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THE RESEARCH OF A ONE-STEP AND TWO-STEP EJECTOR WITH A COMPACT AND DISPERSED JET OF LIQUID

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***Abstract:** The work of the jet sulphitator ejector of sugar production is analyzed. The tests of a gas-liquid ejector with a compact and dispersed liquid jet in a wide range of changes in geometric characteristics (1.3 ... 11.25) were tested on the test-bench at the laboratory and the range of their optimal values (4 ... 7), which allowed to reach the maximum ejection coefficient, was found experimentally. The ejection coefficient for an ejector with a compact liquid jet is 15 ... 20% lower than for an ejector with a dispersed jet at the same flow rates.*

The design of a new two-stage ejector with improved expendable characteristics is offered, the basic geometric dimensions are justified. An increase of the ejection coefficient without additional energy penalties is experimentally proved. The field of application of the offered design ejector is not limited to food industry and it is recommended to use in those cases where heat-mass transfer processes take place.

***Keywords:** liquid-gas ejector, mixing chamber, ejection coefficient, dispersed, compact fluid jet, two-stage ejector.*

INTRODUCTION

Ejectors are widely used in engineering as pumps, devices for various technological processes, heat pumps, air purifiers, etc. In comparison with other equipment their advantages are the absence of moving parts, extreme simplicity of design and high reliability of work, their disadvantage is low efficiency (Alexandrov V., Klimovsk K., 2012).

Processes which can be carried out in sugar industry in ejection apparatus are implemented for the sulphitation of water, juice and syrup. Jet sulphitators were developed at the beginning of the last century. They were modernized on the basis of new scientific achievements for carrying out sulphitation instead of bubbling and irrigation devices in the 70s of the 20th century.

Their advantages are intensity of mass-exchange processes, specific metal consumption of devices, which is a lot of times less, and a significant reduction in emissions of sulfur dioxide to the atmosphere.

At the same time sulphitators have a number of disadvantages which are caused by the instability of sugar plant work. The main reason is a constant change in the flow rate of the liquid which leads to frequent changes in pressure on spray jet nozzle and consequently to unstable work of the ejection apparatus. So it becomes difficult to maintain the optimal pH of the solution which is strictly regulated by the technological process.

In sugar production sulphur consumption is quite significant: 0.25 kg for an irrigation sulphator and 0.39 kg for a jet sulphator are used per 1 ton of raw material. They exceed similar costs in foreign plants (Razladyn Y., Razladyn S., 2010).

The widespread introduction of ejectors into the sugar industry is hindered by a lack of knowledge of the processes that occur in ejectors with a cylindrical mixing chamber and a compact or dispersed liquid jet at low pressures of the active flow.

EXPOSITION

The object of the study is a physical model of a sulphatory ejection apparatus with a jet nozzle (compact liquid jet) and a centrifugal-jet (dispersed liquid jet).

The purpose of the study is to define the laws of hydrodynamics of the flow of water-gas emulsion in the mixing chamber of the ejector.

To achieve this goal the following tasks were solved:

1. To research the work of a typical (jet) sulphitator with the help of a physical model and to identify patterns and features of the flow of water-gas emulsion.
2. To research the operation of the ejector with a dispersed liquid stream, to identify patterns and features of the flow of water-gas emulsion.
3. To develop a new design of an ejector (two-stage) with a higher ejection coefficient on the basis of the studies which were carried out.

Main material exposition. A jet nozzle is traditionally used as an active nozzle in ejection apparatuses. Such devices have been widely studied (Tshehel'skyy V. 2003, Bouhanguel A., Desevaux Ph., Gavignet E. 2011, Riffat B., Gan L. Jiang and G. 2005, Kandakure V., Gaikar A. 2005, Patwardhan Cui Li, Yanzhong Li, Wang Lei. 2012, Cramers PHMR, Beenackers AACM 2001, Byung H., Hwan Ji Lim, Woongsup Y. 2008) both theoretically and experimentally. However most of the known studies of ejectors were conducted at fluid velocities close to or exceeding the speed of sound.

