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NUMERICAL ANALYSIS OF THE FLOW FIELD IN A HELICO-AXIAL MULTIPHASE PUMP STAGE WITH SPLITTER BLADE IN THE DIFFUSER

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Abstract. *The multiphase pumping is used essentially for the energy increase in a fluids mixture (liquid-gas-particle), becoming a good alternative in the transport of multiphase fluids. Helical-axial multiphase pump (BMHA) stage is composed of a helical-axial rotor that transmits to the fluid the kinetic energy and of a diffuser used for fluid homogenizing and directing for the following stage. The turbomachine rotor or diffuser may have only the main blades (conventional rotor), or may have a splitter blades set (interrupted blades) located between the main blades. Splitter blades are not found in the rotor/diffuser inlet region, as this would produce geometric strangulation, causing loss levels high. However, the splitter blades proper use allows reduction of loading of the main blades, such as vortex breakage or recirculations present in the flow. The present study aims to numerically simulate a BMHA stage, considering diffusers with different numbers of blades. The diffusers have a splitter blades set, placed in various angular positions (0.45-0.5-0.55) of the channels formed by the main blades with string length of 0.7 of the main blade. The highest efficiencies were obtained with a splitter blades number high and when the splitter blades are closer to the main blades internal surface.*

Keywords: *Helico-Axial Multiphase Pump, Computational Fluid Dynamics CFD, Splitter blades.*

1. INTRODUCTION

Multiphase flow is the term used to refer to any simultaneous flow, on a macroscopic scale, of two or more phases in direct contact. They can be easily found in many technological processes, such as in the chemical, pharmaceutical, food, nuclear and oil industries.

In the transport of multiphase fluids, two methods are commonly used, in one of them, a pre-separation of the phases is done, then compressing the gas and pumping the liquid. In the other method, a multiphase pump system is used, which Diaz (2010) increases production because it eliminates the separation and burning of the gas, thus reducing the complexity of the operations and the environmental impact. In addition to the infrastructure and cost involved in the first process (Kong *et al* 2010).

BMHA is a multistage pump for multiphase flow, where each stage (Fig. 1) is composed of a helical-axial rotor and a diffuser responsible for homogenizing and directing the fluid to the next stage (Falcimaigne *et al* 2002). The rotor has a special shape that favors the mixing of the fluids, preventing the separation of the mixture (liquid-gas), this allows characteristics of stable flow pressure and an increase in the overall efficiency.

The employment of splitter blade is one of the techniques frequently used for performance optimization, and consequent improvement of the flow field in Turbomachinery. Harano *et al*. (2006), used splitter blade in a Francis turbine, obtaining the effect of rectifying the flow, thus improving efficiency, (under particular partial loading), and reducing the vibration induced by the pressure pulsation. Yang *et al* (2012) found that with the increase in the number of splitter blade, the required pressure head of a centrifugal pump working as turbine drops and its efficiency increases. Créder (2013) found that increasing the length of the splitter blades, leads to increase the total pressure of a centrifugal fan. Li *et al*. (2015) determined that the length of the splitter blade influences the performance and acoustic characteristics of an axial fan.

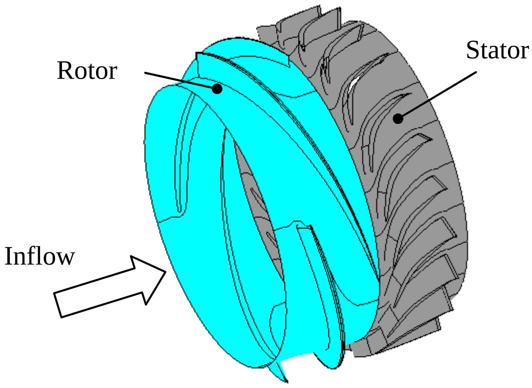

Figure 1. Schematic diagram of the BMHA stage

Thus, in this research, we considered the idea of adding a set of splitter blade in the diffuser passage, between two main blades, to improve performance and the condition of multiphase flow. That is, altering two parameters of evaluation in the use of splitter blades, such as: The numbers of splitter blades (*N_pa*) and the angular position (*Fa*) of these. For the analysis of the parameters influence, numerical simulations of the multiphase flow were performed through the CFD techniques and, therefore, local results of the flow fields will allow to better understand the regions of energy dissipation, based on appropriate turbulence models considering the nominal condition of operation.

