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Qualification tests for ICV cycling and scale formation

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Abstract
Intelligent completion systems, designed to reduce cost and maximize oil output, do not always have inhibition injection lines for scale control in downhole equipment. The oil industry has reported scaling in downhole Internal Control Valves (ICV) that can damage the valves' key actuation features, leaving them inoperative and permanently stuck. Traditionally, scale prediction relies on thermodynamic and kinetic analysis but neglecting fluid dynamic effects over precipitated crystals. This paper details a Euler-Lagrange approach for modeling the liquid-solid turbulent flow with adhesion to simulate of scale formation in ICVs. Numerical simulation is performed through the Finite Volume method coupled with the Discrete Element Method (CFD-DEM). Results concern the accumulated mass in fouling hotspots and the transient pressure uptrend due to flow blockage. The paper also describes a Lagrange approach for modeling the actuation (valve cycling) of ICV with scales deposits. DEM simulates the valve closing movement and assesses the interaction of the movable parts with the adhered particles, indicating whether the available driving force is capable of wiping out the deposit and reaching the fully closed position. The methodology and results presented are helpful for valve qualification in terms of scale formation potential and reliability of valve actuation mechanism.

Keywords
scale formation; calcium carbonate; internal control valve; cycling; DEM; CFD-DEM.

Introduction
The Brazilian pre-salt reservoirs have shown scale issues with very low water cut measures. Calcium carbonate scale has been observed even at the beginning of the well lifespan, which indicates the need for significant care concerning flow assurance and reliability of the valves [1].

Modern multiple-zones completion systems use remote-controlled valves to control the production flow rate in each zone [2]. The valve itself is a scale-prone spot for a number of reasons [3]. First, the choke has a local pressure drop that may trigger the precipitation of calcium carbonate as a consequence of carbon dioxide dissolution. Second, the choke concentrates the flow and previously precipitated crystals in the bulk, bringing crystals closer and supporting the formation of agglomerates. Furthermore, it is not always possible to inject chemical inhibitors in all the production zones in some sort of cableless completions, leaving downhole equipment unprotected.

Issues regarding scale deposition, or fouling, arise mainly due to flow assurance, as the deposits may increase the pressure drop of the production system. In fact, a local deposition on a valve choke would lead to relevant production losses and require expensive workover joins for its remediation. Moreover, the fouling may damage movable parts and eventually let valves stuck permanently in the open, or close, position, reducing the reliability of intelligent completion system.

In such scenario, Petrobras has developed new scale forecasting strategies with the use of numerical simulation of the field flow. Recently, Maciel et al. [4] presented results using the Computational Fluid Dynamics and the Discrete Phase Model (CFD-DPM) approach to model the transport of calcium carbonate crystals until the adhesion on the Inflow Control Valve (ICV) walls. Bouamra et al. [5] developed a methodology to evaluate the risk of calcium carbonate deposition along the wellbore production string focused on the understanding the scale in an ICV. The CFD also features the potential of being coupled to the Discrete Element Method, CFD-DEM [6], empowering the method by computing contact particle interactions (collision, friction and adhesion) with the formation of agglomerates and deposits. Poletto et al. [1] have presented the liquid-solid turbulent flow with adhesion to simulate scale deposition in Sliding Sleeve Valves (SSV). They investigated the influence of particle size distribution and solids concentration.

Considering the diversity of commercially valves, such as the multi-position internal control valve (ICV) which allows adjusting the flow and opening-closing mechanism, each model has a unique behavior under a scaling-prone scenario. Therefore, the company purchasing the completion equipment can ask the supplier to meet a technical specification as a criterion for acceptance.