It should be paid attention that the process of sulphation is a mass-exchange process and not only the amount of ejected gas but also the contact surface of phases is important for it.

The jet nozzle cannot provide the necessary contact area of the phases. The change in the type of atomizer from jet to centrifugal jet or cavitation allowed improving the process of sulphitation but no studies of this replacement of the nebulizer with the ejector hydrodynamics were carried out.

Methods of research. A laboratory installation was designed and manufactured to identify patterns of the current of a two-phase flow in an ejection apparatus. Its structure includes an ejection device, a pump, nozzles for supplying liquid and gas and control measurement instrumentation.

The pressure was monitored using a spring-type manometer OBM1-160 (Ukraine). The liquid consumption was measured by a water meter ETP KV 1.5 (Ukraine). A gas meter PREMA G 1.6 (Ukraine) was used to measure gas consumption. Rarefaction in the intake chamber of the ejector was controlled by a differential manometer. Pictures of the liquid current in the mixing chamber were taken with a digital camera Canon SX130 (China). The processing of the experimental data and the construction of the graphs were carried out using a Microsoft Office Excel spreadsheet.

The ejection apparatus with a jet nozzle with a nozzle diameter $d_n = 3, 4, 6, 8$ mm was researched. Transparent tubes of diameter $D_{m.ch.} = 8, 15, 19, 27, 45$ mm were the mixing chamber. The excess fluid pressure on the nozzle varied within the range of 0.05 ... 0.25 MPa.

A characteristic graph of the dependence of the volume ejection coefficient on the pressure of the liquid supply to the working nozzle of the ejector with a geometrical characteristic (ratio of the diameter of the mixing chamber to the nozzle diameter) is 4.75 ($D_{m.ch.} = 19$ mm, $d_n = 4$ mm) is shown in Fig. 1.

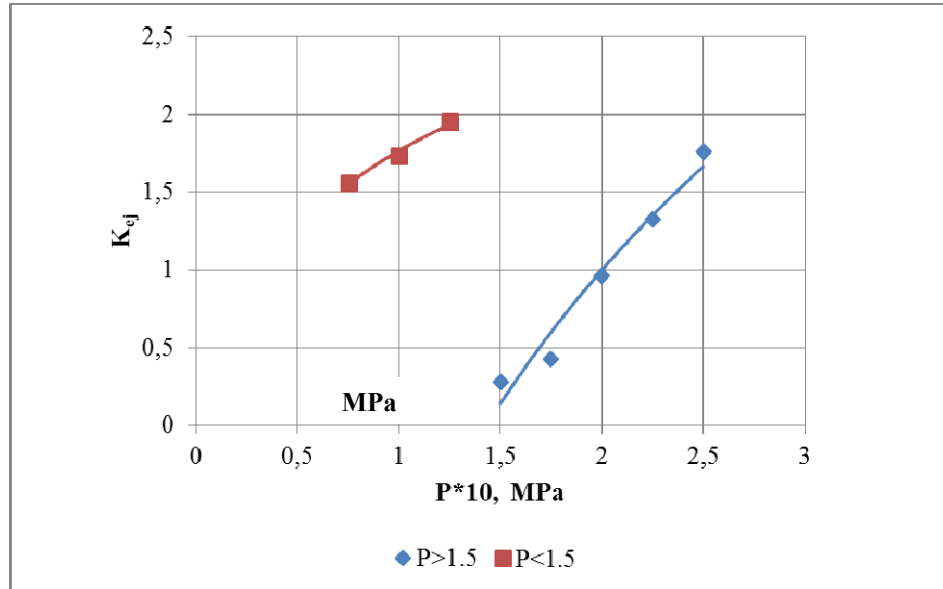


Fig. 1. Dependence of the ejection coefficient on the supply pressure for an ejector with a compact liquid jet

The ejector is locked i.e. there is no ejection of the gas phase at a certain pressure of the liquid on the nozzle ($P \sim 0.15$ MPa). Such a regime springs up in connection with the crisis of liquid drops resistance at Reynolds transition numbers $Re \approx 40 \dots 130$. The locking regime at low ejector pressures was discovered for the first time.

