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NUMERICAL INVESTIGATION OF CALCIUM CARBONATE SCALE AT SLIDING SLEEVE VALVES FOR WELL COMPLETION

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Abstract. *One of the concerns regarding the development of the Brazilian pre-salt cluster is due to scale issues. The huge carbonate reservoirs have a high potential for salt adhesion due to the precipitation of the crystals from the solution along with the production tubing as well as at the internal surface of the entire completion system. This paper presents a methodology for enhancing scale prediction studies applying Computational Fluid Dynamics (CFD) techniques to describe the fluid flow through a completion accessory. Then, an Euler-Lagrange approach is applied to simulate the transport of the crystals toward the adhesion surface. This approach coupled the CFD study to the Discrete Phase Method (DPM) and aims to estimate the scale rate at a Sliding Sleeve valve used as Inflow Control valve (ICV) in a well completion environment. The scale is modeled using the critical velocity of adhesion criterium, implemented in a user-defined function to modify the DPM boundary condition.*

Keywords: *Sliding Sleeve valve, Ansys Fluent, UDF.*

1. INTRODUCTION

The increase of demand and natural exhaustion of easier hydrocarbon reserves have been leading the oil industry to even more complex scenarios of oil exploration. Because of that, new technologies have been constantly demanded in order to maintain the oil and gas supply while the reservoir and production system is managed toward the production efficiency aim flow assurance as well as cost reduction. In the context of oil well completion, means as the process of equipping the well to make feasible the production or injection (Bellarby, 2009), the intelligent well completion is gaining notoriety. According to Hu et al (2016), Al-Khalifa et al. (2013), Denney (2010), Al-Zahrani et al. (2008), and Konopczynski et al. (2002) such a system is capable of collecting, transmitting and analyzing production and reservoir data, along with data from the completion system itself.

Bouamra et al. (2019), Guan et al., (2018), Joubran (2018), and Maciel et al. (2019) evaluate, using Computational Fluid Dynamics (CFD) techniques, equipment like inflow control valves (ICV) and discuss the scale trand in those systems. These authors point to the feasibility of CFD techniques application for the representation of fluid dynamics in well completion equipment and the evaluation of the scale.

This paper aims to present a methodology for enhancing scale prediction in completion equipaments. Computational Fluid Dynamics (CFD) techniques are applied to describe the fluid flow through ICV configuration. Then, an Euler-Lagrange approach allows to simulate the transport of the crystals toward the adhesion surface. This approach coupled the CFD study to the Discrete Phase Method (DPM), and to estimate the scale rate at a Sliding Sleeve valve used as Inflow Control valve (ICV) in a well completion environment. Along this process, the scale is modeled using the critical velocity of adhesion criterium, implemented in a user-defined function to modify the DPM boundary condition allowing to estimate the rate of adhesion along the inners surfaces of a conceitual ICV.

2. METHODOLOGY

The present methodology follows the further sequence of steps:

I Physical modeling, where the control volume of a conceptual ICV is built.

II Discretization and mesh independence study. In the first step, a suitable computational mesh is developed in order to accurately modeling the time and spatial scale of the liquid-solid flow. The second step comprises a mesh independence study to identify the most accurate and time-saving mesh for computational simulation.

III Development of a user-defined function (UDF) to modify the boundary condition of the DPM simulation in order to model the scale of $CaCO_3$ at the ICV inner surfaces.

IV Post-processing the results of the results to achieve the scale rate and identify the scale hot-spots as well as it quantification in each internal surface of the modeled control volume.

2.1. Cfd-Dpm Approach

The Euler-Lagrange approach allows modeling the fluid flow and the particle transport in a diluted system, i.e. volumetric fraction lower than 10 % (Ansys, 2017). The liquid phase is treated as a continuous phase, so the velocity and pressure fields are obtained from the solution of the mass and momentum conservation equations. The Lagrangian phase, that is, the dispersed phase, the velocity and the particle position are obtained individually for each particle from a differential equation raised from Newton's second law so describing the movement of a theoretic particle (Eq. (1)).

$$\frac{d\vec{u}_p}{dt}=F_D\left(\vec{u}-\vec{u}_p\right)-\frac{\vec{g}_i\left(\rho_p-\rho\right)}{\rho_p}+\vec{F} \qquad (1)$$

More details can be obtained in (Ansys, 2017).

