Comparison of the effect of optical properties of liquid on the accuracy of the measurement by PIV method

Miloš Kašpárek[1]

[1] CTU in Prague, Faculty of mechanical engineering, Department of fluid dynamics and thermodynamics, Technická 4, 166 07 Prague 6, Czech republic

Abstract

Thesis is concerned on the quantification of the error measurement by PIV method. Error is caused by different optical properties of liquid and the model of stenosis. Different optical properties of two materials cause light refraction at the interface of the materials. This light refraction causes the interference of the measurement that unable the measurement nearby the wall. Further problem is the optical deformation of the scan area that is caused by the curvature of the model. This deformation causes the error in the measurement. Elimination of the negative effects from the measurement is performed by comparing the refractive index of the liquid and the model of stenosis. Change of refractive index is performed by adding iodide sodium to the liquid. Measurement by PIV method with solution of iodide sodium and distilled water is done for the error quantification.

Keywords: Refractive index, error of measurement, PIV

1. Introduction

PIV method is optical nonintrusive method for flow field measurement Principle of this method is illumination of measured area by the sheet of light and addition of small seeding particles into the liquid. The image of this area is acquired by the camera. How Raffel et al (1998, page 4.) describe: "*For evaluation the digital PIV recording is divided in small subareas called interrogation areas. The local displacement vector for the images of the tracer particles of the first and second illumination is determinate for each interrogation area by means of statistical methods. The projection of the vector of the local flow velocity in to the plane of the light sheet is calculated taking into account the time delay between the two illuminations of the magnification at imaging.*"

For accurate measurement by PIV method, it is important to prevent light refraction and to ensure clear optical access to the measured area. Light refraction causes the noise in the measurement. This interference complicates the measurement nearby the wall. Light refraction occurs at the interface of two materials with different optical properties. If there is not clear optical access to the measured area, pictures are deformed. This deformation causes the error in the measurement. Deformation is caused by the curvature of the model. It is possible to solve both mentioned problems by changing refractive index of the liquid. If refractive index of the liquid is identical with refractive index of the model, the interface of two materials and curvature of the model disappear.

In this paper, refractive index is changed by adding iodide sodium to the liquid. The error evaluation is realized by the experiment using solution of iodide sodium and distilled water. There are used Fluorescent Polymer Particles (FPP) and Silver Coated Hollow Glass Spheres (S-HGS) in the experiment. Several modes with solution of iodide sodium and distilled water are measured. For measurements with FPP particles the light filter is used. The size of the error is determined comparing different modes of measurement.[1][2]

2. Scheme of the experiment

Scheme of the experiment is on Figure 1. The fluid flow is provided by the peristaltic pump. Above the model of stenosis there is placed the high speed camera (iSpeed). This camera scans the measured area. Light source is the continuous laser diode of wavelength of 532 nm, which is placed on a tripod. Sheet of light is created by the cylindrical lens.

3. Model and measurement methodology

Flow field in the measured area is measured for a one mode, but with different liquids and particles. First fluid is a distilled water. The second fluid is the solution of iodide sodium. Two types of particles are added to these fluids. First type of particles is Fluorescent Polymer Particles. These particles absorb the light of the laser diode and emit the light at different wavelengths. FPP particles are usually used with the light filter. This filter transmits only light emitted by the FPP particles and eliminates all unwanted reflections. Second type of particles is Silver Coated Hollow Glass Spheres (S-HGS). The light sheet is set to be in the longitudinal axis of the model and the thickness of the sheet is 1 mm. Camera scans the entire area of the model.

