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A graphic method for determining pressure losses due to air friction in mine airways

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A GRAPHIC METHOD FOR DETERMINING PRESSURE LOSSES DUE TO AIR FRICTION IN MINE AIRWAYS

BY

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A

THESIS

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INTRODUCTION

One of the most important factors that influence the selection of a fan or blower for circulating a desired quantity of air through mine workings is the total pressure that is required to overcome the resistance of the airways. Ordinarily, the major portion of this resistance is that caused by friction of the moving air on the surface of the airways. The pressure that is required to overcome this frictional resistance is calculated by means of the friction formula (1);

$$F = \frac{K\ S\ V^2}{5.2\ A}$$

(1) Weeks, W. S., Ventilation of Mines, N.Y., McGraw-Hill, 1926, pp. 46-49

in which:

F = pressure loss in inches water gage.

K = friction factor = coefficient of friction (c) times the weight of one cubic foot of air (w).

S = rubbing surface in square feet = perimeter (P) times length (L).

P = perimeter in feet = two times the width (b) plus two times the height (h).

L = length in feet.

V = velocity of the air in feet per minute = quantity (Q) divided by the cross-sectional area (A).

Q = rate of air flow in cubic feet per minute.

A = cross-sectional area of the airway in square feet = height

(h) times width (b).

5.2 = factor for converting the units of pressure from pounds per square foot to inches water gage.

In order to determine the pressure required to overcome the frictional resistance of an airway, for any desired rate of air flow, it is necessary to determine the dimensions of the airway; then to calculate the cross-sectional area,

$$A = h\ b\ ;$$

the rubbing surface,

$$S = (2h + 2b)\ L\ ;$$

and the velocity of the air in the airway,

$$V = \frac{Q}{A}$$

The value for "K" is taken from Table I as modified after McElroy and Richardson. [2] This factor is then corrected for the actual

(2) McElroy, G. E., Richardson, A. S., Friction Factors for Metal Mine Airways, U. S. Bureau of Mines, Report of Investigations 2663, 1925.

air density as all values in the table are given for air weighing .075 pounds per cubic foot. The correction is accomplished by multiplying the selected value of "K" by the actual air density divided by .075, that is,

$$K\ (\text{selected}) \times \frac{\text{actual air density}}{.075} = K\ (\text{corrected})$$

When the values of A, S, V, and K are properly determined, as defined above, they are substituted in the friction formula and the value

TABLE I - FRICTION FACTORS FOR MINE AIRWAYS

Type of Airway	Irregularities of Surfaces, Areas, and Alignment	Values of 10^{10} X K*											
		Straight			Sinuous or Curved								
					Slightly			Moderately			High Degree		
		Clean	Slightly Obstructed	Moderately Obstructed	Clean	Slightly Obstructed	Moderately Obstructed	Clean	Slightly Obstructed	Moderately Obstructed	Clean	Slightly Obstructed	Moderately Obstructed
Smooth Lined	Minimum	10	15	25	20	25	35	25	30	40	35	40	50
	Average	15	20	30	25	30	40	30	35	45	40	45	55
	Maximum	20	25	35	30	35	45	35	40	50	45	50	60
Sedimentary Rock	Minimum	30	35	45	40	45	55	45	50	60	55	60	70
	Average	55	60	70	65	70	80	70	75	85	80	85	95
	Maximum	70	75	85	80	85	95	85	90	100	95	100	110
Timbered	Minimum	80	85	95	90	95	105	95	100	110	105	110	120
	Average	95	100	110	105	110	120	110	115	125	120	125	135
	Maximum	105	110	120	115	120	130	120	125	135	130	135	145
Igneous Rock	Minimum	90	95	105	100	105	115	105	110	120	115	120	130
	Average	145	150	160	155	160	165	160	165	175	170	175	195
	Maximum	195	200	210	205	210	220	210	215	225	220	225	235

* 10 in the table represents K = 0.000 000 001; 100 in the table represents K = 0.000 000 01

NOTE: All values for K are for air weighing 0.075 pounds per cubic foot.

for F is then calculated.

