

On-line Monitoring and Control of an Oil Well Drilling Process

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During oil well drilling, the pore pressure (minimum limit) and the fracture pressure (maximum limit) define mud density range. As a result, the drilling fluid hydrostatic pressure needs to be higher than pore pressure, in order to avoid formation fluid invasion into the well. Simultaneously, the drilling fluid hydrostatic pressure needs to be smaller than fracture pressure, for avoiding formation damage. On-line monitoring and control schemes concerning the drilling process constitutes a powerful tool for operating under desired pressure levels and simultaneously maximizing the penetration rate, which reduces costs, as oil derrick operation demands around U\$220,000.00/day. In this paper, studies concerning on-line monitoring and control strategies to an oil well drilling process were carried out, also using an experimental well plant, in order to guarantee safe operation (target annulus bottom hole pressure) and maximizing drilling rate. The major objective of this paper is bottom hole pressure regulating inside operational window, between pore pressure (minimum limit) and fracture pressure (maximum limit), in order to assure safe environment during oil well drilling.

1. Introduction

A drilling system consists of a rotating drill string, which is placed into the well. The drill fluid is pumped through the drill string and exits through the choke valve. An important scope of the drill fluid is to maintain a certain pressure gradient along the length of the well. Well construction is a complex job in which annular pressures must be kept inside the operational window (limited by fracture and pore pressure). Monitoring bottom hole pressure to avoid fluctuations out of operational window limits is an extremely important job, in order to guarantee safe conditions during drilling job. Several operational parameters have a direct impact on bottom hole pressure such as flow rate, rate of penetration, drilling fluid properties, etc. This way, due to the several parameters to be handled, bottom hole pressure control is a complex task and is (nowadays) a manual and very subjective job. Thus, control and automation of drilling operations is a required activity for future challenge of petroleum engineering.

This job presents the results of the implementation of a phenomenological model aiming the development of a classic PI (proportional - Integral) controller for bottom

hole pressure during a drilling job. Some strategies were investigated by handling flow rate and a choke opening. An experimental unit was built to study pressure control, when the system is disturbed by an ROP (rate of penetration) steps or choke openings. Results show a non linear behavior, what requires the system investigation in different operational conditions in order to make a classic PI controller reliable. This fundamental study represents an important step in the understanding the requirements for the implementation of the drilling automation process.

2. Materials and Methods

A well drilling unit was built using a drill string of 2.8 m, containing on-line flow – density sensors (Metroval - RHM20), based on Coriolis effect and a pressure transducer (SMAR - LD301-M). The unit has two feeding tanks - water (8 ppg) and mud (15 ppg – pseudo plastic behavior), making feasible the annulus injection of varying solid concentrations, which in fact represents the implementation of different rates of penetration. A mud pump (Weatherford - 6 HP) connected to a frequency inverter, a choke line (choke valve – ASCO - 290PD-25MM) and butterfly valves (Bray – series30/31) connected to the feed tanks (rate of penetration) are the experimental unit manipulated variable candidates that may be used for controlling annulus bottom hole pressure. In addition, a computational program was built in order to monitor and control the drilling unit, using C++ language (Fig. 1). A detailed description of the oil well drilling unit may be found in Vieira (2009).

3. Results

3.1 Simulation studies

A nonlinear mathematical model (gas-liquid-solid), representing the drilling system, was developed based on mass and momentum balances. The annulus bottom hole pressure was defined as the summation of annulus compression and hydrostatic pressures, frictional losses, pressure loss over the choke and atmospheric pressure.

The mass balance comprised two systems: the drill string and the annulus between the wall of the well and the drill string. The momentum balance was evaluated at the drill bit and at the choke valve, taking into account frictional losses and compression and hydrostatic pressures. The flow from the reservoir into the well was modeled using a simple relation named productivity index, which is a constant scalar defining the mass flow rate based on the pressure difference between the reservoir and the well. The dynamic simulation of the drilling system phenomenological model for varying choke opening index and flow rates is shown in Fig. 2.

