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QUALITATIVE ANALYSIS OF THE REGION OF FLOW DEVELOPMENT IN THE ENTRANCE OF BIFURCATIONS

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Abstract: *In previous works published in the last four years, the authors, as well as other collaborating partners, have been doing equations surveys to predict the extension of the flow developing region at the entrance of bifurcations. Initial conditions were adopted for artisanal simulation via finite differences, which consider that the flow is deformed when entering the outlet, in proportion to its half-angle. Now using a new approach, this work intends to make a qualitative analysis of the flow developing region, considering CFD simulation in which an elementary volume, when reaching the end of the feeder channel, will have an equal possibility of going through the right or left channel. In the simulations, a standard asymmetric bifurcation was used, with the diameter of the feeder channel equal to the outlets diameters, with water flowing under NTP conditions. Images published in the specialized literature show that the main flow tends to touch the internal wall of the bifurcated channel and that the greater the half angle of the fork, the greater the formation of vortices next to the external wall. In the present qualitative analysis, this phenomenon is confirmed and it is shown in complementary images that the flow developing region grows proportionally to the growth of the flow rate in the feeder channel, as well as it is proportional to the growth of the tube diameter and inversely proportional to the growth of the half-angle that constitutes the structure. Given that all previous work done in this area by the authors is basically quantitative, this qualitative analysis aims to complement the service and advance the state of the art of the matter.*

Keywords: *Bifurcations, Qualitative Analysis, Flow Development*

1. INTRODUCTION

In Amado et al, 2018a, it was stated that the initial conditions of velocity at the bifurcations entrance are given by Eq. (1). As can be seen in Fig. (1) proposed there, the velocity field is divided into two when reaching the fork outlets.
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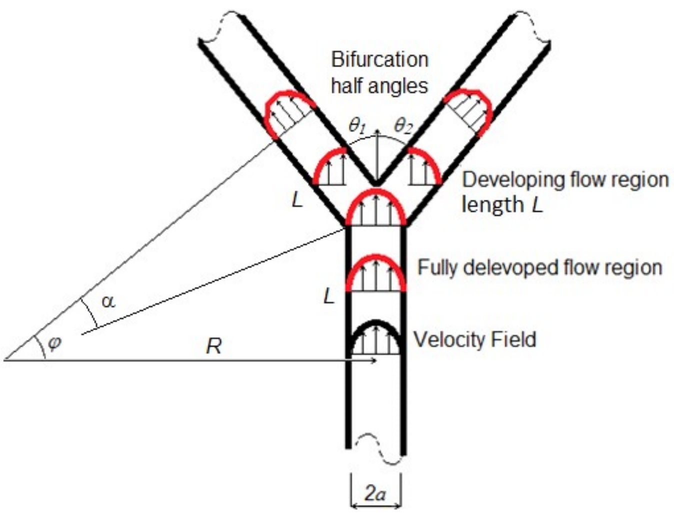


Figure 1 Sketch of a bifurcation with half angles θ_1 and θ_2, showing the developing flow region in the fork entrance, by Amado et al, 2018a.

$$v_{axial} = \frac{2Q}{\pi r^4}(a^2 - r^2) \pm \cos\theta_i \quad (1)$$

For very low Reynolds Number values (flow rates between 1.39 x 10^{-10} m^3/s and 5.56 x 10^{-10} m^3/s), in Amado et al, 2018b, it was shown that the bifurcation node region has the shape as shown in Fig.2.

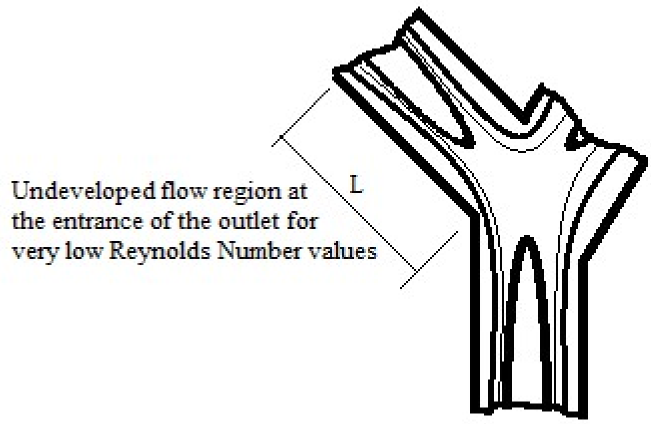


Figure 2. Scheme showing the flow developing region at the entrance of a bifurcation with a flow under very low Reynolds Number (Amado et al, 2018b).

