EXPERIMENTAL INVESTIGATION OF TURBULENCE LEVEL IN ENHANCED EXCHANGERS WITH ACTIVE INSERT DEVICES

D. Crespí[1],* , P.G. Vicente[2], J.P. Solano[1], A. García[1], A. Viedma[1]

1 Universidad Politécnica de Cartagena, Departamento de Ingeniería Térmica y de Fluidos, Campus de la Muralla del Mar, 30202 Cartagena, Spain. Corresponding author: damiancrespi@yahoo.es

2 Universidad Miguel Hernández, Departamento de Ingeniería de Sistemas Industriales, Avenida de la Universidad, s/n 03202 Elche, Spain

ABSTRACT

This work presents a visualization study carried-out on a dynamic insert device. The flow pattern is obtained by employing the Particle Image Velocimetry (PIV) technique. The insert device is moved alternatively along a tube and consists of several circular elements with six circumferentially distributed holes on them, which are mounted on a shaft with a pitch of 5D. The whole is moved alternatively along the axial direction by a hydraulic cylinder. The increase of the turbulence level of the flow will be analyzed and related to the heat transfer augmentation.

By the use of Particle Image Velocimetry technique and water as test fluid, the 2-Dimensional pattern of the turbulent flow is obtained on the two symmetry planes of the device: hole center and between holes. The results permit to establish the flow pattern along the devices.

In static conditions of the scraper, experiments are carried out at three different Reynolds ranging from 4000 to 6323. In dynamic conditions, the Reynolds number has been kept constant at 7400, while varying the velocity of the scrapper in relation of 0.5, 1 and 2 with the bulk velocity of the flow. Co current and counterflow directions of the scraping device have been analyzed, and results show the insert device movement on flow behavior.

INTRODUCTION

Insert devices have been deeply investigated in order to improve their efficiency: heat transfer vs. pressure drop. Webb (1994) classified the Heat Transfer Enhance techniques into “active” and “passive”. The “passive” ones, like inserted wire coils or mechanically deformed pipes have been studied during the last 30 years and have become commercial solutions. Webb deduced from his work that “active” techniques can produce very high increases on heat transfer.

The fouling problem of heat exchangers has a significant impact on chemical, petrochemical and food industries. Preventing fouling on heat exchanging devices is essential to avoid: heat transfer inefficiencies, corrosion due to deposits formation and pressure loss, what affects to the devices' performance (Bergles 2002).

Mechanically assisted heat exchangers, where a heat transfer surface is periodically scraped by a moving element, might be used to increase heat transfer and avoid fouling. Equipment with rotating scraping blades are found in commercial practice: they prevent fouling and promote mixing and heat transfer. Many investigations have focused on these anti-fouling devices, studying flow pattern characteristics (Wang et al, 1999), their thermo-hydraulic performance (Goede and Jong, 1993) or scraping efficiency (Sun et al, 2004).

Reciprocating devices can be used working to generate slurry ice. Some investigations have focused on these applications (Kauffeld et al, 2005, Stamatiou et al, 2005).

This work presents a visualization study carried-out on a heat exchanger with a dynamic inserted device. The flow pattern is obtained by employing the Particle Image Velocimetry (PIV) technique. The active insert device consists of several circular elements with six circumferentially distributed holes on them, which are mounted on a 18 mm diameter shaft with a pitch of 5D (Fig. 1). The whole is moved alternatively along the axial direction by a hydraulic cylinder. The increase of the turbulence level of the flow will be analyzed and related to the heat transfer augmentation.

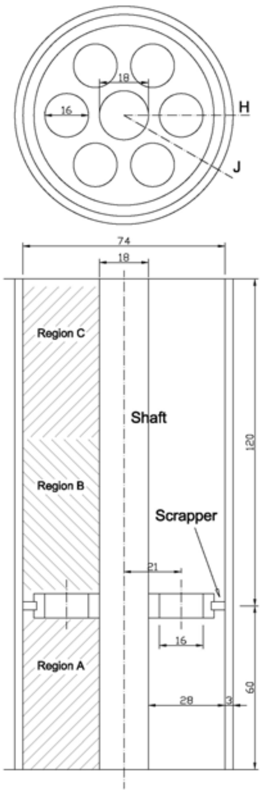

Fig. 1 Sketch of the active insert device analyzed

EXPERIMENTAL FACILITY

The facility depicted in Fig. 2 was built in order to study the flow pattern induced within a device inserted inside a tube. The main section consists of a 74 mm diameter acrylic tube installed between two reservoir tanks that stabilize the flow. In the upper reservoir tank the flow temperature is regulated by an electric heater. The flow is impelled from the lower calm deposit to the upper one by a gear pump, which is regulated by a frequency converter. By using water as test fluid at temperatures from 25ºC to 60ºC, a Reynolds number range between 3500 and 28000 can be obtained.