The interaction between particles and the boundaries of the control volume leads to a boundary condition for Eq. (1).

The condition Trap (Ansys, 2017) corresponds to the total adhesion of particles in the boundary regions, defined, for instance, by a completion equipment surface walls. However, to better represent this interaction this condition was modified via UDF (User Defined Function). In the adhesion phenomenon it can be accounted the location and number of particles on the surface, which are used in the post-process step of the simulation resulting in the adhesion rate. At this point it is important to define the adhesion critical velocity, that is, the threshold velocity for the particle adherence on the surface. Above this velocity the phenomenon does not take place. Abd-Elhady *et al.* (2009) models the adhesion critical velocity of calcium carbonate crystals based on the maximum surface impact velocity. Above this velocity particles are elastically or semi-elastically reflected. The adhesion critical velocity is defined by Eq. (2).

$$v_c=1{,}184\left[\frac{\left(\frac{\Gamma}{R}\right)^5}{\rho^3 E^{i2}}\right]^{\frac{1}{6}} \qquad (2)$$

where Γ represents the bodies interaction surface energy and is worth 2.29 J/m² for the carbon-steel and the calcium carbonate. R is the particle radius ($23\,\mu m$, obtained experimentally). E^i corresponds to the Reduced Young Modulus obtained from Eq. (3) and ρ is the calcite density (2,970 kg/m³).

$$E^i=\left(\frac{1-\upsilon_1^2}{E_1}-\frac{1-\upsilon_2^2}{E_2}\right)^{-1} \qquad (3)$$

where E_1 and E_2 correspond to the calcium carbonate (0.35 x 10^{11} J/m²) and the carbon-steel (2.15 x 10^{11} J/m²). elasticity modulus, respectively. v_1 and v_2 represent the Poisson ratio of the calcium carbonate (0.27) and the carbon-steel (0.28), respectively.

Figure 2 represents the control volume, with somewhat simplifications, of a SSV model (reduced scale) tested in a laboratory flow-loop to quantify calcium carbonate deposition. For this test, the set up was arranged in the horizontal. Although it is not a usual arrangement, it works for validation purposes. Two gauges were placed in the SSV setup ends to measure the differential pressure in the valve.

The adhesion critical velocity acts as a filter, which the adhesion is only accounted if there is a collision between the particle and the SSV control volume surface with impact velocities lower than the threshold value. The following steps were performed in order to evaluate the effect of the computational grid discretization on the scale rate accuracy:

i Initially two different tetrahedral computational grids were generated and then converted into a polyhedral grid. Such grids were obtained considering a discretization of a suitable boundary layer with five prismatic elements. The calculation of the first layer takes into account the $k-\varepsilon$ turbulent model, the average fluid velocity, the parameter y^+ of 30 and the hydraulic diameter of the cross section. The refinement parameter is the maximum thickness of the cell, being 10^{-4} m for the fine grid and 8 x 10^{-4} m for the course grid (see Fig. 3).

ii Two simulations are performed, both with the target of evaluating the effect of the mesh in the quantification of the adhesion through the UDF. Thus, it is considered for those tests the critical velocity of 0.036 m/s.

