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Research Paper

Study on wellbore heat loss during hot water with multiple fluids injection in offshore well

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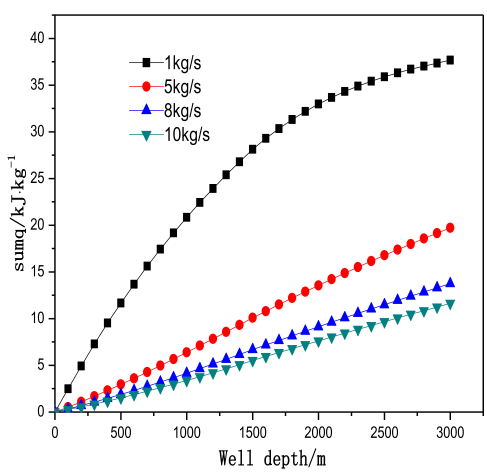
HIGHLIGHTS

- A heat loss model of hot water with multiple fluids in offshore well was presented.
- Multiple fluids were regarded as real gas mixture replacing ideal gas-assumption.
- The heat loss of offshore thermal well was analyzed.
- Injection rate and hot water proportion have a great effect on heat loss.
- Injection pressure and injection time have little effect on heat loss.

GRAPHICAL ABSTRACT



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ABSTRACT

For estimating heat loss of offshore well, an analysis model of flow and heat transfer for hot water with multiple fluids injection in offshore well was established, in which multiple fluids were regarded as real gas mixture replacing the ideal gas-assumption in conventional models. Validation of the model by measured data in Bohai offshore oilfield showed that model calculation agreed with the measured data, the pressure average relative error was about 0.7%, and temperature average absolute error was about 1.4 °C. Through a simulation wellbore, the influence of some factors on heat loss of offshore well was analyzed. It was found that the heat of multiple thermal fluids lost to environment ranged from 2.3% to 9.5% under different injection parameters, and heat lost to seawater was dominant. The injection rate, injection temperature, hot water proportion and insulated tube have a great effect on heat loss of offshore well, while injection pressure, injection time and environment temperature have little effect on heat loss. An increase in injection rate, hot water proportion and depth of insulated tube, or a decrease in injection temperature and insulation thermal conductivity, leads to a decrease in heat loss, especially the heat lost to sea.

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1. Introduction

The global offshore oil resources were about 135 billion tons, and the proven reserves were about 38 billion tons [1]. In China, the heavy oil reservoir accounts for 64% of total offshore oil reserves, and the heavy oil production has already accounted for 60% of total offshore crude oil output [2]. For heavy oil with high viscosity, steam injection technique is usually applied to reduce viscosity of heavy oil and increase heavy oil production in onshore field. But steam injection technique cannot be applied for the offshore heavy oil due to the limited offshore production platform and complex external environment. In order to recover offshore heavy oil and reduce green gas emissions, multiple thermal fluids injection technique was developed for offshore heavy oil exploration. Multiple thermal fluids are the flue gas mixture produced by complete combustion of diesel. According to the state of water, multiple thermal fluids can be divided into steam with multiple fluids and hot water with multiple fluids, and multiple fluids are mainly composed of N_2 and CO_2 working under high pressure and high temperature. In conventional thermal recovery, high temperature steam or hot water injection in wellbore can significantly reduce viscosity of reservoir, and have a good effect on viscosity reduction and formation relieving for sedimentary organic matter of near wellbore zone. Even though steam can take more heat, the higher density difference and flow ratio between steam and heavy oil could easily lead to excessive gravity overload steam channeling and lower volumetric sweep efficiency, and thermal effects of steam cannot make full play, and hot water can effectively mitigate these adverse effects. Compared to the steam or hot water acting on heavy oil reservoir alone, multiple fluids can generate a synergistic effect with steam [3]. The synergistic principles of multiple thermal fluids include reduction viscosity of heavy oil by heating and gas dissolution, enlargement of heat sweeping efficiency by multiple fluids, reduction of heat loss in reservoir, expansion of heated porous enhancement, reduction of interfacial tension, gravity drainage and other favorable reaction by chemical additives such as foaming agent [4–7]. Multiple thermal fluids injection thermal recovery technology has been successfully applied in Bohai offshore oilfield.