It is obvious that the calculations involved are lengthy and that the procedure must be repeated for each individual airway of a ventilation system unless a method of ratios is used for other airways after the computation is made for the first. These ratios must conform to the laws of air transmission [3] and can become very

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(3) Weeks, W. S., Ventilation of Mines, N. Y., McGraw-Hill, 1926, 228 p.

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involved when all of the airway conditions differ. In either case, the determination of frictional resistance in mine airways requires calculation and this, in turn, consumes both time and effort. In the larger mines, where the ventilation system is composed of a vast number of individual airways, the amount of time and effort spent on calculation becomes very great. For this reason it was decided to investigate the possibility of eliminating these calculations through the use of a chart.

DISCUSSION

It was apparent that if a chart could be compiled to represent the friction formula the problem would be solved. With the great number of variables in the formula and the calculation required for A, S, V, and K, however, the final result appeared as complicated as the present method of computation. The first step, then, was to group as many of the variables as possible and to rewrite the formula in such a manner that all of its values would be in their simplest form in order to present a method of solution that would require the least amount of time and effort.

For the sake of simplification the formula was revised as follows:

from its present form,

$$F = \frac{K\ S\ V^2}{5.2\ A}$$

it was corrected for actual air density by multiplying as follows:

$$F = \frac{K\ S\ V^2}{5.2\ A} \times \frac{w}{.075},$$

Then, since

$$V = \frac{Q}{A}$$

and

$$V^2 = \frac{Q^2}{A^2}$$

the preliminary calculation for V was eliminated by substituting the quantity $\frac{Q^2}{A^2}$ for V and changing the formula to

$$F = \frac{K\ S}{5.2\ A} \times \frac{Q^2}{A^2} \times \frac{w}{.075}$$

Then to eliminate the calculation for S the value (PL) was submitted for S since

$$S = PL$$

At this stage the formula appears as follows:

$$F = \frac{KPL\ Q^2\ W}{.075 \times 5.2\ A^3}$$

or

$$F = \frac{P}{A^3} \times Q^2 \times \frac{LKw}{.075 \times 5.2}$$

Certain values were then assumed for L, K, and w and these, combined with the fraction $\frac{1}{.075 \times 5.2}$, were grouped into a constant leaving the friction formula in the final form,

$$F = \frac{P}{A^3} Q^2 C$$

Since the value of $\frac{P}{A^3}$ remains constant for any given airway cross-section its value was calculated for each of the common cross-sectional dimension combinations. Then by assuming a certain reasonable value for Q a corresponding value of F was calculated. This value of F was then platted, as the abscissa, against the assumed value of Q, as the ordinate, on a two-cycle logarithmic base. The result was a series of points falling in a straight line and representing P/A^3. Since this value represents the actual cross-sectional dimensions of the airway, the line was labeled to indicate these dimensions. By this method one line was platted for each dimension combination within the desired range of airway sizes.

In order for the chart to represent values of K, L, and w other than those previously assumed it was necessary to plat a series of parallel diagonal lines that were labeled to indicate actual values of these functions according to the practicable subdivisions of their respective ranges. Each of these lines represents a ratio of the value labeled on the line to the previously assumed value for that particular function. By mathematically rotating the

F scale about one of these lines the pressure is multiplied by the ratio represented by the line thus correcting the assumed value, for that particular function, to the value actually labeled on that line. In a more practicable sense, this multiplication is accomplished by carrying a point perpendicularly from one pressure scale, say the ordinate, to intersect with the proper diagonal line, and then projecting this point perpendicularly to a scale placed at 90 degrees to the first, in this case the abscissa. As three such multiplications are necessary, one for each of the three functions K, L, and w, it was apparent that two of the three corrections could be made by projection along like paths thus requiring only two sets of lines to be platted. That is, in order to correct for one function a point is projected from one scale, say the ordinate, to intersect with the proper diagonal line, and then to the abscissa; the correction for the second function follows in reverse order; and the third repeats the order followed by the first. The first and third multiplications are accomplished by a single set of lines. To further simplify this relationship, the previously assumed values of L and K were adjusted so that all of the ratios for one function coincided with those of the other. Because each of the two sets of lines causes a multiplication by projection in an opposite direction of the other, the scales for L and K are graduated in the opposite direction of the one for w. In order to avoid the possibility of mistaking one set of lines for the other, those lines representing w are broken.