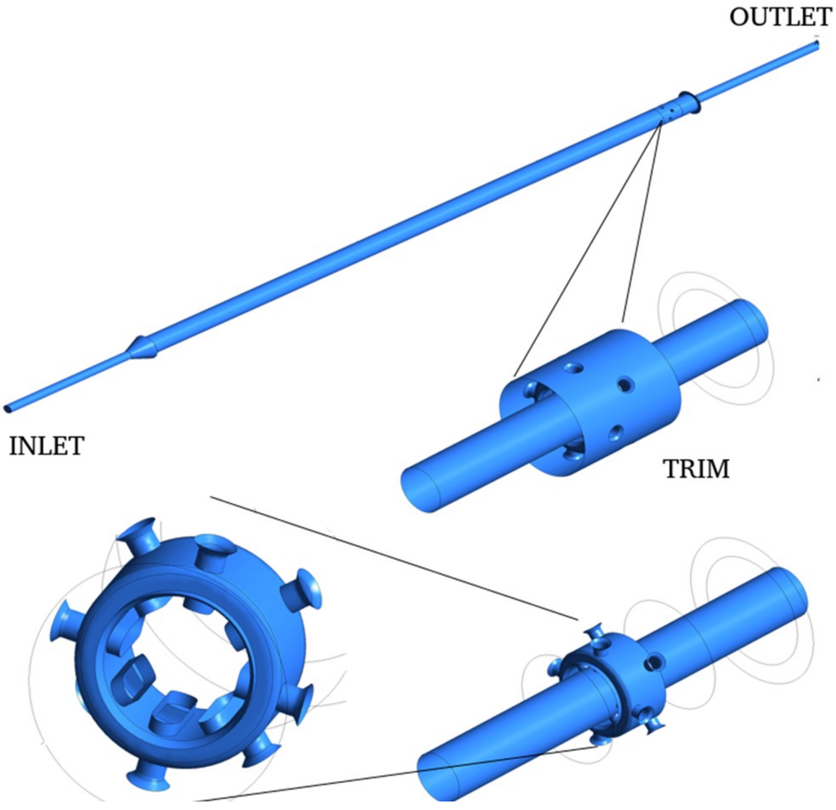

Figure 1. Control volume of the simulated SSV close of the TRIM region.

After the selection of the suitable computational mesh in terms of accuracy, precision and computational cost, the computational study is then continued. To fit the appropriate simulated scale rate to that one obtained from the experimental test it was proposed a sensitivity analysis varying the adhesion critical velocity. The critical velocity of 0.018 m/s is obtained from Eq. (2) considering the calcium carbonate parameters according to (Abd-Elhady *et al*., 2009).

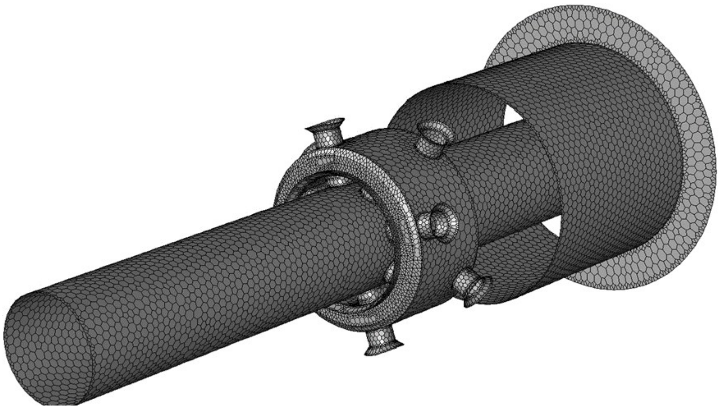

Figure 2. One of the SSV computational mesh used in the mesh convergence study.

3.1. FLUID DYNAMIC ANALYSIS

Investigate some aspects of the fluid dynamic within the control volume is of fundamental importance for the understanding of how the flow interacts with the $CaCO_3$ crystals recently precipitated from the solution. More details on the interaction between these particles and fluid in the context of transport, deposition, adhesion and fouling erosion are presented and discussed by Collins (2002), Maciel (2017), Cosmo (2013) and Jamialahmadi and Muller-Steinhagen (2001).

According to Ansys (2017) and Nichols (2008), for turbulent k-Epsilon modeling the computational mesh must be specially designed so that there is the correct discretization of the boundary layer. More specifically, it is necessary to dimension the thickness of the first each of elements in the control volume wall using the methodology presented by Ansys (2017) and Fox and Mcdonald (2000), and summarized in LEAP CFD (2013) for the k-Epsilon modeling Achievable, setting Y^+ equal to 30, the geometric conditions of Fig. 1 and hypotheses of Tab. 1.

