Research on Minimum Length Calculation of Skid-Mounted Small-Diameter Pipe Weight Bar

Xue Jijun
Mechanical Engineering College
Xi'an Shiyou University
Xi'an, 710065, Shaanxi, P.R. China
E-mail: xue_jijun@163.com

***Abstract*—The drainage gas recovery operation with small-diameter continuous pipes is applicable to the one in natural gas well with low pressure, low production and low water content. Its advantages exhibit as the following: 1) high efficiency on continuous running of pipe string under pressure; 2) production while operation; 3) correct monitoring the position of ejection head; and 4) précised control of ejection quantity. Due to the small diameter, thin wall thickness and relative low rigidity of pipe string, it is easy to cause bending and deformation during down-hole process and affect the capability of small diameter pipe operation. Aiming at shutting and opening of the well, this thesis analyzes the force of the small-diameter pipe during down process, establishes the corresponding digital model and proposes the calculating method required to run the small-diameter pipes under different status. Taking G25-5 well as example, the appropriate minimum length of weight bar under different working status is given to verify the validness of the method to determine the minimum length of weight bar.**

Keywords-Skid-Mounted Small-Diameter Pipe; Drainage Gas Recovery & Weight Bar

I. INTRODUCTION

Partial gas wells of Changqing Gas Field exhibit the characteristics of low pressure and low production upon the time of operation. When the production reaches certain degree, the gas well cannot meet the requirements of the minimum liquid carrying flow. Since the water content carried upon to the ground is relatively low, the liquid is generated at the well bottom and cylinder which leads abnormal operation of gas well. The drainage gas recovery operation with small-diameter continuous pipes is applicable to the one in natural gas well with low pressure, low production and low water content. Its advantages exhibit as the following: 1) high efficiency on continuous running of pipe string under pressure; 2) production while operation; 3) correct monitoring the position of ejection head; and 4) précised control of ejection quantity. Due to its small diameter of thin wall thickness, the rigidity of pipe string is relative low to hardly bear the longitudinal compression load. During the down-hole process, the medium within the well generates lift force which leads unbalance, bending and deformation easily during down-hole process. To have the small diameter pipe run down the well smoothly, the weight bar with certain weight shall be added reasonably at the lower end of the small diameter end. If the weight bar is too short, it is unable to maintain the stressed status of the small diameter pipe during down-hole process which might leads failure to placing the small diameter pipe into the well. If the weight bar is too long, many problems occur to the construction of small diameter in spite of advantages to the down-hole process.

This thesis detailed discusses the force analysis of pipe string within mineshaft under both well startup and shutdown and researches the best calculating method of weight bar assignment to provide theoretical basis for the construction operation of small-diameter pipe drainage and gas recovery.

II. SMALL DIAMETER PIPE STRING FORCE ANALYSIS DURING DOWN-HOLE PROCESS

See the force analysis during down-hole process in Figure 1. The ID and OD of small diameter are d1 and D1 respectively while the ID of tubing is d3. The weight bar adopts sold cylinder body with diameter of d2. To prevent the small-diameter pipe from bending during the lifting and down process, the "neutralized point" shall fall on the heavy weight rod, i.e. the weight of weight bar under the neutralized point shall be balanced with all the external force functioned on the heavy weight rod. If the length of weight bar is 1, the neutral point is right at the connection part between the weight bar and small diameter pipe. 1 refers to the minimum length of weight bar required by the small-diameter pipe from bending.

Then, the force on weight bar includes gravity G, force on the upper end F_r, force on the lower end F_s and friction surrounding of heavy weight rod, F_f. If the neutral point is just right at the connection part between the weight bar and small diameter pipe, the above forces shall reach balance status, i.e.

$$G + F_T - F_B - F_f = 0 \,. \tag{1}$$

Where, each parameter adopts international unit, i.e. SI unit system. In case of no statement, this also applies to the equations hereinafter.