The test section has been placed within a distance of 15 diameters from the tube inlet in order to ensure fully developed flow conditions. To improve the optical access in this section, a flat-sided acrylic box has been placed. This box was filled with the same test fluid that flows through the test section.

Water is the test fluid chosen for the experiments. It is pumped through the conducts by a gear pump, regulated by a frequency converter which allows to control its bulk velocity, messed by an electromagnetic flowmeter. In order to control the fluid temperature, there is an electric heater in the upper reservoir tank. With the rest of the variables fixed, these two parameters determine the Reynolds number.

The Particle Image Velocimetry is a broadly used technique which allows to measure velocity patterns in a flow. For that the flow is seeded with little particles with the same density of the testing fluid, in this case 50 microns diameter polyamide particles have been chosen. As shown in Fig. 3, a laser illuminates planar slices of the flow which contain the axis of the pipe (longitudinal section). The camera is situated in orthogonal position in relation to that plane, so that it can have a front view of it. Taking two consecutive images of the particles and knowing the time gab between them, the 2-Dimensional velocity field can be obtained.

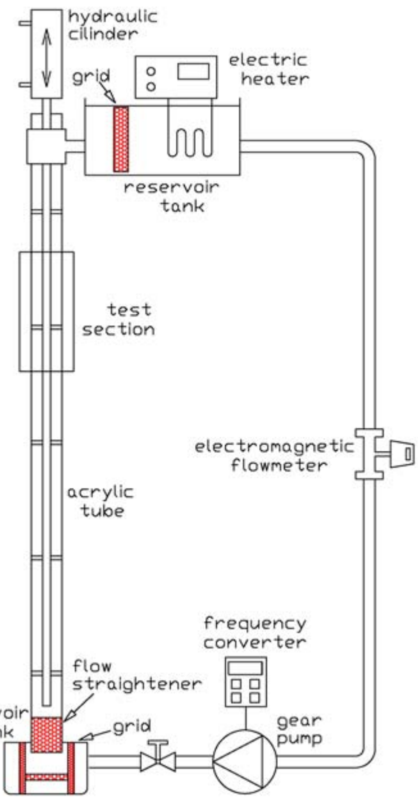

Fig. 2 Sketch of the experimental facility

The 1 mm thick plane laser light, is pulsed at 100 Hz in order to obtain multiple pair of images. Its wavelength is 808 nm. The camera is controlled by a computer, which is also in charge of synchronizing it with the laser pulse. On the dynamic experiments, the pictures are taken in pairs, triggered by the movement of the scraping device.

For each experiment, between 500 and 1000 pairs of images have been processed using the software UraPIV, which applies cross-correlation algorithm between consecutive images.

In static conditions, a window size of 16x16 pixel has been used for the PIV processing and an overlap of 50%, while it was of 32x32 pixel with a 100% overlap in dynamic conditions. In post processing, a global and a local filter are applied to eliminate out-layers. No interpolation has been made and the obtained velocity field is the result of averaging the total number of image pairs of each experiment.

