QUALITATIVE MOTION OF A LIQUID IN AN ACCELERATING GAS STREAM

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Experimental data are examined on the interaction of liquid drops with the gas stream in a Venturi scrubber, the most promising available equipment.

In the technical literature there very often appear papers on the use of a Venturi scrubber as an absorption apparatus [1–3,6]. These papers deal with the influence of gas velocity, specific flow rate of the liquid, point of input of liquid, structural dimensions of duct, etc. on the total absorption of components and the resistance of the apparatus. A study of these so-called "external" factors, however, does not allow one to elucidate completely the essential physical features of the phenomena occurring in the Venturi scrubber [1–3,7,8, etc.]. The present paper is an attempt to study the physical picture of phase interaction in the Venturi scrubber.

A phase contact surface is created in the Venturi absorber by spraying the input liquid into a mass of gas. Secondary subdivision of these drops takes place subsequently in the gas stream because of the energy of the latter, and fresh surfaces are formed. There is no doubt that a study of these phenomena would permit a more informed choice of optimum conditions for the absorption process, and possibly theoretical calculation of absorber resistance.

The mechanism of atomization of a liquid by a turbulent gas stream has been studied in papers by Lane and Volynskii [4,5]. The tests were carried out at constant gas stream velocity, corresponding to the critical velocity for subdivision of the drops. For this reason the results of these papers should not be used to explain the processes occurring in the Venturi scrubber. We have attempted to do this using high-speed photography.

Some workers have pointed out that good absorption may be obtained at comparatively low gas velocities in the throat of a Venturi scrubber [2,3,6], and hence at low gas stream resistance. A study was therefore undertaken of the processes of deformation and subdivision of drops at gas velocities of 15–40 m/sec in the throat of a Venturi scrubber. Study of the test data has made it possible to offer the following explanation. For a drop moving in a gas stream along the axis of the duct in a nozzle, three periods are observed:

1. A period of fluctuating acceleration of the drop. The stream forces acting on the drop are not large enough to overcome surface tension. In this period, therefore, insignificant deformation of the drop is observed. It is in a state of dynamic equilibrium, as if it "breathes." The head and the tail deform alternately. Since action of the stream shapes the drop, while the drop itself controls the flow washing it, one observes not only fluctuations of the drop, but also considerable fluctuations of its absolute velocity. The period of fluctuating acceleration is terminated by deformation of the drop into the shape of an ellipsoid of revolution.

2. The second period is characterized by regular deformation of the drop by the gas stream. There is smooth change of shape from the ellipsoid of revolution to a plano-convex or disk shape. The action of the stream on the drop is directly proportional to the increase of the drop mid-section area (Fig. 1a,b). Whereas the drop could rotate in space during the first period, its motion now is strictly directed along the gas stream. The diameter of the deformed drop is twice the original, so that there is a considerable increase in the phase contact surface. *

3. In the third period inflation and subdivision of the drop occur. Here two mechanisms are observed. The popular picture of breakup of a drop by blowing out "like a bag" (Fig. 1b) is observed only at a velocities of 20 m/sec in the throat of the nozzle. At a flow velocity of 30 m/sec in the throat the subdivision mechanism differs markedly from the above (Fig. 1c). It may be seen from the photographs that the drop blows up "like a straw hat" with the convex part directed against the stream. Later the edges of the "straw hat" are crushed into separate filaments from which very fine liquid droplets are stripped off (Fig. 2). It should be noted that a similar picture is generally characteristic of the breakup of a jet of liquid situated in a high-velocity gas stream. A velocity of 25 m/sec appears to be transitional, both the first and the second pictures of drop breakup being observed. In an accelerating gas stream the force on the drop, in accordance with the aerodynamic flow around it, leads to deformations which may be called critical (Fig. 1b,c), and predetermine one or the other pattern of breakup.

A number of authors [7–9] consider that the additional losses associated with the injection of a liquid into a Venturi scrubber are mainly due to acceleration of the drops to a velocity close to that of the stream. However, examination of the motion-picture

*Synchronous photographs of the deformed drop by two motion-picture cameras in mutually perpendicular planes showed that the dimensions of the diameters in plan view differed considerably.

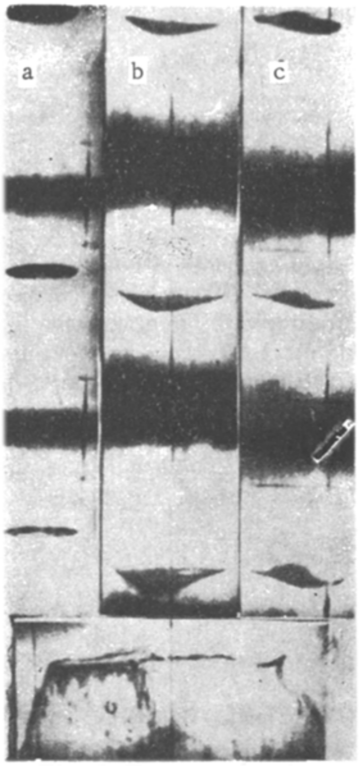

Fig. 1. Frames showing the critical stage of deformation and the first mechanism of subdivision of a drop.

