D. MURGUE'S
THEORIES & PRACTICE
OF
CENTRIFUGAL VENTILATING
MACHINES

BY

A. L. STEAVENSON

Mining Machinery

THE

THEORIES AND PRACTICE

OF

CENTRIFUGAL VENTILATING MACHINES.

BY

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TRANSLATED, AND SUPPLIED WITH AN INTRODUCTION,

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INTRODUCTION.

Little if anything was done towards the application of machinery to the purposes of ventilation until very recent years, although, so early as the year 1657, Agricola, in his interesting work "De re Metallica," gives particulars and a drawing of a mechanical ventilator for mines, driven by water-power, and at the Hartz mines, nearly 200 years ago, another, somewhat similar to the Struve, was in operation.

In the year 1849, Mr. Warrington Smyth referred to this in his evidence before the House of Lords' Committee, and at the same time Mr. Struve said his ventilator at the Eaglesbush Colliery, then the only place where it was yet applied, began its work in February 1849.

Mr. Brunton also then explained and gave drawings of his centrifugal ventilator.

But so late as the year 1852 a Committee of the House of Commons reported :—

"Your Committee are of opinion—

"That any system of ventilation depending on complicate machinery is undesirable, since under any disarrangement or fracture of its parts the ventilation is stopped or becomes inefficient.

"That the two systems which alone can be considered as rival powers are the *furnace* and *steam jet.*

"Your Committee are unanimously of opinion that the steam jet is the most powerful and at the same time least expensive method for the ventilation of mines."

In 1861 the centrifugal fan at Elsecar was described to the North of England Institute of Mining Engineers by the late Mr. J. J. Atkinson, and to him must be given the credit of having, in several valuable papers on the subject, first shown clearly the superiority of mechanical ventilators over every other system.

From that time until now the question as to which fan is the best has been a source of constant contention; every fresh invention being introduced as at least 10 per cent. better than anything which preceded it.

Numberless experiments have been made by private individuals and committees to ascertain the truth of these questions. Nearly all the results obtained have varied, and the question to-day still remains unanswered—"Which ventilator is the best; and which, taking all circumstances into account, should I, as a mining engineer, adopt?"

The cause of this unsolved state of the problem is not far to seek.

The useful effect of a fan is not the only question involved. We must consider—

1. First cost;
2. Durability;
3. Efficiency.

The enormous first cost and want of durability of some of our largest ventilators, has overshadowed in a great degree the question of efficiency, especially where, as at many collieries, steam is obtained from the heat of coke-ovens. Some of the results published as to efficiency, are the work of experimenters quite unused to the rigorous accuracy demanded in scientific research, still it is very important, and to appreciate reliable data, such for instance as the recent report of the North of England Institute, there is wanted a general knowledge of the laws governing the variation in results under varying conditions of work. To supply this hitherto unsupplied need of the engineer in England, I have been led to translate and publish the very excellent treatise of M. Murgue. Many attempts have been made to follow these laws of ventilators, but nothing approaching the lucidity of his methods has been attained; a little attention and study on the part of those who care thoroughly to understand the various questions involved, will give a perfect mastery over them, and then when seeking to know which is the best ventilator, they will at least be able to make the selection with their eyes open.

The leading ideas given by M. Murgue are—

First, That every mine may be assimilated to an orifice in a thin plate, which he calls its "*Equivalent Orifice.*"

Second, That a ventilator, even whilst exhausting the air from the mine, forms at the same time an obstacle to the passage of this air, causing a sensible loss of duty, so that the depression produced by the ventilator is always higher than what we observe in the galleries of approach, some part of this depression being employed in overcoming the various resistances in the fan; this he treats as the "*Orifice of Passage.*"

Third, The theoretical depression or water gauge, due to the speed of the periphery, is in a perfect fan equal to twice the height of column necessary to generate such velocity in a falling body.

This meets a difficulty experienced by a writer on the subject,* who says "It is especially worthy of notice that the water gauge indicated at the inlet is greater than the theoretical result," the hitherto recognised theory having been $\frac{u^2}{2g}$, where u = speed in feet per second, and $g = 32 \cdot 2$.

Fourth, That there is an initial depression which each fan

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* See 'Proceedings of Northern Mining Institute,' vol. xiv., p. 80.

gives when acting on a closed space, and which approaches the theoretical limit in proportion to the perfection of the ventilator.

Fifth, That this depression gradually varies and lowers according to conditions.

A little further explanation of these theories seems desirable for the benefit of those whose time has been more given to the distribution of air in mines, than to its economic production.

The equivalent orifice depends upon well known laws of the flow of fluids:—

1st. That the speed of flow is the velocity due to the height of fall or height of column of the flowing air, which is represented by the formula for gravity—

$$h = \frac{v^2}{64 \cdot 4}, \text{ or } v = 8\sqrt{h}.$$

2nd. That the quantity which passes through an orifice in a thin plate is two-thirds or 0·65 that of the quantity due to the area of the full orifice, and the formula then becomes, for what is known as the "vena contracta,"—

$$Q = 8\, m\, a \sqrt{h},$$

where Q = quantity, $m = 0 \cdot 65$, a = area, and h the height which must be reduced to air column, or as M. Murgue puts it—

$$Q = 0 \cdot 62\, a \sqrt{2\, g\, h};$$

reducing this we get

$$a \text{ (or equivalent orifice)} = \frac{V}{0 \cdot 62 \sqrt{2\, g\, h \frac{\delta_o}{\delta}}},$$

where $\delta_o = 1000$, and $\delta = 1\cdot2000$, or the relative densities of water and air. Simplifying this for water gauge as usually taken in inches—

$$a = \frac{V}{1\cdot43\sqrt{h\frac{\delta_o}{\delta}}}, \text{ or } \frac{\cdot70\,V}{\sqrt{h\frac{\delta_o}{\delta}}};$$

and if we assume these as normal densities we may remove the fraction and obtain

$$a = \frac{V}{41\cdot26\sqrt{h}} \text{ or } \frac{0\cdot0243\,V}{\sqrt{h}}.$$

In this case V = volume in cubic feet per second; but as we generally speak of cubic feet per minute we may say

$$a = \frac{0\cdot403\,V}{\sqrt{h}},$$

taking $V = 1000$ cubic feet per minute, and h = inches of water gauge.

The great value of this fiction is that it enables us to grasp at once the conditions under which a fan is working.

We hear of one machine giving 100,000 cubic feet per minute under a water gauge of 3 inches, and of another where 75,000 cubic feet is got with a water gauge of 4 inches; but this is not a tangible statement. If, however, we are told that the equivalent orifice of the first mine is equal to 22 feet, whilst that of the second is only 14, the difference is clearly demonstrated.

Then as to the *Orifice of Passage*, as M. Murgue says, the fan suited to blow a cupola may give a depression as great as the largest Guibal, but it would be useless to ventilate a mine—its orifice of passage is insufficient.

To obtain this in any case we must refer to his theory of initial and effective depressions (p. 4)—

$$h = H - h_o,$$

where h_o represents the deficiency or difference between the initial and effective water gauge; and we see a little further on that $\frac{h_o}{h} = \frac{a^2}{o^2}$, or as the orifice of passage diminishes the loss of effective depression increases.

To calculate the area of this orifice of passage we must refer to its value in the equation—

$$H - h = h_o = M V^2,$$

or,
$$h_o = \frac{V^2}{0 \cdot 62^2 \, o^2 . 2 g}.$$

That is to say, after finding for any ventilation the value of the initial and effective depression, the loss or useless depression is equal to a function of the volume which depends upon the orifice of passage, and from the above equation

$$o = \sqrt{\frac{V^2}{0 \cdot 62^2 \, h_o \, 2 g}},$$

reducing of course h_o to the density of air in feet. We are now enabled to understand what is termed "the characteristic curve of the ventilator."

In order to compare two machines they are regulated to the same speed of periphery, or their results may be easily reduced to equal speeds since the volume varies as the revolutions and the depressions as the squares of the speeds.

The mine is altered, to say five different conditions: first by obstructing the passages; then in the normal state; and afterwards by opening some of the doors.

With the equivalent orifices of these five different mines, or conditions of mine, plotted as abscissæ, and the volumes as ordinates, we get a curve which shows clearly the effectiveness of each fan, and is called its "*characteristic curve.*"

We are next shown how the effective depression varies and diminishes by a function of the volume depending upon the orifice of passage.

The experiments upon the four different ventilators tested by the Commission of Gard are tabulated, and from them an equation for each is obtained, giving the initial depression and its coefficient of diminution as the volume increases. Taking, say Nos. 1 and 2 experiments on the Créal fan, with the square of the volume and depression observed, we get—

$$x - y\,(89{,}283) = 1{\cdot}0598,$$
$$x - y\,(195{,}766) = 1{\cdot}0183,$$

and from these constants are found.

The average of the various experiments should be taken.

Little more need be added, but a short reference to the remarks on the effect of the natural ventilation of the mine upon such investigations, given in the report of the Commission of Gard, of which M. Murgue was a leading member, will be useful.*

The effect of natural ventilation is much less than is commonly supposed, since it is not the yields which are to be added, but the depressions, and the volume to be obtained therefore, is like the hypothenuse of the rectangular triangle, thus say in cubic metres $x = \sqrt{20^2 + 5^2} = 20{\cdot}615$, and as all conditions additive or subtractive are covered by the equivalent orifice, it may be entirely neglected.

If then, as is clearly demonstrated, the covered Guibal with *évasée* chimney most nearly meets theoretical requirements, how can its acknowledged defects in point of size, structural weakness, and heavy cost, be best met, so as to produce a machine perfect in every respect? The answer is to be found in a ventilator I have recently designed, and which will be at work at Pagebank Colliery by the time this issues from

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* See 'Bulletin de la Société de l'Industrie Minérale,' 1878, p. 495.

the press. It is 20 feet diameter, built with, and from, a central wrought-iron diaphragm, like the Rammel and Schiele fans. It has the vanes in shape according to M. Murgue's demonstrations, made of iron and riveted to the diaphragm with angle irons, the sheet-iron cover, *évasée* chimney, and sliding shutter of Guibal type, with air admitted on both sides. The fan is driven by ropes, and will run about 110 revolutions, and much more if needed.

A. L. STEAVENSON.

DURHAM, *3rd February*, 1883.

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In publishing towards the end of 1872 the first part of this study, I entertained the hope that I should be able shortly to announce a new theory, firmly based on experience with large ventilating machines by centrifugal force—a theory which up to that time appeared to me to be still somewhat cloudy. Seven years have since elapsed, and to-day only am I able to keep the promise I then made. This long interval will surprise few people who know how difficult it is to conduct experimental researches and make them subservient to the exigencies of active life. It has not been altogether sterile, for beyond the unconscious labour of thought which I have given, by the sole aid of time the matter has become much clearer, and it has been permitted to me to add my study on the works incidental to the Commission on Ventilation of the district of Gard—the results of which have been published in the later volume of 1878—being myself a member of that Commission, with M. Aguillon, then Government Engineer for Alais. The theoretical study which I propose to develop here comprehends not only that on ventilators with centrifugal force, but also many machines now almost abandoned which draw in the air by oblique surfaces, such, for example, as the ventilator or screw by

M. Motte, and the helix, by M. Pasquet, and that with vanes like a windmill by M. Lesoinne. M. Devillez distinguishes them as ventilators by direct impulsion. But to separate these from the centrifugal machine does not seem to me to be justified, these machines being in fact exactly the same as those with centrifugal force, producing in the atmosphere of the mine a certain depression, which is ruled by the square of the speed. If the seam is thin, the circulation obtained is small; if it is thick the result is considerable, but the depression remains in every case theoretically the same. It is not, however, the same with the pneumatic machines of Fabry and Lemielle studied in the first part of this work, their mode of action being absolutely the reverse. These machines draw the air from the interior, cutting it off and throwing it out, so to speak, in equal quantities. It is not then the depression which remains constant, but the volume drawn. This difference of action between the two classes of machines presents itself with sufficient clearness. We shall show shortly how to replace the word "volume" by the word "depression," and conversely, so as to pass from the one to the other without any change in the theory. Also, having in my preceding memoirs on pneumatic machines, with the approbation of my friends, used the generic denomination of Volumogen ventilators, I am now naturally led to call the machines which I discuss to-day Deprimogen ventilators, and I will shortly enumerate their principal characteristics and advantages. First, their mechanism is extremely simple; all is reduced to the rotative system, turning on two bearings if the axis is horizontal, and on a foot-step and collar if it is vertical. Second, they leave free communication between the interior and the exterior air. Third, they can only give in thin seams a feeble result, but for thick seams otherwise. All their characteristics are in complete opposition to those of the well-known volumogen ventilators. I shall apply at every step in the course of the discussion which I am undertaking the method of the equivalent orifice through a thin plate—a method which I have developed in my two previous studies. I shall employ as notations the letter *a* to designate the equivalent orifice, V will be the volume of air yielded per second, *h* will express the depression, for convenience of calculation, in the column of the fluid in movement, that is to say, in the column of air. I am supposing that air is an incompressible fluid, which is perfectly legitimate under the conditions, and on all occasions I shall simplify as far as possible every remark, knowing well that for a theory to be useful, the supreme quality after exactness is simplicity.

1. ESTABLISHMENT OF TWO GENERAL FORMULÆ FOR DEPRIMOGEN VENTILATORS.

Let us consider the deprimogen ventilator placed on a mine and turning at a rigorously uniform speed. Profiting by the fiction of the equivalent orifice, let us replace the mine ventilator by an orifice in a thin plate, which we can reduce or increase at will. If we suppose at first the equivalent orifice equal to zero, that is to say, that the mine is completely shut off, the ventilator will produce in a confined space adjoining the *ouïe* or inlet a certain depression, which I will call H. If now I open out and increase by degrees the equivalent orifice, what will become of this depression? Theoretically it should remain invariable, the exhausting power of the vanes acting equally well upon the air whether in motion or in repose. But in effect it will be weakened in proportion as the ventilator is traversed by larger volumes, and finally it will disappear when the equivalent orifice is increased to infinity. If I call this gradual reduction of initial depression h_o, the effective depression may then be expressed by the equation

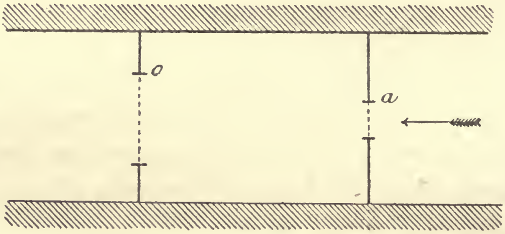
$$h = H - h_o. \qquad (1)$$

h_o may increase from zero to H.

What are the causes of this fall in depression h_o? Evidently the frictions and losses of active force which the air experiences in passing through the ventilator—frictions and losses which increase in proportion to the volume of air yielded, and absorb an increasing fraction of the initial depression.

Those who have occupied themselves in studying this theory have generally sought to determine by calculation these frictions and losses of active force, which always leads them to complicated expressions. It has appeared to me much more simple to introduce here the method of the equivalent orifice, which evidently lends itself sufficiently well to represent the difficulty of the passage of the air through a ventilator as well as through a mine. I have already spoken in the second part of this work of this new application of the method, and I call it *the orifice of passage.*

FIG. 1.



We may, then, replace in imagination the mine and its ventilator by two orifices, *a* and *o*, placed one behind the other (Fig. 1), and successively traversed by the current of air; the first in virtue of the depression h, the second in virtue of the depression h_o—volume, depressions, and orifices being connected by the formula for flow through a thin medium :—

$$V = 0 \cdot 65\, a \sqrt{2\, g\, h}. \tag{2}$$

$$V = 0 \cdot 65\, o \sqrt{2\, g\, h_o}. \tag{3}$$

From these two relations I obtain the interesting proportion

$$\frac{h_o}{h} = \frac{a^2}{o^2}.$$

If now we substitute for h_o, in the equation (1), the value which results from this proportion, it will become

$$h = \mathrm{H} - h \frac{a^2}{o^2},$$

and, resolving it by the proportion to h,

$$h = \frac{\mathrm{H}}{1 + \frac{a^2}{o^2}}. \tag{4}$$

Such is the formula for the effective depression h. To obtain that of the effective volume V, it suffices to introduce the preceding value of h in equation (2).

