Stabilizing gas-lift well dynamics with free operating point ⋆⋆

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Abstract: Gas-lift is one of the most used artificial lift methods worldwide. In Brazil it responds for more than 70% of the total oil production. Gas-lift wells are known to present oscillatory behavior associated with phenomena like heading and density wave. This work presents an innovative way to control these oscillations. The approach adopted controls the well dynamics without fixing any operational set point, decoupling the dynamic control from the optimization algorithm.

Keywords: gas-lift simulation, gas-lift control.

1. INTRODUCTION

One dynamic phenomenon observed in gas-lift well operation is heading. Heading is explained as an interaction between the annular and production tubing flow. Typically, gas enters in the production tubing through an orifice type valve working in the non-critical region, Hu (2004), Sinegre et al. (2005). For sufficient low gas mass flow-rate, the gas-lift operating valve is blocked by the weight of the production tubing fluid. The constant top casing gas inflow causes the annular pressure to rise in a ramp form which eventually overcomes the counter-pressure causing a strong gas inflow in the production tubing. This has two consequences: i) forces the production of most of the fluid inside the production tubing lowering the counter pressure in front of the perforations, ii) depletes the annular, lowering its pressure. As a consequence, there is a high liquid inflow from the formation which develops a back pressure that rapidly becomes higher than the annular pressure on the other side of the gas-lift operating valve and the process repeats.

One way to prevent heading is to operate with critical flow in the gas-lift operating valve. For orifice valves this requires using an orifice diameter that would result in a pressure ratio between downstream valve and upstream valve smaller than a critical value (around 0.55). This means too high pressure in the annular and the solution came with the development of Venturi type valves. These valves develop critical flow with a downstream-upstream pressure ratio around 0.9. But wells with Venturi type gas-lift valve also develop oscillations. Apart from the cyclic nature of the behavior, common to the heading case, a new phenomenon called density wave happens with stabilized annular pressure and constant flow in the gas-lift operating valve. Below a certain gas flow-rate the gas accumulates in the proximity of the gas-lift operating valve. As more gas enters in the production tubing the liquid is pushed upwards until it is produced as a slug. The back pressure in front of the perforations is decreased and liquid enters in the production tubing. Gas continues to enter at a low flow-rate and the process repeats. As shown in Sinegre (2006) the gas mass fraction dynamics explains the density wave phenomenon seen in gas-lift wells. These phenomena results in dynamics known as limit cycle and in intermittent production rates. There is a tendency in the oil industry to refer to heading and density wave as completely different phenomenon. What about the oscillations that happen before the development of the sustained oscillations? Although there is a clear difference when the flow in the gas-lift operating valve is critical or not, we believe that the gas mass fraction dynamics is at the center of the problem. We believe that gas mass fraction behavior along the production tubing height is associated with both phenomena. Based on its dynamics, a control technique is developed which suppress the oscillations due to both cases.

The paper is organized as follows. In section 2 the gas-lift well control strategy is introduced. In section 3 a simplified gas-lift well simulator is presented. The control algorithm is detailed and its implementation is discussed in section 4. In section 5 the simulation results are shown. All variables and parameters are defined in table 1.

2. CONTROLLING GAS-LIFT WELL DYNAMICS

Several papers have been published about gas-lift wells modeling and control as in Eikrem et al. (2004), Hu (2004), Imsland et al. (2003) and Plucenio et al. (2009). In Camponogara et al. (2010) an optimization and control strategy was developed to distribute the gas arriving in a gas-lift manifold (GLM) shown in figure 1 following a set of objectives:

⋆ A. Plucenio and D. J. Pagano are supported by CENPES-Petrobras under project Real Time Optimization and Control of Oil Production Systems, C. A. Ganzaroli is supported by the Brazilian Institute of Petroleum (IBP)

⋆⋆ Contribution to invited session on Production stabilization

- The incoming gas flow-rate is distributed to the N wells in order to maximize an objective function
- The sum of the GLM output gas should be controlled in order to have a desired GLM pressure
- The gas flow-rate to each well is constrained to minimum and maximum values

