USE OF INTEGRATED PRODUCTION MODELING TO ESTIMATE THE INFLUENCE OF SUBSEA MANIFOLDS IN RESERVOIR PRODUCTION MANAGEMENT

Igor Ricardo de Souza Victorino  
CEPETRO (Center for Petroleum Studies)  
UNICAMP, PO BOX 6052  
Campinas, São Paulo, Brazil  

João Carlos von Hohendorff Filho  
CEPETRO (Center for Petroleum Studies)  
UNICAMP, PO BOX 6052  
Campinas, São Paulo, Brazil  

Marcelo Souza de Castro  
Department of Energy - Division of Petroleum Engineering, School of Mechanical Engineering and CEPETRO - UNICAMP  
PO BOX 6052, ZIP CODE 13083-970  
Campinas, São Paulo, Brazil  

Denis José Schiozer  
Department of Energy - Division of Petroleum Engineering, School of Mechanical Engineering and CEPETRO - UNICAMP  
PO BOX 6052, ZIP CODE 13083-970  
Campinas, São Paulo, Brazil

ABSTRACT

Integrated analysis of reservoir and production system models for field development can improve production forecasts. This integration allows the evaluation and optimization of parameters of both systems for both financial return and accurate production prediction. This work evaluates the presence and position of manifolds and their influence on production. We use a Brazilian benchmark case to perform an integrated analysis of oilfield production evaluating the influence of various aspects of manifold systems to increase financial return. The results showed that integrated analysis of optimized manifold locations and the number of connected wells improved financial return. Thus, we recommend the inclusion of this integrated production modeling in field management.

INTRODUCTION

In studies to develop offshore field production, the integration between reservoir and production systems is an important alternative, mainly in evaluations involving pressure interaction between reservoirs, the gathering network for submarine production and surface facilities (Al-Mutairi et al, 2010). This work analyzes the integration of reservoir and subsea production systems through simulations.

Barroux et al. (2000), Kosmala et al. (2003), and Rotondi et al. (2008) described the importance of an integrated methodology for commercial simulators and developed models for more reliable production forecasting. In this context, parameters and operating conditions of the production system should be carefully analyzed, especially when complex. Complex production systems mean more complex models and generally higher computational effort.

One such complexity in production systems is the insertion of manifolds. Oil recovery from a subsea well is either sent directly to the platform or through subsea equipment, which combines the flow of a group of wells to send to the platform. These intermediary units are called manifolds and are used in offshore oil field production when physical platform constraints limit the number of direct connections. These constraints pertain to the size and weight of platforms.

Manifolds allow a single connection with a platform between several wells, reducing the need for further platforms and so reducing cost (Silva et al., 2007). Other aspects influencing design and cost should be considered when including manifolds in production systems. These are the location and distance to the platform, the number, type, and material of the manifold.

Manifolds are usually used when several neighboring wells are far from the platform. Manifolds reduce the number of subsea flowlines, gathering production lines and consequently the weight of the platform. In summary, the number and location of manifolds are key to success. The number of
manifolds is determined by the number of wells to be interconnected. The maximum production rates should offset the high CAPEX of a system comprising many manifolds.

Optimal positioning of a manifold considers the distance to the connecting wells and their distance from the platform.

Another consideration is the number of platforms used in a production project. Although the cost to build a platform is higher than for a manifold, the total cost of many manifolds could be unfeasibly high. Therefore, platforms must be designed to optimize processing capacity and be able to receive all pipelines directly. To reduce costs for the benchmark case with irregularly distributed wells, we consider the minimum number of platforms and manifolds, shortest possible pipe length between wells, manifolds and platforms and suitable platform location.

These production system requirements should be analyzed jointly with reservoir constraints to maintain or increase oil production while reducing costs.

There has been little study of manifold allocation in terms of the number of wells to be connected and platform location until recently (Echeverría and Wagenaar, 2016; Sales et al., 2016). The proposed strategy contributes further knowledge, procedures, and strategies in this area.