It becomes then, all reductions made,

$$V = \frac{0 \cdot 65\, a \sqrt{2\, g\, \mathrm{H}}}{\sqrt{1 + \frac{a^2}{o^2}}}. \tag{5}$$

From this we learn at once to determine the initial depression H as a function of the diameter and of the speed. The equivalent orifice of the mine a is supposed to be known; that of the passage o depends upon the dimensions and arrangements of the ventilator, and we see that it may be determined *à priori.* The depression and the volume of air yielded are found then to be expressed by our two formulæ (4) and (5), with the aid of known quantities, which was the object to be gained.

This forms but the first part of our theory, and there remains for us to see how to determine the initial depression H. This determination will be the object of the next paragraph; but before undertaking it, I have pleasure in showing the wonderful parallelism which exists between the preceding theory and that which I have proposed in the two former parts of this study for the volumogen ventilator. I have said already that to pass from the one to the other it is sufficient to change the word "volume" to that of "depression," and conversely. This will be clearly seen from the following.

Volumogen.	*Deprimogen.*
In theory the volumogen ventilator should give a constant volume of air, equal to that which it affords when working freely on the atmosphere. In reality the volume obtained is always less than the theoretic volume, because of the unavoidable play of the joints of the machine, which gives place to a re-entry direct from the exterior air.	In theory the deprimogen ventilator should afford a constant depression equal to that which it reaches when acting upon a closed space. In reality the depression obtained is always less than this initial depression. A great part of this latter will be found to be absorbed by the frictions and losses of active power in the air traversing the machine.
If W represents the theoretical volume, V_o the re-entry of air, and V the effective volume, I may write the equation—	If H represents the initial depression, h_o the part absorbed by the frictions, h the effective depression, I may write the equation—
$V = W - V_o;$	$h = H - h_o;$
a being the equivalent orifice of the mine, we will call *o* the equivalent of the pas-	*a* being the equivalent orifice of the mine, we will call *o* the equivalent of the passage,

sage, more or less complicated by the re-entry of the air. The depression produced by the ventilator being the same over the two orifices, the corresponding volumes will be evidently in the same proportion as the orifices themselves—

$$\frac{V_o}{V} = \frac{o}{a}.$$

If, then, I substitute for V_o in the first equation the value resulting from the preceding proportion, I obtain the equation—

$$V = W - V\frac{o}{a};$$

which, reduced in the proportion to V, will give the first formula required—

$$V = \frac{W}{1 + \frac{o}{a}}.$$

If, now, in the value of the given depression by the well-known formula for the flow of air through a thin medium,

$$\sqrt{h} = \frac{V}{0{\cdot}65\, a \sqrt{2\, g}},$$

If I replace V by the preceding value, I obtain the second formula—

$$\sqrt{h} = \frac{W}{0{\cdot}65\,(a + o)\sqrt{2\, g}}.$$

more or less complicated, formed in the ventilator itself. The two orifices *a* and *o* being traversed by the same volume of air, we easily perceive that the corresponding depressions are in the inverse proportion of their squares—

$$\frac{h_o}{h} = \frac{a^2}{o^2}.$$

If, then, I substitute for h_o in the first equation the value resulting from the preceding proportion, I obtain the equation—

$$h = H - h\frac{a^2}{o^2};$$

which, reduced in the proportion to *h*, will give the first formula required—

$$h = \frac{H}{1 + \frac{a^2}{o^2}}.$$

If, now, in the value of the given volume by the well-known formula for the flow of air through a thin medium,

$$V = 0{\cdot}65\, a \sqrt{2\, g\, h},$$

If I replace *h* by the preceding value, I obtain the second formula—

$$V = \frac{0{\cdot}65\, a \sqrt{2\, g\, H}}{\sqrt{1 + \frac{a^2}{o^2}}}.$$

We see the parallelism is perfect, and also that their characteristics are absolutely opposite. Thanks to this remarkable reciprocity, the two theories render each other more clear; and I may say that more than once the volumogen ventilator has assisted me to understand the deprimogen. In reality, it is not between the volume and the depression that the reciprocity is established, but between the volume and the square root of the depression. But that changes nothing in the curious result which I am about to show.

Of the two formulæ which we are about to establish, as well for the volumogen ventilator as for the deprimogen, the most important is evidently that which gives the volume of air yielded per second. This volume is most especially interesting. The curve expressed by this formula, the equivalent orifice being drawn as abscissæ and the volume of air as ordinates, characterises most distinctly the ventilator to which it is applied, and furnishes a very simple and sure means to compare different machines. It is this curve which the Commission of Gard has set itself to determine for the six ventilators submitted to their tests. They have given it the name of the *characteristic curve* of the ventilators.

2. DETERMINATION OF THE INITIAL DEPRESSION FOR VENTILATORS WITH CENTRIFUGAL FORCE.

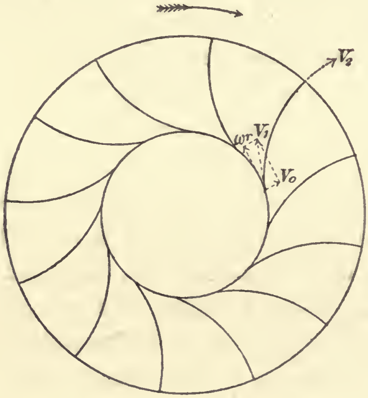
I preserve the name of *Initial Depression* for that value of the depression which is shown when the mine is shut off and rests virtually constant when we do away with the friction of the air. We know that in the volumogen ventilator the mechanical combinations which give place to the volume engendered, differ absolutely in one machine from those in another, and require each time, for the determination of the volume, special methods of calculation. It is the same for deprimogen ventilators; each type of machine produces the depression by particular methods, each requiring their special calculation. But I will not occupy myself here except with the centrifugal ventilator, the most perfect and therefore the most interesting of all. I will study first the uncovered ventilators with centrifugal force, such as were made by the first inventors (Combes, Letoret, Lambert, &c.), to whom the cover appeared, no doubt, the greatest obstacle to the free escape of the air into the atmosphere. This manner of looking at it, very plausible at first sight, is in reality quite erroneous. We know that to M. Guibal belongs the honour of having first shown that the cover is indispensable for making the ventilators develop their full useful effect. To-day almost every ventilator at work on the collieries possesses this ingenious addition. In order to proceed with regularity we must begin with those which have not got them.

To avoid any difficulty in the establishment of my calculations, I will suppose that the air of the mine before reaching the *ouïe* is expanded in a large chamber where its speed may be considered almost nothing. In reality, this vestibule will be more useless than useful, but for our theory it has the advantage of placing the ventilator between two motionless atmospheres, the air being drawn from one and thrown into the other. The situation is clear, and the analysis equally so.

I propose, then, in the course of this discussion, to consider only an ideal ventilator, presenting no play, nor shocks, nor losses of quantity of any kind. In practice, of course, it is very far from attaining this ideal, the necessity of a simple construction, so as to work with certainty, obliging us to preserve numerous imperfections in detail; but to introduce these imperfections in the calculation would be to expose ourselves to inextricable complications. It is much better to go straight to the theoretical result.

The ventilator with centrifugal force without cover is represented in its essential features by Fig. 2, the vanes as drawn showing the profile somewhat bent and approaching the *ouïe* in a manner to afford the desired inclination, so that the air penetrates without shock between these spaces.

FIG. 2.



These vanes are sufficiently numerous to assure the regular drawing of the air from the centre to the periphery without eddies or disturbances. I will call r the radius of the *ouïe* or inlet, R that of the external circumference, ω the angular speed of rotation. The result, ω R, expresses the absolute speed of the extremities of the vanes. This speed plays a preponderating *rôle* in all this discussion. I will call it the *tangential speed,* and I will mark it by the letter u.

The depression produced by such a machine will result from a series of actions, some additive and some subtractive. We may, then, determine them successively and in their order, so as to draw the balance.

First, the motionless air in the vestibule is brought to the speed V_o, with which it traverses the *ouïe* and penetrates between the spaces of the wings. There is then to the debit of the depression the height generative of this speed

$$-\frac{V_o^2}{2g}.$$

Second, the air once drawn between these vanes has a double movement, the movement relative to the dragging after the surface of the vanes, and the movement of drawing produced by the rotation of the machine, but theory requires that the total depression should be the sum of the elementary depressions due to each of these movements. Let us look first at the relative movement.

The interval between two consecutive vanes forms an *évasée* canal which the air enters with a certain speed V_1, and leaves with a less speed V_2. From this slowing action results, according to Bernouilli's theory, a gain of depression expressed by the difference—

$$\frac{V_1^2}{2g}-\frac{V_2^2}{2g}.$$

But the speed of entry V_1 is the resultant of two rectangular speeds, the one V_o following the radius, the other ωr equal and opposite to the tangential speed of the wings. In the ideal ventilator which I have here supposed, the interior surface of the wings is directed exactly in accordance with this result, so that the composition of the speeds is produced without obstacle, and the air slides without shock on the cutting surface of the vanes; I may, then, replace in the preceding expressions V_1^2 by the sum $V_o^2+\omega^2 r^2$, and bring to the gain of the depression the algebraic sum—

$$+\frac{V_o^2+\omega^2 r^2}{2g}-\frac{V_2^2}{2g}.$$

Third, the movement of drawing in, which is a uniform rotation, creates the centrifugal force, which in its turn produces a gradual increase of pressure from the *ouïe* to the exterior circumference. If I isolate in imagination a prismatic element of the air drawn in, placed at a distance x from the centre and presenting a height $d\,x$ in the direction of the radius, a base S in the perpendicular direction, and a density δ, the mass in this element will be

$$\frac{\mathrm{S}\,d\,x\,\delta}{g},$$

and the centrifugal force developed by the rotation

$$d\,\mathrm{F} = \frac{\mathrm{S}\,d\,x\,\delta}{g}\,\omega^2\,x.$$

The increase of depression per unit of surface from one base to the other of this little prism will be got by dividing the preceding expression by S. We will divide again by δ, to have this pressure expressed as usual in the column of air, and we shall have finally for the differential increase of the pressure due to the centrifugal force

$$d\,h = \frac{\omega^2\,x\,d\,x}{g}.$$

And integrating from $x = r$ up to $x = \mathrm{R}$, we shall have for a total difference of pressure from the circumference of the *ouïe* to that at the outside of the vanes

$$+\frac{\omega^2\,\mathrm{R}^2 - \omega^2\,r^2}{2\,g},$$

a value to be carried to the credit of the depression produced by our ventilator.

Our analysis is now complete, and we may make the addition. Many terms, some positive and some negative, cancel themselves, and there will only remain, when designating by the letter u the tangential speed ωR, the simple expression—

$$H = \frac{u^2}{2g} - \frac{V_2^2}{2g},$$

an expression which subsists whatever may be the curve given to the wings and the inclination under which they reach the exterior circumference.

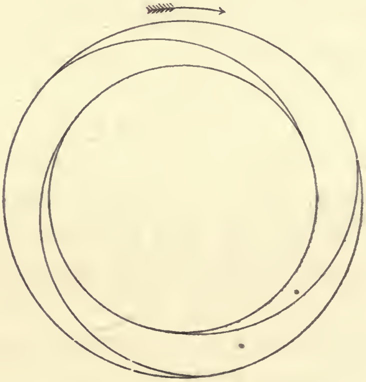
The ventilator which we are now studying is in reality a very bad machine. Although it responds sufficiently well to the first of the two conditions which every machine must fulfil in which fluids circulate, that is to say it receives the air *without shock*, it is still far from realising the second, the *escape without speed*. The air extracted from the interior is thrown into the atmosphere with considerable speed, resulting from the tangential speed u and the speed relative to the outlet V_2.

This important defect has not escaped constructors, who have generally sought to provide a remedy. The first means which they have employed, and which presented itself naturally, consists in giving a large inclination to the wings, so that they arrive in an angle more or less sharp at the periphery. In opposing in this way the relative speed of outlet to the speed at the extremity of the vanes, they hope if not to annul at least to diminish to a great extent the absolute speed of expulsion into the atmosphere, and so to improve the result. This arrangement was adopted by Combes, who carried things to an extreme, making his vane tangential to the exterior circumference, that is to say, at an angle of 0°. We reproduce (Fig. 3) the curve of his ventilator, but success has not responded to this theoretical view. To understand the cause it is sufficient to reduce to its value the depression expressed by the difference—

$$H = \frac{u^2}{2g} - \frac{V_2^2}{2g}.$$

This difference constitutes in effect a veritable antithesis. To weaken in a sensible degree the absolute speed of expulsion by opposing to the tangential speed u the relative speed V_2, we must admit for this last a considerable value approaching u, but then the negative term $-\frac{V_2^2}{2g}$ increases, the depression weakens, and the machine loses its power. If to recover it we have recourse to an increase of the speed of rotation, we increase at the same time the passive resistance of the machine and its motor, and that which we gain on one side we lose on the other.

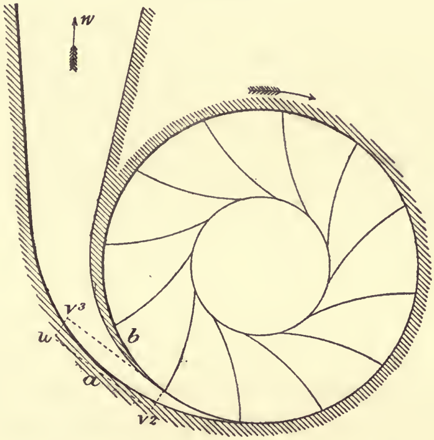
FIG. 3.



Such is certainly the principal if not the only cause of results so little satisfactory as those given by the experiments of M. Glepin on the Combes ventilator, the tangential speed being almost three times that which is required under the same conditions by the Guibal ventilator, and the proportion of useful work to the motive power measured by Prony's brake has never exceeded 29 per cent. There exists, happily, a very efficient means for improving the resultant of ventilators—it is that connected with the name of M. Guibal.

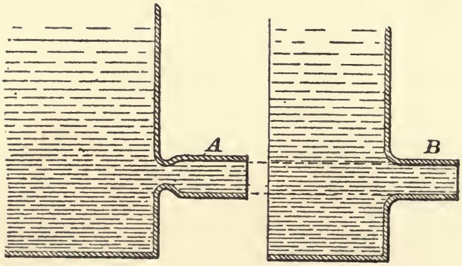
The ventilator is inclosed in a cover, more or less eccentric, which does not permit of the exit of the air except by a narrow passage *a b*, Fig. 4, regulated according to the yield of the machine. This passage is continued into the long *évasée* chimney. The speed of expulsion existing in the orifice *a b* is extinguished little by little, just as the air rising in the chimney fills larger areas, until it becomes inactive at the moment when it is expelled into the atmosphere. This extinction of speed occasions, as theory requires, a considerable depression, which is added to that produced by the centrifugal force, increasing in a marked manner the power of the machine.

Fig. 4.



This effect, so remarkable in the Guibal chimney, has surprised many persons not familiar with the theory of the flow of fluids. For those who have any doubt I advise a study of the description of the ajutage of Venturi, given in all treatises on hydraulics. This ajutage presents at first a narrowing, then a space gently expanding, like a Guibal chimney. But this theory requires that in this expanding part there should be an integral restitution of active force developed to recover the obstruction; consequently the yield of the ajutage is the same as if the narrowing did not exist.

Fig. 5.



As in our Fig. 5 above, the yield of A will be the same as that of B. We cannot hope, however, in practice, in the Guibal chimney any more than in the ajutage of Venturi, to see realised a perfect restitution of active force. It is certain, however, that this effect is produced to an important degree, as has been witnessed by numerous observers.

In place of a single chimney we may imagine a series of small chimneys starting from each point in the circumference. This arrangement has been proposed by M. Harzé in the *Revue Universelle* of Liège, 1870. The effect may be the same, perhaps better, but I do not believe that the idea has ever been carried out.

What assistance does the Guibal chimney give to the depression? The answer is immediately given by the theory of Bernouilli, the application of which presents itself at each step in this study. If in effect V is the speed of the air at the bottom of the chimney and W the speed at the top, this theory will immediately give for the corresponding increase of pressure the difference

$$+\frac{V^2}{2g}-\frac{W^2}{2g}.$$

The speed V is that which the air possesses on leaving the vanes; it is thus the resultant of the tangential speed u and of the speed relative to the outlet V_2. The parallelogram of these speeds furnishes the known relation between them

$$V^2 = u^2 + V^2_2 - 2\,u\,V_2 \cos a,$$

a being the angle at which the vanes strike the exterior circumference.

