Simulation of hydrodynamics of the dispersed layer of fruit during solar-convective drying

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Abstract. The article proposes a hydrodynamic model of forced convective drying of fruits and vegetables, in which the direction of the coolant flow to the product being dried, the degree of dispersion of the product layer, the hydrodynamics of drying fruits and vegetables in the form of spheroids, flat disks and flat plates, as well as supports with plastic, metal and wooden gratings, modeled based on the necessary equations and criterion equations.

1 Introduction

The study of the hydrodynamics of the dispersed layer of fruits under conditions of forced convective drying has important applied significance: determination of the hydraulic resistance of the dispersed layer of fruits and energy costs in the forced ventilation system; solving structural, technological and operational problems.

In the existing literature on solar drying, the problems of hydrodynamics of the dispersed layer of various fruits under conditions of forced convective drying are solved in a simplified manner: the hydraulic resistance of the dispersed layer of fruits is established tentatively; it is not substantiated theoretically or experimentally.

Both during traditional thermal and solar-convective drying of various fruits, the drying material is placed on shelving racks in one layer [1] (Figure 1).

When considering the hydrodynamics of a stationary layer, two main models are used [2-3], in which a layer of particles is considered as:

- A system of winding channels with a characteristic hydraulic diameter (internal task filtration model).
- A set of particles flown around a moving flow (external problem - flow model).

The first model is most widespread. The second model is more natural and reflects the physical picture of fruit drying processes. The pressure drop in the fruit layer will be determined by the hydraulic resistance of the layer itself and the retaining grid; which depends on the flow regime (speed) of the coolant flow, geometry and orientation, porosity, roughness of the layer and lattice; presence of walls.

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2 Material and methods

In drying processes, the hydrodynamics of the stationary layer of fruits is considered under the following conditions (Figure 1):

- The direction of coolant flow is perpendicular to the plane of the layer. This direction is the most optimal and provides equal drying conditions for all particles.
- The dimensions of the dispersed layer are two orders of magnitude larger than the particle sizes, so the influence of walls (or absence) on the hydrodynamics of the layer is not taken into account.
- Fruit drying material is divided into three types according to shape:
  - Spheroids: apricot, grapes, plums, etc. (Figure 1A).
  - Flat disks: apples, quinces, pears, etc. cut into slices (Figure 1B).
  - Flat plates: melons cut into slices (Figure 1C).

- Plastic and metal meshes and a wooden grid were used as holding grids.

To determine the flow regime in the layer, the granulometric parameters of dispersed layers of various fruits as drying objects at initial $W_{\text{in}}=100\%$ and final $W_k$ humidity, most typical in drying practice, were established experimentally: apricots (spheroids), apples (discs), melons (plates).

The flow rate in the layer is determined by the porosity of the layer:

$$w_0 = \frac{w}{\varepsilon}. \quad (1)$$

The flow regime in the layer will be determined by the Reynolds number:

For the filtering model

$$Re = \frac{wd_0}{\nu \chi}; \quad (2)$$

For the flow model

$$Re = 2\frac{wd_0}{3\nu \chi} \quad (3)$$

Flow velocity within the range $w=0.05...0.2 \text{ m/s}$ is characteristic of natural convection. Naturally, with forced convection, the flow velocity must exceed $w<0.2 \text{ m/s}$. At a speed $w>0.5 \text{ m/s}$, complete turbulization of the flow occurs, and the hydraulic resistance of the layer increases sharply. For the hydrodynamic characteristics of the dispersed layer of fruit, the coolant flow velocity range $w=0.2...0.5 \text{ m/s}$ is considered.

Table 1 shows the parameters of the flow regime in the layer of various fruits, obtained by calculations, at the determining temperature of the coolant - air $40^\circ \text{C}$. As can be seen from Table 1, for all the fruits under consideration the condition $Re<2*10^3$ is met and the flow regime in all cases is laminar.