2. COMPUTATIONAL PROCEDURE

Computational Fluid Dynamics techniques as a tool in the numerical simulation of multiphase flows have become indispensable in the analysis of complex flows, allowing the study of different geometries and contour conditions.

2.1 Geometry

The BMHA original geometry with conventional diffuser was designed applying a combined approach method, based on the blade element theory, the radial equilibrium condition (free vortex), 824 NACA report information (Abbott, 1945) and two-phase flow concepts for the development of the rotor- diffuser considering multiphase fluids (water-air). A Fortran® computational code was generated to obtain the preliminary geometrical characteristics of the rotor-diffuser. These characteristics were imported to ANSYS BladeGen® to obtain the geometries (see Fig. 1).

Subsequently, based on the pump stage original geometry, Fig. 1, there were made changes, for projects, including splitter blade on the diffuser. In these were modified the number of splitter blades and the positions circumferential of them.

2.1.1 Parameterization of geometry

In pumps, the use of splitter blades in the channels is an alternative way to increase the pump head, besides improving the speed and the pressures distributions thus improving the performance of the pump. The use of splitter blades in the diffuser, allows the reduction of the main blades load, improving the direction of the fluid and the rupture of vortices or recirculations, avoiding the high regions of losses in the flow.

Therefore, this work presents an analysis in a BMHA stage, considering diffusers with different numbers splitter blades (*N_pa*). The diffusers present a set of splitter blades, placed in different angular positions of the channels formed by the main blades, evaluated by a circumferential position factor, (*Fa*). Scheme of diffusers with splitter blades at various circumferential positions are shown in Fig 2. These models were created using the ANSYS BladeGen®.

The Design of Experiments used was a full factorial, selected three levels for the splitter blades numbers (*N_pa*) and for the circumferential position factor (*Fa*). See Table 1, totaling 9 experiments in the exploration phase

Table 1. Values for geometry parameterization.