To define the numerical value of the geometrical characteristic of the ejector which allows reaching the maximum ejection coefficient the study was carried out in the range of its variation 1.8...12.25. Its results are shown in Fig. 2.

The regime of the emulsion current in the mixing chamber changed qualitatively when the type of atomizer was changed to centrifugal-jet (Fig. 3.). The opening angle of the sprayed liquid is about 40° and the liquid touches the spray chamber walls.

Visual observation of the liquid current in the mixing chamber of the ejector with $d_n = 4$ mm and $D_{m.ch.} = 27$ mm shows the presence of significant backflows of liquid in the lower part of the chamber to the nozzle of the injector. This leads to a decrease in the efficiency of its work as in the case of using a jet nozzle as a working nozzle. Reverse fluid flows are formed already when liquid droplets form. The trajectory of the droplet movement in the direction is opposite to the trajectory of motion of the main mass of droplets due to rarefaction in the receiving chamber which is seen in Fig. 3.

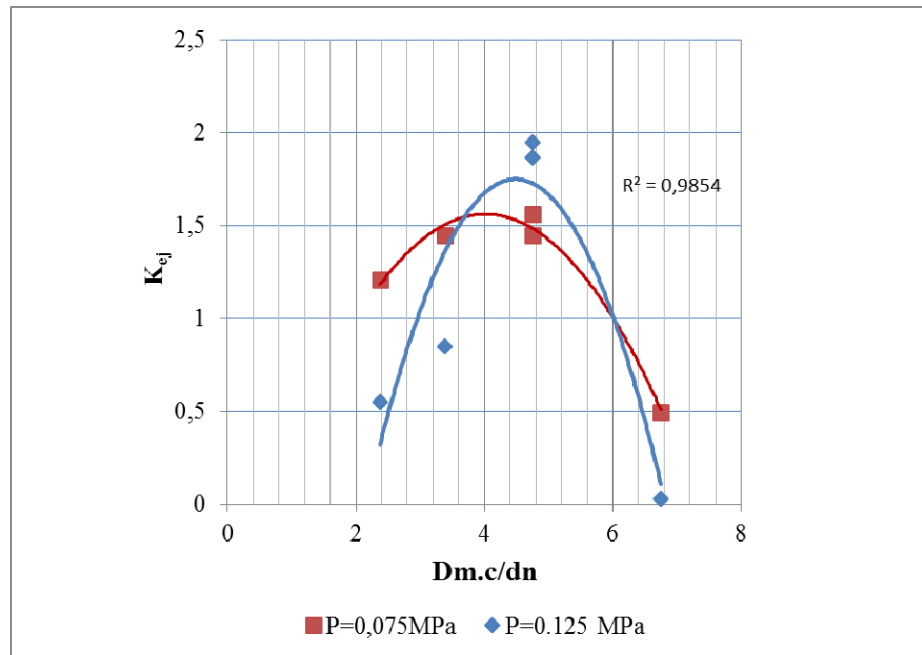


Fig. 2. Dependence of the volume ejection coefficient on the main geometric characteristic of the ejector ($D_{m.ch.} / d_n$) with a compact liquid jet