In substituting this value of V^2 in the preceding expression we shall have for this latter

$$+\frac{u^2}{2g}+\frac{V^2_2}{2g}-\frac{u\,V_2 \cos a}{g}-\frac{W^2}{2g}.$$

The ventilator alone without envelope or chimney has given already

$$+\frac{u^2}{2g}-\frac{V^2_2}{2g}.$$

Adding together, then, it becomes, all simplifications made,

$$H=\frac{u^2}{g}-\frac{u\,V_2 \cos a}{g}-\frac{W^2}{2g},$$

an expression of the total depression developed by the Guibal ventilator.

We have now this interesting question, Under what inclination a should the vanes strike the exterior circumference for the machine to develop the maximum of depression? The reply is simple. It is that this inclination is 90°, in fact this value of a makes the negative term

$$-\frac{u\,V_2\cos a}{g}$$

disappear, and there remains only for the theoretical depression

$$H = \frac{u^2}{g} - \frac{W}{2g}\,.$$

So the vanes of the Guibal ventilator, and in general every ventilator intended to restore the active force, should strike normally to the exterior circumference. We may besides foresee, without any analysis, from the moment in fact that the speed of expulsion is utilised, that a gratuitous waste of power takes place if the vanes are inclined.

However, this condition was not apparent at once to the inventor, for his first machines generally had inclined vanes. But it has been realised in machines recently constructed, as we saw in the large ventilator which was shown at the Champ de Mars in the Belgian section.

I will assume now that throughout the remainder of this study I need not trouble myself further as to the angle a. The line which results for the vanes of the ventilator is given by Fig. 6. The vanes begin at the circumference of the *ouïe* with an inclination to enable them to receive the air without shock. They continue upwards with a gentle curve, and end in a right line following the radius.

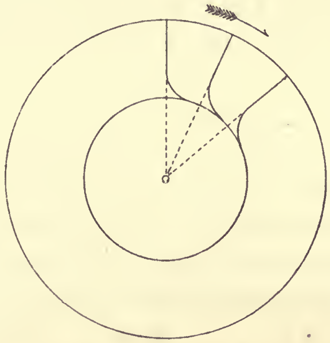
One condition still remains to be fulfilled in order that the ventilator may be, so to say, perfect—an ideal of which we have spoken above: it is necessary that the air expelled should escape without speed. From the theoretical point of view in which we place it, the solution is clearly shown. We have only to imagine that the chimney is prolonged with an increasing capacity to a sufficiently great height, so that the speed of the air at its summit may be considered as nothing. Then W becomes equal to zero, and the total depression developed by the perfect ventilator takes the unquestionably simple form—

$$H_o = \frac{u^2}{g},$$

which we may translate into ordinary language by saying that the *theoretical depression is the double of the height created by the tangential speed.*

This value forms the basis of the theory, but I repeat that it only applies to an ideal ventilator. In practice, a thousand imperfections of detail will prevent the initial depression attaining such an elevated point. We are obliged to introduce a coefficient of reduction, and to write

FIG. 6.



$$H = K\frac{u^2}{g},$$

K being a fraction more or less near unity in proportion as the constructor shall have made more or less effort to realise the indications of reasoning and calculation. This fraction

K, which expresses the proportion of the initial depression to the theoretical depression, is, properly speaking, the useful effect in depression in the ventilator. I will call it afterwards the manometrical yield, reserving, according to usage, the mechanical yield, or the yield, properly speaking, of the proportion of the work utilised to the work of the motor. Already we have seen that for uncovered ventilators the manometrical yield must be always less than half. In fact, the maximum depression in these machines, $\frac{u^2}{2g} - \frac{V_2^{\,2}}{2g}$ is already less than half of $\frac{u^2}{g}$. With the covered ventilators the yield largely exceeds this limit, but will remain far short of unity.

I should observe incidentally that this value of the depression fully justified the principle admitted by the Commission of Gard, that all the ventilators having the same tangential speed are theoretically equal.

Having thus determined the value of the initial depression, there remains nothing more for us than to carry forward the two formulæ established in the preceding paragraph. We then obtain the two following expressions, which comprehend the whole theory of centrifugal ventilators:—

First, The value of the effective depression—

$$h = \frac{K u^2}{g\left(1 + \frac{a^2}{o^2}\right)};$$

Second, Value of volume yielded per second—

$$V = \frac{0 \cdot 65 \sqrt{2 K} a u}{\sqrt{1 + \frac{a^2}{o^2}}}.$$

The ventilator is defined by its tangential speed and its orifice of passage—data which depend only on the constructor;

the mine, by its equivalent orifice; the other terms being constants. In these two expressions there only enter known quantities, which is the object we pursue.

We easily see, without it being necessary to insist upon it, that these formulæ apply equally well to blowing ventilators as to drawing ventilators. It is sufficient in such a case to replace the word depression by that of compression.

If we remember that the tangential speed u is equal to the product ω R of the angular speed by the radius, the two preceding formulæ immediately show the two well-known laws:—First, The volume yielded varies as the speed of rotation. Second, The depression varies as the square of this speed.

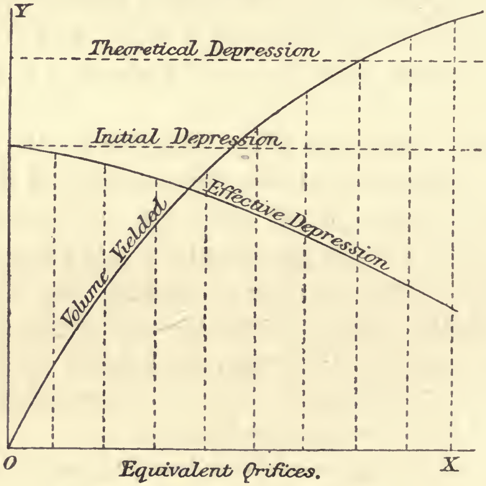
These two laws have effect according to the radius or diameter of the ventilator, with the condition that the angular speed is invariable. Those which connect the volume and the depression with the equivalent orifice of the mine cannot be easily translated in ordinary language. We may say, no doubt, that the volume increases as the depression lowers when the mine is made larger, but it would be difficult in precise and simple terms to express the law of this variation. I prefer to have recourse to a drawing.

I place on the line of abscissæ the increasing value of the equivalent orifice. This line will represent, if we wish, by the aid of a figure, a long rectangular orifice, closed by a sliding door, which we may draw by degrees. In the ordinates will be given the corresponding values of volume yielded and of the depression. We thus obtain the two curves reproduced in Fig. 7.

On the first of these curves we see the depression commences, when the mine is closed, with its initial value $\frac{\mathrm{K}\,u^2}{g}$; then, in proportion as the mine is enlarged, the depression lowers, and is not destroyed altogether except when the orifice of the mine becomes equal to infinity. This is the case of the ventilator acting freely in the atmosphere, when in effect the whole depression is absorbed by the interior frictions of the machine.

The curve of the volume afforded commences at the same point, for when the mine is shut off the yield is naturally nothing. From that it rises rapidly, then bends little by little, and terminates by a long horizontal branch where the asymptote has for its ordinate the volume $0 \cdot 65 \sqrt{2 K} o u$. This volume is that which the ventilator affords when the mine is suppressed and the air has free access to the *ouïe;* it depends alone on the orifice of the passage and specifies its influence.

FIG. 7.



We observe in this latter curve the characteristic curve of the Commission of Gard. The same graphic method permits us to study the influence of the orifice of passage on the volume and upon the depression, but I think it useless to discuss it. Such is the theory which for many years I have had under consideration. If we recall the numerous essays on like theories which have appeared in scientific publications, we shall find that the authors have been generally induced to follow the phenomena step by step from the moment when the air penetrates the passages of access up to that when it escapes into the atmosphere. Each friction, each bend, each loss of air or of duty gives rise to a new analytical expression, where the succession extends often beyond measure. The last work which has appeared, that of M. Ser, Professor at the Central School, concludes with no less than fifteen distinct relations between twenty-six quantities.

In that which I propose now, all these innumerable facts of detail or of minute analysis will be found stated in a manner easy to be understood and with perfect clearness; such as are exterior to the ventilator to be studied, being expressed *en bloc* by the "equivalent orifice" of the mine. It is, doubtless, unnecessary to add that this fiction is equally adapted to represent the resistance of furnaces, cupolas, and various other conditions as well as the galleries of mines. As to the resistance and imperfections proper to the ventilator itself, they divide themselves into two groups differing in their nature, each one appearing with pleasing simplicity. First, The frictions and losses of duty, all quantities proportional to the square of the yield, are expressed simply by the orifice of passage o. Second, The imperfections of every kind, independent of the yield, which prevent the initial depression reaching the theoretical value $\frac{u^2}{g}$ are summed up in the manometrical result K. These two ideas may be translated in ordinary language in a manner which assists their being studied and easily remembered. We may distinguish, in fact, in every deprimogen ventilator that which I will call the depressing power and the power of yield.

A cupola fan may give considerable depressions or compressions, but it is incapable of furnishing a yield sufficient for the ventilation of a mine or a hospital. We say of it that its depressing power is high and its yield power low. On the contrary, the large machine, with curved vanes or with a screw, has the power to afford enormous yields, but can never produce great depressions; here the two powers must be inversely qualified. But the yielding power has its expression naturally in the orifice of passage and the power of depressing in the manometric yield.

3. Experimental Verification.

I shall stop a little to consider the first two laws resulting from our formulæ, which connect the volume of air and the effective depression with the speed of rotation. No one today will dispute that the volume is proportionate to the speed of rotation and the depression to its square. All the published experiments up to this time put these facts clearly; and for my part I have verified them many times. To leave no doubt in the mind of the reader, I have given, in an additional note (B), a few of the most noteworthy of these experiments.

The influence of the speed of rotation being thus established beyond question, I may suppose in the remainder of this work that the ventilators studied turn at an invariable strictly regulated speed whatever may be the resistance. Matters are thus simplified, and it will be under these simplified conditions that I shall pursue the experimental consideration of the theory described in the preceding paragraph.

As I have said at the beginning, the work of the Commission of Gard has furnished me with numerous and sure data, prepared fortunately for the verification which concerns us. We may recall in a few words the object and result of these experiments.

Four ventilators with centrifugal force have been studied by the Commission, viz. :—

The ventilator of Lalle, a kind of turbine 12½ feet in diameter, without cover, and throwing out the air by its whole circumference;

The ventilator of La Sagnette, a small machine of 9¼ feet in diameter, turning at a high speed, having a cover, but without a chimney;

The ventilator of Créal, 19·68 feet in diameter, covered, and with rectangular chimney;

Lastly, the ventilator of Bessèges, 16·4 feet in diameter, representing the Guibal type, with a cover, movable slide, and expanding chimney, but without the last improvements introduced by the inventor, the straightening of the vanes in the direction of the radius.

By creating and removing obstacles to the course of the ventilation we make for each machine five imaginary mines, corresponding to five degrees of resistance to the circulation of the air, degrees sufficiently marked to distinguish all the usual values of this resistance from the thinnest seams to the thickest. For each of these we measure the speed of rotation, the depression, and the volume of air yielded, without prejudice to the atmospheric observations such as the pressures and temperatures. By the aid of these data we make a calculation of the equivalent orifice; then we obtain the volume of air observed at the same speed, for comparison, called the *normal speed;* lastly, we carry these results into a drawing, the equivalent orifice being the abscissæ, the volume in ordinates, and the five points so obtained enable us to draw the characteristic curve of the machine.

We have now to examine these same results, verifying the two fundamental formulæ established above. For instance, for the depression

$$h = \frac{K u^2}{g\left(1 + \frac{a^2}{o^2}\right)};$$

for the volume yielded

$$V = \frac{0 \cdot 65 \sqrt{2 K} a u}{\sqrt{1 + \frac{a^2}{o^2}}}.$$

At the same time, it is not only by these formulæ themselves that I establish the verification.

It is preferable, in order to simplify the matter, to combine these two formulæ in one, by eliminating from them the equivalent orifice a. We obtain thus the equation—

$$h = K \frac{u^2}{g} - \frac{V^2}{\overline{0 \cdot 65}^2 o^2 2 g}.$$

It may be written by replacing the initial depression $\frac{K u^2}{g}$ by H, and the constant factor $\frac{1}{\overline{0 \cdot 65}^2 o^2 2 g}$, by M.

Then

$$h = H - M V^2.$$

With this new equation I find this double advantage:—First, the avoiding of the calculation of the equivalent orifice. Second, the obtaining of a straight line by a drawn curve, V^2 in abscissæ and h in ordinates.

Nothing is more easy than the verification when a series of points form a straight line. We may even say, in a general manner, that there is no method more convenient and more qualified to make us certain that experiments are true than when the equations expressing this law can be shown by a straight line.

I strongly recommend this formula to the study of engineers desirous of making observations or experiments on their ventilators. It forms the exact counterpart to the well-known formula established by M. Trasenster for the volumogen ventilator—

$$V = W - M \sqrt{h},\text{*}$$

from which it differs only in the substitution of h for V, and over which it possesses a great advantage, since it shows directly, without previous transformation, the volumes and depressions given by the experiments, as it remains applicable whatever may be the intensity of the natural action, which at all times governs the mechanical action of the ventilator.

This latter point is rather difficult to show clearly, and I fear, in wishing to show too much, that I shall not succeed in making myself sufficiently understood. I am led, then, to say, leaving to the reader to use his own discretion, that the natural effect, whether additive or subtractive, should equalise in fact either a diminution or an increase of the resistance which the air must overcome to traverse the mine, the resistance being expressed by the equivalent orifice of the mine. But the connection between h and V is expressed by each of the two formulæ, whatever this orifice may be.

I should observe that these formulæ do not change when the depression is expressed in inches of water, as is usual when making such experiments. The transformation necessary in effect is to multiply the constants by the proportion, itself constant, of the densities of the air and water $\frac{\delta}{\delta_o}$. These

---

* W is the volume per second, and M a constant coefficient.

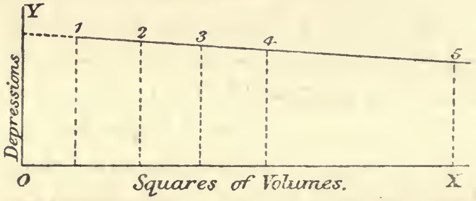
preliminaries given, I will at once turn to the experiments of the Commission, and first, to those made on the ventilator of Créal, which verify with perfect exactness the formula we have given. These experiments are summarised in the following table:—

Order.	Equivalent Orifice.	Speed of Rotation.	Volume per Second.	Square of Volume, X.	Observed Depression, Y.	Calculated Depression.	Difference.
	sq. ft.		cub. ft.		in.	in.	in.
1	6·604	63·66	298·82	89283·39	1·0598	1·0582	+0·0016
2	9·985	,,	442·45	195766·00	1·0183	1·0193	−0·0010
3	12·199	,,	532·16	283194·46	0·9866	0·9873	−0·0007
4	14·846	,,	635·99	404483·28	0·9452	0·9428	+0·0024
5	20·922	,,	839·31	704441·28	0·8314	0·8308	+0·0006

But if we draw to a scale the numbers of the fourth column in abscissæ, and those of the fifth in ordinates, the five points so got will show with great perfection that the same drawing of the straight line covers everything.

We may see besides by the numbers of the seventh column, the difference existing between the points and the absolute straight line.

FIG. 8.



The equation for this straight line is

$$h = 1{\cdot}0908 \text{ in.} - {\cdot}000000365\ V^2,$$

from which I may conclude that this excellent verification of the theory established above for ventilators with centrifugal force is in every case rigorously the expression of facts.

But we shall presently see that it is prudent to make certain reservations.

