Scientific quarterly journal e-ISNN 2449-5999
Agricultural Engineering
2015: 1(153):47-55
Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.105

A PRELIMINARY ASSESSMENT OF USING THE OPERATING HEAD WITH OVAL NOZZLES FOR IMPINGEMENT FLUIDIZATION OF VEGETABLES

Dariusz Góral*, Franciszek Kluza, Katarzyna Kozłowicz, Marek Domin

Department of Refrigeration and Food Industry Energetics, University of Life Sciences in Lublin
**Contact details: ul. Doświadczalna 44, 20-280 Lublin, e-mail: dariusz.goral@up.lublin.pl*

ARTICLE INFO

Article history:
Received: November 2014
Received in the revised form: November 2014
Accepted: December 2014

Keywords:
impingement fluidization
air distribution
jet nozzles
oval cross section

ABSTRACT

The operating system of cooling and freezing by impingement and impingement fluidization techniques was modified using oval cross-sectional air jet nozzles at three different configurations of air distribution. The air jet exit velocity at different preset values of 30-50 $m \cdot s^{-1}$ as well as the velocity of air rebound from the operating chamber bottom were measured by applying three heads with oval nozzles and one with classical nozzles for comparative purposes. All of the nozzles had the same cross section. Freezing tests of French fries were performed in these conditions. An analysis of the rebound air velocity fields indicated that both an oval nozzle design and air velocity at the nozzle outlet determine the rebound air velocity. It was found that the limited use of oval nozzles at the impingement fluidization freezing process is possible and that 40 $m \cdot s^{-1}$ was the most appropriate velocity for air jets leaving the nozzles.

Introduction

The efficiency of the impingement freezing method is associated with high heat transfer coefficients in the product surrounding and, therefore, jet impingement is a high performance technique for heating, cooling and drying processes in many industrial applications (Ovadia and Walker, 1998; Lee&Lee, 2000). It consists in directing high velocity impingement air jets leaving vertically arranged nozzles to flow around the product.

The impingement method is used in combination with classical fluidization freezing in thermal treatment, and there are two technical possibilities of conducting the impingement method in fluidization. In the first technical possibility, the thermally treated air jets are directed into the product bed through nozzles from below, i.e. upward to induce fluidized bed boiling. This is a specific modification of classical fluidization and the technical problems that occur in both cases are similar (Ovadia and Walker, 1998).

In the second technical possibility, product fluidization is done by directing the air jets leaving the nozzles from above, i.e. downward into the product placed on a solid base. As a consequence of air jet impingement on and through the product bed and its rebound of air against the base, the particles are carried upward, the bed expands and specific fluidized boiling of the bed starts. Unlike devices using the impingement system, a combination of the fluidization process and impingement effect, called impingement fluidization, is still under experimental studies (Góral and Kluza, 2004).

In order to induce such a fluidization process, a fountain must be created due to interactions between the air jets. Air pressure in the fountain core should be high enough to overweigh the forces of gravitation and to product adhesion to the bottom (fig. 1).