However, at higher flow rates, but still in a laminar regime, a higher velocity current tube tends to form near the inner region of the bifurcation outlet and a vortex appears next to the outer region. See the sketch in Fig. 3. Many studies have confirmed the formation of vortices, in different configurations. Vasconcelos, 1993, studying turbulent flow in bifurcations, performed a good bibliographic review, citing works by Kawaguti and Hamano, 1979, and Hayes et al, 1989, on laminar flow in forks, with vortex formation.

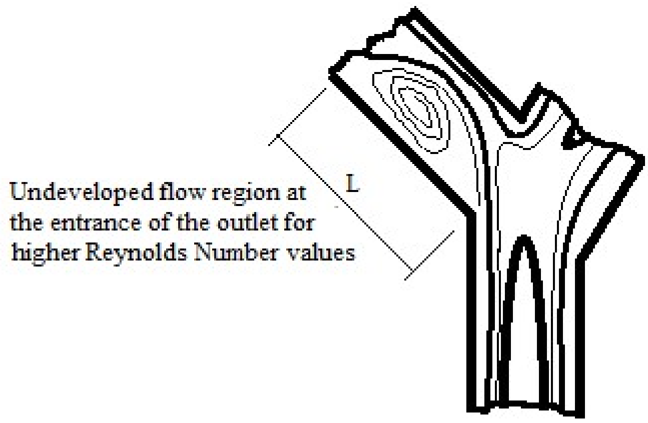
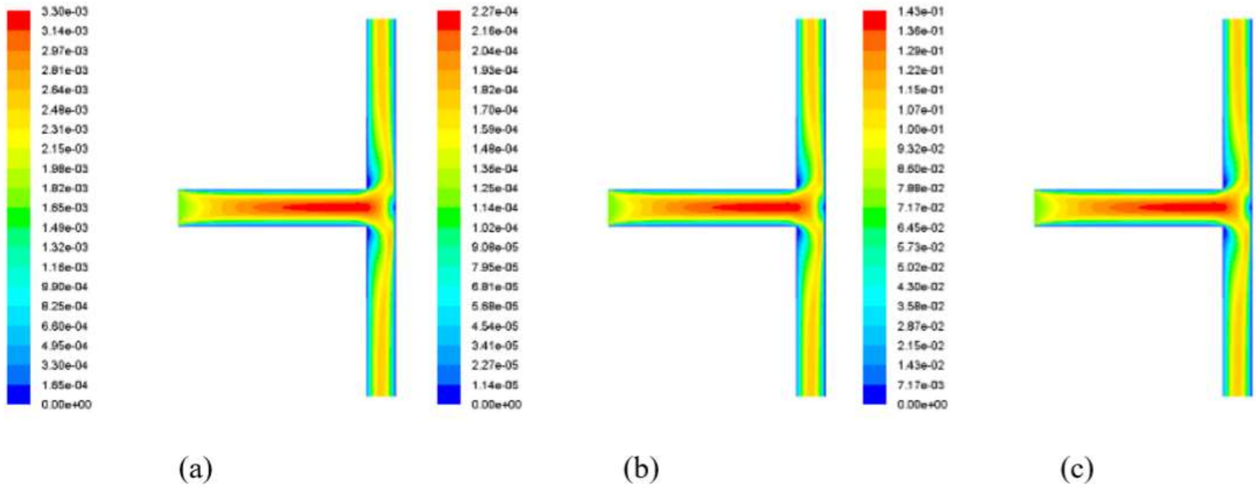


Figure 3. Vortex formation in the outermost wall of the bifurcation at higher flow rates

Figure 4 shows flow simulations of air, water and glycerin performed by Pepe, 2018, at forks half-angled in 90º and Reynolds Number equal to 100. In them, the approximate shape of the flow developing region shown in the Fig. 3 diagram can be seen.

Nascimento et al, 2019, in their work published in the proceedings of the last international congress of mechanical engineering held in Brazil, showed vortices formed after flow sinuosity, resulting from the sudden expansion of a jet of incompressible fluid, through a geometry channel built with the shape shown in Fig. 5.

