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Research Article

The Experimental Research on the Reduction of Heat Loss Rate of Wellbores with two-Phase Closed Thermosyphon Wellbore

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Abstract: In order to compare heat losses of the wellbore fluids in a two-phase closed thermosyphon wellbore with that of the conventional wellbore during the flow process, different conditions of heat losses of fluid flow in wellbore have been compared with each other firstly. Through laboratory experiments, heat losses of the wellbore fluids in a two-phase closed thermosyphon wellbore have been measured to analyze influences to the heat loss caused by factors like working medium, filling ratio, vacuum degree, temperature and flow rate of the simulation oil. According to the results, a two-phase closed thermosyphon wellbore is helpful in the reduction of heat loss of wellbore fluids, different working media influence the heat loss rate differently and under different temperatures of simulation oil, there is a working medium for the lowest heat loss rate respectively. Freon is the working medium when the temperature of the simulation oil is 50°C, methanol for 70°C and distilled water for 90°C the heat loss rate of the wellbore fluids in two-phase closed thermosyphon wellbore decreases first and then increases as the filling ratio goes up. The heat loss rate reaches the minimum when the filling ratio is 15%; heat loss rate also increases as the temperature of the simulation oil increases and decreases as the flow rate of oil goes up. However, it has a similar heat loss rate with that of conventional wellbore fluids as the flow rate increases to a certain amount.

Keywords: A two-phase closed thermosyphon wellbore, heavy oil, heat loss, temperature profile

INTRODUCTION

As the flow of heavy oil in the wellbore is limited to a large extent by its temperature, the heat is lost towards the formation in bottom-up flowing process, which will lead to the decrease of temperature and flowability of crude oil and bring more difficulties to well production.

A two-phase closed thermosyphon wellbore is a brand new technique for wellbore heating in heavy oil recovery. In this technique, at first the hollow sucker rod was vacuumized to inject working medium into its intracavity and then the heat of the high temperature fluid at the bottom of the well was continuously transferred to the low temperature fluid at the top of the well making use of the cyclic phase changes of the working medium in the intracavity, which will improve the temperature profile of the whole wellbore fluid. Therefore, it does help increasing the fluid temperature at the top of the wellbore, decreasing the viscosity of fluids and improving the flow ability in the wellbore, which are significant to the well production.

As we can see, this technique doesn't need to consume extra energy, which has great advantages like energy-efficient, lower cost of treatment for produced fluid over the common heating methods in oilfields like heat liquid recycling, electric heating and adding viscosity breaker chemicals.

In China, several scholars (Ma *et al*., 2006; Wu *et al*., 2006; Zhang *et al*., 2007, 2010, 2011) have studied improvements of temperature profile and heat losses of the flowing fluid in wellbore but with the only consideration of influences of fluid temperature and fluid amount to the heat losses. Besides, a two-phase closed thermosyphon wellbore does help in reducing heat loss of the fluids in the wellbore according to the recent researches. At the bottom of wellbore, the working medium absorbs heat of the fluids leading to a lower temperature, which also reduces the heat loss to the formation for the lower fluids temperature; However, at the top of the wellbore, the working medium in gas phase gives heat out to increase the temperature of the wellbore fluids, which increase the heat loss to the formation at the same time. However, there have not been any studies researching the above two aspects internationally**.** In this study, analyses on working medium, filling ratio, vacuum degree and temperature and flow rate of the simulation oil have been carried out through experiments on a two-phase closed thermo siphon wellbore, which will have