3.1. The change of the refractive index

Change of the refractive index of the liquid is achieved by adding hydrophilic substances. These hydrophilic substances must have a high refractive index in

* milos.kasparek@fs.cvut.cz

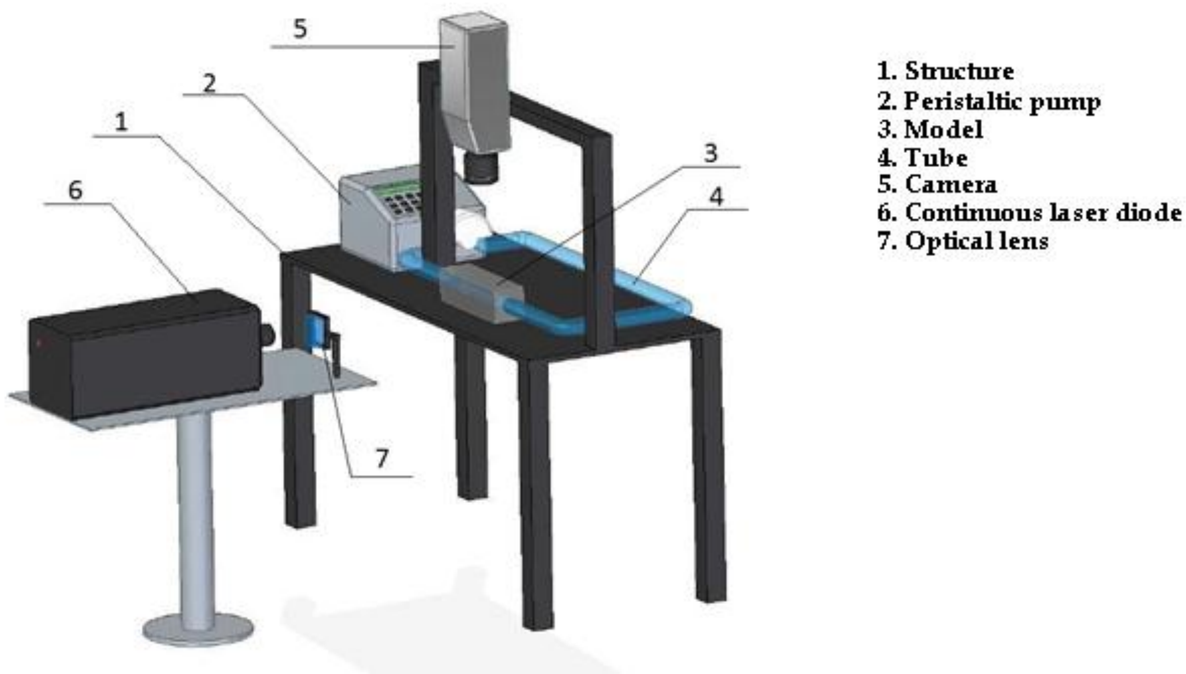


Fig. 1. *Scheme experiment*

order to achieve required refractive index of the solution. In the experiment we used sodium iodide to target the required refractive index. Sodium iodide is chosen because of its excellent solubility in water, high refractive index and accessibility. The refractive index of sodium iodide is 1.744. Preparation of the solution is carried out by gradual addition of iodide sodium to the distilled water. After each addition of iodide sodium, refractive index of the solution was measured. Sodium iodide is added until the required refractive index of solution is reached. The required refractive index of the solution is 1.491. This refractive index is identical to the refractive index of the material of the model. The refractive index is measured using a digital refractometer. On Figure 2. is seen dependence of refraction index and weight ratio. On