During the process of offshore heavy oil thermal recovery, one of the most significant technologies is how to reduce the high viscosity of heavy oil efficiently by heating heavy oil reservoir so that heavy oil can flow to production well easily [8]. Influenced by the seawater, heat loss of offshore well above the mud line could be strikingly large [9]. The heat loss from multiple thermal fluids in injection well to environment directly affects the yield of heavy oil and energy consumptions, so it is necessary to analyze the condition of heat loss of the offshore thermal recovery well.

At present, the researches on heat loss of well mainly focused on onshore well injected with steam [10–12], as steam injection is the conventional thermal recovery technique in onshore heavy oil field. However, there is little analysis on heat loss of offshore thermal recovery well to be published currently, especially in deep water. The study on heat loss of offshore well mainly focused on the drilling well and conventional production well. Romero and Touboul [13] proposed a method to calculate bottom-hole circulating temperature in deep water drilling wells. Song and Guan [14] provided a model for circulating temperature and pressure of gas–liquid two-phase flow in deep water drilling wells. Wang et al. [15] proposed a numerical model for temperature and pressure distribution in deep water drilling well. Hasan et al. [16] offered a generalized model to study well two-phase flow and heat transfer of gas/oil in offshore well. S. Fidan [17] studied on wellbore heat loss calculation during steam injection in onshore and offshore environments. Lin et al. [18] studied on two-phase flow and heat transfer of offshore wells using electrical submersible pump. The researches on the flow and heat transfer regulation of well injected with multiple thermal fluids mainly focused on onshore well injected with steam with multiple fluids. Lin and Li [19] proposed the flow and heat transfer model of steam with nitrogen gas injection in well. Li et al. [20] provided the flow and heat transfer model of steam with multiple fluids injection in well. Dong et al. [21,22] analyzed heat loss of dual-string horizontal well injected with steam with multiple fluids and the thermal fluids' effect on reservoir. In the models for temperature and steam dryness [20–22], in order to simplify calculation, the multicomponent real gas mixture including steam, N_2 and CO_2 was simplified as an ideal gas mixture. In the model for temperature of super steam with multiple fluids [21], the specific enthalpy of multiple thermal fluids was simplified as a function of mixing specific heat and temperature. The models [20–22] for steam dryness and temperature of steam with multiple fluids were established based on Dalton law and ideal gas mixing rules, in which N_2 and CO_2 were treated as ideal gas whose specific enthalpy was only related to temperature. As we know, Dalton law is only applicable for ideal gas. It would make a greater error if the multicomponent real gas mixture was treated as ideal gas mixture [23], especially the steam works under high pressure near the saturated zone. Accurate prediction of heat loss and temperature profile in thermal injection lines and wells is essential to designing and evaluating thermal operations [24]. What's more, the structure of offshore well in seawater is different from well structure in formation, and the mechanism of heat exchange with sea is more complex than with rock formation, requiring additional inputs such as sea current, riser geometry and insulation [13]. As the previous temperature model for steam with multiple fluids was deduced by dry degree model based on Dalton law and ideal gas mixing rules, this model could not be applicable for temperature of hot water with multiple fluids injection in wellbore.

Above all, the heat loss from hot water with multiple fluids injection in offshore well to environment could not be predicted by the previous ideal gas models. Therefore, in order to improve the precision of previous model and analyze heat loss of offshore well injected with hot water with multiple fluids, it is necessary to make a correction for previous model and establish the model of hot water with multiple fluids injection in offshore well.

Considering the special well configuration and operating environment of offshore well, a flow and heat transfer model of hot water with multiple fluids in offshore well was established, based on real mixing rules, real gas state equation and characteristics of multiple thermal fluids, in which multiple fluids were regarded as real gas mixture replacing the ideal gas-assumption in conventional models. Validated by the measured data of well in Bohai offshore field, the accuracy of the model was verified effectively. By this numerical calculation model, the heat loss of offshore well injected with hot water with multiple fluids was analyzed, and the influence of the factors including injection parameters, well structure and marine environment on heat loss of offshore well was studied.

2. Heat transfer model for wellbore

According to the external environment, offshore well can be divided into the section of air, seawater and formation, shown in Fig. 1. Multiple thermal fluids are usually injected into the inner tubing, and heat will transfer through wellbore into environment because of temperature difference between the multiple thermal fluids and environment.

In order to simplify the numerical calculation model for flow and heat transfer of multiple thermal fluids injected in offshore well, the following reasonable assumptions are made:

1. In the process of thermal fluids flow, the mixture gas in multiple thermal fluids is the stable parts, and nitrogen and carbon dioxide will not dissolve into hot water.