Variables	Values adopted
N_pa	9 - 11 - 13
Fa	0,45 - 0,5 - 0,55

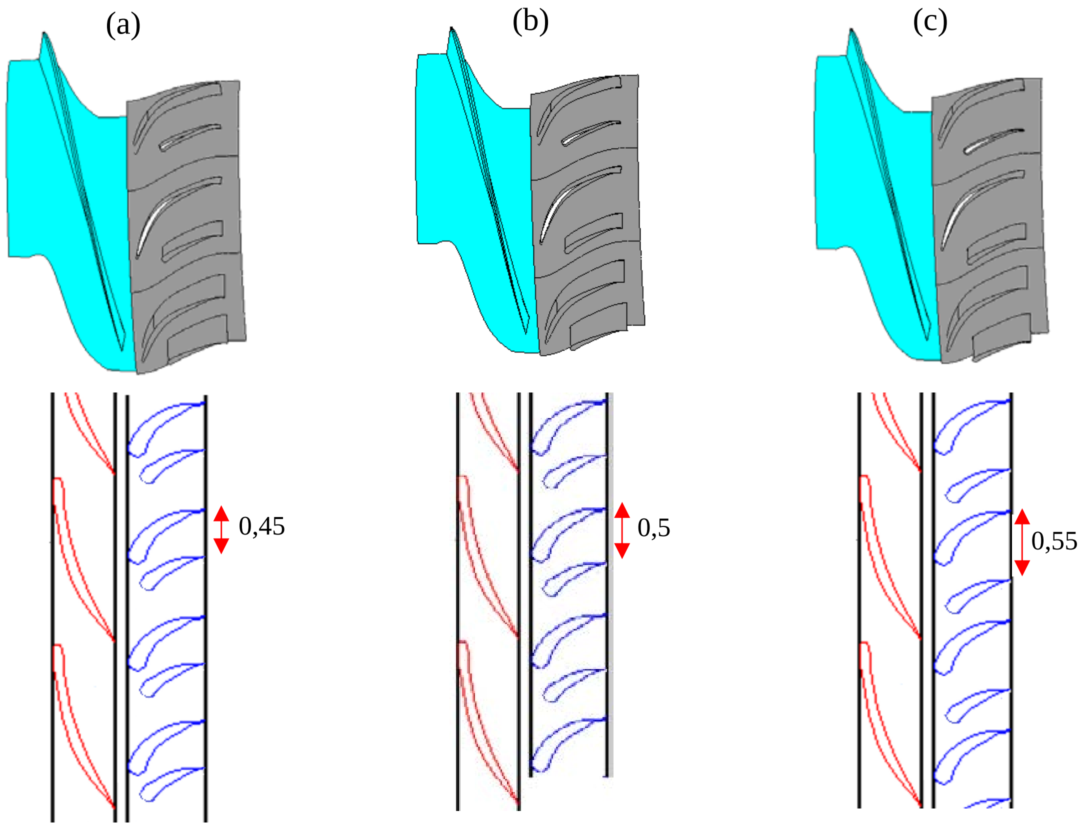

Figure 2. Schematic of the BMHA stage, with different circumferential position factor, Fa. a)0,45 b)0,5 e c)0,55

2.2 Mesh

The computational mesh was generated in ANSYS TurboGrid®, using the topology ATM optimized, which is an excellent alternative when it comes to turbomachinery topologies, such as the case of rotors and stator of pumps, fans or turbines. This option allows to easily create high quality meshes, due to the fact that it is not necessary to adjust the mesh's control points. The type of mesh that uses this template is a multi-block hexahedral mesh with refinement near the walls, controlled by the dimensionless distance between these (y^+), to the first element of the mesh, which depends on the local Reynolds number.

Figure 3 shows the general configuration of the meshes in the rotor-stator passage, as well as the refinement near the walls.

2.3 Numerical simulation

The flow simulations of the helico-axial multiphase pump were made in ANSYS-CFX15®, in order to obtain the hydrodynamic performance characteristics of the stage of BMHA, operating two-phase flow (water-air).

For the simulation of the rotor-diffuser assembly, the geometry at the rotor inlet extended 100 mm (half the rotor chord) in order to observe the development of secondary flows due to the influence of parameters such as the leading edge. Between that, the output of the stator was extended 200 mm, this also the purpose of ensuring the development of the flow.

At the entrance of BMHA according to the observations reported by Zhang *et al* (2015), and Zhang *et al.* (2016) a bubble flow pattern is found, which can be analyzed by the Particle Model (Ansys, 2011), content within the Eulerian-Eulerian Model, for multiphase flow.

In the multiphase Particle Model it is necessary to impose a bubble diameter for the dispersed phase. In this case, a bubble diameter db = 1.8 mm was used for a GVF flow of 30%, corresponding to values observed by Zhang *et al.* (2015), and Zhang *et al.* (2016). In their experimental studies, where they visualized the drop size as a function of gas volumetric fraction (GVF) at the entrance of multi-phase helico-axial pumps.

In the analysis of the different cases studied the flow is considered as permanent, isothermal and without mass transfer between phases

The turbulence model k-ω SST was selected for the continuous phase, and the zero equations model was used in the dispersed phase (Ansys, 2011).

