Evaluation of the Shutdown Time of Subsea Pipeline for Oil Transportation

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Introduction: The maintenance plan or rush-to-repair of a subsea pipeline for oil transport may result in the shutdown of the line, in other words, may stop the flow of fluid. During the shutdown, the temperature of the oil tends to decrease continuously, and the heavy molecules tend to crystallize and suspend in the oil, which increase the viscosity of the oil, and even form a paraffinic compound or freeze the production line.

Once the line is frozen during the shutdown, it is necessary to use complex time consuming procedures and expensive methods to unlock it and restart the production. Therefore, it is important to conduct experimental and computational studies to analyze and better understand the behavior of lines submitted to a shutdown of the production and the evaluation of the time required to reach critical freezing temperatures (shutdown time), in order to present a safe, effective and economic proposal for the restart of the production.

Figure 1. Analyzed subsea pipeline (Bouchonneau *et al.*, 2010) and examples of paraffinic encrustation

This work was carried out in order to analyze the temperature distribution in an insulated pipeline during its restart (transient state), work (steady state) and shutdown, and estimate the time required to reach the critical temperatures of approximately 40 and 25 ºC during the shutdown.

Simulations with the Finite Element Method (FEM) were performed with COMSOL Multiphysics® to compare numerical results with those obtained experimentally and numerically in the literature. Therefore, one expects to find values consistent with the actual obtained in the subsea oil industry, and characterize insulated pipelines in service conditions.

Computational Methods: The computational geometry, finite element mesh and boundary conditions of the improved model used to study the thermal insulation pipe multiple layers are presented in Figure 2. This model follows the conditions described by Bouchonneau *et al.* (2010), which are based on following hypotheses: internal convection between the air and the inner surface of the prototype, external convection between the water and the pipeline, hydrostatic pressure of the water on external surfaces, and internal heat flux. Besides, the model consider the presence of the connector to link the experimental sensors, which lies at the center of the PTFE cap and is responsible for much of the longitudinal heat loss.

