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The Research of Dynamic Simulation of Gas-Lift Well Unloading Process Based on OLGA

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Gas-lift unloading process is a transient process. Sufficiently considering the characteristics of the unloading transient process, this paper firstly built the new transient dynamic model of the gas-lift well unloading by using a commercial available dynamic multiphase flow simulator OLGA. In this new model, we designed four gas-lift valves and we used LEAK components with corresponding response curves which were obtained by the energy equation. And then the gas-lift unloading process was simulated by OLGA. Finally, the trend plots of the simulation results versus time were given and were analyzed in detail. The results showed that the gas-lift well reached the steady production after the gas-lift unloading process is finished.

Based on the simulation results and the analysis, this paper showed that it is feasible to use OLGA modelling and simulating the gas-lift unloading process by using LEAK components with the corresponding GLV response curves. It also showed that we can use this method to verify the reasonability of the design parameters of the gas- lift well.

1. Introduction

Gas lift is one of the most widely used artificial lift technique in oil fields. If the well has no sufficient reservoir pressure to produce or it can’t satisfy the production requirement, gas lift operation injects high-pressure gas from the casing into the wellbore to decrease the density of gas-liquid mixture and lifts the tubing liquid to the surface. The wellbore of gas-lift well is filled with kill liquid firstly. Before we begin to operate the gas-lift, the kill liquid above the injection points must be discharged. This process is called unloading. The gas-lift unloading process is a typical transient flow process. If we use steady-state equations to simulate the transient unloading process, we will meet many troublesome problems. In order to analyze the dynamic process of the gas-lift well and improve the design of the gas-lift well, this paper simulates the dynamic gas-lift unloading process based on OLGA which is a commercial available dynamic multiphase flow simulator, and it is a world’s leading software.

Many researchers had studied the dynamic analysis methods of gas-lift unloading process.The existing work which is about the simulation of gas-lit well unloading has two aspects. One aspect is that the researchers programed and calculated by using the finite element method with the model which they build by themselves which were confirmed (K. H. Bendlksen et al. (1991), Yula Tang et al. (1997) and A. Bahadori et al. (2001)). Another aspect is that the researchers simulated the results based on the simulators in which OLGA is almost the best one because of the good simulation effect which was confirmed (T. A. Everitt (1994), D. Denney (2002), R. Vazquez-Roman and P. Palafox-Hernandez (2005), F. Gutierrez et al. (2007), M. S. Nadar et al. (2008), Hu B and Golan M. (2003), Poblano E. et al. (2005) and Guerrero-Sarabia I. and Fairuzov Y.V (2004)). But all the simulations of gas-lift unloading were based on the GLV component of OLGA. After analysis, we found that we can use the LEAK component combining with the GLV response curves to realize the simulation of gas-lift unloading process. We analyzed the results in detail and the simulation results were consistent with the practical situation.

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2. The unloading process of continuous gas-lift well

The continuous gas-lift well consists of the reservoir, casing, tubing, a surface injection choke, packer and gas lift valve which is replaced by LEAK components in this paper. We install a check valve at the bottom of the tubing to protect the formation against the damage from the kill fluid.

The unloading process can be divided into two phases. In the first phase, the injection gas is injected into the annulus from the surface choke until the uppermost gas lift valve which is submerged in the kill fluid shows above fluid level and begins to be injected gas. The main characteristic of this phase is that no injection gas enters the tubing and only kill fluid is pushed into the tubing from the annulus through the gas lift valve. In the second phase, the injection gas enters the tubing from the annulus via gas lift valve.

Typically more than one gas lift valve is placed after each other down the annulus. The intention is that the gas lift valve closest to the wellhead opens first, and as the tubing pressure decreases this gas lift valve will close and the next gas lift valve opens (this might already be open depending on the response curve). This cycle is repeated until the injected gas reaches the operating gas lift valve (lowermost active gas lift valve). Once the gas lift gas reaches the operating gas lift valve, gas is continuously injected through this gas lift valve and stable production is optimized by regulating the optimum amount of gas (injection gas rate).

