INTERACTION OF A TWO-PHASE GAS-LIQUID FLOW IN A VENTURI SCRUBBER

F. S. Yugai and B. P. Volgin

Inzhenerno-Fizicheskii Zhurnal, Vol. 10, No. 6, pp. 771–775, 1966

UDC 536.246

Results are given on an investigation of the disintegration of a liquid jet at various gas velocities in the throat of a Venturi scrubber.

Reference [1] describes the results of an investigation, carried out by means of high-speed photography, of the flight and disintegration of individual liquid drops in an accelerating gas flow.

The present paper gives similar data on the flight and disintegration of a liquid jet under the same conditions.

The tests were conducted in nozzles 1–5 mm in diameter mounted at a distance from the beginning of the throat of a Venturi tube equal to its diameter, i.e., 20 mm.

The amount of liquid issuing from the nozzle was varied in such a way as to keep constant the location at which disintegration of the jet began in the throat of the Venturi tube.

Figure 1A shows the test results for a nozzle 1 mm in diameter. The photographs show three characteristic regimes of jet disintegration.

At a low gas throat velocity—20 m/sec—the jet is broken down into individual drops under the influence of its own static instability caused by the aerodynamic and surface tension forces. The action of the gas stream results in considerable nonuniformity of the drops formed.

At moderate gas throat velocities—30 m/sec—a transition regime arises. The jet is first deformed by aerodynamic forces, becomes wavy, and is then broken up into separate pieces, whose ends, under the influence of surface tension forces, assume the form of spherical drops. The relative velocity at which the transition regime is observed, does not have sharp boundaries, and for jets from nozzles up to 4 mm in diameter, the velocity lies in the range 20–25 m/sec. (It was established in [1] that the velocity of a drop in the throat is 20–25% of the throat velocity of the gas stream; the same ratio is maintained for a liquid jet.)

At large gas throat velocities—50 m/sec—the aerodynamic forces are the decisive factor. The jet disintegrates without being broken up into individual drops. The boundaries between individual pieces of the jet become unclear.

Figure 1B shows the state of a liquid jet issuing from a nozzle 3 mm in diameter. At the same value of the gas throat velocity, there is a noticeable difference in comparison with a jet issuing from a nozzle 1 mm in diameter. Because of the larger jet diameter and the smaller discharge velocity, the aerodynamic forces begin to become decisive earlier than in the previous tests. Thus, at a gas throat velocity of 20 m/sec, the transition regime has already developed,

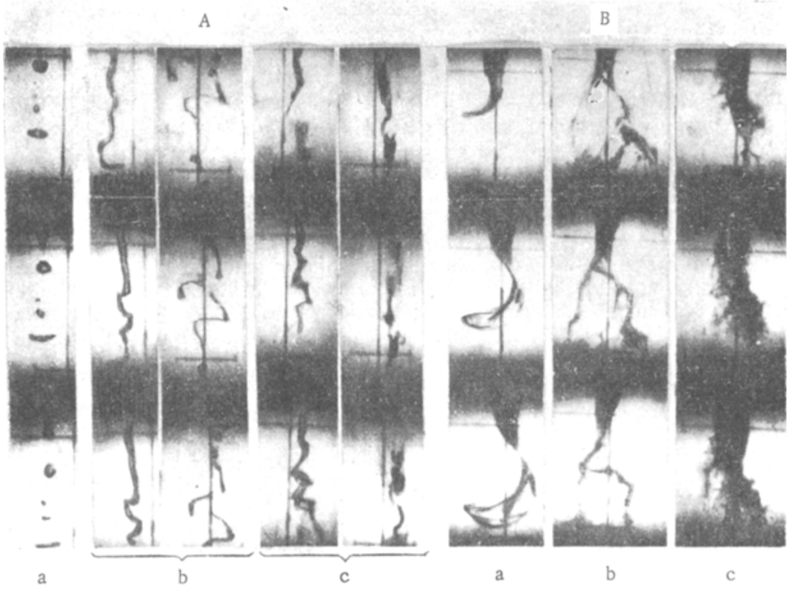

Fig. 1. Regimes of disintegration of a jet from a nozzle 1 (A) and 3 (B) mm in diameter in the throat of a Venturi scrubber at stream velocities: a) 20; b) 30; c) 50 m/sec.

but the ends of the pieces of the jet take the form not of a sphere, but of a drop of irregular shape.