The present paper proposes the application of numerical simulation for the qualification of commercial intelligent completion valves regarding inorganic scaling. The fouling process numerical simulation, carried out through liquid-solid two-phase flow models such as Computational Fluid Dynamics coupled to the Discrete Element Method (CFD-DEM), provides transient results for the tendency of pressure increase and accumulated mass. The DEM simulation of fouled valve cycling compares the force required to break down carbonate deposits with the mechanical force available to actuate the valve. The technical specification details the set-up procedure for a reference case, explaining how to obtain the simulation domain, generate the mesh (if necessary), apply initial and boundary conditions, and run the simulation with the proper model, yielding meaningful data for the equipment characterization. The technical specification establishes criteria for the suppliers' equipment to meet, allowing the contracting party to purchase valves focusing on increasing the completion system reliability for inorganic scaling.

Methodology for qualification tests

The framework for the technical specification comprises two tests: Test 1 is the CFD-DEM numerical simulation of the scaling process in valves and Test 2 refers to the DEM numerical simulation of fouled valves cycling. For the contracting party, the main value generation is the possibility of not only selecting valves according with acceptance criteria but also accessing standardized information in terms of scale-related issues.

•Test 1: CFD-DEM numerical simulation of the scaling process in valves;

•Test 2: DEM numerical simulation of fouled valves cycling;

•Value generation for the contractor:

i. Selecting valves as a function of acceptance criteria;
ii. Standardized response variables for qualification.

Each test comprises two steps: Step 1 is the reproduction of benchmark results, and Step 2 refers to the replication of the procedure for the supplier's valve.

The main idea of Step1 is providing an extensive and detailed procedure for the simulation set-up. For the sake of verification, the supplier runs the simulation and compares the results with the benchmark. Therefore, Step 1 works as either an auxiliary step for the adjustment and verification of the supplier's simulation or to provide credibility to the results. In Step 2, the suppliers must replicate the simulation procedure with the same flow rate and solid concentration in the valve geometry. The valve results are then compared with acceptance criteria established in the technical specification in terms of allowed pressure increase.

The main aspects are depicted in Figure 1, highlighting important points of the verification and qualification tests and steps.

Results and Discussion

The suggestion of using the CFD-DEM for the simulation of the turbulent liquid-solid flow with adhesion comprehends a robust 4-way coupling scheme that works well with all turbulence models and complex geometries. Benchmark results for the CFD-DEM are exemplified in Figure 2 for a 45º