3. Mathematical model

3.1 Mass Conservation Equation in the Tubing

For any short pipe segment in the tubing, to phase i ($i=l$, liquid, and $i=g$, gas), the mass conservation equation is

$$\frac{\partial}{\partial t}(\rho_i H_i)+\frac{\partial}{\partial l}(\rho_i v_{si})=m_{vi}\cdot\delta\ , \tag{1}$$

In the above equations, the parameters are described as follow. H_i represents holdup. v_{si} is the superficial velocity with the unit $\mathrm{m/s}$. m_{vi} is mass flow rate per unit volume through gas-lift valve with the unit $\mathrm{kg/(m^3\cdot s^{-1})}$. If there is no gas-lift valve in this segment, the value of m_{vi} is zero. Suppose that there is no mass exchange between the liquid phase and the gas phase. ρ_i is density which change with time and position, with the unit $\mathrm{kg/m^3}$. δ is the switching coefficient. If there exists fluid passing through the gas-lift valve in this pipe segment, $\delta=1$. Otherwise, $\delta=0$. t represents the time with unit s. l represents the position with unit m.

3.2 Momentum Conservation Equation of the Mixture in the Tubing

The momentum conservation equation for the gas-liquid mixture is described as the following form.

$$\frac{\partial}{\partial t}(\rho_l v_{sl}+\rho_g v_{sg})+\frac{\partial}{\partial l}\left(\frac{\rho_l v_{sl}|v_{sl}|}{H_l}+\frac{\rho_g v_{sg}|v_{sg}|}{H_g}\right)+(144g_c)\frac{\partial p}{\partial l}+\rho_m g\sin\theta+\left.\frac{\partial p}{\partial l}\right|_{fric}=0\ , \tag{2}$$

where ρ_m is the density of two-phase mixture and $\left.\frac{\partial p}{\partial l}\right|_{fric}$ is the friction pressure loss gradient.

3.3 Mass conservation equation in the annulus

The mass conservation equation in the annulus is given by considering the several aspects which are gas injection through the surface choke, gas injection through the gas-lift valve, fluid discharge from the annulus to the tubing and the gas state change in the annulus. Capucci and Serra derived an equation for single tubing and casing strings without considering the gas column weight within the annulus:

$$\left.\frac{\partial p}{\partial t}\right|_{surface}=\frac{1}{V_g\left.\frac{d\rho_g}{dp}\right|_{surface}}\left(\rho_{gsc}q_{g,inj}-\rho_{gsc}\sum q_{vg,i}-\rho_g\sum q_{vl,i}\right)\ . \tag{3}$$

In the eq. (3), $q_{g,inj}$ is the gas injection through the surface choke with unit $\mathrm{m^3/s}$. $q_{vg,i}$ and $q_{vl,i}$ are the gas flow rate and liquid flow rate through the *i*th gas-lift valve respectively with unit $\mathrm{m^3/s}$. ρ_{gsc} is the gas density at the standard condition with unit $\mathrm{kg/m^3}$. V_g is the volume which the gas occupies in the annulus with unit $\mathrm{m^3}$. From the eq. (3), we must calculate $q_{g,inj}$, $q_{vg,i}$ and $q_{vl,i}$ firstly, then we can derive the rate of change of annulus wellhead pressure with respect to the time. In the gas-lift unloading process, if a gas-lift valve is covered by liquid, $q_{vl,i}$ can be derived by using the energy conservation equation as follow.

$$q_{vl,i} = 8048 d_{p,i}^2 C_d [\frac{(p_{1i} - p_{2i})}{\rho_L}]^{0.5} , \quad (4)$$

where the discharge coefficient C_d is approximately equal to 0.82. $d_{p,i}$ is the port diameter of the *i*th valve. p_{1i} and p_{2i} are the upstream pressure and the downstream pressure at the *i*th valve with unit psig. ρ_L is the kill liquid density.

