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Evaluation of the Shutdown Time of Subsea Pipeline for Oil Transportation

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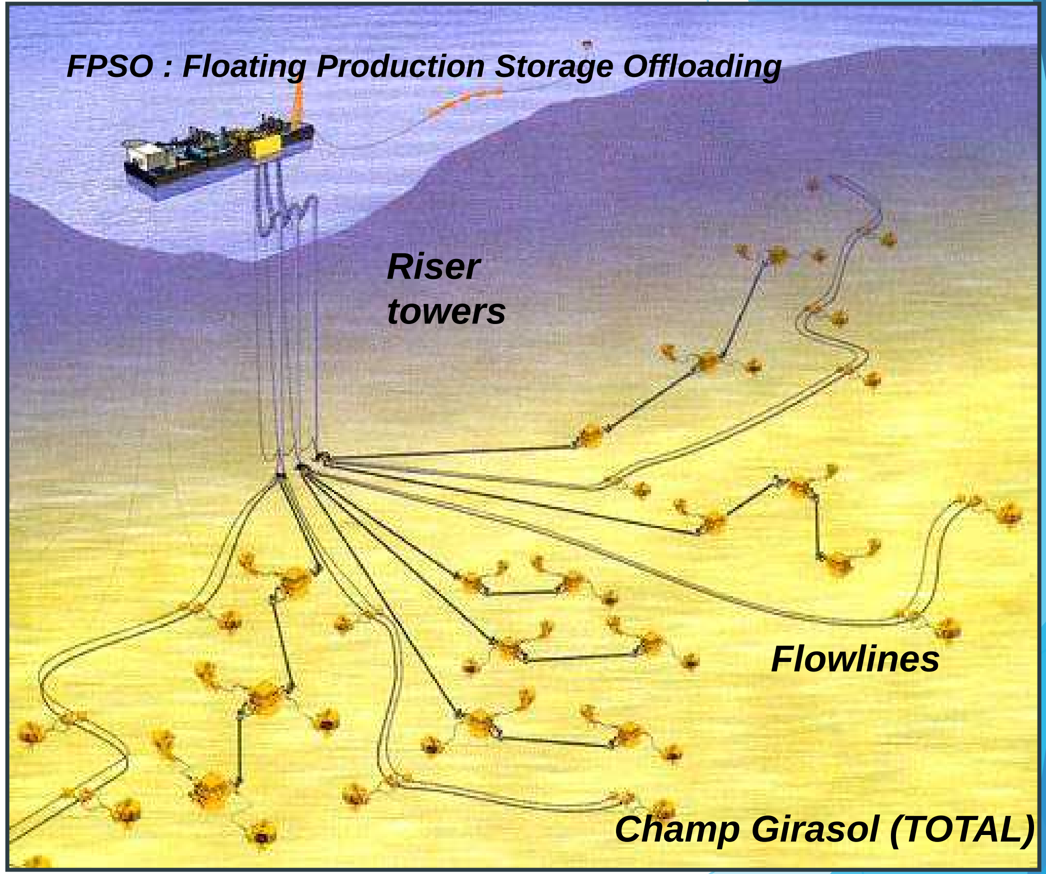
Introduction

- The ultra-deep waters (up to 3000 m) and the "pre-salt" are the next frontier for exploration of the offshore oil in Brazil.
- For this, the use of pipelines, which have long-term resistance (durability about 25 years) to the mechanical and environmental conditions, is required.
- One of the most important points is the thermal insulation of the structure to prevent hydrate and paraffinic compound formation inside the pipe, which affects the fluid flow.



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.

