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Innovative Applications of O.R.

Scheduling pumpoff operations in onshore oilfields under electric-power constraints☆

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ABSTRACT

In onshore oilfields, several sucker-rod pumps are deployed over a large geographic area to lift oil from the bottom of production wells. Powered by electric rotary machines, the rod pumps operate according to cyclic control policies that alternate between on and off pumping periods which are designed to drive maximum production. This cyclic behavior gives rise to the problem of scheduling pumpoff operations in order to minimize the system power peak and thereby smoothen the power-consumption profile. To this end, this paper develops MILP formulations for the coordination of control policies and their reconfiguration during operations. Following a column-based approach or using integer variables to model the power-consumption profile, the resulting MILP formulations are put to the test in a host of synthetic, but representative oilfields.

1. Introduction

The development of an oilfield is a complex undertaking that extends for several years, evolving from the discovery of the reservoir to the planning of production facilities, well drilling, and production. Typical oilfields can cover large geographic areas with dozens of production and water-injection wells—the injection of water is applied to maintain the internal pressure of the reservoir. As the oilfield matures, artificial lifting techniques are required to bring the oil from the bottom of the wells to the surface where the multiphase flow of water, oil, and gas is separated and processed (Camponogara & Nakashima, 2006; Codas & Camponogara, 2012). The artificial-lifting technique adopted in an oilfield depends on a number of factors, such as the depth of the reservoir, the viscosity of the oil, and its location, whether being onshore or offshore.

In onshore fields, sucker-rod pumping is a widely applied technique for its relative low investment and maintenance cost, inherit flexibility, and variable production rate (Lake, 2007; Ordoñez, 2008; Ordoñez, Codas, & Moreno, 2009). A rod-pump system consists of a rotary machine connected to a plunger that runs inside the production tubing. In combination with the coordination of the opening and closing of valves, the alternating up-and-down movement of the plunger lifts a certain amount of oil to the surface (Thomas, 2001). When the oilfield matures, rod pumps operate according to pumpoff control policies that split the control cycle in on and off pumping periods. Such policies are implemented to allow the reservoir to replenish the fluids around the perforation zone of the well, preventing the plunger from hitting the well bottom with an empty chamber and thereby avoiding equipment damage.

Onshore oilfields are typically operated with several rod pumping units that draw electric energy from a power line and possibly share flowlines that connect wells to a processing station. In particular, the operation of oilfields located in remote areas to the north and northeast of Brazil are severely constrained by the limited electric-power supplied by the utility company (Ribeiro, 2012). These limitations give rise to the problem of scheduling pumpoff operations in order to minimize the system power peak. Besides stressing the power grid, an uneven system power-consumption profile induces oscillations in the flowlines which are transferred to the separation station. Related problems are found in the operation of offshore oilfields which instead consider the scheduling of electric submersible pumps (ESPs), such as in the Peregrino oilfield located off the coast of Brazil (Solbraekke, 2014).

Aiming at improving production operations of onshore oilfields, this work formalizes the problem of scheduling pumpoff operations so as to minimize the system power peak and to induce a smooth power-consumption profile. MILP formulations are developed for the scheduling problem following two principles, one based on integer variables and the other on column variables that define a feasible pumping profile over time. Akin to the scheduling of pumpoff operations, related problems in which binary variables play a major role are