In this paper, we use constant gas injection through the surface choke. That means that $q_{g,inj}$ is a constant valve. The standard volume gas flow rate $q_{vg,i}$ through the gas-lift valve is found by linear interpolation in the response curves using the calculated upstream pressure and downstream pressure. The response curves must be defined in advance. In order to obtain the response curve of the gas-lift valve, the gas flow rate through the gas-lift valve is calculated by the energy equation under the hypothesis of isentropy as follow:

$$q_g = C_d A p_1 \sqrt{\frac{2g}{\gamma_g T_1 Z} \frac{k}{k-1} \left[\left(\frac{p_1}{p_2} \right)^{\frac{2}{k}} - \left(\frac{p_1}{p_2} \right)^{\frac{k+1}{k}} \right]} , \quad (5)$$

where A is the diameter of the gas-lift valve. p_1 and p_2 represent the upstream pressure and the downstream pressure at the valve. γ_g is the relative density of the injected gas. T_1 is the upstream temperature at the valve. Z is the compressibility factor of the injected gas. k is the isoentropic exponent of the injected gas.

4. Initial conditions

The model represents a newly completed well that is filled with water in both casing (annulus) and tubing. The bottomhole pressure caused by the kill fluid equals the static reservoir pressure. No flow exists through the tubing, the annulus, the surface choke or the gas-lift valves. Liquid holdup equals one in the region below the static liquid level within the tubing, while it is zero above the static liquid level. The well is unable to start up by itself and requires gas-lift in order to do so. The casing head pressure cannot exceed the operational rating of 120 bara. A first simulation attempt with only the bottom operational valve was unsuccessful as the gas was not able to reach the gas-lift valves. An unloading valves above were used and the well was able to start up within 10 hours.

The initial wellhead casing pressure behind the surface choke is 110 bara. The upstream pressure (p_1) on the gas-lift valve equals the gas column weight plus the static liquid pressure. The downstream pressure (p_2) on the gas-lift valve equals the wellhead tubing pressure plus static liquid pressure above the valve.

5. Boundary conditions

This research assumes that the wellhead tubing pressure and the injection gas mass flow rate upstream from the surface choke are constant in the process. The reservoir is modeled with linear IPR with a reservoir pressure of 198 bara and 123 degC. Thus, the superficial liquid velocity can be calculated. The superficial gas velocity also can be calculated. In this study, there is a check valve at the bottom of tubing, so no backflow happens. The production index for linear inflow equation is 3 Sm^3/d/bar.

6. The model of the gas lift well unloading

A comprehensive transient dynamic model of gas-lift well unloading is built by OLGA. The well consists of two flow paths: The annulus which is used to transport the lifting gas from surface down to the four GLVs and the tubing which is receiving the reservoir inflow and the gas from the four GLVs. The measure depth of the well is 2999.76 m. The outer diameter of the tubing is 0.0889 m. The outer diameter of the annulus is 0.1778 m. The initial conditions are set so that the well annulus and tubing is filled with water. The injection gas mass flow rate is 0.28 kg/s. The fluid compositions are taken from PVTSim database.

Four gas lift valves (LEAK components) are placed after each other down the annulus. The basic information of each GLV is showed in Table 1. OLGA determined the GLV response curve for each LEAK by interpolating by using three response curves which are calculated by the Eq. (5) with the parameters of the GLV. The intention is that the gas lift valve closest to the wellhead opens first, and as the tubing pressure decreases this gas lift valve will close and the next gas lift valve opens (this might already be open depending on the response curve). This cycle is repeated until the injected gas reaches the operating gas lift valve (lowermost LEAK). Once the gas lift gas reaches the operating gas lift valve, gas is continuously injected through this gas lift valve and stable production is optimized by regulating the optimum amount of gas. If the tubing pressure is increased for any reason (e.g. choke back production at the wellhead, a big liquid slug coming from the productive formation, etc.), this may cause the opening of some LEAKs. This opening is the automatic response of the GLVs to stabilize the flow. The injection of gas will reduce the liquid head pressure in the tubing until the LEAKs are closed again. The model is showed in Fig.1.