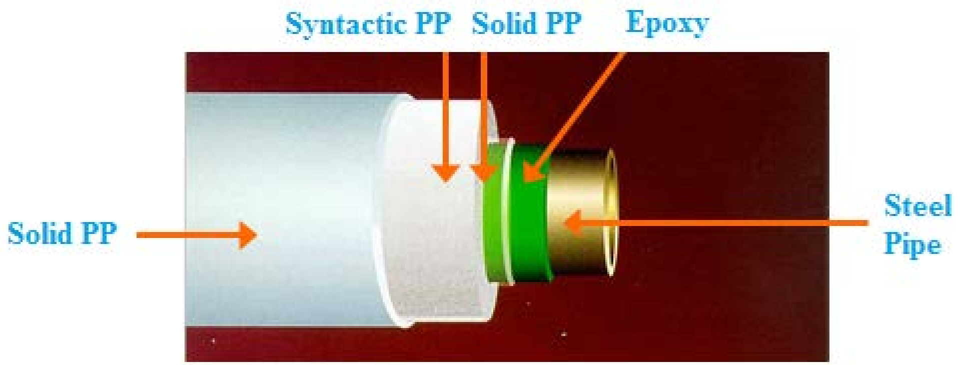
Introduction

- Therefore, the main objective of this work is to develop and validate a suitable numerical model, which can predict the thermomechanical behavior of pipes with multilayer insulation subjected to conditions of ultra-deep service, and thus determine the critical time of shutdown according to the operation field.
- In order to study the behavior of insulated structures, simulations based on the Finite Element Method (FEM) were performed with COMSOL Multiphysics software to compare numerical results with those obtained experimentally in the literature.

Insulated Pipe Structure

- The industrial structure (1.2 m initial length) consists of a steel pipe (internal diameter of about 180 mm, thickness about 18 mm) and a 5-layer insulating coating (total thickness 61mm) which were industrially applied by side extrusion process.

Material	Thickness (mm)
Steel pipe	18,26
Epoxy powder primer	0,25
Adhesive PP	0,25
Solid PP	3
Syntactic PP	55
Solid PP	2,5



Material Properties

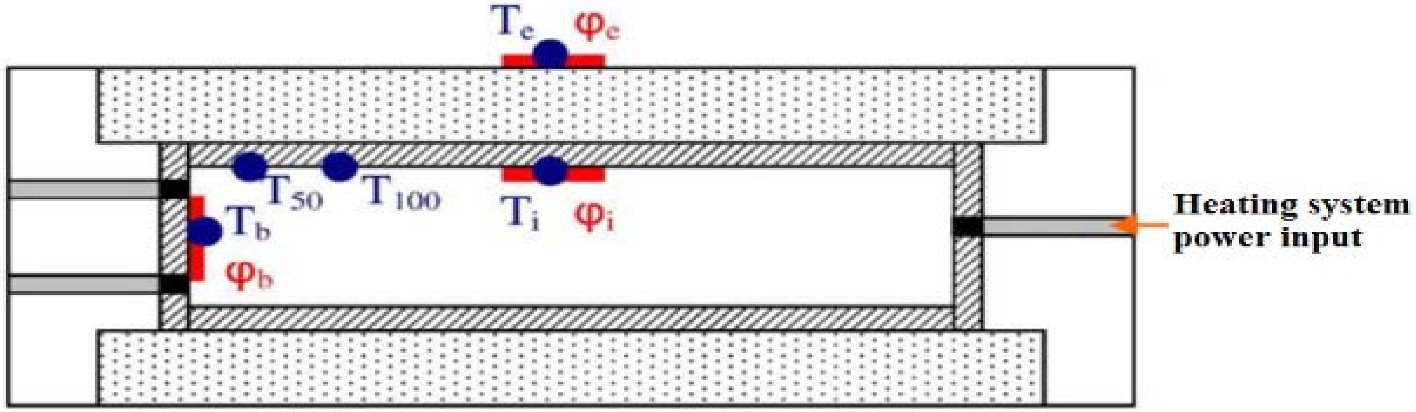
Material	Thermal conductivity (W/m.K)	Heat Capacity (J/kg.K)
Steel pipe	45	475
Fusion bonded epoxy	0,3	2000
Adhesive PP	0,22	2090
Solid PP	0,22	2000
Syntactic PP	$0,165+10^{-4}.T$	1506,6+6,26.T
Steel cap - APX4	19	460
PTFE (insulating end cap)	0,24	1050

Material	Density (kg/m³)	Elastic modulus (GPa)	Poisson coefficient	Expansion coefficient (ºC^{-1})
Steel pipe	7850	218	0,33	1.10^{-5}
Epoxy	1200	3	0,4	$5,3.10^{-5}$
Adhesive PP	900	1,3	0,4	$1,6.10^{-4}$
Solid PP	900	1,3	0,4	$1,6.10^{-4}$
Syntactic PP	640	$1,1-0,94.10^{-3}.T$	0,32	5.10^{-5}
Steel cap	7700	211	0,33	1.10^{-5}
PTFE	2200	0,4	0,46	$1,3.10^{-4}$

Obs: Values are given at 20 °C when the temperature dependence is not specified and the temperature is in °C.