DESCRIPTION OF THE CHART

The final form of the chart is shown in Figure I; the "F" and "Q" scales are both platted along the ordinate, of a two-cycle logarithmic base, with the scale on the left side indicating Q, "rate of air flow", and the scale on the right showing F, "pressure loss due to air friction". A set of lines sloping 27 degrees to the lower right represents the airway dimensions. The third and fourth sets of lines slope forty-five degrees to the lower right and represent the length of airway, air density, and friction factor.

MANIPULATION OF THE CHART

To manipulate the chart the following data must be assembled:

1. the rate at which the air will flow through the airway in cubic feet per minute;
2. the cross-sectional dimensions of the airway in feet;
3. the length of the airway in feet;
4. the friction factor for the airway raised to the tenth power and representing an air density of .075 pounds per cubic foot;
5. the density of the air in pounds per cubic foot.

Once the above information is compiled the chart is manipulated in the following steps:

1. The chart is entered from the left at the proper point on the "rate of air flow" scale and the line is followed horizontally to the right to intersect the diagonal line representing the proper cross-sectional dimensions.

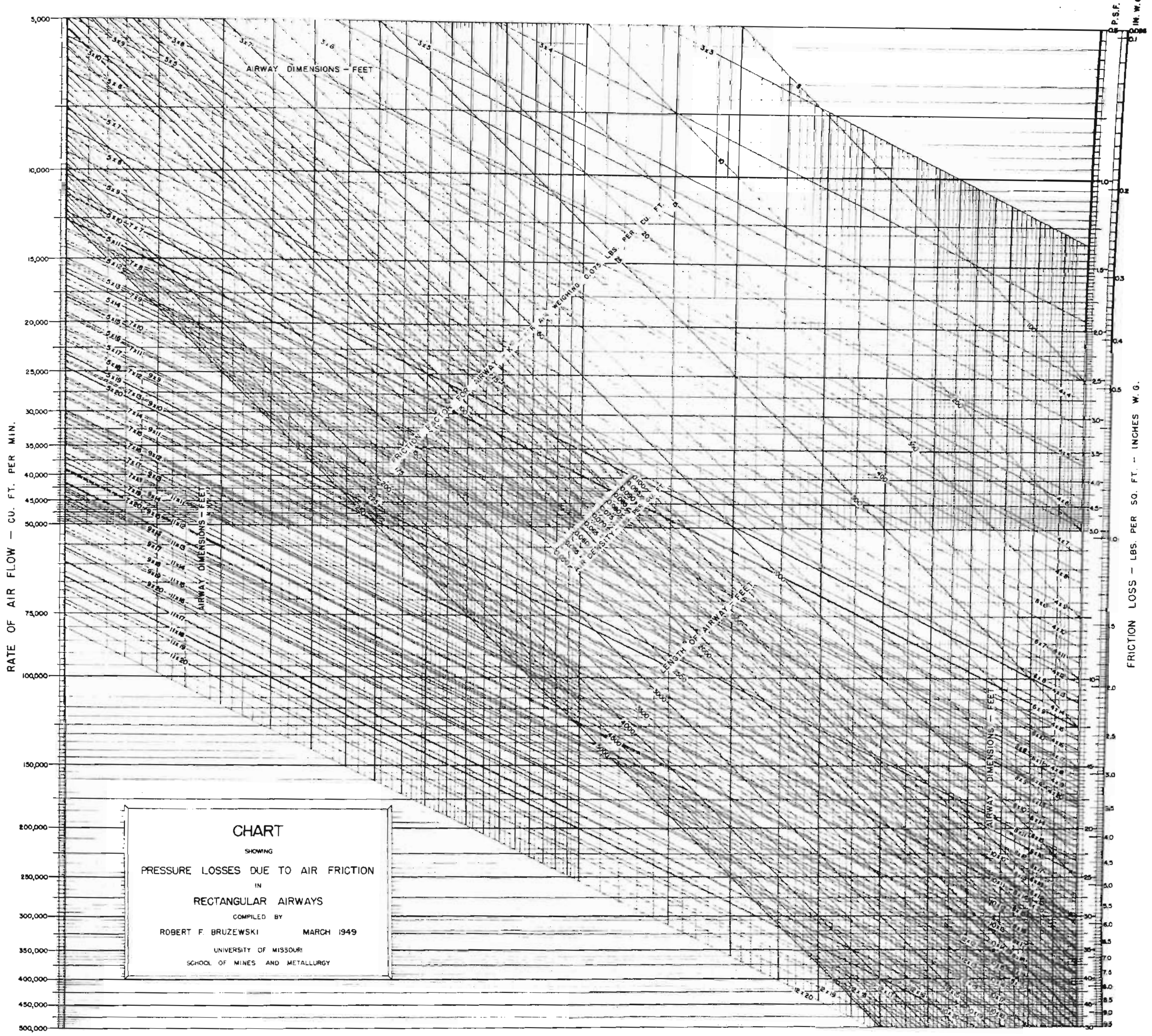

Figure 1, Chart Showing Pressure Losses Due To Air Friction In Rectangular Airways

2. From this point of intersection a vertical line is traced to intersect the line representing the proper airway length.
3. A horizontal line is followed from this intersection to a line indicating the proper air density.
4. From this intersection a line is traced vertically to the line for the chosen friction factor.
5. Then by reading horizontally to the right, from this intersection, the pressure is read from the scale on the right ordinate.

When the chart is manipulated with due care the results are reasonably accurate [4] and the time and effort spent are but a

(4) Weeks, op. cit. p. 4

fraction of that required to perform the calculations when the friction formula is used. These facts are readily demonstrated by the following example:

