SOME FEATURES OF THE HYDRODYNAMICS OF TURBULENT AIR STREAMS TWISTED BY A VANE SWIRLER

A. A. Khalatov, V. K. Shehukin, and V. G. Letyagin

The structure of an isothermal air stream twisted by a vane swirler with a central body mounted at the entrance to a tube is examined. The effect of the structural parameters of the swirler on the hydrodynamics of the stream is analyzed.

The twisting of a stream is one effective means of hydrodynamic action on the stream for the purpose of intensifying the processes of heat and mass exchange taking place in channels of different profiles. The variety of the procedures for twisting and their constructive design [1] require an individual approach and a detailed study of the structure of the twisted stream which completely determines the effects indicated above. Moreover, it is impossible to conduct a theoretical analysis without knowing the structure of such a stream.

We studied experimentally the features of the hydrodynamics of isothermal turbulent air streams, twisted by a vane swirler with a central body, in the initial section of a tube in the range of \( \text{Re}_d \) from \( 4.5 \times 10^4 \) to \( 1.5 \times 10^5 \). A diagram of the experimental apparatus, the structural parameters of the swirler, the method of conducting the experiments, and the initial data on the structure of a twisted stream are presented in [2].

The experiments were conducted on straight and profiled vanes; the profiling made it possible to obtain a power function for the variation in construction angle of the vane at the exit from the swirler [2]

\[
\tan \varphi = \left( \frac{R}{r} \right)^n \tan \varphi_s.
\]

It has been noted earlier [2] that a zone of potential flow exists outside the boundary layer in which the tangential velocity component varies according to the function \( w_\varphi r = A(x) \), while below the potential zone the velocity profile \( w_\varphi \) is satisfactorily described by a function of the type

\[
\frac{w_\varphi}{w_{\varphi \text{max}}} = \left( \frac{2r r_{\varphi \text{max}}}{r^2 + r_{\varphi \text{max}}^2} \right)^k.
\]

The experimental data presented in Fig. 1 for one of the swirlers show that with increasing distance from the swirler the width of the potential zone increases while \( A(x) \) decreases.

Let us examine in more detail some relationships of the variation in the tangential and axial velocity components in a twisted stream.

The tangential velocity varies in a curve with a maximum, and the radius of the surface of maximum velocity always lies in the zone...
Fig. 2. Variation in tangential velocity component of motion over radius of channel as a function of \( \text{Re}_d \) (a), of \( n \) (b), and of \( \phi_s \) (c). For a: 1) \( \text{Re}_d = 1.6 \cdot 10^5 \); 2) \( 1.07 \cdot 10^5 \); 3) \( 4.51 \cdot 10^4 \); \( \phi_s = 45^\circ \); \( n = 3 \); \( x/d = 7 \); for b: 1) \( n = -1 \); 2) \( 1 \); 3) \( 3 \); 4) straight vanes; \( \phi_s = 45^\circ \); \( x/d = 7 \); \( \text{Re}_d = 1.07 \cdot 10^5 \); for c) \( n = 3 \); \( \text{Re}_d = 1.07 \cdot 10^5 \); \( x/d = 7 \). \( w_{\phi}, \text{m/sec}. \)

### TABLE 1. Values of A and B

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>( \phi_s = 45^\circ )</th>
<th>( \phi_s = 45^\circ )</th>
<th>( \phi_s = 45^\circ )</th>
<th>( \phi_s = 45^\circ )</th>
<th>( \phi_s = 45^\circ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A )</td>
<td>0.155</td>
<td>0.30</td>
<td>0.52</td>
<td>0.52</td>
<td>0.51</td>
</tr>
<tr>
<td>( B )</td>
<td>0.005</td>
<td>-0.01</td>
<td>-0.023</td>
<td>-0.023</td>
<td>0.007</td>
</tr>
</tbody>
</table>

of rarefaction (Fig. 2). The value of \( r_{\phi_{\text{max}}} \) depends weakly on the twist angle \( \phi_s \) and the number \( \text{Re}_d \) and very essentially on the exponent \( n \) in the twist function. With an increase in \( n \) at \( \phi_s = \text{idem} \) the position of the maximum shifts closer to the wall of the tube. Consequently, \( n \) is one of the important factors affecting the position of the radius of maximum tangential velocity. At the same time we note that with an increase in \( \phi_s \) (\( n = \text{idem} \)) the absolute value of \( w_{\phi_{\text{max}}} \) increases markedly whereas it is almost unchanged upon a change in \( n \) (\( \phi_s = \text{idem} \)).

Since the self-similarity of the \( w_\phi \) profile must be preserved for swirlers having the same values of \( r_{\phi_{\text{max}}} \) one can conclude that the exponent \( k \) in Eq. (1) must depend on \( n \) and very weakly on \( \text{Re}_d \) and \( \phi_s \). Therefore the values of \( k \) given in [2] for swirlers with \( \phi_s = 15, 30, \) and \( 45^\circ \) (\( n = 3 \)) differ little from one another. It can be concluded from this that the values of \( k \) obtained can be used for swirlers having any value of \( \phi_s \) at a fixed value of \( n \).

The equation of the surface \( r_{\phi_{\text{max}}} \) is satisfactorily approximated by the linear equation

\[
r_{\phi_{\text{max}}} = A - B(x/d),
\]

in which the values of \( A \) and \( B \) for several swirlers are presented in Table 1.

Since \( r_{\phi_{\text{max}}} = f(\text{Re}_d, \phi_s) \), the values of the coefficients \( A \) and \( B \) at a given \( n \) can be used for any \( \text{Re}_d \) and any angle \( \phi_s \) in the range of 15-45°.

It must be noted that the radius of the surface at which \( w_{\phi_{\text{max}}} \) is reached is not equivalent to the radius of the surface of zero pressure in a given cross section. This must be taken into account in calculating the static pressure distribution over the radius of the channel.

Let us examine the relationships of the variation in the axial velocity component of the stream. At the exit from the swirler the stream is thrown out to the periphery of the channel by the centrifugal effect, pressing against the inner wall. Therefore the actual velocity \( w_x \) at the wall (in the potential zone) considerably exceeds the average flow rate velocity. For a swirler with \( \phi_s = 60^\circ \) and \( n = 3 \) this excess is about 37% for \( \text{Re}_d = 4.4 \cdot 10^4 \) and 54% for \( \text{Re}_d = 1.07 \cdot 10^5 \). This must be taken into account in an analytical evaluation of the processes of heat and mass transfer in channels with twisted streams.

A characteristic property of twisted streams in short channels is the appearance of return air currents from the surrounding atmosphere at the end face. The presence of a zone of return flows leads to an additional increase in the axial velocity component in the potential zone because of the decrease in the straight-through cross section of the main stream and the inflow of outside air. These effects promote