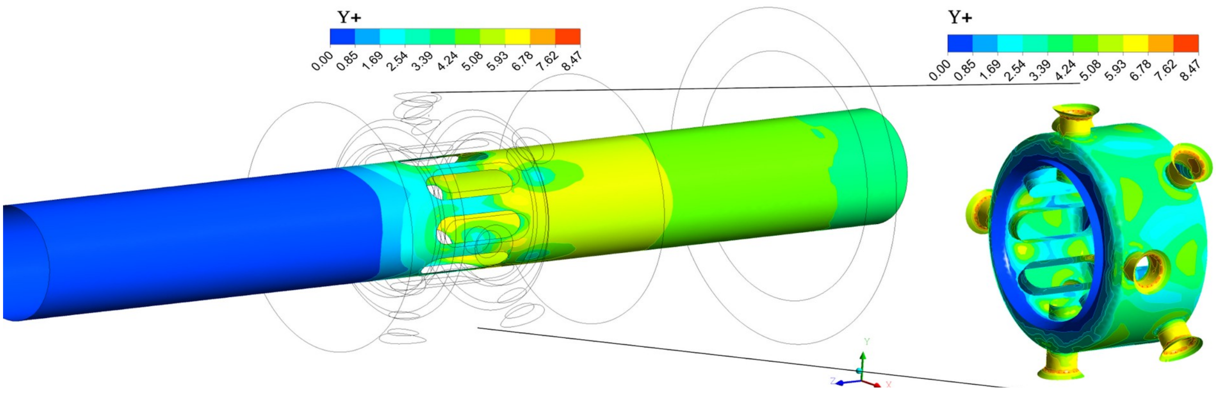

Figure 3. Y + contours in the modeled SSV regions.

Figure 3 shows the profile of the Y^+ metric for two important regions of the control volume. It is observed that its maximum quantity is 8.47, indicating that the current computational mesh is suitable for the turbulence model used with respect to the representation of the turbulent boundary layer.

In Fig. 4., the velocity magnitude field plotted in the plane is observed (X = 0, Y, Z). Its analysis shows the complexity of the internal fluid flow to the region called TRIM, which, having a very reduced thickness in the SSV, is a critical area in terms of the flow guarantee. Low-speed zones are observed approaching a high-speed zone, such disparity is an ideal scenario for the induction of a local pressure and speed gradient, causing the transport of fouling crystals that are in the fluid body by diffusion mechanisms. turbulent to the internal surfaces of the SSV.

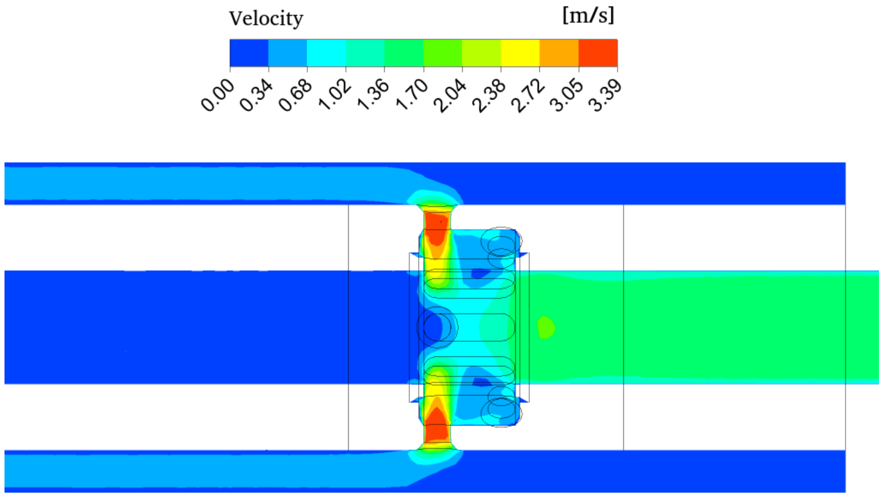

Figure 4. Magnitude profile of the fluid velocity plotted in the plane (X = 0, Y, Z).

