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FLOW NOZZLE WITH VARIABLE COEFFICIENT OF EFFLUX

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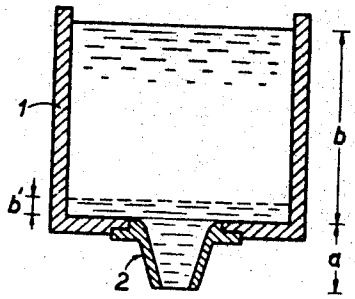



Fig.1.

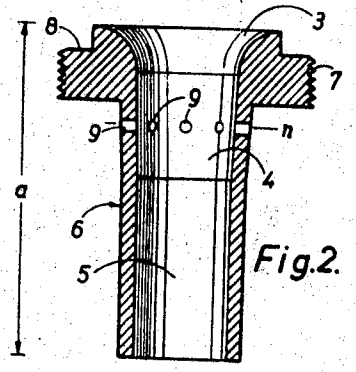



Fig.2.

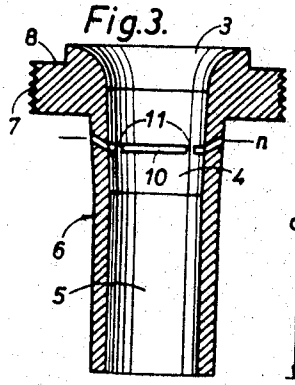



Fig.3.

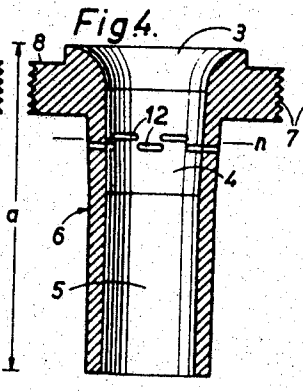



Fig.4.

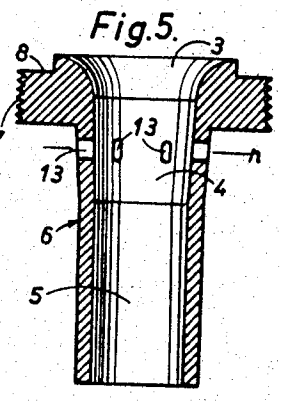



Fig.5.




Fig.7.




Fig.6.

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# FLOW NOZZLE WITH VARIABLE COEFFICIENT OF EFFLUX

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U.S. Cl. 239—428.5 4 Claims

## ABSTRACT OF THE DISCLOSURE

A variable coefficient of efflux nozzle for use in an incompressible fluid distribution system. The nozzle has a convergent zone at the input end and a plurality of lateral apertures in the walls forming the convergent zone at a point whereat the internal fluid pressure at rated output is substantially equal to the pressure externally of the nozzle.

This invention relates to a flow nozzle having a variable coefficient of efflux and more particularly suitable for devices utilised to distribute a liquid substantially uniformly over a horizontal surface. These devices are provided with numerous orifices which may be distributed either over surfaces or over networks of channels which are open at the top or of pipes which are closed at the ends. The orifices may be constituted by simple perforations formed in the bottom of a tank of liquid or in the bottom of the channels or in the pipes, or, as is the case within the scope of the present invention, by nozzles installed in said perforations.

The efflux of a nozzle is given by the expression

$$Q=mS\sqrt{2gH}$$

in which

Q is the efflux
S the outlet section of the nozzle
H the height of liquid above said section or, in the case of an immersed pipe, the corresponding load expressed as head liquid
$g$ acceleration due to gravity
$m$ a coefficient of efflux

The coefficient $m$ varies depending on the shape of the nozzle. For a smooth conical or cylindro-conical nozzle with widened entry, $m$ is very close to unity.

In order to obtain uniform efflux through all the apertures, it is necessary that the latter should be under the same load or static pressure, for example in the case of a tank or of channels open at the top under a head of liquid having the same value throughout. In practice, however, the static pressure of the liquid is not equal for all the apertures, either because of the loss of head or because of the variation of the dynamic pressure ($v^2/2g$) of the liquid circulating in an open channel or in an immersed or exposed pipe, or because of both these factors acting simultaneously.

