Mechanistic time dependent modeling & simulation of Underbalanced Drilling operations (a case study)

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Abstract

Uderbalnaced drilling is a drilling method stands on keeping bottomhole pressure below formation pore pressure which leads to formation fluid(s) production under a controlled situation. This paper presents an advanced dynamic model and computer simulation using commercial multiphase flow simulator (OLGA) for underbalanced drilling. The model is formulated based on the theory of multiphase transient flow referring to the drilling mud, water, oil, gas. Many of important factors affecting underbalanced drilling have been taken into account comprehensively in the model, including IPR relation, physical properties and mass transfer behavior of fluids, flow regime and phase migration features, geometry and deviation of wellbore as well as the different operating modes which may be carried out in practical underbalanced drilling. Through a number of simulating computations, tests and verifications, it is shown that the model and dynamic multi phase flow simulator (OLGA) give acceptable results in accordance with an actual drilling practice.

Keywords: Underbalanced drilling (UBD), dynamic multiphase flow simulator (OLGA), multiphase phase flow, Mechanistic time dependent modeling

Introduction

Underbalanced drilling (UBD) is the drilling process in which the wellbore pressure is intentionally designed to be lower than the pressure of the formation being drilled. This underbalanced pressure condition allows the reservoir fluids to enter the wellbore during drilling, thus preventing fluid loss and related causes of formation damage. As a result, special and additional equipment, and procedures are required before, during, and after a UBD operation. In addition, to improving well productivity by preventing fluid loss and formation damage, underbalanced drilling offers several other significant benefits that are superior to conventional drilling techniques. These include increased penetration rate and bit life, reduced probability of sticking the drillstring downhole, and improved formation evaluation.[1]

In underbalanced drilling, the concept of primary well control (containing the formation fluids by means of hydrostatic columns greater than the formation pressure) is replaced by the concept of flow control. In flow control the bottomhole pressure (BHP) and influx of formation fluids must be controlled. Therefore, in UBD operations the BHP must be maintained between two pressure boundaries, which delimit the underbalanced drilling pressure window. Figure 1 illustrates this UBD pressure window in which the lower limit on BHP is determined by the borehole stability or the flow rate or pressure capacity of the surface equipment. Whereas, the formation pore pressure gives the upper limit on BHP.[2]

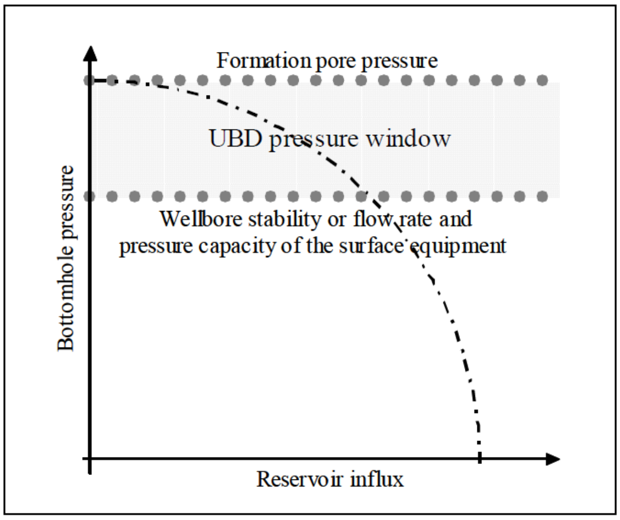

Figure 1- Underbalanced drilling opearting pressure window [2]

Steady State Modelling Approach

Guo et al developed a computer program to predict the optimum air injection rate that ensures a maximum penetration rate and cuttings transport capacity. Although they recognize that four principal flow patterns can be distinguished in multiphase flow (bubbly, slug, churn, and annular), based on experiences gained from well control, they assumed that the aerated mud can be treated as a homogeneous mixture of liquid, gas and solids, provided that it is flowing in the bubbly regime.[3]