With this information as a background, the objectives of this manuscript are established: to carry out a qualitative analysis of the flow developing region in bifurcations, having as variant parameters: the fork half-angles, the channel diameter and the flow rate, with water under NTP conditions flowing inside.



$Re = 10^2$

Figure 4. Field of velocities in the central plane in a T-shaped bifurcation, with Newtonian fluid flow: (a) air, (b) water, (c) glycerin (Pepe, 2018).

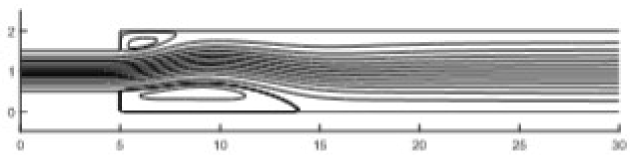


Figure 5 - Streamlines for Re = 200, shown by Nascimento et al, 2019, where vortices formed in the expansion of the flow can be seen after sudden widening of the channel.

2. MATERIALS AND METHODS

CFD-type artisanal simulations (from an in house code) were made in finite differences, according to the method shown in Amado et al 2018a, and applied in Amado et al, 2018b,c,d,e and Amado et al, 2019a,b, reproducing three types of water flow situations in NTP conditions:

- Variation of half-angles from 15º to 90º, in pair with a fixed half-angle outlet of 45º, with constant flow rate of $1.6\text{x}10^{-4}$ m^3/s in tubes with 0.02 m in diameter;
- Flow rates varying from 0.9 x 10^{-4} m^3/s to 1.6 x 10^{-4} m^3/s, with a pair of half-angles fixed at 30º and 45º, as well as a fixed pipe diameter of 0.02 m;
- Channel diameters ranging from 0.010 m to 0.035 m, with a pair of half-angles fixed at 30º and 45º and constant flow rate of $1.6\text{x}10^{-4}$ m^3/s.

The same simulations were carried out in a commercial code, for comparison of images and validation of the handmade simulation developed. All this in order to observe the behavior of the bifurcations entrance region, where the flow develops after the instability formed by the fork positioned after the feeder channel.

3. RESULTS AND DISCUSSION

Figure 6 was generated in a commercial software and shows the flow simulation in a bifurcation with 0.02 m of pipe diameter, half-angles of 30º and 45º and flow rate of $1.6\text{x}10^{-4}$ m^3/s. The circled area is the beginning of the flow developing region shown in the images in Fig. 7 to 10.

Specifically, Fig 8 shows images of the flow developing region in outlets with a half-angle ranging from 15º to 90º, in pair with a 45° fixed half-angled outlet. Fig. 9 and 10, show images of the regions of undeveloped flow in the outlets at 30º, respectively for variation of diameter (from 0.010 m to 0.035 m) and flow variation (between 0.9 x 10^{-4} m^3/s and 1.6 x 10^{-4} m^3/s).

The detailed analysis of Fig. 8 shows that the smaller the half-angle, the greater the peak of velocity at the entrance of the bifurcation, because the velocity vector in the axial direction is a function of the cosine of this angle. The fastest current tube tends to occupy the most central region of the outlet. In addition, Gongnan et al, 2014, studying symmetrical bifurcations with half angles equal to zero, demonstrated that the change in flow characteristics is practically imperceptible, as can be seen in Fig.7. At higher angles, the higher speed chain tube tends to stick to the inner region of the fork and presents a profile with lower velocities.

When analyzing the variation in diameter shown in Fig. 9, it can be seen that there is a relationship of direct proportion between the extent of the undeveloped flow region and this dimension. Likewise, this relationship is seen in Fig. 10 between increases in volumetric flow and the length of the region in vogue.