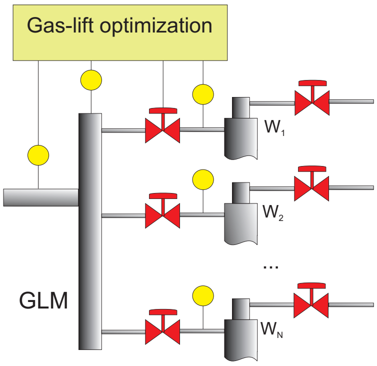

Fig. 1. Gas-lift manifold

In that work no action is taken to suppress the oscillations that may appear as a consequence of changes in the gas flow-rate of each well. One conservative approach is to constrain the minimum gas-lift flow-rate to a value much higher than the one which induces heading or density wave phenomena. This would limit the oscillatory behavior. If the oscillations are suppressed, the minimum gas-lift flow-rate of each well could be smaller meaning that the optimal distribution would be improved and more wells could be kept opened with a limited availability of gas. In this paper we develop a control strategy to suppress gas-lift wells oscillations with free operating point. The approach is based on the stabilization of the gas mass fraction on the production tubing side of the gas-lift operating valve. The strategy is applied with success in a simulated well equipped with an Orifice and Venturi gas-lift valve.

One well accepted approach to describe liquid and gas flow in pipes is the drift flux model, Zuber and Findlay (1965). It relates the averaged gas and liquid velocities with the total fluid average velocity and the drift velocity of gas bubbles,

$$V_g = C_o V_m + V_d. \tag{1}$$

C_o is the profile parameter which is supposed to take into account non-uniform flow and concentration profiles. V_d is the drift velocity of the gas normally written as a function of the rise velocity of a single bubble, Holmes (1977). Acceptable values for C_o vary between 1.2 to 1.0. Considering $V_m = V_{sg} + V_{sl}$, $V_{sg} = \alpha V_g$ and $V_{sl} = (1-\alpha)V_l$, the following equation is obtained, where α is the void fraction.

$$V_g = \frac{C_o(1-\alpha)}{1-C_o\alpha} V_l + \frac{V_d}{1-C_o\alpha} \tag{2}$$

Using the same equations an expression for α can be written as

$$\alpha = \frac{V_{sg}}{C_o(V_{sg}+V_{sl})+V_d} \tag{3}$$

Assuming $C_o = 1$ and using $V_d = V_\infty$, a bubble rise average velocity, Sinegre (2006) proposed the slip model.

$$V_g = V_l + \frac{V_\infty}{1-\alpha}. \tag{4}$$

Using the gas mass fraction defined as

$$x = \frac{\alpha\rho_g}{\alpha\rho_g + (1-\alpha)\rho_l}, \tag{5}$$

and the mass conservation equations for the gas and liquid phases, the Riemann invariant is obtained,

$$\frac{\partial x}{\partial t} + V_g \frac{\partial x}{\partial z} = 0. \tag{6}$$

This means that for a constant gas velocity V_g the gas mass fraction at the wellhead, at time t, would be equal to the one that happened at the bottom, at a time $(t-\tau)$ with $\tau = \frac{L}{V_g}$, where L is the distance between wellhead and well bottom. The gas mass fraction travels inside the production tubing and it manifests itself as a changing gas volume fraction at surface. For a sufficient low gas flow-rate entering in the well annular, the heading or density wave phenomenon is established causing intermittent production at surface. We propose stabilizing the gas-lift well by making

$$\frac{\partial x}{\partial t} = 0 \tag{7}$$

on the production tubing at the depth of the gas-lift operating valve. By doing so, according to (6), we force $\frac{\partial x}{\partial z} = 0$, condition that should stabilize also the gas and liquid volume fractions avoiding slug flow in the wellhead.

Replacing equation (3) in (5),

$$x = \frac{q_g}{q_g + q_l + V_\infty A \rho_l}, \tag{8}$$

where q_g and q_l are respectively the gas and liquid mass flow-rate. The term $V_\infty A\rho_l$ represents a virtual mass flow-rate due to the drift gas velocity, defined here as q_v. The gas mass fraction x is considered here as the key variable to explain the dynamic of the gas-lift wells. We believe that it is possible to implement $\frac{\partial x}{\partial t} = 0$, using feedback control to force $\frac{\partial p_{wf}}{\partial t} = 0$.

