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An integrated workflow to design screen/slotted liners in geothermal wells

Ruiyue Yang, Zhongwei Huang*, Gensheng Li, Huaizhong Shi, Xianzhi Song, Yu Shi

State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum, Beijing, China

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ABSTRACT

Screen/slotted liners can be used in geothermal well completions. However, the thermally-induced stress caused by elevated temperature could substantially deteriorate the collapse strength. This paper presents an integrated workflow which complementarily utilizes analytical and numerical methods to design screen/slotted liners in geothermal wells. The collapse rating of a screen/slotted liner is obtained by a modified analytical approach. The thermally-induced stress is estimated through the Finite Element Method Subsequently, the collapse strength assessment for a screen/slotted liner when subjected to high-temperature is made by combining these two approaches. Finally, a selection guide for the schematic of holes/slots configuration is provided. The result depicts that high-temperature could substantially impair the collapse strength of a screen/slotted liner. It also suggests that prediction of the critical temperature for plastic deformation is important in the safe design of the screen/slotted liners in geothermal wells. The method is simple and versatile, without complicated mechanical-thermo-coupling process. It can provide a guidance for completion engineers to modify the design of screen/slotted liners prior to the actual treatment in geothermal wells.

1. Introduction

Ongoing rapid development of geothermal energy worldwide has led to an increased focus on developing robust tubular design bases for extreme service conditions. The high-temperature downhole environment encountered in geothermal wells produces adverse effects on the integrity of the tubulars (Edwards et al., 1982). The associated compressive axial stress caused by constrained thermal expansion can weaken the collapse resistance of the tubulars (Torres 2014).

Screen/slotted liners are often used in geothermal well completions (Edwards et al., 1982). In the Akiira Ranch Geothermal Field, Kenya, well AW-01 was drilled to a total depth of 2877 m with a 7” slotted liner set at 2874 m (Letvin et al., 2016). In McGinness Hills, Nevada, USA, most of the geothermal production wells were completed with 9⅝ ” slotted liners through the production zone (Lovekin et al., 2016). Well HLS-E1 in Hululais geothermal field, which is the deepest geothermal well in Indonesia, was completed with a 7” screen liner as the last section (Toni et al., 2016). In Reykjanes geothermal field, a 7” screen liner was completed in the geothermal well IDDP-2, which is the deepest high-temperature geothermal well in Iceland (Stefánsson et al., 2017). Screen/slotted liners used in geothermal wells must provide a stable structure under extreme thermally-induced loading in order to maintain the wellbore stable and to prevent any unwanted debris. A successful screen/slotted liner design will ensure that the liner provides the maximum inflow area and minimum strength reduction compared to an intact liner. Previous attempts for specifying the structural integrity of screen/slotted liners can be categorized into two types: numerical simulation (Placido et al., 2005; Yang et al., 2014) and laboratory experimental works (Kumar et al., 2010; Huang et al., 2012; Yang et al., 2017). However, these works neglected the thermal effects, which is acceptable in conventional oil and gas wells. Even API grade degradation defined the mechanical property requirements at room temperature. In heavy oil reservoirs, similar problems resulted from the occurrence of high-operating temperatures. Industry Recommended Practice (IRP) has provided some design guidelines for thermal wells (IRP, 2002). Researchers also developed tubular material formulations that were specifically designed for use in slotted liner installations in Steam Assisted Gravity Drainage (SAGD) wells (Slack et al., 2000; Dall’Acqua et al., 2010). However, the IRP didn’t present a detailed schematic for slot configurations, and the development of material formulation was based on a series of comprehensive analytical/theoretical and experimental works which was a time-consuming and complicated process. Torres (2014) discussed the design criteria for tubulars in geothermal wells, including thermally-induced axial stress and plastic deformation. However, the method was only valid for intact pipe, which cannot be directly used in the design of a screen/slotted liner. Okech et al. (2015) have discussed the completion design in geothermal wells by reviewing conventional and unconventional deep geothermal development well concepts. However, there was no systematic analysis for the collapse strength reduction for a screen/slotted

* Corresponding author.
E-mail address: huangzw@cup.edu.cn (Z. Huang).

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liner. Hence, an efficient method to design the screen/slotted liner in geothermal wells where high-temperature effects are considered is still desirable.

The topic of discussion for this paper is a hybrid approach. The collapse rating of a screen/slotted liner is reduced compared to that of an intact liner. To quantify this reduction, a simple analytical method of evaluating the collapse rating of a screen/slotted liner developed by Abbassian and Parfitt (1998) is introduced first. Then, we modified the model to consider two patterns of screen/slotted liners, including inline and staggered patterns. Subsequently, Finite Element Method (FEM) is employed to account for the thermally-induced axial stress on the reduction of the collapse strength. Finally, an integrated workflow is provided by combining the analytical and numerical efforts to design the screen/slotted liners in geothermal wells. Based on the workflow, different liners with varied arrangements of holes and slots have been proposed to study its structural response under high-temperature effects.

This approach, although not as conclusive as collecting hard data, offers a cost-efficient workflow to rapidly estimate the collapse resistance for screen/slotted liners in geothermal wells subjected to high-temperature effect. The key findings of the work are expected to provide valuable design criteria for screen/slotted liners completion in geothermal wells.