I pass to the ventilator of Lalle, and present in a second table the results given by this machine :—

Order.	Equivalent Orifice.	Speed of Rotation.	Volume per Second.	Square of Volume, X.	Observed Depression, Y.	Calculated Depression.	Difference.
	sq. ft.		cub. ft.		in.	in.	in.
1	4·045	100·52	177·98	31676·78	1·0303	1·0228	+0·0075
2	8·289	„	354·75	125847·56	0·9673	0·9677	−0·0004
3	11·434	„	471·34	222163·19	0·8976	0·9114	−0·0138
4	12·893	„	525·80	276465·64	0·8760	0·8799	−0·0039
5	14·868	„	595·76	354929·98	0·8543	0·8342	+0·0201

Here the five points do not appear with the same perfection as in that of Créal. Still the average straight line is exhibited with sufficient clearness. We may see by the numbers of the seventh column that the divergence exceeds hardly one-third of a millimetre. I may add that at Lalle the section for measuring is in a very inconvenient situation for observers, which will sufficiently explain the slight irregularity in the results. The equation for the average straight line is

$$h = 1{\cdot}0413 \text{ in.} - {\cdot}00000058\ V^2.$$

Let us go, now, to the Guibal ventilator of Bessèges. The experiments made on this machine are collected in the third table :—

Order.	Equivalent Orifice.	Speed of Rotation.	Volume per Second.	Square of Volume, X.	Observed Depression, Y.	Calculated Depression.	Difference.
	sq. ft.		cub. ft.		in.	in.	in.
1	3·921	76·39	187·32	35088·78	1·1795	1·3042	−0·1247
2	7·455	„	364·79	135269·26	1·2779	1·2763	+0·0016
3	20·914	„	951·05	904496·10	1·0665	1·0681	−0·0016
4	25·521	„	1114·00	1240986·00	0·9827	0·9764	+0·0063
5	29·343	„	1225·15	1500992·52	0·8996	0·9059	−0·0063

Here the four latter points range themselves in a straight line, having for their equation

$$h = 1{\cdot}3137 \text{ in.} - {\cdot}00000027\ V^2.$$

The first point is certainly below this line. The variation is much too great to permit this to be attributed to any error in observation. Some experiments made before on the ventilator of Créal having always given me the same irregularity, I am led to assert as a fact that for very thin seams the depression is always below the mark which the results give for larger ones.

If, putting the thing to an extreme, we shut completely off the gallery yielding the air to the ventilator, instead of the initial depression H, we find only a less value. Thus for the ventilator of Bessèges 1·128 in. in place of 1·313 in.

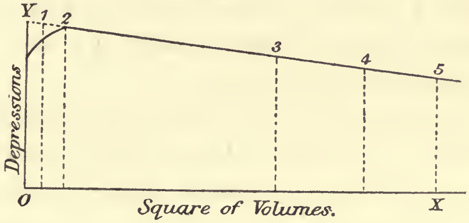
To what can we attribute this depression, this shortcoming, if I may say so, of the depression in the case of thin mines? The causes are numerous. A moment of reflection will enable us to discover them. As soon as we lower the movable shutter to accommodate the orifice of the outlet to the diminished yield, we transform this orifice into a straight rectangle, by which the air escapes in a thin stream. The perimeter friction increases in proportion to the section, and the loss of duty assumes a rapidly increasing importance.

In the second place, the inclination which the vanes at their commencement present to the air so as to strike it without shock, only applies to a given yield; with a circulation of air greater or less, there naturally follows a shock. In general this inclination is calculated for thick mines, and the useless effect, although unfelt, for average seams, rapidly increases for very thin ones, and helps to reduce the depression.

At the same time, with thin seams it becomes certainly more difficult to obtain a flow with full mouth in the spaces of the vanes and in the Guibal chimney—a flow indispensable to realising the full restitution of the *vis viva*, in the manner of the ajutage of Venturi. This remark seems to be corroborated by the fact that in the case of thin seams the depression lacks absolute fixity: it is so vacillating that measurements taken at a few minutes' interval give quite different results.

It follows from the preceding remarks that the straight line required by our theory cannot be followed up rigorously to the original ordinate. It bends when applied to very thin seams of from 4·304 sq. ft. to 5·38 sq. ft. of equivalent orifice, as is shown in Fig. 9, the inflection beginning more or less quickly according to the machine. On the other hand, they seem to demand an indefinite continuation in the case of thick seams.

FIG. 9.



This experiment on the Bessèges ventilator shows it in fact as far as a mine of 29·33 sq. ft. of equivalent orifice, a value rarely exceeded even in England. Mines having seldom if ever been found with less than 4·30 sq. ft. of equivalent orifice, we may admit that within the limits met with in practice our theory is justified.

I have not been able to utilise for the verification I seek the results obtained by the Commission with the ventilator of La Sagnette. This machine has a peculiarity which puts it outside of our theory. I said above that in covered ventilators the outlet constructed for the expulsion of the air should be regulated to the yield of the machine—small with thin seams and larger for thick ones. At Bessèges, with the aid of the moving slide, at Créal by taking away or adding deal boards to the cover, the Commission was able on each occasion to make this previous adaptation. At La Sagnette the disposition of things did not adapt themselves to this: the orifice of outlet remained invariable, and would only suit, therefore, a particular mine. With seams thinner or thicker, and with these latter especially, considerable resistances arise, preventing the depression and yield from attaining the values we have a right to expect. The five points in this latter case did not range in a straight line; the depression, at first feeble, gradually rose to a maximum for the state of mine for which it was intended.

We may, then, with the aid of the numerical values which we have found for the constants H and M of our equation, determine the characteristic data of the three ventilators studied by us. I wish to speak of their manometrical result and of their orifices of passage. We have in effect the two following equations:—

$$\mathrm{H} = \frac{\mathrm{K}\,u^2}{g},$$

$$\mathrm{M} = \frac{1}{\overline{0{\cdot}65}^{\,2}\,o^2\,2\,g}.$$

If, taking the first of these equations, I give successively to H the three values obtained above, having taken care to divide them by the proportion $\frac{\delta}{\delta_o}$ of the densities of air and water, the following corresponding values of manometrical result will be obtained:—

For the ventilator of Bessèges	·691
,, ,, Créal	·572
,, ,, Lalle	·542

These results fully confirm the theory that the Guibal ventilator fitted with *évasée* chimney has the best results. That of Créal comes only second on the list, for its chimney is insufficient; while the Lalle ventilator, which has neither cover nor chimney, necessarily comes last.

We may, indeed, be astonished that this last machine reaches even so high a result. We have said above that a ventilator without a cover cannot obtain a result in manometrical effect superior to ·50; but if we refer to the report of the Commission we shall find that this machine turns in a semicircular passage, which must certainly affect the yield in the same manner as a cover.

I reach, then, the second equation and the data affecting M, and as I did to H, so the three values obtained in the course of this paragraph must always be divided by $\frac{\delta}{\delta_o}$. From the three equations which result I deduce for the orifice of passage *o* the following values:—

For the ventilator of Bességes	43·81 sq. ft.
„ „ Créal	37·87 „
„ „ Lalle	30·02 „

The order of the orifices of passage is the same as that of the depressions, but we must not in consequence draw general deductions, for the theory will not warrant it. We understand in effect that the orifice of passage depends above everything on the construction and on the width which is given to the vanes and to the *ouïe*, and to the section which allows the passage of the air.

The Guibal of Bességes is 7·56 feet in width and 9·84 feet in the *ouïe*. The ventilator of Créal is a large machine of 19·58 feet diameter and 11·5 feet in the *ouïe*, but the width has been reduced to 3·6 feet. As to the ventilator of Lalle, the *ouïe* is not more than 5·8 feet in diameter and the width from 4·32 feet at the axis to not more than 1·95 foot at the circumference.

We find frequently in the industrial publications results of experiments made on ventilators with centrifugal force, especially since the impulse given by M. Guibal to machines of this class. The authors of these experiments have rarely taken the trouble to vary the resistance of the mine as was done by the Commission of Gard. In general they have only changed the speed of the ventilator, which, in virtue of the proportional law established, is equivalent to only one experiment. Such work cannot be utilised for the determination of the orifice of passage and manometrical result. I must, however, make an exception in favour of a study of great interest published in the *Annales des Mines* in 1860 by M. Tournaire. I reproduce the results obtained by him, but they only apply to the forge fan; still, it is interesting to show them in connection with large machines examined by the Commission.

The ventilator of M. Tournaire was studied with the greatest care in its smallest details, excepting one point, which as we have seen above is of the highest importance—it was not covered; the air being driven out all round the circumference. It was 2·788 feet in diameter, and turned with a speed of 1500 to 1700 revolutions per minute, which gave a tangential speed of 219 to 250 feet per second. Nevertheless, to render these experiments comparable to those of the Commission, I have reduced them all to the tangential speed of 65·6 feet. This new table is drawn in the same manner as the preceding ones. The equivalent orifice which I show in the first column is nothing but the sum of the surfaces of the open orifices:—

Order.	Equivalent Orifice.	Speed of Rotation.	Volume per Second.	Square of Volume, X.	Observed Depression, Y.	Calculated Depression.	Difference.
	sq. ft.		cub. ft.		in.	in.	in.
1	·2540	449·38	8·94	79·92	·7551	·7645	−·0094
2	·4230	„	14·48	209·67	·7142	·7185	+·0043
3	·5069	„	17·34	300·68	·6996	·6862	+·0134
4	·5435	„	19·95	398·00	·6831	·6512	+·0319
5	·7610	„	24·86	618·22	·7000	·6520	+·0480
6	·8450	„	26·03	677·56	·5512	·5521	−·0009
7	·9300	„	27·97	782·32	·5134	·5149	−·0015
8	1·0462	„	29·77	886·25	·4807	·4779	+·0028

The first three points and the last three range themselves sufficiently near to a straight line, where the equation is

$$h = \cdot 793 - \cdot 000355\ V^2.$$

The two intermediate points place themselves above very distinctly.

It is difficult to distinguish the causes which produce this difference, perhaps there exists a special yield for which the ventilator is particularly well proportioned.

The constants of this straight line permit me to calculate, as for the preceding ventilators, the manometrical yield and the orifice of passage of this new machine. I obtain thus the two following values—

Manometrical yield	·403
Orifice of passage	0·141 sq. feet.

As the theory requires, the manometrical yield is inferior to 0·50. The addition of an eccentric envelope, following out M. Guibal's idea, certainly increases in a very great measure the compressing power of this ventilator. As to the orifice of passage, its lessened value is explained quite naturally by the small dimensions of the machine. Beyond the interesting data which I have given, I find no observations relating to the same degree of resistance to the circulation of air, or in other words to the same equivalent orifice.

Data so incomplete do not allow us to arrive at a knowledge of the orifice of passage or of the manometric yield, but for this latter we are enabled to obtain a value roughly approaching it, and which in default of any other may possess some interest and utility.

The manometric yield, we have said, is the coefficient of reduction to be applied to the theoretical depression to obtain the initial depression before mentioned.

If, in default of this latter, we are content with the effective depression observed under ordinary conditions, the result obtained will be very poor, and still more feeble as the seam ventilated is thicker ; but, in general, the difference of this approximate value will not be so considerable but that it may aid us in forming an opinion as to the exact value.

Let us take, for example, the three ventilators of Bessèges, Créal, and Lalle, studied by the Commission of Gard.

The exact manometrical yields of these machines are respectively—

0·691 .. 0·572 .. 0·542.

If, instead of calculating the manometrical results with the aid of the initial depression, we use the effective depressions observed on the three mines of Bessèges, Créal, and Lalle, we shall obtain " approximate results "—

0·569 .. 0·524 .. 0·468.

Without doubt the differences are very great, especially for the mine of Bessèges, which is very thick; but the order of these values approaches what is their true value, and, in default of more precise indications, they may suffice to compare different types of ventilators. It is with this idea that I have drawn up the table which follows. I have introduced all the ventilators, to the number of sixty, of which I have been able to procure any information. The approximate result which is shown in the last column, is calculated, as we have seen above, by comparing the observed depression with the theoretical expression where the expression is in water column—

$$\frac{u^2}{g}\,\frac{\delta}{\delta_o}.$$

The error diminishes with thin seams, and increases with thick ones. I have taken into account the manometrical result as an important base for the examination of the equivalent orifice of the mine ventilated.

The ventilators are given in the order of their perfection. First, the primitive machines without a cover; second, those simply covered without chimneys; third, the machines covered, but with a chimney to a constant section; and lastly, the Guibal, with a slide and cover and the *évasée* chimney. In each category the order followed is that of increasing diameters.

Published experiments are rarely accompanied by atmospheric observations which permit a calculation to be made of the density of the air. I have allowed in each case for this density the average of 1·200 to 1000 for that of water. With these conditions the formulæ which enable me to establish the numerical value of this table take the following simple form for the equivalent orifice—

$$a = \frac{0 \cdot 2\,V}{\sqrt{h}},$$

V being the volume given per second, and h the depression observed in inches of water.

Second, for the theoretical depression—

$$H_o = \frac{N^2D^2}{800947},$$

N being the number of revolutions per minute, and D the diameter of the machine in feet.

Third, and consequently, for the manometrical yield—

$$K = \frac{800947\,h}{N^2D^2}.$$

Sometimes the observation of the yield has been defective, and then the equivalent orifice could not be determined.

TABLE

FAN

No.	Date.	Mine.	Dimensions.		
			Exterior Diameter.	Diameter of *Ouïe.*	Width.
			ft.	ft.	ft.
1	June 25, 1842	Shaft No. 5 of Grand Hornu	5·57	4·46	1·11
2	Mar. 28, 1844	Ditto	5·57	4·46	1·11
3	May 24, 1844	Pit No. 2 at Sauwartan	6·56	5·21	1·31
4	Apr. 23, 1847	At Pit St. Caroline of the Colliery of St. Victor Frameries.	6·26	..	..
5	June 28, 1849	Shaft No. 1 at Escouffiaux Colliery ..	5·57	3·28	3·93
6	June 1, 1843	Pit No. 3 at Marcinelles	6·62	2·06	1·96
7	Oct. 4, 1842	Pit No. 3 of Agrappe and Grisœil, at Frameries.	8·29	4·26	3·21
8	Oct. 1, 1849	Bayemont Colliery	8·52	4·48	3·77
9	June 20, 1849	Shaft No. 3, Grand Trait, of Agrappe and Grisœil, at Frameries.	9·05	4·92	4·92
10	Jan. 7, 1848	Shaft called No. 12 at Agrappe, Noirchain Colliery.	9·05	4·92	4·92
11	Nov. 28, 1848	Large Seam of the Epinois Wood and Elouges Colliery.	9·18	4·59	3·93
12	Oct., 1847	Shaft No. 5 (St. Barbe) at Escouffiaux Colliery.	9·38	4·59	3·93
13	Nov., 1847	Shaft No. 7 (St. Antoine) at Escouffiaux Colliery.	9·38	4·59	3·93
14	July 30, 1863	Great Seam of the Epinois Wood at Elouges.	9·84	..	4·10
15	Nov. 20, 1842	Shaft No. 1 at Grand Picquery Colliery, Frameries.	10·00	4·78	3·24
16	Nov. 25, 1842	Pit Ste. Caroline of St. Victor Colliery, Frameries.	10·29	5·24	3·11
17	Apr. 30, 1865	Crachet and Picquery Pits, Shaft St. Placide.	22·96	9·84	5·57
18	..	Shaft No. 12 at Marcinelles Colliery ..	21·32	7·38	4·59
19	..	Ormont Colliery at Chatelet	26·24	..	4·59

No. I.

UNCOVERED.

Publications.	Authors.	Equivalent Orifice.	Approximate Manometrical Result.	Remarks.
		sq. ft.		
Memoir on Apparatus applied to Ventilating Mines, p. 58.	G. Glepin	1·88	·132	Type, Combes; vertical diameter, 1 *ouïe*, 3 vanes.
Ditto, p. 58	Ditto	3·56	·090	Ditto. The mine being increased the yield is diminished.
And also the manner of working at Combes, Vol. II., p. 491.	Ditto	2·94	·173	.. ..
Ditto, p. 63, & Combes, p. 499. Notes by M. Cabany.	A. Cabany	5·54	·400	Ditto; horizontal axis, 2 *ouïes*, 2 vanes. Type, Letoret; a well-constructed fan, but rather small.
Ditto	Ditto	4·22	·476	Ditto.
Memoir on Apparatus applied to the Ventilation of Mines.	G. Glepin	3·70	·121	Ditto, 2 *ouïes*, 8 vanes, in sheet iron, slightly curved.
Ditto, p. 49	Ditto	3·65	·438	Ditto; vanes inclined at 110° to the radius, 2 *ouïes*.
Annals of Public Works in Belgium, Vol. XI., p. 1.	Jochams	2·91	·323	Ditto; 4 vanes at an angle of 130° to 150°.
Notes by M. Cabany ..	A. Cabany	8·01	·393	Ditto. Very strong inclination of vanes.
Ditto	Ditto	9·82	·303	Ditto. Average of 11 experiments made with assistance of MM. Toilliez, Albert, Hamel, and Toilliez, J.
Annals of Public Works in Belgium, Vol. XI., p. 1.	Jochams	4·11	·285	Ditto.
Notes by M. Cabany ..	A. Cabany	4·13	·474	Ditto.
Ditto	Ditto	4·40	·377	Ditto. Vanes at 110°.
Annals of Public Works in Belgium, Vol. XXII., p. 5.	Hamal and Schorn.	51·43	·368	Ditto.
Memoir on Apparatus applied to the Ventilation of Mines, p. 50.	G. Glepin	2·926	·163	Ditto. Vanes curved, following a surface inclined to the radius of 137° to 153°.
Ditto, p. 46	Ditto	3·109	·354	Ditto. Vanes inclining to 135°. Five experiments.
Ventilation of Mines, by M. Devillez, p. 227.	Gille and Franeau.	8·661	·496	Type, Guibal, before covering.
Supplement to Account of Working, by Ponson, Vol. I., p. 395.	..	7·661	·439	Type, Lambert; 6 radial vanes. Of two experiments I have chosen the most favourable to the machine.
Ventilation of Mines, by M. Devillez, p. 181.	Devillez, Letoret, Delhaise, and Gilbert.	8·199	·455	Ditto; 8 radial vanes.

