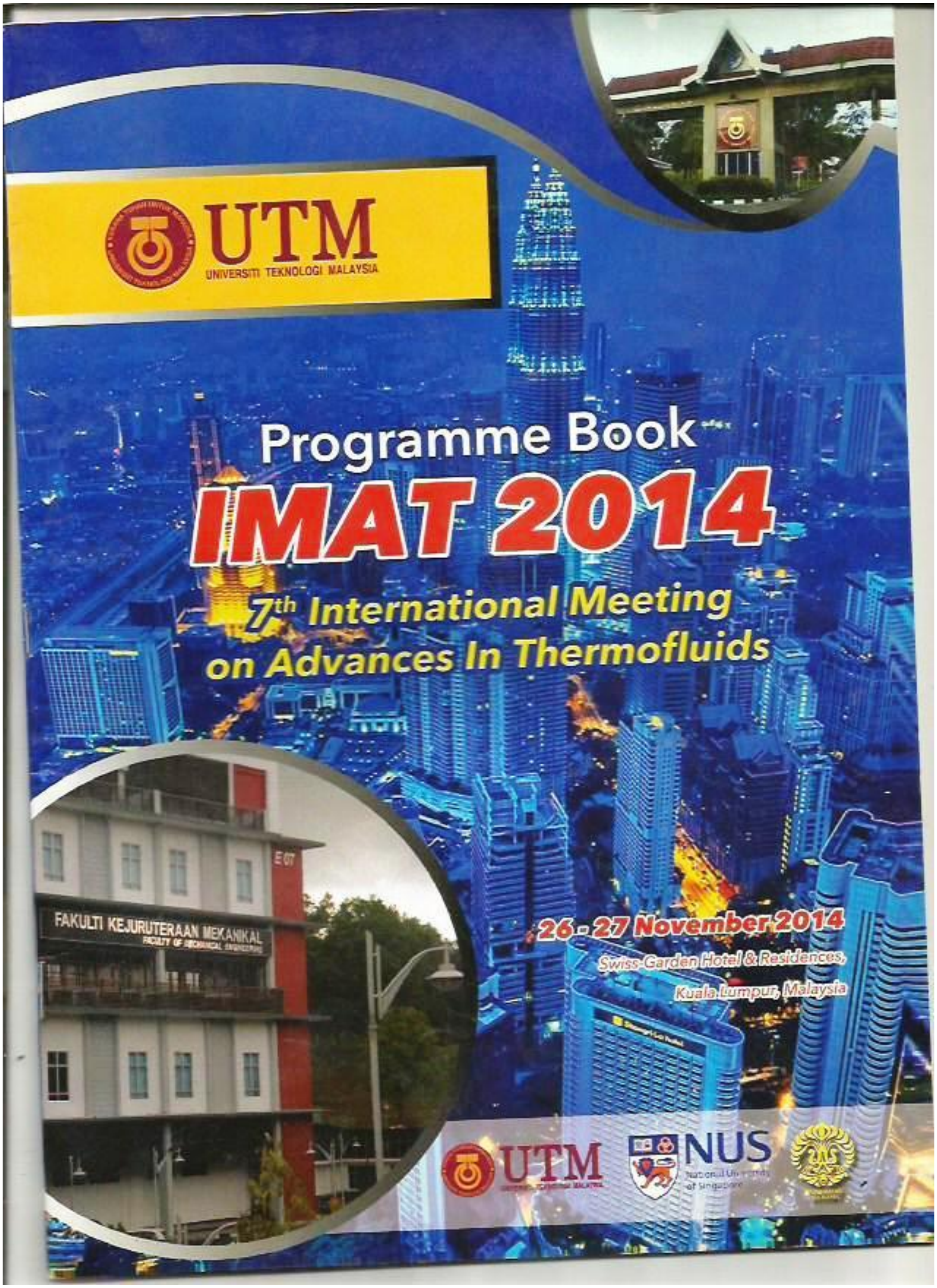

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IMAT 2014

7th International Meeting on Advances In Thermofluids

26 - 27 November 2014

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An Experimental Investigation on Fluid Flow Characteristics in Elbows Using Particles Image Velocimetry

Muhammadu Masin Muhammadu[1,2], Kahar Osman[1], Esah Hamzah[3]
[1]Department of Thermo-fluids Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310, Skudai, Johor Bahru, Malaysia
[2]Department of Mechanical Engineering, Federal University of Technology P.M.B. 65, Gidan-Kwanu, Minna, Nigeria
[3]Department of Materials, Manufacturing and Industrial Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310, Skudai Johor Bahru, Malaysia

