ANALYTICAL MODEL FOR FALLBACK FACTOR IN INTERMITTENT GAS LIFT

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ABSTRACT

During intermittent gas lift, a low-density fluid (gas) is used to lift a high-density fluid (oil) from the bottom of the well to the surface. As a result of the oil having a higher density than the gas, some amount of the oil falls back in the form of droplets or in a film along the wall of the tubing to join the next slug of oil. However, there is still no method to accurately estimate the fallback factor in the presence of several variables in the process.

In this paper, an attempt was made to develop an analytical model to predict the fallback factor of an intermittent gas lift cycle by continuing the mechanistic model from literature to include the change in length of liquid slug to estimate the fallback factor.

INTRODUCTION

In intermittent gas lift (IGL), a slug of liquid is first allowed to build up in the tubing string. A gas lift valve injects high-pressure gas held in the casing-tubing annulus beneath the slug after it reaches its specified length. The energy of the expanding and moving gas below the liquid slug propels it higher. The length of the liquid slug continuously decreases because of the faster-moving gas bubble constantly penetrating or overrunning the liquid slug bottom (Schmidt et al., 1984). As the liquid slug travels up the tubing, the length of the slug reduces as mentioned and the amount of the initial slug length which is not produced at the surface is known as fallback. The liquid fallback occurs as entrainment or along the wall of the tubing as shown in Figure 1.

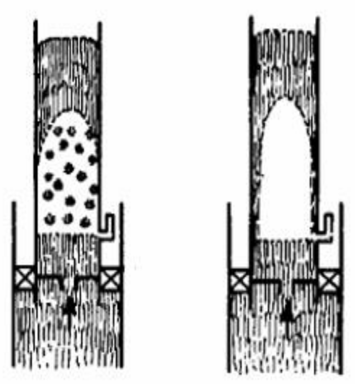

Figure 1: Depiction of Liquid Fallback (Brill et al., 1967)

The highly transient nature of the process has made it difficult to come up with an appropriate model to estimate the amount of liquid fallback. Correctly estimating the performance of a gas lift valve also increases the effectiveness of gas lift operation (Sagar et al., 1992).

(Brown et al., 1962) investigated the effect of surface restrictions on the fallback factor in IGL. (White et al., 1963) made an advancement on coming up with a formula for the amount of liquid fallback but faced problems with the correct method to estimate the penetrating velocity of the gas. (Brill et al., 1967) made an effort to come up with an empirical model for fallback factor by conducting series of experiments. (Neely et al., 1974) conducted field tests to accounts for the liquid afterflow in the concept of fallback. (Hernandez et al., 1997), (Hernandez et al., 1998), (Hernandez et al., 1999) and (Hernandez et al., 2001) showed how the operational conditions and properties of the liquid affects the fallback factor.

According to (Carvalho Filho, 2004) the present IGL cycle consists of 5 stages as shown in Figure 2 below.

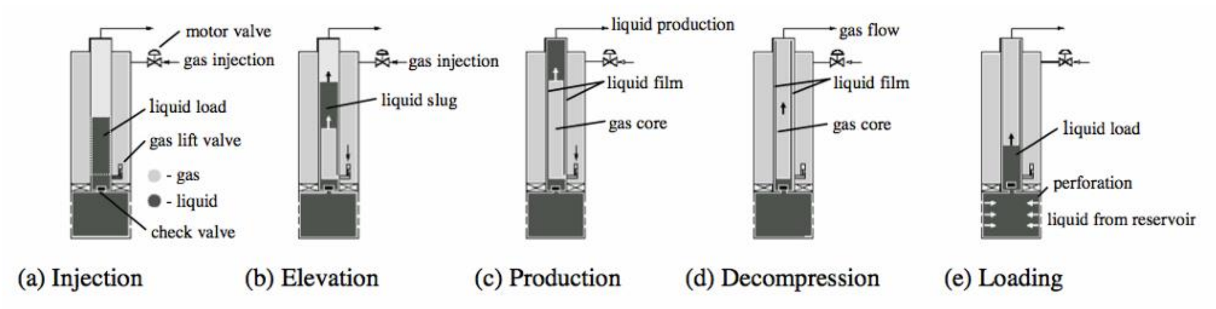

Figure 2: Schematic Representation of an IGL cycle (Carvalho Filho, 2004)

During the injection stage, gas is fed into the casing. At the elevation stage, gas enters the tubing from the casing which causes the liquid slug to rise. Liquid leaves the tubing and enters the production line during the production stage. Gas leaves the tubing during the decompression stage and the loading stage is when the liquid from the reservoir is allowed to build up to a certain height in the tubing.