To optimize two of the most influential aspects in an integrated analysis: the number of wells connected to a single manifold, and the manifold location, we evaluate the predicted financial return and compare this with a strategy that uses only satellite wells. Systems with manifolds are more complex, changing the boundary conditions and limits of the production of the reservoir.

This work is an extension of the 12-Step decision analysis methodology by Schiozer et al. (2015). The methodology has obtained good results in many decision analyses relating to the development and management of oil fields considering: reservoir simulation, risk analysis, uncertainty reduction techniques, representative models, and production strategy selection. The authors suggested integration with production systems in Step 6 (selection of deterministic production strategy for base case). The decision (production strategy) and the risk quantification have mutual influence so using an iterative technique to select the production strategy is important. Step 11 identifies potential for change in the production strategy without manifolds.

In stage 1, the manifold coordinates are chosen randomly in a predetermined search space to consider different sets of wells to be connected to the manifold. In each selected coordinate for a manifold, some wells are connected while others remain unconnected as satellite wells. This procedure evaluates manifolds individually for each group of wells defined in a given region. The best results for manifold coordinates and wells to be connected are selected and used in the next step.

In stage 2, different combinations of pipe diameters are tested to find the combination with the highest NPV.

Stage 3 combines manifolds to generate new production systems, the strategy with the highest NPV is selected and compared with a production strategy without manifolds.

The methodology of this work is compared to the optimization methodologies presented by Gaspar et al. (2014) and Victorino et al. (2016). However, the many variables to be optimized could render the process impractical because of the complexity of evaluating multiple variables.

APPLICATION

The study uses the reservoir from the UNISIM-I-D benchmark case (Gaspar et al., 2015). We used the environmental conditions (reservoir pressure and temperature) for each well and the same base scenario of satellite wells as detailed by Hohendorff Filho et al. (2016). Only one type of fluid was considered, also under the same conditions. Empirical correlations of multiphase flow behavior by Beggs & Brill (1991) and of fluids by Standing (1947) were used.
The explicit integration methodology between reservoir and production system simulators was developed by Hohendorff Filho and Schiozer (2012). The reservoir simulator is CMG's IMEX and a proprietary multiphase flow simulator provides the multiphase flow data. The manifold computation code was developed by our research group, which uses a network balancing analysis, getting data of multiphase flow from the simulator when necessary. The explicit methodology calculates the production system sequentially only at the beginning of the time step, keeping it fixed until the end of the step. It allows the user greater flexibility to apply predefined well management rules. A black-oil model represents the fluid and we consider several parameters of the production system.

For all the conditions and procedures of explicit integration between reservoir and production system used in this work, see Victorino et al. (2016).

The work develops steps 6 and 11 of the 12-Step decision analysis methodology by Schiozer et al. (2015). Step 6 defines a basic production system for the base scenario and Step 11 identifies potential for change in production strategies to increase flexibility and robustness. Step 6 considers a base scenario of the production system developed in a multiphase flow software and Step 11 analyzes the manifolds and changes in pipeline diameters. NPV was selected as it considers maximized production and minimized costs (Neves, 2004).

Evaluation of well sets to be connected to manifolds

Potential coordinates for manifolds were randomly decided and spaced by 200 meters in x and y directions within a predetermined area to select the best set of wells to connect to a manifold.

This was assessed by the proximity of the wells to each other and to a platform. Table 1 presents the set of wells tested for a given manifold.

<table>
<thead>
<tr>
<th>Manifolds</th>
<th>Set of Wells Evaluated</th>
<th>Representation (Area - color)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manifold 1 (M1)</td>
<td>A. P9 and P21</td>
<td>1 - Yellow</td>
</tr>
<tr>
<td>(Group 1)</td>
<td>B. P9, P21, and P5</td>
<td></td>
</tr>
<tr>
<td>Manifold 2 (M2)</td>
<td>C. P14 and P24A</td>
<td>2 - White</td>
</tr>
<tr>
<td>(Group 2)</td>
<td>D. P14 and P25A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E. P24A and P25A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F. P14, P24A, and P25A</td>
<td></td>
</tr>
<tr>
<td>Manifold 3 (M3)</td>
<td>G. IL_NA1A and P12</td>
<td>3 - Black</td>
</tr>
<tr>
<td>(Group 3)</td>
<td>H. IL_NA1A, P12, and P10</td>
<td></td>
</tr>
<tr>
<td>Manifold 4 (M4)</td>
<td>I. P23A and P26</td>
<td>4 - Red</td>
</tr>
<tr>
<td>(Group 4)</td>
<td>J. P6 and P7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K. P23A, P6, P7, and P26</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 - Different sets of wells for each manifold.

