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Tubing Stress, Basic Analysis

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Abstract

This paper briefly describes in the introductory section general issues regarding tubing movement. Next sections try to set up a methodology for tubing movement and tubing stress assessment.

Key words: *tubing stress, piston effect, buckling.*

Introduction

This paper investigates the effects of changing well conditions to an installed packer and the tubing string. During any service operation or when producing, the well conditions will change from those in which the packer was installed. Knowing the magnitude of these changes aids in proper tool selection and installation. Changing the tubing pressure, annulus pressure or the well temperature results in either a tension force on the end of the tubing string or a change in the length of the tubing string. If the tubing is not free to move, tension forces are generated inside the tubing string. If the tubing is free to move, it will either shorten or elongate. There are five basic effects which can occur if the well conditions change. Each effect can be analyzed separately and then combined with the others to get the total effect. They are:

1. Piston effect.
2. Ballooning and reverse ballooning.
3. Buckling due to pressure inside the tubing.
4. Temperature effect.
5. Applied forces from the surface.

The piston effect, buckling and ballooning are all a result of pressure changes. The temperature effect and any applied forces are independent of the well pressure. Each effect is considered individually and then combined with the others to achieve a total effect. The end result could be a force or a length change. The total effect depends on the type of tubing-packer connection.

In this paper there are considered two possibilities:

1. Latched Tubing (no motion).
2. Stung Through Tubing (free motion).

There are considered two stages of operations:

1. Initial stage, after setting the packer, before operation.
2. Final stage, during operation.

All the measure units used in this paper are according to International System.

Piston Effect Calculations for Stung Through Tubing

The piston effect only occurs at the packer and is also called an end area effect. Figure 1 is an illustration of a simplified packer showing the areas where pressurects.

Tubing pressure P_t will act on the difference between the packer seal bore A_s and the tubing I.D. area A_i creating force F_1. Annulus pressure P_a acts on the difference between the packer seal bore area A_s and the tubing O.D. area A_o creating force F_2.

Piston force F_P

$$F_P = F_2 - F_1$$

where

$$F_2 = \Delta P_a \cdot (A_s - A_o) \quad \text{and}$$

$$F_1 = \Delta P_t \cdot (A_s - A_i)$$

in which ΔP_a is the pressure change in the annulus at the packer depth and ΔP_t is the pressure change in the tubing at the packer depth:

$$\Delta P_a = P_{af} - P_{ai} \quad \text{and}$$

$$\Delta P_t = P_{tf} - P_{ti}$$

where: P_{af} - final annulus pressure; P_{ai} - initial annulus pressure; P_{tf} - final tubing pressure; P_{ti} - initial tubing pressure.

Each above mentioned pressure has two components: a hydrostatic one noted with *h* index and another one applied from the surface, noted with *s* index.

$$P_{af} = (P_{af})_h + (P_{af})_s$$

$$P_{ai} = (P_{ai})_h + (P_{ai})_s$$

$$P_{tf} = (P_{tf})_h + (P_{tf})_s$$

$$P_{ti} = (P_{ti})_h + (P_{ti})_s$$

If $F_P > 0$ piston force from inside the tubing string is a tensile force. If $F_P < 0$ piston force from inside the tubing string will be a compressive force.

Tubing movement due to piston force, according to Hooke's law ΔL_P

$$\Delta L_P = \frac{L \cdot F_P}{E \cdot A_m}$$

where: $E = 2{,}07 \cdot 10^{11} N/m^2$ - *Young* modulus of elasticity for steel; A_m - metallic tubing cross-sectional area; L - length of tubing (packer setting depth).

Ballooning and Reverse Ballooning

Ballooning is a result of higher pressure inside the tubing string than outside. The pressure differential creates stresses which tend to burst the tubing string. The burst stress causes the tubing to swell. As the tubing swells, its length becomes shorter, if free to move.

If the pressure in the annulus is higher than that in the tubing, the pressure differential creates stresses which tend to collapse the tubing. As the tubing collapses, it elongates, if free to move.

If the tubing is anchored inside the packer, ballooning creates a tensile force and reverse ballooning creates a compressive force inside the tubing string.