There are many equations for calculating the pressure drop in random packages of spherical and lumpy (irregularly shaped) granular bodies [2-11]. In foreign and domestic practice, the Ergan equation (internal problem) is most often used at $0.1<Re<10^4$ according to equation (2) [2-5].

$$\Delta P_0 = \frac{\eta \cdot x^2 \cdot \rho \cdot v \cdot w}{\varepsilon^3 \cdot d_0^2} \cdot \xi_0; \quad (4)$$

And Karman-Kozeny (external problem) for $Re<2*10^3$ according to equation (3) [2-3, 5].
ΔP₀ = \frac{9 \cdot H \cdot \chi^2 \cdot \rho \cdot v \cdot w}{2 \cdot \varepsilon^3 \cdot d^2} \cdot \xi₀; \quad (5)

At low Reynolds numbers (laminar mode \(Re<2*10^3\)), equation (4) turns into equation (5).

The hydraulic resistance coefficient of the layer can be represented as [4-5]:

\[ \xi₀ = A + B/Re; \quad (6) \]

which expresses the relationship between the coefficient of viscous friction and the Reynolds number. Constant A in equation (6) reflects the resistance in the midsection in the \(Re>10^3\) mode (drag), the second term \(B/Re\) in the Stokes mode \(Re<10^3\) (viscous resistance). In the literature, expressions (6) are given for spherical bodies and lump materials:

For an internal task:

\[ \xi₀ = 150 + \psi \cdot 1.75Re; \quad (7) \]

And external task:

\[ \xi₀ = 73 + 0.28Re/\psi; \quad (8) \]

For spherical bodies, equations (7) and (8) give fairly accurate results [2, 5]. For flat disks \((d>>h)\) and plates \((h<d<<l)\), equations (7) and (8) give significant deviations, since these equations are for bodies of isometric shape \((d=h=l)\). Using interpolation and least squares methods, we determined our constants in equations (7) and (8) for disks and plates:

1) For internal task:
   Flat discs:
   \[ \xi₀ = 120 + \psi \cdot 0.45 \cdot Re; \quad (9) \]
   Flat plates:
   \[ \xi₀ = 95 + \psi \cdot 0.21 \cdot Re; \quad (10) \]

2) For an external task:
Flat discs

\[ \xi_0 = 17 + 0.18 \cdot \frac{Re}{\psi}; \]  
(11)

Flat plates

\[ \xi_0 = 17 + 0.16 \cdot \frac{Re}{\psi}; \]  
(12)

3 Results and Discussions

Table 1 shows the results of calculations of the hydrodynamics of various dispersed layers. The coefficients of hydraulic resistance \( \xi_0 \) for spheroids are higher than for disks and plates. Spheroids are dominated by viscous friction resistance (flow around spherical surfaces) and low drag. The pressure drop \( \Delta P_0 \) in the layer of spheroids is lower than that of disks, for plates it is higher than that of disks. This allows us to state that the pressure drop in the layer mainly depends on the drag, since [2-10]:

- Spheroids have well-streamlined surfaces, low drag with comparable viscous resistance.
- Discs have large horizontal surfaces - high drag and short vertical surfaces - low viscous resistance.
- The plates have commensurately large horizontal and vertical surfaces - commensurately large drag and viscous resistance.

As can be seen from Table 1, dependence (4) gives higher values of pressure drop in the layer than (5).

As a result of fruit shrinkage during drying, the concentration of the \( \chi \) layer decreases by 1.4...5.8 times. At the final moisture content of the material \( W_k \to \), the pressure drop in the layer \( \Delta P_0 \) decreases by 10 or more times (Table 1).