The nonlinear mathematical model was employed in order to analyze the performance of a PI controller scheme, using pump flow rate as the manipulated variable, for regulating annulus bottom hole pressure. The simulation studies were carried out in order to investigate the viability of that input-output control scheme for plant implementation purposes. Fig. 3 illustrates servo and regulatory control tests, using Jenner et al. (2004) mechanical system, developed to be able to continuously pumping the drill fluids, even during the pipe connections. Fig. 3a presents the disturbance

related to varying rates of penetration, including a pipe connection procedure (drilling rate, $v_d=0$). Fig. 3b presents the control moves (manipulated variable) in order to regulate annulus bottom hole pressure. Fig. 3c illustrates a servo control test implementation, being required set point tracking at 300 bar. Next, controller performance is analyzed for a disturbance rejection situation, related to lost circulating problems, as pore pressure is modified for being smaller than annulus bottom hole pressure. It can be observed that the controller action was also efficient in rejecting rate of penetration changes, even in the pipe connection procedure, where the rotation of the drill sting is stopped.

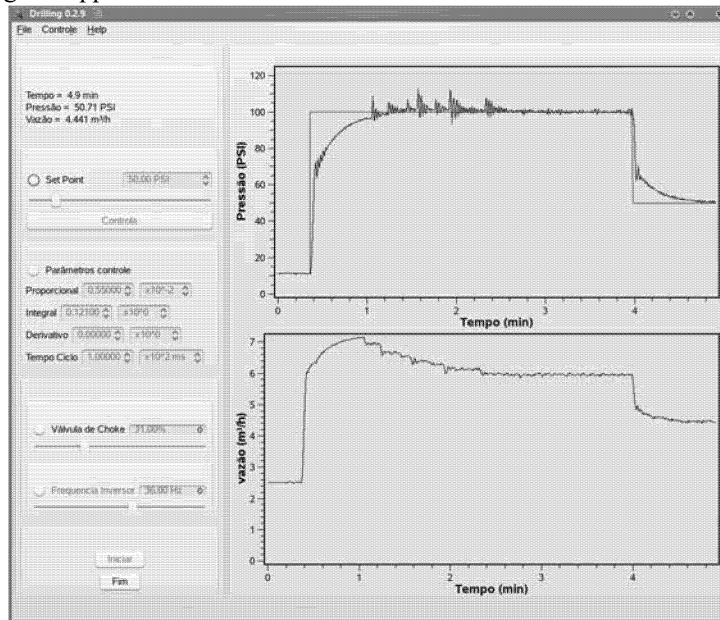


Fig. 1 - Monitoring and control C++ computational program.

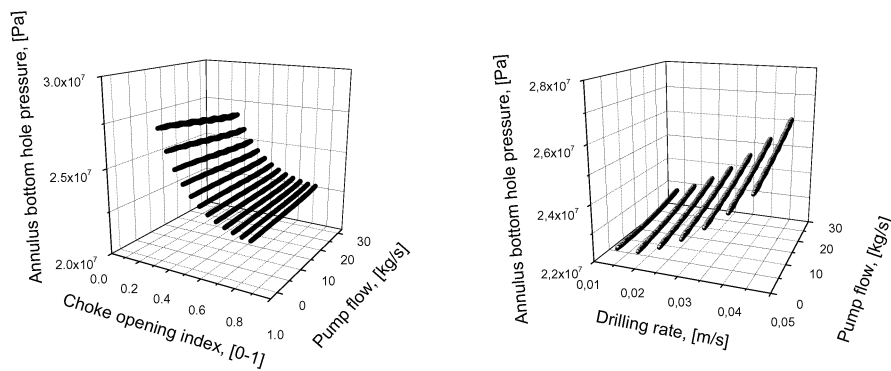


Fig. 2 - The drilling system model dynamic simulation.