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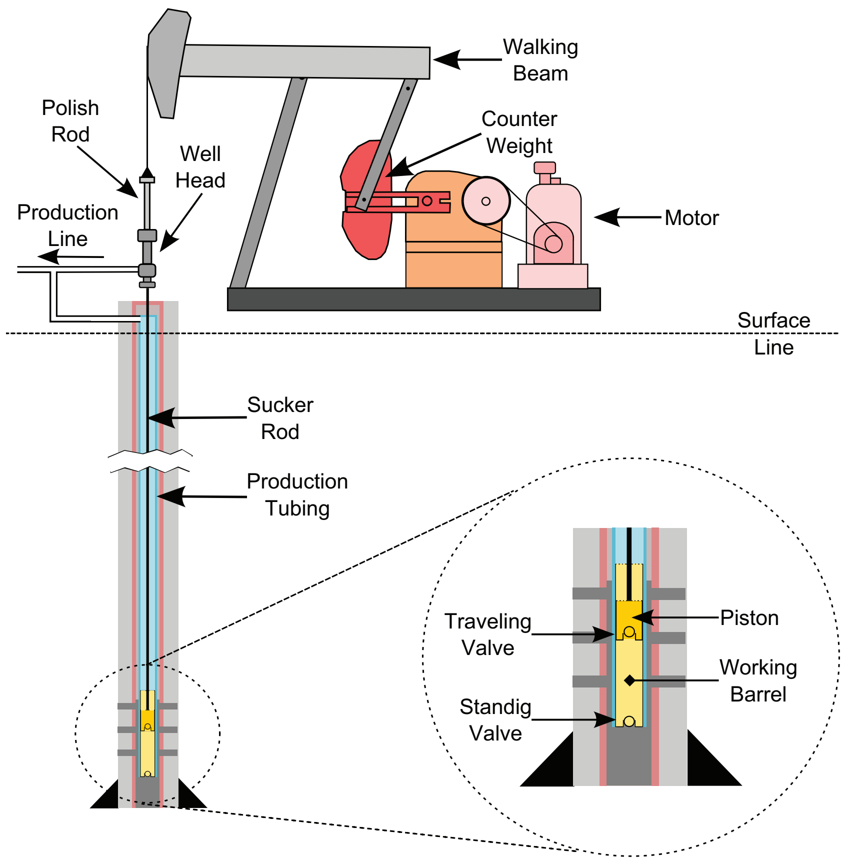

Fig. 1. Schematics of a sucker-rod pumping unit (adapted from Wikipedia).

found in practice and the technical literature. A relevant problem is the scheduling of electric-power generating units to meet the forecast load and spinning reserve, while adhering to generator and transmission constraints, a class of problems collectively known as unit commitment (Bertsimas, Litvinov, Sun, Zhao, & Zheng, 2013; Hobbs, Rothkopf, O'Neill, & Hung-po Chao, 2001).

The paper is organized as follows. Section 2 presents the basic operation of rod pumps and introduces the problem of scheduling pumpoff operations. Section 3 introduces the concept of hyperperiod and formally defines the problem. Section 4 develops three Mixed-Integer Linear Programming (MILP) formulations for the scheduling problem. Section 5 presents the problem of adjusting pumpoff control policies in response to equipment failure and deviation from the nominal operation. Section 6 reports on results from computational analyses aimed at assessing the performance of the scheduling and rescheduling models. Finally, Section 7 offers a summary and suggests directions for future research.

2. Sucker-rod pumping systems

Sucker-rod pumping is one the first artificial-lifting strategies to have been deployed in oilfields. Having a relative low investment and maintenance cost, rod pumping has found widespread application in mature onshore oilfields for its inherit flexibility and variable production rate (Bhatkar & Anwar, 2013; Ordoñez, 2008; Torres, Schnitman, & de Souza, 2013). The technique converts the energy of an electric- or combustion-powered rotary machine into the movement of a plunger that runs inside the well tubing. In combination with the coordinated opening and closing of the standing and traveling valves, the alternating up-and-down movement of the plunger lifts an amount of oil from the bottom of the production tubing up to the surface (Thomas, 2001). The main elements of a rod pumping production system are illustrated in Fig. 1.

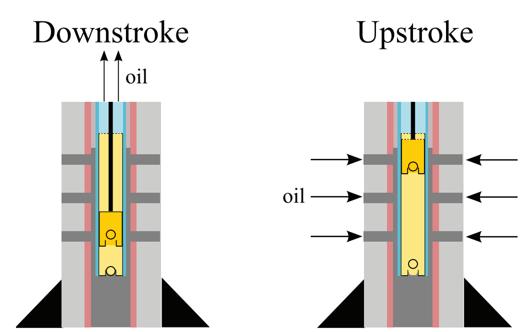

Fig. 2. Upstroke and downstroke phase of the pumping cycle (adapted from Wikipedia).

The artificial lift with rod pumping consists of a cycle with two distinct phases: the *upstroke* and *downstroke* as illustrated in Fig. 2. During the upstroke phase, the piston is elevated to the top part of the working barrel. At this moment, the traveling valve is closed due to the weight exerted by the oil in the production tubing, thereby reducing the pressure within the working barrel. The difference between this pressure and the pressure of the annulus at the perforations forces the standing valve to open, allowing oil from the reservoir to flow inside the working barrel. During the downstroke phase, the piston plunges down to the bottom of the well, exerting pressure on the standing valve which is forced to close. As a result, the piston compresses the oil inside the working barrel, forcing the traveling valve to open which in turn allows the oil to flow into the production tubing.