The model of small-diameter pipe during down-hole process shall be established under two status, well shutdown and startup.

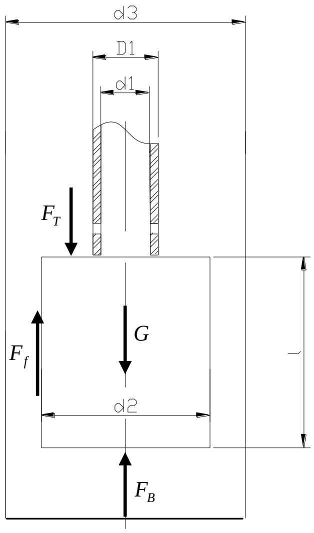

Figure 1. Dimensional Parameters and Force Model of Small-Diameter Pipe weight bar

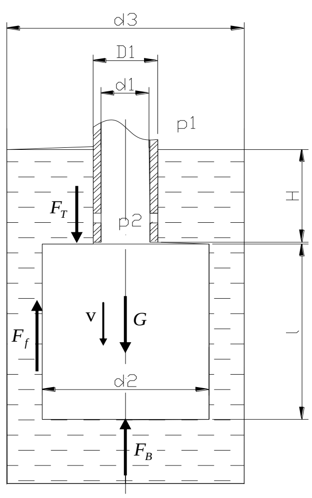

Figure 2. Force Model under Well-Shutting Status

III. FORCE ANALYSIS OF WEIGHT BAR UNDER WELL SHUTDOWN STATUS

When water-content gas well is shut down, the flow with raw water would accumulate at the well bottom to form two quite different portions of flows during to the function of gravity differentiation, including upper gas column and lower liquid column. Under the most disadvantageous condition: both the weight bar and small diameter pipe are run down below the liquid level by H under the speed of v. Assuming the pressure at gas-liquid interface is p_1 as indicated in Figure 2, the gravity G, force at upper end F_r, force at lower end F_s and the surrounding friction of weight bar F_f shall be calculated as the following methods:

A. Gravity G.

The gravity of the weight bar shall be:

$$G = \frac{\pi}{4} d_2^2 l \rho_{Fe} g \tag{2}$$

Where, ρ_{Fe} refers to the density of heavy weight rod, taking $7.8 \times 10^3 kg/m^3$; and g refers to gravitational acceleration.

B. Force at upper end FT

The force at upper end is generated by two parts, i.e. gas-liquid interface pressure and hydraulic string pressure. In case of running down small –diameter pipe only without the operation of frothing agent injection, the injection orifice is closed. The pressure within small-diameter pipe p2 can be regarded as 0. However, when the frothing agent is injected stably, p2 shall be a little higher than the upper end force on the weight bar slightly and can take its lower end pressure approximately for calculation. When the small-diameter pipe is running down without any frothing agent operation, the force at upper end shall be:

$$F_T = \frac{\pi}{4}\left(d_2^2 - D_1^2\right)\left(p_1 + \rho_L gH\right) \tag{3}$$

Where, ρ_L refers to liquid density by $1.0 \times 10^3 kg/m^3$.

When the small-diameter pipe is running down with stable injection operation of frothing agent, the force at upper end shall be:

$$F_T = \frac{\pi}{4}\left(d_2^2 - D_1^2\right)\left(p_1 + \rho_L gH\right) + \frac{\pi}{4} d_1^2 (p_1 + \rho_L gH) \tag{4}$$

C. Force at lower end FB

The force at lower end is generated by two parts, i.e. gas-liquid interface pressure and hydraulic string pressure, therefore

$$F_B = \frac{\pi}{4} d_2^2 \left[p_1 + \rho_L g (H + l)\right] \tag{5}$$

D. Friction force F_f surrounding heavy weight rod

The friction force surrounding weight bar shall be:

$$F_f = \mu A \frac{dv}{dy} \tag{6}$$

Where, μ refers to the coefficient of liquid viscosity taking $\mu = 1.005 \times 10^{-3} Pa \cdot s$; A refers to the contact area between the weight bar and flow layer and $A = \pi d_2 l$; $\frac{dv}{dy}$ refers to the gradient of flow layer speed and

$\frac{dv}{dy}=\frac{v}{\frac{1}{2}(d_3-d_2)}=\frac{2v}{d_3-d_2}$; and v refers to the running-down speed of small diameter pipe.