For that purpose we note that

$$\frac{\partial x}{\partial t} = \dot{x} = \frac{\dot{q}_g(q_l+q_v) - \dot{q}_l q_g - \dot{q}_v q_g}{(q_g+q_l+q_v)^2}. \tag{9}$$

An assumption is made that $\dot{q}_v = 0$ since V_∞ do not vary too much with time for low void fraction values.

The variable gas mass fraction is not usually measured. On the other hand new gas-lift wells are being equipped with downhole gauges to measure pressure and temperature. To enforce $\frac{\partial x}{\partial t} = 0$ in equation (9) means to ensure $\dot{q}_g = 0$ and $\dot{q}_l = 0$. For critical flow q_g does not depend on p_{wf}, so, for a constant upstream pressure on the gas-lift operating valve $\dot{q}_g$ is zero. For subcritical flow $q_g = f(p_{wf})$, so $\dot{q}_g = \frac{\partial q_g}{\partial p_{wf}} \frac{\partial p_{wf}}{\partial t}$. Therefore, for $\dot{p}_{wf} = 0$, $\dot{q}_g = 0$. q_l depends on the inflow performance curve which is written as function of p_{wf} and $\dot{q}_l = \frac{\partial q_l}{\partial p_{wf}} \frac{\partial p_{wf}}{\partial t}$. Again, by making $\dot{p}_{wf} = 0$ we have $\dot{q}_l = 0$. We conclude that $\dot{x} = 0$ can be warranted by forcing $\dot{p}_{wf} = 0$.

3. THE GAS-LIFT WELL SIMULATION

In order to test the control approach a simple gas-lift well simulator was developed. Its development was based in the mass and momentum conservation laws in the annular and production tubing. It is assumed that temperature is constant and that there is no mass transfer between the gas and liquid phase. The gas flow from the annular to the production tubing happens through an orifice valve with a check valve. On the surface there is a gas-lift valve connecting the gas-lift manifold to the casing and a production choke between the wellhead and the separator with controlled opening. In order to simplify the model the well is assumed to be vertical and the gas-lift operating valve is considered to be at the same depth as the perforations. The formation fluid inflow is modeled according to a Vogel equation. Two PDEs (Partial Differential Equations) describe the flow in the annular on the variables pressure, p_A and mass flow-rate q_A. Three PDEs describe the flow in the production tubing with the variables gas volume fraction, α, pressure p_T and total mass flow-rate q_T.

$$\begin{aligned}
\frac{\partial p_A}{\partial t} &= -\left(\frac{RT}{A_A M}\right)\frac{\partial q_A}{\partial z} \\
\frac{\partial q_A}{\partial t} &= \frac{2RT}{MA_A}\frac{q_A}{p_A}\frac{\partial q_A}{\partial z} + \frac{MA_A g}{RT}p_A - \\
&\quad \frac{RTf}{2MA_A D_A}\frac{q_A^2}{p_A} - \left(A_A - \frac{RT}{MA_A}\frac{q_A^2}{p_A^2}\right)\frac{\partial p_A}{\partial z} \\
\frac{\partial \alpha}{\partial t} &= \frac{1}{\rho_l A_T}(1-x)\frac{\partial q_T}{\partial z} - \frac{1}{\rho_l A_T}q_T\frac{\partial x}{\partial z} \\
\frac{\partial p_T}{\partial t} &= -\left(\frac{RT}{MA_T}\right)\frac{1}{\alpha}\frac{\partial x q_T}{\partial z} - \left(\frac{1}{\rho_l A_T}\right)\frac{p_T}{\alpha}\frac{\partial (1-x) q_T}{\partial z} \\
\frac{\partial q_T}{\partial t} &= -\left(\frac{2q_T}{A_T\rho_m}\right)\frac{\partial q_T}{\partial z} + \left(\frac{q_T^2}{A_T\rho_m^2}\right)\frac{\partial \rho_m}{\partial z} - A_T\rho_m g - \\
&\quad \frac{f}{2D_T A_T}\frac{q_T^2}{\rho_m} - A_T\frac{\partial p_T}{\partial z} \qquad (10)
\end{aligned}$$