Evaluation of pipe diameters

Using the results from the previous stage, optimized well set and manifold location, we evaluate different pipe diameters. We evaluated the FL and RI diameters of satellite wells and for the manifold systems FLm and RIm diameters. For each simulation, the chosen diameters were considered the same for each set of wells connected to their respective manifolds (for comparison).

For satellite wells, we used the following diameters: PC = 5”, FL and RI = 6”, and 8”. We evaluated diameters of 8”, 10”, and 12” for FLm and RIm. Table 2 shows the combinations for each case.

Figure 1 presents the region with the x and y coordinates for manifold positioning. As shown in Table 1, for each manifold (1, 2, 3, and 4), the set of wells tested has the same coordinates, for example, to evaluate the manifold 1 with two possibilities: 1 (P9 and P21) and 2 (P9, P21, and P5) the coordinates of the manifolds were the same for both cases. The same principle was applied to the other manifolds and their respective sets of wells tested. For each manifold coordinate the set of wells connected (of a specific group) was changed until finding the largest NPV, the coordinate is updated and the process is repeated.

The process ends with the highest NPV for the manifold position and the group of wells. For these simulations, the diameters for flowlines (FL) and risers (RI) = 6”, production columns (PC) = 5” for satellite wells as suggested by Victorino et al. (2016). The diameter of pipes comprising a manifold system, flowlines (FLm) and risers (RIm) was set at 8”.

![Figure 1 - Area considered in the evaluation of the best coordinate for manifolds.](image-url)
Table 2 - Simulated cases with different combinations of pipe diameters in satellite wells and manifolds for each set of connected wells.

<table>
<thead>
<tr>
<th>Cases</th>
<th>PC,FL,RI (in)</th>
<th>Manifolds (Mi)</th>
<th>Combinations FLm and RIm (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5,6,6</td>
<td>M1,M2</td>
<td>8,8; 8,10; 8,12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M3,M4</td>
<td>10,8; 10,10; 10,12</td>
</tr>
<tr>
<td>2</td>
<td>5,8,6</td>
<td>M1,M2</td>
<td>8,8; 8,10; 8,12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M3,M4</td>
<td>10,8; 10,10; 10,12</td>
</tr>
<tr>
<td>3</td>
<td>5,8,8</td>
<td>M1,M2</td>
<td>12,8; 12,10; 12,12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M3,M4</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5,6,8</td>
<td>M1,M2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M3,M4</td>
<td></td>
</tr>
</tbody>
</table>

Considering four manifolds and 36 scenarios, we ran 144 simulations to define the combination diameters for satellite-well pipes and those connecting to manifolds. The best combinations were selected for the next stage.

**Analysis of manifold combinations for the production system integrated to the reservoir**

We considered 11 cases evaluating 4 manifolds (M1, M2, M3, and M4). Six cases comprise two manifolds, four cases comprise three manifolds, and one case with all manifolds.

**RESULTS**

Table 1 summarizes the sets of wells for each manifold. The set presenting the highest NPV for each manifold was selected and the coordinates identified for each manifold and respective well set. The combination of pipe diameters was optimized for NPV. The combinations of 2-4 manifolds were tested through several production scenarios, using NPV to identify the optimum configuration for this field. We identified various configurations with increased NPV over the strategy without manifolds. The results showed that the integration technique contributed to the improvement of the production strategy.

**Choice of well sets to be connected to manifolds**

Figures 2 to 5 present the performance results of well sets, those with the best NPV are selected for the following stage based in the search area in Figure 1.

