**Hydrology.** — *How can intermittence of springs be explained?* By J. VERSLUYS.

(Communicated at the meeting of February 23, 1929).

A mixture of gas or vapour and liquid in a subterranean channel can rise regularly under two conditions, called the foam and the mist conditions. Which of these will arise depends on the proportion in which gas and liquid are mixed. This proportion is not only determined by the proportion in which they flow out but also by their difference of speed and their absolute velocity. Due to the fact that difference of speed is not the same under both conditions, direct transition from one condition to the other is impossible. If in a part of the channel the intermediate conditions prevail intermittant flow will be the result.

Irregularity of flow frequently occurs with hot and gaseous springs, and in many cases this irregular flow passes into intermittence.

No satisfactory explanation of this phenomenon has yet been given. In the middle of last century intermittence of springs was explained by the assumption that the channel through which the liquid is conveyed to the surface had the shape of a syphon. (II). This assumption is not very tenable and it does not allow for the presence of gas and vapours.

L. DE LAUNAY's theory (III) concerning the intermittence of hot springs is, it is true, less artificial, but it cannot be accepted in general because of its being based on the supposition that there are domeshaped enlargements in the crevice through which the liquid and gas rise to the surface. Such a dome might disturb the regular flow of the spring in the following manner :

Let us assume for a moment that the dome is filled with water. Then the rising gas will collect in this space, and as long as this takes place the column of liquid in the crevice from the dome upward is filled with water only. After the dome is entirely filled with gas, however, the gas will pass this dome and rise to the surface, reducing the weight of the liquid column above the dome. The gas in the dome will then expand and be partly discharged, still further diminishing the specific gravity of the mixture of water and gas in the crevice from the dome to the surface. Still more gas will escape, but eventually the gravity of the mixture will increase again when the gas in the dome is compressed and the gas coming from below will again collect therein. A dome shaped enlargement of the crevice may cause intermittence, but, as intermittence and irregular flow are often observed with oil wells producing a mixture of oil and gas through a straight string without contractions, there must be another and more general cause of irregular flowing and intermittence with mixture of liquid and gas rising through a vertical or inclined channel.

Generally hot springs originate from crevices, establishing a connection between deep-seated strata and the surface. Such crevices are filled with water. The pressure of the water occluded in the pores of the earth layers increases according to the depth, sensibly at the same rate as the hydrostatic pressure ; thus pressure increases one atmosphere at about ten metres depth.

Where normal conditions prevail temperature increases 1 degree centigrade at about 30 to 35 meters' depth, and due to this increase of temperature vapour pressure also increases with the depth, though at a smaller rate than hydrostatic pressure. Therefore no evaporation can take place in deep seated strata, nor in crevices under normal conditions. Only in volcanic regions may vapour be generated in deeper strata.

Gas-bearing sediments and volcanic rocks may cause water to rise in crevices due to the gas entering therein. But also artesian pressure may establish the motion. Once motion is started in a crevice, water with a higher temperature is lifted to shallower depths where smaller pressures prevail and vapour may form. As soon as these conditions arise vapour promotes the flow by reducing the weight of the liquid column in the channel.

The fact that irregular flow and even intermittence are so often observed with hot and gaseous springs, whilst the same occurs in straight tubes of oil wells, may probably be explained by the following considerations.

In the mixture of gas and liquid, gas may be dispersed in the shape of bubbles in the liquid, but also the liquid may be dispersed in the gas in the shape of drops. The two conditions here described will be called the "foam" and the "mist" conditions.

Under both conditions in a vertical or inclined channel gas rises at a greater speed than does liquid (see V). Suppose the proportion of volumina in which gas and liquid pass a cross-section to be $n : 1$, i.e. every unit of volume of liquid is accompanied by $n$ of the same units of gas, then if the gas has a velocity of $u$, and the liquid one of $u—b$, the unit of volume of liquid flowing through in a unit of time occupies an area

$$\frac{1}{u-b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in the cross section, and the $n$ units of volume of gas, accompanying this liquid occupy an area of

$$\frac{n}{u} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Thus the area of the cross section of the channel per unit of volume of liquid flowing through per second is :

$$S = \frac{n}{u} + \frac{1}{u-b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From (1) and (2) it follows that gas and liquid are mixed in the proportion

$$\varphi = \frac{n}{u} : \frac{1}{u-b} = n : \frac{u}{u-b} \quad \ldots \ldots \quad (4)$$

or

$$\varphi = \frac{n(u-b)}{u} \quad \ldots \ldots \ldots \ldots \quad (5)$$

In (4) being $\frac{u}{u-b} > 1$ the proportion $\frac{gas}{liquid}$ in the mixture is always smaller than the proportion $n$ in which gas and liquid flow through.