Corresponding author: kahar@fkm.utm.my

Abstract: An advanced particle-tracking and flow-visualization technology of particle image velocimetry (PIV), was utilized to investigate the transparent fluid flow in pipe elbow. The laser-based PIV system was used together with a settling column to capture the frames around the elbow. The results show that PIV is a powerful flow visualization technique capable of determining the intensity of flow and velocity vectors. For the characterization of turbulent flows it is often required to measure both, the temporal behaviour of the velocity fluctuations along with their spectral contents and the spatial flow structure. The various velocities were measured vis-a-viz 1.5, 2.0 and 2.5 m/s respectively. The results showed that as the velocity increases, the turbulent intensity increases. It was also observed that the values of mitre bend produced were significantly higher than the values of smooth bend and all the regions marked "E" of both elbows were the areas that produce more vortices. It becomes possible to measure other relevant quantities required for the understanding of turbulent flows such as the complete velocity and other parameters for example.

Keywords: flow visualization, particle image velocimetry, intensity, streamlines, velocity

INTRODUCTION

Turbulent flow fields have been subject of experimental investigations for many decades. For example, the first systematic analysis of the coherent near wall structures in a turbulent boundary layer has been performed by means of qualitative flow visualization techniques employing tracers such as smoke in air flows or dyes in water flows [1]. The recording of the visualization images by means of video cameras, their storage in analogy format on video tape and especially the recently possible storage in digital format in the memory of a computer and the slow motion observation of the images after the experiment allowed detailed analysis of the spatial structures in turbulent flow fields. By means of technological progress in video and computer technique such qualitative information, stored as images in two-dimensional (2D) format, became easily available at low costs for turbulence research. The temporal resolution is typically that of the standard video technique (i.e. 25 to 30 frames per second). However, as the qualitative Visualization' approach basically marks the streamlines of the flow, the interpretation is quite difficult as shown by Hama (1962). Moreover, details about the amplitude, wavelength and orientation of the structures can hardly be estimated [1].

There is limited information in the literature about the experimental flow characterization studies of pipe in elbows. In a recent paper, research to investigated the flow of a pipe in two-dimensionally (2D) by Particle Image Velocimetry (PIV) measurements was carried out [2].

One of the most widespread and economically important turbulent flow geometries, where the fluid mechanics is not entirely understood, is the accelerative flow from a large cross-section via an abrupt or angular entry into a smaller cross-section. Circular and slit cross-sections are of particular interest. Such flows are commonly referred to as entry flows [3]. Not only is an understanding of entry flows essential for efficient design of flow systems, but such flows are of extreme importance in processing industries, in the measurement of fundamental flow properties of materials, and more recently, for numerical simulation methods due to widespread use of the pipe in elbows flow as a test problem. The flow of a fluid from a reservoir through the entrance region of a tube of circular cross-section is also encountered in fibre spinning, tubular heat exchangers and capillary-tube velocimetry [7]. From the late 1960's until now there has been a gradual development of sophisticated numerical techniques and a virtual revolution in digital computation to such an extent that numerical solutions for the entry flow problem bounded by a region of fully developed flow upstream can be accomplished without any assumptions in the governing differential equations. Similar to developments in computational techniques, measurement methods for flow visualization have shown considerable advancement in recent decades. An extensive review of Particle

Imaging Techniques for experimental fluid mechanics is given (Angeli P. et al, 1998). In this paper, PIV was used for modes of operation and experimental of PIV are given in detail. Velocity measurements in processing flows may provide the most direct method of determining conditions under which the flow becomes unstable, how efficiently materials are being mixed, where dead zones are occurring that may lead to heat or mass transfer problems especially in the elbows [4].

The ratio of the diameter of the large tube to that of the smaller tube was varied from 1 to 8. They presented velocity profiles, entrance lengths and equivalent lengths to be accurately and conveniently used for the design of equipment and analysis of Newtonian flow data [5]. Their photographs of the flow field through the bends at high Reynolds numbers clearly showed the presence of a stationary vortex on the upstream side of the bend when axial diffusion of momentum is significant. They also found that the stationary vortex is absent at higher Reynolds numbers when the effect of axial diffusion of momentum can be neglected [6]. Contrary to the previous studies for Newtonian fluids, Particle Image Velocimetry, to study the fluid flow in a pipe elbow. However, from the results obtained as the velocity increases, the flow intensity increases. The results were presented details of flow fields of velocity vector maps, average velocity and vorticity contours as well as velocity profiles for different Reynolds number values.