Table 1: The basic information of the GLV

valve	The depth of the valve（ft）	type	The diameter of the valve(in)	The surface debugging pressure（psig）	The surface opening pressure（psig）	The surface closing pressure（psig）
1	3112.5	R20	3/16	1846	1813	1786
2	5537.1	R20	3/16	1668	1773	1756
3	7173.8	R20	3/16	1648	1736	1726
4	8171.7	R20	1/4	1604	1605	1598

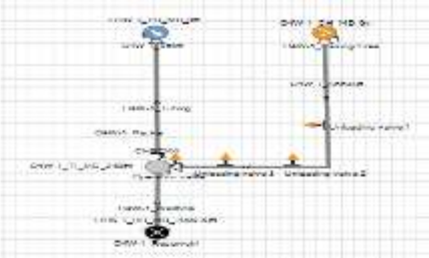

Figure 1: The model of the gas-lift well unloading

7. The simulation results and analysis of the gas-lift unloading process

7.1 The wellhead casing pressure

The wellhead casing pressure against time is showed in Fig. 2. The wellhead casing pressure increases firstly, and then decreases. Repeat this regulation several times, and the wellhead casing pressure reaches the steady state.

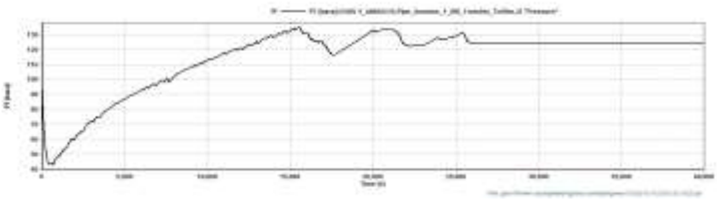

Figure 2: The change of wellhead casing pressure versus time

From Fig. 2, the wellhead casing pressure is about 110.32 bara at the initial time, because the annulus is filled with kill fluid. After the injection gas is injected into the annulus, the wellhead casing pressure decreases because of the decreasing of the liquid level in the annulus until 675 seconds. Although in this process the gas injection rate increases, the decreasing of the liquid level in the annulus plays a major role. From 675 seconds, the wellhead casing pressure begins to increase because the gas injection rate increases further. After 15000 seconds, the wellhead casing pressure begins to decrease because the injection gas is injected into the tubing through the first gas-lift valve and then the second gas-lift valve. From 17576 seconds, the wellhead casing pressure begins to increase because the first and second gas-lift valves close. After several seconds, the wellhead casing pressure increases and then decreases because of the same reasons which are aforementioned. After 28705 seconds, the wellhead casing pressure reaches the steady state.

7.2 The total liquid content in the gas-lift well

The total liquid content in the annulus and tubing are showed in Fig. 3. The high pressure gas pushes liquid entering the tubing, so in the earlier time of phase 1, liquid content in the annulus decreases and liquid content in the tubing maintains because tubing is full filled liquid at initial time and no gas is injected into the tubing. The bottomhole pressure is greater than the reservoir pressure and there is a check valve stalled at the bottom of the tubing, so there is no backflow and no liquid is produced during this period. When any valve is uncovered and open, the second phase of unloading starts. The high pressure gas is injected into the tubing, and the liquid content in the tubing decreases because the gas-liquid mixture exists in the tubing. As further increasing of the gas in the tubing, the bottomhole pressure drops because the liquid is lightened by injection gas. When the bottomhole pressure is less than the reservoir pressure, the oil is produced and the liquid content increases and arrives at the wellhead. In this case, the fluctuations occur in the tubing. At the same time, the liquid content in the annulus decreases continually until the lowest valve is uncovered (8171.7 ft). Finally, all the production parameters achieve stable conditions.

7.3 The gas flow rate through gas-lift valves

The gas flow rate through gas-lift valve 1, 2, 3 and 4 are showed from Fig. 4 and Fig 5. From the figures, we note that the four valves open successively. It is what the designer desired and consistent with the original conventional design. We also can get that in the unloading process there occurs the phenomenon that four valves close after they open several seconds because of the GLV response curves and the global system behavior. This cycle is repeated until only the operating gas lift valve opens and works all the time. After 28705 seconds, the gas flow rate through the operating valve maintains a constant value. This means that the production reaches the steady-state.