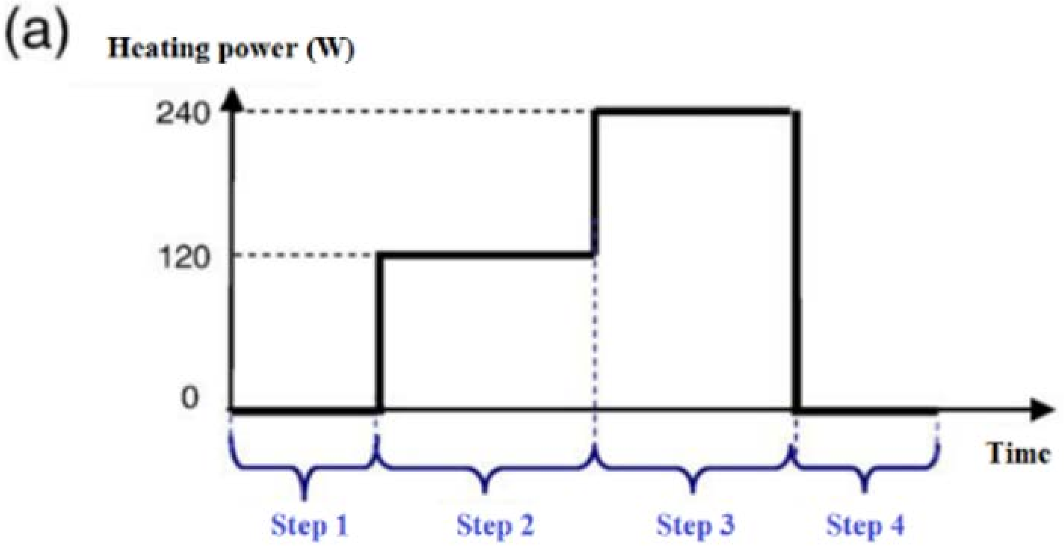
Instrumentation

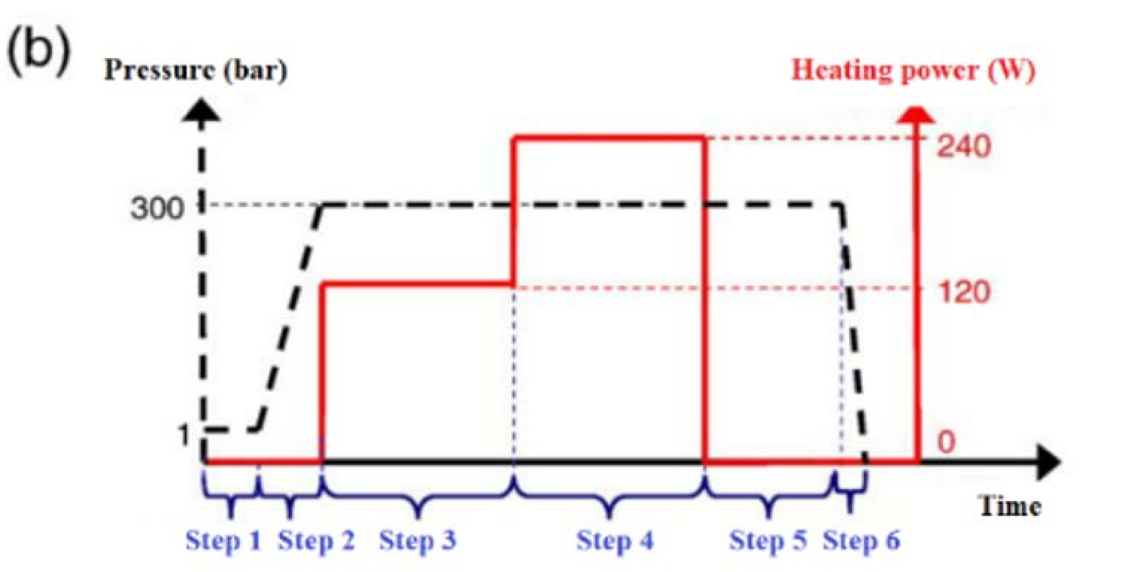
- T_i (°C): inner temperature of the steel surface in the center of the pipe (one measurement);
- T_e (°C): outer temperature of the coating surface in the center of the pipe (one measurement);
- T_b (°C): inner temperature of the steel surface in the center of one cap (one measurement);
- T_{100} (°C): inner temperature of the steel surface along the pipe 100 mm distant from cap (one measurement);
- T_{50} (°C): inner temperature of the steel surface along the pipe 50 mm distant from cap (one measurement).