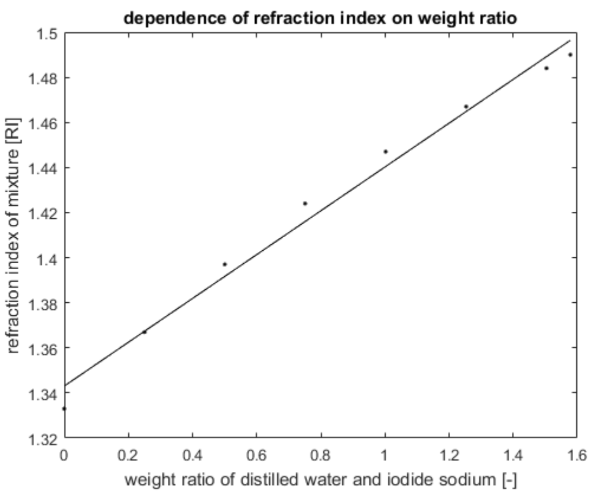


Fig. 2. *Graf of dependence of refraction index on weight ratio*

the x-axis (Fig. 2) there are plotted solutions concentrations. On the y-axis (Fig. 2) there are the measured values of refraction index. Points are correlated by the linear regression represented by Eq. (1).

$$m = a \cdot n + b \tag{1}$$

Using this dependence the amount of iodide sodium can be determined to obtain the required refractive index.[2][3][4]

3.2. Model

The model used in the experiment is the model of stenosis. Material of the model of stenosis is cast plexiglass. The model is made through machining. Semi-finished product of the model of stenosis is a block. The shape of the outer surfaces improves optical access. Geometry of model of stenosis is shown on Figure 3. This geometry has eccentric narrowing of 50% of the inner area. Two countersinks are used for fixing the model. All surfaces are polished with special polishing paste.

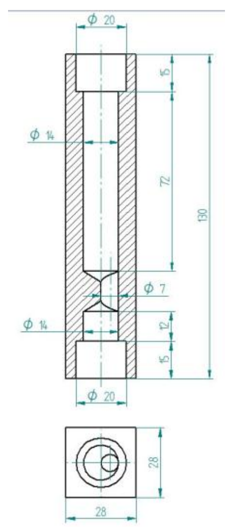
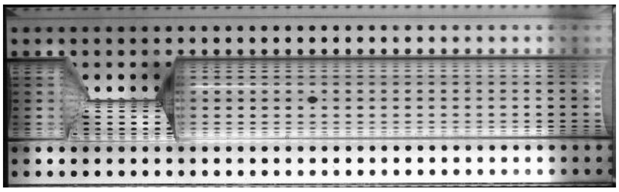


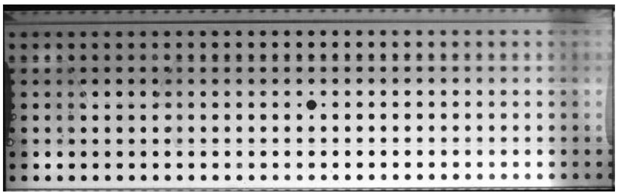
Fig. 3. *Geometry of model of stenosis*

3.3. Deformation of optical access

It is created visualization of the deformation of the optical access for each fluid. For visualization is used grid. In Figure 4 is a deformation of the optical access using distilled water. On this figure is seen maximum of deformation near the wall the model. In Figure 5 is a deformation of the optical access using solution of iodide sodium. On this figure is seen that deformation of optical access is minimized.



