

LOCAL APPROACH TO IMPROVE THE AERODYNAMIC CHARACTERISTICS OF THE FINAL DRYING PROCESS

Suprun T.T.

Institute of Engineering Thermophysics, National Academy of Sciences of Ukraine, Kyiv,
suprun@secbiomass.com

Energy-saving technologies are widely used in various technological processes, in particular for the final drying of plant waste. The purpose of the study is to ensure optimal flow distributions and making targeted changes in the design of the coolant supply system based on measurements of local velocities at characteristic points in space, using the methods of hot-wire anemometry. The measurements were carried out in stages and covered eight modifications of the installation. Based on the analysis of the data obtained, specific measures were developed to improve the design of the coolant supply system.

Keywords: coolant supply system, local aerodynamic characteristics

Introduction

Currently energy-saving technologies are widely used in various technological processes, in particular, in drying processes. One of these technologies is the use of a jet system. Impact jets are often used in industry to dry, cool or heat a variety of products. Impact drying and cooling is especially common for continuous sheets such as paper, textiles, and metals. For example, results described in [1] for heat transfer mechanism of a slit jet impingement, will help to optimize cooling equipment and controlled parameters for the industrial-scale hot steel strip/plate cooling technology.

Another drying technology using a jet system has been developed at the Institute of Engineering Thermophysics (IET) of NASU. This technology was used for the secondary processing of waste of the original product, in particular plant raw materials. The use of dried plant waste as additional products for the food, pharmaceutical, and tobacco industries is a significant factor in energy saving. In this technology the final drying of plant raw materials with subsequent technological conditioning is carried out in a single-tier conveyor drying unit by vertical blowing of the coolant in a thin layer of the processed material.

One of the criteria for ensuring the high quality of the resulting product is the organization of the optimal flow distribution of the coolant along the entire working line in the presence of a layer of plant raw materials that is being processed. A significant role in the organization of such a flow distribution is assigned to the coolant supply system, which in this case was formed by rows of slots through which vertical jets flow, blowing a conveyor working line. The intensity of the heat and mass transfer process is determined precisely by the parameters of the coolant supply system (velocity and temperature), as well as by the flow conditions around the layer of the processed product.

The organization of the optimal coolant flow distribution was carried out using the local approach adopted at the IET NASU [2]. The main parameters characterizing the flow distribution are the absolute values of the average velocity and the degree of local velocity field non-uniformity at the characteristic points of the working zone. The values of these parameters are set based on a preliminary assessment of the intensity of heat and mass transfer, taking into account the upper velocity limit, which ensures high quality of the processed material and does not move the material outside the working line. For this installation, the recommended values are $U_{av} \sim 0.5-0.8$ m/s with a permissible degree of non-uniformity 0.6-1.8.

Despite the fact that the design of the installation is preceded by an aerodynamic calculation of the coolant supply system, the influence of the structural elements of the installation on the hydrodynamic structure of the flow is not sufficiently taken into account. As a result, in practice, deviations from the calculation results are observed.

To study the processes of heat and mass transfer occurring in difficult conditions, typical for various heat and power equipment, physical modeling is one of the most successful methods [3]. Therefore, to test

the installation before its commissioning on a full-scale model, pilot tests are carried out on an experimental model, during which the discovered shortcomings are eliminated.

The article presents the results of a local approach in aerodynamic tests of an experimental model of an installation for final drying and technological conditioning of plant raw materials, the purpose of which was to ensure optimal flow distributions based on measurements of local velocities at characteristic points in space and making targeted changes in the design of the coolant supply system. Taking into account the obtained experimental data, specific measures were developed to improve the system for supplying the coolant to the working line. As a result, it was possible to significantly improve the design of the installation and provide the required flow distribution parameters.

Experimental technique

This section describes the design of a specially made experimental model, which fully reproduces the operating conditions of the installation in terms of geometric parameters and the air supply system. The main difference was that the experiments were carried out without heating the coolant (air) and with a fixed working line. The processed material was located on a horizontal working line in the form of a thin layer and was blown with vertical air jets. To assess the uniformity of the flow velocity field, the hot-wire method of measurements was used. Such method is commonly applied to study the structure of complex flows in a wide range of velocities [4], starting from 0.1 m/s, as was the case in the present setup. The calibrations of the hot-wire anemometer sensors were carried out in a special low-speed calibration device developed by IET of NASU. This device allows calibration in the velocity range starting from 0.1 m/s. Simultaneously with the values of the time-average velocity (U , m/s) the hot-wire method makes it possible to determine the value of longitudinal pulsations (u'/U , %), which, as is known [5], has a significant effect on the intensity of heat and mass transfer processes.