Table 1. The main granulometric and hydrodynamic parameters of dispersed layers of various fruits with the maximum possible packaging: in the numerator at \( W_m \), in the denominator at \( W_k \).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Spheroids</th>
<th>Disks</th>
<th>Plates</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W_k, % )</td>
<td>19-20</td>
<td>19-20</td>
<td>17-19</td>
</tr>
<tr>
<td>( d, m )</td>
<td>0.0315/0.0211</td>
<td>0.049/0.0405</td>
<td>0.035/0.0238</td>
</tr>
<tr>
<td>( h, l, m )</td>
<td>0.01/0.004</td>
<td>0.02/0.005; 0.3/0.25</td>
<td></td>
</tr>
<tr>
<td>( f )</td>
<td>0.921</td>
<td>0.648</td>
<td>0.527</td>
</tr>
<tr>
<td>( \psi )</td>
<td>1.09</td>
<td>1.543</td>
<td>1.897</td>
</tr>
<tr>
<td>( d_3, m )</td>
<td>0.523/0.234</td>
<td>0.773/0.55</td>
<td>0.795/0.136</td>
</tr>
<tr>
<td>( \chi )</td>
<td>0.477/0.766</td>
<td>0.227/0.45</td>
<td>0.205/0.864</td>
</tr>
<tr>
<td>( \epsilon )</td>
<td>0.477/0.766</td>
<td>0.227/0.45</td>
<td>0.205/0.864</td>
</tr>
<tr>
<td>( w, m/s )</td>
<td>0.2-0.5</td>
<td>0.2-0.5</td>
<td>0.2-0.5</td>
</tr>
<tr>
<td>( w_0, m/s )</td>
<td>0.42-1.05/0.26-0.65</td>
<td>0.88-2.2/0.44/1.11</td>
<td>0.98-2.44/0.23-0.58</td>
</tr>
<tr>
<td>Re by (2)</td>
<td>744-1861/1114-2786</td>
<td>501-1252/501-1252</td>
<td>544-1360/1415-3536</td>
</tr>
<tr>
<td>Re by (3)</td>
<td>496-1241/743-1857</td>
<td>333-834/334-835</td>
<td>363-907/943-2358</td>
</tr>
<tr>
<td>( \xi_0 ) by (7,9,10)</td>
<td>1564-3689/2263-5444</td>
<td>467-989/468-989</td>
<td>312-637/658-1504</td>
</tr>
<tr>
<td>( \xi_0 ) by (8,11,12)</td>
<td>201-393/265-552</td>
<td>48-93/97-216</td>
<td></td>
</tr>
<tr>
<td>( \Delta P_0, Pa, ) by (4)</td>
<td>0.401-2.398/0.426-0.25</td>
<td>1.21-6.202/0.0013-0.007</td>
<td></td>
</tr>
<tr>
<td>( \Delta P_0, Pa, ) by (5)</td>
<td>0.235-1.15/0.0223-0.117</td>
<td>56-114/57-114</td>
<td>0.834-4.097/0.0008-0.005</td>
</tr>
</tbody>
</table>

Filtration rate of coolant flow through the grille:
\[ w_z = w_0/z. \]  
(13)

Grid pressure drop:

\[ \Delta P_z = \frac{\rho \cdot w_z^2}{2} \cdot \xi_z. \]  
(14)

Hydraulic resistance coefficients:

\[ Re = \frac{w_z \cdot d_z}{v}. \]  
(15)

For plastic mesh and wooden grates:

\[ \xi_z = \frac{A_1}{z^2} + A_2 \cdot A_3; \]  
(16)

At:

\[ 25 < Re < 10^5: A_1 = \varphi_1(Re,z); A_2 = \varphi_2(Re); A_3 = \frac{(1+0.707\sqrt{1-z-z})^2}{z^2}. \]

For metal mesh:

\[ \xi_z = (A_1 + A_2) \cdot A_3; \]  
(17)

At:

\[ Re = 50: A_1 = 1,3(1-z) + \left(\frac{1}{z} - 1\right)^2; A_2 = 22Re; A_3 = 1; \]

At:

\[ 50 < Re < 50: A_1 = 1,3(1-z) + \left(\frac{1}{z} - 1\right)^2; A_2 = 0; A_3 = \varphi_3(Re); \]

At:

\[ Re > 10^3: A_1 = 1,3(1-z) + \left(\frac{1}{z} - 1\right)^2; A_2 = 0; A_3 = 1. \]

Functional dependencies \( A_1 = \varphi_1(Re,z); A_2 = \varphi_2(Re); A_3 = \varphi_3(Re) \) determined by diagrams 8-1, 8-5, 8-6 [6].