TABLE No. I. (*continued*).—COVERED

No.	Date.	Mine.	Dimensions.		
			Exterior Diameter.	Diameter of *Ouïe.*	Width.
			ft.	ft.	ft.
20	Nov. 5, 1876	Grand Combe Mines, La Sagnette Fan	9·18	4·39	3·93
21	Aug. 10, 1859	Grisœil Colliery, No. 10	13·12	5·24	5·01
22	From Aug. to Oct., 1859.	Ditto	13·12	5·24	5·01
23	July 25, 1861	Escouffiaux Colliery	13·12	..	..
24	June 23, 1861	Basse Sambre Colliery	13·12	..	..
25	May 28, 1865	Crachet and Picquery Collieries, Shaft St. Placide.	22·96	9·84	5·57
			COVERED FANS WITH CHIMNEY		
26	Feb. 19, 1859	Jean Bart, Cie. d'Anzin	11·80	5·24	4·92
27	Mar. 22, 1859	Ditto	11·80	5·24	4·92
28	Jan. 7, 1865	Stiring Mines, Pit St. Joseph	13·12	6·56	4·92
29	..	Grand Buisson Colliery, Shaft No. 3	22·96	9·84	5·57
30	..	Society of Hornu Wasmes	29·52	9·84	3·28
			COVERED VENTILATORS, WITH SLIDE		
31	..	Sainte Hortense at Paturages	13·12	6·56	4·92
32	June 25, 1862	Verger, Cie. d'Anzin	16·40	8·200	6·56
33	Aug. 11, 1861	Grosse Fosse, Cie. d'Anzin	16·40	8·200	6·56
34	..	Montceau-Fontaine, Charleroi	19·68	..	..

FANS WITHOUT CHIMNEY.

Publications.	Authors.	Equivalent Orifice.	Approximate Manometrical Result.	Remarks.
		sq. ft.		
Minutes of the Mineral Society, Vol. XII., p. 533.	Ventilation Commission of Gard.	7·132	·638	This quantity follows from the second experiment of the Commission. The other four gave a less quantity.
Annals of Public Works in Belgium, Vol. XXII., p. 5.	Hamal and Gille.	12·95	·429	The nine experiments show an action sufficient to destroy the regularity of the results.
Supplement to Account of Working, by Ponson, Vol. I., p. 384.	Ditto	13·17	·505	Concerns, no doubt, the same fan as above. Experiments do not agree.
Ditto	Gille	..	·682	Experiments agree but slightly. The quantity not having been measured the equivalent orifice remains unknown.
Ditto	Masy	..	·613	Same observations as above.
Ventilation of Mines, by M. Devillez.	Gille and Franeau	9·50	·491	Same fan as at No. 17. The covering has been put on but not the slide or the chimney.
OF CONSTANT SECTION.				
Notes by M. Cabany..	A. Cabany	12·00	·583	First Guibal type, with the slide in a groove. The chimney square from 4·92 feet. Average of two experiments most favourable to the machine.
Ditto	Ditto	17·49	·352	Ditto. The mine being very thick explains the diminution of result.
Minutes of the Mineral Society, Vol. X., p. 437.	Laigneaux and Distinghin.	10·01	·284	Ditto. The chimney square from 4·37 feet. We do not see the cause of so poor a result.
Ventilation of Mines, by M. Devillez, p. 236.	..	43·36	·626	Ditto. The chimney has not yet its *évasée* slope in the interior.
Ditto, p. 253	..	..	·609	Special type. The chimney has from top to bottom a uniform section of 6·56 feet by 5·9 feet.
AND EVASÉE CHIMNEY (GUIBAL TYPE).				
Ventilation, by Devillez, p. 221.	..	..	·570	Yield not given. Equivalent orifice unknown.
Manuscript Notes, M. Cabany.	Atkinson, Dickenson, and Greenwell.	8·57	·651	Experiments agree, and are good.
Ditto	A. Cabany	17·56	·633	Result high, regarding thickness of seam.
Supplement to Treatise on Working by Ponson.	..	6·56	·595	

TABLE No. I.—Covered Ventilators, with Slide

No.	Date.	Mine.	Dimensions.		
			Exterior Diameter.	Diameter of *Ouïe.*	Width.
			ft.	ft.	ft.
35	Apr. 22, 1866	Forchies	19·68	9·84	..
36	July 31, 1865	Crachet and Picquery	22·96	9·84	5·57
37	Mar. 25, 1866	Ditto	22·96	9·84	5·57
38	..	Stiring	22·96	9·84	5·74
39	..	Bourbier	22·96	9·84	5·57
40	..	Grand Buisson	22·96	9·84	5·57
41	Sep. 11, 1870	Grand Mambourg	22·96	9·84	8·20
42	1866	Nœux (Pas de Calais)	22·96	9·84	5·57
43	1865	Elswick	22·96	9·84	6·23
44	July 24, 1869	Von der Heydt. Hérne-Bochum, Westphalia.	29·52	..	9·84
45	Feb. 14, 1869	Rhein-Elbe, Westphalia	29·52	..	9·84
46	..	Montceau-Fontaine	29·52	..	..
47	..	United Collieries at Charleroi	29·52	9·84	5·57
48	..	Colliery of Grand Mambourg at Montigny-sur-Sambre.	29·52	13·12	6·56
49	Oct. 24, 1869	Colliery of Rieu Du Cœur	29·52	9·84	6·56
50	May 17, 1869	Colliery of La Louvière	29·52	9·84	6·56
51	June 21, 1869	Colliery of Grand Buisson	29·52	9·84	6·56
52	1865	Pelton Colliery, Durham	29·52	13·12	9·84
53	Apr. 20, 1867	Middle Duffryn Colliery, S. Wales ..	29·52	..	9·84
54	Mar. 2, 1868	Gethin Colliery, S. Wales	29·52	..	9·84
55	..	Colliery Lwynpia, S. Wales	29·52	..	9·84
56	..	Ebbw Vale, S. Wales	39·36	..	11·8
57	..	Colliery of Trieu-Kaisin	39·36	9·84	9·84
58	Mar. 25, 1877	Colliery of Crachet and Picquery ..	39·36	13·12	8·2

AND EVASÉE CHIMNEY (GUIBAL TYPE).—*continued.*

Publications.	Authors.	Equivalent Orifice.	Approximate Manometrical Result.	Remarks.
		sq. ft.		
Ventilation, by Devillez, p. 239.	Stoesser and others.	10·16	·642	
Ditto, p. 229	Gille and Franeau.	8·98	·654	Same as Nos. 17 and 23. Machine complete.
Ditto, p. 240	Stoesser and others.	6·80	·728	No doubt the same machine. The increase in yield may be attributed to less equivalent orifice.
Ditto, p. 221	..	..	·598	Particulars are incomplete.
Ditto, p. 221	..	..	·579	Ditto.
Ditto, p. 236	..	4·33	·711	Same as No. 29. Interior circular casing in chimney complete.
Ditto, p, 237	De Poitier, Havrez and Halley.	11·14	·628	The great width of this machine has no effect on result.
Unknown	C. Brice	9·12	·633	Communicated by M. Brice.
North of England Inst., Vol. XIV.	W. Cochrane	20·15	·590	Ditto.
Annales des Mines, 1873, p. 297.	Extracted by M. Voisin.	14·72	·684	Ditto.
Ditto	Ditto	15·83	·673	Ditto.
Supplement to Treatise by Ponson, Vol. I., p. 374.	Atkinson and Dickenson.	13·78	·751	Volume of air in these experiments is very irregular.
Ventilation of Mines, by M. Devillez, p. 221.	..	..	·583	The details are very incomplete.
Ditto, p. 21	..	..	·545	Ditto.
Ditto	Brunier	11·41	·665	The two first experiments differ; the seven others agree.
Ditto, p. 237	Roger	8·38	·675	Ditto.
Ditto, p. 238	..	25·24	·680	Ditto.
Proceedings of S. Wales Institute, by W. Armstrong.	..	21·19	·709	The three first experiments only; the others do not agree.
Ditto, Vol. V., p. 257 ..	G. Wilkinson	21·83	·307	We do not see what causes the bad result.
Ditto, Vol. VI., p. 67	M. Bates	31·52	·661	It is remarkable that for such a thick seam the result is so good.
Annales des Mines (7th Series), Vol. XIV.	Leon Lecornu	24·74	·696	Details insufficient.
Ditto	Ditto	17·54	·627	Ditto.
Ventilation of Mines, by M. Devillez.	..	..	·700	Ditto.
Revue Universelle of Mines (2nd Series), Vol. II., p. 59.	Hubert	13·78	·668	The vanes are directly as the radius.

From this table result some interesting indications, all conforming to the theoretical views expressed above. For ventilators without cover we find at the bottom of the scale the machines of Combes, of which the manometrical result never exceeds ·132. With the arrangement of Letoret the result is better. It gradually improves as the dimensions of the ventilators are increased, but without exceeding, as theory would require, the maximum of ·500, even for the Lambert ventilator, in which the arrangements are more intelligent, and mark a distinct progress over those of M. Letoret.

With the covered ventilators without chimneys, there appear to be some results better than ·600, which proves that already in the cover a restitution of *vis viva* has commenced. However, the experiments made by Messrs. Gille and Franeau on the ventilator of Crachet (Nos. 17 and 25 in the table), before and after putting on the cover, have shown in both cases the same result ·496 and ·491. There ought, however, to have been a difference, and I cannot understand this anomaly.

The examples of covered ventilators with a chimney of constant area are not numerous. I have arranged them with Guibal ventilators of the primitive type, those where the movable slide is formed by a door turning on a hinge.

An apparatus of this kind fixed on the pits of St. Joseph at the mines of Stiring, has only given a very feeble result, ·284. The cause of this inferiority is not very clear. The second experiment on the pit of Jean Bart gives also a poor result, but here there is a reason, viz. the great thickness of the mine; the other results are much better and give an average superior to ·600. Is it to the square chimney that this result is to be attributed, or is it due only to the cover? It is difficult to point out the exact share of these two influences.

The long series of Guibal ventilators with the *évasée* chimney permit us to be more decided. If we strike out the Duffryn ventilator at Aberdare (No. 53), for the very small results from which I can give no reason, we meet with nothing but high results, often exceeding ·700, and giving an average of ·650. The influence of the *évasée* chimney is thus manifest. There remain also the comparative experiments made by Messrs. Gille and Franeau on the ventilator of Crachet and Picquery. Before the erection of the chimney the result observed was only ·491, and after ·654 (Nos. 25 and 36 in the table). An experiment still more significant is that which is given without the name of the author by M. Devillez, at page 236 of his treatise on ventilation. Whilst the chimney had an equal section throughout its whole height the result was ·626, but after the fixing of the interior casing it increased to ·711 (see Nos. 29 and 40 in the table).

The approximate manometrical result does not seem to increase in any sensible manner with the dimensions of the ventilator. Perhaps, however, it is to this cause that we must attribute the good results presented by the ventilators of Pelton, Gethin, and Lwynpia, notwithstanding the very great thickness of the seams which they ventilate (52, 54, and 55). These machines are not less than 29·52 feet in diameter, and 9·84 feet in width.

The new ventilator of Crachet, however, of 40·56 feet diameter, and with vanes in the direction of the radius as theory requires, which has been the subject of a recent memoir by M. Laguesse, gives only ·668. This result is good, no doubt, but it might have been better had not the object of the constructor been less to improve the manometrical result than to obtain with a moderate speed of the engine a great tangential speed. This latter speed is, in effect, the essential basis of the power of ventilators for creating depression.

If we accept as characteristic of our four categories of ventilators the average of the results obtained as they figure in our table, we obtain the interesting series following:—

For ventilators without cover	·327
Covered, without chimney	·560
Covered, with a rectangular chimney ..	·606
Covered, with *évasée* Guibal chimney ..	·650

This series dispenses with all comment. It is, however, right to remark that the precision of these averages is somewhat illusory, and they form only a rough indication. It follows from these figures that by the dimensions and arrangements actually adopted for ventilators with centrifugal force, we have obtained almost double the power of depression of the old ventilators of Letoret, but it is necessary to avoid thinking that for the mine-worker the gain is really very considerable. In effect, that which concerns the mine-worker is not so much the depression itself, but rather the circulation of air which it induces in the workings. If we increase the depression the result is only in the proportion of the square root of this increase, so that when we have doubled the manometrical result of a ventilator we have only been able to increase in the proportion of 1 to the square root of 2, or about as 5 is to 7, the volume of air passing through the works.

This same observation may assist us in judging of the improvements still possible to be adopted for ventilators. The approximate manometrical results in our table permit us to estimate at ·750 the actual manometrical yield of a well-made Guibal machine.

4. DETERMINATION OF THE INITIAL DEPRESSION FOR VENTILATORS WORKING WITH DIRECT IMPULSION.

I define thus, following the example of M. Devillez, the ventilators which act by oblique stroke on the air which they displace.

Although these machines are falling into disuse, it is better that the reader should know them. Works on mining never fail to devote a few lines to the subject. The three typical machines are—First, the screw of Motte, with single or double spiral turning in a cylindrical tube, like the Archimedean screw; Second, the ventilator with the helix, by M. Pasquet—an annular crown fitted with helicoidal partitions, cutting the air with a rapid rotation; Third, the ventilator, with vanes like a windmill, of M. Lesoinne, in which the preceding partitions are replaced by numerous little vanes.

To these three I should add the Davaine ventilator at the mines of Bully-Grenay, formed of four helicoidal vanes fixed on a thick spindle or newel. This machine has been the object of a notice by M. Sens, in the 'Annals of Mines' for 1860.

The whole of these machines are based upon the same principle and differ only in their details.

Fixed in general on thin mines, this being the condition of most Belgian mines, these ventilators have small power of depression, and have always given an insufficient quantity of air, so that they have been readily abandoned. It is certainly possible, however, in following step by step the indications of a theory, to improve in a great measure the manometrical results, and even to obtain certain advantages inherent to this kind of machine, and it may be the last word has not been spoken on this subject. I will consider them presently.

I need not repeat the general conclusions established above. The theory developed in the first paragraph applies, as I have taken care to show, to all deprimogen ventilators without exception. The notion of the initial depression, and of orifice of passage, has not been less evident for ventilators by direct impulsion than for those with centrifugal force. It remains for us now to determine a new analytical value for the initial depression.

I will take as a type of machine, the ventilator with the vanes of the windmill, since it will present itself to us readily. I will adopt for it, as for the ventilator with centrifugal force, the hypothesis of a perfect ventilator.

Fig. 10.

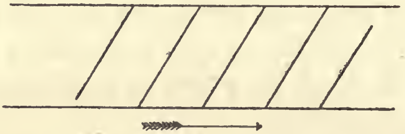
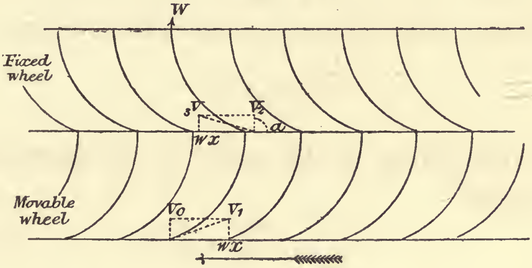


Fig. 10 is a section of the vanes made at a distance x from the axis, consequently following a cylindrical surface of radius x. According to the inventor, the wings should be flat and act by an oblique stroke on the air drawn in. But such a machine can never have any claim to be considered a perfect ventilator. It receives the air with a shock, and allows it to escape with a considerable whirling speed.