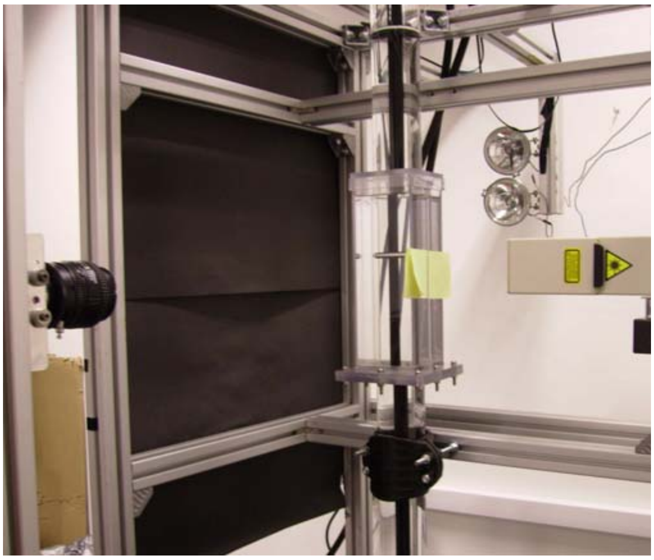

Fig. 3 Photograph of the PIV facility

RESULTS

The laser light is 1 mm width and 100 mm high. The PIV technique can only give good results in a region 60 to 80 mm high. Velocity results are processed in three regions as shown in Fig. 1: Region A, upstream the scraper, Region B, immediately downstream the scraper and Region C after Region B.

STATIC DEVICE

The flow pattern has been analyzed in static conditions, where the scraper device does not move. Experiments have been carried out at different Reynolds, ranging from 4000 to 6500. The bulk velocity has been kept constant, varying the water temperature from 30ºC to 56ºC.

In these conditions, three groups of images have been taken, each one composed of 500 pairs of images. The first group is made up of pictures of the flow just before the scraper and the other two are located in consecutive positions after it.

The 2-dimensional images, represent a plane of the flow. As this type of flow only has two different symmetry planes, experiments have been carried on both of them, which are in radial direction. The first one is located crossing each hole of the scrapper through its diameter and the second one is situated in the middle of the gap between two consecutive holes.

Figures 4 and 5 show the measured velocity fields in both symmetry planes: center hole (H) and between holes (J). Fig 4 shows that the flow pattern is similar to a jet flow. The "jet" produces high velocities downstream the holes and flow recirculations in the near wall region and in the region between the holes (plane J)

The insert devices produce 6 round jets of 16 mm diameter each one. The jets induce a reverse flow of 4-5 jets diameters long (64-80 mm). Figures 6 and 7 show the evolution of the flow profiles at different axial locations, from 32 mm upstream the device to 130 mm downstream the device.

The maximum velocity in axial direction decreases downstream the device. At the device exit (L=4 mm) the velocity profile is nearly constant (Vy/Vm =4.3). 70 mm downstream the device, the maximum non-dimensional flow velocity is around 3.2 and at 130 mm is around 2.

In the region between holes, a big recirculation is produced by the effect of the jet flow. At 70 mm downstream the device, the jet has expanded to the region between holes (plane J) and the flow becomes axilsymmetric, having higher velocities next to the shaft. From this point on, the turbulence induces an homogeneous velocity profile.

DYNAMIC DEVICE

On the experiments where the scraping device moves in cocurrent direction, the relative velocity between the device and the flow is lower than in static ones. As a consequence of that, the effect that the device has on the flow becomes less significant.

On Fig.8 and Fig.9 the velocity field in planes H and J are represented. The relative velocity between the insert device and the bulk velocity of the flow is ω=0.5. The velocity profiles are presented in Figs 10 and 11.

The "jets" formed from the holes on, are less vigorous and so are the resulting recirculations on the near-wall region and upstream the scraper in the plane between the holes (plane J). As it is shown in Fig. 8 and Fig. 10, the "jets" have almost disappeared at a distance of 43 mm from the scraper as well as the induced recirculations. At a distance of 83 mm the flow has the characteristics of a turbulent flow in annulus: the effect of the device has disappeared.

The flow upstream the device is very similar to the typical profile of a turbulent flow along an annulus region. This profile changes just some millimetres before passing through the insert device. Due to the insert device movement in flow direction, the maximum velocity in axial direction is 2.5 times the bulk velocity (Vy/V=2.5), which is lower than in the static device case (Vy/V=4.3).