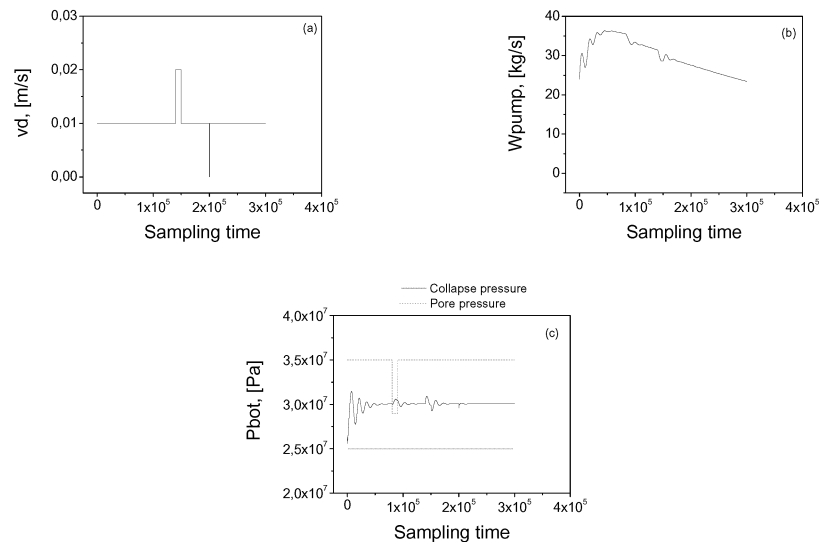


Fig. 3 – Servo and regulatory under-balanced drilling control tests (simulation).

Vega et al. (2008) reported that manipulating mud density is difficult for practice implementation purposes, and pointed out that the use of penetration rate, as manipulated variable, is inappropriate during pipe connection procedures, performed at equal time intervals during drilling. In addition, it was mentioned that the use of choke valve would be an interesting approach, for this device produces rapid and severe changes at annulus bottom hole pressure. As a result, analyzing simulating results, it may be concluded that the use of pump flow is appropriate for annulus bottom hole pressure control, during oil well drilling. In addition, pump flow affects annulus bottom hole pressure through changes of both frictional losses and solid concentration, altering solid residence time into the well. The use of choke opening index impacts annulus bottom hole pressure, through varying pressure drop produced by valve restriction, otherwise, has no cleaning action for positive displacement pump imposes constant solid residence time, no matter the choke valve position. In fact, there are oil well drilling rigs that do not have the choke valve device. As a result, in this work, experimental control studies employed pump flow as the manipulated variable in order to control annulus bottom hole pressure.

3.2 Experimental studies

A non linear analysis (step test), plant identification and controller parameter estimation were implemented over different operational levels. Step test results showed a non linear plant behavior, what required the system investigation in different operational conditions in order to make a classic PI controller reliable. PI controller parameters were developed through a priori implementation of reaction curve (Ziegler-Nichols, 1942) and Sundaresan & Krisnaswany (1977) identification methodology, using the strategies of Ziegler-Nichols, 1942 and Cohen-Coon (Cohen-Coon, 1953).

Servo control test concerns the implementation of a set point change for annulus bottom hole pressure, which must be tracked through manipulated variable moves (pump flow or frequency inverter devices). Pump flow is varied according to the controller parameters fed to the C++ computational program, which remotely operates the plant, using a sampling time of 0.1 seconds. Fig. 4 illustrates the successful servo tests implementation, using water as the drilling fluid, assuring drilling conduction inside operational window, between pore pressure (minimum limit) and fracture pressure (maximum limit), using 25%, 55% and 95% choke valve opening index.

Regulatory control tests were successfully implemented through introducing a plant load disturbance in the rate of penetration levels, which were experimentally produced by changing the drilling fluid from water to a 15 ppg drilling mud. Fig. 5 illustrates a set point change implementation followed by a regulatory control test, rejecting a density disturbance (water to 15 ppg drilling mud), using 25%, 55% and 95% choke valve opening levels. It can be observed that the discontinuous flow behavior is always present, being associated to the experimental unit configuration (parallel feeding).