Testing Procedures

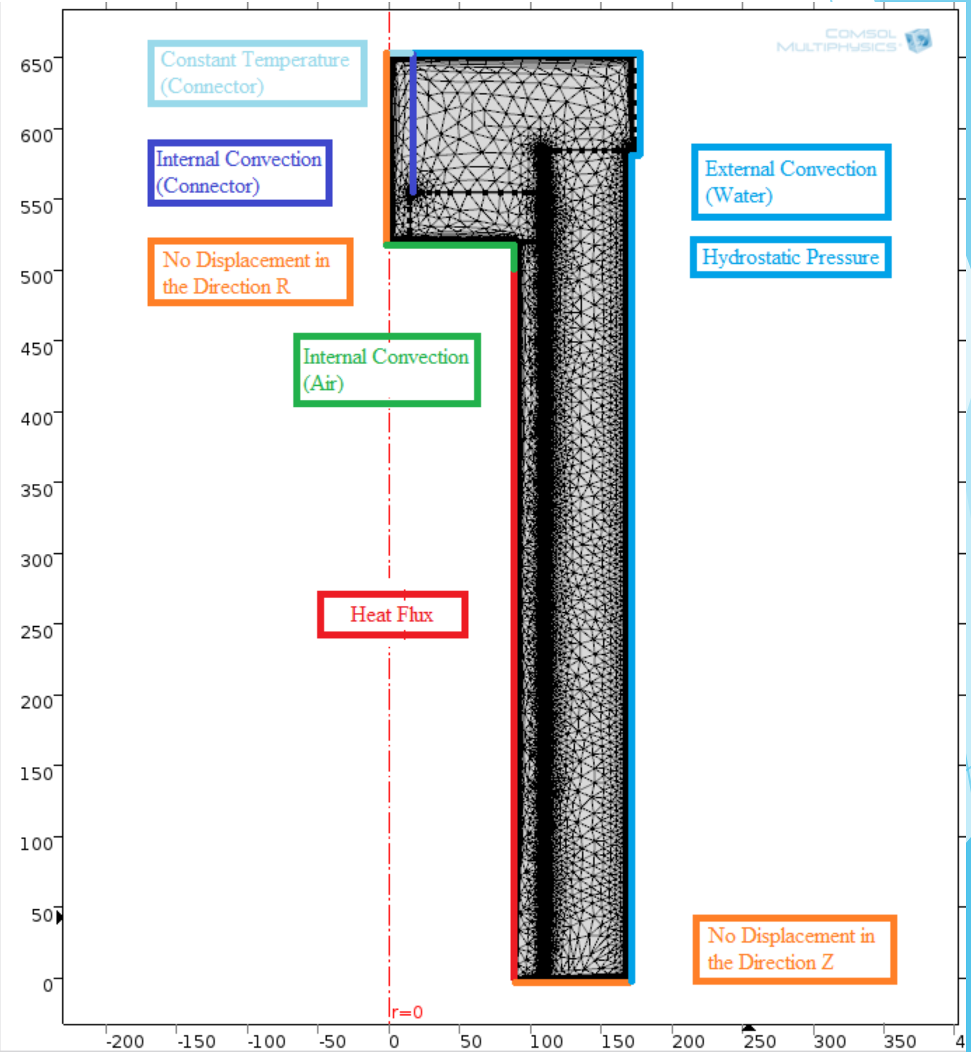
- For the experimental testing, a prototype structure has been instrumented and tested successively without additional pressure (external pressure of 1 bar – test A) and under 300 bar hydrostatic pressure (test B).