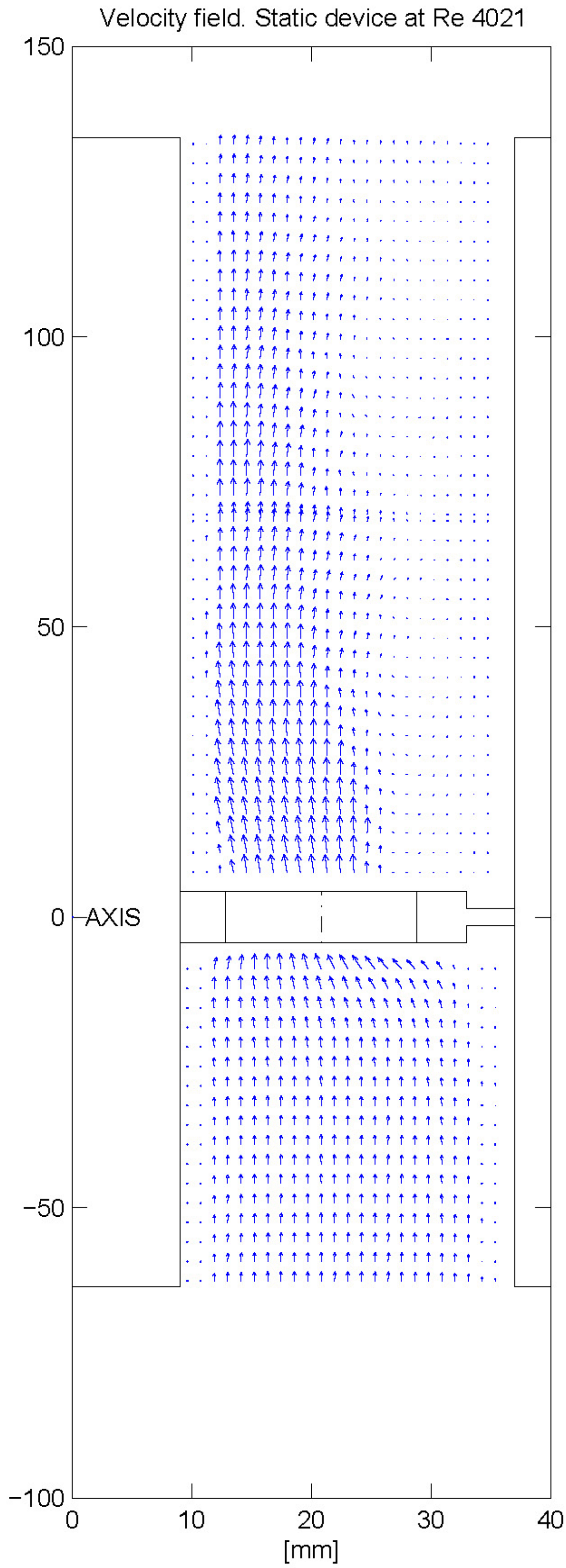

Fig. 4 Velocity field in plane H at Re =4021. Static device.