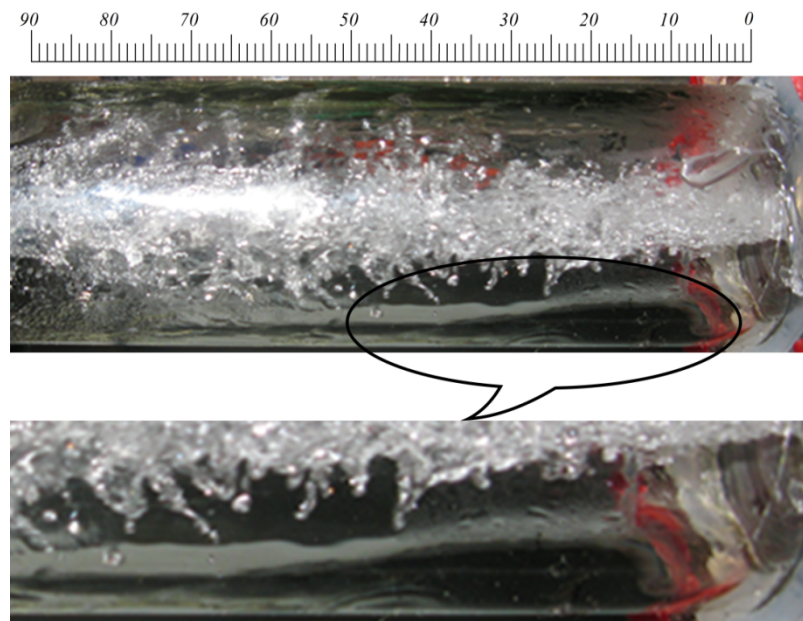


Fig. 3. The regime of liquid current when leaving nozzle

The dependence of the volume ejection coefficient on the pressure of the liquid on the nozzle in the research of ejectors with a dispersed liquid jet and the geometric characteristics of 3.75 ($D_{m.ch.} = 15$ mm and $d_n = 4$ mm), 4.75 ($D_{m.ch.} = 19$ mm and $d_n = 4$ mm), 6.75 ($D_{m.ch.} = 27$ mm and $d_n = 4$ mm) are shown in Fig. 4. The dependence of the volume ejection coefficient on the main geometric characteristic of the ejector is shown in Fig. 5. The ejection coefficient reaches its maximum value of in the range of values of $D_{m.ch.} / d_n$ of the ejector 4 ... 7.

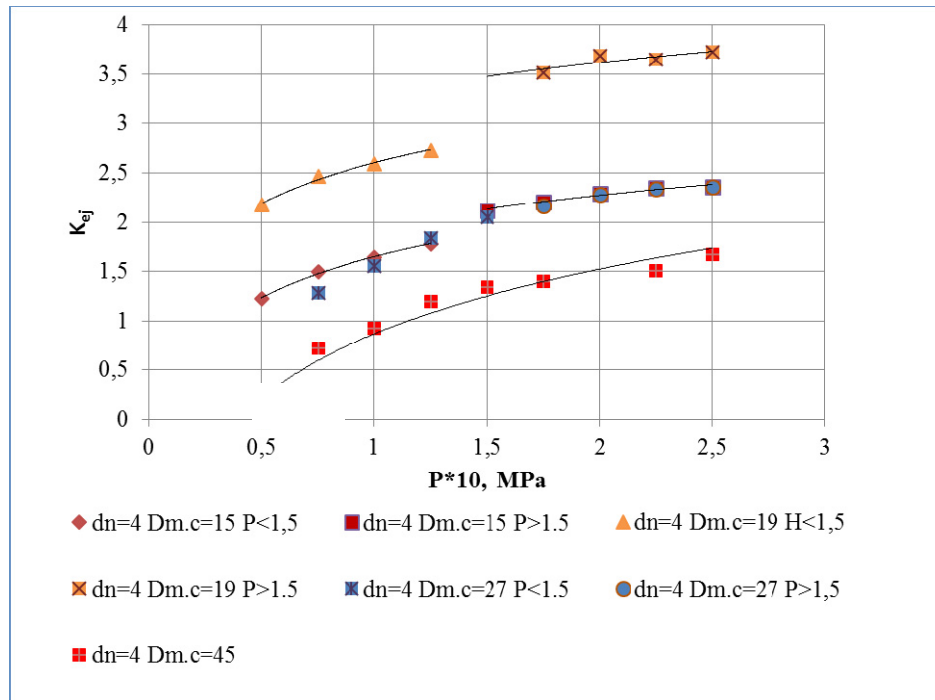


Fig. 4. Dependence of the volume ejection coefficient on the liquid pressure on the nozzle at $d_n = 4$ mm and $D_{m.ch.} = 15, 19, 27, 45$ mm

