Oil well placement

Mathematical models

The oil well placement problem, a crucial problem in reservoir engineering, consists in determining the optimum number, type, and location of oil wells so as to optimize the hydrocarbon production and the drilling costs. In industry, the decision to drill a well or not and its location is taken by reservoir engineers trusting their professional expertise. These decisions strongly relate with the understanding of the impact of different influencing engineering and geological parameters. However, such influence is very complex (non linear) and changing over time, thus a deep understanding of such phenomena requires more than human experience. Satisfying solutions could be provided by practitioners, but optimization methods can lead to improved configurations.

From a mathematical modelling viewpoint, the number of injector and producer wells, the number of branches could be represented by integer variables, completed by continuous variables as wells and branches location in the reservoir, the length of the branches, etc. The functions to optimize and the constraints are generally computed from the outputs of a reservoir fluid flow simulator, costly in computational time: the outputs to optimize are the quantities of produced oil and water, and the quantities of injected (to facilitate the production). As we do not have access an analytic formula of the objective function, we have a Black-Box optimization problem. Hence we have no knowledges of the continuity, differentiability or convexity of the objective function. Localization constraints and number of wells constraints could also be included to problem.

Thus, the oil well placement problem can be modeled as a Black-Box MINLP problem, a very challenging problem both from a theoretical and a computational viewpoint. Note also that, as no convexity assumption holds, in optimal well placement one should perform some kind of global search in order to avoid being trapped in local minima.

A few more details on the model:

Objective function

The two most widely used objective function are:

i. maximize the quantity of produced oil;

ii. evaluate the revenue of a well configuration with Net Present Value (NPV) function. This function combines oil revenue, water management (water injection and separation), and drilling costs.

Modeling and algorithmic considerations:

Automatic well placement optimization is an iterative procedure that can be divided into following procedures:

1. Using engineering judgment, guess initial well(s) location
2. Use an optimization engine based on user-defined decision variables to suggest possible improved well location(s).
3. Apply a reservoir response model to report to the optimization engine the performance of the proposed well locations.
4. Include the effect of uncertainty in reservoir properties, economic factors, etc, which can be an optional step.
5. Calculate the objective function (e.g. Net Present Value or NPV).
6. Repeat steps 2 to 5 until stopping criteria (set by user) are met.

The approaches to problems 1 to 5, may differ in the optimization algorithm, reservoir response modeling technique, and available decision variables and constraints. We now turn our focues to the modelling aspect of the problem

Concentrating our attention to the optimization problem after the initial guess (problem n. 2), the well placement problem is translated into optimization of an objective function (NPV or cumulative hydrocarbon production). Applying MILP models one can for instance, solves this problem through finding locations of a given number of wells (out of total possible well locations) that minimizes the difference between the production and scheduled demand. Hence, the drilling decision can only be made at particular locations i which have to be identified beforehand (guess problem n. 1).

Constraints

The most complex constraints come from the interaction between withdrawal rates and pressures at all the wells, that must be defined by the nonlinear gas flow equation. However this nonlinear constraint has a very good linearization substitute, called influence equations. In these equations, the pressure drop at well i is a linear function of withdrawal flow rates from all drilled wells. This is defined by influence function matrices. After this proper linearization, the resulting problem is a mixed integer programming problem, which can be solved by well known techniques.

Constraints are generally physical ones, ensuring the practical realizability of the solution and the correct behavior of the simulator. A useful constraint is also the water cut constraint that consists in applying some reactive control on each producer to avoid producing much water which impacts negatively on the NPV. Such reactive control shuts off producers when the water cut, i.e., the ratio between the water rate produced and the sum of water and oil rates produced, is higher than a given threshold. It is also possible to add constraints during the production, e.g., produce a minimal quantity of oil for instance.

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Contributors:

Dr. Claudia D'Ambrosio, CNRS LIX, Ecole Polytechnique