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Gas Field Multi-period Optimization Under Harmonic Decline

Introduction In operating a gas field, petroleum firm needs to produce natural gas at the nomination rate to satisfy the gas sale agreement (GSA) made with the buyer. Meanwhile, they try to maximize condensate production to increase their revenue. To achieve this, they collect fluid properties from different gas wells and construct production decline curve to capture the production potential over time. A specific type of such curve is called Harmonic decline where the production rate at time t is described by $q(t) = q_{pot}/(1+dt)$ where q_{pot} is the initial potential of that well and d is the decline rate. The average production rate q_g over time period Δt can be calculated by integrating the aforementioned rate equation from the open time $t^{(j-1)}$ to the close time $t^{(j)}$ of any period j of that well. This leads to the relation $q_g \times \Delta t = \frac{q_{pot}}{d} ln(\frac{1+dt^{(j)}}{1+dt^{(j-1)}})$. Note that $t^{(j)} - t^{(j-1)}$ needs not be Δt as we might not open that well for the full period. This eqaution poses a nonlinear and, specifically, non-convex constraint in gas field optimization. Attempts have been made to solve such problem including using Taylor's series approximation to this constraint. As this constraint is still smooth, we would like to apply numerical optimization technique to try to obtain a local solution that could represent a good field production plan.

Problem Formulation

$$max_{t_i^{(j)}, q_{g,i}^{(j)}} \sum_{j=1}^{T} \sum_{i=1}^{N} CGR_i \times q_{g,i}^{(j)} \times \Delta t^{(j)} \times Price^{(j)} \tag{1}$$

$$s.t \sum_{i=1}^{N} q_{g,i}^{(j)} \times \Delta t^{(j)} \leq Q_{nom}^{(j)} \quad \forall j \in \{1, \ldots, T\} \tag{2}$$

$$q_{g,i}^{(j)} \times \Delta t^{(j)} = \frac{q_{pot,i}}{d_i} ln(\frac{1 + d_i t_i^{(j)}}{1 + d_i t_i^{(j-1)}}) \quad \forall j \in \{1, \ldots, T\}, \forall i \in \{1, \ldots, N\} \tag{3}$$

$$0 \leq t_i^{(j)} - t_i^{(j-1)} \leq \Delta t^{(j)} \quad \forall j \in \{1, \ldots, T\}, \forall i \in \{1, \ldots, N\} \tag{4}$$

The variables to be adjusted are the open time and average rate for each well $(t_i^{(j)}, q_{g,i}^{(j)})$ while the rest are constants. The first constraint represents the nomination rate. The second one is the Harmonic decline relation and the last set of constraints are to enforce reasonable open and shut in time. To simplify the problem further, we may assume that some of these constants does not change over time or limit the amount of well and production period to a small number.

Methodology We plan to investigate the augmented Lagrangian method if possible. If it fails, the contingency plan is to do problem 2.