INVESTIGATION OF HEAT AND MASS TRANSFER IN JET DRYING

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The results are given of a combined experimental investigation of the aerodynamics and heat and mass transfer for various nozzle systems. The influence of the system parameters on the drying process is established. Criterial relations are obtained for calculating heat and mass transfer in the jet drying of paper and cardboard.

One means of drying with jet blowing is accomplished by blowing a drying agent with high-performance parameters out of a system of nozzles onto the material to be dried. A number of papers [1-5] have been devoted to this method of drying.

In order to determine the essential mechanism of heat and mass transfer during drying, and to discover the optimum construction parameters and the influence of the operating parameters, a combined study has been carried out of the aerodynamics and mass transfer for various nozzle systems. In addition, heat and mass transfer during combined nozzle and conduction drying have been investigated.

The investigation was carried out in equipment consisting of two high-pressure centrifugal blowers, an electric air heater, a pressure box, a nozzle system, and a screw traverse mechanism. The equipment provided air discharge velocities at the nozzle exits of up to 100 m/sec, and air temperature up to 400°C. The nozzle systems had a nozzle slit width of 0.5-5.0 mm, and an internozzle distance (pitch) of 15-55 mm. Using the screw traverse mechanism, devices mounted on it could be shifted in the vertical and horizontal directions, with a reading accuracy of 0.1 mm.

The device for determining the pressure distribution on the wall due to the jets issuing from the nozzles, consisted of a plate with holes through which were passed two micro-pressure tubes connected to a differential manometer.

The device for determining the local intensity of mass transfer consisted of a plate with a slit 2 mm wide, covered with filter paper, to which water was supplied from a distributing chamber. The chamber was joined to a microburet, which gave a reading of the amount of liquid evaporated. In a test steady mass transfer was realized, during which the filter paper surface was in a saturated condition.

To study nozzle drying combined with conduction drying, a device was used consisting of a heating surface, heated by steam, and a clamp.

During a test, measurements were made of the temperature of the material being dried, and of the drying agent in the pressure box and in the inter-nozzle space, as well as the velocity of the drying agent and the moisture loss in mass transfer and drying. Because of the symmetry between the heat- and mass-transfer processes on the two sides of each nozzle in the nozzle system, the progress of these processes was examined in the region from the axis of the nozzle to the half-pitch along the surface of the material being dried.

It was established that the nature of the pressure distribution over the surface of the material (Fig. 1) is identical in form for all the nozzle systems investigated. The beginning of the minimum pressure section is almost independent of s. Decrease of δ leads to a reduction of the maximum pressure values, while the start of the minimum pressure section approaches the critical point. It was observed that with δ of 5 mm, the pressure at a distance equal to one half-pitch from the critical point (midway between nozzles) was greater for h = 10 mm than for h = 5 mm, and greater for h = 5 mm than for h = 3 mm. With s = 15 mm for the same nozzle, no pressure maximum between the nozzles was observed.

Measurement of pressure in the expanding jet (at a distance of 0.2 mm from the surface) revealed the existence of a rarefaction region corresponding to the section of constant pressure on the surface.

The aerodynamic investigation made it possible to understand the mechanism of flow of a jet against and in interaction with the other jets, as well as the structure of the resulting jet. The jet issuing from a slit nozzle has an expansion angle of 10°-14° C, depending on the nozzle shape and the treatment of the nozzle rim. When it flows up to the wall at right angles, the jet experiences a compression, in which part of its kinetic energy is transformed into potential energy. After impact with the surface, the potential energy of the jet is transformed into kinetic energy, the jet is reversed, and the velocity of the spreading jet so formed increases sharply. As the experiments showed, a "neck" was formed at the beginning of the spreading jet, this being a section of the jet of constant width, less than the half width of the jet approaching the surface (Fig. 2). As h increases, the width of the neck and its length for constant velocity of discharge from the nozzle increase. As δ decreases, the width and length of the neck are reduced. The parameter s has almost no influence on the neck dimensions. The neck width B may be determined from the empirical formula

\[ B = 0.290\delta + 0.0812 \cdot h \]  

At the end of the neck the spreading jet begins to expand. The tests showed that the expansion angle of
the jet was the same as for the jet discharging from a nozzle. When the jets meet and merge (at half-pitch), a single jet is formed, whose axis is perpendicular to the surface. With increase of $h$ the width of this jet increases, while the expansion angle of the newly formed jet remains the same as in the approaching and spreading jets.

An experimental determination of the maximum velocity over the section of the spreading jet (Fig. 3) showed that this velocity depends on $h$, $\delta$, $w_0$. The qualitative nature of the velocity variation along the coordinate is preserved both for varying $h$, $w_0$ and $s$.

The nature of the variation mentioned for this velocity points to the impossibility of using as characteristic values velocities calculated from formulas for a free turbulent choked jet, as some investigators have done.

From the experimental data we may find the value of the ratio $h/\delta$ at which the velocity on the jet axis is still equal to that at the nozzle exit. This ratio proved to lie in the range 3–4.5. While it is natural to seek to reduce $h/\delta$, this is possible only up to a known limit, since when $h \leq \delta$, a decrease of the velocity of the agent is observed owing to the occurrence of resistance due to compression of the jet.

The local intensity of mass transfer varies continuously along the surface of the material (Fig. 3). The maxima and minima of mass transfer intensity shift as $h$ increases, moving away from the critical point. The form shown for variation of local mass transfer is characteristic of cases where values of the ratio $h/\delta$ are small (up to 8.0, approximately) and the velocities of the drying agent are large. In the rest of the cases the local mass transfer intensity decreases continuously along the surface being dried, and no clear intensity maxima and minima are observed. It should be noted that for narrow nozzles ($\delta$ up to 1 mm) at large values of $s$ (55 mm) and with $h$ up to 15 mm, some increase of local mass transfer intensity is observed, beginning at a distance equal to approximately a quarter pitch and beyond.

The combined aerodynamic and mass-transfer investigations allow us to identify four characteristic sections, apparent from an examination of Figs. 1–3.

![Fig. 1. Pressure distribution on the surface of the material with $s = 35$ mm and $\delta = 2$ mm: 1) $h = 5$ mm; 2) $h = 10$ mm; 3) $h = 15$ mm.](image)

![Fig. 2. Jet contours with $s = 35$ mm and $\delta = 2$ mm: 1) $h = 5$ mm; 2) $h = 10$ mm; 3) $h = 15$ mm.](image)