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Original article

# Study on temperature distribution along wellbore of fracturing horizontal wells in oil reservoir

Junjun Cai*, Yonggang Duan

*State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu 610500, Sichuan Province, PR China*

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ABSTRACT

The application of distributed temperature sensors (DTS) to monitor producing zones of horizontal well through a real-time measurement of a temperature profile is becoming increasingly popular. Those parameters, such as flow rate along wellbore, well completion method, skin factor, are potentially related to the information from DTS. Based on mass-, momentum-, and energy-balance equations, this paper established a coupled model to study on temperature distribution along wellbore of fracturing horizontal wells by considering skin factor in order to predict wellbore temperature distribution and analyze the factors influencing the wellbore temperature profile. The models presented in this paper account for heat convective, fluid expansion, heat conduction, and viscous dissipative heating. Arriving temperature and wellbore temperature curves are plotted by computer iterative calculation. The non-perforated and perforated sections show different temperature distribution along wellbore. Through the study on the sensitivity analysis of skin factor and flow rate, we come to the conclusion that the higher skin factor generates larger temperature increase near the wellbore, besides, temperature along wellbore is related to both skin factors and flow rate. Temperature response type curves show that the larger skin factor we set, the less temperature augmenter from toe to heel could be. In addition, larger flow rate may generate higher wellbore temperature.



## 1. Introduction

Fracturing horizontal wells have been used widely to enhance production by increasing wellbore contact with the reservoir. Meanwhile, the local inflow rates along a horizontal well may vary because of reservoir heterogeneity and well completion methods and so on. Recently, advanced technology, such as distributed temperature sensor (DTS), has been installed in horizontal wells as a part of well completion. This new technology provides us continuous downhole temperature data with certain accuracy. It is possible to reveal the downhole flow conditions from interpretation of measured temperature and pressure data. Therefore a temperature distribution model of fracturing horizontal well is necessary.

Temperature logs have been used successfully in vertical wells to locate gas entries, detect casing leaks, evaluate cement placement, and estimate inflow profiles [1]. 10 years ago, interpretations of temperature profiles in horizontal wells are reported to be useful to identify types of fluid flowing to a wellbore [2,3]. Foucault et al.[4] used DTS data to detect the water entry location at a horizontal well. Fryer et al. [5] monitored the real time temperature profiles to identify and correlate production changes for the well in multizone reservoir. Johnson et al. [6] and Huebsch et al. [7] calculated gas flow profiles from the measured DTS data. Julian et al. [8] showed that DTS data can be used to determine the leak location in vertical wells. Huckabee [9] applied the DTS data to diagnose the fracture stimulation and evaluate well performance. Li et al. use of DTS temperature data in bottom water reservoir, inversed inflow profile along the

* Corresponding author. Tel.: +86 18608035254.
*E-mail address:* 286759969@qq.com (J. Cai).
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horizontal section, and set up with a downhole inflow control valve (ICV) in the reservoir to research the relationship between temperature profile and the inflow profile. Gonzalez et al. [10] thought conventional testing methods are not suitable for the development of shale gas reservoir, and presented the application of DTS technology that could be able to provide continuous real-time downhole information to describe the shale gas well fracture and production.

Temperature models started from the temperature logging, development so far, researchers have put forward some models to simulate temperature changes under the steady state condition or non steady state conditions. Ramey [11] put forward the earliest temperature model. Based on the Ramey's model, considering the condensation factor (namely, the change of phase state), Satter [12] modified the model of steam injection well, and calculated the heat loss and wellbore temperature. Witterholt et al. [13] put forward the model that described the heat exchange model between the fluid, wellbore and reservoir, the wellbore temperature and surrounding reservoir temperature distribution are calculated. Smith et al. put forward the Joule–Thomsen effect generated in the pressure drop when the fluid flows can significantly affect the temperature curve. Miller [14] presented one of the earliest transient temperature of reservoir models, this model also presented the temperature changes of reservoir will be affected by fluid inflow or outflow from a wellbore. Sagar et al. [15] established a general model to predict the temperature profiles in two phase flow well. Sagar et al. [15] also extended Ramey's equation to inclined wells, and considered Joule–Thomson effect caused by pressure change along the wellbore. Hasan and Kabir [16] further developed Ramey's model. Izgec et al. developed a coupled wellbore/reservoir model for transient fluid and heat flow. Yoshioka et al. studied on the horizontal wellbore temperature with analytic method. Using numerical solution, Li and Zhu [17] also researched on the horizontal wellbore temperature.

