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*"PID parameters need to be tuned properly in order to drive the process to stability with error close to zero."*

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## OSCILLATION MITIGATION IN SUBSURFACE AND SURFACE COUPLINGS USING PID CONTROLLERS

KILDARE GEORGE RAMOS GURJÃO

### Introduction

Simulations integrating subsurface and surface systems, known as Integrated Asset Modeling (IAM), are important in field development/optimization studies [1] as it can lead to better prediction of reservoir performance and consequent higher production and financial outcomes. Proper subsurface/surface integration brings greater accuracy in predicting reservoir deliverability as it captures the complex interactions between reservoir, wells, pipelines and surface/process facilities.

A relevant technique used to integrate reservoir and production systems is the explicit coupling: managed by a coupling program, multiple selected simulators are combined to simulate the fluid flow in each system of the field.

In this process, data exchange between reservoir simulator and coupling program is required, which is accomplished by the passage of Inflow Performance Relationship (IPR) curves from reservoir simulator to coupling program and well operating point (fixed constraint) from coupling program to reservoir simulator. Since the balancing between simulators takes place at the beginning of each time step (non-continuous), IPR curve and fixed constraint sometimes may not be representative for the entire coupling interval, causing errors and oscillations in the results throughout the simulation.

What makes the process more susceptible to instabilities is the fact that reservoir simulator traditionally calculates the IPR curve (Figure 1) based on Peaceman equation [4], which is dependent on well block pressure ($p_{Block}$) instead of well drainage pressure ($\bar{p}$).

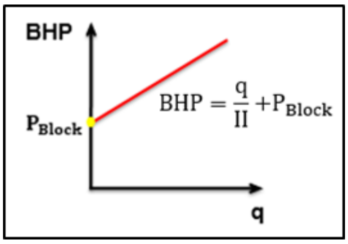


***Figure 1:*** *IPR used in reservoir simulator for injector well.*

In order to mitigate subsurface/surface explicit coupling instabilities in a simple and efficient way, a new methodology based on PID controller that corrects the traditional IPR curve attempting to determine a more representative operating point for the entire coupling time step was developed [3].

### Introduction to PID control theory

The PID (proportional, integral and derivative) controller is a control loop feedback mechanism widely used in engineering problems. The popularity of this type of controller can be attributed to its robust performance and function simplicity, which allows engineers to operate them in a simple and straightforward manner.

The fundamental operation of a PID controller can be represented in the block diagram of Figure 2. Based on calculated error (difference between set point and measured variable), controller output is updated every time step in order to determine a new manipulated variable that will be applied in the process to keep the measured variable at the set point value.

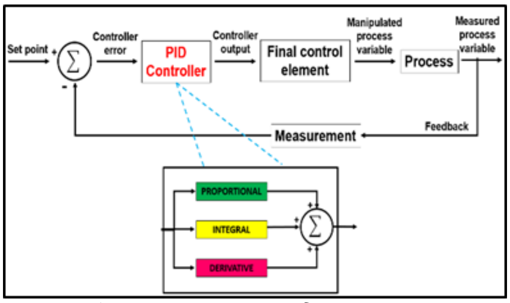


***Figure 2:*** *Block diagram of PID controller.*

The output of a PID controller is determined by the sum of proportional, integral and derivative terms, and can be calculated by the continuous PID controller algorithm (Equation 1).

$$u(t) = \underbrace{K_C e(t)}_{Proportional} + \underbrace{\frac{K_C}{\tau_I}\int e(t)dt}_{Integral} + \underbrace{K_C \tau_D \frac{de(t)}{dt}}_{Derivative} \quad [Equation\ 1]$$

where $K_c$ is proportional gain, $\tau_I$ is integral time and $\tau_D$ is derivative time. They are known as PID parameters and need to be tuned properly in order to drive the process to stability with error close to zero. The specific characteristics of each component of PID controller (proportional, integral and derivative) can be found in [2].

### Methodology

At the beginning of each time step, coupling program receives the IPR curve from reservoir simulator, applies a correction to it based on the PID controller actuation strategy (process described next) and calculates a new operating point ($q_{op}$, $BHP_{op}$).

The operating point flow rate ($q_{op}$) is imposed in the reservoir simulator as fixed constraint (4 in Figure 3) for the entire coupling interval, operating point bottom-hole pressure ($BHP_{op}$) is defined as PID controller set point (1 in Figure 3), and well bottom-hole pressure calculated by reservoir simulator ($BHP_{RS}$) is taken as measured variable (5 in Figure 3). At the end of coupling interval, the difference between set point and measured variable is the error (2 in Figure 3).