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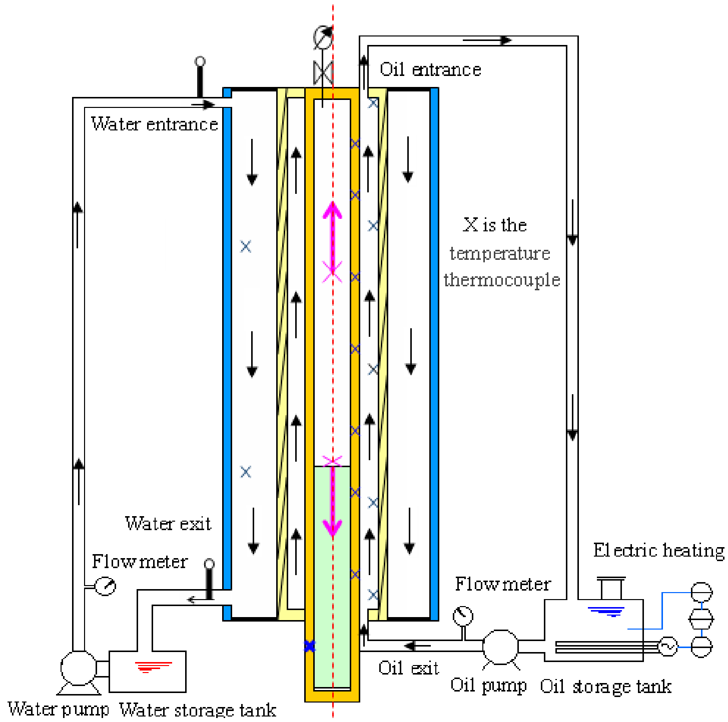

Fig. 1: Configuration diagram of the physical experimental simulation system for a two-phase closed thermosyphon wellbore

positive effects on the application of a two-phase closed thermosyphon wellbore in improving temperature profile of wellbore fluids.

EQUIPMENTS AND MATERIALS OF EXPERIMENTS

Equipments of experiments: In this study, all the experimental statistics were obtained from the physical experimental simulation system for a two-phase closed thermosyphon wellbore built by the author. The main part was made up of three sets of concentric tubing whose inner surfaces had been specially treated. From the outside to the inside, the tubing were respectively for cold water flowing from the top to the bottom, the tubing for simulation oil flowing from the bottom to the top and the closed intracavity for a two-phase closed thermosyphon wellbore within working medium, which were all presented in Fig. 1. By measuring the changes in the exiting cold water's temperature, the heat loss from the simulation oil to the cold water can be calculated.

Materials of experiments: Working medium: according to the previous experimental results, simulation oil at the temperatures of 50, 70, 90°C, respectively matches Freon, methanol and distilled oil, respectively.

Cooling water: Tap water, whose flow rate is 300L/H, at room temperature.

ANALYSIS ON THE RESULTS OF EXPERIMENTS

Analyses on the effects of a two-phase closed thermosyphon wellbore: In order to compare heat loss in two kinds of wellbore, a two-phase closed thermosyphon wellbore without any working medium was used to simulate the conventional wellbore flow. The heat loss of simulation oil was measured at three different conditions under which the temperatures of simulation oil are 50, 70, 90°C, respectively matching the working medium Freon, methanol and distilled water, respectively. The various conditions of experiments were presented in Table 1 and the results of experiments were presented in Fig. 2. According to Fig. 2, the simulation oil at three different temperatures all had less heat loss of fluids in a two-phase closed thermosyphon wellbore than in conventional wellbore. Through the analysis on the temperature profile for fluids in a two-phase closed thermosyphon wellbore, the length of the section absorbing heat was longer than that giving out heat, which resulted in more heat saved in the heat absorbing section was than loss in the heat giving out section. Therefore, the heat loss rate for a two-phase closed thermosyphon wellbore is less than that for conventional wellbores.