In Amado et al 2018b, Eq (1) was proposed, considered broad-spectrum. This correlation mathematically corroborates the behavior shown here through the sequences exposed in these three figures. It can be seen a relation of direct proportion of the length L with the diameter of the channel D and with the flow rate (quantity embedded in the calculation of the value of the Reynolds Number, Re), as well as an indirect proportion with the angle of the fork (in this case, embedded in the calculation of the radius of curvature R of the virtual circle that contains the bifurcation).

$$L = 2.69(2R)^{-0.1}Re^{0.59}D^{1.1} \tag{1}$$

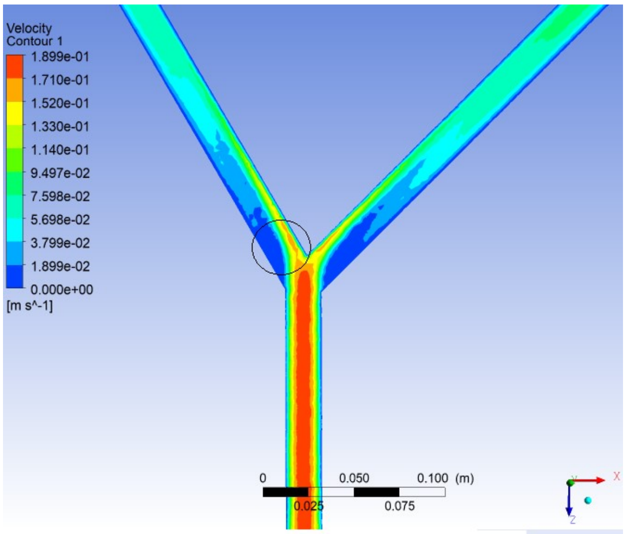


Figure 6. Flow in a bifurcation with 0.02 m pipe diameter, with half angles of 30º and 45º, flow rate of $1.6x10^{-4}$ m^3/s. Featured in the circle, the flow developing region

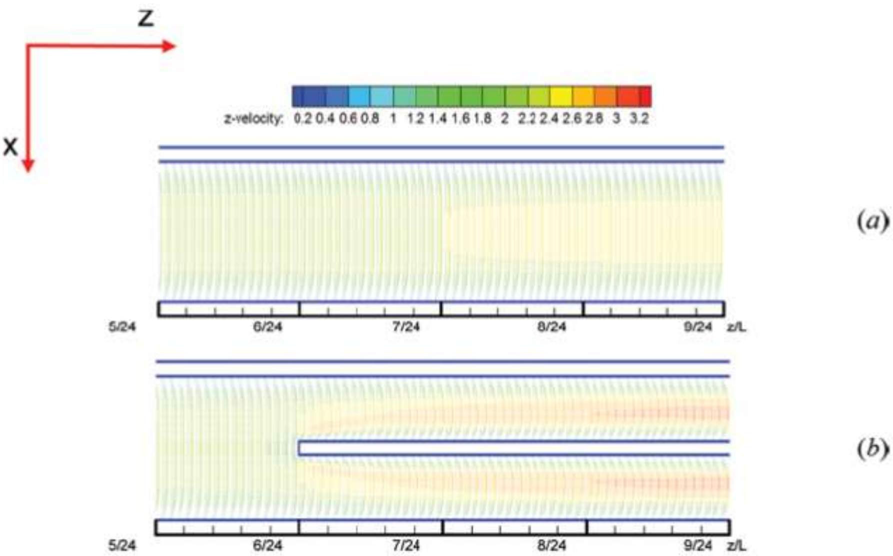


Figure 7. Symmetric zero-angled bifurcation, in a study developed by Gongnan et al, 2014, showing the almost imperceptible effect of small half-angles