As can be seen from Fig. 1, the original plant material (1) is placed on a fixed working line, which is a thin metal plate (2) perforated with holes 4 mm in diameter. The working line is blown with vertical air jets flowing from the system of longitudinal slots (3). The slots were formed using corners (4) with movable walls (5) fixed in the air distribution box, which made it possible to independently adjust the slot width over a wide range (from 3 to 14 mm) to ensure the required flow rate through each slot. On the surface of the air distribution box with an area of $1.5 \times 2 \text{ m}^2$ 33 rows of slots were placed, the distance between the axes of which was 59 mm. To improve the mixing of the jets 33 cylindrical rods with a diameter of 8 mm were placed behind the slots.

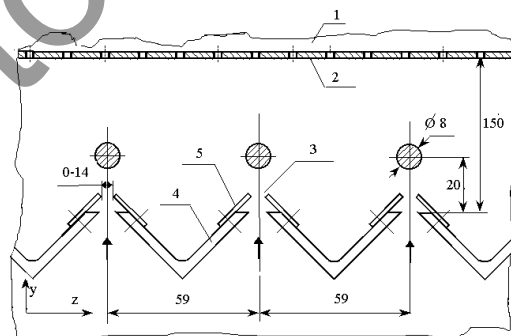


Fig. 1. Scheme of air supply to the working line: 1 - plant material; 2 - perforated metal plate; 3 - a system of longitudinal slots; 4 - corners; 5 - movable walls;

As shown in Fig. 2, the distribution box consisted of two parts: the input and the main one, where the rows of slots were located. The rows were counted along the flow in the z direction. The beginning of each row was counted from the main part of the box in the x direction, and the end corresponded to the dead end zone of the main part. In this case, y was measured behind a specific element (slot, cylinder, or working line) in the vertical direction, i.e. in the direction of the jets flowing from the slots. Both parts of the box were confused, which was supposed to provide the necessary amount of air to the periphery, i.e. to the last rows and to the end of all rows of slots.

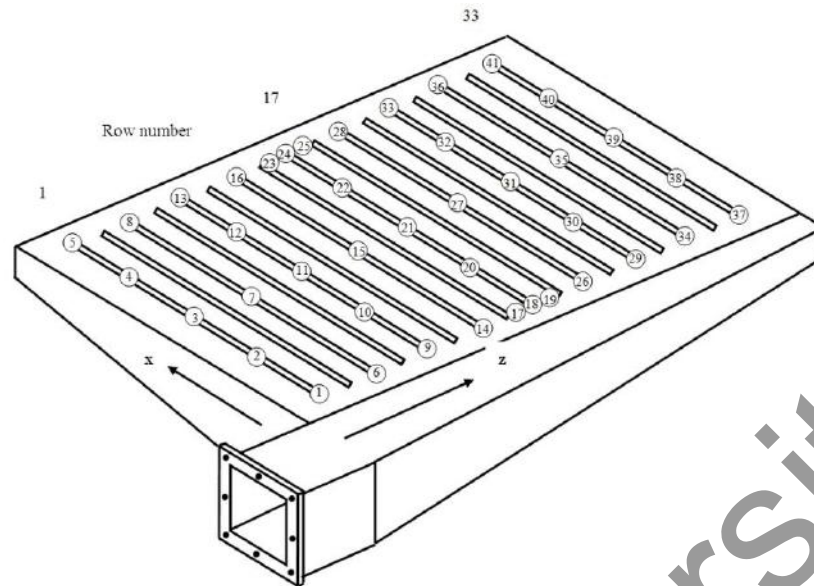


Fig.2. Location of rows and measurement points

The hot-wire anemometer sensor was installed in a special coordinate device, which allows it to be moved along the coordinate axes and fixed at a selected point in the measuring space. The non-uniformity of the flow velocity field was estimated based on the results of measurements at various points in space. For convenience, the measurement points were chosen above the odd rows. The location of the 41 measurement points is shown in Fig. 2, where only the odd rows of slots are shown.

Results and Discussion

Analysis of the measurement results using the local approach gave a complete picture of the spatial non-uniformity of the flow in the entire measuring volume. Based on local flow control, it was possible to carry out targeted measures to change airflow rates. In total, eight design modifications were tested and specific measures were developed to improve the coolant supply system.