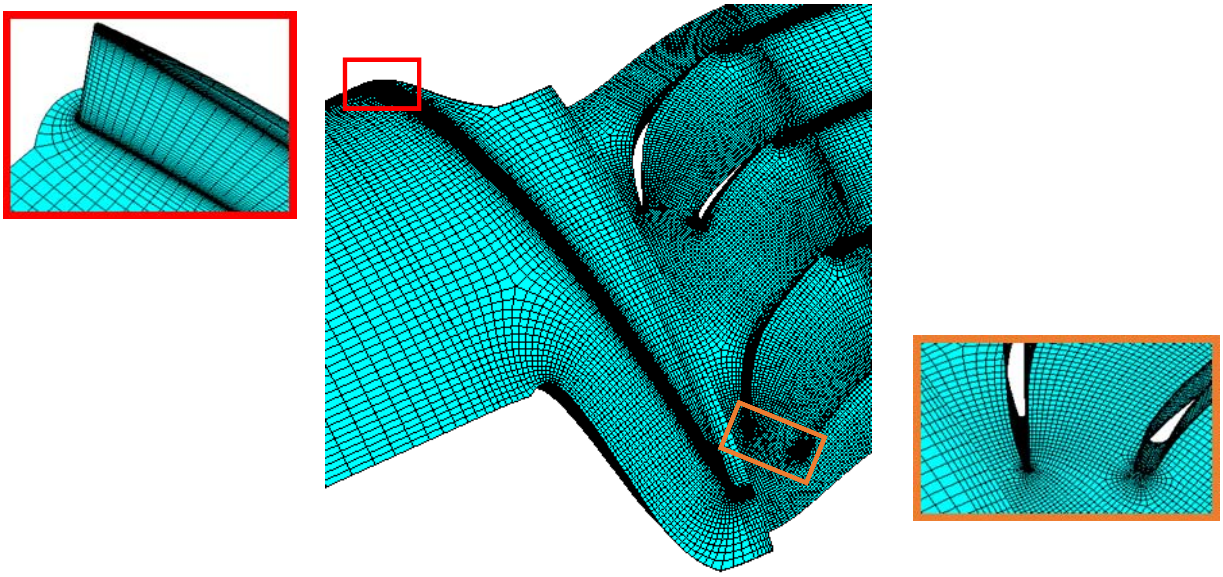

Figure 3. Computational mesh of the rotor and stator

The boundary conditions, outlined in Fig. 4, were imposed in the CFX®, which solves the governing equations for the discretized domain. Therefore, the boundary conditions employed are:

1) *Inlet surface*: In the input surface of the rotor extension, the mass flow condition for a single channel and the volumetric fraction of each of the fluids composing the flow mixture were set.

2) *Outlet surface*: On this surface, corresponding to the output of the stator extension was used the condition of static pressure.

3) *Periodic Surfaces*: Because the domain repeats on each blade, it is not necessary to simulate the complete stage, so the mesh is generated for a single channel imposing the periodicity condition (See Fig. 4) which represents 1/4 part of the rotor and 2 or 3 stator channels (approx. 1/4 stator).

4) *Interface surfaces*: For the simulation, "frozen rotor" interfaces were used to link the rotating domain (rotor) with the stationary domain (stator).

5) *Wall*: The “no-slip condition” was taken into account and must be satisfied on the walls, because the average velocity field is affected by it. Normally, the wall influences the flow, resulting in a velocity gradient near the wall. This condition is used in the hub and shroud rotor and stator.