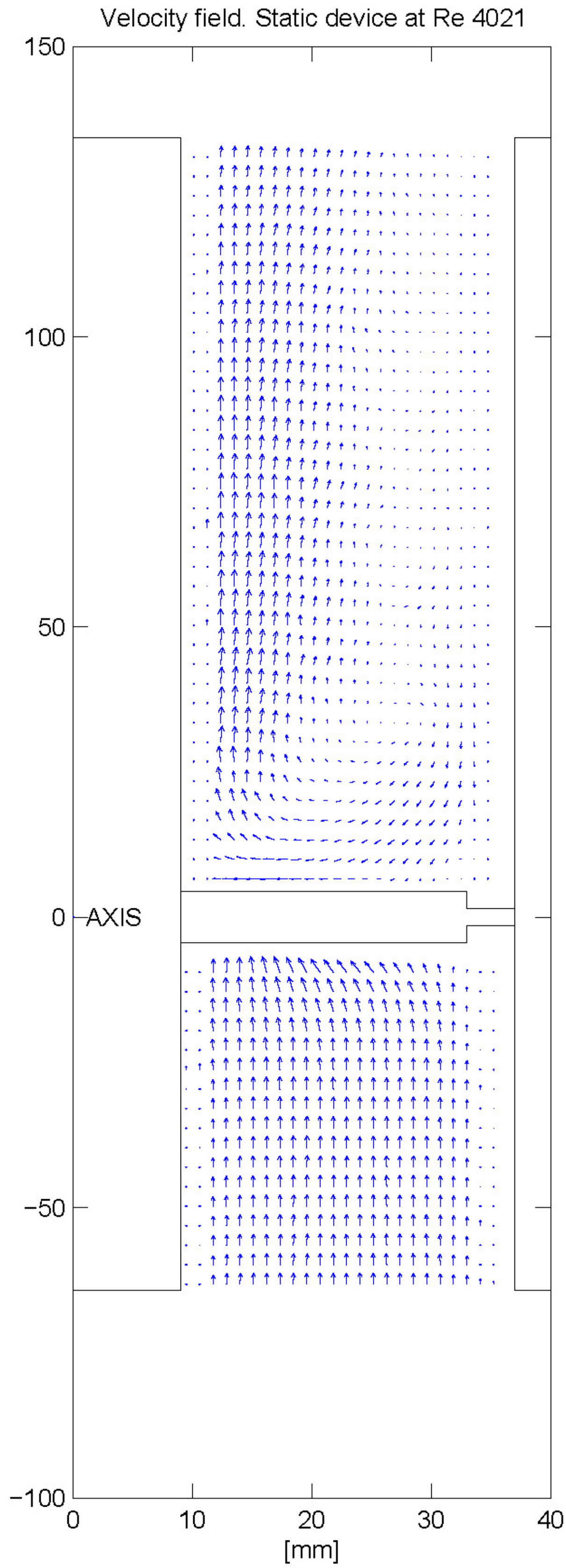

Fig. 5 Velocity field in plane J at Re =4021. Static device.

