THE CO-EFFICIENT OF FRICTION IN MINE AIR COURSES AND THE CALCULATION OF CENTRIFUGAL FANS.

BY F. W. SPERR.

It is often a question whether the theoretical conclusions of scientific investigators will hold good in practice. The scientific man often finds his theories fail when he attempts to appply them in practical work. The practical man cuts and trims his machine until it will do the work required. The one often fails to consider all the elements involved in his problem when he makes his calculation, and the other does not often calculate at all. Another question is whether the same rules can be applied for calculation upon the data obtained by the rough and ready methods of the practical engineer, as are found to apply in the case of data obtained by scientific investigators with costly and elaborate methods of observation.

It would be interesting and valuable to know whether we could determine the most economical fan for ventilating a given mine; and, I shall endeavor to show that, with a given number of fans, all of different sizes and details of construction, we may calculate which fan will give the highest mechanical efficiency when applied to ventilate a certain mine. I can give at least one instance in which the co-efficient of friction as determined by calculations based upon measurements of practical engineers, agrees very closely with the co-efficient found by M. Daniel Murgue. * The data were kindly furnished me by Mr. Austin King, Superintendent of Leisenring Mine No. 3 of the H. C. Frick Co., and consisted of a map of the mine showing the volumes of air going in the different splits, the demensions of

* Bulletin de la Sociêtê de l'Industrie Minêrale.—Troisiême Sêrie, Tome VII., 1re livraison, 1893. "Recherches Expêrimentales sur la Perte de Charge dans les Parcour D'Air Souterrains," par D. Murgue.

Also Trans. A. I. M. E. Vol. XXIII., pp. 63–112.

the air courses, and the pressure at the fan producing the ventilation.

From these data the co-efficient of friction was calculated the well known equation $K = \frac{h\ A}{S\ v^2}$ for the four principal splits, with the following results:

Split No. 1,	K = .05910
Split No. 2,	K = .05162
Split No. 3,	K = .05853
Split No. 4,	K = .05869
	.22794

which divided by 4 gives an average of K=057. The co-efficient obtained by M. Murgue when reduced to our system of measurement is .061. This is less than one-fourth of that obtained by Atkinson, .26881, and which has been very generally accepted in this country.

Having then a survey of the mine and the proper co-efficient of friction, we can make a tolerably accurate calculation of the pressure necessary to produce a certain amount of ventilation. Having the pressnre and volume, we can calculate the equivalent orifice of the mine and carry out M. Murgue's theory for the calculation of the best fan to ventilate that mine.

One of the conclusions reached by a recent investigation is that, "the influence of the mine on the efficiency of the fan does not seem to be very clear." * The paper giving the results of the investigation referred to, is begun with an introduction to Murgue's method of studying fans, without afterwards making any application of the "theory". **

The manometrical yield and orifice of passage of the fan are not determined. And if only the right kind of observations had been made for such determination, we might work out the equation which establishes the curve of efficiencies with different conditions of mine.

If the investigators, instead of making a series of observations on the same air-way with different fan speeds, *** as is generally

* Centrifugal Ventilators, by R. Van A. Norris, Trans. Am. Institute of Mining Engineers, Vol. XX., pp. 637–677.

** "Essai sur les Machines d'Aérage" par M. D. Murgue, Bulletin de la Société l'Industrie Minêrale, Tome IX. Also "D. Murgue's Theories and Practice of Centrifrugal Ventilating Machines," by A. L. Steavenson.

*** "Such work cannot be utilized for the determination of the orifice of passage and manometrical result." Murgue by Steavenson, p. 34.

done, would always make a series under different conditions of mine air-way, the influence of the mine upon the efficiency of the fan could be clearly shown. Mr. Mergue has indicated the means by which we may determine the frictionless orific s which are the equivalent of the mine air-way and the fan-passage, and the relations between these orifices and the work of the fan. There is, however, a slight error, or perhaps oversight, in his line of argument. When he shows that the theoretical depression generated by the fan is $\frac{u^2}{g}$ he also shows that half of this is due to the theoretically perfect chimney which is supposed to reduce the velocity of the air leaving the fan to zero. And when he writes that the motive power applied is $T_m = VH^o + T_p$, * he should write $T_m = \frac{1}{2} H_o V + T^p$, because the engine develops only $\frac{u^2}{2g} V + T_p$. It will be found in practice that the frictional resistence, T_p, becomes a negative quantity, if the equation is used as first given.