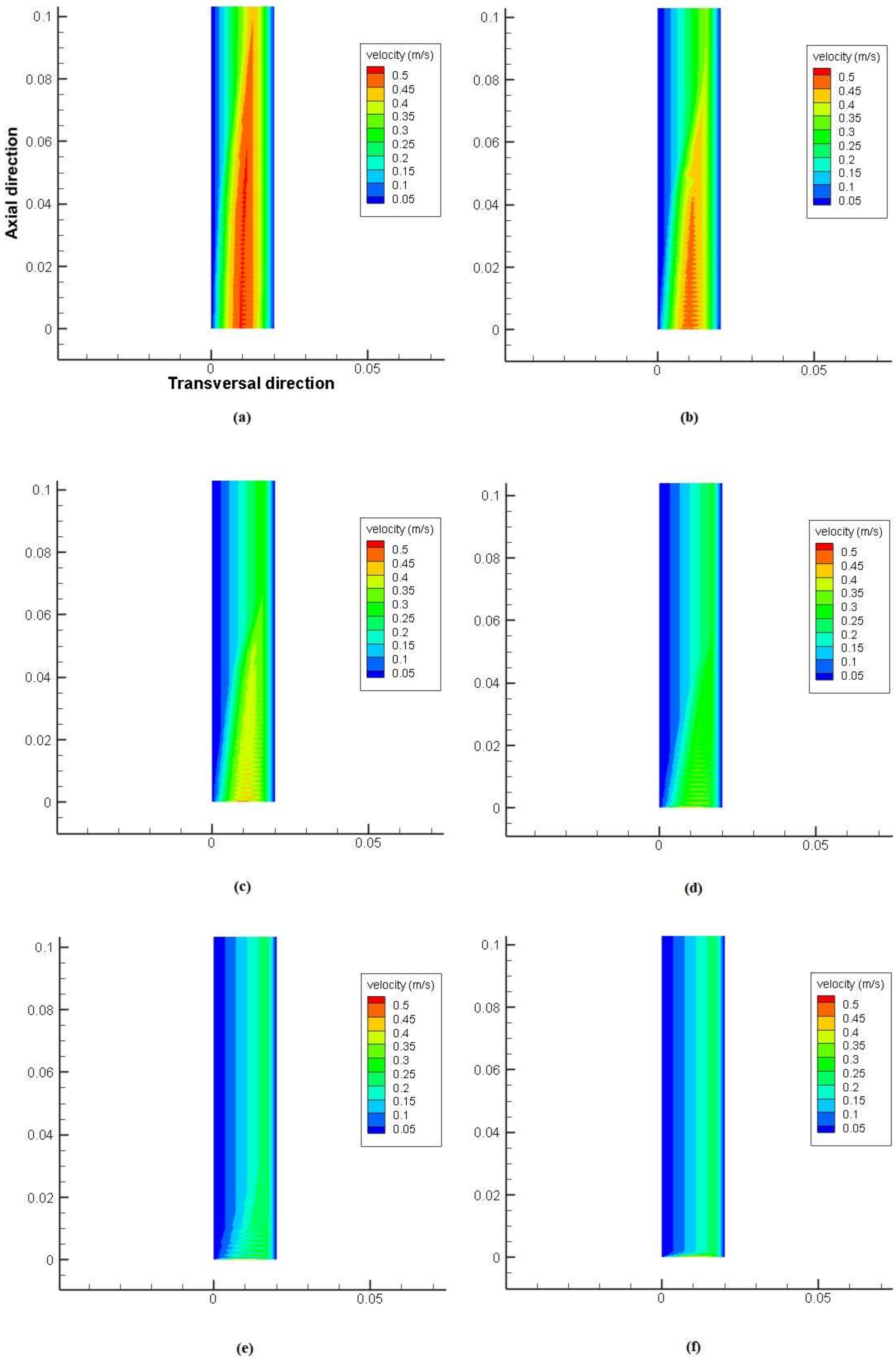


Figure 8. Behavior of the flow developing region at a bifurcation outlet, depending on the variation of the half-angle: (a) 15º, (b) 30º, (c) 45º, (d) 60º, (e) 75º and (f) 90º.