In Figure 2, the well set comprising P9-P21-P5 presented the highest NPV. Figure 3 includes the well set with P14 and P24A, selected for the best NPV.

In Figure 4, the well set IL_NA1A and P12 presented the best NPV values. The results of these well sets indicated overall lower performance compared to the previous well sets. This may indicate that these wells should remain unconnected and produce as satellite wells instead. Further analyses are required to confirm this.
Figure 5 shows the highest NPV values were from the well set with P6 and P7, indicating this set to be most suitable for connection to a manifold.

The analysis identified the best well set for each manifold to be: Manifold 1 M1: P9, P21, and P5; M2: P14 and P24A; M3: IL_NA1A and P12; and M4: P6 and P7.

Sensitivity analysis for pipe diameters

The well sets selected in the previous stage were used to test different combinations of pipe diameters. We categorized two classes of pipes, the first for satellite wells not connected to manifolds (comprising production columns (PC), flowlines (FL), and risers (RI)) and the second class for pipes connected to manifolds by flowlines (FLm) (arriving) and risers (RIm) (leaving) the manifold. We compared this against the work of Victorino et al. (2016) where the production columns all measured 5". Table 2 gives the diameters evaluated.

Figure 6 presents the results of different combinations for satellite wells (PC, FL, and RI); and diameters for FLm and RIm of pipes connected to manifolds (Φ).

The best combination for satellite wells was 5", 8", 8". We found differing values for each manifold.

The best diameters measured by NPV were FLm=8" and RIm=12" for M1; FLm=10" and RIm=10" for M2; FLm=10" and RIm=12" for M3; and FLm=10" and RIm=12" for M4.

Based on the integrated analysis by Victorino et al. (2016), the best results for a system without manifolds used the diameters PC=5", FL=6", and RI=6". This work selected the combination of PC=5", FL=8", and RI=8" in a system using manifolds. This highlights that using manifolds in a subsea gathering network increases the complexity of the system. The production behavior, limits and boundary conditions of the reservoir can change and consequently the financial return. Thus, a more realistic and thorough evaluation is needed for the project development and the production strategy for this oil field.

Evaluation of the allocation and combinations of manifolds for the submarine production system

This work examines the results of using four manifolds (M1, M2, M3, and M4) and whether using all of them improves the financial return. Figure 7 shows the location of each manifold and the respective optimized well sets selected in this work. With the best NPV, M1M4 is used to configure the production system. In this case, manifolds M2 and M3 are unnecessary. We analyzed combinations of 2, 3, and 4 manifolds comprising the production system integrated with the reservoir, evaluating the manifolds and respective well sets. The difference between the NPVs was minimal and this allowed us to decide the best system to be adopted (the study suggests other complementary evaluations that can be discussed for a definitive decision) (Figure 8).
Figure 7 - Location of manifolds M1, M2, M3, and M4.

Figure 8 shows the NPV for different simulated manifold combinations. The two best values were for the combination of M1 and M4 and, the combination of M1, M2, M3, and M4. M1 and M4 presented the best NPV of 3155.81 MM US$ compared to the R1 reference value (2943.00 MM US$) obtained by Victorino et al. (2016). Note that our economic evaluation excluded intervention and maintenance costs, among others. These issues may influence the NPV value and we suggest further research.

Figure 8 - Analysis and evaluation of manifold combinations.

**Evaluation and comparison of production between satellite wells and wells connected to manifolds**

Using the scenario for M1 and M4, we compared the oil and water production and BHP (Bottom-hole Pressure) of wells, selected to be connected to manifolds, as satellite wells and when connected to manifolds.

This comparison was a good indicator of the complexities and details involved for equipment and geometry as well as for different well conditions (reservoir temperatures, pressures, and fluid composition). We achieved increased NPV for a system with manifolds, but adverse situations could occur, especially for such a highly complex system. Figure 9 (A and B) shows the oil production flow rates comparing satellite wells and wells connected to manifolds.