Through the analysis of the turbulent intensity profile (Fig. 5) it is possible to confirm that the passage of the fluid through the SSV, under the simulated conditions, is able to modify the flow regime. This effect is quite evident in the TRIM region and downstream. This outcome indicates a possible influence of the turbulence in the crystal transport to the adhesion surface.

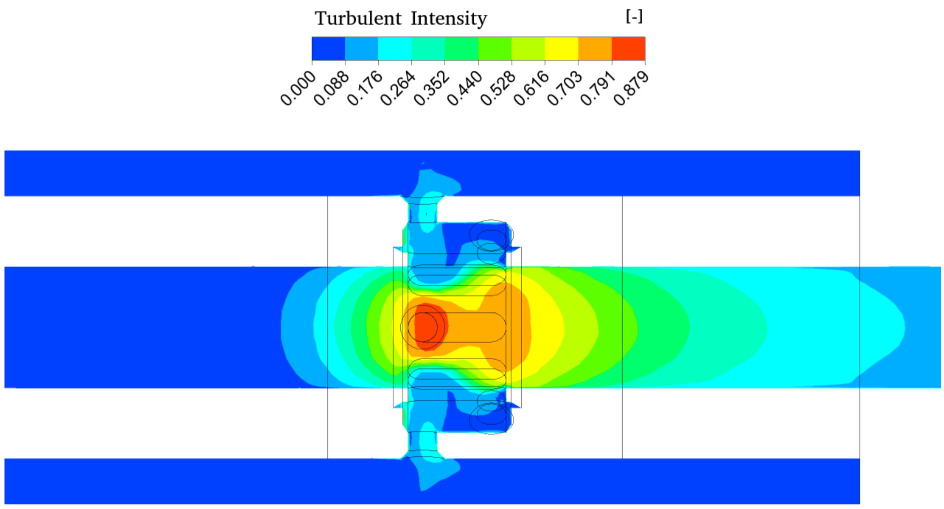

Figure 5. Turbulent intensity profile plotted in the plane (X = 0, Y, Z).

4.1. EMPIRICAL ADJUSTMENT OF THE CRYSTAL SCALE RATE

Table 1 shows the estimated scale rate for various numerical values of the critical adherence velocity. These results sport that the adhesion critical velocity influences the scale rate in a significant manner.

Also, the observation might be applied, along with experimental data show the correct scaling rate, and regulating the simulated scale rate to match with the experiment's quantitative results. In other words, the average phenomenon of adhesion observed and measured in an experimental ICV's might be a suitable support to simulate the real conditions of production in which there is a fluid dynamic equivalence between the analyzed scales.

Table 1. Results of estimated scale rate for critical velocity of scaling.

Critical adhesion speed [m/s]	Simulated Time [s]	Scale rate [kg/s]
0.018	226.612	2.3727E-07

0.036	131.538	2.2910E-07
0.042	154.591	3.8541E-07
0.056	127.981	5.0190E-07

4.2. QUALITATIVE EVALUATION OF THE SCALE HOT-SPOTS AT THE ICV INTERNAL SURFACES

The system analyzed assumes a critical velocity of adhesion of 0.042 m/s, and injecting 1.37E-5 kg/s of $CaCO_3$ crystals of $23\,\mu m$ of diameter, and with the fluid flow rate of 600 L/h. Then, the results allow to evaluate the scale hot-spot as well as to quantify the rate of scale in each inner surface of the valve (Fig. 3).

Although these deposition sites are isolated, their growth can lead to some future possible operational problems, partially or completely reducing the area available to the flow. In the case of partial decrease, there is an increase in the localized pressure drop due the scale at the SSV inner walls, committing the oil production. Another aggravating factor is the locking of the moving parts in this type of valve, which acts by sliding a sleeve on an inner shirt. This blockage would make the production management system of a given zone in the well unfeasible.