At a moderate gas throat velocity—30 m/sec—there are not even rudimentary drops, but atomization of the jet, i.e., the same state as for a nozzle 1 mm in diameter at a velocity of 50 m/sec.

At a high gas velocity—50 m/sec—we get not disintegration of the ends of individual pieces of the jet, but disruption of the pieces themselves.

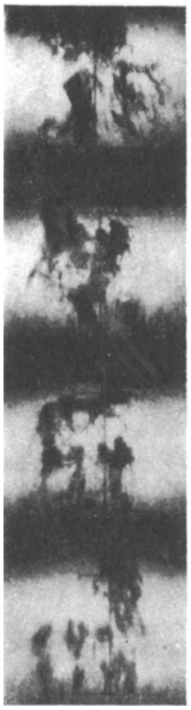

Fig. 2. Disintegration of a jet from a nozzle 5 mm in diameter in the throat of a Venturi scrubber at a stream velocity of 60 m/sec.

In studying the flight of individual drops it was also established that drops of larger diameter are broken up at a lower gas throat velocity than drops of smaller diameter. Thus, for breakdown of a drop of diameter 3.5 mm in the Venturi scrubber, a relative velocity of 19.4 m/sec is required, while the corresponding value is 21.2 m/sec for a drop of 3.0 mm.

Figure 2 shows the state of a liquid jet issuing from a nozzle 5 mm in diameter at a gas throat velocity of 60 m/sec. In this case there is neither jet nor drops, but turbulent "threads" of liquid distributed in the turbulent gas stream.

This work makes possible a critical examination of part of the currently adopted optimal conditions of operation of the Venturi scrubber.

Attempts were made in [2, 3] to calculate the completeness of trapping of aerosols and the resistance of a Venturi scrubber, starting from the assumption that a liquid in a gas stream is in the form of spherical drops. The mean diameter of a liquid drop is usually determined from the empirical formula of Nukiyama and Tanasawa [4].* However, as may be seen from the photographs, the concept of mean drop size is arbitrary and does not reflect the physical aspect of the process occurring in the Venturi scrubber. In particular, it cannot explain the fact, noted in [5, 6], that the absorption of gases and the trapping of aerosols occurs with greatest effectiveness at the time of disintegration of the liquid. Motion-picture studies of the disintegration of jets and liquid drops shows that, in fact, a greater phase contact surface is formed in comparison with that calculated from the mean drop diameter. Obviously, it is precisely this development of the surface at the time of disintegration of the liquid that is very important for absorption of gases and trapping of aerosols, and not the surface of the liquid drops formed after disintegration, as postulated when a drop of mean diameter is examined. Moreover, it may be assumed that the development of the surface at the time of disintegration of the liquid is accompanied not only by an increase of the absolute amount of absorbed component or aerosol, but also by an increase of the coefficient of absorption or trapping.

Operation with drops of mean diameter and the desire to obtain a greater phase contact area leads to a tendency to work at high gas throat velocities. The mean diameters of water drops, according to the Nukiyama-Tanasawa formula with a gas throat velocity of 60–120 m/sec and specific liquid mass flow rates of 0.25–1.25 l/m^3 are equal, respectively, to 120–40 μ, while the Reynolds number, calculated from the relation

$$\mathrm{Re} = Wd/\nu,$$

for the case of these drops washed by a gas stream will be: $\mathrm{Re}_{60} = 515$, $\mathrm{Re}_{120} = 345$.