Then in M. Murgue's otherwise correct argument, we find the following equations.

$$(1).\quad V = 0.65\, a\, o\, u \frac{\sqrt{2\,K}}{\sqrt{o^2 + a^2}}$$

$$(2).\quad H_o = \frac{u^2}{g}$$

$$(3).\quad h = \frac{H}{1 + \frac{a^2}{o^2}}$$

$$(4).\quad H = K\frac{u^2}{g}, \text{ whence } h = \frac{o^2\ K\,H_o}{o^2 + a^2}$$

Taking T_m as the number of foot pounds per minute of work applied by the engine, 60 V as the number of cubic feet of air handled per minute, T_p as the number of foot-pounds per minute of work necessary to overcome the frictional resistances of the machinery, and assuming that T_p varies as u^2, we may write $T_m = 30 X .074\, H_o V + cu^2$, and substituting the values of H_o and V from (1) and (2), and representing horse-power by H-P,

* Essai sur les Machines D'Aêrage par M. D. Murgue, Troisième Partie, p. 71. Also Murgue by Steavenson, p. 59.

$$\text{H-P} = .00000192\, a\, ou^3 \frac{\sqrt{K}}{\sqrt{o^2 + a^2}} + .0000303\, cu_2 . \quad (I).$$

Substituting h for H_o in the first term of the rignt hand member of this equation gives the effective horse-power for ventilation equal to

$$\frac{.00000384\, a\, o^3\, u^3\, K^{\frac{3}{2}}}{(o^2 + a^2)^2}$$

We can now apply some constant horse-power to the fan, and calculate the mechanical efficiency for different assumed values of a, the equivalent orifice of mine. Let 100 horse-power be applied and let E represent the mechanical efficiency:

$$E = .0000000384 \frac{a\, o^3\, u^3\, K^{\frac{3}{2}}}{(o^2 + a^2)^{\frac{3}{2}}} \quad (II).$$

Equation (I) reduces to

$$u^3 + 15.78 \frac{cu^2}{ao} . \frac{\sqrt{o^2 + a^2}}{\sqrt{K}} = 52080000 \frac{\sqrt{o^2 + a^2}}{ao \sqrt{K}} \quad (III).$$

From the data given for the East Howle Colliery Capell fan, * laying off to any convenient scale the depressions as ordinates and the *squares* of the volumes in cubic feet per second as abscissae, we find the manometrical yield, orifice of passage and the constant c as follows:

1. TO FIND THE MANOMETRICAL YIELD.

The initial depression is where the line joining the points of effective depressions cuts the axis of Y (at H, plate I.). Divide the initial depression expressed in feet of air, by the square of the periphery speed in feet per second, and multiply by $32.2 = K = .530$.

2. TO FIND THE ORIFICE OF PASSAGE.

Take any volume squared and its corresponding effective depression. Tne depression necessary to carry the air through the fan is tne difference between the initial depression and effective depression. The equation for the air passing through the fan is $V = .65\, o\sqrt{2gh_o}$, where V is the volume in cubic feet per

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* Colliery Engineer, October, 1890, p. 63.
Trans. A. I. M. E., Vol. XX., p. 642.

second, o the orifice of passage, and h_0 the difference between the initial and effective depressions expressed in feet of air.. Whence o = 83.5 square feet.

3. TO FIND THE CONSTANT c.

Find the horse power in tne air with half the theoretical depression $\frac{u^2}{2g}$. Subtract this from the indicated horse power and and divide the remainder by u^2.

$$c = \frac{29.26 \times 33000}{\left(\frac{7540}{60}\right)^2} = 61.14$$

Substituting these values of c, o and k, in equations II. and III. we get

log 1.200608 log 5.932847

$$u^3 + 15.87\, u^2 \frac{\sqrt{o^2 + a^2}}{a} = 856700 \frac{\sqrt{o^2 + a^2}}{a}$$

log—3.935803

$$E = .008626 \frac{a\, u^3}{(o^2 + a^2)^{\frac{3}{2}}}$$

Assigning different values to a and solving these two equations for u and E, we find:

When	$a = 0$,	E = 0	
"	$a = 1$,	u = 215.3	E = .148
"	$a = 2$,	u = 203.2	" = .248
"	$a = 3$,	u = 193.6	" = .323
"	$a = 4$,	u = 186.0	" = .380
"	$a = 5$,	u = 179.5	" = .426
"	$a = 10$,	u = 157.3	" = .565
"	$a = 20$,	u = 134.7	" = .666
"	$a = 30$,	u = 122.3	" = .678
"	$a = 40$,	u = 114.5	" = .653
"	$a = 50$,	u = 109.2	" = .609
"	$a = 60$,	u = 105.3	" = .556
"	$a = 80$,	u = 100.3	" = .450
"	$a = 100$,	u = 97.3	" = .359
"	$a = \infty$,	E = 0.	