Apart from the differential equations (10) the following algebraic equations are used,

$$\begin{aligned}
\rho_m &= \alpha\rho_g + (1-\alpha)\rho_l \\
q_o^f &= q_o^{max}\left(1 - .2\left(\frac{p_{wf}}{p_r}\right) - .8\left(\frac{p_{wf}}{p_r}\right)^2\right) \\
q_w^f &= = \left(\frac{BSW}{1-BSW}\right) q_o^f \frac{\rho_w}{\rho_o} \\
q_g^f &= GORq_o^f\frac{\rho_g^{sc}}{\rho_o} \qquad (11)
\end{aligned}$$

The equations for the friction factors, orifice and control valves are not presented due to lack of space. The variables used in the model are presented in table 1 while the parameters used in the simulation are shown in table 2.

3.1 Simulation results

The set of PDEs were first solved for steady state to obtain valid initial conditions considering the boundary conditions determined by the gas-lift manifold, reservoir and separator pressures. Next, the annular and production tubing were divided in N sections and the space derivatives were written using a central difference scheme. An ODE solver was used to obtain the solution. The steady state results are shown in figures 2, 3 and 4.

Table 1. Model variables

Symb.	Description	Unity
z	Vertical distance	$[m]$
p	Pressure	$[Pa]$
p_{wf}	Pressure in front of perforations	$[Pa]$
q	Mass flow-rate $[Kg/s]$	
V	Fluid velocity $[m/s]$	
ρ	Density	$[kg/m^3]$
α	Void fraction	$[-]$
x	Gas mass fraction	$[-]$
f	Friction factor	$[-]$
Subscripts		
A	Annular	
T	Prod. Tubing	
m	Average	
o	Oil component	
w	Water component	
g	Gas phase	
l	Liquid phase	
d	Drift	
sg	Gas superficial	
sl	Liquid superficial	
r	Reservoir	
vi	Injection valve	
ch	Production choke	
Superscripts		
sc	Standard conditions	
f	Formation	
max	Maximum	

Table 2. Simulation Parameters

Symb.	Description	Unity
g	Av. Earth gravity	$[9.81 m/s^2]$
T	Well temperature	$[300\ K]$
M	Gas molar weight	$[0.016\ Kg/mol]$
R	Universal gas const.	$[8.31\ J/Kmol]$
L	Distance wellhead-bottom	$[2500\ m]$
D_T	Prod.Tub. ID	$[0.1092\ m]$
D_A	Annular ID	$[0.221\ m]$
A_A	Annular cross-section area	$[m^2]$
Φ	Orifice valve diam.	$[0.0127\ m]$
API	Oil API	[22]
GOR	Oil RGO	$[25 stm^3/d/stdm^3/d]$
BSW	BSW	[15%]
μ_o	Oil viscosity	$[0.15\ Pas]$
μ_w	Water viscosity	$[0.001\ Pas]$
μ_g	Gas viscosity	$[0.00002\ Pas]$
ϵ_A	Annular wall roughness	$[.0001\ m]$
ϵ_A	Prod. Tub. wall roughness	$[.0001\ m]$
q_o^{max}	Max. well mass flow-rate	$[54\ Kg/s]$
rho_a	Water density	$[1000\ Kg/m^3]$
P_r	Reservoir mean pressure	$[18 \times 10^6\ Pa]$
P_s	Separator pressure	$[1 \times 10^6\ Pa]$
τ_{vi}	Time const. inj. choke	$[5\ s]$
τ_{ch}	Time const. prod. choke	$[5\ s]$
τ_q	Time const. Inflow	$[30\ s]$

Figures 5 and 6 show the dynamics obtained with the gas-lift simulator developed for manipulations in the gas-lift valve opening. The simulation starts with a injection valve opening of 50%. After one hour the gas-lift valve opening is reduced to 18% and to 11% after four hours. The dynamic of pressure and flow-rates that follow are very similar to what is observed using commercial simulators. With the opening of 11% the well develops a heading behavior characterized by an intermittent flow-rate on the