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 the figure here.
- This model follows the conditions described by Bouchonneau *et al*. (2010).
- 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.



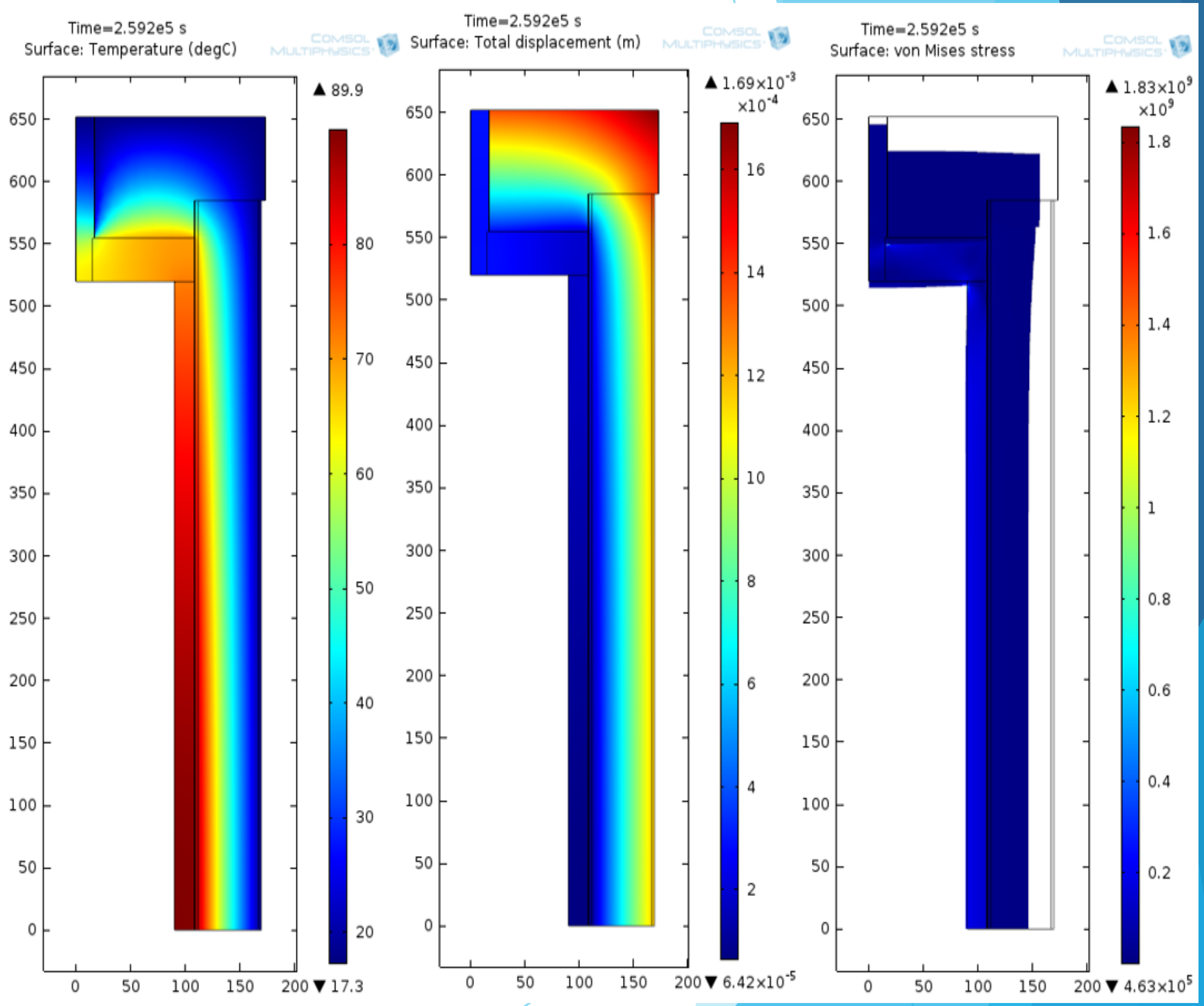
Computational Methods

- Depending on the test and step, different experimental conditions (temperature, pressure, etc.) are applied to the structure. Furthermore, the 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