Table 2 and 3 shows the hydrodynamic parameters of the holding grids and dispersed layers of various fruits. The hydraulic effect of the screen depends on the type of screen, the type of fruit and the filtration and flow rate. Metal meshes have the best hydraulic performance, plastic meshes have the worst (small cells), and wooden grates are in between. The lower the hydraulic resistance of the layer (spheroids), the greater the influence of the lattice. The greater the hydraulic resistance of the layer (plate), the less the influence of the grid. As the flow speed increases, the influence of the lattice increases, which is natural. At finite fruit moisture content \( W_k \), a decrease in the pressure drop in the layer \( \Delta P_0 \) increases the influence of the retaining grid on the total pressure drop \( \Delta P \).
Actually the sum of the r and during the drying, for hydrodynamic calculations, expressions recommended for separately streamlined bodies are used. External problem of the dispersed layer are considered as the sum of individual particles (a completely rarefied, the filtration model becomes more and more artificial, and in the extreme it is not suitable at all.

Provided [13], L>2δ the mutual influence of particles can be ignored and the elements of the dispersed layer are considered as the sum of individual particles (a completely external problem - a flow model). Under these conditions, for hydrodynamic calculations, expressions recommended for separately streamlined bodies are used.

**Table 2.** Cell dimensions of holding mesh grids, mm, F=a-b; F₀=a₀+b₀; z=F/F₀; Π = 2(a+b).

<table>
<thead>
<tr>
<th>Grid view</th>
<th>d₁</th>
<th>d₂</th>
<th>a</th>
<th>a₀</th>
<th>b</th>
<th>b₀</th>
<th>z</th>
<th>d₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Plastic mesh on a fiberglass base</td>
<td>0.7</td>
<td>0.7</td>
<td>3.3</td>
<td>4</td>
<td>2.7</td>
<td>3.7</td>
<td>0.65</td>
<td>4F/P</td>
</tr>
<tr>
<td>2. Wire mesh, steel, galvanized</td>
<td>2.1</td>
<td>2.1</td>
<td>45.8</td>
<td>47.8</td>
<td>13.8</td>
<td>15.9</td>
<td>0.83</td>
<td>d₁ = d₂</td>
</tr>
<tr>
<td>3. Wooden slatted grill</td>
<td>10</td>
<td>15</td>
<td>300</td>
<td>315</td>
<td>15</td>
<td>25</td>
<td>0.571</td>
<td>4F/P</td>
</tr>
</tbody>
</table>

Total pressure drop in the layer with the retaining grid:

\[ \Delta P = \Delta P₀ + \varepsilon \Delta P_z. \]  

(18)

As already noted, the model of flow around particles in a layer is more realistic from a physical point of view, since the total resistance of the layer is actually the sum of the resistances of all particles [12-15].

**Table 3.** Basic hydrodynamic parameters of retaining lattices and dispersed layers of various fruits: 1-plastic and 2-metal mesh; 3-wooden lattice; in the numerator – at \( W_m \), in the denominator – at \( W_k \).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lattice type</th>
<th>Spheroids</th>
<th>Disks</th>
<th>Plates</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w_x, m/s )</td>
<td>1</td>
<td>0.64...1.6</td>
<td>1.35...3.36</td>
<td>1.49...3.72</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.5...1.26</td>
<td>1.06...2.65</td>
<td>1.17...2.94</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.73...1.84</td>
<td>1.54...3.86</td>
<td>1.71...4.27</td>
</tr>
<tr>
<td>( \text{Re, at } (15) )</td>
<td>1</td>
<td>108...271</td>
<td>227...568</td>
<td>252...629</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>60...151</td>
<td>127...317</td>
<td>140...351</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1195...2988</td>
<td>2512...6279</td>
<td>2781...6953</td>
</tr>
<tr>
<td>( \xi_z )</td>
<td>1</td>
<td>0.848...0.73</td>
<td>0.735...0.712</td>
<td>0.726...0.727</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.378...0.305</td>
<td>0.316...0.276</td>
<td>0.311...0.274</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.171...0.17</td>
<td>0.170...0.183</td>
<td>0.169...0.186</td>
</tr>
<tr>
<td>( \Delta P_z, \text{ Pa } )</td>
<td>1</td>
<td>0.189...1.02</td>
<td>0.726...4.39</td>
<td>0.879...5.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.104...0.21</td>
<td>0.183...0.399</td>
<td>0.199...0.439</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.0504...0.313</td>
<td>0.221...1.49</td>
<td>0.269...1.85</td>
</tr>
<tr>
<td>( \Delta P, \text{ Pa } )</td>
<td>1</td>
<td>0.497...2.88/</td>
<td>0.957...5.19/</td>
<td>1.68...7.33/</td>
</tr>
<tr>
<td>at (4) and (18)</td>
<td>2</td>
<td>0.125...0.578</td>
<td>0.135...0.720</td>
<td>0.0509...0.235</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.457...2.50/</td>
<td>0.834...4.28/</td>
<td>1.32...6.29/</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.085...0.366</td>
<td>0.0889...0.313</td>
<td>0.04...0.121</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.431...2.55/</td>
<td>0.0842...4.53/</td>
<td>1.36...6.58/</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.0576...0.348</td>
<td>0.0644...0.372</td>
<td>0.0147...0.087</td>
</tr>
<tr>
<td>( \Delta P, \text{ Pa } )</td>
<td>1</td>
<td>0.326...1.64/</td>
<td>0.591...3.18/</td>
<td>1.3...5.22/</td>
</tr>
<tr>
<td>at (5) and (18)</td>
<td>2</td>
<td>0.105...0.439</td>
<td>0.117...0.617</td>
<td>0.0505...0.233</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.285...1.25/</td>
<td>0.468...2.27/</td>
<td>0.939...4.19/</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.0648...0.227</td>
<td>0.0701...0.210</td>
<td>0.0402...0.118</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.259...1.30/</td>
<td>0.477...2.52/</td>
<td>0.976...4.48/</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.0374...0.210</td>
<td>0.045...0.268</td>
<td>0.0142...0.084</td>
</tr>
</tbody>
</table>

