COLD START 4

A Joint Industry Project

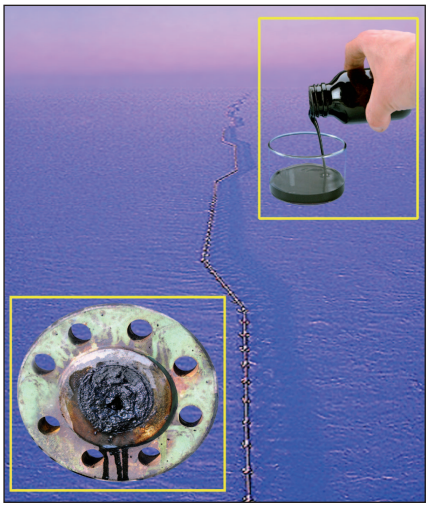
Waxy Crude Oil Flow Restartability at Low Temperatures

Objectives

The objective of this Phase 4 of the Cold Start JIP is to improve our understanding, management and prediction of gelled waxy crude oil flow restartability in pipelines.
In essence, the project consists in enhancing the Cold Start methodology and adding new features to StarWaCS-1.5D software, as well as validating the method by comparing existing and new experimental data.

An industrial challenge

Restarting waxy crude oil flows in pipelines is a major problem linked to the complex rheological behavior of gelled oil. In fact, below the WAT (Wax Appearance Temperature), the gelled oil exhibits viscoplastic, thixotropic, temperature dependent and compressible properties due to the interlocking gel-like structure formed by the crystallized paraffin compounds and thermal shrinkage of the oil. Field operators are primarily concerned with determining the minimum pressure necessary to restart the flow, as well as the time required to flush



the gelled oil out of the pipeline and recover steady flow conditions.

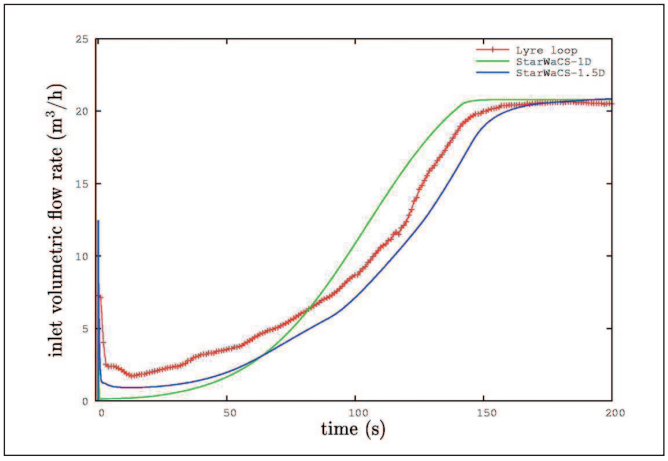
Program

In previous phases, IFP Energies nouvelles gained a sound understanding of the whole process (production conditions, shutdown and restart) via laboratory rheological characterization, experimental campaign on the 150-meter-long/2-inch diameter Lyre loop and development of the StarWaCS-1.5D numerical research code. This led to a patented methodology for more efficient management of the waxy crude oil flow restart issue: the Cold Start methodology.

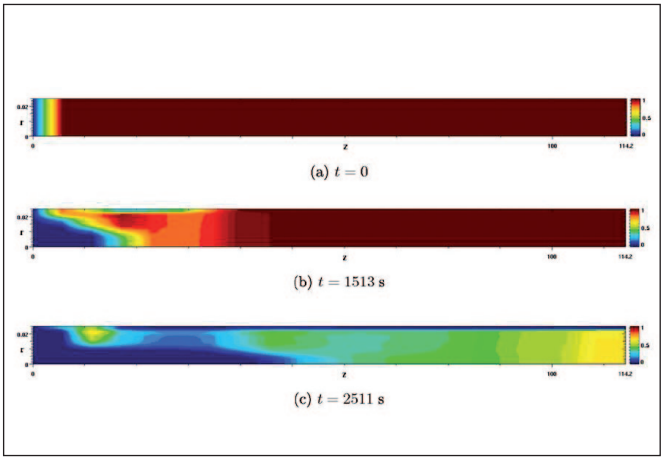
The project combines numerical and experimental components. The main objective is to further validate StarWaCS-1.5D, developed in Phase 3, based on comparisons with both existing and new experimental data. On a numerical level, the aim is to continue developing and documenting StarWaCS-1.5D. On an experimental level, additional experiments are scheduled on the Lyre loop, along with the corresponding laboratory rheological characterization.
More specifically, the proposed scope of work covers the following tasks.

Task 1 - Validation of StarWaCS-1.5D and the Cold Start methodology

- new experiments carried out on the Lyre loop with a constant inlet pressure will make it possible to enhance our experimental database;



Comparison between the recorded volumetric flow rate in the Lyre loop and the numerical predictions of StarWaCS-1D and 1.5D data.



Time evolution of the gel structure parameter computed with StarWaCS-1.5D in an axisymmetric pipe.

- new laboratory rheological measurements will help to elucidate the slip effect and to quantify it in order to explain discrepancies obtained in previous phases between the Lyre loop and lab measurements for extremely low restart temperatures. Additional measurements of the elastic modulus G' are also planned, in order to assess the value of the structure parameter in the rheological (Houska) model;
- validations of our model using the new experimental Lyre loop data.

Task 2 - New features of StarWaCS-1.5D

The developments are compatible with both Linux and Windows operating systems and the sources of StarWaCS-1.5D components are implemented in C++:

- implementation of a flow rate imposed boundary condition to compare StarWaCS-1.5D predictions with flow rate controlled data from the Lyre loop experiments;
- implementation of new boundary conditions making it possible to define an insulation layer and consider a heat flux boundary condition;
- ability to simulate a complete restart process (i.e., steady flow conditions corresponding to production, shutdown and cooling down in static conditions (gelling), and subsequent restart of the gelled oil). By combining these new features with the existing components of StarWaCS-1.5D, we will enable users to run a complete simulation;
- evaluation of the effect of natural convection during holding time.

Deliverables

The main deliverables of this program are:

- a technical report on the Lyre loop campaign and lab measurements;
- a technical report on StarWaCS-1.5D validations: comparisons with experimental data;
- release of a new StarWaCS-1.5D executable prototype version;
- a technical report on the StarWaCS-1.5D evolutions;
- a technical report on the natural convection problem.

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