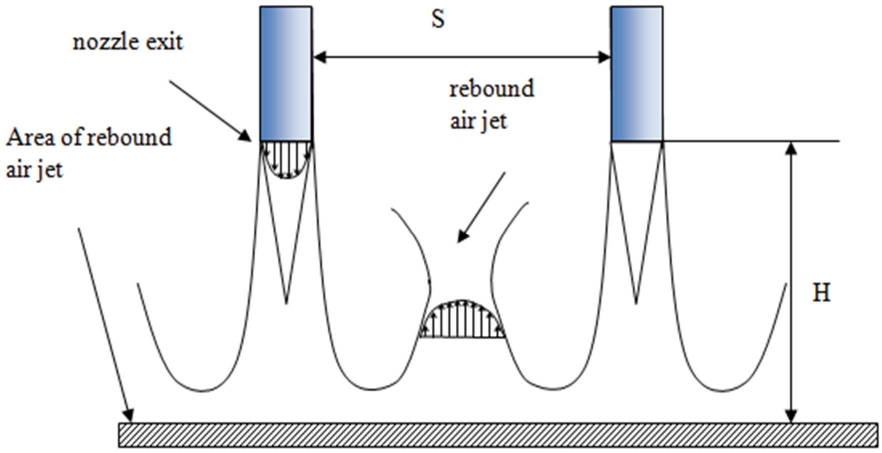

Figure 1. Interaction between air jets

At the minimum fluidization velocity the buoyancy imposes a product upward from the fountain base towards its top. Interactions between bed particles entrain a single particle to the fountain top edge to be later pushed to the lower pressure zone or to get under the air jet leaving the nozzle. Then the particles fall down rapidly onto the working chamber bottom and recirculation starts (Kluza and Stadnik, 2009; Góral and Kluza, 2012).

The feasibility of applying impingement fluidization to fruit and vegetable cooling or freezing in industrial conditions depends on how the physical properties essential for the formation of stable fluidized beds are designed. This is connected with the necessity of achieving a uniform distribution of fountains in the whole working chamber of the installation as well as suitable pressure of the air rebound from the chamber bottom. The studies conducted so far have focused primarily on characteristics of the impingement system, especially on the effect of nozzle spacing as well as the distance between the nozzle exit and the chamber bottom on the heat transfer coefficient between the product and air (Downs and James, 1987; Jambunathan, Lai, Moss and Button, 1992; Huber and Viskanta, 1994a; Huber and Viskanta, 1994b). Besides, the influence of nozzle spacing and configuration on heat transfer was evaluated and a numerical analysis of the nozzle arrangement with two turbulence models was made (Zuckerman and Lior, 2006). The only paper discussing the impact of the nozzle design and spacing on the potential formation of a fluidized bed using the impingement fluidization technique is the research work of Stadnik

(2010). This work indicates that nozzle spacing (S) to its diameter (D) ratio should be found in a range from 1.8 to 4; values above 4 contributed to the creation of a dead zone (no fluidization observed). The optimal nozzle length ranges are within the limits of $6<S/D<20$. The author confirmed a direct relationship between the type of the applied head and uniformity of the temperature fields obtained with it.

Due to the lack of studies on the application of working heads with nozzles of different non-round, cross-sectional shapes for impingement fluidization freezing, we analysed heads with nozzles of an oval cross-section. The aim of the investigations was to find the characteristics of the influence of the nozzle configuration in the head on the rebound air velocity field and to assess the mean values of rebound air jet velocities in relation to the velocity of the air jet at the nozzle exit.

Material and methods

The studies were carried out at the Department of Refrigeration and Food Industry Energetics, University of Life Sciences in Lublin, on a test stand used for impingement fluidization freezing within a temperature range from -30ºC to 0ºC. The process conditions were provided by the installation of 3.9 kW cooling capacity fitted with a centrifugal fan (Nyborg-Mawent type WP-20/1.5) of 0.6 $m^3 \cdot s^{-1}$ air capacity at 2.6 kPa pressure with an inverter LG SV0751G52 for smooth regulation of fan capacity.

Working heads of dimensions 410x360x18 mm (fig. 2) were fitted with nozzles made from round copper tubes 20 mm in inner diameter and 270 mm in length.