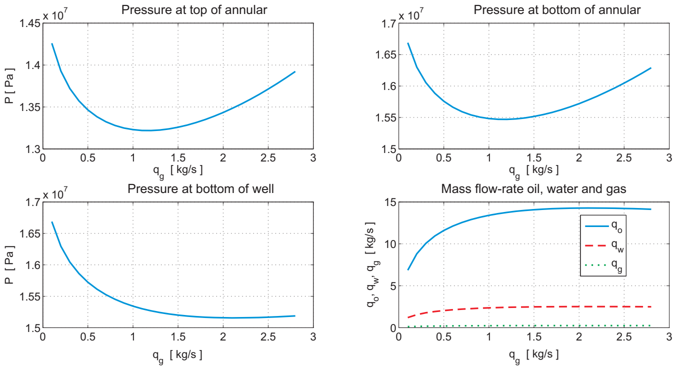

Fig. 2. Steady state results I

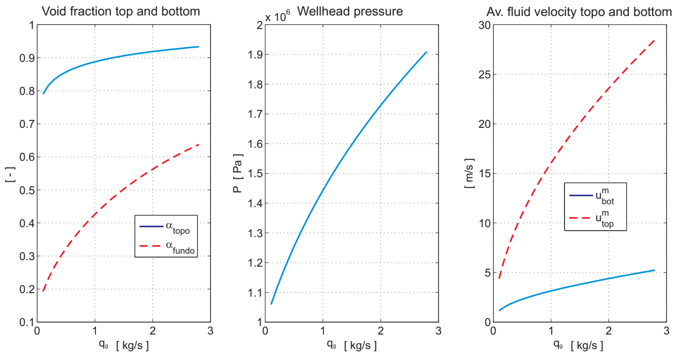

Fig. 3. Steady state results II

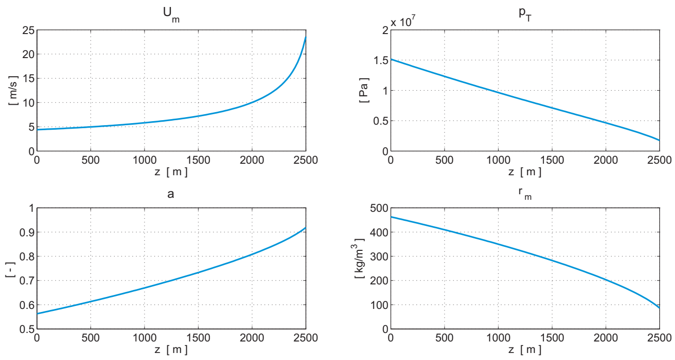

Fig. 4. Steady state results for $q_g = 2\ kg/s$

orifice valve at the bottom of the annular and a limit-cycle pressure at the bottom of the production tubing.

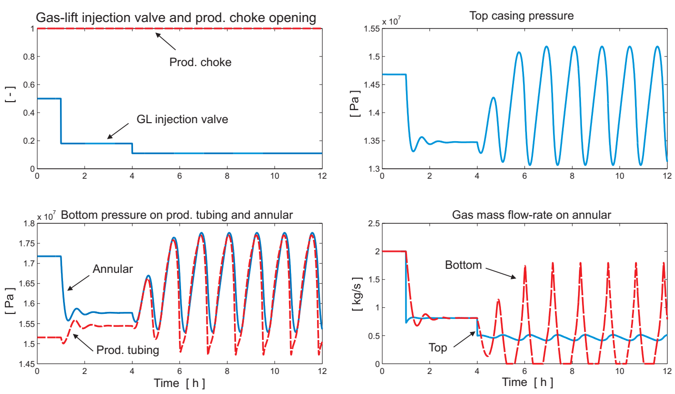

Fig. 5. Transient behavior I

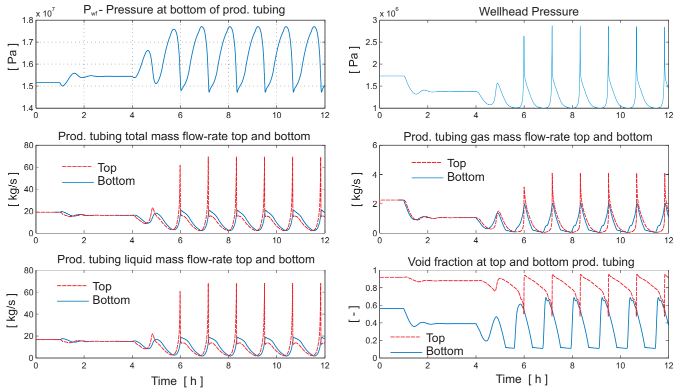

Fig. 6. Transient behavior II

4. PROPOSED CONTROL ALGORITHM

Regardless of the phenomenon taking place, heading or density wave, there is a gas injection flow-rate, q_g^{HB} which takes the system to a Hopf Bifurcation characterized by the development of a stable limit cycle with a fundamental frequency w_n. With the well operating on the limit cycle the bottom hole pressure P_{wf} is written as