Obr. 4. *Deformation of optical access using distillet water*

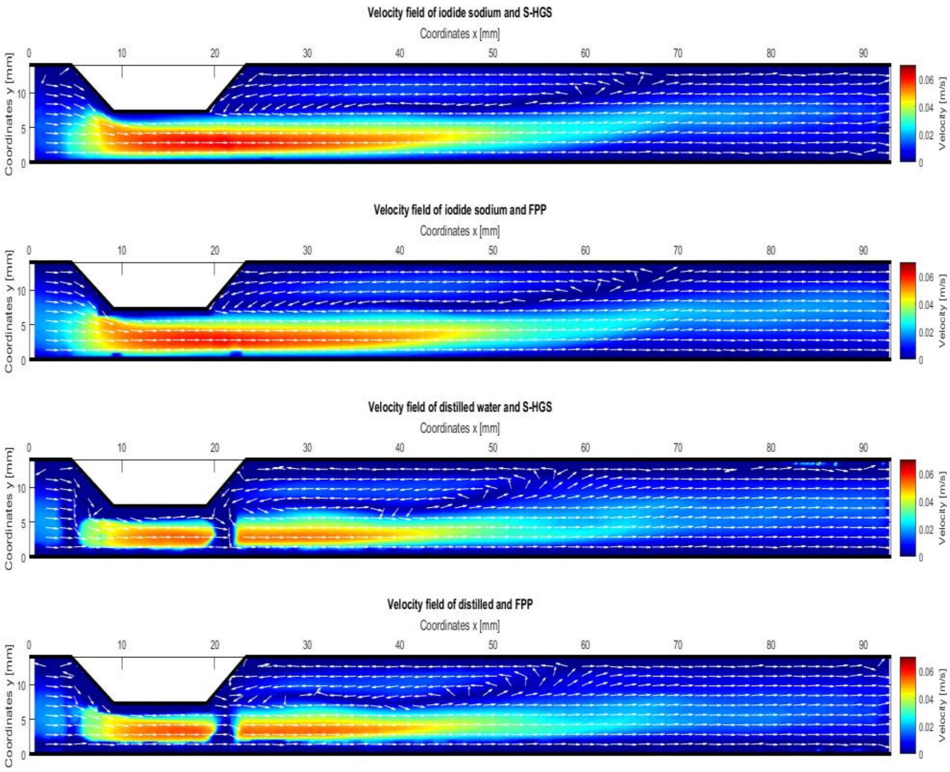


Obr. 5. *Deformation of optical access using iodide sodium*

4. Results

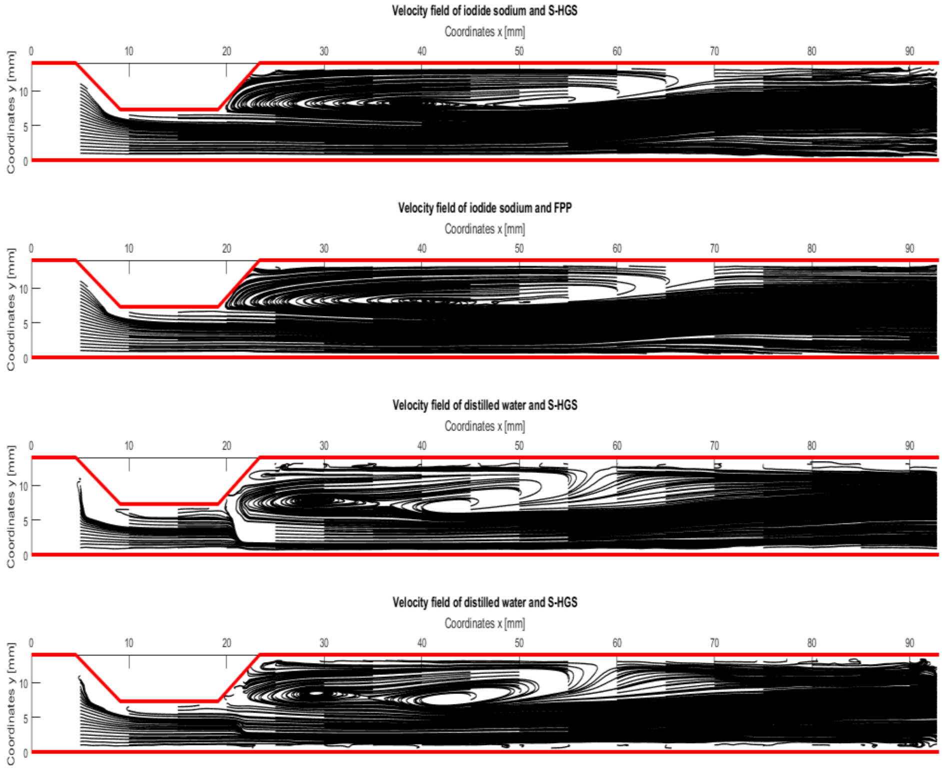
The result of the measurement is the velocity field in the measured area. Velocity profiles in the respective sections of the model are determined from the measured data. These sections are at the distance of 14.5 mm, 21.8 mm, 27.3 mm and 76.6 mm on the x-axis of the model. All modes are measured with the same volumetric flow rate to be 77 ml/min and the setting according to the above parameters. Measured plane go through the longitudinal axis of model. High speed camera scans the entire area of the model. Critical part of the model for measurement accuracy is the neck of model. At this point, there is essential curvature of the surface and it leads to significant deformation of the image.