EXPERIMENTAL SET-UP

The experiments were performed in a transparent elbows pipe schematic diagram is shown in Figure 1. In the test section, the calibrations were done in the elbows for the smooth running of the experimental. The elbows were transparent pipe which have the following dimensions: a length of 250 mm, width of 200 mm and thickness of 3 mm. The water was used as the test fluid in the test section. The water is transparent, chemically and thermally stable. These characteristics made it ideal for flow observation and visualisation at good room temperature.

The fluid flow velocities of both mitres and smooth elbows were 1,5, 2.0, and 2.5 m/s, in other word 46, 60, and 73 LPM respectively. The fluid is pumped through the test section from the tank which flow through 25 mm PVC pipe with the flow meter attached to the pipe which was used to changes the Reynolds number with respect to velocity of the water.

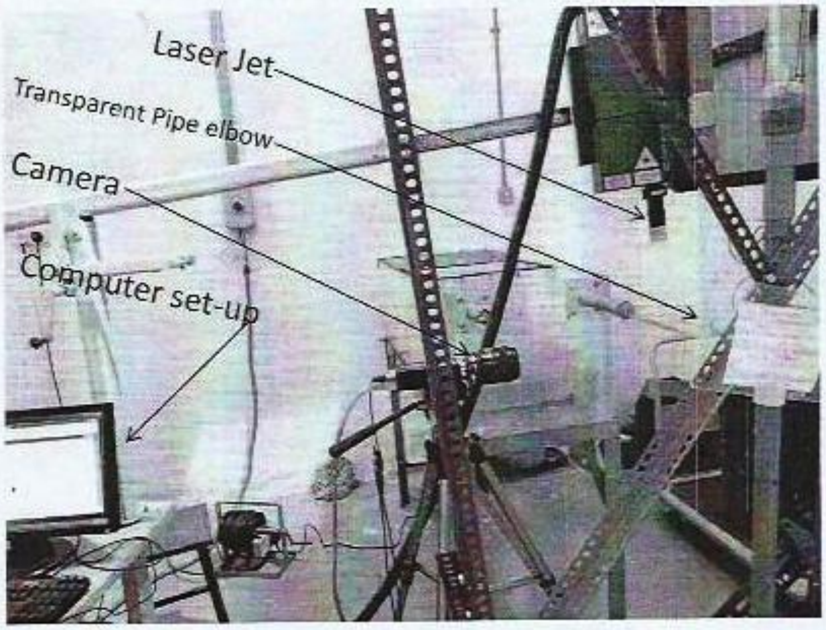


Fig. 1: Schematic view of the experimental set-up

The length of the entrance length of test section is kept long enough to provide fully developed flow conditions. This avoids the transport of any deformation history of the fluid into the test section due to entrance length connections (elbow, valves, etc.). A schematic of the test section including the orientation of laser beam, computer and camera are shown at the side section of figure 1 together with the coordinate system. A laser sheet with a thickness of less than 1.5 mm was generated to illuminate the particles in the view of plane. In order to generate this laser sheet thickness, the laser was sent through a cylindrical lens with an effective focal length EFL = −15 mm followed by a spherical lens which had an EFL = 1000 mm. The flow was illuminated with two Nd:Yag pulsed lasers (532 nm) mounted with a single casing and operating nominally at 120 mJ/pulse. The camera was equipped with a 55 mm focal length lens. Dantec flow grabber digital PIV software employing frame-to frame cross-correlation technique was employed to calculate the raw displacement vector field from the particle image velocity data.

Particle Image Velocimetry is a nonintrusive measurement technique used to simultaneously determine the velocities at many points in a fluid flow [6]. The technique involves seeding the flow field, illuminating the region under investigation and capturing velocity images of that region in rapid succession. From the displacement of the tracer particles, a velocity vector map can be calculated in the flow field provided that the time interval between image captures is known.

Images were received from CCD camera that has a resolution of 1008 pixels × 1016 pixels at a rate of 20 frames per second. The image was recorded on a CDD array. A Frame Grabber in the computer reads the camera image from CCD camera and stores it as the digital image file format (TIFF) in the RAM. These digital images were processed and analysed using the flowmap software. During each continuous run, a total of 300 images were taken. In order to ensure high spatial resolution, image magnification was 1:1.12 for all experiments, which yielded an effective grid size of 1.05 mm × 1.05 mm in the physical plane of the laser sheet corresponding to 62 × 62 velocity vectors.