Influences caused by different kinds of working medium to the heat loss for a two-phase closed thermosyphon wellbore: In order to analyze the

Table 1: Experiments comparison with the conventional wellbore on heat loss

	Working medium		Cooling water		Simulation oil		
Wellbore	Type	Filling ratio %	Temperature °C	Flow rate L/H	Temperature °C	Flow rate L/H	Vaccum degree KPa
TPCT wellbore	Freon	15	Air temperature	300	50,70,90	200	80
	Methanol	15	Air temperature	300	50,70,90	200	80
	Distilled water	15	Air temperature	300	50,70,90	200	80
Conventional wellbore	-	-	Air temperature	300	50,70,90	200	0

Table 2: The experiment of influences caused by filling rate of working medium to heat loss in a two-phase closed thermosyphon wellbore

	Working medium		Cooling water		Simulation oil		
Wellbore	Type	Filling ratio %	Temperature °C	Flow rate L/H	Temperature °C	Flow rate L/H	Vaccum degree KPa
TPCT wellbore	Distilled water	5,10,15,20	Air temperature	300	90	200	80

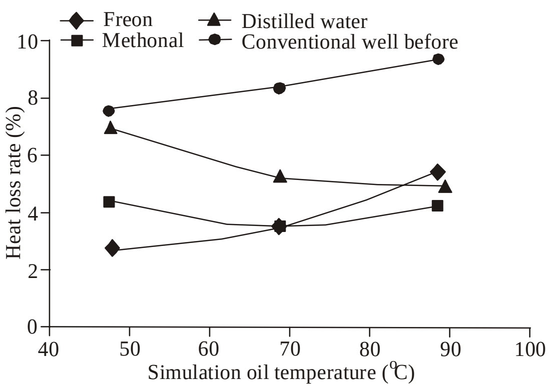

Fig. 2: Comparisons of heat loss rates of fluids in a two-phase closed thermosyphon wellbore and conventional wellbore

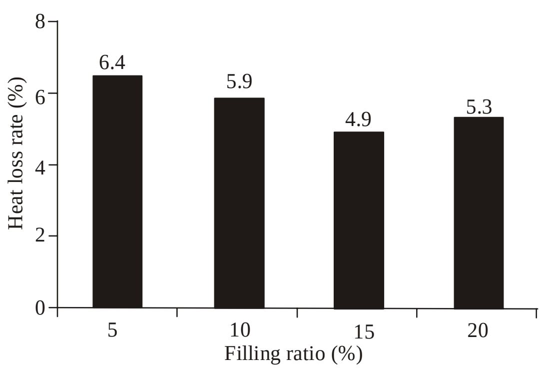

Fig. 3: Influences caused by filling rate of working medium to heat loss in a two-phase closed thermosyphon wellbore

effects of working medium to heat loss for a two-phase closed thermosyphon wellbore, experiments measuring heat loss of fluids were conducted when the temperatures of simulation oil were 50, 70, 90°C, respectively for three different kinds of working media one by one, which was showed in Table 1. According to the experiments in Fig. 2, the tendency of heat loss rate with different working medium varied as the temperature of simulation oil went up. When working medium was Freon, the heat loss rate increased gradually along with the temperature increase. When working medium was distilled water, the heat loss rate decreased gradually with temperature increase. When working medium was methanol, the heat loss rate decreased first and then increased along with the increasing temperature. From the above results, there would be an optimal working medium for simulation oil at different temperatures. Freon is a suitable working medium for simulation oil at 50°C, methanol for simulation oil at 70°C and distilled water for simulation oil at 90°C.

Influences caused by filling rate of working medium to heat loss for a two-phase closed thermosyphon wellbore: Taking the temperature of simulation oil as 90 °C, distilled water as the working medium and the filling rate of working medium as 5, 10, 15, 20%, respectively experiments were done for the analysis on influences of filling rates to heat loss for a two-phase closed thermosyphon wellbore, which were presented in Table 2. According to the experimental results in Fig. 3, the heat loss rate of fluids in a two-phase closed thermosyphon wellbore decreased first and then increased with the increasing filling rate. When the filling rate was 15%, the heat loss rate 4.9% was the smallest. The influences caused by the filling rate to heat loss are mainly because of the influences of filling rate to the working conditions of a two-phase closed thermosyphon wellbore.