2. Methodology

Before the model development, we want to name the convention where:

- "Screen liner" refers to a pre-perforated liner. Numerous holes are made on the base pipe before the liner is run into the wellbore.
- "Slotted liner" refers to a liner has numerous long and narrow openings (slots), which are milled into the base pipe to allow fluids to flow into the liner (Furui et al., 2005).

2.1. Analytical method

An analytical method developed by Abbassian and Parfitt (1998) for calculating collapse strength of a screen/slotted liner subjected to external pressure is utilized. We modified this model by taking different hole/slot patterns into account. The original method is based on pre-collapse elastic ovalization and subsequent plastic collapse through the formation of four plastic hinges. The model assumes that the collapse behavior of liners under external pressure consists of two distinct and independent behavior regimes: elastic ovalization and plastic collapse via a four-hinge mechanism. Comprehensive descriptions of the model development can be seen in the literature. Here, we present the calculation outline in a concise manner.

2.1.1. Elastic ovalization and plastic collapse pressure

A liner with initial ovality will deform and ovalize further when subjected to external uniform pressure. The elastic ovalizaition pressure for a screen/slotted liner is given by Abbassian and Parfitt (1998):

$$P_{eo} = \lambda P_e\left(1 - \frac{u_o}{u}\right) \tag{1}$$

where Peo is the elastic ovalization pressure, MPa;Pe is the elastic buckling collapse pressure for a thin walled liner, MPa; uo is the amplitude of initial ovality, mm; u is the ovality amplitude at a certain pressure value, and λ is the reduction factor for elastic bending stiffness with respect to that of an intact liner.

For a thin walled liner, the elastic buckling collapse pressure Pe is expressed as (Abbassian and Parfitt 1998)

$$P_e = \frac{2E}{1 - v^2}\left(\frac{h}{d_t}\right)^3 \tag{2}$$

where E is the material's Young's modulus, MPa; v is the Poisson's ratio;h is the tubing thickness, mm; and dt is the tube mean diameter, mm.

The ovality amplitude u, based on small displacement theory of thin cylindrical shells, is given by (Timoshenko and Gere 1961)

$$u = u_o\frac{1}{\left(1 - \frac{P}{P_e}\right)} \tag{3}$$

where Pis the external pressure, MPa.

For a screen liner, assuming a uniformly distributed hole pattern, the reduction factor λ is estimated as (Abbassian and Parfitt 1998)

$$\lambda = 1 - \frac{d_p}{s_p} \tag{4}$$

where dp is the hole diameter, mm; and sp is the screen holes' longitudinal separation, mm.

For a slotted liner, assuming a uniformly distributed slot pattern, the reduction factor λ is estimated as (Abbassian and Parfitt 1998)

$$\lambda = 1 - \frac{l_s}{s_l} \tag{5}$$

where ls is the slot length, mm; andsl is the slots' longitudinal separation, mm.

The plastic collapse pressure is derived based on the four-hinge collapse mechanism, which produces the well-known dog bone final post-collapse configuration (Palmer and Martin, 1975). As a function of ovality amplitude, it can be expressed as (Abbassian and Parfitt 1998)

$$P_{pc} = \mu P_y\left[-2\frac{d_t}{h}\left(1 - \frac{u}{d_t}\right)\frac{u}{d_t} + \sqrt{1 + 4\frac{d_t^2}{h^2}\left(1 - \frac{u}{d_t}\right)^2\frac{u^2}{d_t^2}}\right] \tag{6}$$

where μ is the reduction factor for plastic bending strength capacity with respect to that of an intact liner, which equals λ for both screen and slotted liners; and Py is the pressure at the onset of yield from hoop compression, referred to here as yield pressure, MPa. Py can be calculated by (Abbassian and Parfitt 1998)

$$P_y = 2\frac{\sigma_y h}{d_t} \tag{7}$$

where σy is the material yield stress, MPa.

For staggered holes, we expect slightly higher collapse strength than for inline holes. Previous research showed that staggered-pattern penetrations could have less strength loss than the inline ones (Yang et al., 2014). Therefore, we modified the model by introducing an effective holes number around the circumference of a staggered screen liner, which is given by Furui et al. (2005)

$$N_{ap}' = N_{ap}\left(1 + e^{-N_{ap}d_{hD}/\delta_p}\right) \tag{8}$$

where Nap′is the effective number of holes around the circumference of a staggered screen liner; Napis the number of holes around the circumference of an inline screen liner; dhDis the dimensionless hole diameter (dp/rw), and rw is the wellbore radius; and, δp is the hole penetration ratio, defined as the diameter of holes per unit length of liner (=dp/sp).

Similarly, the effective number of slots around the circumference of a staggered slotted liner must be modified. The following equation is introduced (Furui et al., 2005)

$$N_{al}' = N_{al}\left(1 + e^{-N_{al}l_{sD}/\delta_l}\right) \tag{9}$$

where Nal′is the effective number of slots around the circumference of a staggered slotted liner; Nalis the number of slots around the circumference of a inline slotted liner; lsDis the dimensionless slot length (=ls/rw); and, δl is the slot penetration ratio, defined as the diameter of holes per unit length of liner (=ls/sl).