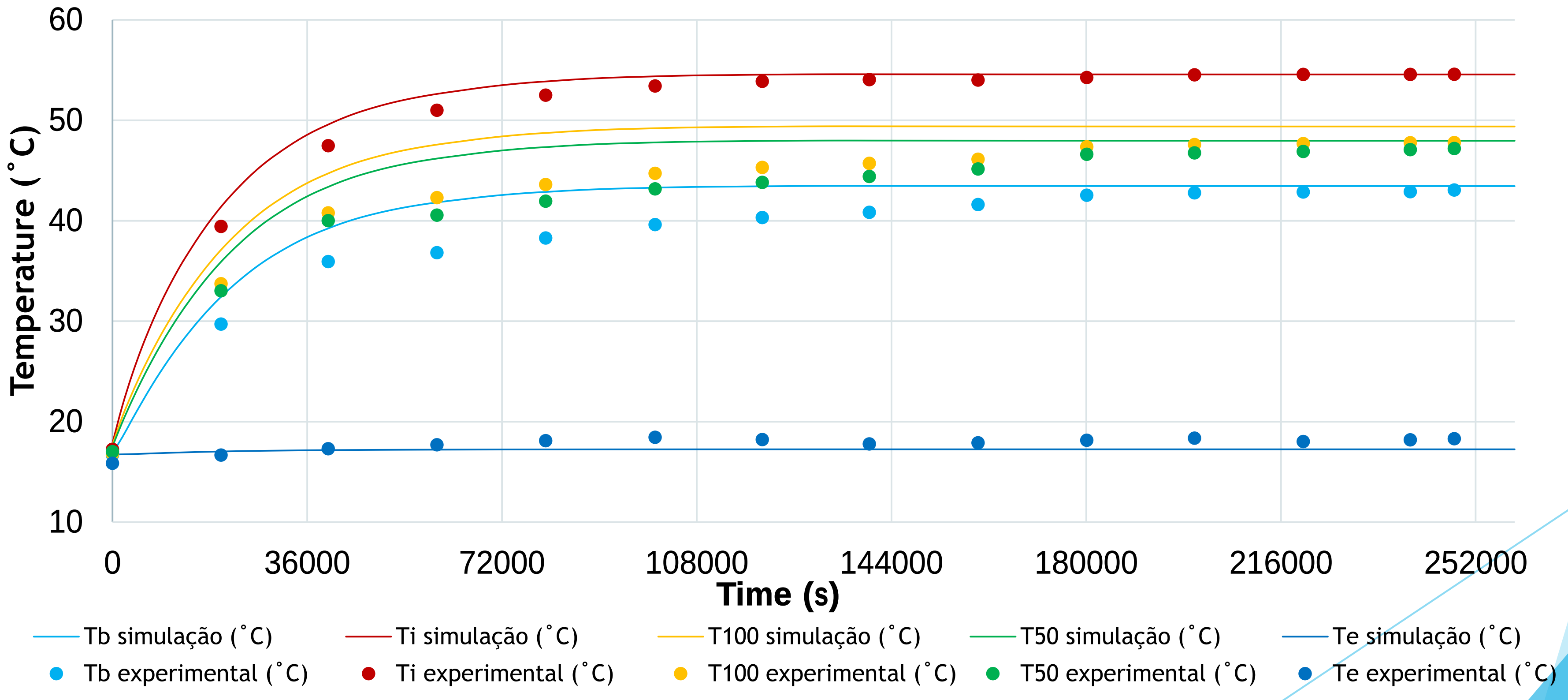
Results

- The results of the temperature distribution in all stages of testing, shows a temperature gradient in the longitudinal direction, which indicates that there is a significant heat loss in that direction.
- This loss of heat is obtained mainly because of the metal cap and the connector, which have high thermal conductivity, allowing heat to pass more easily.