Figure 9 - Comparison of oil flow rate of wells connected to manifolds and without manifold (*) (A) shows wells P5, P9, and P21 and (B) the wells P6 and P7.

Figure 9 (A) shows the oil production flow rates for wells P5, P9 and P21 connected to manifold M1 and also as satellite wells (indicated by *). We observed periods of time when oil production fluctuated whether manifolds were used or not. The oil production was similar for manifold and satellite systems, but with big differences in NPV due to reduced costs.

Figure 9 (B) shows little difference for P6 and P7 as satellite or connected to manifolds. Figure 10 (A and B) shows the water flow rate of each well along the productive life of the field. We compared cases with and without manifolds and their respective diameters (PC=5", FL=6", and RI=6") (Victorino et al., 2016) and (PC=5", FL=8", and RI=8") to evaluate manifold combinations (with changes of diameters of pipes FLm and RIm).

Figure 10 - Comparison of water flow rate of wells connected to manifolds and without manifold (*) (A) shows wells P5, P9, and P21, and (B) the wells P6 and P7.
The simulations for the same wells, as satellites and connected to manifolds, presented significantly increased water production for all wells when manifolds were used.

Figure 11 (A and B) compares the BHP profiles for wells connected to manifolds and as satellites.

![Figure 11](image)

Figure 11 - Comparison of bottom-hole pressures of wells connected to manifolds and as satellite (without manifold - *) (A) shows P5, P9, and P21, and (B) the wells P6 and P7.

We increased financial return using manifolds but found that changes to the gathering system may be necessary for enhanced performance and informed field management.

CONCLUSIONS

The significant changes to the production system including new equipment or new modifications to the submarine gathering network changed production behavior and so needs evaluation. The limits and boundary conditions of reservoir production vary and also affect the production strategy.

Including manifolds in the integrated system increased the complexity of the gathering system, implying new limits and boundary conditions in the reservoir production. The optimization strategy applied in this production system allowed understanding and decision-making to amend and improve the system. We also developed and managed the field with greater efficiency and control. Our promising results, compared with the work of Victorino et. al. (2016), supported the practical application of the strategy and methodology.

This work used NPV as the objective function to identify changes in the production system influencing reservoir production. The case with manifolds showed a higher increase of the financial return, despite similar oil production. While the overall production was similar for cases with and without manifolds, it varied at different periods.

The best locations for the manifolds were at intermediate distances between wells and the platform, and in some cases, near the platforms.

The integration of the reservoir and the production system considers changes (in real time) of the reservoir conditions in the simulations. This influences well production and the position of the manifolds by balancing pressure between the wells and the manifolds, improving production.

The changes in pipe diameters for both satellite and manifold systems were optimized, the latter due to the influence of the pressure equilibrium in the manifolds and consequently production, generating additional costs as well as revenue.

This supports the use of more complex boundary conditions to improve result reliability and create a more realistic production considering the production of real oil fields. However, more complex production systems require higher and often infeasible computational effort for the integration technique between the reservoir and multiphase flow (production) software.

The study highlighted better options to analyze choices and criteria when applying evaluation and optimization methodologies. Thus generating more reliable results to base decisions for production strategy changes in complex projects.

NOMENCLATURE

PC: Product Column (connected to satellite well)
FL: Flowline (connected to satellite well)
RI: Riser (connected to satellite well)
FLm: Flowline (connected to manifold)
RIm: Riser (connected to manifold)
Pᵢ: Producer Well i
IL_NA1A: Producer Well Mi: Manifold i (i=1,2,3 and 4)
BHP: Bottom-hole Pressure

ACKNOWLEDGMENTS

This work was conducted with the support of Foundation CMG and Petrobras within the ANP R&D tax as "commitment to research and development investments". The authors are grateful for the support of the Center of Petroleum Studies (CEPETRO-UNICAMP/Brazil), the Department of Energy (DE-FEM-UNICAMP/Brazil), Foundation CMG, and Research Group in Reservoir Simulation and Management (UNISIM-UNICAMP/Brazil). In addition, special thanks to CMG for software licenses.

REFERENCES