In this paper, an analytical model for the fallback factor in IGL is proposed based on the equations developed by the mechanistic model presented by (Liao, 1991). Some of the assumptions made are no formation gas is present, liquid is incompressible, Thornhill-Craver equation is used for the flow in the gas lift valve, liquid fallback is only due to entrainment and the reservoir Inflow Performance Relationship (IPR) is known.

PROPOSED ANALYTICAL MODEL

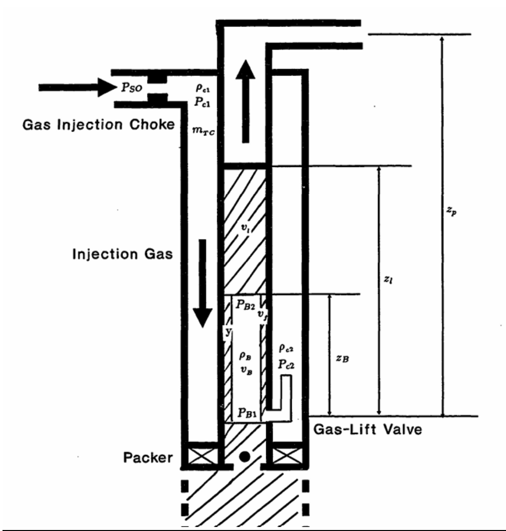

Figure 3: Depiction of the Lift of Liquid Slug (Liao, 1991)

From the mechanistic model of IGL presented by (Liao, 1991) where he considered the liquid slug as the control volume, (Liao, 1991) developed the following mass balance equations on it.

$$\frac{dm}{dt} = \frac{d}{dt}\int \rho dV + \frac{d}{dt}\int \rho(v_r \cdot n)dA \dots\dots\dots\dots\dots\dots (1)$$

Where v_r = Velocity of the fluid relative to the control surface.

n = The outer normal unit vector everywhere on the control surface.

The first part of the RHS of the equation represents the control volume and the second part of the RHS represents the control surface.

(Liao, 1991) simplified the first part of the mass balance equation as:

$$\frac{d}{dt}\int \rho dV = \frac{d}{dt}\int [\rho_L(z_L - z_B)A_t] = \rho_L A_t\left(\frac{dz_L}{dt} - \frac{dz_B}{dt}\right) \ldots\ldots\ldots\ldots\ldots..(2)$$

Where z_L = Distance covered by liquid slug.

z_B = Distance covered by gas.

$$\frac{d}{dt}\int \rho dV = \rho_L A_t(v_L - v_B) \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(3)$$

The above equation represents the change in mass due to the gas penetrating the control volume.

(Liao, 1991) simplified the second part of the RHS as follows:

$$\int_{bot.an} \rho_L(v_r \cdot n)dA = \int_{bot.an} \rho_L[(v_f - v_B)\cdot n]dA = -\rho_L(A_t - A_B)(v_f - v_B) \ldots\ldots\ldots\ldots(4)$$

The above equation also accounts for the change in mass across the control surface.