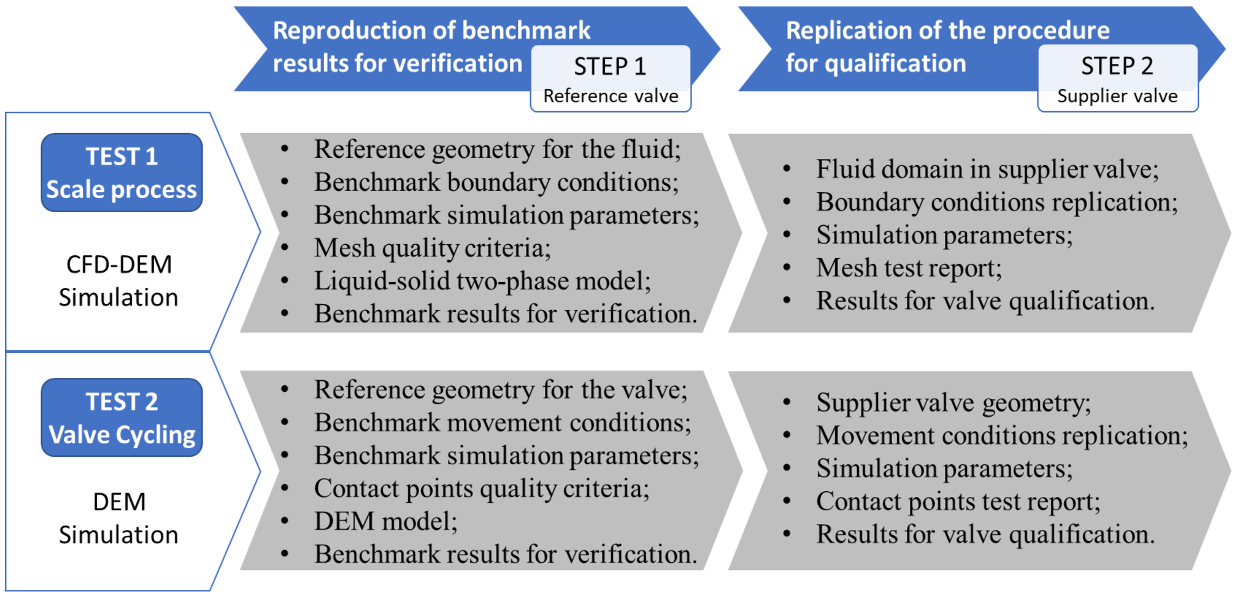

Figure 1. Summary of testes and steps for valve qualification.

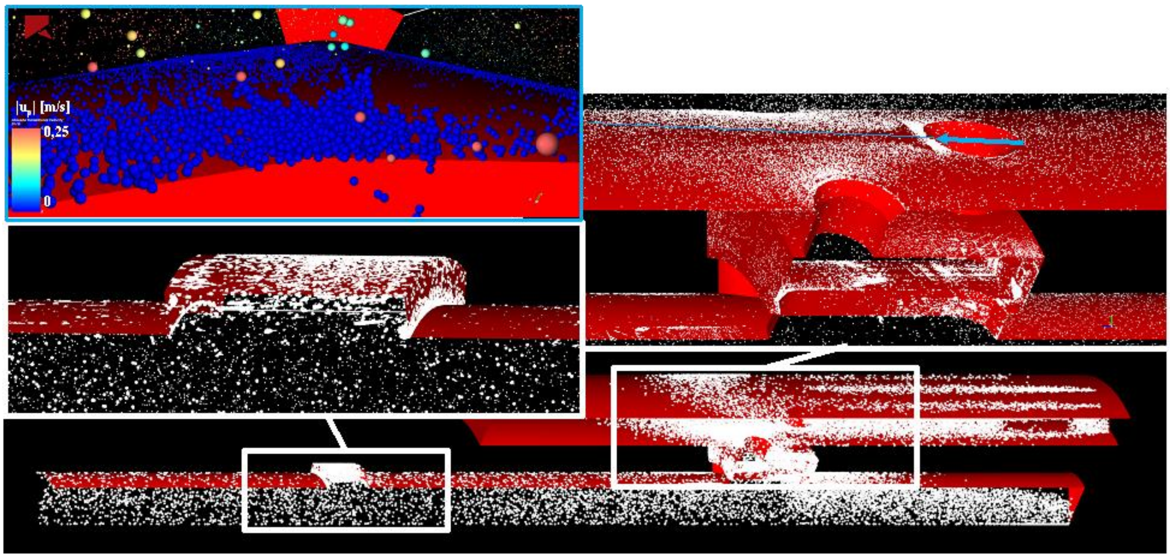

Figure 2. Example of benchmark results for scaling process with the CFD-DEM (Test 1).

slice of the reference geometry. Particles (white dots) represent the precipitated carbonate crystals in the bulk that may interact with each other, building an agglomerated that eventually adhere to the walls. The output response, exemplified in Figure 3 (a), concerns the accumulated mass in the valve as a function of time, computed by the sum of all the particles adhered to the wall. In fact, the CFD-DEM simulation runs for just 5s, but a curve fitting yields a function to represent the data. The function m(x) is then used to compute the total mass at the end of 2h, reaching 12,73g. The pressure over time, shown in Figure 3 (b), also has a linear uptrend for the 5s simulated. Again, linear regression to obtain the curve fit with the function used to calculate the pressure in 2h reaches 2.68 bar.

