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Measurement of the airflow velocity upstream and downstream a wire mesh using constant temperature anemometry

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Abstract. Measurement of velocity upstream and downstream a special wire mesh was performed to ascertain the effect of the mesh on the flow. The mesh consisted of two components, a basic rectangular mesh with mesh width 1.22 mm and wire diameter 0.2 mm, and a top steel wool with random position of wires and wire diameter 0.05 mm. The velocity was measured by Constant Temperature Anemometry using single wire probe in a Plexiglas channel of rectangular cross-section. As a first step, measurement of one horizontal and one vertical measuring line was performed 10 mm upstream and 6 mm downstream the wire mesh. A spatial velocity profile upstream of the wire mesh was smooth, while the downstream velocity profile was highly disturbed. However, velocity fluctuations expressed in terms of turbulence intensity downstream of the wire mesh were attenuated down to 1%. Further measurements of the area downstream the wire mesh will be performed to describe the development of the flow.

1 Introduction

Wire meshes are commonly used to modify the flow conditions, often to remove particles from the flow or to adjust the level of velocity fluctuations. They are applied as parts of deposition devices [1] or as gas burners [2]. The most detailed attention was however devoted to wire meshes used for generation or reduction of turbulence in wind tunnels.

The first studies on the use of wire meshes for adjustment of flow in wind tunnels dates back to 1930s, but the research continues until nowadays [3]. According to Corrsin [4] three conditions have to be satisfied to achieve homogenous turbulent flow field in the wake of a mesh. First, the porosity, β, which is defined as a ratio of open to total area of a mesh in a planar projection, should be large enough to prevent coalescing jets and large-scale instability downstream of the mesh. Corrsin suggested the existence of a certain critical porosity value above which unstable jet coalescence does not occur. The value of critical porosity was then investigated by many researchers and they proposed critical porosities values between 54 % and 63 % [5]. Second, the height of a flow channel should be much larger than the length scale of the energy-containing eddies, which is of the same order as the mesh size. The mesh width, M, is defined as a distance between centers of two adjacent wires. The second condition ensures that the effect of walls on the flow will be minimal. Third, the measurements should be taken at least 40 mesh sizes downstream of the mesh, since only after this distance the turbulence becomes homogenous.

As follows from previous discussion, the characteristic features of a mesh are its width, M, diameter of wire, d, and porosity, β.

$$\beta = \left(1 - \frac{d}{M}\right)^2 \tag{1}$$

Also its counterpart, i.e. the solidity, σ, which is given as 1− β, is often used.

Current study was performed on a wire mesh with more complicated structure than the meshes used in wind tunnels. The current mesh is being used for an industrial application, where the flow field immediately downstream is significant. Data presented here are result of the first preliminary measurement and will be supplemented in near future with more detailed measurement in multiple downstream positions.

The mesh consists of a basic rectangular mesh with M_b = 1.22 mm and d_b = 0.2 mm and a top steel wool with random position of wires and d_t = 0.05 mm. Ratio of the volume of the pure steel calculated from weight and the outer volume of the mesh is 0.1. This value can be considered as the volume porosity. However, porosity β in planar projection is inhomogeneous due to random position of top steel wool wires and can be assessed by values 10 % to 20 %. It means that jets emerging from the mesh are coalescing and create large-scale instabilities. Mesh Reynolds number can be calculated as

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$Re_M = U.M/\nu$, where U is the mean velocity, M is the mesh width and ν is the kinematic viscosity [5]. The fact that a wire mesh either generates or damps turbulence depends on a value of Reynolds number. Under a critical value of Re = 40 viscosity helps to damp eddies as they pass through the screen, whereas over this value vortices are generated by the mesh [3]. In our case mesh Reynolds number $Re_M = 7$ means that the mesh should suppress the turbulence. It is worth noting that the above mentioned theoretical assumptions are valid for simple or multi-scale [6] grids, however, their validity for current mesh with top steel wool should be verified.

2 Description of a test bench

The main part of a test bench is a transparent Plexiglas channel formed from 2 sections. The first, input section, has internal dimensions 1000 x 200 x 60 mm, the second, output section, has internal dimensions 500 x 200 x 60 mm. The wire mesh was fastened between the two sections and sealed by plastic sealant Lukopren T 1990. Four entrance holes for CTA probe were drilled into the channel. Two on the upper surface, upstream and downstream the wire mesh, and two on the side, again upstream and downstream the wire mesh approximately 10 mm distant from the mesh. The test bench was horizontally aligned using water-level. A scheme of the test bench is in Figure 1.