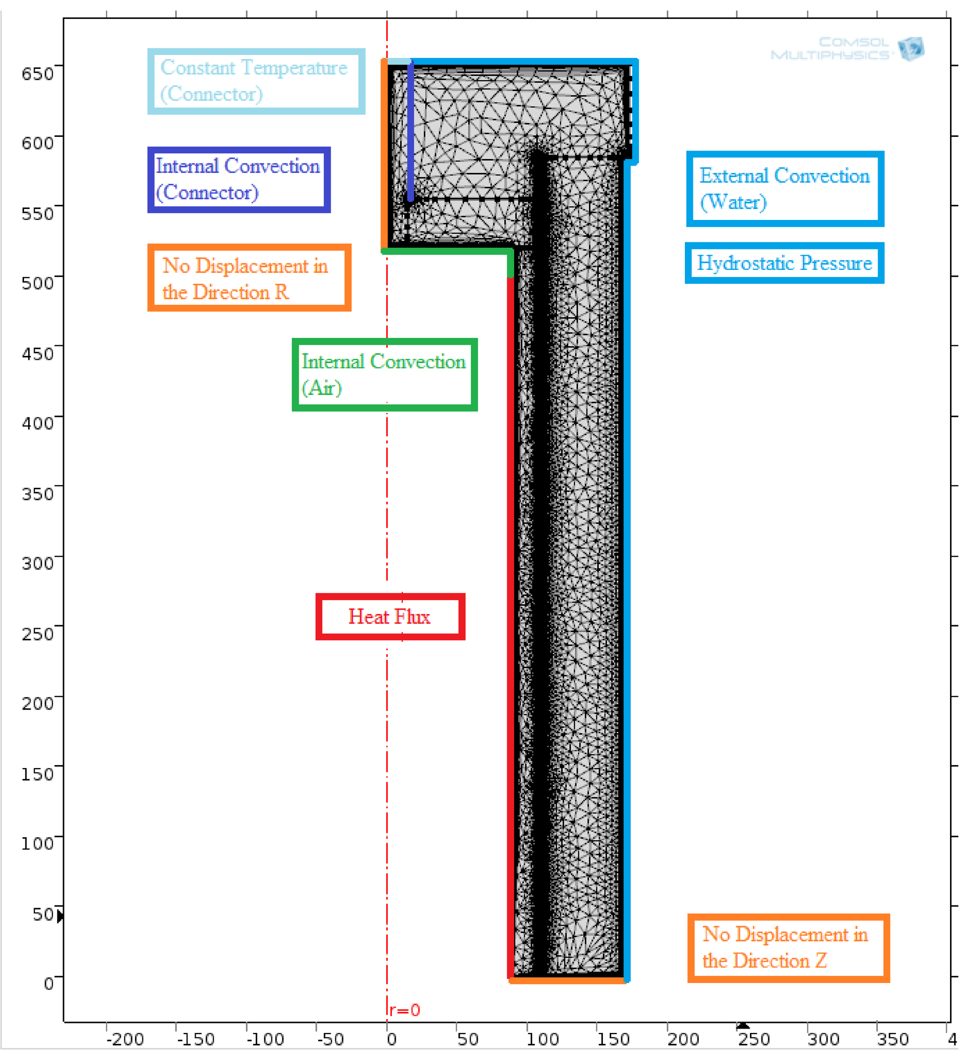

Figure 2. Geometry, mesh and boundary conditions of the improved model

Depending on the test and step, different experimental conditions are applied to the structure. Therefore, the boundary and initial conditions of the model vary and are presented in Table 1. Initial temperatures of 240 W models are evaluated from the result of the steady state in 120 W models.

Experimental Step	Pressure (bar)	Heat Flux (W/m²)	Initial Temp. (˚C)	Water Temp. (˚C)	Coefficient of External Convection - h_e (W/m².K)	Air Temp. (˚C)	Coefficient of Internal Convection - h_i (W/m².K)	Constant Temp. in the end of Connector (˚C)	Coefficient of Internal Convection in the Connector - h_{i2} (W/m².K)
Test A/ Step 2	1	210	15,36	15,25	125	30	3	15,25	0,29
Test A/ Step 3	1	420	-	15,3	155	60	3,7	15,3	0,29
Test B/ Step 3	300	210	16,62	16,75	170	30	3	16,75	17,6
Test B/ Step 4	300	420	-	17,27	230	60	3,7	17,27	96,7

Table 1. Boundary conditions described by Bouchonneau *et al.* (2010)

Results: First, the stationary state or operation state of the pipeline with multilayer insulation was simulated, resulting in multiple charts for each test step. Figure 3 shows the distributions of temperature, displacement, stress, and the deformed shape resulting from the simulations for the case of 300 bar and 240 W.