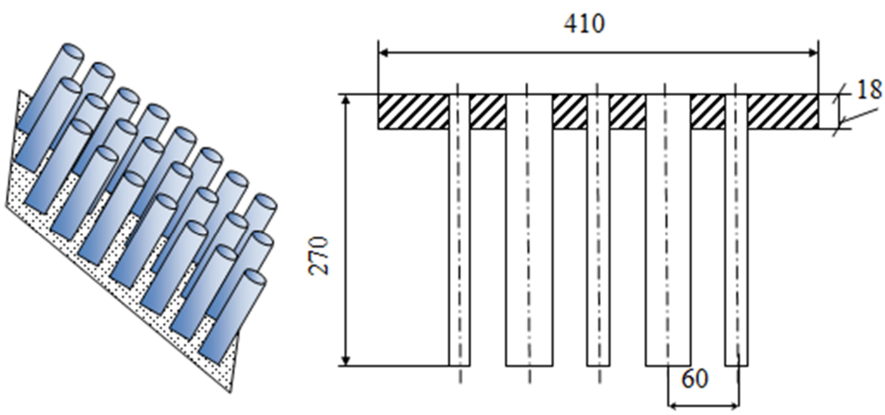

Figure 2. Scheme of head with nozzles

The tubes, at a distance of 230 mm from the nozzle outlet, were formed on a hydraulic press to obtain an oval cross-section of dimensions 10x25 mm. The nozzles were arranged in a parallel, staggered and mixed staggered configuration with a constant nozzle number and distance between the nozzle centres (fig. 3).

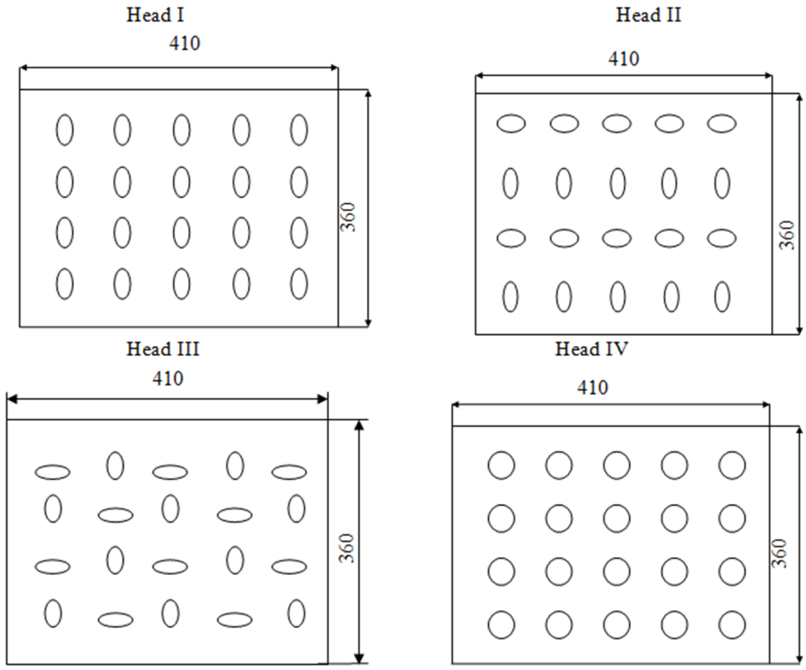

Figure 3. Scheme of head with oval nozzles in the configuration: parallel (head I), staggered (head II), mixed staggered (head III) and classical nozzles (head IV).

A container for the product bed 135 mm in height was used during the studies. The distance between the nozzles and the container bottom was constant – 125 mm.

The aerodynamic values obtained from the tests with the working heads with oval nozzles were compared to the results depicting the head with classical nozzles (nozzle number – 20, inner diameter – 20 mm, nozzle spacing – 50 mm).

Measurement of the rebound air jet velocity was performed by a micromanometer MP 120 (KIMO Instruments) with a Pitot tube type L 3 mm in diameter (fig. 4).

The direction of the Pitot tube tip was perpendicular to the container bottom and parallel to the working head nozzles. The distance between the Pitot tube end and the container bottom was equal to 110 mm each time.

The Pitot tube, as a standard measuring device, was positioned in the working space of each nozzle at measuring points according to the scheme presented in figure 4.

For the purpose of confirming the usability of oval cross-sectional nozzles for a real freezing process, fluidization freezing of French fries and green beans was conducted. French fries were prepared from disease-free potatoes of the same firmness and equal size. The initial treatment involved removal of the outer layer, rinsing under cold tap water and drying on filter paper to take out any excess water. This raw material was cut into cube-shaped fries of a 10x10 mm cross section and little varying length.