Then the mass balance by (Liao, 1991) concludes as:

$$\frac{dm}{dt} = \rho_L A_t(v_L - v_B) - \rho_L(A_t - A_B)(v_f - v_B) \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

If the liquid slug is considered as the control volume, then the mass of the liquid slug will decrease with time due to liquid fallback. Hence the mass balance proposed by (Liao, 1991) was further continued to introduce the change in the length of the liquid slug.

$$\frac{d(\rho_L A_t h_L)}{dt} = \rho_L A_t(v_L - v_B) - \rho_L(A_t - A_B)(v_f - v_B) \ldots\ldots\ldots\ldots\ldots.(6)$$

$$\rho_L A_t\frac{dh_L}{dt} = \rho_L A_t(v_L - v_B) - \rho_L(A_t - A_B)(v_f - v_B) \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(7)$$

$$\frac{dh_L}{dt} = (v_L - v_B) - (1 - \gamma_g)(v_f - v_B) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

$$\frac{dh_L}{dt} = (v_L - v_B) - \gamma_L(v_f - v_B) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

<u>METHOD</u>

(Hernandez et al., 1998) defined fallback factor as: $\left(\frac{Q_a - Q_p}{Q_a}\right)/dov$ ……………… (10)

<u>Elevation Stage of the current IGL cycle</u>

Considering the elevation stage of the present IGL cycle, the flow rate of the gas entering the tubing can be calculated using the Thornhill-Craver equation as follows:

$$q_g = \frac{155.5 C_d A_p P_1\sqrt{2g\left(\frac{k}{k-1}\right)}\sqrt{\left(r^{\frac{2}{k}} - r^{\frac{k+1}{k}}\right)}}{\sqrt{\gamma_g T_1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

The initial velocity of the liquid slug can be calculated from the flow rate:

$$v_L = \frac{q_g}{A_t} \dots\dots\dots\dots\dots\dots\dots\dots\dots . (12)$$

The rest of the instantaneous slug velocities are calculated by dividing the tubing into equal sections and equipping the sections with sensors to measure the time it takes for the slug to reach each section.

Velocity of Gas Bubble

Knowing the pressure and the temperature, the average gas compressibility factor can be calculated from any known correlation or from charts such as the Standing-Katz chart. Then the density of the gas is estimated from the modified ideal gas equation for real gases. The velocity of the gas is estimated using the formula in equation (14) by (Ansari et al., 1994).

$$v_B = 1.2v_L + 0.35\left[\frac{gd_t(\rho_L - \rho_g)}{\rho_L}\right]^{1/2} \dots\dots\dots\dots\dots\dots\dots\dots (13)$$

Liquid Holdup

The liquid holdup is calculated from the formula below by (Ros, 1961) in equation (14).

$$\gamma_L = \frac{20}{{N_d}^2}$$

Where N_d is known as the diameter number.

$$N_d = d_t\sqrt{\frac{\rho_L g}{\sigma}}$$

The calculated values are substituted into equation (9) to estimate the change in length effected by the liquid slug traveling between the two successive sections of the tubing. The procedure is repeated till the slug makes it to the surface and the knowing the initial length of the slug and the produced length of the slug, the fallback factor is calculated using equation (10) suggested by (Hernandez et al., 1998).

CONCLUSION

An analytical model for estimating the fallback factor is presented. This method relies on accurate time measurement in order to calculate the slug velocities. The accuracy of this model depends also on the accurate pressure calculations of the assumed gas-liquid interface as the slug travels up the tubing. Actual experiments need to be done to accurately measure time.

However, this analytical model has not been verified yet with well data. By equipping wells with sensors to recognize the location of slug, this model can be effectively tested.

NORMENCLATURE

A_B = Area occupied by gas

A_p = Port area of gas lift valve

A_t = Area of tubing

C_d = Discharge coefficient

d_t = Diameter of tubing

g = Acceleration due to gravity

h_L = Length of liquid slug

$k = \frac{c_v}{c_p}$, Ratio of specific heats

N_d = Diameter number

n = The outer normal unit vector everywhere on the control surface

σ = Surface tension

ρ_L = Density of liquid

P_1 = Casing pressure (psia)

P_2 = Tubing pressure

v_B = Gas velocity

v_f = Film velocity

v_L = Slug velocity

v_r = Velocity of the fluid relative to the control surface

$r = \frac{P_2}{P_1}$

T_1 = Casing pressure at where the valve is located

γ_g = Specific gravity of gas

z_L = Distance covered by liquid slug

z_B = Distance covered by gas

Q_a = Initial length of liquid slug

Q_p = Final length of liquid slug

dov = Depth of valve

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