1
Introduction

Even with sophisticated exploration and production techniques currently available, it is still necessary to develop and manage reservoirs under considerable uncertainty. Thence, the optimization of the reservoir development strategy under uncertainty has been recognized in recent years as an important tool for the production of oil. Reservoir simulation can be used in order to understand the reservoir performance for various possible reservoir models and under various development scenarios. Based on these forecasts we will be able to choose the development plan that maximizes the reservoir value (Klein, 2002). In reservoir management, optimizing reservoir exploitation therefore requires the development of a strategy that produces the greatest possible economic return within the physical and economic limits (Almeida *et al.,* 2010), and also considering the uncertainty.

Numerous fields worldwide have been producing at rates considerably below their potential; and marginal reserves have been overlooked and discarded because the technology required for profitable exploitation has been elusive, expensive or unproven (Konopczynski *et al.,* 2003). Some technologies and concepts have been developed and deployed to maintain the profitability of development of oil fields; among them, smart well technologies are one of the most significant breakthroughs (Gao *et al.,* 2007).

The smart well technology can be defined as systems, with the so called “intelligent completions”, capable of collecting, analyzing and transmitting data from remote sensors, along with the ability to remotely actuate downhole flow control devices, with the main objective of optimizing reservoir production. Thus, the smart well enables operators to monitor and control remotely the production of the fluids through completion systems (Gao *et al.,* 2007). These benefits are amplified many times over in deep-water and subsea operations due to the high costs and technically demanding challenges associated with these locations.

However, common challenges in applying smart-well concepts and hardware include: accounting for geological, reservoir and resource-price uncertainties in deciding how to operate the down-hole inflow control valves (Almeida *et al.*, 2010) (Yadav *et al*., 2012), balancing the benefits of smart wells against their cost in mature fields (Akram *et al*., 2001), accounting for the reliability of down-hole inflow control valves and sensors (Cullick & Sukkestad, 2010), and identifying suitable candidates for smart wells (Ajayi *et al*., 2007). These challenges share a common theme: the need to optimally design, value, and control the hardware in the presence of uncertainty. Therefore, operators intuitively understand the benefits of the technology, but are unable to represent it with conventional valuation techniques, and thus are unable to justify the deployment of intelligent completion instead of more conventional, better-understood, but less flexible, completion technology (Han, 2003).

1.1. Motivation

Smart well technology provides a broad spectrum of value generating functionality for oil and gas field operations, all derived from the ability to monitor and control fluid production and injection by zone in real-time without the need for costly intervention. A major barrier to smart well technology adoption has been the lack of a method to quantitatively define the value associated with various applications of the technology (Han, 2003). This technology becomes particularly important in the case of offshore fields where well costs, injection costs, liquid lifting costs (for oil and water) and water processing costs are considerably greater than in onshore wells. The introduction of smart well systems is rapidly moving from the more obvious, high-cost offshore applications to more revenue-sensitive operating arenas, including mature and marginal fields (Gao *et al*., 2007). In summary, smart wells allow optimal operational combinations, and ensure excellence in the different stages of design, planning, installation and implementation.

In the presence of reservoir uncertainties, the use of smart well technology is beneficial, leading to potential gains, but there are challenges around how to control the valves and how to use the future information to reduce uncertainties. So, if a poor flow control strategy is used, the full benefit of smart well technology will not be realized. For this reason, the search for an optimum flow control strategy to be used by smart wells has attracted interest in the area of reservoir development and management (Armstrong & Jackson, 2001), (Brouwer & Jansen, 2002), (Yeten *et al.,* 2004), (Almeida *et al*., 2010), (Ghosh & King, 2013), (Barreto & Schiozer, 2014). However, there is not yet available a standard methodology for measuring the benefits of smart completions and determining how to make best use of them, particularly when faced with uncertainty in the reservoir description. In addition to the direct cost of the smart well technology, its reliability and increased potential for failure when compared with simpler technologies cannot be ignored. For these reasons, managers hesitate to approve the implementation of this technology (Almeida *et al.*, 2010).