On the basis of predecessors' work, this paper established both wellbore, reservoir model and coupled model by considering skin factor. Reservoir temperature distribution which impacts arriving temperature along wellbore is researched. Wellbore temperature distribution curves of fracturing horizontal wells are plotted. Finally, the effects of relevant parameters are analyzed as well, especially for the skin factors and flow rate profile along wellbore.

## 2. Model development

The model consists of a wellbore model, a reservoir model and a coupled model, these models are as follow.

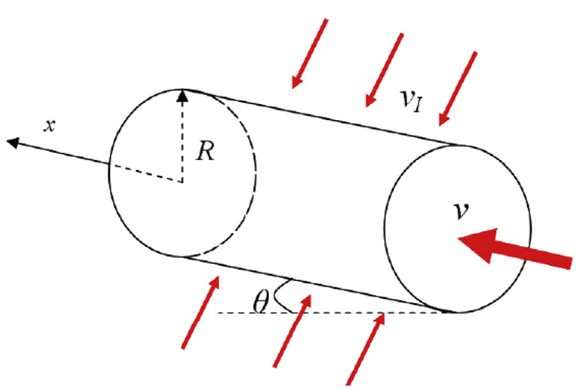


**Fig. 1.** Differential volume element of a wellbore [17].

### 2.1. Wellbore model

The model which consists of wellbore flow model and wellbore thermal model developed by Yoshioka et al. [18] was adopted directly in this study. Wellbore flow and thermal behaviors are steady state (Fig. 1).

#### 2.1.1. Wellbore flow model

The mass conservation equation of the wellbore under steady state conditions is:

$$\frac{d(\rho v_x)}{dx} = \frac{2\gamma}{R}\rho_I v_I \tag{1}$$

$\gamma$ is the ratio of the opening section versus the total well length.

According to momentum balance, the pressure equation is obtained by the following formula:

$$\frac{dp}{dx} = -\frac{\rho f v_x^2}{R} - \frac{d(\rho v_x v_x)}{dx} - \rho g(\sin\theta) \tag{2}$$

$f$ is the friction factor. Ouyang [19] established a friction factor model of horizontal wells.

#### 2.1.2. Wellbore thermal model

Based on the energy balance equation of temperature in the wellbore, the horizontal well is assumed to be at steady state with one-dimensional temperature. Ignoring the kinetic shear, viscous shear and heat transfer between fluids, the ultimate one-dimensional single-phase steady-state wellbore temperature equation is:

$$\frac{dT}{dx} = K_{JT}\frac{dp}{dx} + \frac{2}{R}\frac{(\gamma\rho_I v_I C_p + (1-\gamma)U_T)}{\rho v_x C_p}(T_I - T) - \frac{g}{C_p}\sin\theta \tag{3}$$

The general expression of $U_T$ is first proposed by Willhite [20]; where

$$U_{T,I} = \gamma(\rho v C_p)_{T,I} + (1-\gamma)U_T \tag{4}$$

Also, we neglect the heat conductions between fluids. Therefore, the heat flux in the pipe open area consists of only convection as depicted in Fig. 2.

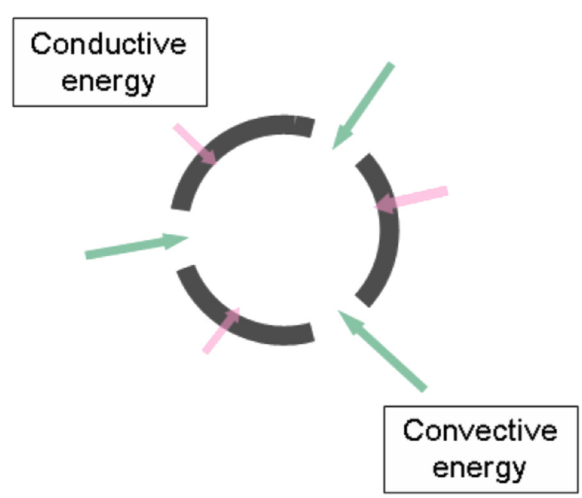


**Fig. 2.** Energy transport through a perforated/slotted pipe [21].