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Model Predictive Control with quality requirements on petroleum production platforms

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ABSTRACT

In this work, the potential of model predictive control (MPC) on an offshore production unit starting from the well up to the processing plant was investigated. Analyses of control strategies through computer simulation were performed using mathematical models of wells, flow lines and separation plant. The goal is to control the gas-lift and ensure quality specifications of products of primary processing of petroleum. Improvements are made in models of wells and three-phase separator found in the literature to make them capable of representing physical behavior important for the analysis of control, namely, the head loss by friction in the flow and the variation of the separation efficiencies depending on the level of the three-phase separator interface are also described. Credible scenarios were analyzed, showing the satisfactory behavior of the proposed control strategy.

1. Introduction

In exploitation of oil wells, in order for the oil to reach the offshore production platform, it is necessary that the reservoir have sufficient energy (in the form of pressure) to push the oil from the bottom of the well to the platform. If such a well produces oil only with the power available in the reservoir, it is called a flow well. If a well is not a flow well, then artificial lifting techniques become necessary to supplement this energy (Thomas, 2001).

Among these techniques, the main one is the gas-lift, which consists in increasing the fraction of gas dissolved in the oil in order to lower the density of the fluid, reducing the pressure loss by hydrostatic.

One difficulty is that if the flow of gas-lift is excessive the head loss by friction becomes large enough to be detrimental to production. In addition, oil production is constrained by the quality requirements of the water/oil separation, measured in terms of BSW (basic sediments and water) in the produced oil and TOG (total of oil and grease) in the discharged water, as well as capacity constraints due to space limitation on offshore platforms.

In the literature, some effort has been made in the direction of real time optimization of production systems. Bieker et al. (2007) reviewed the state of art in real time optimization applied to offshore systems. They discussed methods for real time optimization for some benchmark cases such as reservoir planning, wells prioritization, the gas lift and process facilities optimization.

Regarding to gas lift optimization, there are several papers such as those of Alarcón et al. (2002), Sharma et al. (2012), Kosmidis et al. (2004), and Wang and Litvak (2008). De Souza et al. (2010) proposed a framework for optimization of gas lift systems with respect to oil production and profit. However, none of these works included detailed models of processing facilities, or considered any quality constraints.

Rahmawati et al. (2010) evaluate an optimal economic production strategy in integrated reservoir, pipelines and surface process models for the optimization of injection of reservoir fluids.

In summary, although there are several papers related to optimization of offshore production systems, few are specifically devoted to applications of Model Predictive Control (MPC) on gas-lifted offshore production systems. These studies, cited below, have emerged as an effort to convince the oil companies that it is worthwhile to invest in advanced process control in their platforms.

Laing et al. (2001) described a study done to convince Marathon Oil that the implementation of advanced control leads to financial return. The article mentions three areas in which it is believed that financial benefits result from advanced control: (1) Reservoir Management and injection wells, (2) Minimization of

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time shutdown (3) Process variability reduction.

Additionally, Foss (2012) presents some challenges to upstream petroleum industry in which advanced process control, in particular, Model Predictive Control (MPC), may have significant impact on industry.

Some industry insider experiences in applying MPC in offshore applications are presented (Strand and Sagli, 2003; Honeywell, 2005).

Godhavn et al. (2005) applied advanced control strategies in Statoil platforms on two strategic fronts, “suppressing slugs” and “handling slugs.” Active control was used in the suppression of slugs, consisting of a pressure controller on the base of the riser, in cascade with a flow controller in the topside choke. In another approach to handling slugs, an MPC controller was used to prepare separators and compressors for a sudden change of production, in order to avoid *tripping* in cascade. The objectives of MPC were limiting level variations within the constraints and minimizing variations in the flow of oil from the separator to the measuring station. The identified models showed that the slugs could be predicted approximately 1 min in advance, based on a pressure reduction at the top of the riser, and the controller could then prepare the separator to receive the disturbance appropriately. The result of the advanced control design was a reduction of 8 bar at the base of the riser, and hence a 3% increase in the production of the platform. Thus, the financial investment in the project could be recovered in about three weeks.

Plucenio et al. (2009) proposed a Nonlinear MPC in a simulated production system that was composed of four wells, without any separation facility. The objective of the NMPC strategy was to keep the gas lift manifold pressure close to setpoint and to distribute the gas lift in a way that minimizes the distance between the maximum production and the predicted production and simultaneously minimizes the oscillations caused by changes in gas lift injection flow rates. The NMPC algorithm employs a continuous linearization over the prediction horizon.