At the beginning of next time step, error is the input of PID controller (discrete velocity), which is an algorithm obtained by time discretization of Equation 1. The PID controller output [$u(t_k)$] (3 in Figure 3) is used by the coupling program to calculate an estimation of a stable pressure ($P_{stable}$) capable to correct the IPR curve received from reservoir simulator modifying its linear and angular coefficients, in such a way that the new IPR curve can be used to determine a proper operating point for the next entire coupling interval. Equations 2 and 3 are used to calculate the estimation of $P_{stable}$ for producer and injector wells respectively.

$$P_{Stable} = P_{Block}\left[1 + ABS\left(u(t_k)\right)\right] \quad [Equation\ 2]$$
$$-1 \le u(t_k) \le 1$$

$$P_{Stable} = P_{Block}\left[1 - ABS\left(u(t_k)\right)\right] \quad [Equation\ 3]$$
$$-1 \le u(t_k) \le 1$$

*"In the case study, PID controllers shown to be a promising method to mitigate the oscillations in subsurface-surface couplings."*

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This whole process is repeated until the end of the simulation time span.

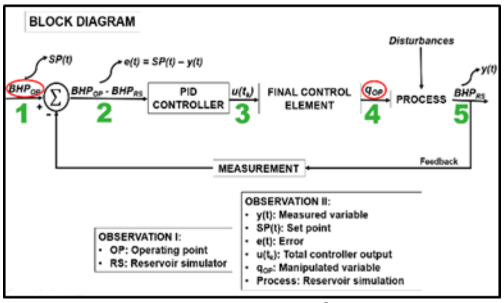


***Figure 3:*** *PID controller block diagram of the methodology implemented to minimize oscillation problems of subsurface/surface explicit coupling.*

### Application

The study is applied to the UNISIM-I-D benchmark, which is based on the Namorado Field, located in Campos Basin in Brazil. The production system considered is comprised by satellite wells connected from the bottom-hole to the separator on the platform by production column, flowlines and riser.

### Results

Explicit coupling between reservoir and production systems of UNISIM-I-D benchmark without PID controllers caused instabilities in 3 out of 13 producer wells (PROD 010, PROD 025A, PROD 026) and in all 7 injector wells (INJ 006, INJ 010, INJ 017, INJ 019, INJ 021, INJ 022, INJ 023). These wells either closed or kept opened with BHP and flow rate oscillating. This is depicted in figure 4 for flow rate of injector wells.

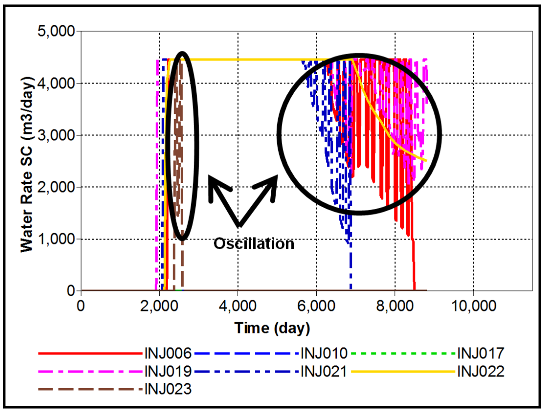


***Figure 4:*** *Water rate of injector wells - explicit coupling without PID controllers.*

To minimize the instabilities, two global and manually tuned PID controllers were implemented in the case study: one for the group of 7 injectors and another for the group of 3 producers. In this case, $K_c = 0.00095$, $\tau_I = 8.7$ and $\tau_D = 6.5$ were selected as ideal constant values for both controllers. Figure 5 show the flow rate of injector wells after the application of tuned PID controller.

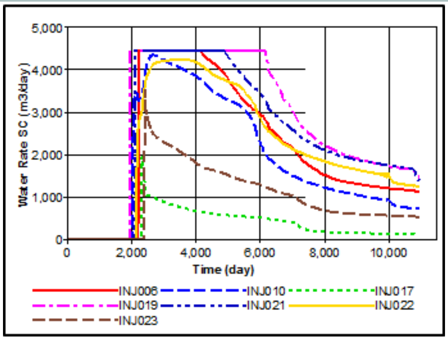


***Figure 5:*** *Water rate of injector wells - explicit coupling with PID controllers.*

Depending on the scenario of application, PID controller can be designed by the selection of different terms as set point, measured and manipulated variables in order to make its performance as better and efficient as possible. However, since not all combinations work suitably minimizing the explicit coupling numerical instabilities, a sensitivity analysis study should be performed with different variables in order to select the possible groups that can work properly for a specific case.

### Conclusions

In the case study, PID controllers shown to be a promising method to mitigate oscillations in subsurface-surface couplings along with low computational cost and avoiding access to the simulator's internal codes.

### References


[1] Ghorayeb, K., Holmes, J., Torrens, R. [2005] Field Planning Using Integrated Surface/Subsurface Modeling. SPE 92381. 14th SPE Middle East Oil & Gas Show and Conference, Bahrain.

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