Ballooning is a distributed effect; therefore all the calculations are based on the average pressure change in the tubing and annulus.

Ballooning force F_B

$$F_B = 2 \cdot \mu \cdot \left(\Delta \overline{P_a} \cdot A_o - \Delta \overline{P_t} \cdot A_i \right)$$

where μ is *Poisson* coefficient and for steel $\mu = 0,3$; $\Delta \overline{P}_a$ - average pressure change in the annulus; $\Delta \overline{P}_t$ - average pressure change in the tubing:

$$\Delta \overline{P}_a = \overline{P}_{af} - \overline{P}_{ai} \text{ and}$$
$$\Delta \overline{P}_t = \overline{P}_{tf} - \overline{P}_{ti}$$

where: $\overline{P}_{af}$ - annulus final average pressure; $\overline{P}_{ai}$ - annulus initial average pressure; $\overline{P}_{tf}$ - tubing final average pressure; $\overline{P}_{ti}$ - tubing initial average pressure:

$$\overline{P}_{af} = \left(P_{af} \right)_s + \frac{\left(P_{af} \right)_h}{2}$$
$$\overline{P}_{ai} = \left(P_{ai} \right)_s + \frac{\left(P_{ai} \right)_h}{2}$$
$$\overline{P}_{tf} = \left(P_{tf} \right)_s + \frac{\left(P_{tf} \right)_h}{2}$$
$$\overline{P}_{ti} = \left(P_{ti} \right)_s + \frac{\left(P_{ti} \right)_h}{2}$$

Tubing movement due to ballooning force, according to Hooke's law ΔL_B

$$\Delta L_B = \frac{L \cdot F_B}{E \cdot A_m}$$

Buckling Due to Pressure Inside the Tubing

Buckling due to pressure inside the tubing is caused by two distinct force distributions. A compressive force on the end of the tubing string and an uneven pressure distribution across the tubing wall. Buckling is most severe at the bottom of the tubing string. There is a point, called the neutral point, above which no buckling occurs. If the buckling is very severe, the neutral point may be above the wellhead, in which case the entire tubing string is buckled.

Buckling due to pressure exerts a negligible force on a packer and is ignored as a force. If the annulus pressure is greater than the tubing pressure, no buckling will occur. A tubing string can buckle even if the tubing is in tension.

Tubing movement due to buckling effect ΔL_F

$$\Delta L_F = -\frac{c^2 \cdot A_s^{\,2} \cdot \left(\Delta P_t - \Delta P_a\right)^2}{8 \cdot E \cdot I \cdot \left(\gamma_t + \gamma_{tl} - \gamma_{al}\right)}$$

where c is radial clearance between tubing and casing

$$c = \frac{D_c - D_o}{2}$$

D_c - casing I.D.; I - tubing moment of inertia

$$I = \frac{\pi\left(D_o^4 - D_i^4\right)}{64}$$

γ_t - tubing linear weight; γ_{tl} - tubing liquid linear weight; γ_{al} - annular liquid linear weight

$$\gamma_t = A_m \cdot \rho_s \cdot g$$
$$\gamma_{tl} = A_i \cdot \rho_{tl} \cdot g$$
$$\gamma_{al} = \mathrm{A_a} \cdot \rho_{al} \cdot g$$

where: ρ_s - steel density; ρ_{tl} - tubing fluid density; ρ_{al} - annulus fluid density; A_a - annular area between casing I.D. and tubing O.D.

Height of neutral point above packer n (see fig. 2)

$$n = \frac{A_a \cdot \left(P_{tf} - P_{af}\right)}{\left(\gamma_t + \gamma_{tl} - \gamma_{al}\right)}$$

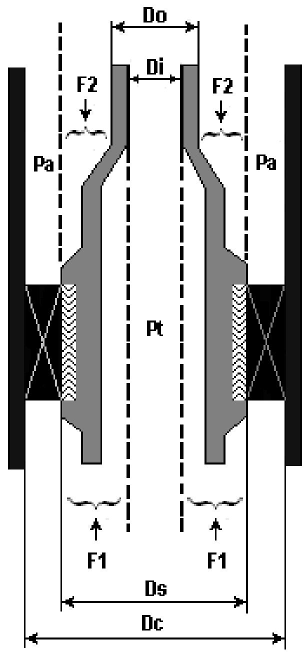

Fig. 1.