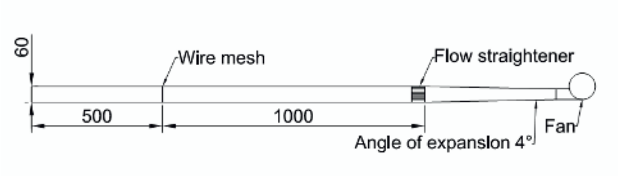

Figure 1. A scheme of the test bench.

The airflow was induced by a fan which was regulated using voltage transformer. A reducing sheet adapter was used to conduct the flow from the circular cross-section to the rectangular cross-section of the channel. The angle of expansion of the adapter was 4° to prevent flow detachment. Honeycomb flow straightener was placed at the entrance cross-section of the channel to ensure homogenous flow. Uniformity of the flow was verified using a smoke visualization (Figure 2).

The flow came to the wire mesh from the side of the basic rectangular mesh, which corresponded to actual position in the real application.

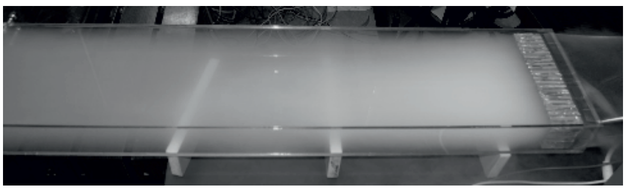

Figure 2. Smoke visualization of the flow upstream the mesh.

3 Methodology

The measurement was performed by the right angle CTA probe 55P04. It has platinum-plated tungsten wire with diameter of 5 µm, whose overall length is 3 mm, however the sensitive wire length is 1.25 mm. The sensor possesses high flow sensitivity and wide frequency response but features considerably low prong-to-sensor influence due to its gold-plated wire ends.

Calibration of the CTA probe was performed before each measurement using standard Dantec calibration unit 54H01. A pressure drop on the calibrator nozzle was measured using pressure measuring calibration device Airflow KAL 84. Calibration was performed for velocities in a range of 0.4 m/s to 6 m/s.

Sampling frequency during measurement was 11 kHz and 32768 samples were measured in each measuring point. Mean velocity was then calculated from all 32768 samples and turbulence intensity $Tu = u_{rms}/U_m$ was calculated from the root mean square value of velocity u_{rms} divided by the mean velocity U_m.

Measurement was performed in four measuring lines (one horizontal line upstream the wire mesh, one horizontal line downstream the mesh, one vertical line upstream and one vertical line downstream the wire mesh). Position of the probe during measurement of horizontal line upstream the mesh is presented at Figure 3. The sensing element of the probe was 10 mm distant from the mesh during the measurements upstream the mesh and 6 mm distant from the mesh during the measurements downstream the mesh.

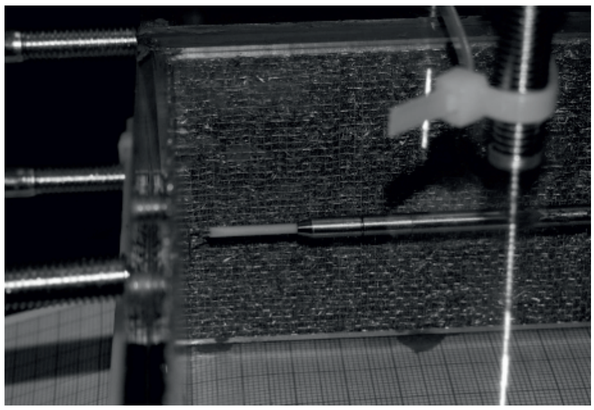

Figure 3. Position of the probe during measurement of horizontal line upstream the mesh.

Positioning of the wire was performed using one-dimensional manual traversing device. Resolution of the device is 0.1 mm. The origin of the coordinate system was always set 1 mm from the side wall of the channel using a graph paper.