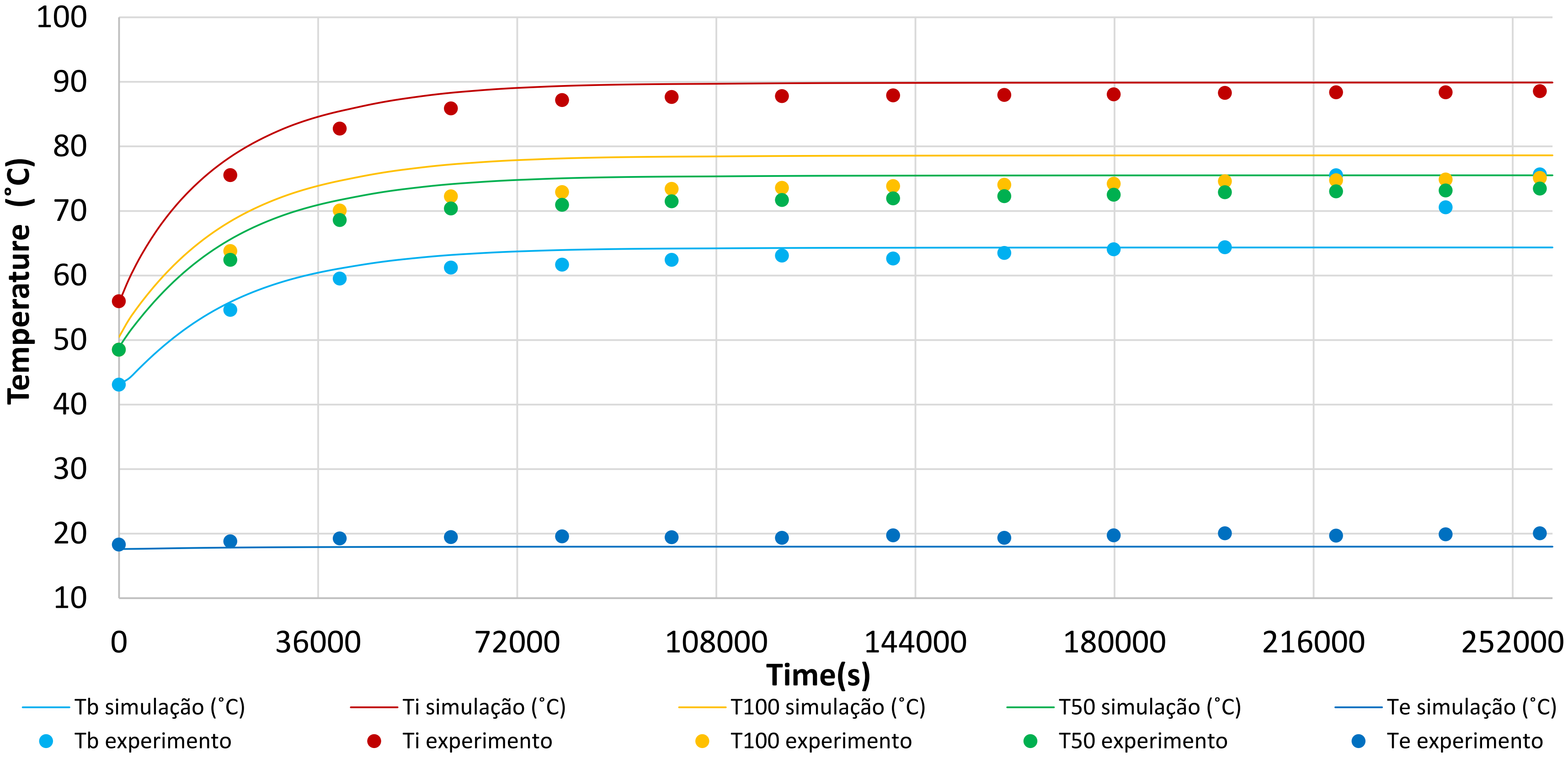


Results

- Then, were made comparisons of the simulated and experimental temperatures of the prototype in the transitional regime, based on the location of the temperature sensors used in the tests. These are presented in the following Graphs, resulting from the simulations for the case of 300 bar (Test B).