We may remedy the first defect at once by twisting the vanes towards their lower attachment in such a manner as to make them cut the air, following the resultant of the ascending speed of the air drawn in and of the speed of rotation of the machine at the point in question. It is exactly what we have done for the ventilators with centrifugal force. As to the second defect it leads by assimilation to an artifice of the same nature as a Guibal chimney. We may reduce the whirling speed of the air thrown out by receiving it in *évasée* passages, where its speed may be slowly extinguished and its *vis viva* restored. We should then obtain the following arrangement. The movable wheel of the Lesoinne machine would be surmounted by a second fixed wheel with the vanes inclined in the contrary way to those in front of them, and forming between them passages of the requisite conformation. Their lower edge would be in the direction following the absolute speed of the air projected by the moving wheel, and their upper edge would follow in the plane of the axis. This is similar to the arrangement indicated long since by M. Harze in the memoir of which we have spoken above.

FIG. 11.



With the machine so completed we have now to determine the depression which it is capable of producing; like centrifugal ventilators this depression results from a series of actions, some additive others subtractive, which we must successively pass in review.

First, The motionless air in the chamber which is in front of the ventilator, is carried with the speed V_0 to the inferior part of the vanes. We must then at once place to the debit of the depression the generative height of this speed.

Let it be,

$$-\frac{V_0^2}{2g} \qquad (1)$$

Second, Once drawn within the vanes, the air passes through their spaces with a gradually decreasing speed, in consequence of the passages opening out in approaching the upper level. If V_1 is this speed at the entry and V_2 that at the outlet the gain of pressure in this passage will be given, as has already been said, by the theory of Bernouilli—

$$+\frac{V^2_1}{2g}-\frac{V^2_2}{2g}.$$

The relative speed of entry V_1 being the resultant of the initial speed V_o, and of the speed of the drawing in of the vanes ωx, its square V_1^2 may be replaced by the sum

$$V_o^2+\omega^2 x^2.$$

I may, then, bring to the credit of the depression the algebraic sum

$$+\frac{V_o^2}{2g}+\frac{\omega^2 x^2}{2g}-\frac{V_2^2}{2g}. \qquad (2)$$

Third, The air reaching the upper level of the moving wheel is thrown out with the speed V_3, which is the resultant of the relative speed of outlet V_2 and of the speed of drawing in ωx.

The parallelogram of these speeds gives for V_3 the known expression,

$$V_3^2=V_2^2+\omega^2 x^2-2V_2\,\omega x\cos a,$$

a being the angle which the vane makes with the upper level.

Animated by this speed V_3 the air enters the diffuser; like the Guibal chimney the *évasée* passages of the diffuser gradually extinguish this speed, and if W represents the value which it possesses at the outlet, the restitution of pressure will be always, according to the theory of Bernouilli,—

$$\frac{V^2_3}{2g} - \frac{W^2}{2g}.$$

Replacing V_3 according to its value as a function of its component parts, I have to carry to the effective side of the depression, the sum,

$$+\frac{V_2^2}{2g} + \frac{\omega^2 x^2}{2g} - \frac{2\,V_2\,\omega\,x \cos\alpha}{g} - \frac{W^2}{2g}. \qquad (3)$$

Here the centrifugal force, acting perpendicularly to the trajectory of thin streams of air, cannot produce any increase in the depression. There remains then only to make the addition of the values (1), (2), (3) which gives, when all reductions are made,

$$H = \frac{\omega^2 x^2}{g} - \frac{2\,V_2\,\omega\,x\cos\alpha}{g} - \frac{W^2}{2g},$$

an expression of the depression sought.

I have supposed up to this time that the movable vanes have on the upper surface an inclination α. The preceding expression shows clearly that this angle should be 90°, that is to say, that these vanes should be in the plane of the axis. It follows that the middle term disappears, and the theoretical depression takes the simple form,

$$H_o = \frac{\omega^2 x^2}{g} - \frac{W^2}{2g}.$$

If, now, we suppose the passages of the diffuser to be so prolonged in height and width that the final speed of expulsion W may be considered as nothing, there remains as the value of the depression developed by the perfect ventilator

$$H_o = \frac{\omega^2 x^2}{g}.$$

Unfortunately this value only applies to the films of air placed at a distance x from the axis, and here appears the great defect of this class of ventilator. Whilst for the great value of x, that is to say for the region near the exterior circumference, the depressional action is very strong, it remains small over the lesser values of x, that is to say over the whole central part of the machine. The inevitable consequence of this inequality of action is that the expulsion of the air remains localised on the borders of the wheel, whilst towards the middle is produced a large re-entry of exterior air. In order to avoid this constructors have fitted to the central part of their machines circular diaphragms, gradually reducing the working part of the wheel to a narrow crown. It is thus with the Motte screw of the pits Montceau-Fontaine, where the exterior diameter was 7·41 feet. A diaphragm of 5·57 feet in diameter has been introduced, leaving an annular passage of only 11 inches in width. Under these new conditions a depression applicable to the ventilator by direct impulsion will be an intermediate, an average between that corresponding to the interior radius $\frac{\omega r^2}{g}$, and that due to the great radius $\frac{\omega^2 R^2}{g}$, and it approaches still nearer to this latter as the diaphragm or central newel is enlarged. Now we cannot increase this diaphragm without reducing at the same time the orifices of passage and lowering in proportion the effective depression; but this danger diminishes with thin seams, and we can understand that at its limit we must admit for the theoretic value of the depression in the perfect ventilator that which corresponds to the exterior radius,

$$H_o = \frac{\omega^2 R^2}{g},$$

and since ωR is the tangential speed which we have expressed up to this time by the letter u,

$$H_o = \frac{u^2}{g},$$

an expression identical with that found for ventilators with centrifugal force. From that we shall pass to the initial depression, with the aid of a coefficient of reduction,

$$H = K \frac{u^2}{g},$$

in which the value, more or less high, forms the manometrical result of the machine: with this exception, that to different causes which reduce the result we must add the difference of force which exists in practice between the interior and the exterior radius.

Thus there is but one and the same theory for all deprimogen ventilators without exception. For machines with direct force as for those with centrifugal force, the power of depression is connected with the tangential speed, the power of yielding volume to the orifice of passage by identical expressions. For the one as for the other the effective depression and the volume yielded result from two formulæ which I shall here repeat—

$$h = \frac{K u^2}{g\left(1 + \frac{a^2}{o^2}\right)}, \qquad V = \frac{0 \cdot 65 \sqrt{2 K}\, a u}{\sqrt{1 + \frac{a^2}{o^2}}}.$$

I have not found in any industrial works experiments sufficiently complete to allow me to make a calculation with sufficient exactness of the manometrical result and of the orifices of passage of a ventilator by direct impulsion. I will content myself, then, by giving, as I did for centrifugal ventilators, a table of manometrical results drawn up with the aid of all the experimental data relating to these machines that I have been able to procure.

TABLE

No.	Date.	Mine.	Dimensions.		
			Exterior Diameter.	Diameter.	Height.
			ft.	ft.	ft.
			PNEUMATIC SCREW		
1	1842	No. 2 Pit, Monceau-Fontaine	2·624	·095	2·624
2	..	Ditto	2·624	·095	2·624
3	Apr. 18, 1842	Colliery of Chatelet	3·936	..	..
4	July 7, 1843	Colliery Sauwartan-sur-Dour	4·59	·150	3·39
5	Nov. 2, 1849	Colliery of Pieton-Campagne	6·56	3·18	3·28
6	July 23, 1849	Colliery of Monceau-Fontaine	7·216	5·576	3·60
7	Ditto	Ditto	7·216	5·576	3·60
8	June 1, 1843	Colliery of Trieu-Kaisin	9·84	·196	2·624
			VENTILATORS WITH HELICOIDAL		
9	May 31, 1843	Colliery of Poirier..	5·576	1·968	3·54
10	June 18, 1843	Ditto	6·56	1·64	3·93
11	July 23, 1848	Colliery of Vivier-du-Couchant	7·54	4·26	·918
12	Aug. 14, 1849	Colliery of the Reunion at Mont-sur-Marchienne	7·20	3·412	·623
13	Ditto	Ditto	7·20	3·412	·623
14	Oct. 26, 1848	Ditto	7·20	5·57	·656
15	Nov. 2, 1848	Ditto	7·20	5·57	·656
			VENTILATORS WITH VANES OF A		
16	..	Grand-Bac	8·72	·918	..
17	..	Ditto	8·72	·918	..
18	..	Colliery of Val-Benoit, near Liége ..	8·85	·918	..
			VENTILATORS WITH HELICOIDAL		
19	Aug. 2, 1860	Mines of Bethune, at Bully-Grenay ..	8·20	3·28	..

No. II.

Publications.	Authors.	Equivalent Orifice. sq. ft.	Approximate Manometrical Result.	Remarks.
OF M. MOTTE.				
Memoir on Machines applied to Ventilation of Mines, p. 42.	G. Glepin	3·583	·050	Two helicoidal slides. This screw is the first constructed.
Annals of Belgian Public Works, Vol. I., p. 236.	Gonot	2·872	·084	The same machine. The mine being narrowed, the result is better.
Memoir on Machines applied to Ventilation of Mines, p. 40.	Glepin	1·883	·121	Two helicoidal slides.
Ditto, p. 40	Ditto	3·034	·183	Ditto.
Annals of Belgian Public Works, Vol. XI., p. 1.	Jochams	3·72	·208	Ditto.
Ditto	Ditto	6·197	·189	Ditto. The machine is fitted with diaphragms which make the air enter at the centre and leave at the circumference.
Ditto	Ditto	3·292	·230	Ditto. The mine had been artificially narrowed, which improved the result.
Memoir on Machines applied to Ventilation of Mines.	Glepin	6·442	·199	Ditto. An inverse current was produced towards the centre of the machine.
VANES, BY M. PASQUET.				
Memoir on Ventilating Machines, p. 64.	Glepin	7·85	·117	Three vanes in a conical form.
Ditto, p. 68	Ditto	2·162	·120	Six vanes, same contruction as last.
Annals of Public Works, Vol. XI., p. 1.	Jochams	4·529	·188	Type, Pasquet modified.
Ditto	Ditto	6·56	·131	Ditto. Helicoidal passage.
Ditto	Ditto	4·163	·182	Same machine. The mine being narrowed increases the result.
Ditto	Ditto	7·42	·123	Ditto.
Ditto	Ditto	3·658	·197	Ditto. The mine being reduced increases the result.
WINDMILL, BY M. LESOINNE.				
Treatise on Working of Mines, by Ponson.	Trasenster	13·66	·080	Six vanes inclined to the centre.
Ditto	Cabany	15·49	·069	The mines were large, giving a bad result.
Ditto	Trasenster	10·32	·131	Ten vanes inclined through the whole length.
VANES, BY M. DAVAINE.				
Annals of Mines, Vol. XVII., p. 425.	Sens	4·633	·161	Four vanes of wood, forming a screw.

The results in this table are all very feeble. The highest does not exceed 0·230. We must not be astonished, for none of the machines named realise the conditions which are so clearly required by the theory; none of them have their vanes straightened to the plane of the axis, and they do not throw out the air into a diffuser.

Another cause occurs to still further diminish the result obtained—the insufficiency of the orifice of passage. The largest of these ventilators is no more than 9·84 feet diameter, and so, if we deduct from that the surface occupied by the diaphragm or the central spindle, there remains only a very narrow passage, which absorbs in pure loss a great part of the depression. We see this at once if we *reduce* or *enlarge* the equivalent orifice of the mine; at the Pit No. 2 of Monceau-Fontaine (Nos. 6 and 7 in the table), a small reduction suffices to increase the result from 0·189 to 0·230. It is the same at the colliery Reunion (Nos. 14 and 15), where, from the same cause, the result rises from 0·123 to 0·197.

These observations warrant the assumption that if the average of the "approximate results" in our table attains to 0·145, the exact manometrical result, based on the initial depression, would certainly exceed 0·300.

It is impossible to say which is the best of the four types of ventilators examined, for our observations were neither sufficiently regular nor sufficiently numerous to demonstrate a marked superiority. The only thing which appears to be at all clear is that the large diameters are favourable to yield. It was to such machines as this that recourse was had for the purpose of ventilating the large hall at the Palace of the Trocadero for *fêtes*. In the excellent communications made by M. Bourdais to the Members of Congress at Paris, he said that they obtained very remarkable results with the employment of machines of the helix type. Are these facts, then, in opposition to what I have shown?

I think not. The truth is that the ventilation of a large hall is incomparably more easy than that of a mine. It is sufficient for M. Bourdais to have a pressure of 0·23 inch of water in order to obtain a circulation of 2000 cubic feet of air per second, but these figures correspond to an equivalent orifice of about 97 square feet. Besides, the work was divided between two machines, each of which had no more than 0·12 inch of pressure to produce. Under such conditions we may say that all ventilators are good, provided that they possess a sufficient orifice of passage. The motive power required is the smallest possible; its economy becomes a secondary consideration; and one is naturally led to choose the most simple machine, the least cumbersome, and especially the least noisy.

It appears from these considerations that ventilators by direct impulsion whilst good for ventilating buildings, could only give very feeble results upon collieries. Is it then possible entirely to proscribe them? I would not say so. Up to the present time there has been so little regard paid in their construction to the requirements of theory, that we may hope that with more intelligent arrangements we may approach as high results as a Guibal ventilator. Besides, these machines possess in some respects an important advantage, which, under certain circumstances, might lead the balance to be given in their favour: they do not occupy in the plane perpendicular to their axis, an area greater than their exterior circumference. To fully understand this advantage, we must assume for a moment that under certain circumstances we might have to place a ventilator within the mine. A Guibal would require an enormous space, not only for its circumference but for the eccentricity of its cover and chimney. A ventilator by direct impulsion would only require a circular chamber equal to that of its vanes.

This hypothesis of a ventilator below the surface, if it has never yet been, might still be realised. Constantly we see in mines currents of water descending unutilised from great heights to reach the sump. Would it not be rational to utilise this force to turn a turbine placed on the axis of a ventilator?

5. Motive Power.

To complete the theoretical study in which we are engaged, it remains for us to determine the motive power necessary to drive the deprimogen ventilators. I mean by motive power the work to be applied to the shaft of a ventilator to set it in motion.

Suppose, then, a deprimogen ventilator attached to a mine where the equivalent orifice is known, and turning with a given tangential speed. To determine the exact condition, let us suppose that it is a centrifugal ventilator, and that its vanes are bent in the direction of the radius as theory requires, what would be the motive power required by this machine?

If we wish to make this determination by rational and direct method, it will be necessary first to establish a polygon of acting forces for any element of the profile of the vane; then to project the resultant on the trajectory of the element; to multiply this projection by the space passed through; and then to pass by an integration of the element to the entire vane. I will content myself here with the following *à posteriori* method:—Let us admit for a moment that our ventilator is a perfect machine, as we have often done during this study. The result will be 100 for 100; or, otherwise, the motive power shall be equal to the power utilised, and as this latter is obtained it follows as a well-known rule in multiplying the volume by the depression that I have for the motive power the simple product

$$T_m = H_o V_o,$$

H_o being the theoretical depression expressed in inches of water and V_o the corresponding value.

If, now, we call to mind machines more or less imperfect, the observed depression will be notably inferior to the theoretical value H_o, and the volume afforded reduced in proportion. But recalling what was said when we commenced we shall remember that this diminution is only apparent—the imperfect ventilator developed the theoretical depression equally as well as the perfect ventilator, only that a certain portion of this depression was absorbed by frictions, losses of duty, and other imperfections in the machine.

In the first of the two factors of motive power H_o there is no change; the second V_o becomes the effective volume given, V. Now add the work of passive resistance inherent to every machine made by human hands, and we shall have for the expression of effective motive power—

$$T_m = H_o V + T_p.$$

Thus the motive power to be applied to a ventilator with centrifugal force and with radial vanes is equal to the product of the theoretical depression by the volume yielded, increased by the work of passive resistance.

All the terms of this expression may be easily calculated in advance, or at least with an approximation sufficiently accurate for the constructor.

The theoretical depression for ventilators with radial vanes, expressed in inches of water, is given by the formula—

$$H_o = \frac{u^2 \delta}{g}.$$

We shall find in the additional note (E), a table of the results of calculations, in which this depression is given for all practical values of the tangential speed.