The above results were obtained for the condition of the maximum possible packing of fruits in a layer. In real conditions, the packing density is lower and during the drying process (as a result of fruit shrinkage), the concentration \( \chi \) decreases. As the layer becomes rarefied, the filtration model becomes more and more artificial, and in the extreme it is not suitable at all.

If the packaging is loose and during the process of drying and shrinking of the fruit, the distance between the particles will increase.
Let us consider a model of the sum of individual fruit particles. Pressure drop per particle

\[ \Delta P_1 = \frac{\rho \cdot w^2}{2} \cdot \xi_1. \] (19)

Total pressure drop in the particle layer [3].

\[ \Delta P_0 = \frac{2 \cdot H \cdot \chi \cdot \rho \cdot w^2}{\varepsilon^2 \cdot d_s} \cdot \xi_1. \] (20)

The coefficient of hydraulic resistance for one particle \( \xi_1 \) is a function of the Reynolds number:

\[ Re = \frac{wd}{v}. \] (21)

There are many interpolation equations that describe this functional dependence [11-17]. All these equations are intended for isometric bodies of various shapes.

In [18-19], a generalized expression in the form (6) is recommended. For spheroids, the following expression is given in [20-25].

\[ \xi_1 = \psi \cdot 0.45 + \frac{36.6}{Re}; Re < 2000. \] (22)

For disks and plates, expressions of the form (6), (23) give significant deviations. Using the interpolation method [5], the following expressions were obtained:

for flat discs

\[ \xi_1 = \frac{9}{(\ln Re)^2}; Re < 2000; \] (23)

For flat plates:

\[ \xi_1 = 0.092 + \frac{1}{\sqrt{Re}}; Re < 3000. \] (24)

The total pressure drop in a layer of particles with a retaining lattice is determined by equation (18).

Table 4 shows the results of the hydrodynamic calculation of the layer of individual fruit particles at final humidity \( W_c \).

Comparative analysis of the results obtained for the dispersed layer model using equations (5), (8), (10), (12), (18) (Table 3) and the model of the sum of individual particles using equations (21), (23)-(25),(18) (Table 4), show their good convergence.

The maximum discrepancy does not exceed \( \pm 18\% \).