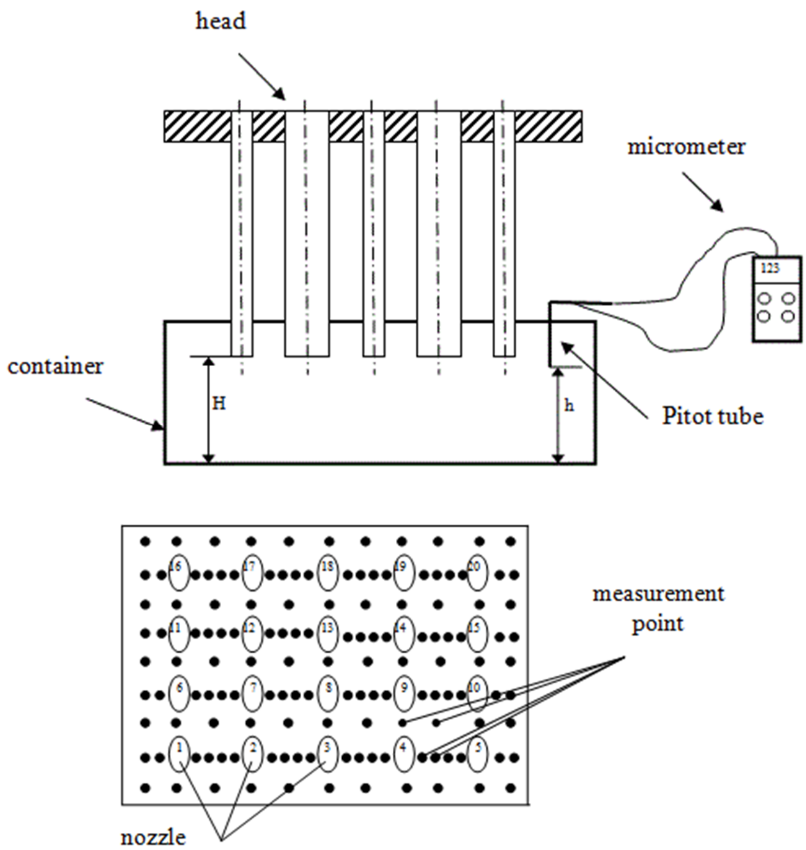

Figure 4. Scheme of measurements of rebound air velocity

Raw material prepared in this way was poured into a container so that it formed an even layer. Then when the fan rotation speed (RPM) was changed over the set range, the velocity of air jet at the nozzle outlet was also changed. Our observations aimed to determine the velocity of air jets leaving the nozzle at which product boiling was obtained and to establish the maximum velocity of air jets at the nozzle exit at which the pneumatic conveying of material did not operate yet.

Results and discussion

A comparative analysis of the rebound air velocity values obtained with four head types at 30, 35, 40, 45, 50 $m \cdot s^{-1}$ velocity of the air jets at the nozzle exit showed a relationship between velocity value, nozzle shape and configuration of nozzle arrangement in the head (fig. 5).

