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Prediction of Liquid Loading

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Summary

The minimum gas rate for unloading liquids from a gas well has been the subject of much interest, especially in old gas producing fields with declining reservoir pressures. For low-pressure gas wells, liquids produced accumulating in the tubing is critical factor that could lead to premature well abandonment and a huge detrimental difference in the economic viability of the well. Some notable correlations that exist for predicting the critical rate required for liquid unloading in gas wells include Turner et al., (1969), Coleman et al., (1991), Nosseir et al. (1997), Li et al. (2001) and Veeken et al., (2003). However, these correlations offer divergent views on the critical rates needed for liquid unloading and for some correlations in particular, at low wellhead pressures below 500 psia. The best result oriented among these models is used to predict liquid loading. One of them is intersected with the IPR and TPR to predict the time and condition where liquid loading starts.

Introduction

Liquid loading, by definition, is the inability of a gas well to remove liquids that are produced from the wellbore. The produced liquid will accumulate in the well creating a static column of liquid, therefore creating a back pressure against formation pressure and reducing production until the well ceases production. In order to reduce effect of liquid loading on gas production, loading problems should be diagnosed in time and dealt properly and efficiently. Liquid Loading problem exists for all type of gas wells. Therefore it is important to recognize liquid loading symptoms at early stages, and design proper solution for the gas wells in order to minimize the negative effects of liquids filling up the wellbore.

Theory and/or Method

PREDICTION MODELS FOR CRITICAL VELOCITY

Turner Model

Turner, Hubbard, and Dukler, observations, proposed two physical models for the removal of gas well liquids. The models are based on: (1) the liquid film movement along the walls of the pipe and (2) the liquid droplets entrained in the high velocity gas core. They used field data to validate each of the models and concluded that the entrained droplet model could better predict the minimum rate required to lift liquids from gas wells. This is because the film model does not provide a clear definition between adequate and inadequate rates as satisfied by the entrained droplet model when it is compared with field data. A flow rate is determined adequate if the observed rate is higher than what the model predicts and inadequate if otherwise. Again, the film model indicates that the minimum lift velocity depends upon the gas-liquid ratio while no such dependence exists in the range of liquid production associated with field data from most of the gas wells (1 - 130 bbl/MMSCF)

The theoretical equation for critical velocity V_t to lift a liquid drop.

$$V_t = \frac{1.593\sigma^{1/4}(\rho_l - \rho_g)^{1/4}}{\sqrt{\rho_g}} ft/sec$$

Turner's expressions (with 20% upward adjustment to fit data) in field units are

$$V_{c,w} = 5.304\frac{(67-.0031P)^{1/4}}{\sqrt{0.0031P}} \text{ And}$$

$$V_{c,cond} = 4.03\frac{(45-.0031P)^{1/4}}{\sqrt{0.0031P}}$$

Coleman Model

Using the Turner model but validating with field data of lower reservoir and wellhead flowing pressures all below approximately 500 psia, Coleman et al. were convinced that a better prediction could be achieved without a 20% upward adjustment to fit field data with the following expressions:

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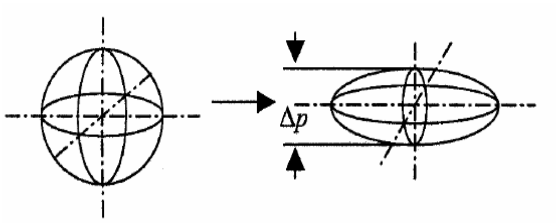
$$V_{c,w} = 4.434 \frac{(67-.0031P)^{1/4}}{\sqrt{0.0031P}} \text{(Field units)}$$

$$V_{c,cond} = 3.69 \frac{(45-.0031P)^{1/4}}{\sqrt{0.0031P}} \text{(Field units)}$$

LI's Model

Li, Li, Sun in there research posited that turner and Coleman's models did not consider deformation of the free falling liquid droplet in a gas medium. They contended that as a liquid droplet is entrained in a high- velocity gas stream, a pressure difference exists between the fore and aft portions of the droplet. The droplet is deformed under the applied force and its shape changes from spherical to a convex bean with unequal sides (flat) as shown in Figure 2.7.



Spherical liquid droplets have a smaller efficient area and need a higher terminal velocity and critical rate to lift them to the surface. However, flat-shaped droplets have a more efficient area and are easier to be carried to the wellhead.

$$V_c = 2.5 \frac{\sigma^{\frac{1}{4}}(\rho_l - \rho_g)^{\frac{1}{4}}}{\sqrt{\rho_g}} \text{(SI Units)}$$

Nossier Model

Nosseir et al. focused their studies on the impact of flow regimes and changes in flow conditions on gas well loading. They followed the path of turner droplet model but they made a difference from turner model by considering the impact of flow regimes on the drag coefficient (C). Turner model takes the value of C_d to be .44 under laminar, transition and turbulent flow regimes, which in turn determine the expression of the drag force and hence critical velocity equations.

On comparing nossier observed that Turner model values were not matching with the real data for highly turbulent flow regime. Dealing with this deviation nossier found out the reason to be the change in value of C_d for this regime from .44 to 0.2.