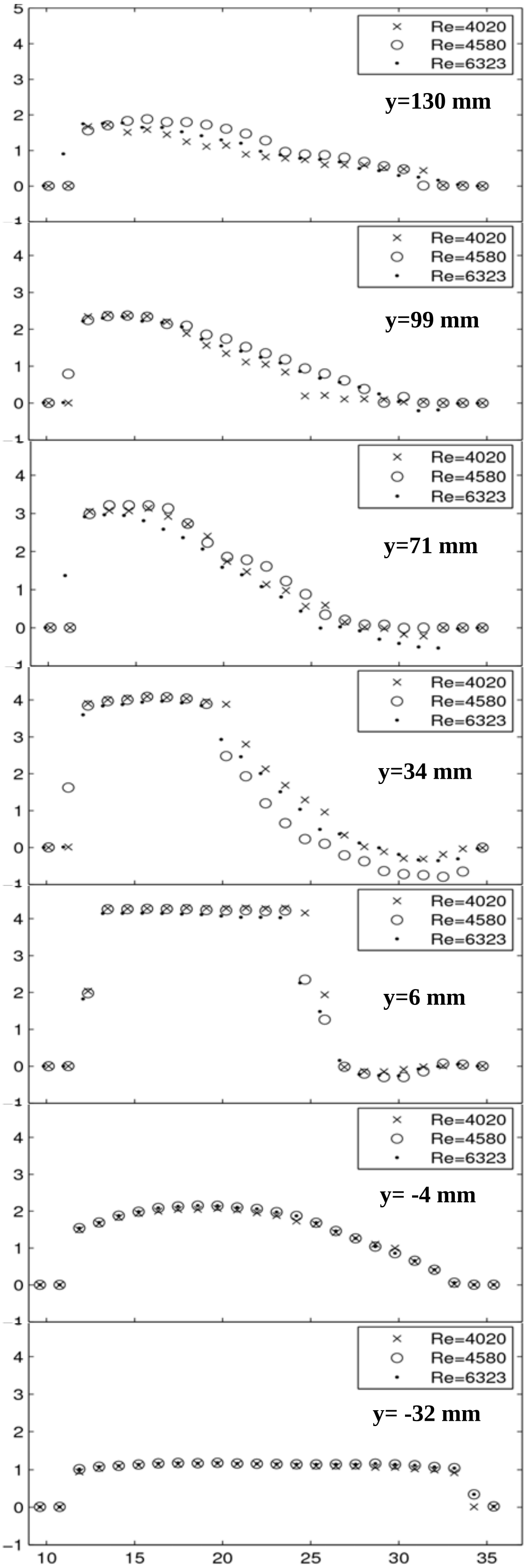

Fig. 6 Vy/V profiles for static device. Plane H

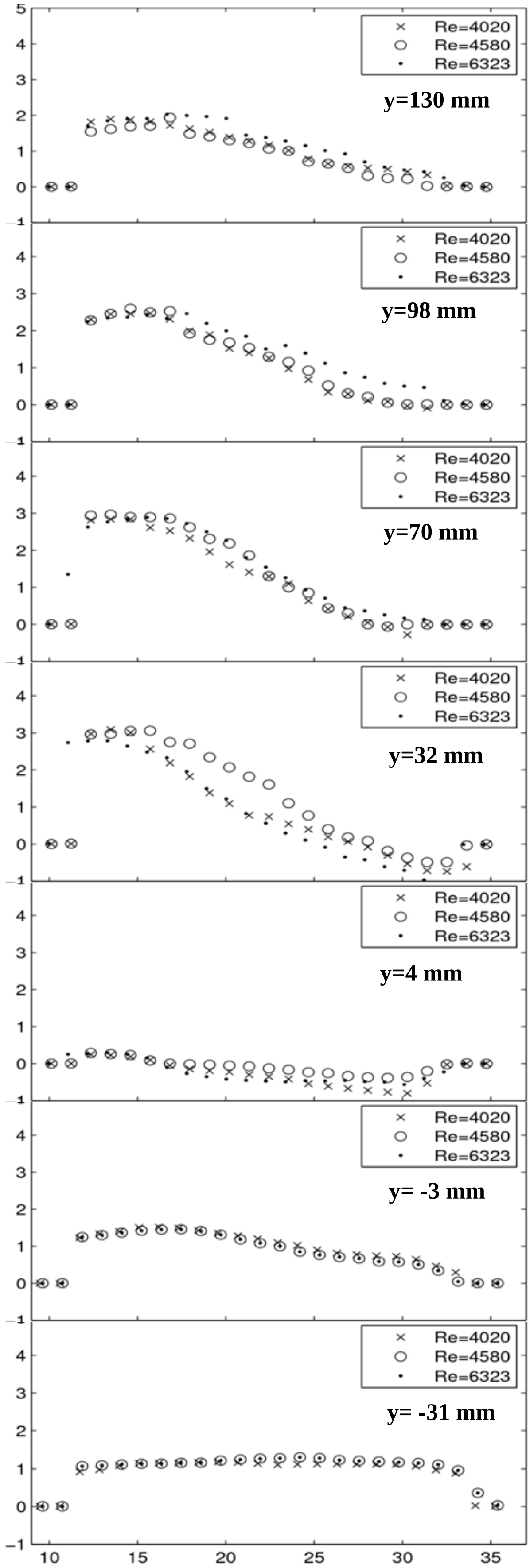

Fig. 7 Vy/V profiles for static device. Plane J

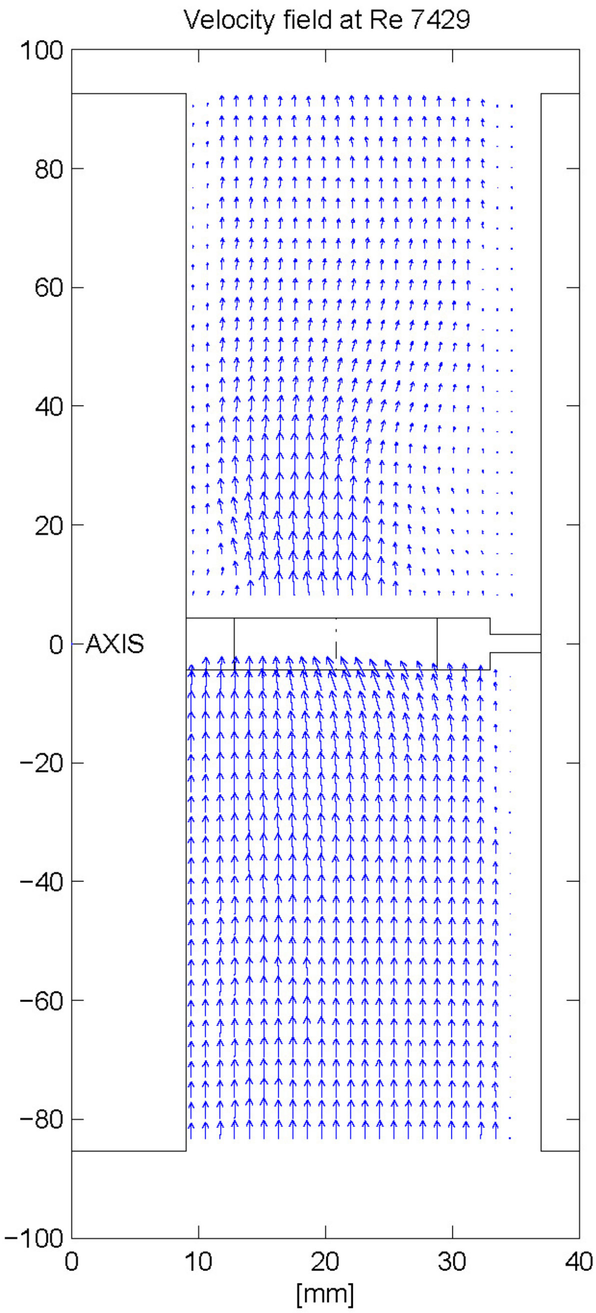

Fig. 8 Velocity field in plane H at Re =4021. Dynamic device at ω = 0,5.