A probe support holder was aligned horizontally or vertically using water-level. A diameter of the probe support is approximately 2 mm, while the diameter of probe support holder is 4 mm. Because the seal of the entrance hole fitted tightly to the support holder, but not to the probe support, it was necessary to restrict traverse range to prevent the probe support run to the hole in order to avoid air leakage around the probe support and deformation of the flow field. Therefore the horizontal measuring lines covered 180 mm of the total 200 mm width of the channel and the vertical lines covered 40 mm of the total 60 mm of the channel height. The distance between measuring points in a measuring line was 1 mm for both horizontal and vertical lines, i.e. horizontal lines have 180 measuring points and vertical lines have 40 measuring points.

The total flowrate through the wire mesh was 14.16 Liter/min, which corresponds to average velocity 1.18 m/s. The flowrate was controlled using laboratory voltage transformer which provided power for the fan.

4 Results

The measurement of horizontal lines upstream the wire mesh was performed three times to evaluate statistical measures of uncertainty. The second repetition was performed in conditions of repeatability; the third repetition was performed in conditions of reproducibility - after a lapse of time, after a new calibration of CTA probe, new setup of ventilator, with new operator of the traversing device and a new positioning of the traversing device. No significant differences were found among the measurements. Coefficient of variation (CV) was calculated from the three measurements with resulting average CV = 1.88 %.

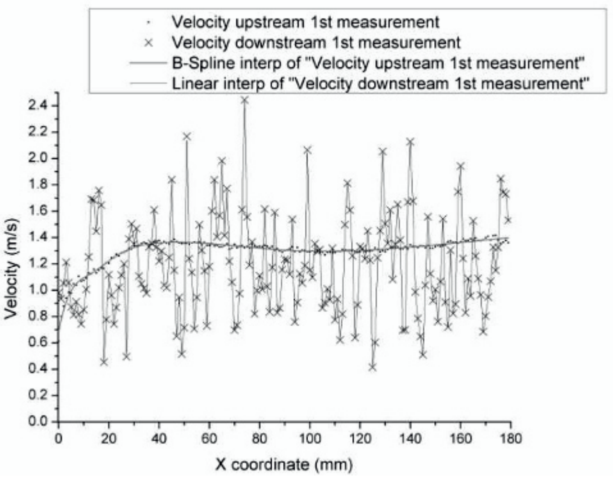

Figure 4. A comparison of velocity profile immediately upstream and downstream the wire mesh in a horizontal measuring line.

The measurement of horizontal line downstream the wire mesh was performed twice to verify the accuracy of positioning of the CTA probe and also to verify stability of the measured velocity profile. The velocity profile downstream the wire mesh was highly nonuniform with sudden changes in velocity along the measured line. It is a result of a flow conditions created by the wire mesh. The measurement revealed series of high-velocity jets behind outlets of mini-channels created by wires of the top steel wool and wakes behind clusters of wires. The two measurements of velocity profile gave identical results; average difference between the two measurements in measured points was 0.28 % of the mean velocity.

Comparison of velocity profiles upstream and downstream the wire mesh is presented in Figures 4 and 5 for horizontal and vertical lines, respectively.

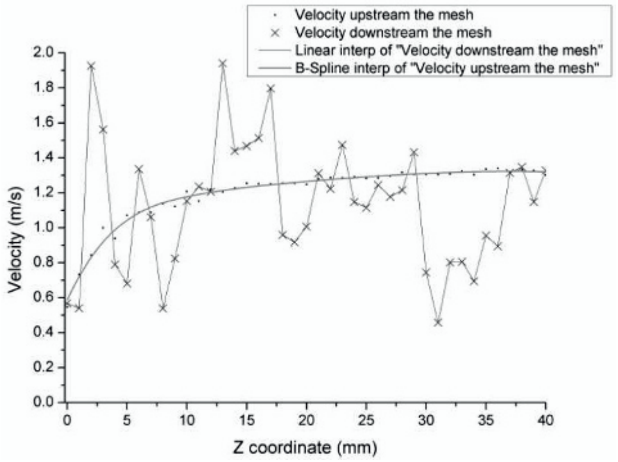

Figure 5. A comparison of velocity profile immediately upstream and downstream the wire mesh in a vertical measuring line.