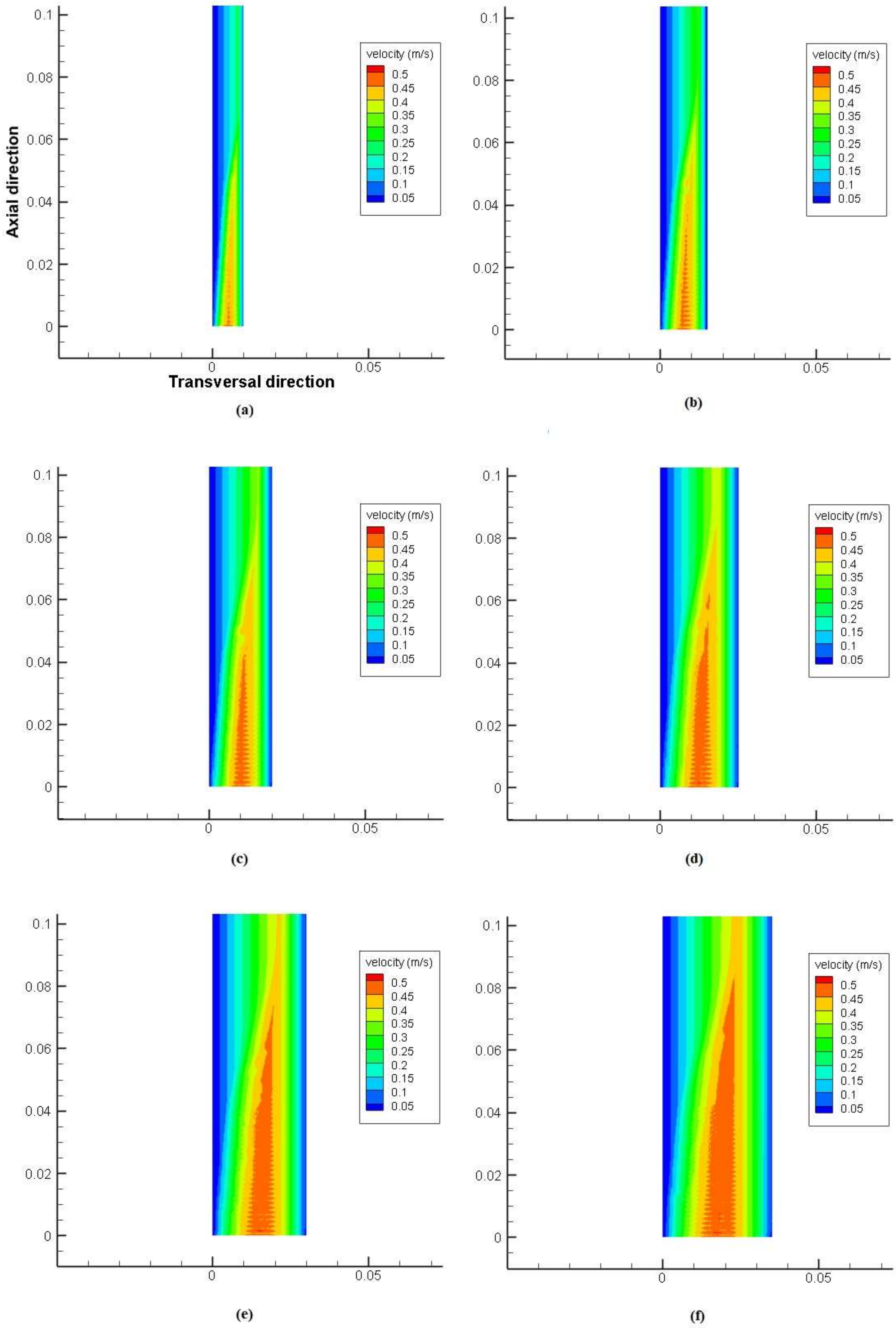


Figure 9. Behavior of the flow developing region in a bifurcation outlet, depending on the variation in tube diameter: (a) 0.010 m, (b) 0.015 m, (c) 0.020 m, (d) 0.025 m, (e) 0.030 and (f) 0.035 m.