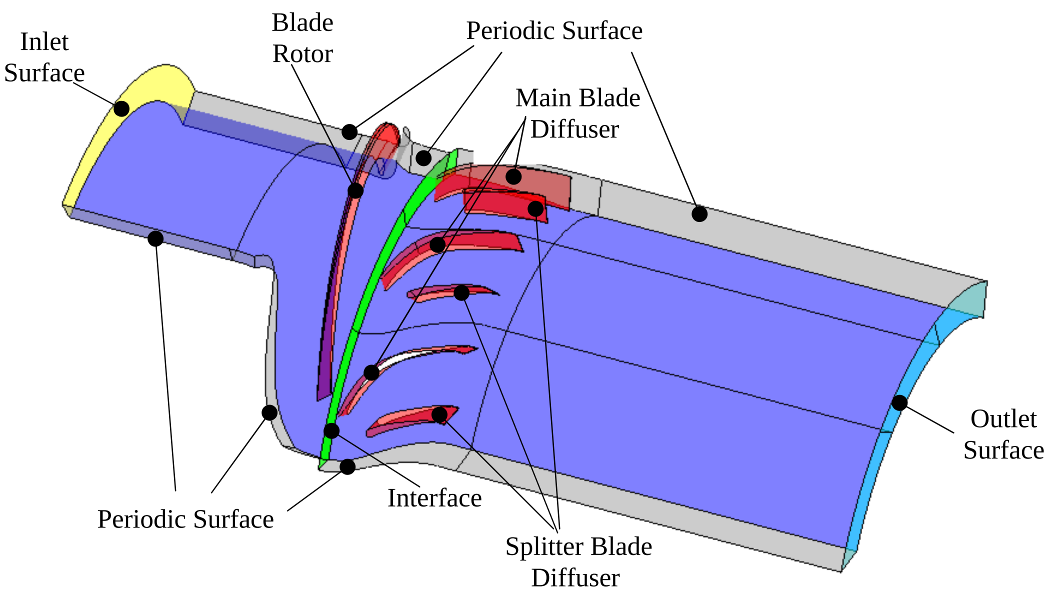

Figure 4. Surfaces and contour conditions of the simulation

3. RESULTS AND DISCUSSION

The results of the biphasic flow simulations, water-air, for the stage of the helico-axial pump working with GVF = 30% are presented.

Figure 5 shows from an isometric perspective, the distribution of gas volumetric fraction contours, which contains a meridional plane from the inlet to the outlet of the pump, for all cases analyzed. Furthermore, details of the suction side and pressure side of the impeller blade are shown. It is observed that the rotor presents the same distribution of GVF for all the cases, but in the diffuser there is less separation in the cases that include splitter blades, being influenced by the number and position of the splitter blades. In these images it is also observed:

- High gas concentration on the rotor hub surface, starting at the middle of the chord and extending to the rotor outlet, as in the work of Zhang *et al* (2016).