Nevertheless, suppliers also may use other liquid-solid flow models providing all the documentation and, most importantly, reproducing accurately the benchmark results. Following the conclusion of Step 1 with the reproduction of the benchmark results, Step 2 follows with the replication of the methodology with the supplier's valve in place.

Whilst Test 1 focuses on the fouling formation process, the purpose of Test 2, shown in Figure 4, is to evaluate the valve cycling capabilities in the presence of particle deposition. The valve cycling is an operation that departs from the fully open position, reaches the full close position and, finally, opens the valve again. The presence of inorganic scale, filling gaps or depositing on sliding guides, might interfere with the cycling process. The available mechanical power must break up the deposits to free the valve movement. The Discrete Element Method is suitable for the simulation of the cycling of fouled valves, since it is possible to represent the fouling as a deposit of micro-sized particles with a prescribed adhesion force. The movement of the valve movable part is configured as free-body translation with a prescribed force matching the valve availability of the mechanical (or electrical) actuator. As the simulation goes, it is possible to track the position of the valve movable part and identify whether it goes all way up, reaching the final course.

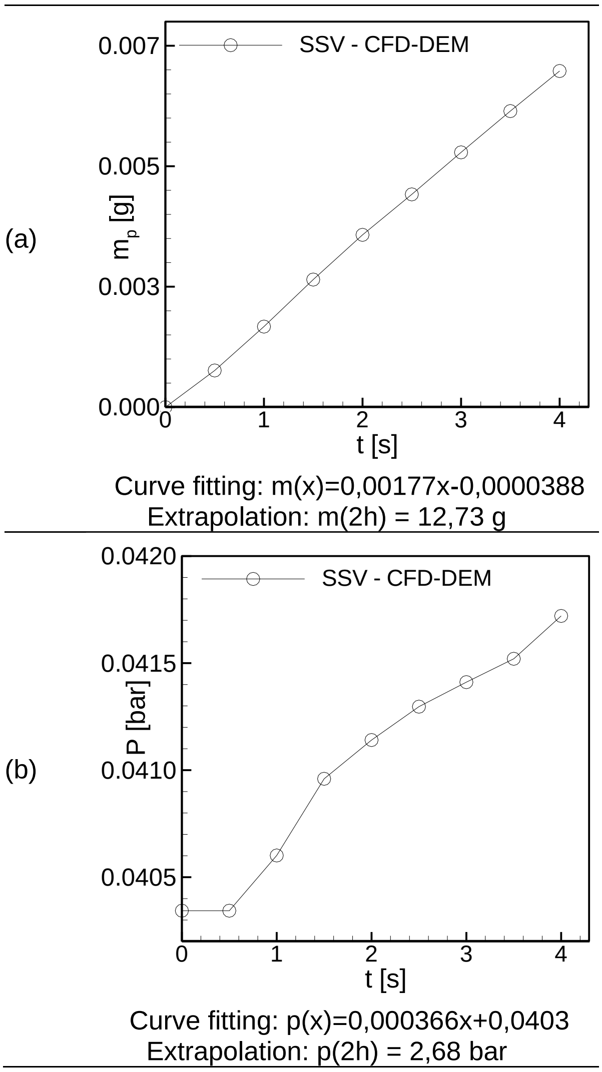

Figure 3. CFD-DEM benchmark results: (a) accumulated mass and (b) pressure increase, both as a function of time and the extrapolation function used to compute the total mass after 2h.