In industry it is not possible to feed all the nozzles under the same static pressure, and a certain tolerance must be accepted. By selecting this tolerance for example



to be ±5% of the efflux and bearing in mind the fact that, as indicated above, this efflux in each nozzle is proportional to the square root of the static pressure of the liquid at the point corresponding to the nozzle in question, the variation of static pressure still admissible between the various apertures may be ±10%.

If in a multi-nozzle liquid distribution device the operation of which is adjusted for a normal efflux Q it is desired for any reason to reduce the flow of liquid, the variation of the head or load of liquid at points corresponding to different nozzles will increase and in this way bring about or accentuate the inequality of flow as between these nozzles, as is shown by an example illustrated in FIGURE 1, which shows an open channel **1** closed at one end and assumed to be equipped with two nozzles **2**.

Assuming that the length $a$ of the nozzles is 8 cm. and that with stable operation at full flow the head $b$ of liquid above the inlet of a nozzle is 40 cm., the head of liquid above the base of said nozzle, $H=a+b$, will be 48 cm.

The efflux of this nozzle will then be equivalent to:

$$Q=mS\sqrt{2gH}$$

If efflux diminishes to $Q'=Q/n$, the load H' measured with reference to the base of said nozzle becomes

$$H'=\frac{H}{n^2}(a+b)$$

For example, for $n=2$, which therefore corresponds to $Q'=Q/2$, the load is reduced to

$$H'=\frac{a+b}{4}=12 \text{ cm.}$$

This results in a head of liquid in the channel $b'=4$ cm., which therefore attains only one tenth of $b=40$ cm. Consequently, the speed of the liquid in the channel increases 5 times. As the loss of head in this channel is proportional to the square of the speed, it will therefore be 25 times greater than when operating at full flow, and this will result in a considerable reduction of the load on the second nozzle, and consequently an increase in the difference of flow between the two nozzles.

As explained above, the efflux of a nozzle depends on the normally invariable coefficient of efflux $m$. When the total efflux diminishes, that is to say when the static pressure at a point corresponding to a nozzle becomes smaller, the distribution of the liquid can therefore be improved by means of nozzles having a variable coefficient $m$ which is modified in the same direction as the efflux. It is true that there are nozzles which for this purpose have mechanical adjusting means, such as for example needles adapted to modify the section of the inlet, but it would be difficult and expensive to attempt to equip the large number of nozzles contained in a liquid distribution device with adjusting means and controls to ensure that they will operate with the desired accuracy. Moreover, the surfaces exposed to corrosion by liquids and gases would be considerably increased.

The nozzle according to present invention is more particularly suitable for multi-nozzle liquid distribution devices and offers the advantage of possessing a variable

coefficient of efflux $m$, while not possessing any movable mechanical part or part forming an obstacle in the stream of flow.

For this purpose the nozzle according to the invention comprises in the convergent zone downstream of the inlet at least one lateral aperture which is situated at the so-called "neutral" level. At this level the static pressure of the liquid inside the nozzle corresponds substantially to the pressure of the gas outside the nozzle, in the case of normal efflux of the nozzle, so that said aperture neither allows liquid to pass from the interior to the exterior nor allows gas to pass from the exterior to the interior of the nozzle. On the other hand, in the case of reduced efflux, gas can penetrate through the aperture to the interior of the nozzle and consequently modify its coefficient of efflux, which has the consequence of increasing the static pressure above the nozzle and thus improving the distribution of liquid between the various nozzles.

The nozzle according to the invention may have at the neutral level a single lateral aperture or a plurality of holes, advantageously distributed over the entire circumference, or else a circular slot interrupted by bridges connecting the bottom portion of the top portion. The holes may thus be situated in a plurality of parallel planes close to the neutral level. They may be circular, oval or polygonal, or else be horizontally or vertically elongated.

The accompanying drawing illustrates by way of example a number of embodiments of the invention.