When the vanes are inclined to the radius, the value of the theoretical depression is modified a little and becomes

$$H_o = \frac{u^2 \delta}{g} - \frac{u V^2 \cos \alpha \delta}{g},$$

V^2 being the relative speed of the air leaving the vanes. It is modified in the same way for ventilators by direct impulsion, or, correctly speaking, the theoretical depression is due not to the tangential speed, but rather to the speed of a certain average point, of which the distance from the axis has for its value—

$$\rho = \frac{\sqrt{R^2 + R r + r^2}}{3}.$$

But the superiority of the ventilators with centrifugal force and the radial vanes appears to be generally recognised, so that the first expression of H_o is alone necessary.

The knowledge of the volume given V results, either from the formula established above, or from a simple hypothesis.

As to the passive resistances they are of two kinds, easily determined by methods familiar to engineers, viz.:—

The friction of the shaft on its bearings; and

The friction of the air drawn in by the vanes against the fixed sides of the ventilator.

For this latter friction it is well to observe that of the two components of the air moving in the machine, one only interests us, that which follows the direction of the circumference described by the vanes. The component parallel to the radius need not in effect increase any resistance to the load of the propulsive vane, since it is perpendicular to its movement. This fact much simplifies the matter, for it permits us to reduce the complex movement of the air to a simple rotation round the axis, as in the case when the mine is shut off and the air turns in its place.

Thus the calculation limits itself to measuring the friction surfaces, estimating the average speed of friction, and applying to these data the coefficient of friction based upon experimental knowledge, in which, according to Aubuisson, the value will be equal to about ·0032. To these two frictions the passive resistances are reduced, which affords the work to be applied to the shaft of the ventilator.

But if we mean by the motive power the work of the steam acting on the piston of the machine as it is measured with the indicator of Watt, it is necessary to add to the passive resistances all the shocks and frictions on the part of this machine, not forgetting the important work absorbed by the belt where this kind of transmission exists.

I have insisted on a simple means of motive power being employed by constructors in this calculation, because they often employ for this object very fantastic methods. I may cite amongst others that which consists in taking for the work of opposing forces the product of the depression by the surface of the vane, but this method is doubly erroneous, for it neglects the yield, which is one of the factors of work, and introduces the surface of the vane, where the influence is nothing.

We may remark, however, that the motive power increases rapidly when we increase the speed of rotation of the ventilator, the volume V varying as the simple speed, the depression H_o as its square, and the first term of the work of the motor, and also the most important, $V H_o$ increasing as the cube of the speed. So it is less easy to make this latter vary within large limits than might at first sight appear. If, on the contrary, we suppose the speed of rotation to be invariable, H_o becomes constant, and the motive power depends only on the yield V. This has the singular effect, which at first appears almost paradoxical, that the more we increase the resistance to the passage of the air, the more the work is reduced, and the ventilator increases in speed. And if, on the contrary, we give the air free access to the machine, the work becomes greater, and the speed of the ventilator is reduced. We observe just the reverse with the volumogen ventilator.

The expression that we have now to find for the engine power to be applied to deprimogen ventilators enables us to establish the mechanical yield of these machines. I say mechanical in opposition to the manometrical useful effect, of which we spoke just now. We know the work useful effect; it is the product $V h$ of the effective volume by the effective depression; the motive power is yet to be determined. Then the mechanical yield is the proportion of useful work to the motive power and it takes the form

$$R' = \frac{V h}{V H_o + T_p}.$$

We may replace in this expression the quantities Vh and H_o by their values in a function of the given characteristics of machines and of the mines which they ventilate (equivalent orifice, tangential speed, &c.), but the term T_p of the denominator not admitting of reduction, we should have a complicated expression, and consequently not to the point. We may also with the slightest reflection observe in the preceding expression the influences of different kinds which vary the results.

We may ask, for example, what becomes of the mechanical yield of a ventilator, when we increase its speed of rotation. The useful work $V h$ and the first term $V H_o$ of the motive power will both increase as the cube of this speed, so that if we can admit that the term T_p of passive resistances increases with the same rapidity, the yield will be obtained independent of the speed. But in reality the term T_p increases much less quickly, hence the yield improves as the speed increases. This is proved by different experiments where care has been taken to vary the speed of the ventilator. I may cite, for instance, the numberless experiments made by MM. Gille and Franeau on the Guibal ventilator of Crachet, to be found in the treatise on ventilation by M. Devillez, page 227.

If, supposing the speed of rotation to be invariable, we increase the equivalent orifice of the mine from zero to infinity, we shall find at first no result, the useful effect being nothing itself. Beyond, the result increases by degrees, but remains feeble in consequence of the importance of the term T_p of passive resistance. In proportion as this influence weakens the yield and the result continue to increase. But then there occur rapidly increasing frictions of the air traversing the machine; quickly this new influence predominates, and having reached a certain maximum the yield begins to decrease, and finally attains a point where it becomes nothing.

This work of the yield is very clearly shown by the experiments of the Commission of Gard, to which I refer the reader. It shows that for every deprimogen ventilator there corresponds a given mine for which its yield is greatest, and to which it is especially appropriate.

As to the influence of the manometrical yield, and of the orifice of passage, it is easy to see that the mechanical yield varies in the same direction as these. When they are weakened, it is because the frictions, losses of quantity, and other imperfections increase, all causes which assist to weaken the yield.

The experiments made to measure the mechanical yield of ventilators are much less abundant than those which are limited to measure the yield and depression.

In many cases they have sought to establish the motive power by applying to the surface of the piston the pressure observed on the boiler gauge; but this method is based on the employment of coefficients more or less arbitrary, and does not appear to me to merit any confidence. I cannot admit as important data results not obtained with the aid of the Prony friction brake, or of the Watt indicator. The use of the former is much more limited than the latter, besides it supposes that we may break the connection between the power and the resistance, a circumstance which does not happen except in machines where the motive power is transmitted by a belt. These inconveniences are unfortunate, for, from the point of view of results, the brake presents a great advantage over the indicator. It measures exclusively work transmitted to the shaft of the ventilating machine, whilst the indicator includes at the same time all the passive resistances of the motive power; the numbers obtained in the result will be different also according to the instrument for measurement to which we have recourse, they will be weaker with the indicator in consequence of the exaggeration of the term T_p of passive resistances.

I have included in the table on pp. 66–69 a certain number of observations of yield selected from industrial works. In general the observations are repeated a certain number of times for each machine, varying sometimes the speed and sometimes the resistance of the mine, and I have reproduced the minimum and maximum results in the table. The signification of these numbers varies with the dynamometer employed; I have been careful to specify this latter in the column observations. The ventilators by direct impulsion are placed at the head of the table in order to follow as nearly as possible the order of increasing yield.

As we may see (Table III.), the ventilators by direct impulsion give only a very poor mechanical result; the highest deduction being made for passive resistance, it does not exceed ·324.

The ventilators without cover present some very irregular results, the cause of which is not clearly seen. Thus it is surprising that the ventilator of Crachet, which is 22·96 feet in diameter, does not exceed ·22, whilst the turbine of Lalle rises to ·47. We may see from these results that if there has been any progress with ventilators by direct impulsion the advantage gained is small. This progress continues pretty equally with covered ventilators, from ventilators with rectangular chimney up to ventilators properly called Guibal, which are at present the most efficient.

If we take as a characteristic of the yield of each type of ventilators the arithmetical average pure and simple of the figures shown in our table, we shall obtain the following series:—

Ventilators by direct impulsion	0·260
,, by centrifugal force, without cover	0·278
,, with centrifugal force, covered, without chimney	0·284
Ventilators with centrifugal force, with cover and rectangular chimney	0·379
Ventilators with centrifugal force, with cover, slide, and *évasée* chimney	0·467

Certainly it is rather the order of these values than their absolute magnitude which we should consider here; but even with this reserve the series is still very interesting and explicit. The most important of these averages is that of the Guibal ventilators, for they result from a number of already important observations. Still I think it rather poor compared with the minimum of our table results in general, though this may be a consequence of taking observations

TABLE

No.	Date.	Mine.	Dimensions.					
			Exterior Diameter.		Diameter of *Ouïe.*		Width.	
			ft.	in.	ft.	in.	ft.	in.
			VENTILATORS BY					
1	Apr. 7, 1843	Motte screw, at No. 1 Pit, Sauwartan-sur-Dour.	4	7·1	0	1·8	2	4·7
2	Aug. 2, 1860	Davaine's Ventilator, with helicoidal vanes, at Bully-Grenay.	6	6·7	0	3·9	..	
			UNCOVERED VENTILATORS BY					
3	Mar. 28, 1844	Combes' Ventilator, Grand Hornu ..	5	6·9	4	5·5	1	1·4
4	Nov. 25, 1842	Letoret Ventilator, Colliery of St. Victoire, at Frameries.	10	3·6	5	3·0	3	0·6
5	Sept. 24, 1876	Turbine Ventilator, Mines of Lalle and Bessèges.	12	5·6	4	4·7	4	1·2
6	Apr. 30, 1865	Guibal Ventilator, Colliery of Crachet and Picquery.	22	11·5	9	10·1	4	7·1
7	..	Lambert Ventilator, Ormont Colliery, at Chatelet.	26	2·9	..		4	7·1
			COVERED VENTILATORS, WITHOUT					
8	Aug. 10, 1859	Grisœil Colliery, No. 10 Pit	13	1·4	5	3·0	5	0·2
9	Nov. 28, 1865	Guibal Ventilator, Crachet and Picquery	22	11·5	9	10·1	4	7·1
			COVERED VENTILATORS WITH					
10	Mar. 22, 1859	Jean Bart Pit	11	9·7	5	3·0	4	11·0
11	July 29, 1877	Créal Mines, Bessèges	19	8·2	11	5·8	3	7·3
12	..	Grand Buisson Colliery	22	11·5	9	10·1	5	6·9

No. III.

Publications.	Authors.	Manometric Yield.		Observations.
		Min.	Max.	
DIRECT IMPULSION.				
Memoir on Ventilating Machines.	Glepin	0·220	0·230	Prony brake.
Annales des Mines, 1860, p. 425.	Sens, Mining Engineer.	0·264	0·324	Watt indicator, motor without load deducted or the result would not exceed 0·253.
CENTRIFUGAL FORCE.				
Treatise on Mine Working, by Ch. Combes.	Glepin	0·270	0·290	Prony brake.
Memoir on Ventilating Machines, p. 46.	Ditto	0·160	0·180	Ditto.
Bulletin of Society of Mineral Industry, 2nd Series, Vol. VII., p. 477.	Aguillon, Fumal, and Murgue	0·277	0·470	Watt indicator, by Commission of Gard.
Ventilation of Mines, by M. Devillez, p. 227.	Gille and Franeau.	0·160	0·220	Type, Guibal, before being covered.
Ditto	Devillez and Letoret, &c.	0·354	0·398	Prony brake.
CHIMNEY, BY CENTRIFUGAL FORCE.				
Annals of Public Works, Belgium, Vol. XVII.	..	0·267	0·390	Watt indicator.
Ventilation of Mines, by Devillez, p. 228.	Gille and Franeau.	0·170	0·310	Ditto, same as No. 6.
CHIMNEY OF CONSTANT SECTION.				
Notes of M. Cabany.	A. Cabany	0·334	0·342	Ditto, Guibal, early type.
Bulletin of Society of Mineral Industry, Vol. VII., p. 477.	Aguillon, Fumat, and Murgue.	0·422	0·517	Ditto. Part of work restored by a canal *évasée.*
Ventilation of Mines, by Devillez.	..	0·320	0·334	Ditto, Guibal, but the chimney of constant section.

TABLE

No.	Date.	Mine.	Dimensions.					
			Exterior Diameter.		Diameter of *Ouïe.*		Width.	
			ft.	in.	ft.	in.	ft.	in.
Covered Ventilators with Slide and								
13	June 25, 1862	Verger Pit, Anzin	16	4·8	8	2·4	6	6·7
14	Aug. 11, 1861	Grosse-Fosse, Anzin	16	4·8	8	2·4	6	6·7
15	July 22, 1877	Grangier Pits, Bessèges	16	4·8	8	2·4	6	6·7
16	Apr. 22, 1866	Mine of Forchier	19	8·2	9	10·1	..	
17	July 31, 1865	Colliery of Crachet and Picquery ..	22	11·5	9	10·1	5	6·9
18	Mar. 1866	Ditto	22	11·5	9	10·1	5	6·9
19	Mar. 25, 1866	Ditto	22	11·5	9	10·1	5	6·9
20	..	Grand Buisson	22	11·5	9	10·1	5	6·9
21	Sept. 11, 1870	Grand Mambourg	22	11·5	9	10·1	8	2·4
22	1866	Nœux	22	11·5	9	10·1	5	6·9
23	Oct. 24, 1869	Rieu du Cœur	29	6·2	9	10·1	6	6·7
24	May 17, 1869	Louvière	29	6·2	9	10·1	6	6·7
25	June 21, 1869	Grand Buisson	29	6·2	9	10·1	6	6·7
26	Mar. 25, 1877	Crachet and Picquery	39	4·3	13	1·4	8	2·4
Workshop								
27	..	Uncovered Fan of M. Tournaire ..	2	9·5	1	6·9	..	
28	July 22, 1855	Ventilator given to Exhibition by M. de Lacolonge.	3	3·0	0	10·2	0	6·0
29	..	Ventilator made for charcoal furnace by M. Rittenger.	5	3·0	1	2·2	0	3·5

No. III.—*continued.*

Publications.	Authors.	Manometric Yield.		Observations.
		Min.	Max.	
Evasée Chimney (Guibal Type).				
Notes	Cabany	0·418	0·460	Watt indicator.
Ditto	Ditto	0·510	0·640	Ditto.
Bulletin of Mineral Industry, Vol. VII.	Aguillon, Fumat, and Murgue.	0·250	0·494	Ditto. The small yield was obtained on a thin mine.
Ventilation of Mines, Devillez.	Stoesser and Devillez.	0·413	0·455	Ditto ditto.
Ditto	Gille and Franeau.	0·380	0·610	Ditto, same far as No. 6, complete.
Ditto	..	0·307	0·749	Ditto. Experiments made when mine much altered.
Ditto	Stoesser and Devillez.	0·440	0·501	Ditto.
Ditto	..	0·426	0·725	Ditto, same fan as No 12, chimney complete.
Ditto	De Poitier	0·426	0·534	Ditto. This fan is of great width.
Unpublished	C. Brice	0·230	0·410	Ditto.
Ventilation by Devillez	Brunin and others.	0·452	0·580	Ditto.
Ditto	Roger and Halley.	0·279	0·513	Ditto.
Ditto	..	0·382	0·382	Ditto.
Revue Universelle, July 1877.	Hubert, Devillez.	0·538	0·555	Ditto.
Blowing Fans.				
AnnalesdesMines,1860	Tournaire	0·240	0·500	Prony brake.
The "Génie Industriel"	Experiments at Conservatoire des Arts et Métiers.	0·132	0·646	Ditto.
Ventilation, by Rittenger, 1858.	Rittenger	0·110	0·230	Ditto. Equivalent orifice very small and so yield and effect is poor.

under inconvenient working conditions and often those unfavourable to the yield. I think that we may accept the number 0·500 as representing with sufficient exactness the average yield of this kind of machine under the conditions in which they generally work. It is the result of experiments made with Watt's indicator, the only dynamometer possible with direct-acting machines. If we could have measured the motive power on the shaft itself with the aid of dynamometers, or even by the torsion on the shaft as has been proposed by M. Hirn, we should certainly have obtained a higher yield.

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6. Conclusions.

I will now give a *résumé*, in a few lines, of the theoretical views developed in the preceding paragraphs. In theory every deprimogen ventilator turning under the action of a motor, gives a certain depression depending entirely on the tangential speed, and consequently independent of the volume of air which it yields. This depression has for its value—

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

In practice two causes occur to prevent the effective depression yielding this ideal value.

First, imperfections of different kinds, independent of yield, oblige us to apply to the preceding expression a coefficient of reduction K, which we have named the *manometrical yield.*

Second, the frictions and losses of the load of air traversing the machine, losses proportional to the square of the yield, and expressed by the area of the orifice of passage *o*.