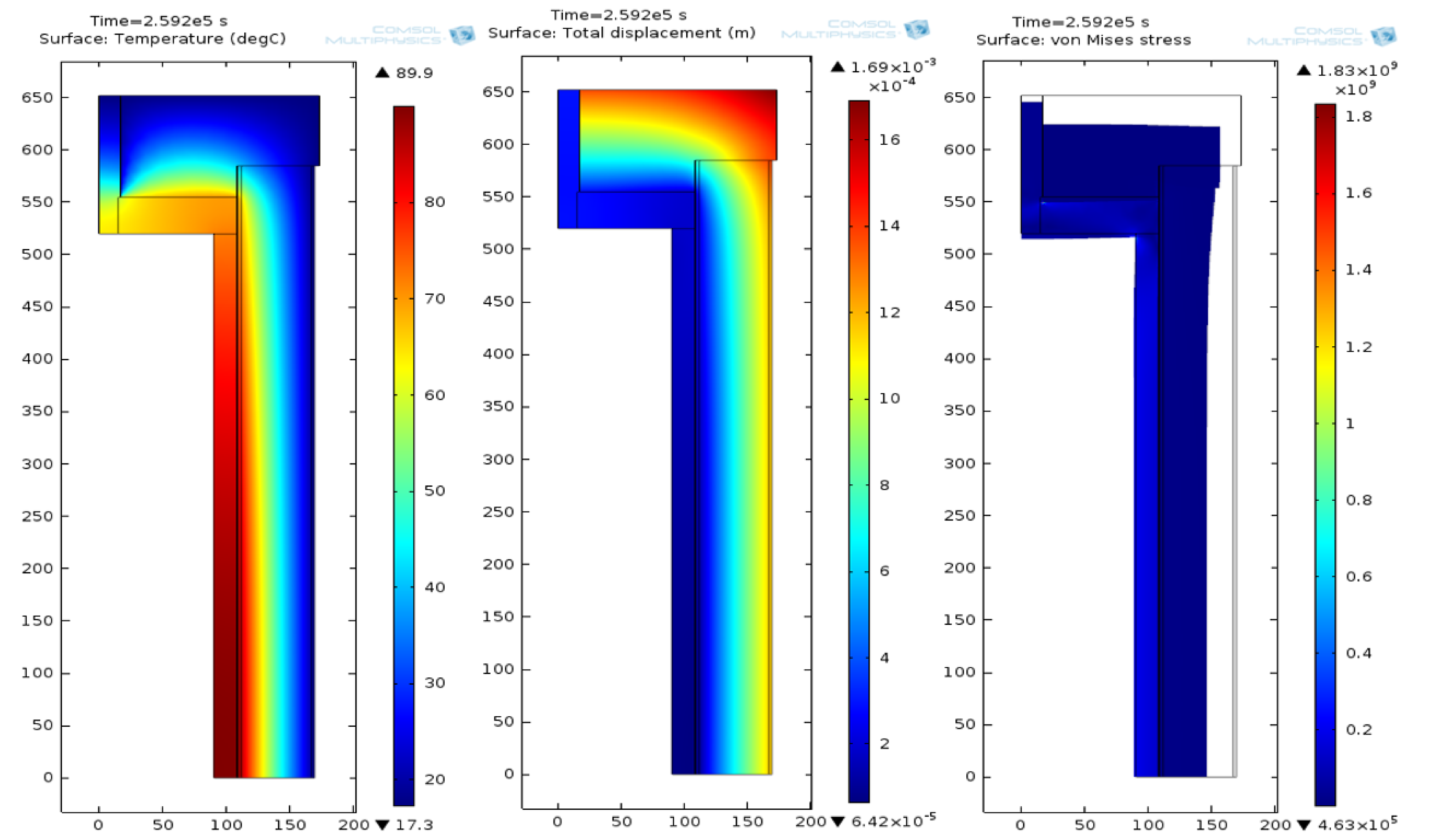

Figure 3. Results of the steady state of the improved model (deformed scale 200:1)

Based on those results, further simulations were performed to evaluate the behavior of the structure during a shutdown, i.e. when the internal heat flow is suddenly turned to zero. In order to evaluate the critical time of shutdown of the insulated pipe, simulations with no internal heating power were performed to models after completion of the stationary state obtained with 240 W, 300 bar. The results of simulated shutdown are presented in Figure 4. These curves enable to estimate the critical time to reach the shutdown temperature of 40 ºC, when the intensification of formation of paraffinic compounds occurs in the line, and at a temperature of 25 ºC, when freezing of the line occurs.