Nossier derived the critical flow equations by assuming C_d value of 0.44 for Reynolds number (Re) 2×10^5 to 10^6 and for Re value greater than 10^6 he took the C_d value to be 0.2.

$$V_c = \frac{14.6\sigma^{0.35}(\rho_l-\rho_g)^{.21}}{\mu_g^{0.134}\rho_g^{0.426}} \text{(Field units)}$$

Again, the critical velocity equation for highly turbulent flow regime is given as:

$$V_c = \frac{21.3\sigma^{0.25}(\rho_l-\rho_g)^{.25}}{\rho_g^{0.5}} \text{(Field units)}$$

Critical velocity

Although critical velocity is the controlling factor, one usually thinks of gas wells in terms of production rate in SCF/d rather than velocity in the wellbore. These equations are easily converted into a more useful form by computing a critical well flow rate. From the critical velocity Vg, the critical gas flow rate may be computed from:

$$Q_g = \frac{3.067PV_gA}{(T+460)Z} MMscf/D$$

Where,

$$A = \frac{(\pi)d_{ti}^2}{4\times144} ft^2$$

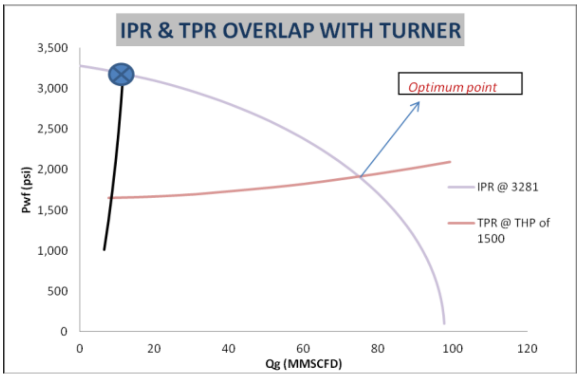
T = surface temperature, ˚F

P = surface pressure, psi

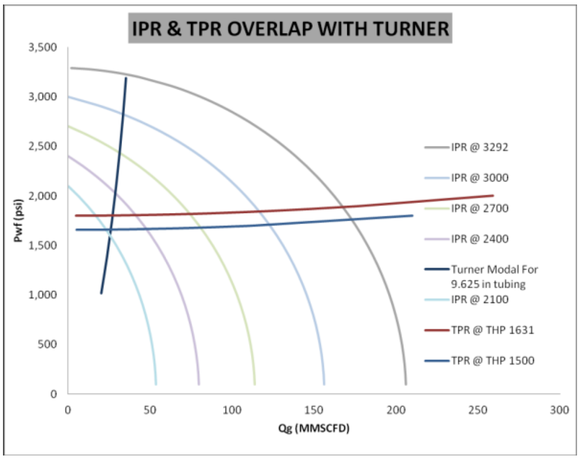
A = tubing cross-sectional area where dti = tubing id, in

Nodal Analysis

Nodal analysis divides the system into two subsystems at a certain location called nodal point. One of these subsystems considers inflow from reservoir to the nodal point selected (IPR), IPR shows the relationship between flowing bottom hole pressure (Pwf) to flow from the well (Qg) while the other subsystem considers outflow from the nodal point to the surface (TPR), . Each subsystem gives a different curve plotted on the same pressure- rate graph. These curves are called the inflow curve and the outflow curve, respectively.The point where these two curves intersect denotes the optimum operating point where pressure and flow rate values are equal for both of the curves.

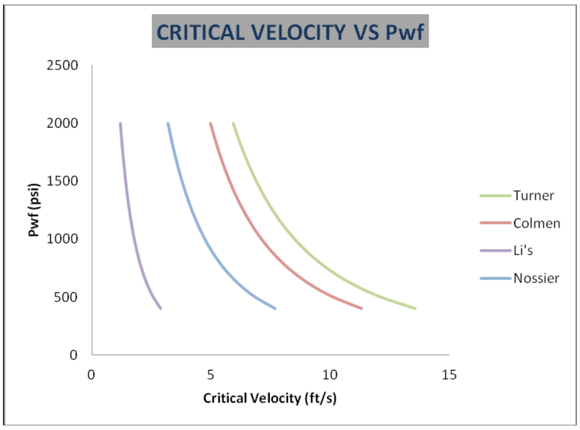


From this graph, we intrepret that as long as the optimum point of the reservoir is on the right side of overlap point og IPR and Turner liquid loading doesnt occur.



In this case, the TPR at THP of 1500 intersects with the IPR on the left hand side of intersection of IPR and Turner. This represents that at that pressure of well, liquid loading occurs.

Conclusions



One can notice that Turner model gives the most conservative value of critical velocity of all the methods for any value of pressure. The turner model is most widely used and accepted in oil and gas industries and moreover all the theories are based on the Turners model.

As it also incorporates the safety factor into it, considering this theory will forecast the liquid loading problem effectively.

We use turner model to predict liquid loading by intersecting turner curve with IPR and TPR as explained above. Predicting the time and condition where liquid loading starts helps us to take early measures to prevent it leading to proper utilization of resources.

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