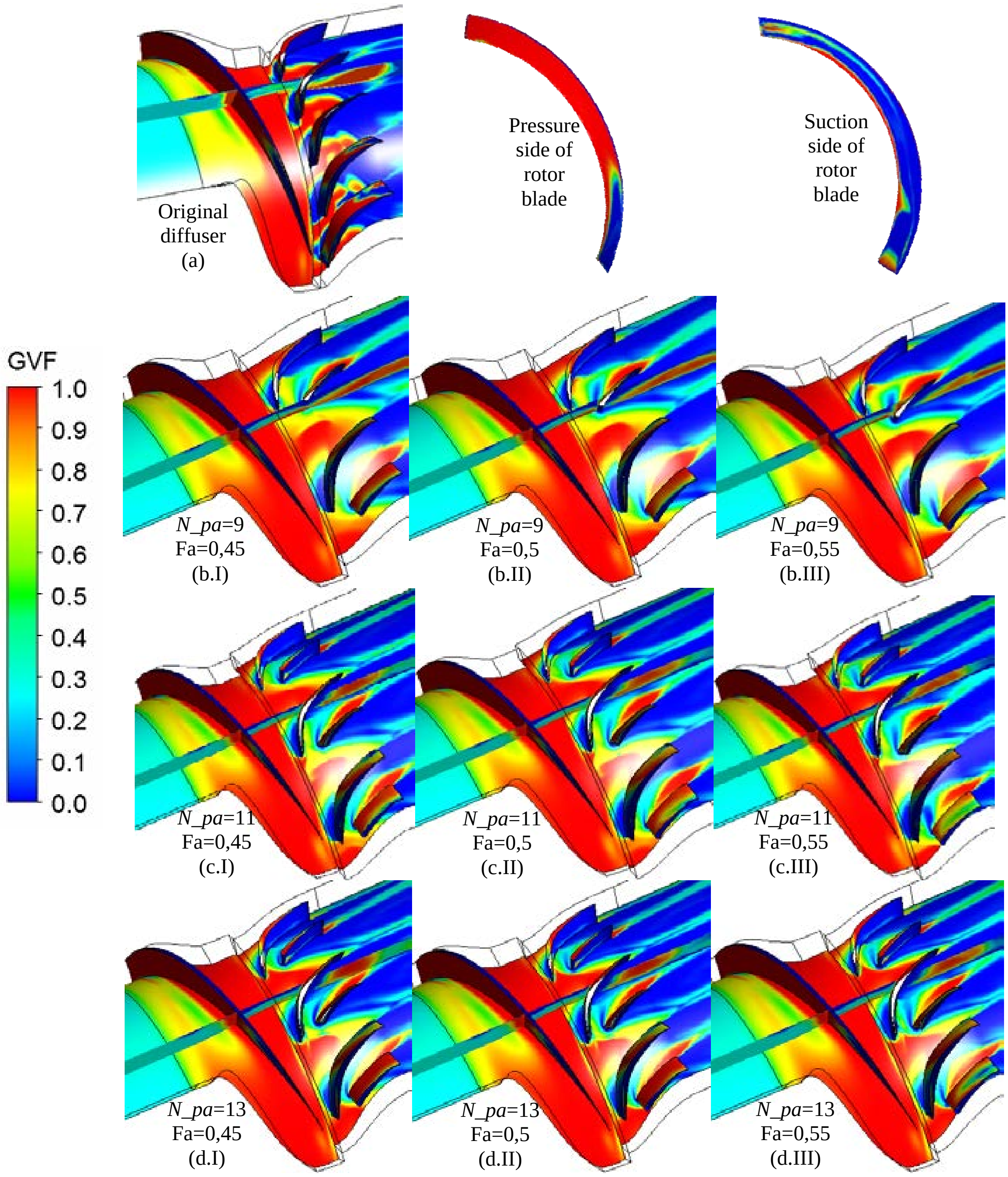

Figure 5. GVF contours of the BMHA stage, containing the different diffusers analyzed. a) Original diffuser b) N_pa=9 I) Fa=0,45 II) Fa=0,5 e III) Fa=0,55. c) N_pa=11 I) Fa=0,45 II) Fa=0,5 e III) Fa=0,55. d) N_pa=13 I) Fa=0,45 II) Fa=0,5 e III) Fa=0,55

- The suction surface of the rotor blade has a wide region of separation of the air phase flow, except for a concentration of water near the trailing edge. These effects agree with the results of Faustini (2006).
- High concentration of water that covers almost the entire rotor blade pressure surface, except for the trailing edge where a concentrated gas bubble appears. This accumulation of water can be justified according to experimental results of Murakami and Minemura (1983) where they describe that the air tends to concentrate on the suction side of the rotor blade.

Figure 6 presents the efficiency curves as a function of the analyzed geometric variables, showing the behavior of all generated projects. The influence of the two variables, *N_pa* and *Fa*, on the multiphase pump efficiency is observed. Note that the highest efficiencies were obtained with a high number of splitter blades (*N_pa* = 13) and when the splitter blades are closer to the main blades internal surface (*Fa* = 0.45).

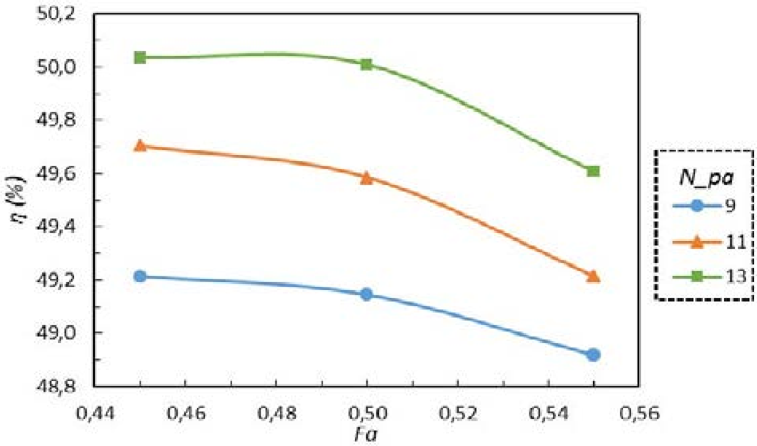

Figure 6. Efficiency curves vs. *N_pa* and *Fa*.