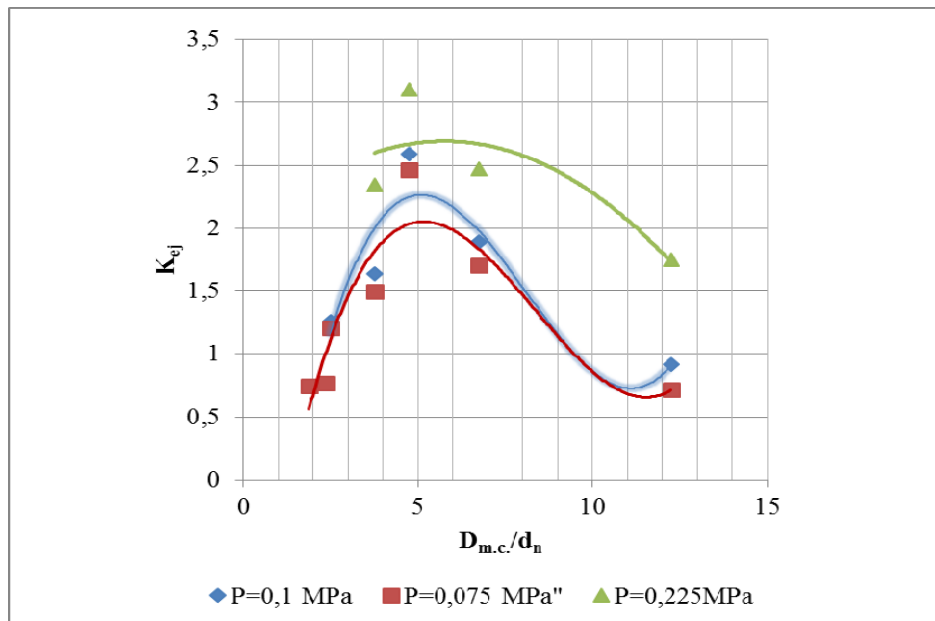


Fig. 5. Dependence of the volume ejection coefficient on the main geometric characteristic of the ejector ($D_{m.ch.} / d_n$) with a dispersed jet of liquid

Efficiency of the ejector with a dispersed liquid jet is higher by 15 ... 20% which can be explained by the more developed surface of the liquid which comes into contact with the gas and involves it in translational motion.

It is proposed to use a two-stage ejector to reach a higher ejection coefficient (Fig. 6.).

The ejector consists of a working nozzle 1 which is in a short orifice 2 and is equal to 3 ... 6 nozzle diameters and a 3 ... 4 diameter orifice. The working nozzle 1 and orifice 2 are placed in the mixing chamber of the second degree of the ejector 3 with a diameter of 3 ... 6 of the diameter of the orifice. The liquid is supplied to the injector via a pipe 4 and the passive medium is sucked with

a branch pipe 5 into the receiving chamber 6 whence is ejected with liquid through the canals 7 and 8 respectively into the orifice 2 and the mixing chamber of the second stage 3.

The range of recommended diameters of the orifice is chosen from those considerations that there is the greatest ejection coefficient at such a ratio of diameters according to the published data and the studies which were carried out. The length of the orifice equal to its 3 ... 4 diameters is selected on the basis of the known hydraulics regulations of fluid current through short orifices. It means the highest fluid discharge coefficient is achieved with this length. I.e. the work of the ejector is the most energy efficient at the specified orifice length.

