Simulating Foam Injection using the STARS Mechanistic Model

STARS

Benefits

- Accurately capture foam effects with correlations (empirical model) or component reactions (mechanistic model)
- Intuitive process wizards enable easy set up of mechanistic or empirical foam simulation models
- Simulate IFT reduction and relative permeability changes from varying foam concentration
- Accurate modelling of changes to foam quality, density, degradation, and regeneration

Why Implement?

Produce incremental oil, via increased mobility and enhanced sweep conformance

Why Simulate?

Develop an accurate forecast when applying foam injection to the Cantarell Field

Results

PEMEX successfully history matched data and confidently forecasted the results of a full-field foam injection

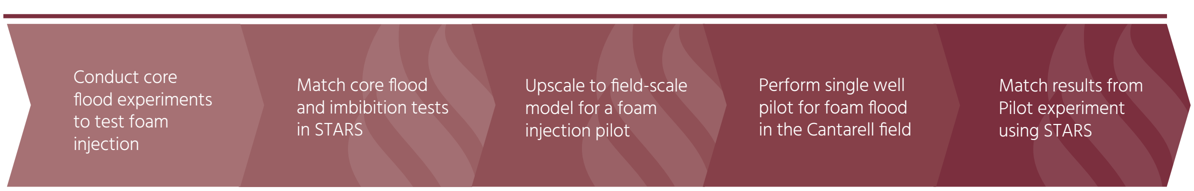
During primary recovery, the continual depletion of the reservoir causes oil production to decrease over time. As a result, secondary recovery methods, such as gas injection, are employed to increase reservoir pressure and overall ultimate recovery. However, gas injection effectiveness is limited because low viscous gas causes unfavourable mobility ratios and other reservoir challenges, including gas coning or gas channelling/fingering.

To solve these reservoir challenges and improve oil recovery, companies are considering foam injection as a tertiary recovery method. STARS, an advanced processes reservoir simulator, offers two methods to accurately simulate foam injection: Empirical and Mechanistic foam models. The empirical model relies on correlations and relative permeability interpolation for foam modelling, while the mechanistic model uses reactions to explicitly model foam. Both models accurately capture the effect of foam, however the mechanistic model provides more robust and detailed modelling.

Cantarell Field

The Cantarell field, located in the Gulf of Mexico, is the largest oilfield in Mexico and has been in production since 1980. For the first two decades, Petróleos Mexicanos (PEMEX) applied primary recovery techniques; however when oil rates started declining, gas injection was used. Gas injection was successful for 10-15 years, but the oil rate declined again due to an increase in gas production. Additionally, gas fingering and channeling through the high permeability natural fractures left the oil in the matrix inaccessible.

In order to solve this problem, PEMEX decided to investigate the potential of sweeping the trapped oil via the enhanced recovery method of foam injection. Due to the complexity of the process and in order to understand the various mechanisms and impact to the overall recovery, PEMEX decided to simulate the process using the mechanistic foam model available in STARS. STARS has the most robust foam model available because it accurately models foam collapse/regeneration, foam quality, foam density, and IFT reduction. These effects play a big role in the Cantarell field because of the reservoir thickness and presence of the natural fractures and low permeability matrix. PEMEX applied the following workflow:



PEMEX's foam injection pilot workflow for the Cantarell field

The goal of the study was to develop a full-field simulation model, using parameters from the pilot well history match, to develop an accurate forecast for applying foam injection to the Cantarell field.

STARS

Step 1: Lab-Scale History Match

Using STARS, three different lab tests were history matched to obtain an accurate representation of the relative permeability, capillary pressure, and foam parameters.

Imbibition Experiment

One main objective of applying foam injection to the naturally fractured Cantarell field is to move the foam into the matrix for IFT reduction and increased oil sweep. In this experiment, natural imbibition was observed in a core sample and history matched in STARS by adjusting the capillary pressure parameters *(Figure 1)*.