RESULTS AND DISCUSSION

To compare fluid flow in smooth and mitre elbows for the PIV measurements applied to Water flow systems, extra care was taken to ensure that the measurements are obtained and evaluated the results. So also, it is very important to acquire sufficient number of statistically independent samples in order to evaluate turbulence intensity statistics. In this study, the PIV system was used to collect more than 300 samples per point, producing good results of velocity vectors at each coordinates. In order to obtain the velocity vectors results each elbow was divided in to six points A to E as shown in figure 2 respectively. Then, a table was superimposed on each frame obtained from PIV flow manager software.

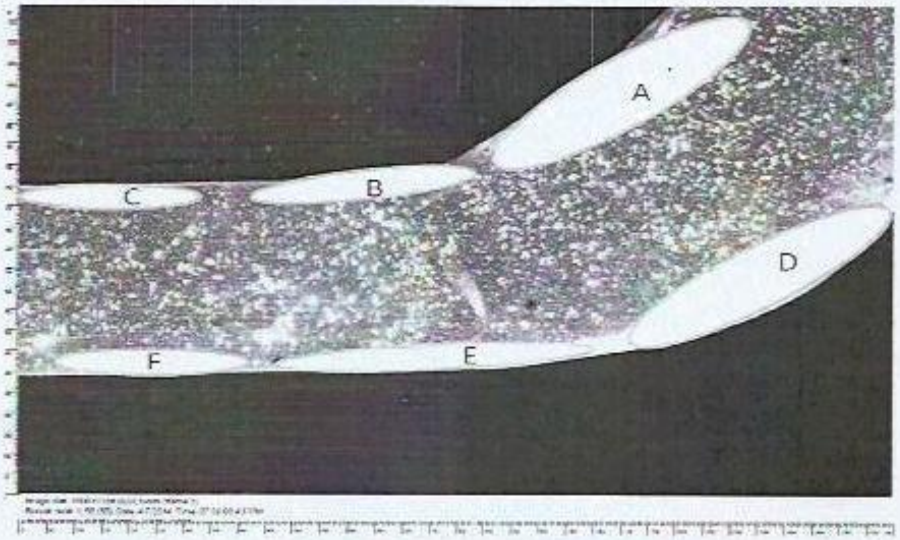


Fig. 2: The elbow with various points of experimental analysis

The figures below presented the PIV experimental results of velocity vector analysis along y-axis.

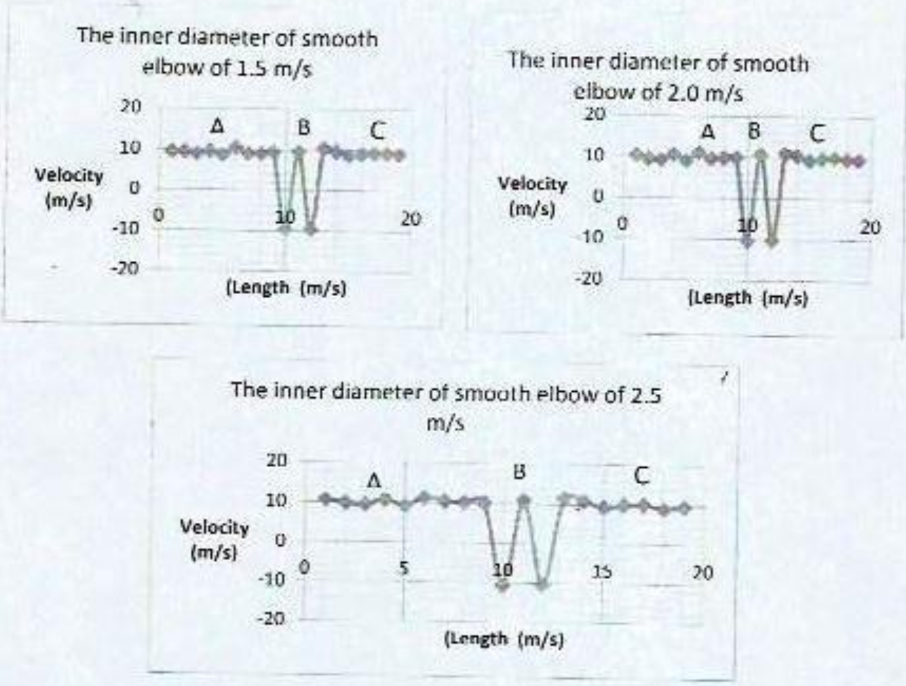
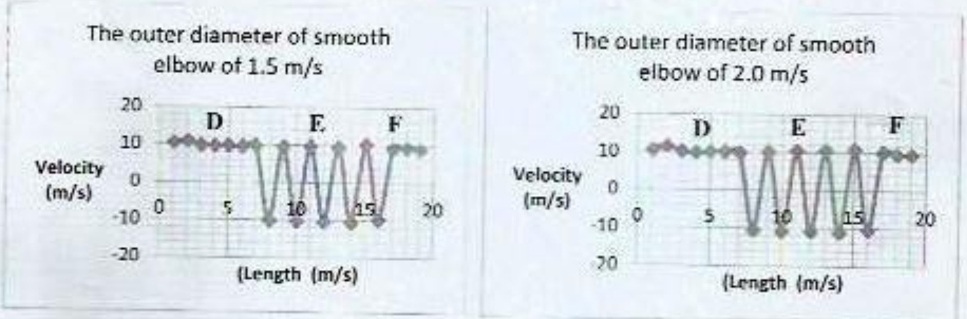


