0.1	0.5	1	1.5	2	3	5	7	10
1	2.176	10.882	21.764	32.646	43.528	65.293	108.821	152.349	217.642
2	1.496	7.479	14.958	22.437	29.917	44.875	74.791	104.708	149.583
3	1.028	5.140	10.281	15.421	20.561	30.842	51.403	71.965	102.807
4	0.707	3.533	7.066	10.599	14.132	21.197	35.329	49.461	70.658
5	0.486	2.428	4.856	7.284	9.712	14.569	24.281	33.994	48.562
6	0.334	1.669	3.338	5.006	6.675	10.013	16.688	23.364	33.376
7	0.229	1.147	2.294	3.441	4.588	6.882	11.470	16.057	22.939
8	0.158	0.788	1.577	2.365	3.153	4.730	7.883	11.036	15.766
9	0.108	0.542	1.084	1.625	2.167	3.251	5.418	7.585	10.836
10	0.074	0.372	0.745	1.117	1.489	2.234	3.724	5.213	7.447
11	0.051	0.256	0.512	0.768	1.024	1.536	2.559	3.583	5.118
12	0.035	0.176	0.352	0.528	0.704	1.055	1.759	2.462	3.518

TABLE III
The values of elbow loss function Fe (Fe • 100)

Tr	Friction factor								
	0.01	0.02	0.03	0.05	0.07	0.09	0.10	0.11	0.12
1.5	0.212	0.262	0.311	0.409	0.508	0.606	0.656	0.705	0.754
2.0	0.161	0.210	0.259	0.357	0.455	0.553	0.602	0.651	0.700
2.5	0.126	0.175	0.223	0.321	0.418	0.516	0.565	0.613	0.662
3.0	0.101	0.150	0.199	0.296	0.393	0.490	0.538	0.587	0.635
3.5	0.085	0.133	0.181	0.278	0.374	0.471	0.519	0.567	0.616
4.0	0.073	0.121	0.169	0.265	0.361	0.457	0.505	0.553	0.601
4.5	0.065	0.113	0.161	0.256	0.352	0.447	0.495	0.543	0.591
5.0	0.059	0.107	0.154	0.250	0.345	0.440	0.487	0.535	0.583
5.5	0.055	0.103	0.150	0.245	0.339	0.434	0.481	0.529	0.576
6.0	0.053	0.100	0.147	0.241	0.335	0.429	0.476	0.524	0.571
6.5	0.051	0.098	0.144	0.238	0.332	0.426	0.472	0.519	0.566
7.0	0.049	0.096	0.142	0.236	0.329	0.422	0.469	0.515	0.562
7.5	0.048	0.095	0.141	0.234	0.327	0.419	0.466	0.512	0.558
8.0	0.047	0.094	0.140	0.232	0.324	0.417	0.463	0.509	0.555
8.5	0.047	0.093	0.139	0.230	0.322	0.414	0.460	0.506	0.552
9.0	0.046	0.092	0.138	0.229	0.320	0.412	0.458	0.503	0.549
9.5	0.046	0.091	0.137	0.228	0.319	0.410	0.455	0.501	0.546
10.0	0.046	0.091	0.136	0.226	0.317	0.407	0.453	0.498	0.543
10.5	0.045	0.090	0.135	0.225	0.315	0.405	0.450	0.495	0.540
11.0	0.045	0.090	0.135	0.224	0.314	0.403	0.448	0.493	0.538
11.5	0.045	0.089	0.134	0.223	0.312	0.401	0.446	0.490	0.535
12.0	0.044	0.089	0.133	0.222	0.310	0.399	0.444	0.488	0.532
12.5	0.044	0.088	0.132	0.221	0.309	0.397	0.441	0.485	0.530
13.0	0.044	0.088	0.132	0.220	0.307	0.395	0.439	0.483	0.527
13.5	0.044	0.087	0.131	0.218	0.306	0.393	0.437	0.481	0.524

2. If these values are available, then the equations presented in the paper may be used to estimate the pressure drop through flexible hoses in conjunction with the assumptions relating to reasonable configurations of the duct(s) used.
3. If the relative roughness value of a flexible duct is unknown, and if facilities are not available for its determination, then the absolute values of 0.002-0.009 inches for metal or close pitched wire enforced heavy duty plastic ducts and values of 0.2- 0.7 inches for light weight wide pitched wire enforced ducts may be assumed in the calculations.

References

1. **Humphreys, C.M.**: Pressure Losses in Flexible Ducts. *Am. Ind. Hyg. Assoc. J. 32*:726 (1971).
2. **First, M.W. and F.J. Viles** : Flow Resistance of Flexible Metal Hose. *Am. Ind. Hyg. Assoc. J. 21*:296 (1960).
3. **Colebrook, C.F.**: Turbulent Flow in Pipes, with Particular Reference to the Transition Region Between the Smooth and Rough Pipe Laws. *J.N.A. Inst. Civil Engrs. 11*:133 (1938).
4. **Durr, D.E., N.A. Esmen, C. Stanley, and D.A. Weyel**: *Pressure Drop for Airflow Through Elbows.* Presented at the *American Industrial Hygiene Conference, Dallas (1986).*

Received 4/14/86; review/decision 9/15/86; revision 10/16/86; accepted 10/22/86

Answers to the "Action Level" questions

1\. d
1\. a
3\. 2.5%
4\. a and b
5\. 164, organic
6\. flame ionization, electron capture and thermoionic detectors
7\. a
8\. hardwood, sanding
9\. Briefly put, gerontogens are agents that accelerate aging.