Influences of temperatures of simulation oil to heat loss in a two-phase closed thermosyphon wellbore: With the same working medium but different temperatures of simulation oil, regularities of heat loss rate of fluids in a two-phase closed thermosyphon

Table 3: The experiment of the influences of temperatures of simulation oil to heat loss in a two-phase closed thermosyphon wellbore

	Working medium		Cooling water		Simulation oil		
Wellbore	Type	Filling ratio %	Temperature °C	Flow rate L/H	Temperature °C	Flow rate L/H	Vaccum degree KPa
TPCT wellbore	Freon	15	Air temperature	300	50	200	80
	Methanol	15	Air temperature	300	70	200	80
	Distilled water	15	Air temperature	300	90	200	80
Conventional wellbore	-	-	Air temperature	300	50,70,90	200	0

Table 4: The experiments on influences of vaccum degree to heat loss of fluids in a two-phase closed thermosyphon wellbore

	Working medium		Cooling water		Simulation oil		
Wellbore	Type	Filling ratio %	Temperature °C	Flow rate L/H	Temperature °C	Flow rate L/H	Vaccum degree KPa
TPCT wellbore	Distilled water	15	Air temperature	300	90	200	80,67,42,12

Table 5: Experiments about influences of flow rate of simulation oil to heat loss rate of fluids in a two-phase closed thermosyphon wellbore

	Working medium		Cooling water		Simulation oil		
Wellbore	Type	Filling ratio %	Temperature °C	Flow rate L/H	Temperature °C	Flow rate L/H	Vaccum degree KPa
TPCT wellbore	Freon	15	Air temperature	300	90	30,50,100,200	80
	Methanol	15	Air temperature	300	90	30,50,100,200	80
	Distilled water	15	Air temperature	300	90	30,50,100,200	80
Conventional wellbore	-	-	Air temperature	300	90	30,50,100,200	0

wellbore varied, which were shown in chapter 3.2. According to the results of experiments in chapter 3.2 and influences of working medium to heat transfer efficiency of a two-phase closed thermosyphon wellbore, heat loss rate of fluids in a two-phase closed thermosyphon wellbore was discussed in various working media and temperatures of simulation oil where the certain working medium matched the simulation oil at the suitable temperature as mentioned above, which were displayed in Table 3. According to Fig. 4, the results of three different working media with the matched simulation oil reflected the same regularity that heat loss rate increased with the increasing temperature of simulation oil, which was in accordance with that of conventional wellbore. As the increase of temperature of simulation oil, heat transferred by a two-phase closed thermosyphon wellbore increased to speed up the steam velocity inside, which resulted in an increase of both film thickness of heat releasing section and heat resistance. Therefore, the length of heat absorbing section decreased and that of heat giving out section increased. Compared with the conventional wellbore, heat loss increased at the heat giving out section of a two-phase closed thermosyphon wellbore, which led to the increase of the wellbore's heat loss.

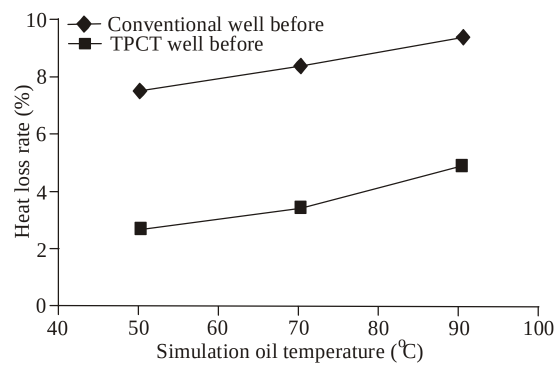

Fig. 4: Influences of temperatures of simulation oil to heat loss in a two-phase closed thermosyphon wellbore

Influences of vaccum degree to heat loss of fluids in a two-phase closed thermosyphon wellbore: Analysis on the heat loss rate of fluids in a two-phase closed thermosyphon wellbore influenced by vaccum degree was done through the experiment with distilled water as working medium, filling rate of working medium as 15% and temperature of simulation oil as 90°C, which were all presented in Table 4. As shown in Fig. 5, along with the increasing vaccum degree, heat loss rate increased because of the influences caused by non-condensate gas in air. When the vaccum degree is low in a two-phase closed thermosyphon wellbore with large amount of air inside, the non-condensate gas ratio is high and will gather at the top of the wellbore and not get involved in vaporization and liquefaction of the working medium. As a result, heat transfer to the fluids