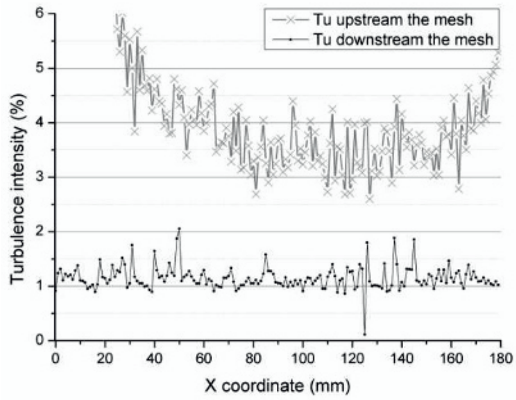

Figure 6. A comparison of turbulence intensity profile immediately upstream and downstream the wire mesh in a horizontal measuring line.

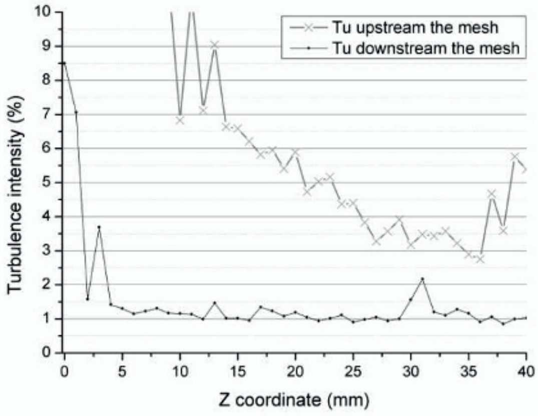

Figure 7. A comparison of turbulence intensity profile immediately upstream and downstream the wire mesh in a vertical measuring line.

Turbulence intensities evaluated from measurements of horizontal and vertical lines upstream and downstream the wire mesh are presented in Figures 6 and 7. It is apparent that the turbulence intensity decreases downstream the wire mesh as a result of increase of local mean velocity in the jets. For all the above mentioned charts the abscissa represents X or Z coordinates, where the coordinate X or Z = 0 denotes the position 1 mm distant from the channel wall. The origin of vertical axis is at the bottom of the channel, while the origin of the horizontal line is on the left side of the channel in the flow direction.

5 Discussion

The presented data are only the preface to the measurement of the influence of the wire mesh with top steel wool on the flow field. The attention will be now focused on the energy decay downstream the wire mesh. Classical theories for grid turbulence suggest following formula for calculation of energy decay:

$$\left(\frac{u_{rms}}{U_m}\right)^2 = a\left(\frac{x - x_0}{l_0}\right)^{-n} \qquad (2)$$

Where, *a,* is a constant that depends on a method of turbulence generation, *n*, is a constant which depends on a type of turbulence, x_0, is the location of the virtual origin and, l_0, is some characteristic length scale, usually the mesh width. However, the expression is valid only if the flow is homogeneous and close to isotropic. It means that the formula can be used only in the far field downstream the mesh.

Krogstad [7] measured energy decay in both near and far field using classical and multi-scale grids and he suggests following expression:

$$\left(\frac{u_{rms}}{U_m}\right)^2 = \frac{a}{\left(x/x_{peak}\right)^n} \qquad (3)$$

Where x_{peak} is a distance where $(u_{rms}/U_m)^2$ reaches its maximal value. However the flow field downstream the wire mesh with top steel wool is expected to be significantly different and hence the energy decay may follow different expression.

The following measurement will be performed using X-probe, it means two components of velocity will be measured simultaneously. Also automatic traversing device will be used to allow for positioning of the probe in order to measure the energy decay. However, as noticed by Krogstad [7], high attention should be devoted to hot wire anemometry measurement in the near field as negative velocities may appear in a distance up to ten times the mesh width from the mesh, which could lead to significant measurement error. Laser Doppler Anemometry can be used for comparison, as two component system is available in the laboratory.

Also the pressure drop on the wire mesh will be measured, as this was identified as an important parameter for the practical application.

6 Summary

A first measurement of two-component special wire mesh was performed to investigate the velocity field immediately upstream and downstream the mesh. The flow through the mesh is different from most cases published in literature, as most measurements were performed using single layer grids either with simple rectangular grid or with multi-scale grids. The porosity of current grid is low and therefore coalescing jets occur downstream the mesh. Constant Temperature Anemometry measurement revealed highly disturbed velocity profile downstream the mesh, whereas turbulence intensity decreased due to the increase in local mean velocity.

Following measurement will be focused on the energy decay downstream the mesh in order to verify applicability of expressions derived for single layer grids.

Acknowledgement

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