Willersrud et al. (2013) applied the NMPC for short term production optimization of an offshore oil and gas production facility. Two approaches were investigated: *Unreachable Setpoints* e *Infeasible Soft Constraints*. Both strategies were used in order to maximize oil production.

The objective of this paper is to investigate Model Predictive Control (MPC) strategies applied to a fairly complete production system model that includes gas lifted wells, separation facilities, gas compression systems and gas lift injection system. The objective of the proposed strategy is to optimize gas-lift and, at the same time, and in an integrated manner, meet the requirements of primary oil processing.

This paper also proposes improvements related to the well models, taking into account the energy loss due to friction, and to the three-phase separator, adding the effect of the water–oil interface level on the separation efficiency.

2. Methodology

The proposed multivariable control must manipulate the flow of gas-lift from each well and the level of the three-phase separator. Therefore, the process will be controlled from the wells to the processing plant. It should be noted that these interconnected systems have very different characteristics.

An important step to permit such a study is the development and computational implementation of wells, flow lines and processing plant models. Such models have been studied in the literature, have gone through some adjustments and were implemented in the simulator EMSO (Soares and Secchi, 2003).

In this work, some changes to the EMSO models of well, riser and the three-phase separator were made, aiming to account for, respectively, the head loss by friction in the flow and the sensitivity of the separation efficiency as a function of the level in the separator. It is important that such behaviors be portrayed by the models in order to allow realistic production optimization and quality control studies.

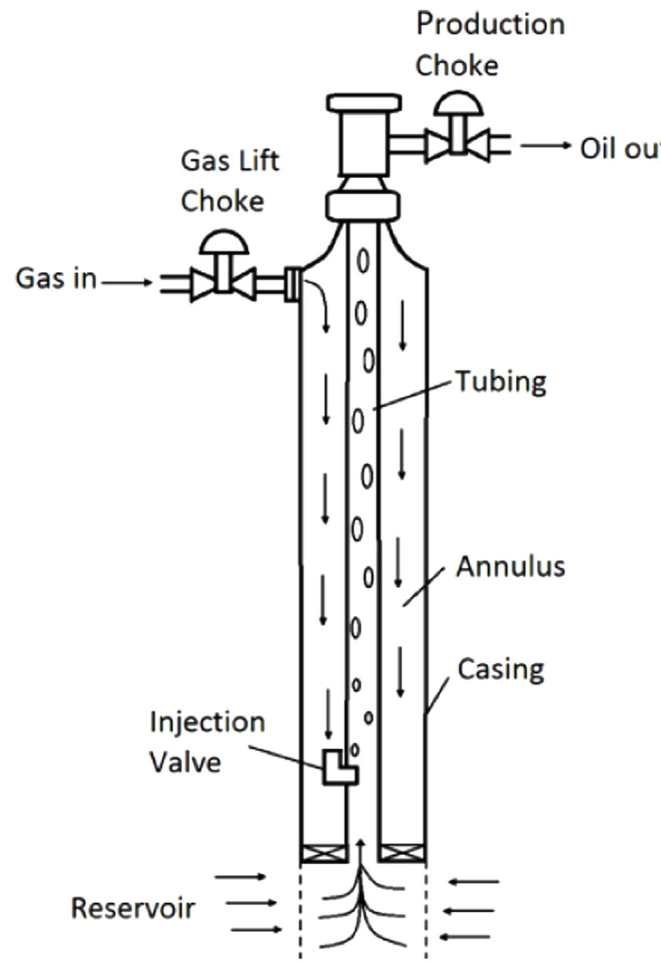

Fig.1. Production well. Adapted from: Eikrem et al. (2008).

2.1. Simplified model of well

The model chosen to represent the production well, illustrated in Fig. 1, is a simplified model that aims to capture the phenomenon of casing heading, developed for control design purposes.

2.1.1. Eikrem et al. (2008) model

The most important assumptions made for the model described in Eikrem et al. (2008) are as follows. Reservoir pressure is treated as a constant; flow rates through the valves can only occur in one direction; two-phase flow in pipe, oil and water is treated as a single phase; no flash effect (release of gas from the liquid phase); low gas–oil ratio (RGO), which is reflected in the fact that the flow from the reservoir is modeled as a liquid phase only; components of oil and gas slowly varying and the following variables are considered constant: the molar mass of the gas (M); specific gravity of the oil (ρ_o), the temperature of the annular space (T_a) and the temperature of the production column (T_w).

The model is composed of three mass balances: the mass of gas in the annulus (x_1), the mass of gas in the tubing (x_2), and the mass of oil in the tubing (x_3).