Eliminating $u$ from (3) and (5) we obtain the following equation

$$S = \frac{(n-\varphi)(\varphi+1)}{\varphi b} \quad \ldots \ldots \ldots \quad (6)$$

Substitution of the values of $n$ and $b$ in this equation leads to a relation between $S$ and $\varphi$.

As stated before two values of $b$ are possible. The velocity of a gas bubble rising in water, which is at rest, is about 20 and 30 cm per second and the velocity of small drops of water sinking or falling in a gas may be about 600 cm per second. Although in a rising mixture the values of $b$ are not constant, for sake of simplicity it will be taken that under foam condition

$$b = 20 \quad \ldots \ldots \ldots \ldots \quad (7)$$

and under mist condition

$$b = 600 \quad \ldots \ldots \ldots \ldots \quad (8)$$

centimeters per second.

As an example, in figure 1 there are plotted in semilogarithmic coordinates the percentages of gas in the mixture against the values of $S$ for $n = 6$. In this diagram the values of $S$ are expressed in square centimeters per cubic centimeter of liquid flowing through per second.

The values of $S$ have been computed by the aid of (6) in which have been substituted the values of $\varphi$ corresponding to the different percentages of gas in the mixture.

On account of the existence of two values of $b$, see (7) and (8), two lines can be traced.

If, now, we assume that foam condition in a mixture is able to exist as long as less than 50 % gas is present, and that with more gas the mist condition would arise which is probably not exactly the case, then only the traced parts, of the two lines would be available, the dotted parts not corresponding to real conditions. Then, although generally speaking with 50 % gas in the mixture, there would be a transition from foam into mist, in the particular case of the mixture rising in a channel no direct transition from foam to mist can be established by gradually decreasing the section. The proportion of 50 % has been chosen, because as soon as nearly 50 %

of the mixture is gas, the bubbles will touch each other and under these circumstances a non stabilized foam will break.

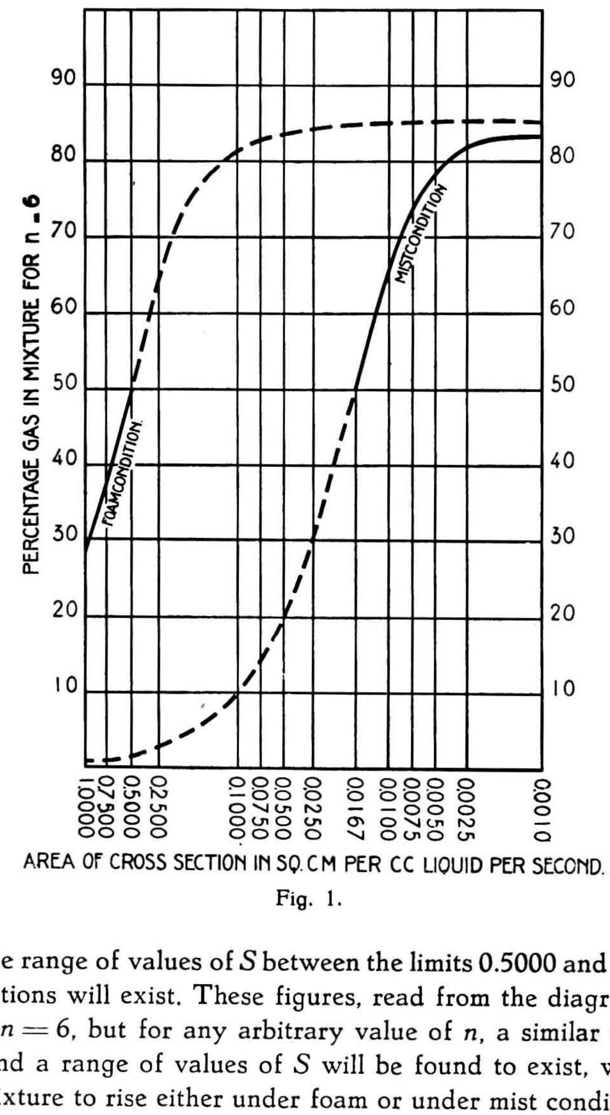


Fig. 1.

Within the range of values of $S$ between the limits 0.5000 and 0.0167, none of the conditions will exist. These figures, read from the diagram, are only available if $n = 6$, but for any arbitrary value of $n$, a similar diagram can be drawn and a range of values of $S$ will be found to exist, which do not allow the mixture to rise either under foam or under mist condition. Within the range of these values of $S$ the mixture is not able to flow regularly.