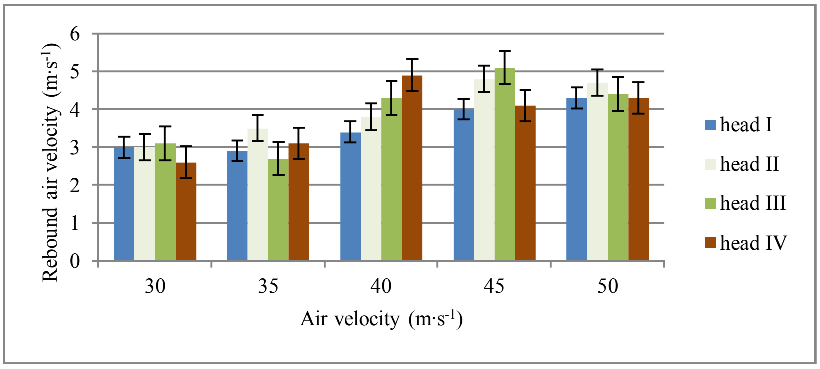

Figure 5. Comparison of mean values of velocity rebound air jets

At 30 m·s^{-1} velocity of air jets leaving the nozzle outlet the heads with oval cross-sectional nozzles (I, II, III) did not bring any significant differentiation in the rebound air jet velocity value, whereas the head with round nozzles (IV) was characterized by a lower mean value of velocity. In the case of 35 m·s^{-1} velocity of air jets at the nozzle exit, marked differences in the mean value of the rebound air velocity were determined in heads II and IV. Application of other head types did not give rise to any significant differences in the mean value of the rebound air jet velocity. A velocity of rebound air jets at the nozzle outlet increased up to 40 m·s^{-1} caused a notable scattering of velocity values, the most intensive was observed for head IV (from 3.4 up to 4.9 m·s^{-1}). When the velocity at the nozzle exit reached 45 m·s^{-1}, the highest rebound air jet velocity (5.1 m·s^{-1}) was recorded for head III. The use of head I and IV provided mean values that were considerably lower as compared to the application of head II and III. Finally, at 50 m·s^{-1} velocity of air jets at the nozzle exit lower mean values of rebound air velocity were noted than at 45 m·s^{-1} velocity of air jets leaving the nozzle. This was most likely the result of some disturbances of the air jet flow due to too high operation pressure in the container under the nozzles of the tested heads.

Views of rebound air jet velocity fields at 30 m·s^{-1} velocity of air jets at the nozzle exit are presented in figures 6.

When analyzing the measurement results for heads with oval nozzles at 30 m·s^{-1} velocity at the air outlet it was found that in all four cases the highest rebound air velocity was recorded at the head edge. Heads with oval cross-sectional nozzles showed a non-uniform distribution of rebound air velocity. A comparison of the present results with those obtained for the head with round nozzles indicated a completely different character of these fields. The fields of rebound air velocity were distributed uniformly, whereas the velocities of air rebound at the application of all four heads were close and ranged between 2 m·s^{-1} and 5.6 m·s^{-1}.

It was also established that changing the nozzle arrangement from parallel to staggered or mixed staggered in the working head did not affect the rebound air jet velocity fields. These velocity fields achieved at 35 m·s^{-1} velocity of air jets leaving the nozzles showed higher levels of distribution uniformity for all of the tested heads. However, as was in the case of 30 m·s^{-1} air jet velocity at nozzle outlet, higher values of rebound air velocities were measured for the edge-mounted nozzles. As was expected, increasing the velocity of air leaving the nozzles caused a growth of the mean velocity of rebound air. The highest air velocities were obtained for a working head with a staggered configuration and in a head with round nozzles, i.e. 7.3 $m{\cdot}s^{-1}$ and 7 $m{\cdot}s^{-1}$, respectively.