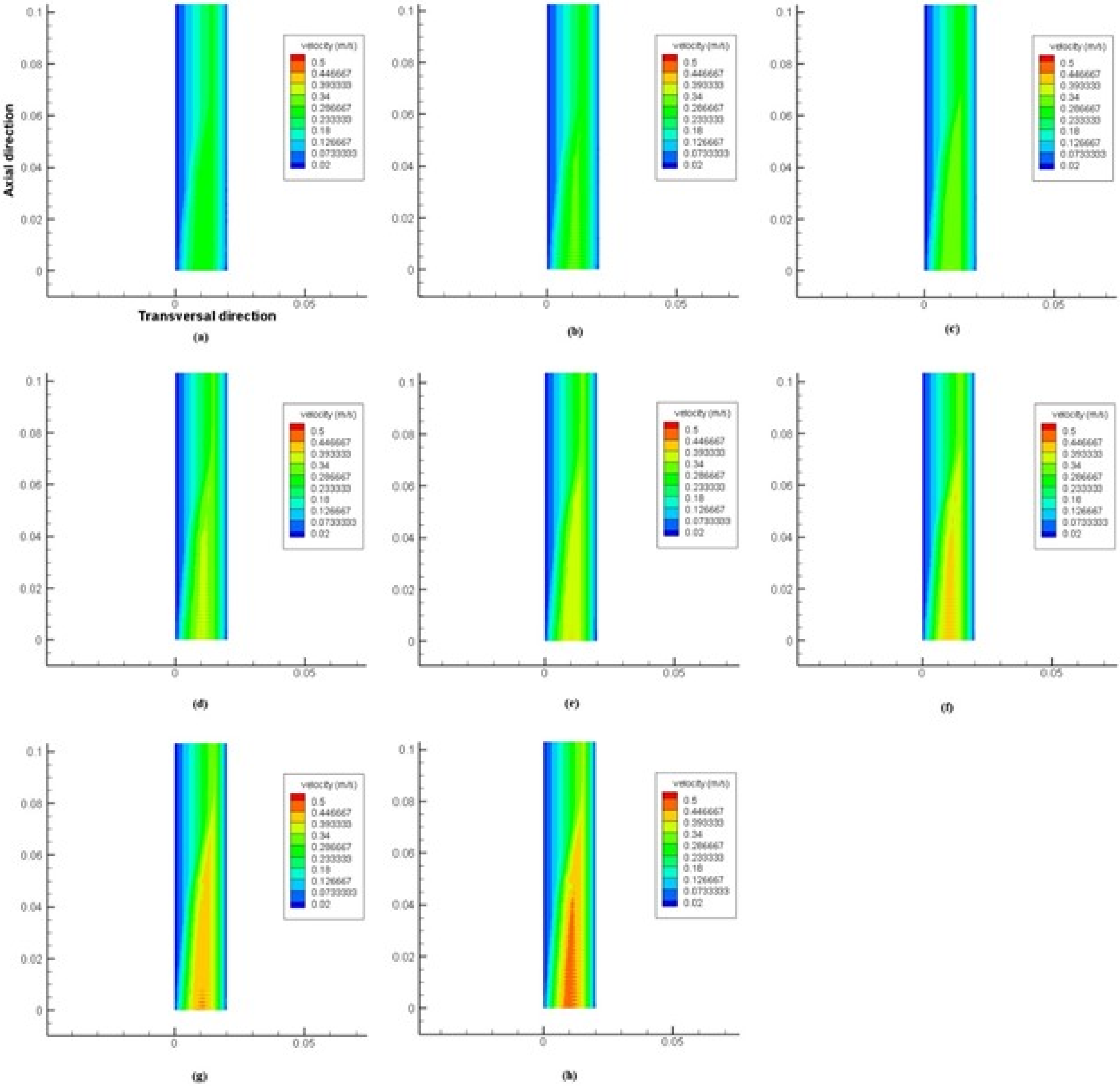


Figura 10. Behavior of the flow developing region in a bifurcation outlet, depending on the flow rate variation: (a) 0.9 x 10-4 m3/s, (b) 1.0 x 10-4 m3/s, (c) 1.1 x 10-4 m3/s, (d) 1.2 x 10-4 m3/s, (e) 1.3 x 10-4 m3/s, (f) 1.4 x 10-4 m3/s, (g) 1.5 x 10-4 m3/s and (h) 1.6 x 10-4 m3/s.

Considering all the previous work of the author and collaborators, who mainly resided in quantitative analysis, this qualitative analysis meets the need for a better explanation of the fluid dynamics in the passage through bifurcations. Such an object is of great use in the design of pipeline projects for the most diverse purposes, such as those found in the oil and gas, air conditioning, water and sewage industries and in general pumped circuits.

As a last observation, it is important to show that the region of thermal development in bifurcations also needs a better qualitative understanding, which the authors intend to accomplish in future work.

4. CONCLUSIONS

Morphological aspects of the not developed flow region in bifurcations were presented with support in the specific literature of this research area. The regions with the highest flow velocity and where vortices are formed were highlighted.

In order to make a qualitative analysis of the region evidenced, CFD simulations were performed in bifurcations where water flows under NTP conditions, employing the finite difference method. The analysis of the variation in the bifurcation half-angles allowed to conclude that the length of that region is inversely proportional to the increase in the half-angle. On the other hand, the variation of the tube diameter and the fluid flow rate show that the flow developing region is directly proportional to the growth of these quantities

Considering that all previous work by the authors and them collaborators was quantitative and mathematical analysis, the present work completes the service with this qualitative analysis. Qualitative work on the thermal development region is necessary and will be carried out in the future.

5. ACKNOWLEDGMENTS

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7. AUTHORAL RESPONSIBILITY

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