3.1 Influence of splitter blade number *N_pa*

From Fig. 6, it can be seen that the highest efficiencies were obtained with a high number of splitter blades (*N_pa* = 13). However, the influence of *N_pa* on the distribution of the gas volume fraction, GVF is shown in fig. 7, for different radial sections, from the hub to tip (for diffusers with the same *Fa*). In these images it is noticed that although the rotor presents the same distribution of GVF for all the stations (hub to tip), in the diffuser with greater number of splitter blades, there is less separation of phases.

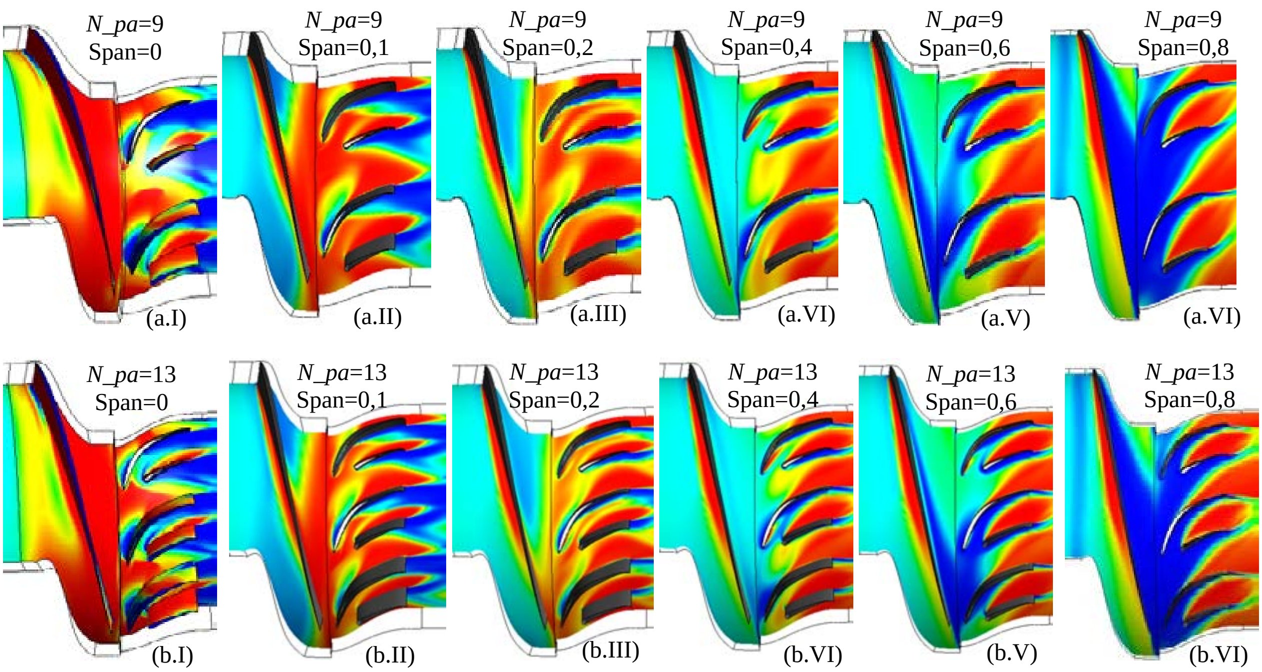

Figure 7. *N_pa* Influence on GVF distribution. a)*N_pa*=9 I)Span=0 II)Span=0,1 III)Span=0,2 IV)Span=0,4 V)Span=0,6 VI)Span=0,8. b)N_pa=13 I)Span=0 II)Span=0,1 III)Span=0,2 IV)Span=0,4 V)Span=0,6 e VI)Span=0,8.

3.2 Influence of the circumferential position of the splitter blade *Fa*

In Fig. 6, it is appreciated that the greatest efficiencies were obtained when the splitter blades are closer to the main blades internal surface, (*Fa* = 0.45). However the influence of *Fa* on the distribution of the gas volume fraction, GVF is shown in fig. 8, for different radial sections, from the hub to tip (for diffusers with the same *N_pa*). In these images it is observed that although the rotor presents the same distribution of GVF for all the stations (hub to tip), in the diffuser of splitter blades closest to the main blades internal surface, *Fa* = 0.45, a better distribution of phases.