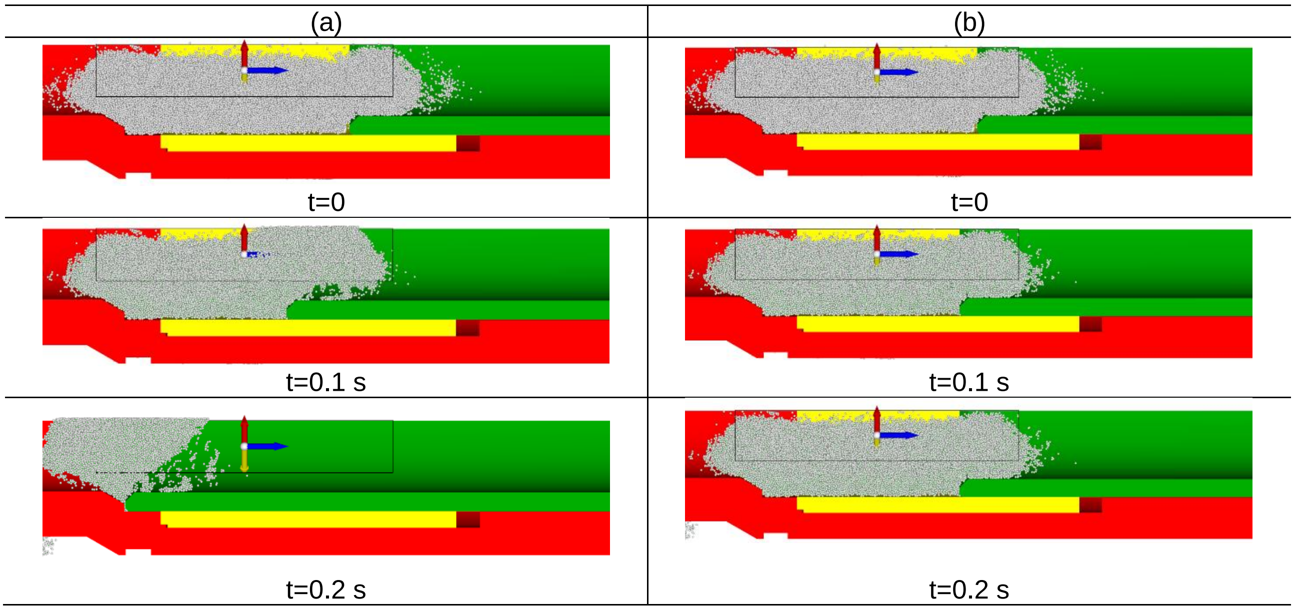

Figure 4. DEM numerical simulation of fouled valves cycling: (a) benchmark results for a valve whose movable part (in green color) fully closes with available force of 1250N, wiping out the deposit layer; (b) example of a valve with available force of 125N whose movable part is incapable of breaking the deposit and gets stuck in open position.

The DEM simulation (Test 2) consists in applying a constant force to the valve movable part to observe whether it reaches the final course and breaks all the adhered particles. The benchmark results for the reference valve shown in Figure 4.(a) refers to a force of 1250N applied to the movable part. At the initial instant, the valve is fully opened, at t=0.1 s the movable part reaches halfway through the sliding guide, and finally, for t=0.2 s, the movable part moves all the way of the sliding guide, wiping out all the deposits away from the valve. Figure 4.(b) exemplifies a valve with 125 N of available force that is unable to detach the particles. In fact, the movable part is at the same position for 0.1 s and 0.2 s, indicating that the part is stuck due the presence of the deposits.

Conclusions

The present paper discusses the use of numerical simulation for the scaling tendency assessment in qualification procedures. The procedures may be used in technical specification stages allowing for the contractor to select equipment as a function of an acceptance criterion. The qualification comprises two tests: i) CFD-DEM numerical simulation of the fouling process in valves, and ii) DEM numerical simulation of fouled valves cycling. Test 1 simulates the liquid-solid turbulent flow with adhesion for the representation of fouling in valves by the application of Euler-Lagrange models. The main response variables are the mass accumulation and the pressure increase. Test 2 simulates the process of cycling the valve, bringing the movable part from the fully open position to the fully close position, in the presence of a particulate deposit with prescribed adhesive force. If the force available for the mechanical actuation is enough to wipe out the deposit and fully retract the movable part, the valve is qualified.

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Responsibility Notice

The authors are the only responsible for the paper content.

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