We may now construct the efficiency curve for this Capell fan, by laying off the values of a as abscissae and the values of E as ordinates. And by plotting the calculations for a number of fans upon the same sheet an interesting comparison at once results as to which is the best fan for any particular mine with a certain determined equivalent orifice. Thus knowing the fan, we are also enabled to calculate the exact horse-power necessary to produce the required ventilation on a given mine.

In the absence of data published with sufficient fullness, we may assume a fan having an orifice of passage of 12 sq. ft., a manometrical yield of .700, and c equal 29.5. Equations II. and III. will become:

log—1.666199 log—6.714969

$$u^3 + 46.36\, u^2 \frac{\sqrt{o^2 + a^2}}{a} = 5{,}187{,}631 \frac{\sqrt{o^2 + a^2}}{a}$$

log—5.589521

$$E = \frac{.0000389\, a\, u^3}{(o^2 + a^2)^{\frac{3}{2}}}$$

When $a = 0$, $E = 0$
" $a = 1$, $u = 273.0$, $E = .462$
" $a = 2$, $u = 244.5$, $E = .657$
" $a = 4$, $u = 213.5$, $E = .747$
" $a = 6$, $u = 194.3$, $E = .708$
" $a = 10$, $u = 179.4$, $E = .589$
" $a = 20$, $u = 165.6$, $E = .278$
" $a = 30$, $u = 162.3$, $E = .147$
" $a = 40$, $u = 160.8$, $E = .089$
" $a = 50$, $u = 160.2$, $E = .059$
" $a = 100$, $u = 159.2$, $E = .015$
" $a = \infty$, $E = 0$.

These results give the efficiency of the 10 ft. fan on the curve sheet, on mines of various equivalent orifices.

It will be observed that the curve for the Capell fan agrees quite closely with the mechanical efficiencies calculated from the observed data and marked $_{o}$ on the curve sheet. And comparing the efficiency curve for this fan with that for the smaller assumed fan, we see that the latter gives a higher efficiency for small air passages, but is a poor machine for large and short airways.

It is unfortunate that Mr. Norris did not secure sufficient data for the application of M. Murgue's theory to the calculation of the large number of fans which he describes in his paper on Centrifugal Ventilators. * In the discussion of this paper, Mr. Storrs has the idea all right in advance of Mr. Norris, that to

* See Trans. A. I. M. E., Voll. XX., p. 637 et seq.

compare fans by M. Murgue's theory, it is necessary to make observations under different conditions of Mine; but he also fails to carry out this theory which leads to the determination of the manometrical yield of the fan and its orifice of passage.

Mr. Henry Palmer finds a manometrical efficiency for each individual observation on his Capell Fan**; and he also evidently fails to comprehend M. Murgue's theory. But the data published for this fan are perhaps the most satisfactory of any that we have.

In the first part of this paper it was shown that the equivalent orifice of a mine may be calculated from the survey notes; and, in the latter part, that by calculation we may determine what is the best fan for a given mine orifice.

It is intended to make a series of experiments on the fans used for ventilation at the Ohio State University, to verify, if possible, the above conclusions. Sheets are prepared with columns headed as shown on inserted sheet. The blank columns are left for observations on engine or electric motor, and the headings for these will be filled in as the different cases require.

According to M. Murgue's method of investigation the "manometrical yield" is a constant quantity for any particular fan for all varying conditions of mine and fan speed. It is the per centage which the "initial" is of the "theoretical" depression. The initial depression, or that actually developed by the fan, has been shown by numerous experiments to vary as the square of the speed (u^2); and the theoretical depression being taken as $\frac{u}{g}$ the relation between the two is necessarily a constant quantity.

** See "The Colliery Engineer", Vol. XI., p. 63.

THE CHAIR: Tomorrow we make an excursion to Congo to see one of the newest and best mines in the state. It gives me pleasure to introduce to you Mr. Ray who will describe these mines in his paper on "The Development of the Congo Mines". He has had so much to do with the equipment of these mines that he speaks with the force of one having authority.

Centrifugal Fan Statistics.

Mining Department Ohio State University.

Name of Fan and Date of Observation.	No. of Experiment	Diameter of Fan	Width of Vanes	Width of Casing	Number of Inlets	Diameter of Inlets	Dimensions of Chimney	Shutter	Revolutions of Engine per minute	Revolutions of Fan per per minute	Periphery Speed in feet per minute	Pressure Gauge	Cubic feet of air per minute	Equivalent Orifice											Temperature	Barometer	Indicated Horse-Power of Engine	Effective H.-P. for Ventilation	Actual H.-P. on air by Engine	Passive Resistance			Mechanical Efficiency		Periphery Speed reduced to 100 feet per second				
																														Fan and Engine	Engine	Fan	Engine and Fan	Fan	Pressure Gauge	Volume Squared	Initial Pressure	Orifice of Passage	Manometric Yield