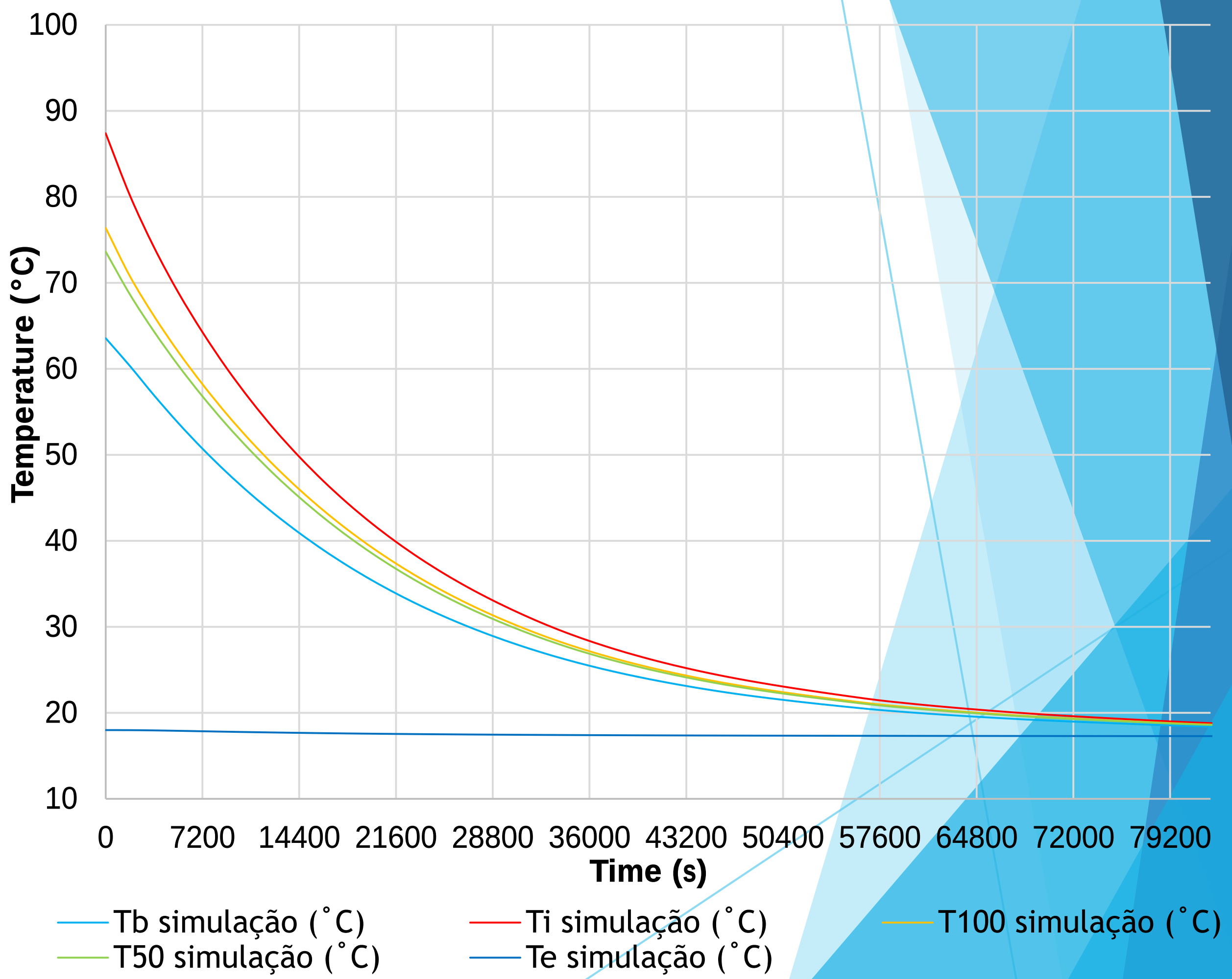
Results



- The numerical results obtained for the improved model showed good agreement with experimental values, particularly regarding to T_i and T_b temperatures. Therefore, it allows to validate the thermomechanical modeling proposed in this work and the stationary state obtained in both structures.

Results

- 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.
- 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.



Conclusion

- The numerical results in transient state obtained for the improved model validated the thermomechanical modeling proposed in this work.
- Based on those 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.
- And 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.
- Furthermore, COMSOL Multiphysics 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.

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