Introduce formula (2) to (6) into formula (1), the minimum weight bar length under well shutdown status is as the following:

When the small-diameter pipe is running down without any frothing agent operation, the minimum length of the weight bar shall be:

$$l=\frac{D_1^2(p_1+\rho_L gH)}{d_2^2 g(\rho_{Fe}-\rho_L)-\frac{8v\mu d_2}{d_3-d_2}} \tag{7}$$

When the small-diameter pipe is running down accompanied by frothing agent operation, the minimum length of the weight bar shall be:

$$l=\frac{(D_1^2-d_1^2)(p_1+\rho_L gH)}{d_2^2 g(\rho_{Fe}-\rho_L)-\frac{8v\mu d_2}{d_3-d_2}} \tag{8}$$

Comparing formulas of (7) and (8), the minimum weight bar length required during small-diameter pipe's running down accompanied by frothing agent operation is larger than the one at the working status during the downing process with the injection of frothing agent. Therefore, the weight bar minimum length shall be determined against well shutdown status.

IV. Force Analysis of Weight Bar Under Well Open Status

From the analysis of well-shutting status, it is found that the minimum length of weight bar required during the down-hole process of small diameter pipes without frothing agent is longer than the one required with frothing agent. Therefore, it is only required to research on the working status without frothing agent for small diameter pipe down hole process for well startup status, i.e. the relative pressure p2 within small diameter pipe equals zero.

During the actual operation, small-diameter pipes might encounter two kinds of statuses during down-hole process, i.e. mist flow within tubing in the form of flowing (With gas of continuous phase and liquid as dispersed phase, the relative moving speed between gas and liquid is quite small. The gas phase is the control element of the whole flowing.) or the blocking flow existed within the tubing (certain part of tubing is completely liquid phase). Obviously, under disadvantageous status, small diameter pipe encounters blocking flow during down-hole process and the blocking flow appears at the well bottom. See the force model in Figure 3. The pressure at the liquid and gas interface at the upper end of blocking flow is well bottom pressure, p_1. The height of weight bar immersed below the liquid and gas interface is *H*.

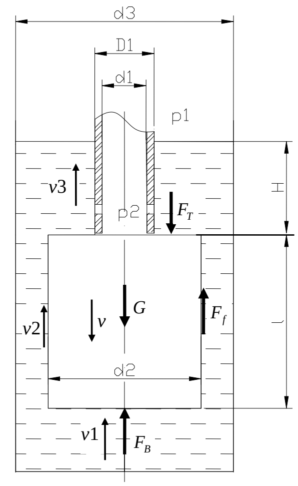

Figure 3. Force Model of Small-Diameter Pipe String

Assuming the daily gas production is q_{sc}, the weight bar and small-diameter pipe is down to the well bottom or the pre-determined maximum depth by speed of v. Then, the weight bar also suffers from the function of gravity G, force at upper end F_T, force at lower end F_B and friction force of surrounding liquid F_f. When the neutral point is located at the connection between the weight bar and small-diameter pipe, these forces shall also meet equation (1). Gravity G, force at upper end F_T, force at lower end F_B and friction force of surrounding liquid F_f shall be calculated as per equation (2), (3), (5) and (6) respectively. Only during the calculation of liquid friction F_f, the gradient of speed at flow layer shall be calculated as the following formula:

$$\frac{dv}{dy}=\frac{v+v_2}{\frac{1}{2}(d_3-d_2)}=\frac{2(v+v_2)}{d_3-d_2} \tag{9}$$