Liu et al developed a computer model to analyze UBD foam operations. They also considered that foam can be treated as a homogeneous fluid and used the mechanical energy equation in which the frictional pressure drop depends on the foam rheology and the equation of state. This mathematical model was coupled with the Beggs and Brill empirical correlation and used to develop the UBD commercial computer program called MUDLITE. In addition to the wellbore pressure predictions, this computer program allows the prediction of flow patterns, liquid holdup, and in-situ gas and liquid velocities. However, it has been shown that the Beggs and Brill correlation over predicts or fails to predict bottom hole pressures.[4],[5]

Hasan and Kabir developed a mechanistic model to estimate void fraction during upward cocurrent two-phase flow in annuli, and Hasan developed a mechanistic model to estimate void fraction during downward cocurrent two-phase flow in pipes. They utilized the drift-flux approach to predict the gas void fraction in bubble and slug flow. However, for slug flow, this represents a simplification that does not rigorously consider the difference in the drift-flux between the liquid slug and the Taylor bubble. Caetano, from experimental and analytical work, stated that two possible conditions must be considered to accurately predict slug flow parameters.[6] Figure 2 Shows dominant UBD flow patterns for drillstring geometries, and Figure 3 shows flow patterns commonly occur in annular geometries, based on steady state modeling and simulation results. Regarding to Figure 3,bottom hole pressure likes to be kept between bubble & slug flow regimes, However, choke(surface) pressure is held in churn flow pattern.

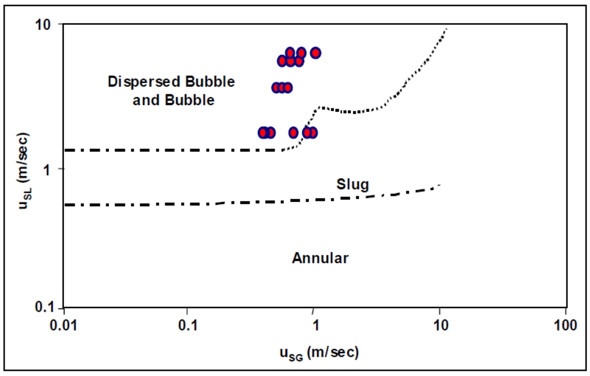

Figure 2- dominant UBD flow patterns for drillstring geometries [2]

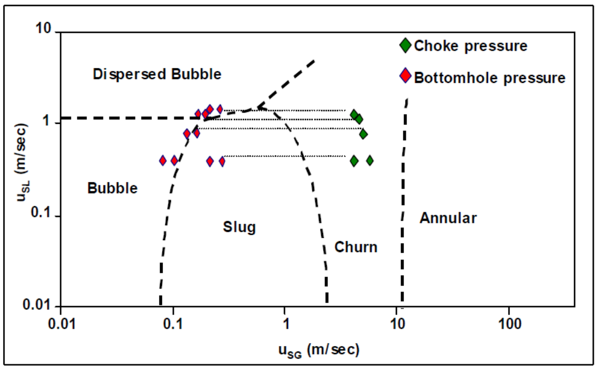

Figure 3- flow patterns commonly occur in annular geometries [2]

Mechanistic Time Dependent Modeling Approach

Application of mass, momentum, and energy conservation permits the calculation of pressure, temperature, and flow parameters as a function of position and time. Considering that in UBD operations the surface temperature and the geothermal gradient are usually known, it is not necessary to solve the equation of conservation of energy. Thus, in the case of two-phase flow, partial differential equations for conservation of mass and momentum should be written for each phase, and constitutive relationships for the fluid properties to specify the interaction between the two phases are needed. This would lead to a complex model with four conservation equations (two for each phase) and a number of problematic interfacial relationships. Since the specification of the interfacial conditions between liquid and gas remains a significant problem in a two-fluid model, a major simplification in the two-fluid model can be made. Instead of writing two momentum conservation equations (one for each phase), a single momentum equation can be written for the mixture as a whole resulting in a drift-flux model. Based on the fact that the motion of two phases in vertical conduits is strongly coupled, the idea of the driftflux model is to concentrate on the mixture as a whole rather than the individual phase. Thus, neglecting mass transfer between phases, the one dimensional form of the three-equation driftflux model is given by Equation 1, represents Mass conservation of liquid, Equation 2 mass conservation of gas, and Equation 3 conservation of mixture momentum in one axial direction (Z). ρ_L, H_L, u_L, are liquid phase density,hold up and. velocity. ρ_G, u_G are gas phase density and velocity. ρ_m, u_m are mixture density and velocity. f_F is funning friction factor and D_h is hole diameter.[2]