Condition (19) is the limiting one, up to which the layer is considered as a dispersed packing, after which – as a sum of individual particles.
Table 4. Basic hydrodynamic parameters of the layer of individual fruit particles at final humidity $W_k$.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Spheroids</th>
<th>Disks</th>
<th>Plates</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w_0$, m/s</td>
<td>0.26...0.65</td>
<td>0.44...1.11</td>
<td>0.23...0.58</td>
</tr>
<tr>
<td>Re, at (22)</td>
<td>261...652</td>
<td>272...689</td>
<td>192...481</td>
</tr>
<tr>
<td>$\xi_1$</td>
<td>0.631...0.547</td>
<td>0.305...0.211</td>
<td>0.164...0.138</td>
</tr>
<tr>
<td>$\Delta P_0$, Pa</td>
<td>0.026...0.143</td>
<td>0.027...0.115</td>
<td>0.0009...0.0005</td>
</tr>
<tr>
<td>$\Delta P_0$, Pa at (21) and (18)</td>
<td>0.109...0.465</td>
<td>0.174...0.62</td>
<td>0.0506...0.238</td>
</tr>
<tr>
<td>0.0686...0.254</td>
<td>0.0647...0.213</td>
<td>0.0403...0.122</td>
<td></td>
</tr>
<tr>
<td>0.0415...0.236</td>
<td>0.0396...0.271</td>
<td>0.0143...0.087</td>
<td></td>
</tr>
</tbody>
</table>

*1-plastic and 2-metal mesh, 3-wooden grid

The thickness of the dynamic boundary layer is determined by the relation [11].

$$\delta = 4.64 \cdot d_s \cdot \sqrt{Re}.$$  \hspace{1cm} (25)

The distance between particles can be represented as:

$$L = d_s \cdot \left( \frac{\chi_{\text{max}}}{\chi} - 1 \right)^{\frac{3}{\chi_{\text{max}}}};$$  \hspace{1cm} (26)

$\chi_{\text{max}}$ - the maximum possible concentration of particles in the layer when $L=0$.

Taking into account (26) and (27), from (19) we obtain the limiting value $\chi_n$:

$$\chi_n = \chi_{\text{max}} \left( \frac{\sqrt{Re}}{\chi} + 1 \right)^{\frac{3}{\chi_{\text{max}}}}.$$  \hspace{1cm} (27)

Thus: provided:

$$\chi > \chi_n; L < 2\delta$$  \hspace{1cm} (28)

The layer of fruits is considered as a dispersed packing - the flow model and hydrodynamic calculation are performed according to formulas (3), (5), (8), (11), (12), (14)-(18);

Given that:

$$\chi < \chi_n; L > 2\delta$$  \hspace{1cm} (29)

The fruit layer is considered as the sum of individual particles - a model of complete external flow; the gyrodynamic calculation is carried out using expressions for separately streamlined bodies (20)-(25), (14)-(18).

The shrinkage of the fruit material during the drying process has a significant effect on the change in $\chi_n$, i.e. change in layer hydrodynamics.

4 Conclusions

The given hydrodynamic parameters of dispersed layers of fruits make it possible to determine the hydraulic costs and installation power of forced ventilation depending on the volume of drying products.
5 Note

$a, b$ – length and width of the retaining grid cell, m;
$a_0, b_0$ – distance between the axes of the longitudinal and transverse elements of the lattice, m;
$d_1, d_2$ – diameter of longitudinal and transverse elements of the lattice, m;
$d$ – diameter of spheroid, disk, plate width, m;
$d_1, d_2$ – diameters equivalent for particle layer and hydraulic for holding grid, m;
$H, h$ – layer height, disk and plate thickness, m;
$F, F_0$ – open cross-sectional area and total for a lattice cell, $m^2$;
$f$ – shape factor; $l$ – particle length, m;
$\Delta P, \Delta P_0, \Delta P_z$ – pressure drops total, in the layer, in the lattice, Pa;
$\Delta P_1$ – pressure drop for one particle, Pa;
P – lattice cell perimeter, m;
$Re$ – Reynolds number;
w, $w_0, w_z$ – flow velocity in the free section, filtration through the layer and grate, m/s;
$W$ – moisture content of the material – fruits, %;
z – duty ratio (porosity) of the retaining grid;
$\varepsilon$ – porosity of the dispersed layer;
$\delta$ – boundary layer thickness, m;
$\nu$ – kinematic viscosity coefficient, $m^2/s$;
$\xi_0, \xi_1$ – coefficients of hydraulic resistance of a layer and one particle;
$\xi_z$ – grid hydraulic resistance coefficients;
$\rho$ – density, $kg/m^3$;
$\chi$ – dispersed layer concentration;
$\psi$ – shape factor.

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