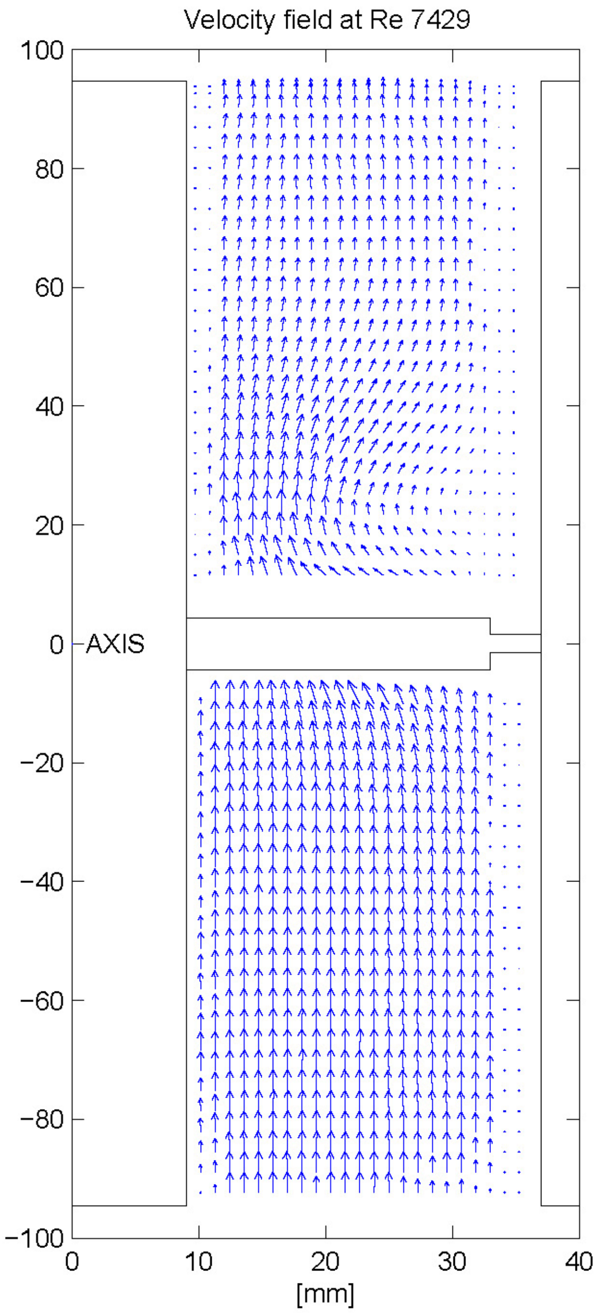

Fig. 9 Velocity field in plane J at Re =4021. Dynamic device at ω = 0,5.