$$\frac{\partial(\rho_L H_L)}{\partial(t)} + \frac{\partial(\rho_L H_L u_L)}{\partial(Z)} = 0$$ **Equation 1**

$$\frac{\partial(\rho_G(1-H_L))}{\partial(t)} + \frac{\partial(u_G\rho_G(1-H_L))}{\partial(Z)} = 0$$ **Equation 2**

$$\frac{\partial(\rho_L H_L u_L + \rho_G u_G(1-H_L))}{\partial(t)} + \frac{\partial(\rho_L H_L u_L{}^2 + \rho_G u_G{}^2(1-H_L))}{\partial(Z)} = -\frac{\partial p}{\partial Z} - \frac{2 f_F \rho_m u_m{}^2}{D_h} - \rho_m g$$ **Equation 3**

Vogel equation (Equation 4) is used as a Well deliverability model in UBD mechanistic time depenent model, beacause most of the time reservoirs which beeing drilled underbalanced,are at saturated conditions. q_o, $q_{o\,max}$ are oil flow rates at corresponding and zero bottomhole pressure. P_{bh} ,$\bar{P}_R$ are corresponding bottomhole pressure and reservoir average pressure.[2]

$$\frac{q_o}{q_{o\,max}} = 1 - 0.2\frac{P_{bh}}{\bar{P}_R} - 0.8\left(\frac{P_{bh}}{\bar{P}_R}\right)^2$$ **Equation 4**

In steady sate approches, all the equations are only a function of space which are considered as Ordinary Differential Equations (ODE's) but,Equation 1to Equation 3 are a funtion of time and space as known to be Pratialy Differential Eqautions (PDE's) which cannot be solved by analytical methods.Thus, using explicite finite difference approximation (Wendroff's explicit approach) marching in time and position, adding intial Conditionas ,and boundary conditions for each case study leads to a numerical solution for combinition of Equation 1 to Equation 3.[2]

UBD simulation Using dynamic multiphase flow simulator (OLGA)

OLGA is a comercial dynamic time dependent multiphase flow simulator, used for networks of wells, flowlines and pipelines and process equipment, covering the production system from bottomhole into the production system. OLGA comes with a steady state pre-processor included which is intended for calculating initial values to the transient simulations, but which also is useful for traditional steady state parameter variations. Modeling UBD operation in OLGA simulator may be a way to overcome complexity of UBD modeling, but OLGA simulation results needs to be validated with real data or an accepted simulation result.

Results and discussion

The validation was carried out usinga case study UBD data published by Jun et al.Although this is a hypothetical simulation and its results were not validated against real field data, it does take into account reservoir influxes. The well geometry, fluid properties, and well temperatures used in this simulation are summarized in Table 1. this case has been studied and reviwed by Carlos Perez-Tellez using the mechanistic time dependent UBD flow model. Jun et al simulation results as an input data for Carlos Perez-Tellez review is stated in Figure 4 including Choke pressure variations, oil & gas production rates and, Drilling fluid injection rate, related to drilling time. The results of both simulations (Jun et al, Carlos Perez-Tellez) are shown in Figure 6 including Bottomhole and choke pressures. The same simulation using OLGA was implemented and results are shown in Figure 7.

Conclusions

Modeling and simulation of UBD operations may be complex and challenging, but there are some ways to overcome this issue, like the comprehensive mechanistic time dependent model (defined by Carlos Perez-Tellez) or using comercial dyanamic multiphase flow simulators like OLGA which has been presented in this paper and validated for a simple case study but, there may exist some limitations and inacuracies with each method.