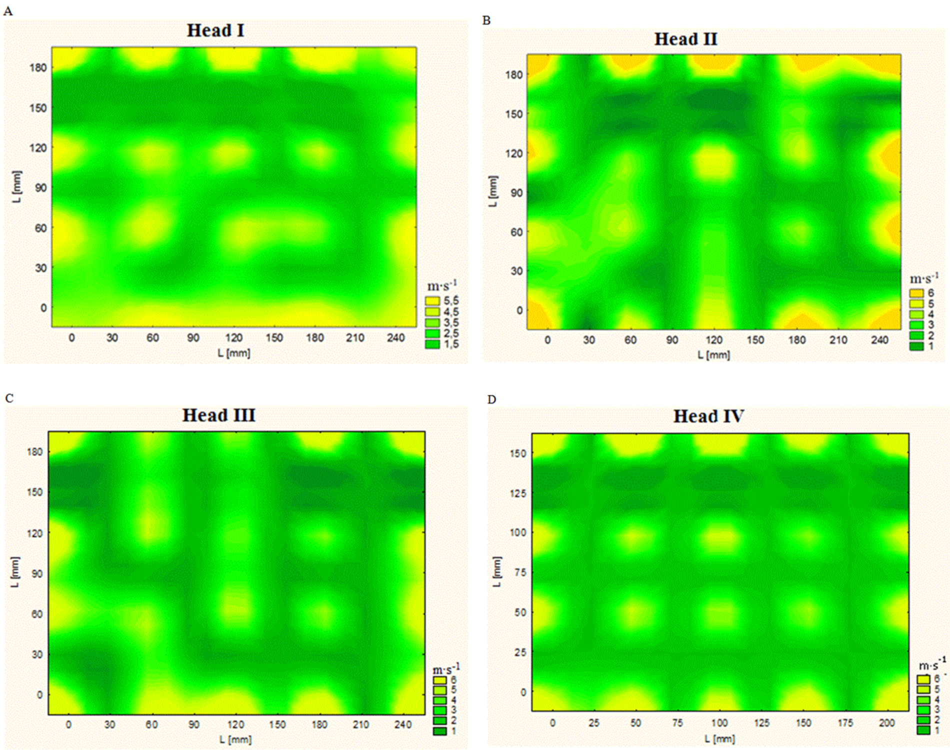

Figure 6. Fields of rebound air velocity at 30 $m{\cdot}s^{-1}$

An analysis of air velocity fields at 40 $m{\cdot}s^{-1}$ showed that, similarly to 30 $m{\cdot}s^{-1}$, the obtained fields were characterized by great non-uniformity, except for the uniform distribution of velocity for the head in the parallel arrangement. Besides, in comparison to heads with oval nozzles, a marked elevation of rebound air jet velocity for the head with round nozzles was reported. The maximal velocity value of rebound air oscillated from 6.1 up to 7.7 for heads with oval nozzles and 10 $m{\cdot}s^{-1}$ for a head with round nozzles. A statistical comparison of the rebound air velocity values indicated no significant differences in the case of the head with oval nozzles arranged parallelly at 35 $m{\cdot}s^{-1}$ and 40 $m{\cdot}s^{-1}$ outlet velocity.

Studies on the distribution of the velocity of air jet rebound against the chamber bottom at 45 $m{\cdot}s^{-1}$ air nozzle velocity showed that the distribution displayed a similar uniformity in the case of the head with oval nozzles and the head with round nozzles. As for the other heads, a markedly more uniform distribution was reported.

When analyzing the velocity field of air jet rebound at 45 $m{\cdot}s^{-1}$ air nozzle velocity, their non-uniform distribution was found. The increased velocity of air leaving the nozzles did not cause a notable increase of the rebound air velocity only in the case of the head with oval nozzles in the parallel arrangement. In the other cases its growth up to the maximum of 10 $m \cdot s^{-1}$ was recorded.

The effect of an oval cross-section of the nozzles on the possibility of bed boiling was estimated during green beans and French Fries impingement fluidization freezing. It was established that the boiling fluidized bed was obtained for heads with oval nozzles in a parallel and mixed staggered configuration and an air outlet velocity of 40 $m \cdot s^{-1}$. In other cases under investigation neither a boiling fluidized bed nor pneumatic transport of raw material was obtained.

Conclusion

The following conclusions were formulated on the basis of the research and analysis of the measurement results:

1. The increased velocity of air leaving the nozzles and the arrangement of oval nozzles in the head affect the velocity of air jet rebound from the working chamber bottom.
2. In the case of air nozzle velocity above 45 $m \cdot s^{-1}$, the mean rebound air velocity decreases due to overpressure in the working chamber.
3. Studies exploring obtaining a fluidized bed of French fried potatoes and green beans using heads with oval nozzles indicated the possibility of applying this head type in the freezing treatment. The most suitable air nozzle velocity proved to be 40 $m \cdot s^{-1}$.