The velocity field for all measurements is shown on Figure 6. The upper picture was obtained for the solution of iodide sodium with S-HGS particles. The second picture is the result of the measurement with solution of iodide sodium with FPP particles. The third velocity field was evaluated with distilled water with S-HGS particles. On the last picture is shown the velocity field for distilled water with FPP particles. Color range shows the velocity magnitude. The direction of the movement of the fluid is represented by unit vectors. The horizontal axis represents the length of the model and the vertical axis the diameter of the model. All pictures show the acceleration of the flow in the narrowing of the model. Behind narrowing there is the region of swirling flow



Obr. 6. *Velocity fields*

in the upper part of the measured area. Further it can be seen that the width of velocity field in the narrowing is smaller for the measurement with distilled water than for iodide sodium. This reduction of the velocity field is region is the high noise level due the light refractions. The graphs on Figure 10 and 11 show very similar profile deformation as the Figure 8.



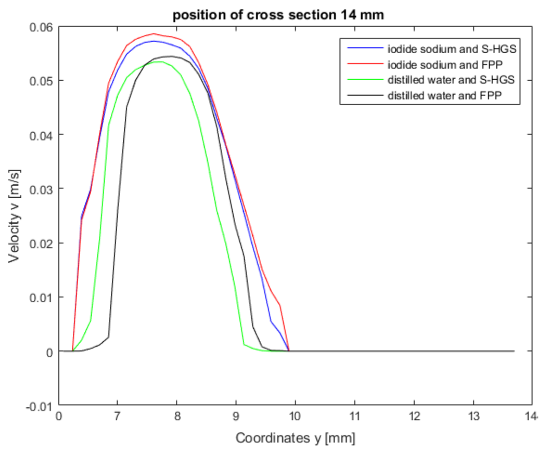
Obr. 7. *Streamlines*

caused by the optical deformation. The deformation is caused by the curvature of the tube.

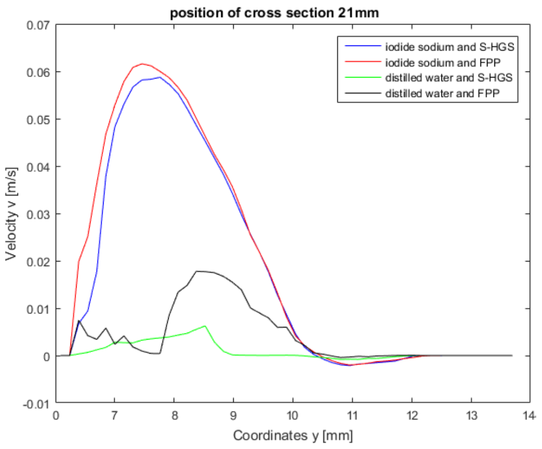
Streamlines for all measurements are on Figure 7. Comparison of streamlines measurement with distilled water shows the advantage of using FPP particles. Using these particles, errors caused by laser light refraction is removed from the measurement and it is possible to obtain some data from area of diameter reduction.

Figures 8 to 11 show the velocity profiles in the several position of cross section in the model. These positions of cross section are set in 14mm, 21mm, 27mm and 76mm in direction of x axis. The first cross section is in the narrowing. The second cross section is in the section of expansion. The third cross section and the fourth cross section are in the large diameter of the model. On each figure there are four velocity profiles (one for each measurement). On the axes of the figure are plotted the values of the velocity and positions on y axis.

