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A simplified model to predict transient liquid loading in gas wells

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ABSTRACT

This paper presents a simplified model to predict the inception of liquid loading in gas wells and its subsequent transient phenomenon. This model enables the estimation of erratic or cease of production due to liquid loading using a simple but robust technique. This approach is validated with field data. The model described in this paper proposes the use of the so-called "nodal analysis technique" to predict liquid loading in gas wells. The approach proposed modifies the tubing performance relationship instead of using the common critical velocity or minimum pressure point concept. This modification enables the simple use of nodal analysis to accurately predict liquid loading initiation, including the amount of time required to cease production after the inception of liquid loading. The model shows good agreement field data on the prediction of liquid loading.

From the modeling results and comparison with field data, it is possible to conclude that this model can provide a reasonable prediction of the liquid loading phenomena. For instance, one of the main objectives of using models to predict liquid loading is to anticipate when a gas well would start suffering from liquid loading problems, and potentially stop flowing. The use of conventional models showed a significant mismatch in the critical flow for liquid loading initiation when compared to field data while the use of the model proposed would reduce this mismatch significantly. In addition to that, the use of this simplified model also enables understanding of the main field symptoms related to liquid loading in gas wells.

1. Introduction

Liquid loading is generally defined as the inability of a producing gas well to lift the coproduced liquids up the tubing, resulting in liquid accumulation in the wellbore. One of the main problems associated with liquid loading is the sudden drop in gas production rates or "death" of the well. Decline curve analysis often fails to predict the sudden drop in gas production observed in the field (Lea et al., 2003), and this mismatch in production forecast can have a significant impact on the prediction of ultimate recovery for gas wells. Thus, liquid loading can be associated with a reduction of ultimate recovery of gas wells. Therefore, it is clear to conclude that the development of a model to predict production forecast for gas wells should include the liquid loading phenomenon and its transient effects.

The main objective of this paper is to present a simplified model to predict production forecast of gas wells, including the transient effects before and after liquid loading initiation. The following section will briefly discuss the current methods and their limitations on prediction of liquid loading in gas wells. Then, the proposed model will be described, the validation of this mode with field data, and also use simulation results to describe liquid loading symptoms often observed in the field.

2. Current methods to predict liquid loading

2.1. Turner et al. (1969) droplet model

Models commonly used to predict the initiation of liquid loading utilize the idea of critical gas velocity to determine when liquid loading will start. The most widely accepted method for predicting liquid loading initiation is the droplet transport model of Turner et al. (1969). In their approach, the balance between downward gravitational force and upward gas drag force on a liquid droplet is solved to determine the minimum velocity (u_{min}) to lift the largest droplet flowing with the gas stream, given by the following expression,

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$$u_{min} = 5.46\left[\frac{\rho_l - \rho_g}{\rho_g^2}\sigma\right]^{1/4} \quad (1)$$

where σ (in N/m) is the surface tension, ρ_g (in kg/m^3) is the gas density and ρ_l (in kg/m^3) is the liquid density.

The development of equation (1) by Turner et al. (1969) was based on a comparison between their droplet model and a liquid film transport model. Both models were compared to field data, and the droplet model showed a superior performance of predicting liquid loading. However, the field data collected by the Turner et al. (1969) only included surface measurements, and key variables such as surface tension and fluid densities were merely estimated based on generic fluid property correlations. Another important information missing in their work was the fact that the work of Turner et al. (1969) did not clearly define how they classified wells as “loaded” or “unloaded”. Furthermore, van't Westende et al. (2007) and Waltrich et al. (2015a) have shown experimentally that for gas velocities lower than the minimum critical velocity of Turner, given by equation (1), liquid droplets flow upwards and not downwards as suggested by Turner et al. (1969). Another limitation of the model proposed by Turner et al. (1969) is the fact that equation (1) only calculates the minimum flow rate for liquid loading initiation. This method cannot be used to simulate the transient effects of liquid loading in gas wells.

2.2. Minimum pressure point and nodal analysis (Lea et al., 2003)

Another commonly used method to predict liquid loading initiation includes the concept of the minimum pressure point in the wellbore curve, as shown in Fig. 1. This concept assumes that when the reservoir Inflow Performance Relationship (IPR) curve intersects the Tubing Performance Relationship (TPR) curve at the minimum pressure point, liquid loading is initiated. This method is often correlated to the transition between annular to churn (or intermittent) flow regime, which is also used as criterion for liquid loading initiation in some studies (Skopich et al., 2015; Riza et al., 2014). In Fig. 1, the difference between IPR$_1$ and IPR$_2$ is the average reservoir pressure, where it is known that the reservoir pressure naturally depletes as consequence of the gas production. A limitation for this method is that it cannot explain the production from reservoirs with low permeability, which normally present IPR curves that intercepts the TPR curve to the left of the point of minimum pressure, and but this wells can still flow without suffering from liquid loading symptoms (Lea et al., 2003). Thus, the concept of minimum pressure may not be the most appropriate to predict liquid loading initiation since it may work for some reservoirs, but not for others, depending, for instance, on the reservoir permeability.