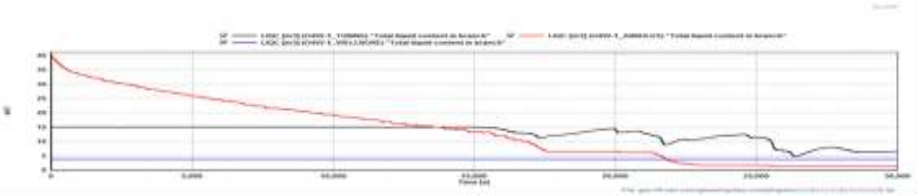

Figure 3: The total liquid content in the tubing, in the annulus versus time during the unloading process

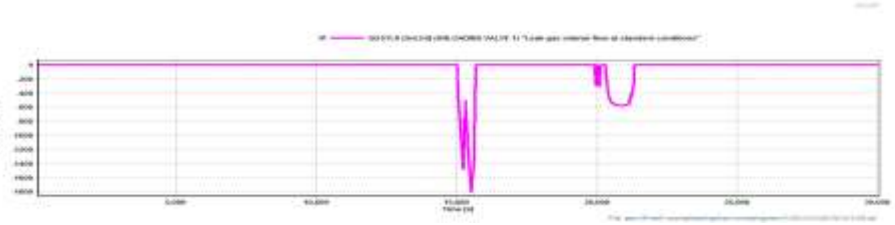

Figure 4: The gas flow rate through the gas-lift valve 1

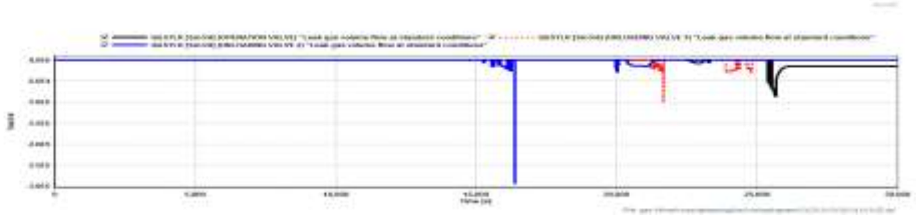

Figure 5: The gas flow rate through the gas-lift valve 2, 3 and 4

This analysis of the simulation results show that the simulation of the gas-lift unloading process by OLGA is feasible. In conventional design, it is usually supposed that the gas-lift valve will be open when it is uncovered. The opening of the uncovered valve actually depends on the wellhead casing pressure which changes with time during the gas-lift unloading process. This paper doesn’t suppose that the gas-lift valve opens or not, but uses the GLV response curve to control the opening of the corresponding gas-lift valve. Hence, if we don’t know the transient process, it is difficult to simulate the gas-lift unloading process reasonably.

8. Conclusion

A comprehensive transient dynamic model of gas-lift well unloading has been built by OLGA. In this model, we used the LEAK components to replace the GLVs. Before we gave this new way which deals with the GLV by using LEAK, we didn’t meet the same way. This model can be used to operate gas-lift optimal design, stability analysis which is still under study as a part research of our work. And then we simulated the gas-lift unloading process by OLGA. The trend plots of wellhead casing pressure, the total liquid content in the gas-lift well and the gas flow rates through GLVs were showed. From the results of gas flow rates through the gas lift valves during the unloading process, we got that gas may not be injected continuously as is conventionally supposed, but depend not only on the GLV response curves but also on the global system behavior. In this model, we don't consider the thermal transmission during unloading process. So in the subsequent study, we will consider the thermal transmission by referring to the references which were confirmed (Giulio Lorenzini et al. (2015), F. Corvaro et al. (2015), Loganathan. P et al. (2015), G. Cannistraro et al. (2015) and M. S. Alam et al. (2015)).

According to the simulation results and the analysis of the results, we get that it is feasible to use OLGA to model and simulate the gas-lift well unloading process.

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