$$P_{wf} = \overline{P}_{wf} + \widetilde{P}_{wf}, \text{ with}$$
$$\widetilde{P}_{wf}(k+1) = a_1\widetilde{P}_{wf}(k) - a_2\widetilde{P}_{wf}(k-1) + bu_{PC}(k) \quad (12)$$

where $\overline{P}_{wf}$ is the offset value of the pressure signal which includes P_s, the separator pressure, $\widetilde{P}_{wf}$ represents its zero average oscillatory component and u_{PC} the pressure drop in the production choke. For the purpose of control design, $\widetilde{P}_{wf}$ is modeled as a sinusoidal wave with the frequency $w_n = 2\pi/T$, where T is the oscilation period of $\widetilde{P}_{wf}$. Equation (12) shows the discrete model of $\widetilde{P}_{wf}$ with the sampling time T_s where $a_1 = 2 - b$, $a_2 = 1$ and $b = (w_nT_s)^2$. Defining

$$e(k+1) = \widetilde{P}_{wf}(k+1) - \widetilde{P}_{wf}(k), \quad (13)$$

the following equation is obtained,

$$e(k+1) = a_1e(k) - a_2e(k-1) + b\Delta u_{PC}(k), \quad (14)$$

One approximate expression for u_{PC} is

$$u_{PC} = \frac{q^2}{C_{vN}^2 f(\phi)^2 \rho_m}, \text{ or } u_{PC} = \frac{B}{f(\phi)^2} \quad (15)$$

with q being the mass flow-rate through the choke, C_{vN} the valve C_v for 100% opening, ρ_m the average fluid density and $f(\phi)$ representing the valve the type of valve response as function of its opening. Since q and ρ_m are not usually measured, a simplified expression is adopted to u_{PC} considering $f(\phi) = \phi$,

$$u_{PC} = \frac{B}{\phi^2}. \quad (16)$$

Obviously the choice of B must be guided by the expression on equation (15).

4.1 Developing the control law

The development of the control law is based in the Lyapunov approach. The following Lyapunov function is proposed

$$L(e(t)) = \frac{1}{2}e(t)^2, \quad (17)$$

which is positive definite since, $L(0) = 0$ and $L(e(t)) > 0 \quad \forall\, e(t) \neq 0$. For the closed loop to be stable,

$$\frac{dL(e(t))}{dt} \leq 0, \tag{18}$$

which is equivalent to the discrete representation,

$$\frac{\Delta L(e(k))}{\Delta(kT_s)} \leq 0, \text{ but} \tag{19}$$

$$\frac{\Delta L(e(k))}{\Delta(kT_s)} = e(k)\frac{(e(k) - e(k-1))}{\Delta(kT_s)}. \tag{20}$$

The control action must ensure that

$$\Delta L(e(k)) \leq 0, \text{ or} \tag{21}$$

$$e(k)\,(e(k) - e(k-1)) \leq 0. \tag{22}$$

If the control algorithm ensures that for any sample time k, $e(k+1) = Ge(k)$ with $0 < G < 1$, then

$$\begin{aligned} \Delta L(e(k)) &= Ge(k-1)\,(Ge(k-1) - e(k-1)) \\ \Delta L(e(k)) &= e(k-1)^2\,(G^2 - G) \end{aligned} \tag{23}$$