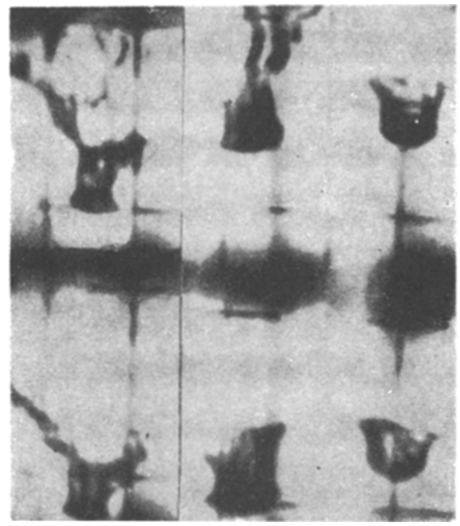

Fig. 2. Frames showing the second mechanism of subdivision of a drop.

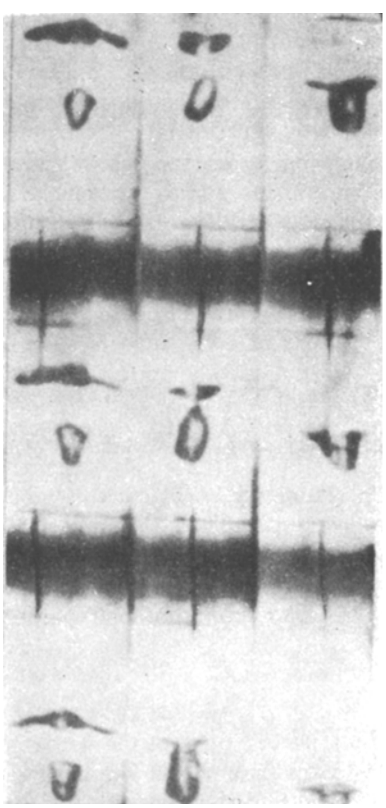

Fig. 3. Deformation of individual drops in a jet liquid.

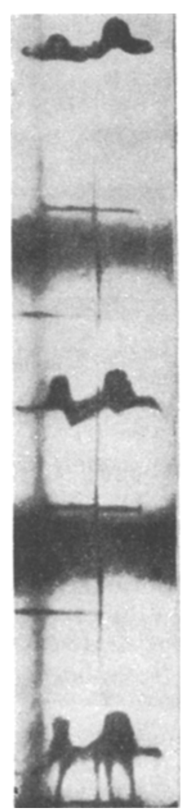

Fig. 4. Deformation and breakup of drops in constrained conditions.

photographs shows that drops accelerated in the convergent section acquire a velocity at the throat of the Venturi scrubber equal roughly to 20–25% of that of the gas stream at the throat. Drops of dimensions 2–4 mm, in streams of velocity 10, 15, 20, 25, 30, 35 m/sec have the following velocities at the throat: 2.35, 2.85, 3.75, 5.15, 5.5, 6.4 m/sec. Hence it is clear that the main part of the energy of the gas stream is expended in deforming the drops, and not in accelerating them.

In order to verify the applicability of the picture of deformation and breakup of the individual drop to the "mass" motion of drops in a Venturi scrubber, tests were conducted with jet injection of liquid. Photographs were taken of the liquid jet discharging at velocities of 1, 3, and 6 m/sec from a nozzle of diameter 1.5 mm. The following situation resulting from this series of tests should be noted.

Firstly, the three periods of drop deformation were retained in their entirety. After the initial breakup of the jet, separate drops were formed, and the distance between two adjacent drops was quite sufficient for free motion of each drop. Only in isolated cases did the situation arise, similar to that shown in Fig. 3, where one deformed drop screens the preceding one.

Secondly, it may be seen from Fig. 4, which is taken arbitrarily from a large number of similar photographs, that the fact that a drop is constrained does not show up in the picture of its deformation and breakup.

Thirdly, the so-called Plateau droplets, measuring 0.2–0.5 mm, formed when large drops break up have almost the same, and in some cases less velocity than the main drops at the throat of the scrubber. With jet injection of liquid, as the discharge velocity increases, some shift is observed in the deformation of drops along the axis of the duct, but the location of the breakup point remains almost unchanged.

SUMMARY

The view exists that the entrainment of a drop by a stream begins in the convergent section and ends at the throat with the attainment of a velocity close to that of the gas, and also that the main part of the energy in a Venturi scrubber is expended in accelerating the drop.

Our tests have shown that the velocities of drops at the scrubber throat comprise 20–25% of the gas stream velocity, and that a considerable part of the energy is expended, not in accelerating the drops, but in their deformation and subsequent breakup (which is possible for gas stream velocities at the throat greater than 20 m/sec).

At mean stream velocities greater than 20 and less than 35 m/sec, favorable conditions for absorption processes result from the considerable increase in surface area and the large relative velocity between phases.

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