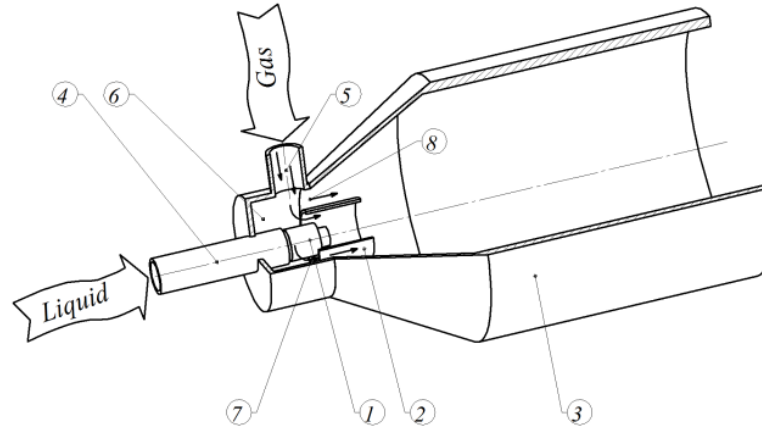


Fig. 6. Two-stage ejector

The results of the pilot studies (Fig. 7.) of the two-stage ejector of the proposed design showed an increase in the volume ejection coefficient by 20% compared to the ejectors of the classical design.

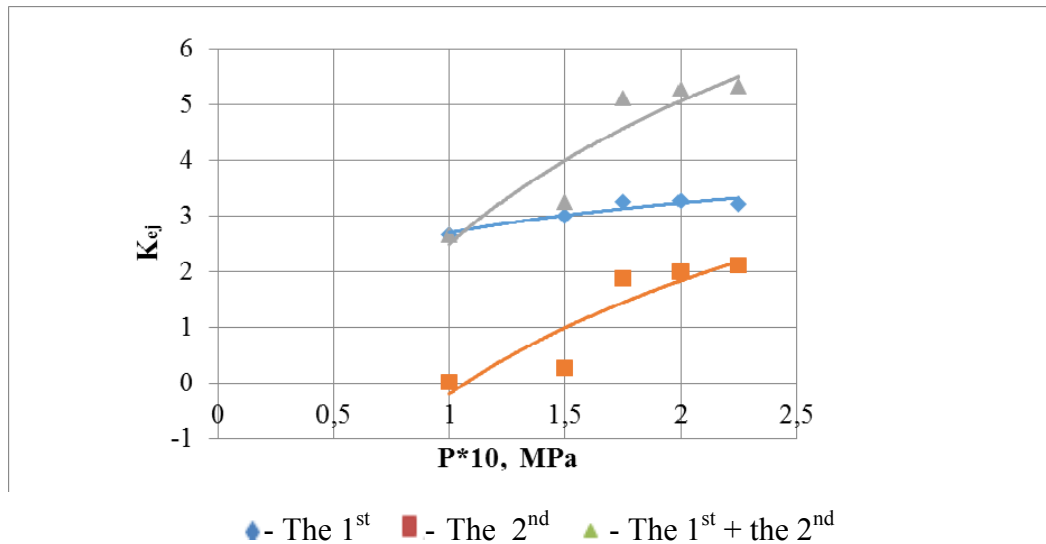


Fig. 7. Dependence of the ejection coefficient on the pressure of the liquid on the nozzle

CONCLUSION

The research of a single-stage ejector with a compact and dispersed liquid jet showed the advantage of the second one since the ejection coefficient is reached by 15 ... 20% higher. The optimum value of the geometrical characteristic of the ejector is in the range 4 ... 7.

The design of a two-stage ejector where a higher ejection coefficient is achieved (by 20 ... 40%, depending on the pressure of the liquid supply to the main nozzle of the ejector) is more perfect.

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