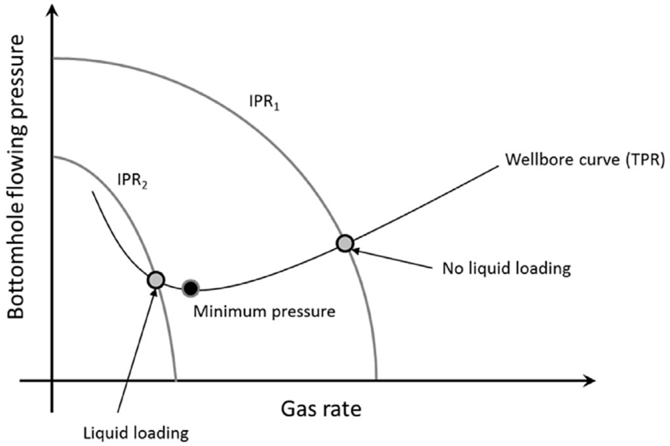

Fig. 1. Nodal analysis technique used to predict liquid loading in gas wells. The intersection between the IPR and TPR curves to left of the minimum pressure point defines if the well is under liquid loading conditions (Lea et al., 2003).

2.3. Coupled reservoir/wellbore modeling

Recently, some investigators (Zhang et al., 2009; Yusuf et al., 2010; Hu et al., 2010) have proposed coupled reservoir/wellbore modeling to predict liquid loading in transient conditions. Although these models provide reasonable solutions for liquid loading in transient conditions, some of these models include the use of commercial simulators or sophisticated modeling techniques that cannot be easily implemented using simple reservoir and tubing performance relationships. The present authors believe that one of the main reasons for the wide acceptance of the droplet model of Turner is due to the fact that equation (1) gives a very simple relationship to indicate liquid loading initiation, which can be easily understood by most engineers. Therefore, the present authors believe that there is a need to develop simplified models to predict liquid loading under transient conditions.

Other investigators have already proposed simplified methods to describe liquid loading under transient conditions using simple reservoir and tubing performance relationships. For instance, Oudeman (1990) proposed the use of multiphase reservoir performance and vertical flow performance of the tubing to improve prediction of wet-gas-well performance and liquid loading. To the knowledge of the authors, Oudeman's work was one of the first attempts to couple the reservoir performance to the tubing flow performance in order to explain liquid loading in gas wells under transient conditions. Following his approach, Dousi et al. (2006) has proposed the use of reservoir inflow performance coupled with a tubing flow performance curve to explain the process of water buildup and drainage in gas wells under transient liquid loading conditions. Dousi et al. (2006) also defined the condition called “metastable flow”, which is observed in the field as shown by these authors. The latter authors define metastable flow as subcritical rates that a well under liquid loading conditions would flow.

Some authors (Chupin et al., 2007; Veeken et al., 2010; Whitson et al., 2012) have also shown the observation of metastable flow using field data. More recently, Limpasurat et al. (2015) have proposed the use of a new boundary condition for a coupled reservoir/wellbore modeling method that was validated with field data. These authors concluded that this new boundary condition improves the prediction of transient effects for gas wells under liquid loading and also enhances the model previously proposed by Dousi et al. (2006). They also concluded that this new boundary condition can show the metastable flow observed in the field, as originally suggested by Dousi et al. (2006). However, Dousi et al. (2006) and Limpasurat et al. (2015) still have to use the minimum velocity criterion of Turner et al. (1969) to trigger liquid loading conditions.

Although the recent attempts of coupled reservoir/wellbore modeling have shown improvements on the understanding of liquid loading, simplified transient models are still exceptions rather than the norm. With the exception of the models using proprietary codes (which do not fully disclose all assumptions and details about their approach), all the other models discussed in this paper use the minimum velocity criterion of Turner et al. (1969) to trigger liquid loading, even though the accuracy of Turner's droplet model has been recently questioned by many authors (Oudeman, 1990; van't Westende et al., 2007; Veeken et al., 2010; Skopich et al., 2015). The present authors believe that the development of a simplified model would encourage engineers to replace the use of