Where, v refers to the running-down speed of small diameter pipe; v_2 refers to the liquid flowing speed at the lower end of small diameter pipe where blocking speed can be regarded as the same moving speed to gas, $v_2=5.096\times10^{-3}\frac{T_1 q_{sc}}{p_1(d_3^2-d_2^2)}$; and T_1 refers to the absolute temperature of calculation position within the bottom, *K*. Introducing formula (9) into formula (6), then introduce formula (2), (3), (5) and (6) into formula (1). After compilation, the minimum weight bar calculation formula at well-shutting status is as the following:

$$l=\frac{D_1^2(p_1+\rho_L gH)}{d_2^2 g(\rho_{Fe}-\rho_L)-\frac{8(v+v_2)\mu d_2}{d_3-d_2}} \tag{10}$$

V. ANALYSIS OF CALCULATION CASE

Taking G25-5 well as the calculation case, the inside diameter of small diameter pipe d_1 =6.5mm, OD D_1 =9.5mm, weight bar diameter d_2 =42mm, density ρ_{Fe} =16240kg/m3, diameter of tubing d_3 =62mm, running down depth 3200m, daily gas production q_{sc} =10000m3/d, pressure at well bottom p_1 =10Mpa, temperature at well bottom T_1 =80℃ and running-down speed of small diameter pipe v =0.17m/s.Assuming the immersed height of weight bar from the upper end H is 1m, the weight bar length shall be determined as per the well startup and shutting status. See the calculation result in Table 1.

TABLE I. MINIMUM LENGTH OF WEIGHT BAR REQUIRED UNDER 6 DIFFERENT WORKING STATUSES

Working status	Well startup Status				Well Shutdown Status	
	Stable running down of small diameter pipe without blocking flow	adding frothing agent without blocking flow	Stable running down of small diameter pipe with blocking flow	adding frothing agent with blocking flow	Stable running down of small diameter pipe	Adding frothing agent during running-down process
Length of weight bar l (m)	3.2586	1.7335	3.4292	1.8238	3.4290	1.8237

From the data in the table, the minimum length of weight bar pipe required for the small-diameter pipe with addition of frothing agent is obviously small than the length required for weight bar without the addition of frothing agent. If the measures can be taken to have the inside of small diameter pipe filled with certain pressure of frothing agent during running-down process, the length of weight bar is reduced obviously which brings conveniences to the implementation of small-diameter pipe drainage and gas recovery operation. In addition, the existence of blocking flow leads the slight addition of minimum length of required heavy weight rod. Under the same conditions, the minimum length of requires more under the blocking flow. Therefore, it shall calculate the blocking flow under working status 3 to determine the minimum length of weight bar when it is unknown whether the blocking flow is existed or not.

VI. ANALYSIS OF AFFECTING ELEMENTS TO MINIMUM LENGTH OF WEIGHT BAR

Many elements would affect the running-down operation of small diameter pipes. Among which, the primary affecting elements include the diameter of the weight bar and the pressure at the well bottom. the weight bar with diameter of 42mm and 47mm is preferred considering the elements of operation, cost, transportation, etc.

VII. CONCLUSIONS

1) Against 6 different working statuses, this thesis makes a detailed analysis on the force of the small-diameter pipe during its running down process and a corresponding digital model is established. Further, this thesis proposes the calculation method of minimum length of the small diameter required for its smooth running-down operation.

2) Taking G25-5 well as example, the appropriate minimum length of weight bar under different working status is given to verify the validness of the method to determine the minimum length of heavy weight rod. From the case calculation result, it tells that the minimum length of weight bar required during the process of running down of small diameter pipe accompanied with the addition of frothing agent is obviously less than the one required without addition of frothing agent. In addition, the existence of blocking flow leads the slight addition of minimum length of required heavy weight rod. Under the same conditions, the minimum length of weight bar increases under the existence of blocking flow.

3) The affecting elements to the minimum length of weight bar are analyzed to give a selection plan the construction operation.

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