To assess the non-uniformity of the velocity field, the so-called non-uniformity coefficient k was introduced, representing the ratio of the local velocity at a given point U to the average velocity U_{av} :

$$k = U/U_{av}, \quad (1)$$

where U_{av} were determined from n measurement data:

$$U_{av} = \sum_1^n U/n. \quad (2)$$

To obtain a general idea of the initial non-uniformity of the flow distribution, the measurement results of modification 1 were used. As can be seen from the analysis of the data presented in Fig. 3, the velocity field was characterized by a significant non-uniformity.

In the first measuring section, located near the beginning of the rows ($x = 40$ mm), the velocities varied from 0.343 m/s in the last row to 0.76 m/s in the 17th central row, with the velocity maximum located in the central row ($z = 1000$ mm). In the second measuring section ($x = 750$ mm) the picture changed qualitatively: the velocity maxima took place in the first and last rows at a higher velocity level (from 1.1 to 2.3 m/s). In the last section ($x = 1460$ mm) the velocity maximum took place in the last row (3.56 m/s), while in the first row the velocity was 1.4 m/s. At the same time, the velocity field non-uniformity along the length of the rows was much greater, reaching ~10 times in the last row. The average velocity calculated from the results of measurements at 13 points was $U_{av} = 1.6$ m/s. The difference in velocities on both sides of the central slot indicated the propagation of the central jet at a certain angle to the working line. It can be caused both by the design of the slot itself and by the influence of the cylinder installed behind it.

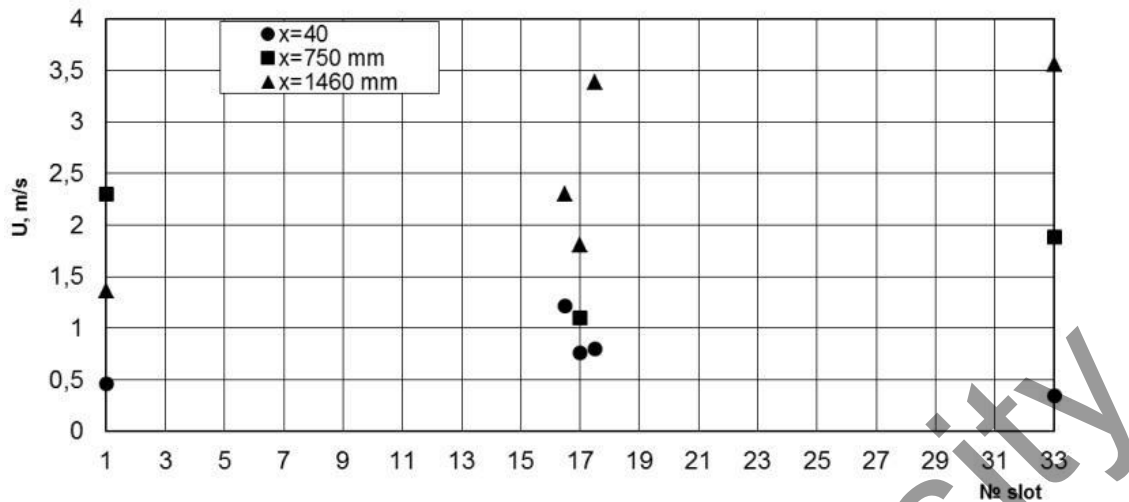


Fig.3. Velocity distribution in modification 1

Based on the obtained measurements, the following main conclusions were drawn:

- velocity distributions are non-uniform, as evidenced by the change in k within the same order;
- in general, higher velocities are observed at the periphery (i.e. in the last row and at the end of the rows);

Thus, based on the local approach, it was confirmed that the initial design of the installation does not satisfy the optimal parameters of the coolant supply system. The obtained experimental data on the non-uniformity of the velocity field formed the basis for measures to improve the installation. In particular, the increase in velocities at the periphery (i.e., in the last row and at the end of all rows) was associated, first of all, with a significant compression of the flow in the confusers of the inlet and main parts of the box. Since the design of the box could not be changed, it was decided to eliminate this defect by adjusting the width of the slots. The general trend of this measure is to widen the slots at the beginning of the rows to increase velocity and narrow them at the end of the rows to decrease it (Table 1).