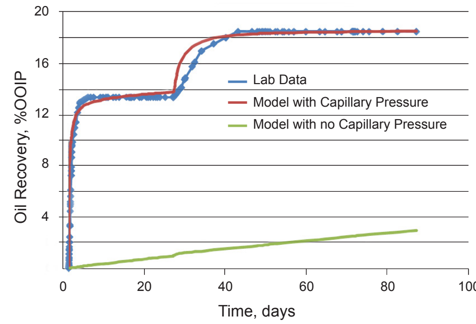


Figure 1 - Imbibition Experiment

Core Displacement Experiment

The goal of this experiment was to history match a waterflood and surfactant flood on a core sample. Using STARS and the experimental data, accurate water-oil relative permeability endpoints and IFT reduction parameters were obtained by matching incremental oil from water and surfactant flood *(Figure 2)*.

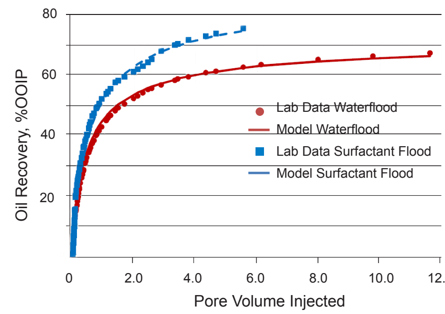


Figure 2 - Core Displacement

Split Core Experiment

The goal of this experiment was to test the impact of foam injection, after the reservoir was re-pressurized by the nitrogen injection. This test was performed using the core sample and results helped determine the foam parameter values that could be used during the full-field simulation.

To obtain a proper oil recovery history match to the split core experiment, the gas-oil relative permeability end-points, foam degradation reaction rates, and foam mobility reduction parameters were adjusted for the mechanistic foam model *(Figure 3)*.

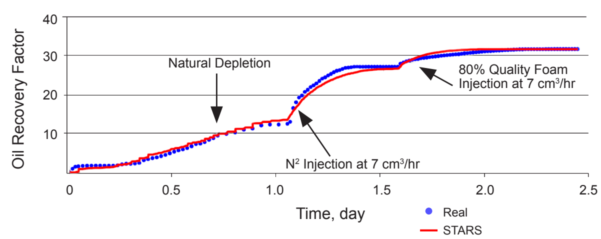


Figure 3 - Split Core Experiment

Step 2: Pilot Well History Match

PEMEX implemented a foam injection pilot for two wells in the Cantarell field as the core experiments displayed an increase in oil recovery after foam injection is applied. For the pilot project, PEMEX injected a single slug of foam into the reservoir, then after a soak period, it was followed by a production from the same location as the initial injection. The field test was successful as most of the injected foam was produced back and the remaining foam was responsible for gas blockage in the reservoir which led to significant Gas Oil Ratio (GOR) reductions.

In order to match the pilot test results, the simulation model was upscaled to a full-field model. It was relatively easy to perform a history match on the field-scale model because the relative permeability, capillary pressure, and IFT were already determined by the lab test history matches. The foam parameters were adjusted slightly because the foam used in the pilot tests was more stable than the foam used during the lab experiments. After the foam degradation and regeneration reaction rates were adjusted, a relatively good history match was achieved.

Summary

The industry leading mechanistic foam model in STARS successfully history matched a complex foam injection process in the Cantarell field because it accurately modelled phenomena such as gas blockage, foam quality, foam regeneration, and foam degredation. Further, STARS also modelled the IFT reduction effects from the surfactant, which led to an increase in incremental oil production. As a result of accurately modelling all these effects, PEMEX successfully history matched the Cantarell field and confidently forecasted the results of a full-field foam injection.

PEMEX created a field-wide prediction for foam injection and proved that foam injection will lead to incremental oil recovery for the Cantarell field.

This case study is based upon SPE 153942-MS "Understanding Foam Flow with a New Foam EOR Model Developed from Laboratory and Field Data of the Naturally Fractured Cantarell Field" †. To read the full technical paper, please visit www.onepetro.org.