References

Downs, S.J.; James, E.H. (1987). *Jet impingement heat transfer – a literature survey*, ASME paper No. 87-Ht-35, ASME, New York, NY.

Góral, D.; Kluza, F. (2004). Experimental identification of refrigeration impingement system work. *Inżynieria Rolnicza, 5*(60), 117-124.

Góral, D.; Kluza, F. (2012). Heat transfer coefficient in impingement fluidization freezing of vegetables and its prediction. *International Journal of Refrigeration*, *35*, 871-879.

Huber, A.M.; Viskanta, R. (1994a). Effect of jet-jet spacing on convective heat transfer to confined, impinging arrays of axisymmetric air jets. *International Journal of Heat* and *Mass Transfer, 37*(18), 2859-2869.

Huber, A.M.; Viskanta, R. (1994b). Impingement heat transfer with a single rosette nozzle. *Experimental Thermal* and *Fluid Science*, *9*(3), 320-329.

Jambunathan, K.; Lai, E.; Moss, M.A.; Button, B.L. (1992). A review of heat transfer data for single circular jet impingement. *International Journal of Heat* and *Fluid Flow*, *13*(2), 106-115.

Kluza, F.; Stadnik, Ł. (2009). Experimental formation of bed under jet tube fluidization conditions used for food cooling and freezing. *Electronic Journal of Polish Agricultural Universities, 12*(3), 07.

Lee, J.; Lee, S.J. (2000). The effect of nozzle configuration on stagnation region heat transfer enhancement of axisymmetric jet impingement. *International Journal of Heat* and *Mass Transfer, 43*, 3497-3509.

Ovadia, D.Z.; Walker (Chuck),. C.E. (1998). Impingement in food processing. *Food Technology, 52*(4), 46-50.

Stadnik, Ł. (2010). *Effect of food freezing conditions realized by impingement fluidization*. PhD Thesis, Uniwersytet Przyrodniczy w Lublinie, Lublin.

Zuckerman, N.; Lior, N. (2006). Jet Impingement Heat Transfer: Physics, Correlations, and Numerical Modeling. *Advances in Heat Transfer, 39*, 565-631.

WSTĘPNA OCENA ZASTOSOWANIA GŁOWICY ROBOCZEJ Z OWALNYMI DYSZAMI DO ZAMRAŻANIA METODĄ ODWRÓCONEJ FLUIDYZACJI WYBRANYCH WARZYW

Streszczenie. Układ roboczy urządzenia do chłodzenia i zamrażania metodami impingement i odwróconej fluidyzacji zmodyfikowano, stosując do rozprowadzania powietrza dysze o przekroju owalnym w trzech konfiguracjach ustawienia względem siebie. Pomiary prędkości powietrza wypływającego z dysz przy założonych zróżnicowanych ich wartościach 30-50 $m \cdot s^{-1}$ i prędkości powietrza odbitego od dna komory roboczej przeprowadzono, wykorzystując trzy głowice z dyszami owalnymi i porównawczo jedną z dyszami klasycznymi. Przekrój poprzeczny wszystkich dysz był identyczny. Wykonano próby zamrażania frytek ziemniaczanych w tych warunkach. Analiza pól prędkości powietrza odbitego wykazała, że układ dysz owalnych oraz prędkość wypływającego z nich powietrza decydują o prędkości powietrza odbitego. Stwierdzono, że możliwe jest ograniczone zastosowanie dysz owalnych w obróbce zamrażalniczej metodą odwróconej fluidyzacji, a najodpowiedniejszą prędkością powietrza wypływającego z dysz było 40 $m \cdot s^{-1}$.

Słowa kluczowe: odwrócona fluidyzacja, rozprowadzenie powietrza, dysze, przekrój owalny