FIGURE 1 shows a cross-section of a channel having a conventional nozzle, this figure having served above to demonstrate the increase of the loss of head when the efflux of a conventional device is reduced;

FIGURES 2 to 5 are sections of nozzles according to the invention;

FIGURE 6 illustrates graphically the increase of static pressure above a nozzle according to the invention and the modification of the coefficient of flow when the efflux is reduced, and

FIGURE 7 shows diagrammatically a closed pipe having two nozzles.

A nozzle according to the invention must have a suitably profiled widened entry **3** followed by a conical portion **4** and possibly by a cylindrical portion **5**, the diameter of which corresponds to the outlet diameter of the conical portion **4**. The dimensions and proportions of the different parts must obviously be those of a nozzle providing a regular, undisturbed flow of the liquid, and the nozzle **2** illustrated in FIGURE 1 and the nozzle **6** illustrated in FIGURES 2 to 5 are obviously only examples of nozzles which may be suitable.

Externally the nozzle may be provided with a threaded portion **7** enabling it to be fastened by screwing in the flat bottom of a tank or of a channel open at the top, or in a closed, immersed pipe, and also may advantageously be provided with a bearing surface **8** limiting its penetration so that the widened entry **3** is flush with the inside face of the wall of the reservoir, channel, or closed pipe.

According to the invention the nozzle has in the convergent conical portion **4** at least one lateral aperture, but preferably a plurality of apertures distributed over the circumference. These apertures may for example be round holes **9** (FIGURE 2), or be constituted by a circular slot **10** (FIGURE 3) interrupted by bridges **11** connecting the downstream side of the nozzle to the upstream side, or else may be holes **12** (FIGURE 4) which are preferably flattened and which are situated in close parallel planes, or else vertically elongated holes **13** (FIGURE 5). These holes are situated at a so-called "neutral" level $n$, or in the immediate proximity of this level.

With normal efflux of the nozzle, the static pressure inside the latter, at the neutral level $n$, is substantially equal to the pressure of the gas outside the nozzle, and



in practice in many cases is substantially equal to the atmospheric pressure of the air surrounding the projecting portion of the nozzle. Because of the identical pressure prevailing on each side of the apertures, liquid does not pass from the inside to the outside neither does gas pass from the outside towards the inside, at least in any substantial quantities, and the nozzle behaves as if it had no apertures. It has a constant coefficient of flow $m$ very close to unity and, as described above for a conventional nozzle, the desired equilibrium is established between the nominal efflux Q and the static pressure above the nozzle, thus ensuring equality of distribution of the liquid between the various nozzles within the limits of the tolerances selected.

The location of the neutral level $n$ can be accurately determined by applying Bernoulli's Law:

$$p_2+\frac{V_2^2}{2g}+h_2-\left(p_1+\frac{V_1^2}{2g}+h_1\right)=\Delta p \qquad (1)$$

in which

$p_2$ equals the pressure at the point under consideration,
$V_2$ equals the velocity of the fluid at the point under consideration,
$h_2$ equals the height of the point under consideration from the nozzle outlet,
$p_1$ equals the pressure at the nozzle outlet,
$V_1$ equals the velocity of the fluid at the nozzle outlet,
$h_1$ equals the height of the nozzle outlet, and
$\Delta p$ equals the loss of charge between sections 2 and 1.

While the density of the fluid must be considered, the term will cancel out and is, therefore, not included in this discussion. Measuring the height in the nozzle in relation to the nozzle output will require that $h_1=0$ and $h_2=$a value $h$, which is the height of the point under consideration of the neutral level from the nozzle outlet. In substituting these values one will arrive at the following relationship:

$$p_2+\frac{V_2^2}{2g}+h-\left(p_1+\frac{V_1^2}{2g}\right)=\Delta p \qquad (2)$$

which may be rewritten as follows:

$$p_2+p_1+\frac{V_1^2-V_2^2}{2g}-h+\Delta p \qquad (3)$$

Taking into account that the nozzle output of section 1 is at atmospheric pressure, the equation may be reduced to the following expression:

$$p_2+p_{\text{atm.}}+\Delta p+\frac{V_1^2-V_2^2}{2g}-h \qquad (4)$$

Because, at the neutral level, it is desired that

$$p_2+p_{\text{atm.}} \qquad (5)$$

the remainder of Equation 4 must equal zero. The height of the neutral level may then be written:

$$h=\Delta p+\frac{V_1^2-V_2^2}{2g} \qquad (6)$$

In practice $\Delta p$ will tend toward zero yielding the following:

$$h=\frac{V_1^2-V_2^2}{2g} \qquad (7)$$

Because the doctrine of flow equality teaches that $V_1A_1=V_2A_2$, where $A_1$ and $A_2$ are the cross-sectional areas at the nozzle output and neutral level, respectively, the following expression may be derived for the height of the neutral level:

$$h=\frac{V_1^2-\left[\frac{A_1V_1}{A_2}\right]^2}{2g} \qquad (8)$$

Thus, it can be seen that the neutral level is located a distance $h$ from the output end of the nozzle which is equal to the expression on the right side of Equation 8

immediately above. The terms $V_1$ and $A_1$ in that equation are fixed values which are determined by the desired rate of output flow velocity and thus the only variable is the area $A_2$ of the nozzle at the point *n*. From an inspection of the latter equation, it can be seen that $A_2$ must be greater than $A_1$ in order that *h* be a positive value and therefore the nozzle must have a convergent section and a neutral level must be located at that point.

It is also evident from the latter equation that it is possible to have several neutral levels and in fact every point within the nozzle may be a neutral level if the nozzle is made to conform to the curve resulting from a part of *h* versus $A_2$ as called for by the latter equation. It is sufficient for the purpose of this invention however that there be at least one point at which the equation is satisfied.

In the case of a reduced flow feeding the tank, channel, or closed, immersed pipe, the static pressure above a nozzle diminishes and negative pressure is formed in the liquid at the level *n*, in relation to the outside pressure. This negative pressure gives rise to the entry of gas to the interior of the nozzle, which has the consequence of reducing the coefficient of flow *m* in dependence on the quantity of air mixing with the liquid inside the nozzle. The lateral apertures therefore have the effect of providing nozzles having variable coefficient of flow by very simple means, and a glance at the formula indicated above will enable it to be understood that, through a reduction of *m*, there is consequently an increase of the static pressure above the nozzles and therefore an improvement in the distribution of the liquid to the different nozzles.

The accompanying graph (FIGURE 6) illustrates the results of comparative tests undertaken with the aid of two nozzles which were identical in length ($a$=8 cm.) and diameter ($S$=2.26 cm.). One of the nozzles has no lateral apertures while the other is provided with 8 holes of a diameter of 0.5 cm. (FIGURE 2).

The abscissa of the graph indicates the flow Q in decreasing order from 4.5 to 2 cubic metres per hour and the ordinates show in one case the head *b* of liquid measured in a channel, expressed in centimetres, and the other the coefficient of flow *m*.

The curve **14** shows the height *b* of the column of water when the flow Q above a conventional nozzle not provided with lateral apertures is reduced. As already explained by way of example and illustrated in FIGURE 1, *b* is reduced to one-tenth when Q is reduced by half. Thus for $Q$=4.5 cubic metres per hour, *b* attains 40 cm. and for $Q$=2.25 cubic metres per hour attains only 4 cm. If Q were to be reduced to 2 cubic metres per hour, it would be found that the flow through the nozzle would become unstable because of the formation of a vortex. The coefficient of flow *m* is invariable and for all flows Q remains close to 1, as indicated on the graph by the broken horizontal line.