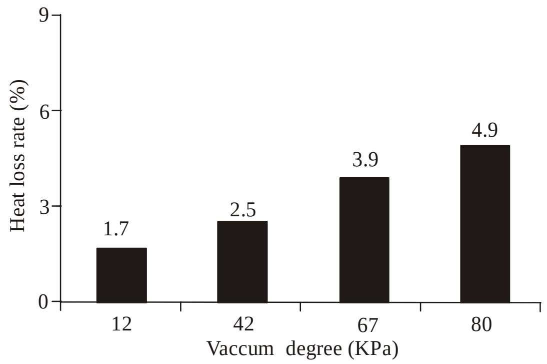

Fig. 5: Influences of vaccum degree to heat loss of fluids in a two-phase closed thermosyphon wellbore

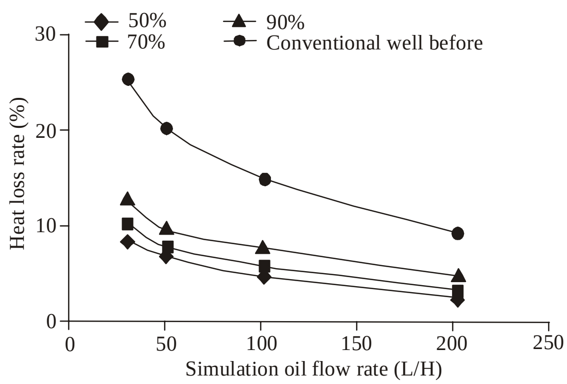

Fig. 6: Influences of flow rate of simulation oil to heat loss rate of fluids in a two-phase closed thermosyphon wellbore

at the top decreases and therefore the heat which would be lose to formations are saved, which will eventually help in reducing heat loss rate of fluids in a two-phase closed thermosyphon wellbore.

Influences of flow rate of simulation oil to heat loss rate of fluids of a two-phase closed thermosyphon wellbore: The results of experiments about Influences of flow rate of simulation oil to heat loss rate of fluids in a two-phase closed thermosyphon wellbore were displayed in Table 5. According to Fig. 6, heat loss rates of fluids in both conventional wellbore and three kinds of a two-phase closed thermosyphon wellbore decreased continuously with increasing flow rate of simulation oil. It is because that vertical heat transfer is strengthened and takes the predominant role in heat transfer with the increase of flow rate of simulation oil so as to decrease radial heat loss. On the other hand, heat loss rate of fluids in a two-phase closed thermosyphon wellbore gets closer to that in conventional wellbore with the increase of flow rate of simulation oil, which implies that the effect of a two-phase closed thermosyphon wellbore is weakened in this process.

CONCLUSION

Through the laboratory experiments on heat loss of fluids in a two-phase closed thermosyphon wellbore and analysis on the factors influencing heat loss rate, several conclusions are reached as the following:

- In comparison with a conventional wellbore, a two-phase closed thermosyphon wellbore can decrease heat loss.
- Influences of working medium to heat loss vary at different temperatures of simulation oil. There is an optimal working medium for simulation oil at a certain temperature with the lowest heat loss rate. The working medium Freon is for simulation oil at 50°C methanol for simulation oil at 70°C and distilled water for simulation oil at 90°C.
- Heat loss rate decreases first and then increases along with the increasing filling rate. Heat loss rate has a minimum value with the filling rate of 15%.
- Heat loss rate increases along with the increasing temperature of simulation oil and decreases with the increasing flow rate of simulation oil. However, when the flow rate of simulation oil increases to a certain value, there is almost no difference between the heat loss rates of a conventional wellbore and that of a two-phase closed thermosyphon wellbore.

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