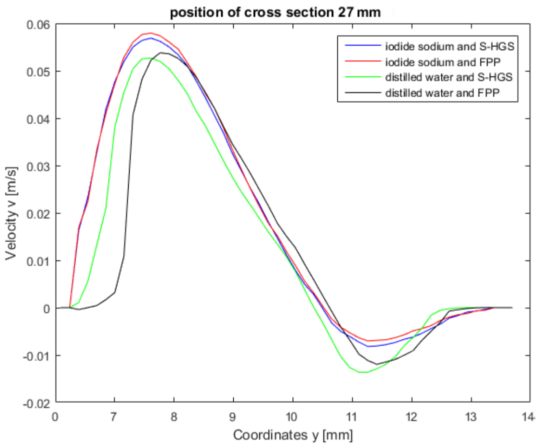
Figure 8 shows the velocity profile distortion for the distilled water and velocity profile for solution of iodide sodium. The narrowing of the velocity profile of distilled water is caused by the optical deformation of the image in the vicinity of the walls. Velocity profiles for distilled water are not evaluated in the section of expansion (Figure 9). The reason of the data loss in this



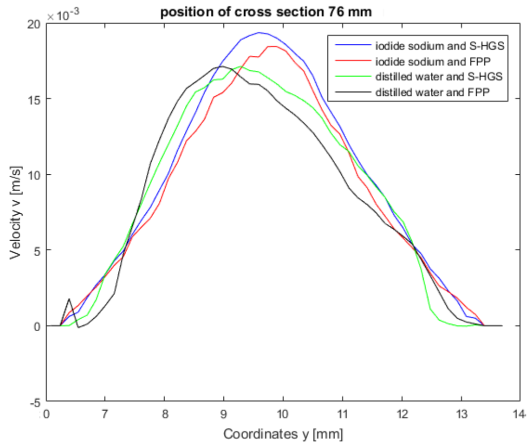
Obr. 8. *Velocity profiles in the position of cross section 14mm*



Obr. 9. *Velocity profiles in the position of cross section 21mm*



Obr. 10. *Velocity profiles in the position of cross section 27mm*



Obr. 11. *Velocity profiles in the position of cross section 76mm*

5. Discussion

The results show that the measurement with distilled water is highly influenced by the optical of deformation. Using distilled water the measurement in area of large optical of deformation is not possible and we are not able to obtain the relevant data. Using iodide sodium the optical of deformation is significantly reduced and this approach allows the measurement in all parts of the model as well. From the results we can conclude that the use of iodide solution significantly improves the measurement by PIV method. Accuracy can be influenced even with calibration during pre-processing analysis.

Nomenclature

m weight ratio (-)
n refraction(RI)

Literatura

[1] Raffel M.,Willert CH., Kompenhans J., Particle Image Velocimetry, A Practical Guide, Berlin: Springer – Verlag Berlin Heidelberg New York, Germany, 1998, ISBN 3-540-63683-8

[2] Yousif, Majid Y.,Holdsworth David, Poepping, Deriving a Blood-Mimicking fluid for Particle Image Velocimetrz in Sylgard/184 Vascular Models, In Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE, 2009 Minneapolis, USA, IEEE, 2009, pp. 1412-1415

[3] Miller P., Danielson K., Moody G., Slifka A., Drexler E., Hertyberg J. Matching of refraction using a diethzl phthalate/ethanol solution for in vitro cardiovascular models., Experiments in fluids, vol. 41, pp. 375-381, 2006.

[4] Jermy Mark, Making it clear: Flexible, transparent laboratorz flow models for soft and hard problems, Conference on Experimental Heat Transfer, Fluid Dynamics and Thermodynamics, 2013 Lisabon, Portugal, 2013, Conference Contribution