In the case of the nozzle provided with lateral apertures, *b* is represented by the curve **15**. For the nominal flow of $Q$=4.5 cubic metres per hour the height *b* is 40 cm. as in the previous case, because with less flow there is equality of pressure at the level *n* and the gas cannot enter through the apertures. Consequently the coefficient of flow *m* is also close to 1. If the flow Q is reduced, negative pressure is created at the level *n* and increases in proportion with the reduction of Q. The quantity of gas drawn in obviously increases with the reduction of Q, thus reducing the value of *m*, as shown by the curve **16**. For a flow $Q$=2.25 cubic metres per hour, *m* attains 0.73. This results in a considerable attenuation of the reduction of *b* and when the flow Q has been reduced by half *b* still attains 10 cm., that is to say 2.5 times the height of the column of water in the case of the nozzle not possessing lateral apertures. This results in a considerably improved distribution of the liquid to the various nozzles. It is still possible to measure the height of the column for $Q$=2.0 cubic metres per hour (about 7 cm. for $m$=0.68), and to find that this time the height of the column of water is still far from the level at which, when no lateral apertures are provided, the flow through the nozzle becomes unstable.

The nozzle according to the invention which has been described above also makes it possible to improve the distribution of the liquid in the case where the nozzles are situated on immersed pipes.

FIGURE 7 shows an immersed pipe closed at one end and provided with two nozzles A and B.

The difference in total pressure of the liquid between the sections *a* and *b* situated immediately upstream of the nozzles A and B may be written as follows in accordance with Bernouilli's law:

$$P_a+\frac{v^2a}{2g}-\left(P_b+\frac{y^2b}{2g}\right)=\Delta P_{ab}$$

where

$P_a$ and $P_b$ are the static pressures in the sections *a* and *b*, $v_a$ and $v_b$ are the speeds in the pipe in the same sections, $\Delta P_{ab}$ the loss of head between the two sections.

The flows of the nozzles A and B depend on the static pressures at points corresponding to each of them, that is to say practically on $P_a$ for the nozzle A and $P_b$ for the nozzle B.

The ratio of these flows depends on the ratio $P_a/P_b$ which, in accordance with the above expression, is equivalent to:

$$\frac{P_a}{P_b}=1+\frac{\Delta P_{ab}-\frac{v^2_a-v^2_b}{2g}}{P_b}$$

When the flows diminish, the nozzle according to the invention has a coefficient of flow which is likewise reduced and, as indicated above, it follows that for a determined flow the static pressure at a point corresponding to the nozzle must be higher, and in particular in the example above the value of $P_b$ is increased.

In accordance with the expression above it follows that the ratio $P_a/P_b$ is close to unity and better distribution of the flow is therefore obtained.

The invention is naturally not limited to the embodiments which have been described and illustrated by way of example, and modifications may be made thereto without departing from its scope.

I claim:

**1.** A variable coefficient of efflux convergent nozzle for a substantially incompressible fluid having a smooth entry fluid inlet wherein said fluid enters the entire cross-sectional area of said inlet, a convergent zone extending downstream from said inlet and a fluid outlet communicating with the downstream end of said convergent zone, said fluid outlet having a cross-sectional area no greater than the cross-sectional area of said downstream end of said convergent zone,

said nozzle having a rated output flow velocity $V_1$ and an output cross-sectional area $A_1$,

said convergent zone having at least one point *n* where the pressure within said nozzle at said point *n* will equal the pressure externally of said nozzle whereat the cross-sectional area $A_2$ of the nozzle is of a value yielding a distance *h* of said point *n* from the output end of said nozzle equal to the expression:

$$h=\frac{V_1^2-\left[\frac{A_1V_1}{A_2}\right]^2}{2g}$$

and

at least one lateral aperture at said point *n* for de-

creasing the coefficient of efflux by allowing the external pressure medium to enter said aperture in response to a decrease in the rated flow velocity of said nozzle.

2. A nozzle according to claim 1, characterised in that at the neutral level it has holes distributed over the circumference of its wall.

3. A nozzle according to claim 1, characterized in that at the neutral level it has a circular slot interrupted by bridges connecting its bottom portion to the top portion.

4. A nozzle according to claim 2, characterised in that near the neutral level it has holes situated in a plurality of parallel planes.



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