Assume a certain airway to be 5 feet by 7 feet in cross-section and 1500 feet long with a friction factor of .000 000 012 5. What is the pressure required to overcome the frictional resistance of the airway when passing 50,000 cubic feet of air per minute that weighs .065 pounds per cubic foot?

SOLUTION BY THE FRICTION FORMULA:

$S = (2h + 2b) L = [(2 \times 5) + (2 \times 7)] 1500 = 36{,}000$ square feet

$A = bh = 5 \times 7 = 35$ square feet

$V = \frac{Q}{A} = \frac{50,000}{35} = 1428.6$ feet per minute

$$F = \frac{.000\ 000\ 012\ 5 \times 36,000 \times \overline{1428.6}^{2}}{5.2 \times 36} = 5.046 \text{ inches water gage}$$

Correcting for air density,

$F = 5.046 \times \frac{.065}{.075} = 4.372$ inches water gage

SOLUTION BY USING THE CHART:

1. Enter chart on the left at 50,000 cubic feet per minute.
2. Follow this line horizontally to intersect the diagonal line representing the 5-foot by 7-foot airway.
3. Follow the vertical line from this intersection to meet the line indicating the 1,500-foot length of airway.
4. Move horizontally from this intersection to meet the diagonal line for an air density of .065 pounds per cubic foot.
5. Trace the vertical line from this point to its intersection with the line representing K^{10} equal to 125.
6. Follow horizontally to the right to the pressure scale and read a pressure loss of 4.37 inches water gage.

CONCLUSION

In conclusion it can be stated that a method has been developed whereby the lengthy calculation involved in determining the pressure losses due to air friction, in mine airways, can be eliminated. By using the chart presented in this manuscript, instead of the friction formula, the results are obtained with sufficient accuracy and with a great saving in both time and effort.

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VITA

The author was born in Auburn, Michigan on March 22, 1918. He received his elementary education at the neighboring city of Bay City and entered the Wisconsin Institute of Technology, Platteville, Wisconsin in September, 1938. Upon graduating from this school, in June, 1942, he entered the U. S. Army where he served until April, 1946. In June, 1946 the author registered at the University of Missouri, School of Mines and Metallurgy and was graduated with the degree of Bachelor of Science in Mining, in June, 1947.