Table 1. Width of the slots (mm)

Row number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$x = 0$ mm	14	14	14	14	14	9	9	9	9	9	9	9	9	9	9	9
$x = 750$ mm	7	7	7	7	9	9	9	9	9	9	9	9	9	9	9	9
$x = 1500$ mm	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

continuation

Row number	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
$x = 0$ mm	9	9	9	13	13	13	13	13	13	13	13	14	14	14	14	14	
$x = 750$ mm	9	9	9	8	8	8	8	8	8	7	7	7	7	8	8	8	8
$x = 1500$ mm	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3

Another measure to improve the non-uniformity of the velocity field was the partial covering of the slots at the ends of the rows.

Based on the measurements, air leaks through the leaky parts of the main box in the area of the first and last rows ends were also diagnosed and then eliminated.

The next measure to improve the aerodynamic characteristics of the installation was the elimination of cylindrical rods, which were originally installed to improve the mixing of jets. It should be noted that the presence of rods in the air supply system:

- generally complicate the air supply system;
- makes it difficult to clean the cracks due to the ingress of plant materials particles into them;
- rods create additional aerodynamic resistance;
- contribute to flow instability and to form the so called “Von Karman” vortex street;
- Lack of strict rules for fixing rods can cause curvature of the flow path.

Based on the known literature data on jet flows (see, for example, [6] and references to it), a preliminary calculation of a system of flat jets was carried out for a given blower capacity of 5000 m³/h. The calculation results showed that the system of flat jets at a distance of about 30 calibers from the exit of the slot creates a velocity field with a non-uniformity $k \leq 2.4$ at a maximum velocity of 1.3 m/s. These data on the absolute value of the velocity and the non-uniformity of the velocity field correspond to the flow distribution necessary for the reliable operation of the installation. Therefore, it was decided to improve the design of the air supply system by eliminating cylindrical rods.

To confirm the correctness of this measure, control measurements were carried out behind the slots above the working line in the absence of cylindrical rods (modification 8). The measurement results are shown below. In the entire measuring volume (Fig. 4), the velocity field non-uniformity coefficient k changed by no more than ~ 1.8 at an average velocity $U_{av} = 0.77$ m/s. Thus, in modification 8, compared with the original version 1, a significant improvement in the velocity field was observed both along the rows and along their length.

Comparative analysis of the obtained results with similar data for the modification in the presence of rods makes it possible to detect an increase of up to 35% in the average velocity with the same non-uniformity coefficient. However, this increase in velocity does not move the material from the working line. Visual observations allow us to conclude that in modification 8 the flow conditions have been achieved, which ensure high-quality processing of the material. Fragments of plant material move, lift slightly above the surface of the working line, but practically do not detach from it and are not carried out by the flow into the surrounding space. The measurement results also showed that in modification 8 there is an increase in the degree of flow turbulence, reaching at some points $u'/U = 52\%$ at an average level of $\sim 30\%$ (Fig. 5).