Since $e(k-1)^2 > 0$ and $(G^2 - G) < 0$, $\Delta L(e(k)) \leq 0$. If the control action ensures that for any k, $e(k) = Ge(k-1)$ for $0 < G < 1$, then $\Delta L(e(k)) \leq 0$ and $e(k)$ tends to zero. Substituting the requirement that $e(k+1) = Ge(k)$ in equation (14),

$$Ge(k) = a_1 e(k) - a_2 e(k-1) + b\Delta u_{PC}(k), \tag{24}$$

which can be arranged to represent a Proportional Integral control algorithm,

$$u_{PC}(k) = u_{PC}(k-1) + \left(\frac{G - a_1}{b}\right) e(k) + \frac{1}{b} e(k-1), \text{ with}$$

$$K_c^o = -1/b \text{ and } T_i = \frac{T_s}{1 - G - b}.$$

It is well known that the production choke has to be kept as much opened as possible since closing it causes the bottom hole pressure P_{wf} to increase resulting in decreased formation fluid inflow. In order to achieve this secondary objective, the control algorithm is modified to include a term which forces the choke opening to a desired opening. This is accomplished with the following modified PI control,

$$\begin{aligned} u_{PC}(k) &= u_{PC}(k-1) + \gamma_o e(k) + \gamma_1 e(k-1) + \\ &\beta_1 \left(u_{PC}^d - u_{PC}(k-1)\right), \text{ with } u_{PC}^d = \frac{B}{\phi_d^2}. \end{aligned} \tag{25}$$

with ϕ_d representing the desired choke opening in steady state and β_1 being a factor to adjust the speed response of this term. The desired opening $\phi_d^{HB} < 1$ is assigned for $q_g \leq q_g^{HB}$. For higher surface gas flow-rates $\phi_d = 1$. In order to have a smooth transition the following rule is proposed for ϕ_d which is used to compute u_{PC}^d.

$$\text{if } q_g \leq q_g^{HB} \text{ then } \phi_d = \phi_d^{HB} \tag{26}$$

$$\text{else}$$

$$\phi_d = \phi_o + (1 - \phi_o)e^{-\beta_2(q_g - q_g^{HB})}$$

A final consideration has to be done as for the application of control for flow-rates higher than q_g^{HB}. Manipulating the production choke should be done only in extreme situations as for the case of heading and density wave. Obviously for q_g close to q_g^{HB} a level of control may be desired. Instead of turning the control off for higher gas flow-rate the control gain K_c can be weighted,

$$\text{If } \quad q_g \leq q_g^{HB} \quad K_c = K_c^o, \tag{27}$$

$$\text{else}$$

$$K_c = \frac{K_c^o}{(\beta_3 q_g)^n}, \text{ with } \beta_3 q_g^{HB} = 1.$$

The value of n can be adjusted to make $K_c = \frac{K_c^o}{10}$ or smaller for the well nominal operating q_g.

5. SIMULATION RESULTS

5.1 Aplication to Heading

Table 3 presents the parameters used in the control for a the well described in section 3.

Table 3. Parameters used in the control implementation for *Heading*

Parameter	Value
T_s	60 s
w_n	0.0015
K_c^o	−124.8
T_i	121 $s(G = 0.5)$
B	230000 Pa
β_1	0.75
β_2	12
β_3	$\frac{1}{0.7}$
n	3
q_g^{HB}	0.7 kg/s
u_d^{HB}	0.8

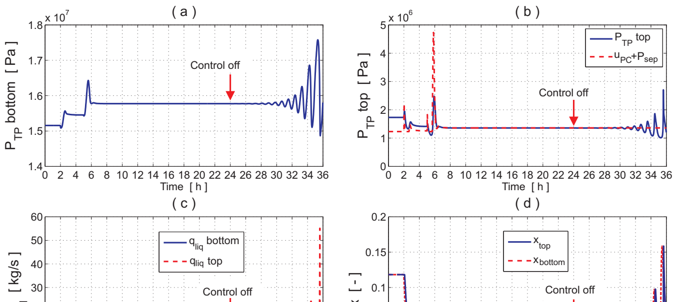

Fig. 7. Results I- Production tubing with control off at $t = 24\ h$

In figure 7 and 8 the results obtained with the control technique are shown. The same sequence of gas injection valve opening shown in figure 5 is implemented with control applied. The oscillations are suppressed but return when the control is turned off and the choke opening is kept fixed at 80%. As planned, the choke opening, shown on figure 8, keeps the desired opening in steady state. Which is 100% for high gas injection flow-rate and 80% for flow-rates around the value q_g^{HB}. At the moments of changing the gas injection, the choke opening reacts in order to suppress the oscillations. The control action u_{PC}