For a gas throat velocity of 20–30 m/sec, and drops 3 mm in diameter, the corresponding Reynolds numbers will be $\mathrm{Re}_{20} = 3480$ and $\mathrm{Re}_{30} = 5300$, and, allowing for the dimensions of the deformed drop, $\mathrm{Re}_{20} = 7000$ and $\mathrm{Re}_{30} = 10\,600$, i.e., 15–30 times larger than in the preceding case. It is logical to assume that the larger the Reynolds number of the flow over the drop, the more energetic the interaction between phases. This assumption is confirmed by tests with ultrasonic disintegration of a liquid jet. In spite of the very small size of the drops and their large specific surface, the degree of absorption during ultrasonic disintegration proves to be less than when the

---

*For specific flow rates of liquid greater than 0.5 l/m^3, as shown in [7], drop sizes calculated from this equation are less than the actual values, and the larger the specific flow rate, the greater the difference. According to the data of [8], when the liquid is introduced along the gas stream, which was the case in our tests also, a better degree of atomization is attained together with less deviation of the mean diameter from calculated values at considerably greater specific flowrates (0.97 to 4 l/m^3 of gas) than when using the Nukiyama and Tanasawa formula.

jet is broken up by a gas stream for identical gas throat velocity and identical specific flow rate.

Certain authors [2, 9] start from the premise that the velocity of the gas and of the liquid in the throat of a Venturi scrubber are similar. Therefore, with the aim of increasing the relative velocity, they recommend that the liquid be introduced at right angles to the gas stream, although this also increases its resistance. Our work casts doubt on the validity of this position. Sufficiently large relative velocities are also obtained with axial supply of liquid, the resistance of the equipment then being less, and the completeness of absorption the same as with radial liquid supply [5]. It is probable that this will also be the case for trapping aerosols.

Our investigations suggest the following recommendations for increasing the effectiveness and economy of the Venturi scrubber:

1. It is inexpedient to aim for atomization of the liquid into fine drops at the time of injection, since large drops or jets (diameter 3–5 mm) are easily broken up by the gas stream, thereupon developing phase contact area which ensures high effectiveness with inconsiderable expenditure of energy.

2. Because of the intense disintegration of the liquid at high gas throat velocities (50 m/sec and above), it is possible to obtain a developed liquid surface at liquid specific flow rates of 0.5–1.0 l/m^3, while, on the other hand, at small gas velocities (20–40 m/sec), the less intense disintegration of the liquid must be compensated by an increase in specific flow rate. This fact has been noted by some investigators [6, 10], but not explained.

3. With axial injection of liquid, quite large relative velocities between gas and liquid are obtained, so that, at rates of energy expenditure small in comparison with those for radial injection, a high degree of completeness of absorption is obtained. Obviously, this method of liquid injection is also favorable for trapping of aerosols.

NOTATION

W – relative velocity of gas in throat, m/sec; d – diameter of drop, m; ν – kinematic viscosity of gas, m^2/sec.

REFERENCES

1. F. S. Yugai and B. P. Volgin, IFZh [Journal of Engineering Physics], **9**, 1965.
2. A. T. Litvinov, Khim. prom-st, no. 8, 1964.
3. Ueoka, Nikhon Kikhkai Gakkai rombunsyu, **23**, no. 129, 309, 1957.
4. S. Nukiyama and I. Tanasawa, Trans. Soc. Mech. Eng. (Japan), **5**, no. 18, 1938.
5. B. P. Volgin and F. S. Maron, NIUIF, Soobshcheniya o nauchno-tekhnicheskikh rabotakh (obmen opytom), nos. 6–7, 1958.
6. H. F. Johnstone and M. M. Roberts, Industr. and Engng. Chem., **41**, no. 11, 2417, 1949.
7. H. C. Lewis, D. G. Edwards, M. J. Goglia, R. J. Rice, and L. W. Smith, Ind. and Engng. Chem., **40**, no. 1, 1948.
8. L. A. Vitman, B. D. Katsnel'son, and I. I. Paleev, Hydraulic Atomization [in Russian], GEI, 1962.
9. H. Staub Güntheroth, **21**, no. 9, 430, 1961.
10. W. P. Jones, Industr. and Engng. Chem., **41**, no. 11, 2424, 1949.

27 December 1965

Kirov Ural Polytechnic Institute,
Sverdlovsk