An Efficient Optimization Workflow for Field-Scale In-Situ Upgrading Developments
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Summary
In-situ Upgrading Process (IUP) is an attractive technology for developing unconventional extra-heavy oil reserves. Decisions are generally made on field scale economics evaluated with dedicated commercial tools. However, it is difficult to conduct an automated IUP optimization process because 1) unavailable interface between economic-evaluator and commercial simulator/optimizer and 2) IUP is such a highly complex process that full-field simulations are generally not feasible.

In this paper, we developed an efficient optimization workflow by addressing three technical challenges for field-scale IUP developments: 1) Derived an upscaling factor based on analytical superposition formulation, and proposed an effective method of upscaling simulation results and economic terms generated from a single-pattern IUP reservoir simulation model to field scale, and validated this approach numerically. 2) Proposed a Response Surface Model (RSM) of field economics to analytically compute key field economical indicators such as NPV, using only a few single-pattern economic terms together with the upscaling factor, and validated this approach with a commercial tool. The proposed RSM approach is more efficient, accurate, and convenient, as it requires only 15-20 simulation cases as training data, compared to thousands of simulation runs required by conventional methods. 3) Developed a new optimization method with many attractive features: well parallelized, highly efficient and robust, and with a much wider spectrum of applications than gradient-based or derivative-free methods, applicable to problems without any derivative, derivatives available for some variables, or for all variables.

This workflow allows us to perform automated field IUP optimizations by maximizing full-field economics target while honoring all field-level facility constraints effectively. We have applied the workflow to optimize the IUP development of a carbonate heavy oil asset. Our results show that the approach is robust and efficient, and leads to development options with a significantly improved field-scale NPV. This workflow can also be applied to other kinds of pattern-based field developments of shale gas and oil, and thermal processes such as steam-drive or SAGD.

Introduction
Heavy oil and oil sand resources are estimated to contain more than 10 trillion barrels in total worldwide. The main difficulty in developing extra-heavy oil resources is due to the high viscosity (>10^6 cp) of the bitumen. The In-situ Upgrading Process (IUP) has proven to be an attractive technology for developing these unconventional assets (Simmer and Thompson, 1977; Hyndman and Luhning, 1991; Xu, 2001, Snow, 2011.). These unconventional IUP processes involve very complicated multi-phase thermal transport and chemical reactions (Karanikas, 2012). As discussed by Alpak et al. (2013), recovery of bitumen in naturally fractured reservoirs via IUP involves four major mechanisms: displacement of bitumen from matrix to fracture due to thermal expansion in the early stage (when reservoir temperature is below the boiling temperature of water) and steam expansion in the second stage (when reservoir temperature exceeds the boiling temperature of water), gravity drainage of bitumen due to significant viscosity reduction in the third stage (when reservoir temperature exceeds 400 ºF), and in-situ upgrading through thermal cracking of heavy components in the fourth stage (when reservoir temperature exceeds 575 ºF).