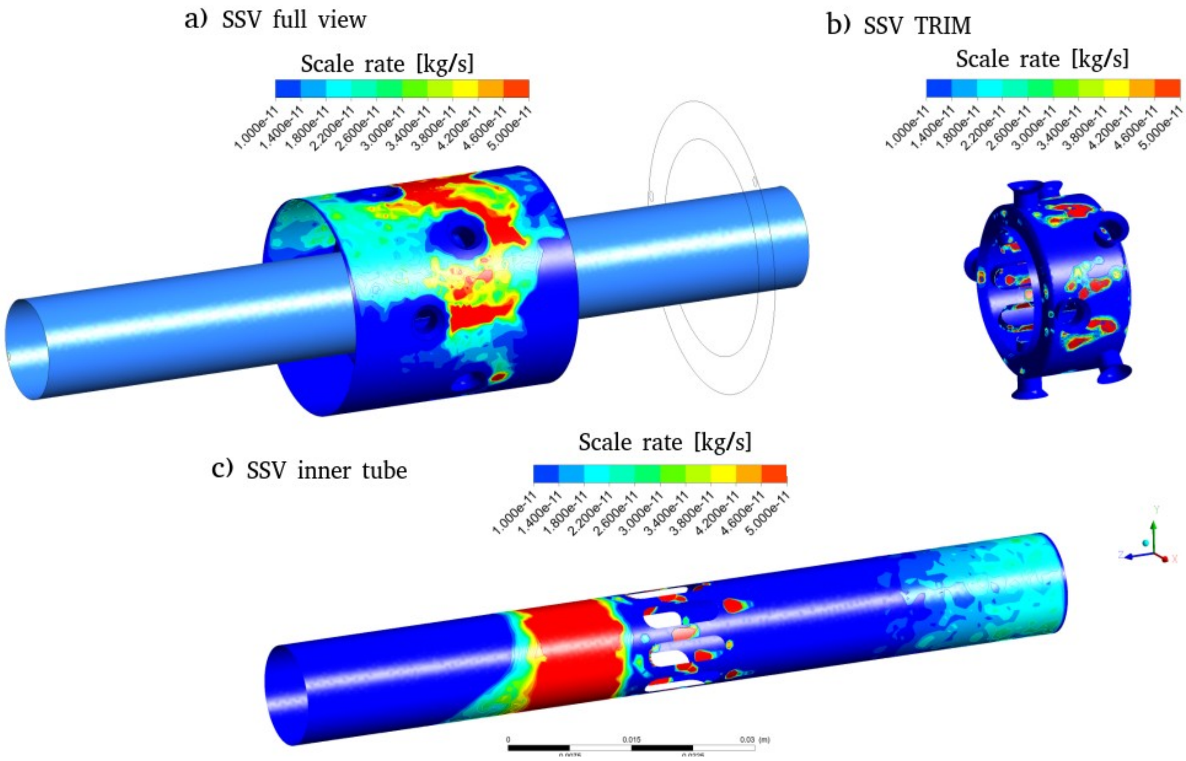

Figure. 6. Simulated scale rate at the SSV internal surface [kg/s] (a, b and c).

5. CONCLUSIONS

The current methodology shows suitable for the estimation of the scale rate on the inner parts of the modeled ICV, indicating that this strategy could be applied to the industrial design of completion systems like the Brazilian pre-salt well completion where the scaling is an actual faced problem.

The results also show that it is possible to apply a simple methodology, adjusting a constant parameter to calibrate the estimated scale rate in a well completion valve. Thus, through quantitative data of $CaCO_3$ scaling in a slide sleeve valves, it is plausible to adjust the critical velocity so that there is a matching of the simulation results with the evaluated experimental results allowing a numerical investigation of the scaling on real systems for industrial purposes.

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7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.

8. ACKNOWLEDGMENT

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