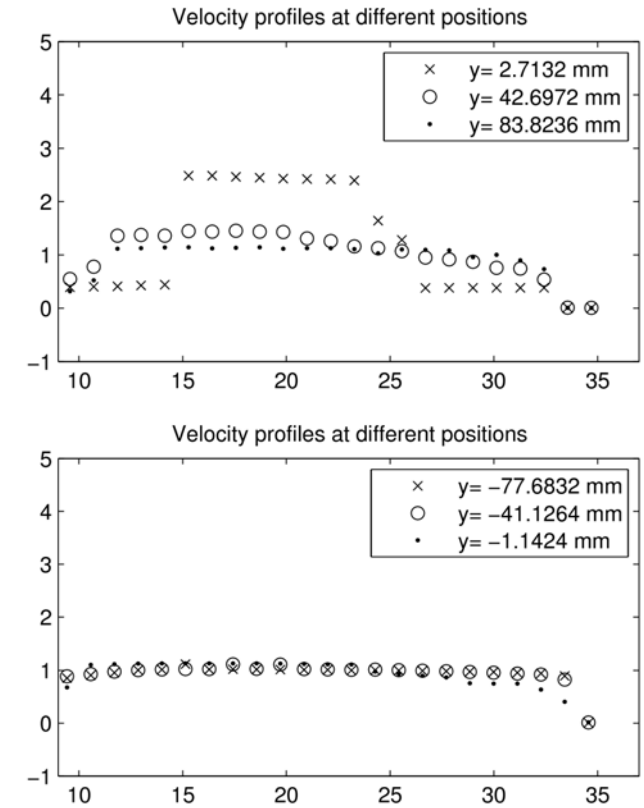

Fig. 10 Velocity profiles in plane H. Dynamic device at ω = 0,5, Re = 7429.

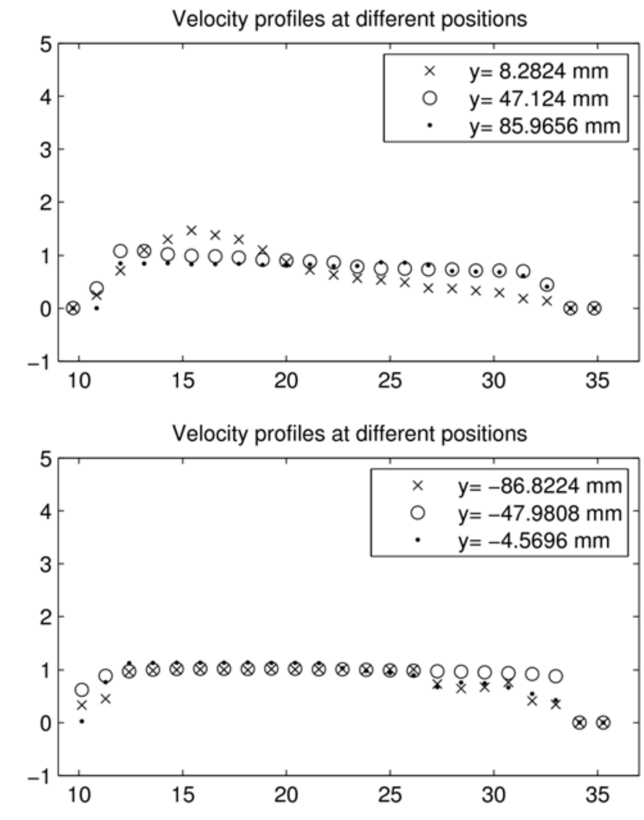

Fig. 11 Velocity profiles in plane J. Dynamic device at ω = 0,5, Re = 7429.

CONCLUSIONS

1. The work presents the velocity field produced downstream and upstream a device inserted in a tube to enhance heat transfer and avoid fouling.
2. In static conditions, the device produces a "jet" flow which yields to maximum axial velocities up to 4 times the bulk velocity and large vortices in the region between holes.
3. The movement of the device in cocurrent direction reduces the device influence on fluid flow. At ω=0.5 the maximum axial velocity is 2,5 times the bulk velocity.

REFERENCES

Bergles, A.E., 2002, "ExHFT for fourth generation heat transfer technology", Exp. Thermal. Fluid Sci., Vol. 26, pp. 335-344

De Goede, R., De Jong, E.J., 1993, "Heat transfer properties of a scraped-surface heat exchanger in the turbulent flow regime", Chemical Engineering Science, Vol. 48, pp.1393-1404

Kauffeld, M., Kawaji, M., Egolg, P.W., 2005, "Handbook on Ice Slurries. Fundamentals and Engineering". International Institute of Refrigeration

Stamatiou, E., Meewisse, J.W., y Kawaji, M., 2005 "Ice Slurry Generation Involving Moving Parts", International Journal of Refrigeration, Vol 28, pp. 60-72

Sun, K.H., Pyle, D.L., Fitt, A.D., Please, C.P., Baines, M.J., Hall-Taylor, N., 2004, "Numerical study of 2D heat transfer in a scraped surface heat exchanger", Computers & Fluids, Vol. 33, pp. 869-880

Wang, W. Walton, J.H., McCarthy, K.L., 1999, "Flow profiles of power law fluids in scraped surface heat exchanger geometry using MRI", Journal of Food Process Engineering, Vol. 22, pp. 11-27

Webb, R.L., 1994, "Principles of Enhanced Heat Transfer", first ed., Wiley Interscience, New York