Table 1- Summary Of input parameters (Jun et al) [7]

Depth of reservoir (m)	4340	Differential pressure (MPa)	-1.8
Thickness of reservoir (m)	8.0	Critical pressure of gas (MPa)	4.82
Permeability of formation (mD)	50	Critical temperature of gas (°K)	198
Porosity of formation	0.15	Relative density of gas	0.65
Pressure factor of reservoir	1.05	Gas viscosity (mPa.s)	0.02
Surface temperature (°C)	20	Oil density (g/cm^3)	0.74
Temperature gradient (°C/m)	0.033	Oil viscosity (mPa.s)	8.0
Mud density (g/cm^3)	1.0	Ratio of gas and oil (m^3/m^3)	120
Mud viscosity (mPa.s)	3.0	Geometry of chock line (d/L)	100mm/100m
Mud volume (L/s)	30	Nozzle diameter of bit (mm)	22/3
Penetrating rate (m/h)	7.0		

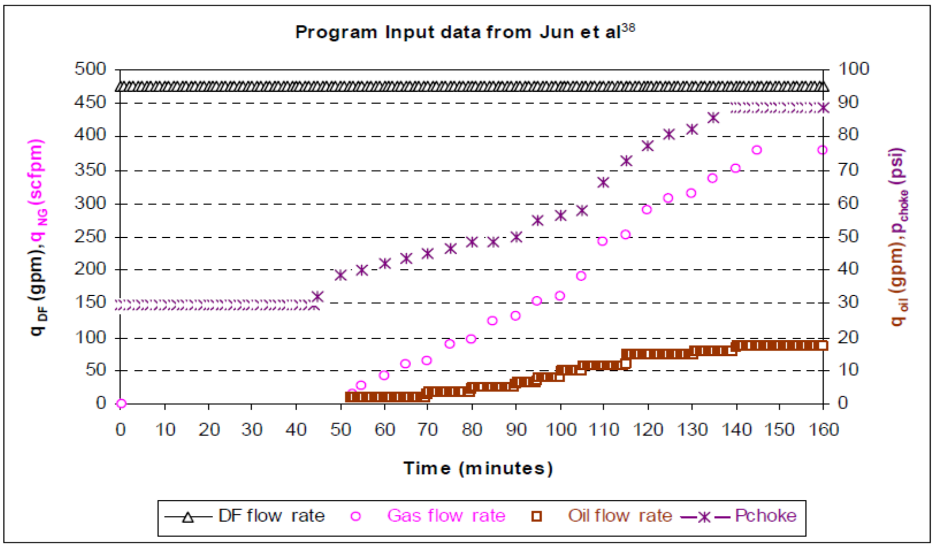

Figure 4- Jun et al’s literature data [2]

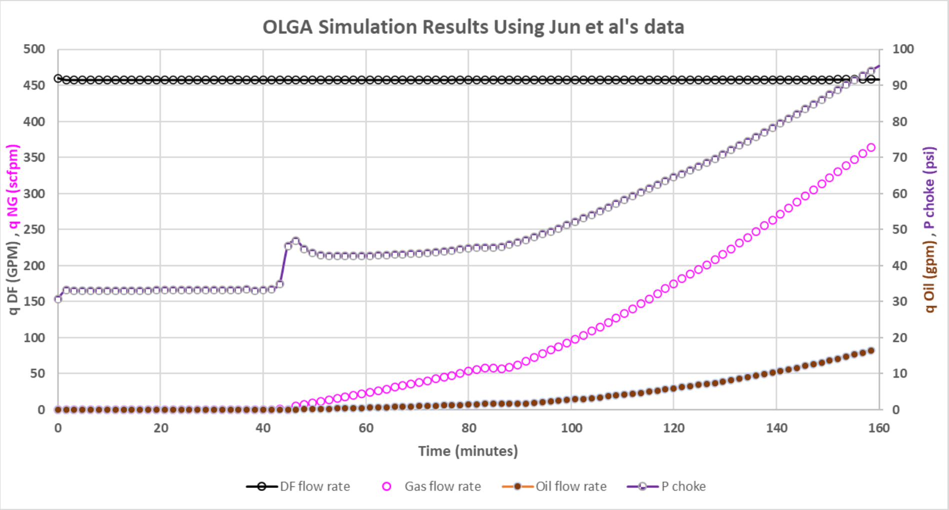

Figure 5- OLGA simulation results using Jun et al data (part1)