From these two enfeebling causes, the value for the effective depression becomes

$$h = \frac{K u^2}{g\left(1 + \frac{a^2}{o^2}\right)}.$$

From the knowledge of the effective depression and the equivalent orifice of the mine, there is deduced by the application of a formula for the flow in a thin medium, the volume of air yielded—

$$V = \frac{0 \cdot 65 \sqrt{2 K} \, a u}{\sqrt{1 + \frac{a^2}{o^2}}}.$$

Finally the product of volume by the theoretical depression which virtually subsists, and gives to the motor the same load as if it had been manifest, gives, in taking account of passive resistances, the value of the motive power—

$$T_m = V H_o + T_p.$$

In the first part of this study, published in 1872, I stated in the following terms the problem of mine ventilation:—

To make a given quantity of air traverse a given mine.

Then, having proposed to represent mines by their equivalent orifices, I thus modified this statement:—

To make a given volume of air circulate through an orifice in a thin medium.

I cannot pretend that it is always in these terms that the problem presents itself to those studying it; but it is at least the most general one, and it cannot give any difficulty in the treatment of it under different forms.

Let a volume V be made to pass through an orifice a.

Let h be the necessary depression to cause this circulation, a depression which will be immediately given by the formula of the flow through a thin medium—

$$h = \frac{V^2}{\overline{0{\cdot}65}^2 a^2\, 2g}.$$

The engineer should then decide upon the type of machine that he intends to adopt. Theory and experience show that the best deprimogen ventilator is the ventilator with centrifugal force, in which the air expelled by the vanes is received in *évasée* channels, like those of the Guibal ventilator. Let us admit, then, that choice is made of the Guibal ventilator. For comparison with existing machines, we observe that the manometrical yield in these ventilators may be estimated at 0·750. As to the orifice of passage, it is more difficult to decide, this element depending especially on the width, on the eccentricity, and on the *ouïe.* I have only given three examples of the orifice of passage, those of the ventilators of Bessèges, Créal, and Lalle; they may assist in suggesting a provisional hypothesis, and then, introducing these two data K and o in the formula for effective depression,

$$h = \frac{K\, u^2}{g\left(1 + \frac{a^2}{o^2}\right)},$$

we have an equation from which it would be easy to deduce the value of the tangential speed u.

This is the exact method arising rationally from our theory; there is another, more approximative but more simple, and in fact sufficient for the application; it is based on the knowledge of the approximate manometrical yield. This yield, according to our first table, is on an average, for

Guibal ventilators, 0·650. This figure increases a little for thin seams and diminishes for thick ones. Dividing the effective depression by this coefficient, always, it is true, somewhat arbitrary, we obtain the theoretical depression

$$\frac{h}{K} = \frac{u^2}{g},$$

whence we deduce easily the value of the tangential speed u.

This tangential speed is a most important factor in the construction of deprimogen ventilators. We may see this either in a small ventilator turning with great speed, or in a large machine turning slowly. On this point the constructor is altogether free, and may be guided by considerations of the place for which it is required, of economy, and of mechanical simplicity.

The form to be given to the vanes has been described before. They should present to the circumference of the *ouïe* an inclination following the resultant of their movement of rotation and of the movement of the air penetrating their spaces. From this they should incline by a gentle curve, and terminate by a part directly following the radius. As to their number, it seems to me that it is an advantage to make them numerous; they guide the air better and shake less. The only objection is that by the thickness being repeated they rather reduce the orifice of passage.

The motive power to be applied to the machine so defined will be given by the formula

$$T_m = V H_o + T_p,$$

whence it suffices to make an hypothesis on the value of the passive resistances as far as it is known; but that is all the simplification possible. We have seen that the average value of the mechanical yield observed at the indicator with Guibal ventilators is 0·500; it is sufficient, then, if we have the elements of useful work $V h$, to double them in order to obtain with a sufficient approximation for practice the work to be applied to the piston of the motive power.

There remain to be determined the diameter of the *ouïe*, the width and the eccentricity, &c., but these elements result from considerations altogether different from those which I have enumerated, and I will return to this study for the fourth occasion, and I hope the last one, if circumstances permit me to establish the theoretical and practical conditions which exist in the best ventilators.

BESSÈGES, *January* 17, 1880.

ADDITIONAL NOTES.

NOTE A.

The Theory of Bernouilli.

This theory, which forms the base of hydraulics, may be thus expressed:—When a fluid vein where there is an established condition flows in any given form, if we make abstraction of the frictions which occur on the sides, at each point, the generative height of the speed, the pressure measured in column of fluid, and the height above an arbitrary horizontal plane, form a total constant—

$$\frac{V^2}{2g} + H + Z = \text{constant.}$$

In the questions relative to ventilation the fluid veins in an atmosphere of the same character and the same density as themselves are not affected by the action of their own weight. Consequently a vein moving primitively in the horizontal plane may be inclined in any direction whatever without being affected by the vertical displacement of its molecules.

This remark enables us to eliminate the term Z of the preceding expression, and to reduce it to the simple binomial—

$$\frac{V^2}{2g} + H = \text{constant.}$$

Thus in the vein of air the generative height of the speed and the pressure mutually compensate each other, the one increasing as the other weakens.

Let us consider two points, more or less distant from one another, in the same vein of air, their pressures and speeds being H and V for the first point, H′ and V′ for the second. We may then write—

$$\frac{V^2}{2g} + H = \frac{V'^2}{2g} + H',$$

or rather, by calling h the increase $H' - H$ of the pressure,—

$$h = \frac{V^2}{2g} - \frac{V'^2}{2g},$$

an expression which may be thus translated: *When the speed of a vein of air gradually diminishes from one point to another, the increase of the pressure is equal to the diminution of the generative head of the speed.* It is this statement which I assume to be present to the mind of the reader whenever in the course of this study I made reference to the theory of Bernouilli.

NOTE B.

Of the law of Proportionality between the Volume yielded and the speed of Rotations, and between Depression and the Square of this Speed.

All the published experiments, and all those which I have made myself on the ventilator of the mine of Créal, agree as to the evidence of this double proportionality. I will record two of the latter experiments taken promiscuously.

The first, on the 26th August, 1876, includes three observations of the volume yielded at three different speeds of the ventilator. Measurements were made with the aid of the anemometer of Combes. Twenty-three observations of speed made in twenty-three spaces being regularly divided over the section of measurement have allowed us to establish an average speed with a very satisfactory exactness. The numbers of the last column indicate the proportion of the yield to the speed of rotation, or, if we prefer, the number of cubic feet yielded per revolution of the machine.

No.	Revolutions per Minute.	Volume per Second.	Proportion of Yield to Speed.
1	40·8	315·4	7·73
2	49·2	386·9	7·86
3	58·3	454·6	7·79

The regularity of the final proportion leaves no doubt, especially if we take account of the difficulty in every particular in this kind of observation.

This proportional increase will evidently continue as far as it is possible to push the speed of the ventilator. Still, it is difficult to understand the opinion which we sometimes hear expressed that beyond a certain speed the yield ceases to increase, or rather only increases very slowly. It cannot be based upon any experiments which are sufficiently exact.

The volume yielded per revolution of the machine remains constant so long as the resistance of the mine itself does not vary; but it is clearly connected with this resistance, so that every variation in the value of the equivalent orifice shows itself by a corresponding variation almost proportionally to the yield per revolution. This observation suffices to show how irrational it is to seek to establish, as some writers have done, a more or less constant relation between the volume yielded and the volume *generated* by the rotation of the vanes. This kind of relation has no serious significance except for volumogen ventilators.

The second series of observations which I produce here was made on the 14th January, 1872; the depressions alone have been observed with a somewhat doubtful approximation to the extent of $\frac{1}{400}$ of an inch. The second column gives the squares of the speeds of rotation, and the last the proportion of the depressions to those of the square of the speed, a proportion of which it is necessary to verify the regularity:—

No.	Revolutions per Minute.	Square of Number of Revolutions.	Water Gauge. (Inches.)	Proportion of Depression to the Square of Speed.
1	33·8	1142·44	0·323	·000282
2	39·8	1584·04	0·444	·000280
3	49·0	2401·00	0·670	·000279
4	56·8	3226·24	0·893	·000276
5	64·0	4096·00	1·134	·000276

Here, again, the regularity of the final proportion proves itself in a sufficiently clear manner, having regard to the difficulty of measuring the depression with certainty in the midst of incessant oscillations.

We observe that the numerical value of this proportion falls in a regular slowly decreasing progression. There is here a certain indication of a natural action which was easily accounted for at the time the experiment was made. The chimney of the ventilator gives rise to a certain amount of aspiration, which is added to the effect produced by the vanes affecting relatively more the cases of weak depressions. When the natural movement is lively it affects very strongly the double proportionality which we seek to establish by experimental verification. To see it most distinctly in the case of the depression the best plan is to make a drawing of it, with the squares of the speeds for abscissæ and the observed depressions as ordinates. The points so obtained arrange themselves in a straight line, which, instead of coinciding with the origin itself, passes above or below it, at a distance which gives the exact measure of the action which is so troublesome. In the case of the volume where this action has an influence still greater we place in the abscissæ not the speed itself, but its square, and in the ordinates the square of the yield. In effect, if h_o represents the depression due to the natural action, and h that due to the ventilator alone, the volume yielded, given by the formula of escape in the thin medium, would have for expression

$$V = 0 \cdot 65\ a\ \sqrt{2\ g\ (h \pm h_o)},$$

and by raising it to the square

$$V^2 = \overline{0 \cdot 65}^2\ a^2\ 2\ g\ (h \pm h_o).$$

Remarking that h is proportional to the square of the speed, and that the product $\overline{0 \cdot 65}^2\ a^2\ 2\ g$ is constant, I may thus transform this equation—

$$V^2 = M\ \omega^2 \pm N\ h_o.$$

If for the present we take ω^2 in abscissæ and V^2 in ordinates, we have a straight line passing above or below the origin at a distance which will measure in size and in sign the value of the square of the yield which exists when the ventilator is stopped.

NOTE D.

Calculation by the Direct Method of the Motive Power to be applied to Ventilators by Centrifugal Force.

This note is of such a highly theoretical character that it seems hardly necessary to repeat it in full. It may be summed up by saying that for every ventilator by centrifugal force and with radial vanes the motive power, deducting passive resistances, is equal to the product of the volume yielded by the theoretical depression expressed in inches of water, confirming the exactness of the indirect method given in the body of the work.

NOTE E.

Of the Theoretical Pressure.

The theoretical depressions which ventilators with centrifugal force develop in the hypothesis of absolute perfection, constitute an interesting and useful study. We see in the preceding note that it forms one of the factors of motive power, and in this respect this knowledge is indispensable for a constructor. Besides, it serves as a term for comparison to establish the exact or approximate manometrical yield of deprimogen ventilators. In the case of a ventilator giving a certain depression it is sufficient to refer to the theoretical depression, and to take the proportion, to obtain this test of prime importance of the value of the machine. We give in the following table, expressed in inches of water, the values of the theoretical depression corresponding to the tangential speeds comprised between the practical limits of 49 and 114 feet per second, and in spaces of about $\frac{1}{120}$ of an inch. These values have been calculated with the aid of the formula

$$H_o = \frac{u^2 \delta}{g},$$

in which δ, the density of the air, has been supposed to be 1·200.

VALUES OF THE THEORETICAL DEPRESSION EXPRESSED IN INCHES.

Speed in feet of the Periphery per second.	Theoretical Depression in inches.	Speed in feet of the Periphery per second.	Theoretical Depression in inches.	Speed in feet of the Periphery per second.	Theoretical Depression in inches.
49·2135	1·0839	56·4315	1·4248	63·6495	1·8126
49·5416	1·0980	56·7596	1·4413	63·9786	1·8315
49·8697	1·1126	57·0877	1·4583	64·3056	1·8504
50·1978	1·1276	57·4158	1·4752	64·6337	1·8693
50·5259	1·1415	57·7438	1·4917	64·9618	1·8881
50·8540	1·1555	58·0719	1·5091	65·2899	1·9075
51·1821	1·1714	58·4000	1·5260	65·6180	1·9263
51·5102	1·1870	58·7281	1·5427	65·9461	1·9455
51·8383	1·2024	59·0562	1·5600	66·2742	1·9647
52·1664	1·2177	59·3843	1·5779	66·6023	1·9846
52·4944	1·2331	59·7124	1·5953	66·9304	2·0043
52·8225	1·2484	60·0405	1·6129	67·2585	2·0240
53·1506	1·2642	60·3686	1·6307	67·5865	2·0436
53·4787	1·2795	60·6969	1·6484	67·9146	2·0638
53·8068	1·2952	61·0247	1·6661	68·2427	2·0838
54·1349	1·3114	61·3528	1·6842	68·5708	2·1039
54·4620	1·3272	61·6809	1·7024	68·8989	2·1240
54·7910	1 3433	62·0090	1·7205	69·2270	2·1445
55·1191	1·3594	62·3371	1·7386	69·5551	2·1645
55·4472	1·3755	62·6652	1·7571	69·8832	2·1850
55·7753	1·3921	62·9933	1·7756	70·2113	2·2059
56·1034	1·4083	63·3214	1·7941	70·5394	2·2264

VALUES OF THE THEORETICAL DEPRESSION—(*continued*).

Speed in feet of the Periphery per second.	Theoretical Depression in inches.	Speed in feet of the Periphery per second.	Theoretical Depression in inches.	Speed in feet of the Periphery per second.	Theoretical Depression in inches.
70·8674	2·2472	85·6325	3·2811	100·4055	4·5098
71·1955	2·2681	85·9596	3·3062	100·7336	4·5394
71·5236	2·2890	86·2877	3·3315	101·0617	4·5693
71·8529	2·3098	86·6158	3·3567	101·3898	4·5988
72·1798	2·3305	86·9439	3·3822	101·7079	4·6287
72·5079	2·3518	87·2719	3·4079	102·0360	4·6589
72·8360	2·3736	87·6000	3·4335	102·3641	4·6880
73·1641	2·3953	87·9281	3·4594	102·6912	4·7179
73·4922	2·4165	88·2569	3·4854	103·0203	4·7488
73·8203	2·4381	88·5843	3·5104	103·3484	4·7791
74·1483	2·4598	88·9124	3·5368	103·6764	4·8094
74·4764	2·4819	89·2405	3·5574	104·0045	4·8401
74·8045	2·5039	89·5686	3·5838	104·3326	4·8705
75·1326	2·5256	89·8967	3·6101	104·6607	4·9012
75·4607	2·5480	90·2248	3·6365	104·9888	4·9319
75·7888	2·5701	90·5528	3·6629	105·3169	4·9630
76·1169	2·5925	90·8809	3·6897	105·6450	4·9941
76·4450	2·6150	91·2090	3·7164	105·9731	5·0248
76·7732	2·6373	91·5371	3·7432	106·3012	5·0563
77·1012	2·6598	91·8652	3·7699	106·6293	5·0868
77·4292	2·6827	92·1933	3·7971	106·9573	5·1189
77·7573	2·7055	92·5214	3·8204	107·2854	5·1504
78·0854	2·7277	92·8495	3·8514	107·6135	5·1819
78·4135	2·7506	93·1776	3·8786	107·9416	5·2134
78·7416	2·7744	93·5056	3·9056	108·2697	5·2453
79·0697	2·7955	93·8337	3·9398	108·5978	5·2772
79·3978	2·8209	94·1618	3·9673	108·9259	5·3090
79·7259	2·8441	94·4899	3·9933	109·2540	5·3409
80·0540	2·8677	94·8180	4·0228	109·5821	5·3729
80·3831	2·8909	95·1461	4·0508	109·9101	5·4051
80·7101	2·9146	95·4742	4·0787	110·2382	5·4378
81·0382	2·9386	95·8023	4·1067	110·5663	5·4700
81·3663	2·9623	96·1304	4·1350	110·8944	5·5018
81·6944	2·9862	96·4585	4·1630	111·2225	5·5350
82·0225	3·0081	96·7865	4·1917	111·5506	5·5677
82·3506	3·0342	97·1146	4·2201	111·8787	5·6008
82·6787	3·0586	97·4427	4·2484	112·2068	5·6334
83·0068	3·0831	97·7708	4·2772	112·5349	5·6665
83·3349	3·1074	98·0989	4·3053	112·8630	5·6996
83·6630	3·1313	98·4270	4·3346	113·1919	5·7327
83·9910	3·1567	98·7551	4·3638	113·5491	5·7661
84·3191	3·1811	99·0832	4·3939	113·8472	5·7996
84·6472	3·2059	99·4113	4·4220	114·1753	5·8331
84·9753	3·2311	99·7384	4·4512	114·5034	5·8659
85·3034	3·2599	100·0775	4·4807		

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