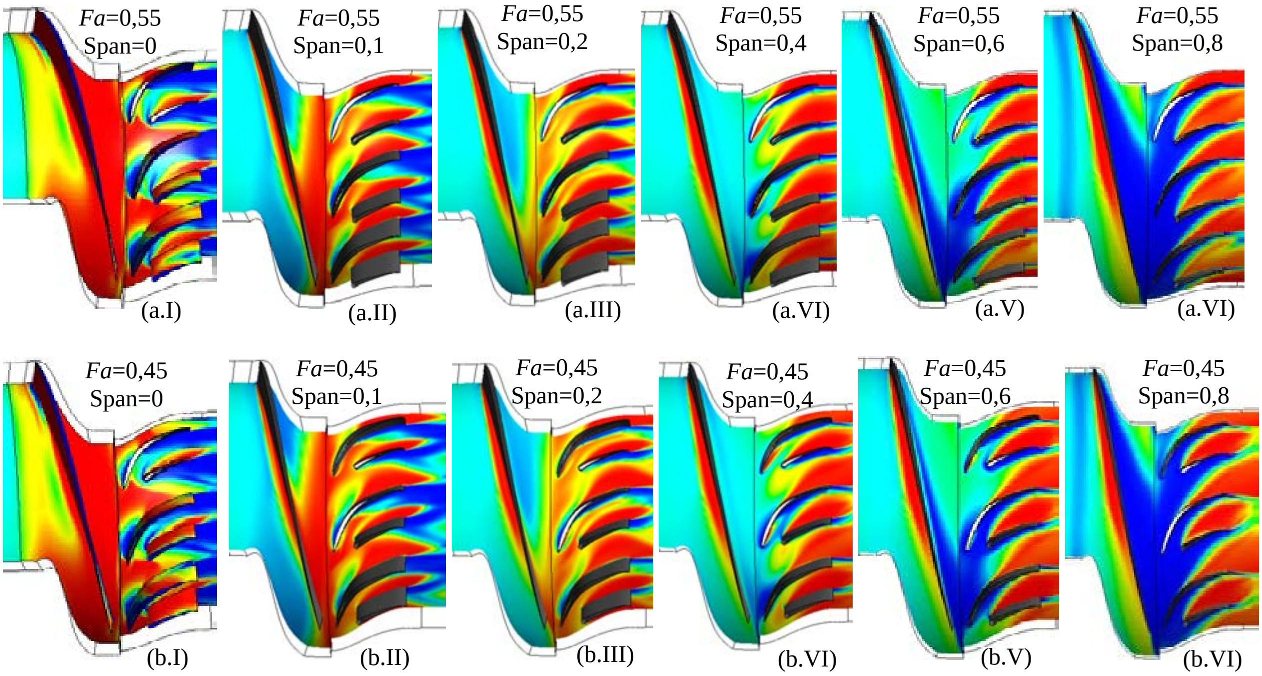

Figure 8. *Fa* Influence on GVF distribution. a)*Fa*=0,55 I)Span=0 II)Span=0,1 III)Span=0,2 IV)Span=0,4 V)Span=0,6 e VI)Span=0,8 e b)*Fa*=0,45 I)Span=0 II)Span=0,1 III)Span=0,2 IV)Span=0,4 V)Span=0,6 e VI)Span=0,8.

For future studies will be added optimization methodologies, using metamodeling techniques, to find the best length of the splitter blade.

4. CONCLUSIONS

The objective of the work was to improve the efficiency at the helical-axial multiphase pump stage, by inserting splitter blades into the diffuser, that is, to determine the proper position for different numbers of splitter blades. For this, CFD simulations were performed, which allowed the construction of the efficiency curves as a function of the analyzed variables (*N_pa* and *Fa*). These curves allowed to find the point of maximum hydraulic yield, η = 50.0374%, obtained for *N_pa* = 13 and *Fa* = 0.45, this value is within the range of this turbomachine in the literature.

5. ACKNOWLEDGEMENTS

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