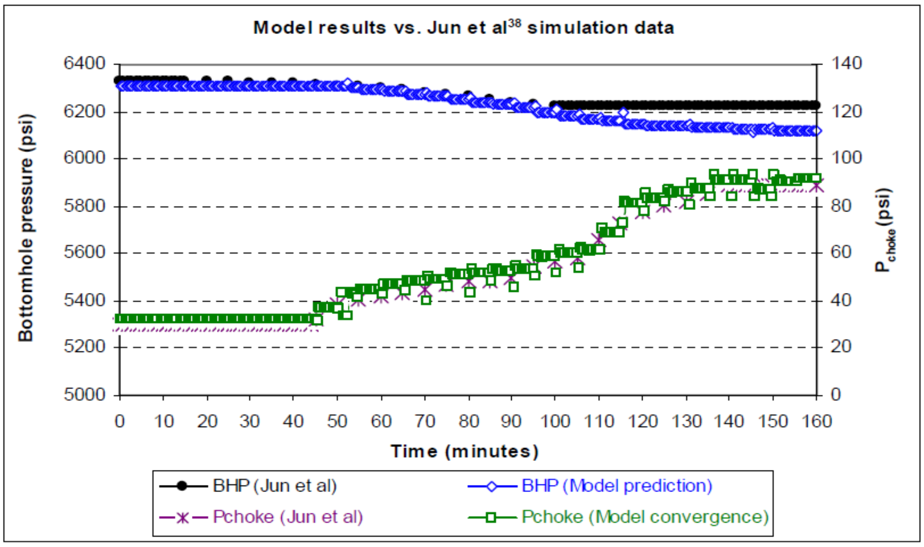

Figure 6- mechanistic time dependent model simulation (by carlos Carlos Perez-Tellez) Vs. Jun et al data [2]

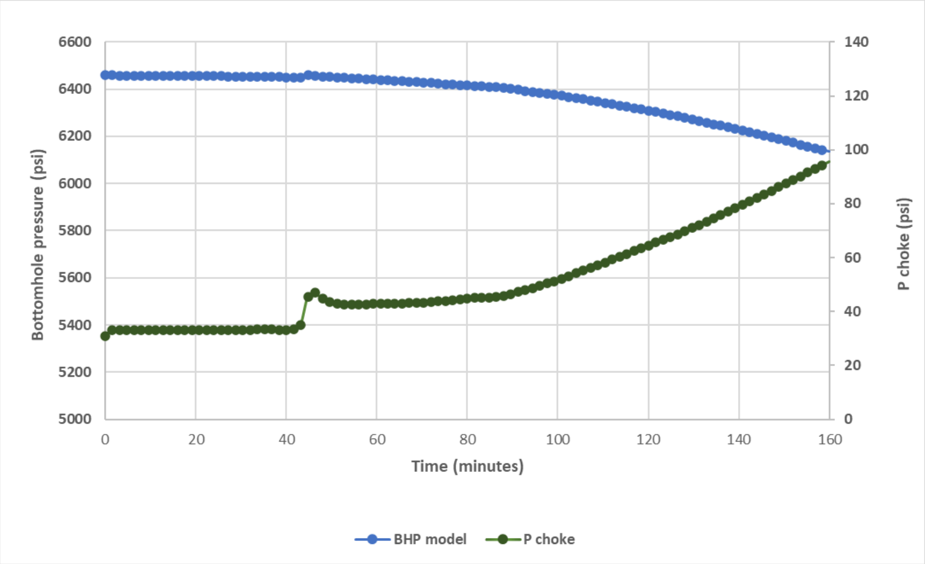

Figure 7- OLGA simulation results using Jun et al data (part2)

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