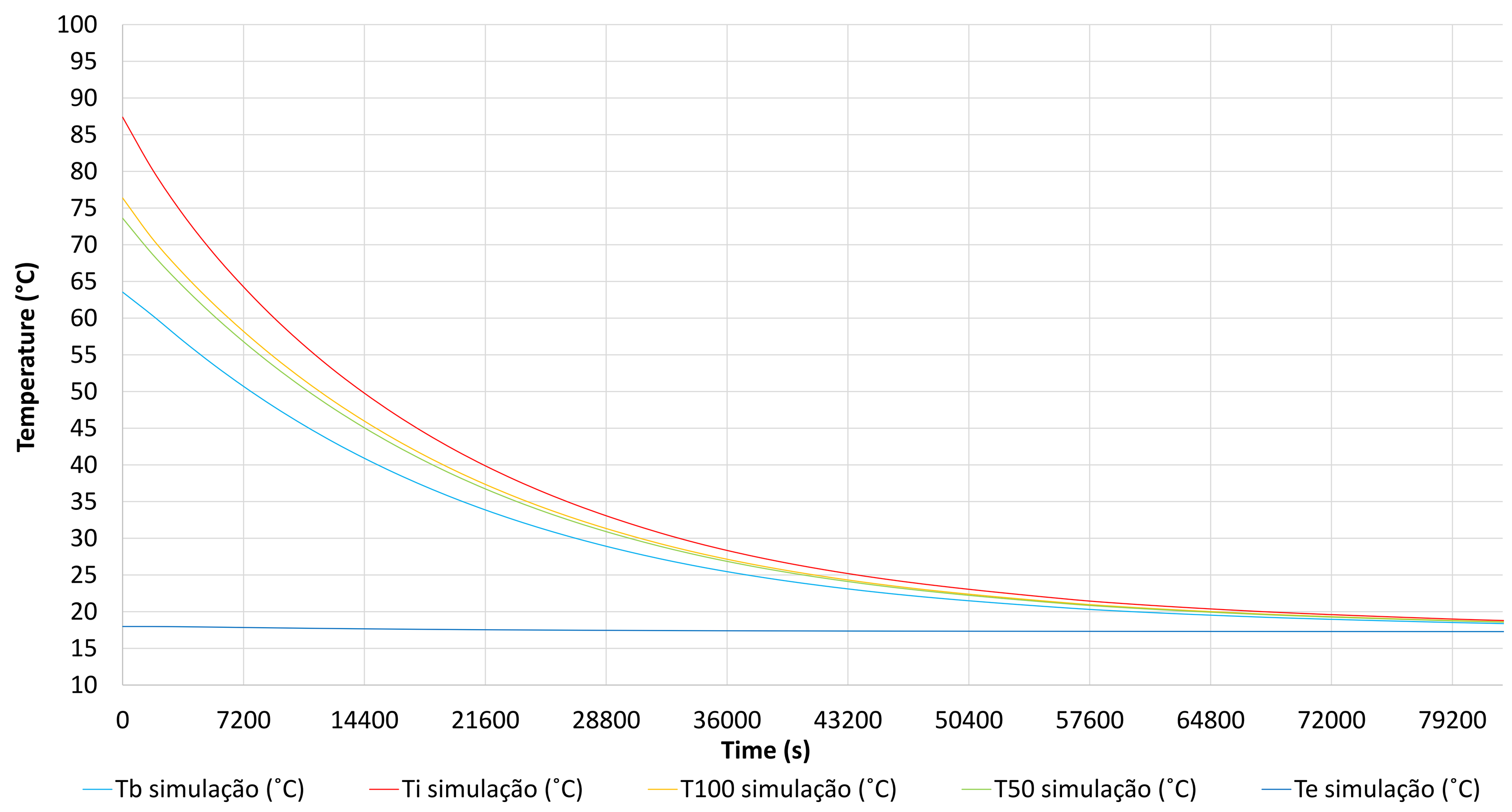

Figure 4. Results of the shutdown in the case of 300 bar and 240 W

Conclusions: Based on numerical results, it could be concluded that after about 6 h of shutdown occurring in such a line of subsea oil transport, intensification will occur in the formation of paraffinic compounds, which could complicate the process of restarting the line. After about 12 h, beginning of freezing will occur in the line, preventing traditional methods of restart, based on the injection of high-pressure fluid. Therefore, such arrangements should be made in the maintenance plans and restarting of subsea lines, to ensure that the procedure taken is safe, effective and economical. COMSOL show to be a great tool to obtain rapidly estimations of critical shutdown times in pipelines, which could thus help to make quickly safe decisions about maintenance and restarting procedures.

References:

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