Fig.3: The velocity vector along inner diameter of the smooth elbows with various velocities

In figure 3 above, point A's have the maximum velocity vectors of 10.4, 10.10 and 11.5 m/s. The point B's have the maximum reverse velocity vectors of -9.8, -10.4 and -10.8 m/s. While, point C's have the maximum velocity vectors of 9.5, 9.11 and 10.3 m/s respectively.



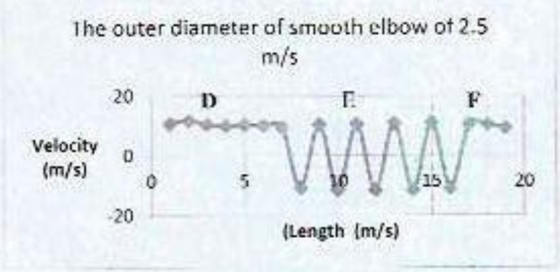


Fig 4: The velocity vector along outer diameter of the smooth elbows with various velocities

In figure 4 above: regions marked "D" have the maximum velocity vectors of 10.8, 11.3 and 11.10 m/s. The regions marked "E" have produces more vortices with the maximum reverse velocity vectors of -10.7, -11.3 and -11.8 m/s. While, regions marked "F" has the maximum velocity vectors of 9.6, 9.11 and 10.6 m/s.

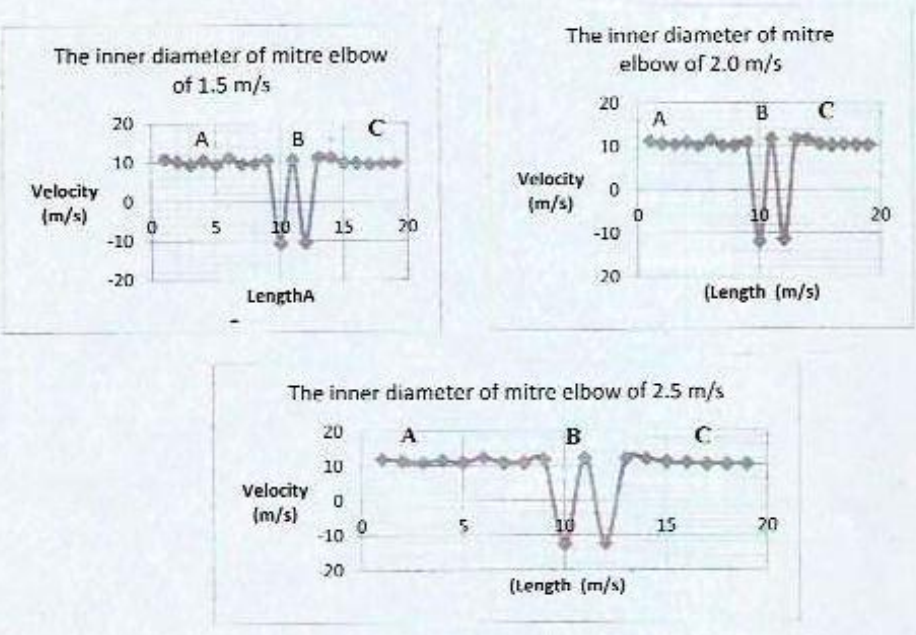


Fig.5: The velocity vector along inner diameter of the mitre elbows with various velocities

In figure 5, the regions marked "A" point A's have the maximum velocity vectors of 10.11, 11.5 and 12.7 m/s. The regions marked "B" have the maximum reverse velocity vectors of -10.11, -11.11 and -12.7 m/s. While, the regions marked "C" have the maximum velocity vectors of 9.11, 10.7 and 11.2 m/s.