All available technologies should be considered in addressing the challenging problems of reservoir management (Moczydlower *et al*., 2012), but sometimes it is difficult to choose the best method or combination of methods to overcome reservoir management issues. When choosing a solution, there are several issues to consider: the robustness of solutions, information acquisition, the flexibility of the solutions, and also the risk of failure.

1.2. Objectives

A qualitative description of the importance of flexibility in reservoir development and management has been extensively noted in the literature. Corroborating with this, the objectives of this work are:

- To study the value of flexibility through the optimal control of smart completions to improve recovery in oil fields, highlighting the principal benefits and challenges involved.
- To propose, implement and evaluate an optimization strategy able to:
  - evaluate the value of flexibility though the use of smart wells, seeking the valve-setting strategy that maximizes the net present value of the project;
  - quantify the benefit of smart wells over a conventional completion development scenario;

  - account for reservoir uncertainties and considering the ability of smart wells to have a flexible response to future information.

1.3. Contributions

The contributions of this work come from the modeling and evaluation of a support-decision system able to evaluate operational flexibility allowing to:

- Evaluate qualitatively and quantitatively the use of smart wells, measuring the benefits of this technology on a field development and showing the impact on the net present value of the development project;
- Propose a flow control strategy (as a playbook), that can determining how to make best use of the valves, where the optimized strategy can be according the available computational resources, getting more or less robust answers;
- Choose the flow control strategy under geological uncertainties, because even with sophisticated reservoir characterization techniques available, nowadays the reservoirs still need to be developed and managed under considerable uncertainty about the true properties of the reservoir;

1.4. Thesis description

The thesis has six further chapters, as follows:

- Chapter 2 is a literature review about the use of smart wells on reservoir development with a study about the optimization strategies of the flow control strategy;
- Chapter 3 presents the theoretical background of this work, with basic concepts from Dynamic Programming and Approximate Dynamic Programming, which are useful for understanding the approach proposed

on this thesis. We also include a summary of methods for optimization of expensive-to-evaluate functions, since this can be the Achilles' heel in the use of reservoir simulations for the evaluation of development strategies;

- Chapter 4 is dedicated to a description of the proposed approach, detailing how it integrates geological uncertainties and the acquisition of future information.
- Chapter 5 describes the application cases and test scenario, as well as the optimization and validation results and discussions.
- Chapter 6 concludes this work and Chapter 7 points possible future works.

The following is a short description of each stage of the research done.

The study of the use of smart wells on reservoir management, in the second chapter, involves a literature review about the flexibility of smart wells, the strategy to manage this technology and also the equipment reliability associated. The literature review and consultations with experts describes how the reservoirs are developed and managed under considerable uncertainties concerning true reservoir properties, even with the sophisticated reservoir characterization techniques currently available. This study finishes with a description about how the flow control strategy of smart wells have been optimized under uncertainty in the academic literature. The literature review therefore identifies different ways to use the available information on the flow control optimization in order to reduce the uncertainties over the time.

In the third chapter, we describe the Dynamic Programming methodology highlighting the possible disadvantages and a variation known as Approximate Dynamic Programming. To understand the approach proposed in this thesis it is important to understand these techniques. In this chapter, we also present the basic concepts of optimization of expensive-to-evaluate functions, describing optimization method that use proxy as part of the evaluation function.

In the fourth chapter, we describe the approach proposed in this thesis to optimize the flow control strategy, explaining how this approach allows reservoir management through the control of flow into the well, considering geological uncertainty and dynamically reacting to the acquisition of information to reduce uncertainties.

In the fifth chapter, we demonstrate our approach with a simple physical model, performing the optimization strategy proposed. We test our approach applying it on a synthetic reservoir model, developed based on selected data from a real reservoir. We created test scenarios to identify the ability of our approach to get reasonable and satisfactory solutions to the flexibility evaluation. We finish this chapter with a discussion of the results obtained.

In the sixth chapter, we conclude this thesis, pointing to the advantages and disadvantages of the proposed approach, and in the seventh chapter, we propose possible future works.