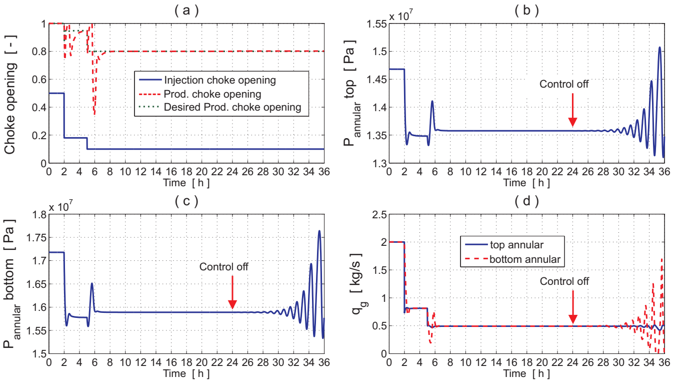

Fig. 8. Results II

added with the separator pressure is presented in figure 7-b. It is very close to the pressure on the wellhead in steady state showing that B value was well chosen.

5.2 Application to density wave

On figure 9 the same control technique was applied to a well using a Venturi valve. This was simulated with a fixed gas mass flow-rate entering the production tubing at the depth of the gas-lift valve. The oscillations are again suppressed with the desired choke opening of 80% in steady state. It must be noticed that the gas mass fraction shown in 9-f at top and bottom of the production tubing are stabilized with the control action. On the same figure it is observed that, indeed, the gas mass fraction at top is very similar to the one at bottom with a delay as pointed out by Sinegre et al. (2005).

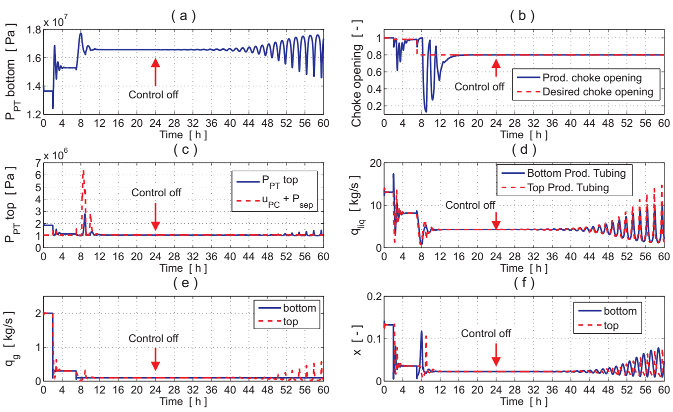

Fig. 9. Results - Control off at $t = 24\ h$

5.3 Choke opening characteristic

The control algorithm proposed does not compute the choke opening but a value expressed by equation (15). Would the control action value be required to be linear with the choke opening, then $u_{PC} = \frac{B}{f(\phi)^2} = C(1-\phi)$, or

$$f(\phi) = \left(\frac{B}{C(1-\phi)}\right)^{1/2}. \quad (28)$$

Plotting $f(\phi)$ as in equation (28) shows that an equal-percentage valve type would be appropriate for the choke.

6. CONCLUSIONS

The control technique proposed and applied to the simulated wells achieved the objective of suppressing the oscillations due to heading and density wave. The main advantage of this technique is its ability to stabilize the well without forcing an operational set-point. This allows for decoupling the optimization strategy from the dynamic control. The controlled steady state value of an unstable downhole pressure is hard to determine and setting an infeasible value as a set-point does not help stabilization. The expected benefits of the proposed approach are

- to enlarge the gas injection flow-rate range of each well, improving optimization results,
- to keep a larger number of wells working for a limited availability of gas for injection,
- to simplify the optimization algorithm.

The same technique has been applied with success on the control of severe slug in risers and the results will be presented in another publication. One approach drawback is the utilization of the bottom hole pressure derivative. Noise measurement is always present and may create difficulties for the application of the technique. Fortunately the downhole pressure is sampled at a rate much higher than the rate used for control application and there are several possible resampling and filtering techniques that can recover the derivative.

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