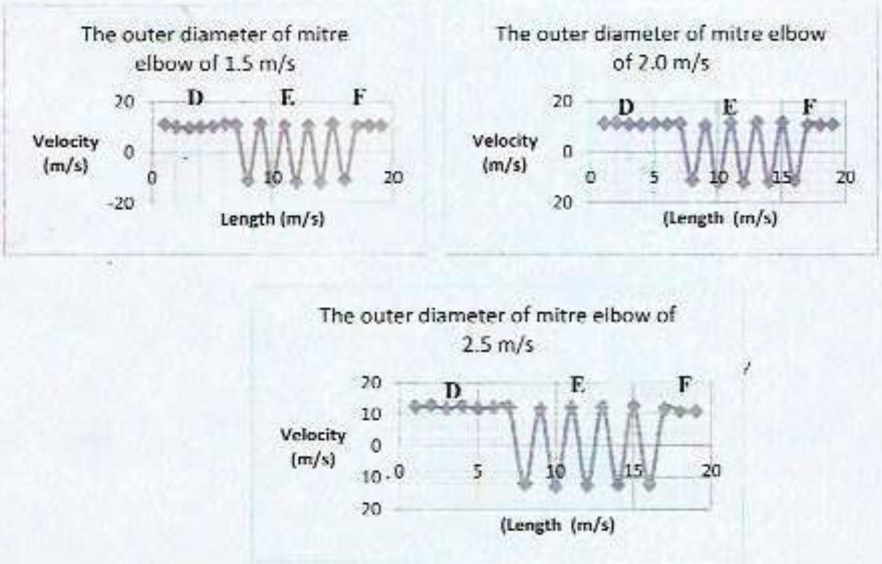


Fig.6: The velocity vector of outer diameter of the mitre elbows with various velocities

Finally, from figure 6, the regions marked "D" have the maximum velocity vectors of 11.8, 12.3 and 12.5 m/s. The regions marked "E" produces more vortices and with the maximum reverse velocity vectors of -11.9, -12.5 and -12.10 m/s. While, the regions marked "F" have the maximum velocity vectors of 10.9, 11.5 and 11.9 m/s respectively.

The PIV measurements of a transparent pipe elbows along horizontal axis (y-axis), were studied, and the vortex structures were also studied in both inner and out layer. In these results of PIV from figures 3 to 6, it was observed that the values of mitre bend produced were significantly higher than the values of smooth bend, so also, all the regions marked "E" which the outer diameters of both elbows were the areas that produces more vortices as results of turbulent intensity, secondary flow and eddies. Hence, the regions marked "B" which are inner diameters also produces vortices but not as much as that of the regions marked "E" which is outer diameter. So also, the vortices along y- axis in the turbulent shear layer continuously repeat the form merge split- disappear process. Multiple vortices in the instantaneous flow field occur at the same time, and the size and shape of the vortices change continuously. Above all, the present research is in agreement with the conclusion drawn by [5-6] where used air as flow medium. They reported that the areas where flow separation takes place, the wall mass transfer gets more connected with turbulence intensity rather than surface shear stress and the mechanism that triggers such a motion is fully understood [7].

Nevertheless, the present research has revealed that as indicated in the regions marked "B" and "E". This is as result of favourable pressure gradient in the stream wise direction, these are the areas where there is secondary flow, turbulent kinetic energy and more eddies. So also, the low velocity area on the inner wall side of flow separation develops specifically are the regions marked "C" and "F".

CONCLUSIONS

The PIV measurements of a transparent pipe elbows along horizontal axis were made, and the vortex structures are studied. According to PIV analysis, from figure 3 to 6, it was observed that the values of mitre bend produced were significantly higher than the values of smooth bend and all the regions marked "E" of both elbows were the areas that produces vortices as results of turbulent kinetic energy, secondary flow and eddies. Meanwhile, the regions marked "B" also produces little vortices. So also, the vortex in a y- axis in the turbulent shear layer continuously repeats the form merge split- disappear process. Multiple vortices in the instantaneous flow field occur at the same time, and the size and shape of the vortices change continuously.

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