According to the assumption that 50 % gas, i.e. equal volumes of gas and liquid in the mixture, would be the limit at which the transition from foam to mist may occur, in (6) can be substituted

$$\varphi = 1 \quad \ldots\ldots\ldots\ldots \quad (9)$$

in order to obtain an equation involving, $n$ and the limit $S_l$ of $S$:

$$S_l = 2\,\frac{n-1}{b} \quad \ldots\ldots\ldots\ldots \quad (10)$$

The expression of the limit of foam condition would be in accordance with (7)

$$S_{lf} = 2\,\frac{n-1}{20} = \frac{n-1}{10} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (11)$$

and the limit of mist condition is constituted by:

$$S_{lm} = 2\,\frac{n-1}{600} = \frac{n-1}{300} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (12)$$

Thus one can write

$$S_{lf} = 30\,S_{lm} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (13)$$

In diagram 2 the lines representing (11) and (12) are traced, the limits $S_{lf}$ and $S_{lm}$ being computed in square centimetres per litre of liquid per second.

This diagram shows that only large quantities of gas or vapour or narrow channels are favourable to the existence of mist condition.

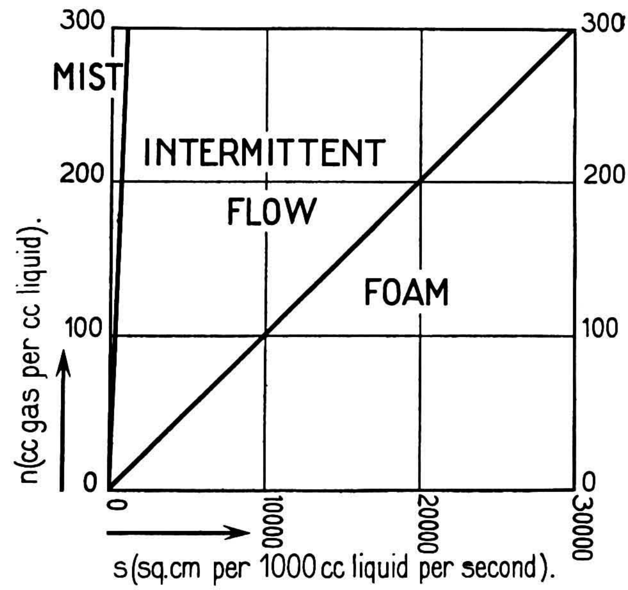


Fig. 2.

Suppose the crevice of the spring has a unform cross section from the bottom to the surface, so that the magnitude $S$ in the above formulae remains constant. But as the mixture rises the pressure decreases, and accordingly the volume of gas ($n$ in the formulae) increases. Suppose the value of $S$ is 10000, and the value of $n$ at the bottom of the channel is about 6, then diagram 2 shows that at the bottom of the well the foam conditions prevail. Following the vertical line 10.000 in the diagram, we see that as the value of $n$ has increased to about 101 the limit if the field of intermittent flow has been reached. What will take place here ? We can imagine that the mixture rises under the foam condition to the cross section where pressure has diminished so far as to make $n = 101$. From this section upwards no foam condition can exist, but the volume of gas is not sufficient to entrain all the liquid in the shape of drops, and in practically all cases the velocity would be smaller than 600 cm per second (see 8) so that no liquid will be lifted at all. Therefore generally all the liquid, and under exceptional circumstances only a part of it will remain at the level of the cross section considered here. In this way more liquid will collect here and for a certain lapse of time less liquid than is yielded by the formation will flow out of the channel.

This will create an unstable condition, as it also interferes with the pressure in the lower parts of the crevice and the result will be an irregular flow and even, if conditions are favourable, intermittence.

In arriving at the above deductions figures have been taken for the rate of fall of the drops of liquid and for the rate at which the gas bubbles rise, but the figures taken here do not always hold good, and they depend upon the circumstances as has been stated above. Therefore the above deduction is only to be regarded as a demonstration of the basic principle.

Probably the limits of the range of values of $S$ causing intermittent flow are not very sharp. If the value of $S$ is near the middle of the range of intermittent flow, then the spring will alternately eject liquid occluding little gas and gas containing a small percentage of liquid in drops. The nearer the value of $S$ approaches one of the limits, the shorter the period of intermittance will become and at last, but still before the critical values have been reached, one can speak of a regular flow, though the liquid forms large, irregularly shaped bodies.

Similar phenomena are observed with volcanos, so that probably the same principles apply to volcanic eruptions. In the case of volcanism however, the specific gravity of the liquid, the magma, is about $2\frac{1}{2}$ and accordingly under mist condition the value of $b$ must also be greater. Due to the viscosity of the magma under foam condition, $b$ is probably very small. Further one may conclude from the fact that certain volcanic material floats on water, that values of $\varphi$ greater than 1 may exist under foam condition.

An example of a viscous liquid rising under foam condition is presented by the pitch lake of Trinidad.

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