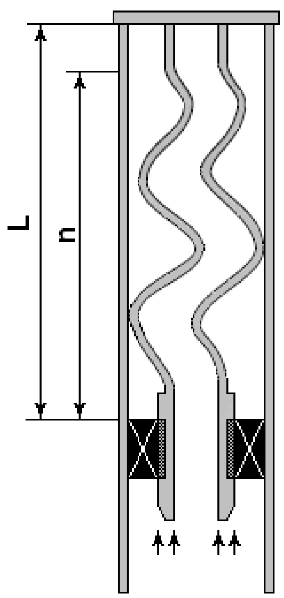

Fig. 2.

If the height of the neutral point n exceeds the length of the tubing string L, then a correction factor for the length change ΔL_F due to buckling should be applied.

$$\Delta L_F' = \Delta L_F \cdot \frac{L}{n} \cdot \left(2 - \frac{L}{n}\right)$$

Temperature Effect

Temperature effect is a distributed one; therefore all the calculations are based on the average temperature change in the tubing string.

When the average temperature of a well increases (either by injecting hot fluids or by producing hot formation fluid), the tubing will elongate if free to move. If the tubing string is anchored to the packer, the temperature change generates a compressive force inside it. When the average well temperature decreases (by injecting cool fluids), the tubing string will shorten if free to move. If the tubing string is anchored at the packer, decreasing the average well temperature will generate a tensile force inside it.

Calculations steps: Initial average temperature T_{ia}

$$T_{ia} = \frac{T_{is} + T_{ib}}{2}$$

$$T_{fa} = \frac{T_{fs} + T_{fb}}{2}$$

where: T_{fs} - final surface temperature; T_{fb} - final bottom hole temperature.

Change in average tubing temperature ΔT

$$\Delta T = T_{fa} - T_{ia}$$

Change in tubing string length (tubing not anchored) ΔL_T

$$\Delta L_T = \alpha \cdot L \cdot \Delta T$$

where α = $1{,}24 \cdot 10^{-5}$ 1/^{o}C - coefficient of thermal expansion for steel.

The temperature force (anchored tubing) F_T

$$F_T = \alpha \cdot E \cdot A_m \cdot \Delta T$$

Applied Forces from the Surface

Forces applied from the surface could be tensile forces or compressive forces. The tubing string is supposed to be latched inside the packer. According to *Hooke's* law, the relation between a tensile force F_t and tubing elongation ΔL_t will be:

$$\Delta L_t = \frac{F_t \cdot L}{E \cdot A_m}$$

When a compressive force is slacked off to set the packer, the relation between the compression force F_c created by compression the tubing string on the ΔL_c length will be:

$$\Delta L_c = \frac{F_c}{E} \cdot \left[\frac{L}{A_m} + \frac{c^2 \cdot F_c}{8 \cdot I \cdot \left(\gamma_t + \gamma_{tl} - \gamma_{al} \right)} \right]$$

Total Effect

To assess the total effect it must be taken into consideration two cases:

1. Stung through tubing (free motion)

$$F_{TOT} = F_P + F_B + F_T$$
$$\Delta L_{TOT} = \Delta L_P + \Delta L_B + \Delta L_F + \Delta L_T$$

2. Latched tubing (no motion)

$$F_{TOT} = F_B + F_T + F_c$$

Elongations and tensile forces are considered to be positive, shortenings and compressive forces are considered negative.

Conclusions

Tubing stress analysis is an important component of completion design. It helps to define the size weight and grade of the completion. It is usefull for choosing the propper type of packer, to assess the loads on it, to determine the length of seal bore and seal assembly or to support the decision to use an expansion joint.

Many designs are analysed using specialised software and the engineer, besides interface knowledge, should have a thoroughly understanding of the physical phenomena to be able to use it.

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O analiză elementară a solicitărilor tubingului

Rezumat

Lucrarea prezintă pe scurt aspectele generale cu privire la problematica manevrării tubingului. Pe această bază se încearcă stabilirea unei metodologii de acţionare şi estimare a valorii solicitărilor.