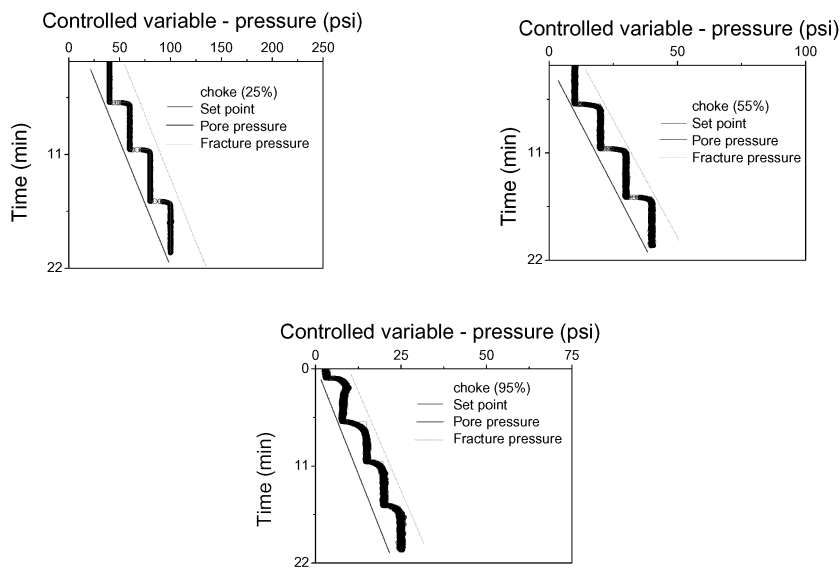


Fig. 4 - Servo control tests under operational window

4. Conclusions

A phenomenological mathematical model was developed based on first principles in order to implement classic control (PI) on an oil well drilling system for regulating annulus bottom hole pressure. Simulation results pointed out that using pump flow as a manipulated variable is feasible, which motivated the use of that variable at plant site. An experimental unit was built for analyzing recurrent phenomena that occur during the oil well drilling process. The experimental plant contained on-line flow – density sensors (Metroval - RHM20), pressure transducer (SMAR - LD301-M), two feeding tanks, mud pump (Weatherford - 6 HP), choke valve (ASCO - 290PD-25MM) and

butterfly valves (Bray – series30/31) connected to the feeding tanks. A non linear analysis (step test), plant identification and controller parameter estimation were implemented over different operational levels. An experimental controller was built in order to guarantee inside operational window drilling path and disturbance (rate of penetration fluctuations) rejection.

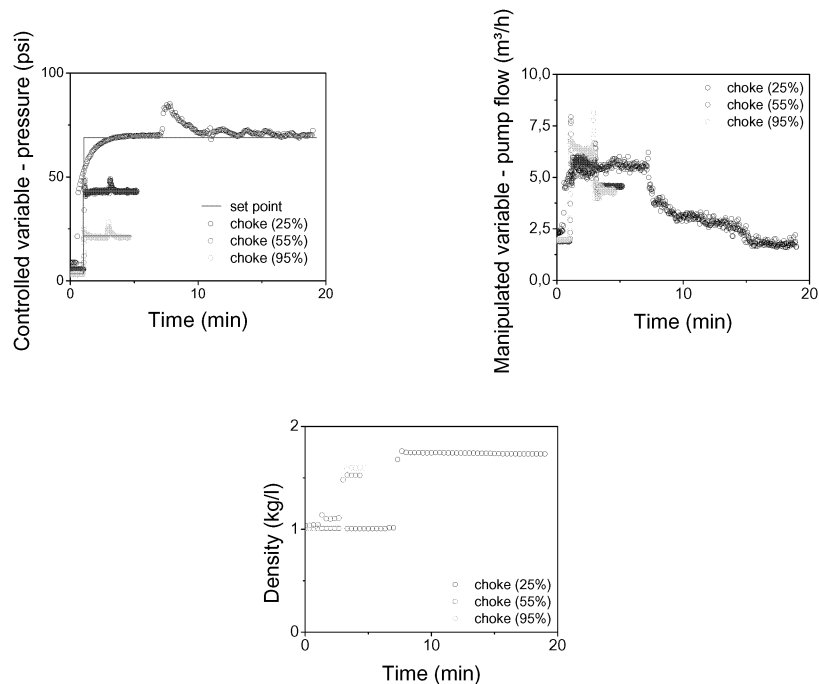


Fig. 5 – Closed loop (regulatory control test)

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