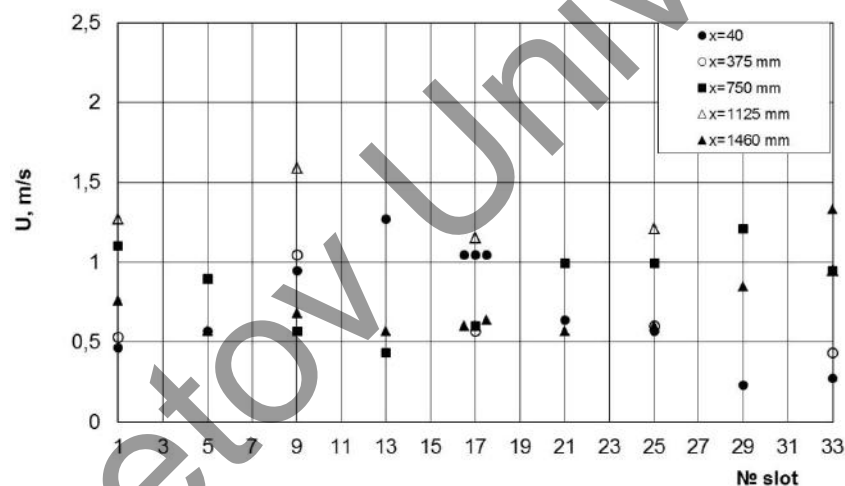


Fig.4. Velocity distribution in modification 8

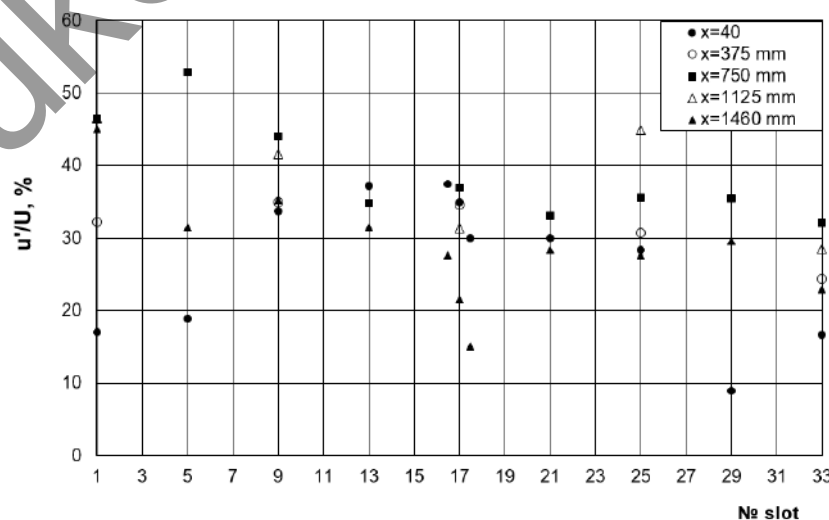


Fig.5. Longitudinal pulsations distribution in modification 8

As shown in [5], an increase in both the average flow velocity of the coolant and its degree of turbulence contributes to the intensification of the heat and mass transfer process. This will improve the quality of the product and reduce the drying time. Thus, based on the use of a local approach to obtain the optimal distribution of the coolant flow, specific measures were developed to improve the design of the installation.

Conclusion

The expediency of using a local approach to control the transfer processes in thermal power equipment for various purposes, developed at the ITTF NASU, was also confirmed during aerodynamic studies of the coolant supply system in the technology of final drying and technological conditioning of plant materials. Using hot-wire measurement technique, the values of average velocities and non-uniformity in the distributions of local velocities, as well as the degree of turbulence at characteristic points of the working space, were estimated.

The paper considers the results of aerodynamic testing of eight modifications of the installation. Specific measures are proposed to improve the design of the coolant supply system, namely:

- significant changes have been made to the size of the slots;
- at the ends of the rows, the sections of the slots are partially covered;
- minimized leakage in the distribution box;
- rows of cylindrical rods were eliminated;

As a result of the measures taken it was possible to achieve the optimal values of the average velocity $U_{av} \sim 0.8$ m/s with a coefficient of non-uniformity $k = 0.6-1.8$, which provides the required quality of material processing without removing fragments of plant material outside the working line.

The introduction of an improved coolant supply system contributes to its productivity while reducing the time of drying and conditioning processes by intensifying heat and mass transfer because of increasing the average velocity of the highly turbulent coolant flow. Aerodynamic tests have confirmed the necessity of carrying out of the finishing experiments on prototypes in full-scale conditions before commissioning a specific installation. Such experiments make it possible to eliminate the existing shortcomings, work out a more efficient version of the designs, and ensure the reliability of the installation during operation.

REFERENCES

- 1 Bingxing Wang, Zhixue Liu, Bo Zhang, Zhaodong Wang, Guodong Wang. Heat Transfer Characteristic of Slit Nozzle Impingement on High-temperature Plate Surface. *ISIJ International*. 2019, Vol. 59, Issue 5, pp. 900-907 <https://doi.org/10.2355/isijinternational.ISIJINT-2018-576>
- 2 Suprun T.T. Local approach for evaluating heat transfer of prismatic elements on a flat surface. *Eurasian phys. tech. j.* 2021, Vol.18, No. 3 (37), pp. 43-47. doi: 10.31489/2021No3/43-47.
- 3 Suprun T. Physical modeling the unsteady flow with wakes. *Eurasian phys. tech. j.* 2017, Vol.14, No. 2(28), pp. 113 - 119. http://phtj.ksu.kz/files_phtj/2018.01/19.pdf
- 4 Bradshaw P. *An Introduction to Turbulence and its Measurement*. Mir, Moscow, 1974, 345 p. [in Russian]
- 5 Epik E.Ya., Suprun T.T. Impulse and heat transport processes at bypass transition. *Eurasian phys. tech. j.* 2007, Vol.4, No.1(7), pp. 52-57
- 6 Dyban E.P., Mazur A.I. *Convective heat transfer in jet stream flow of bodies*. Naukova Dumka, Kiev, 1982, 303 p. [in Russian]