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Study on two-phase flow and heat transfer in offshore wells

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ABSTRACT

According to the characteristics of offshore wells using Electrical Submersible Pump (ESP), the coupled calculating method is adopted to establish the flow and heat transfer model of wellbore. The flow and heat transfer model is compiled by C language and validated by field measurements. The numerical calculation results show that the factors of marine environment, heat emitted by pump and cable, and the Joule–Thomson effect have significant impact on the wellbore temperature and pressure distribution. When temperature decreases on the condition of low water cut and high gas–oil ratio, the increase of gas–liquid ratio and decrease of density will retard the pressure reduction. However, when the temperature decreases on the condition of high water cut and low gas–oil ratio, decrease of the gas–liquid ratio and increase of density will accelerate the pressure reduction.

1. Introduction

Most offshore oilfields are artificial lifted well, in which ESP and Progressive Cavity Pump (PCP) are used. However, the ESP is used more widely. Compared with other Deep Well Pump (DWP), ESP has the advantage of higher displacement which could be more than 3000 m^3/d among various PCP. As it is driven by electricity, ESP is easy to realize and operate and has simple corollary equipment on ground while it needs less floor area. Besides, ESP could be used in high angle deviated hole and horizontal drain hole (Kaya et al., 2001; Shi et al., 2005a, 2005b).

At present, researches of offshore well mainly focus on the flow in the pipe (Hasan and Kabir, 1999; Hasan et al., 2010; Izgec et al., 2010). However, few researches on temperature field are carried out. When needed, it is only calculated independently by using the empirical formula. Besides, the studies on oil pipe (ocean riser pipe) in marine environment mainly focus on mechanics without consideration of its effect on heat transfer in the pipe. This is because nowadays the offshore oil exploitation is limited to the neritic area whose water depth is less than 300 m. Most of them are no more than 100 m and the oil exploited is thin oil. Therefore, the temperature has little effect on the flow, and the ocean riser pipe is so short that the heat transfer of water depth has little impact on the temperature field. While according to the researches on offshore oil during the Eleventh Five-year Plan, we will march into deep sea gas field which could be 3000 m in depth; there we will also meet a lot of inspissated pools. The temperature field of wellbore and heat transfer of ocean riser pipe would be the critical problem during the deep-sea heavy oil production.

First of all, the actual wellbore is simplified to establish a calculable physical model during the numerical analysis. Secondly, the mathematical model of flow and heat transfer of wellbore is established based on the consideration of key equipment of wellbore-lifting system and marine environment, the coupled calculating method for temperature and pressure is drawn out, and the calculation codes are compiled by C language. Finally, the feasibility and accuracy of the mathematical model is validated against the field measurement data, and the variations of marine environment, heat emitted by pump and cable, and the Joule–Thomson effect on the wellbore temperature and pressure distribution change are also investigated.

2. Physical model of wellbore

During the oil production of offshore wells using ESP well, the produced fluid is lifted up combined with the phenomenon of momentum, mass and heat transfer. By simplifying the system of these wells (Li et al., 2008; Lin and Li, 2010), the flow and heat transfer model of wellbore is established (as shown in Fig. 1). The lower part of the wellbore using ESP is located in the stratum, while the middle and upper parts are exposed to air. Based on the need of flow and heat transfer calculations, the wellbore is divided into 11 segments: reservoir section A, make a dynamic analysis of inflow; casing section B, oil pipes C, E, F, G and H, make analyses of multiphase fluid flow in pipe; ESP section D, make an analysis of pumping characteristics calibration; nozzle section J, make an flow analysis on nozzle. However, since the calculations of flow and heat transfer are coupled to each other, the wellbore would be divided into nine segments from A to J in practical calculations.

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Nomenclature

A	cross section area, m^2
c_{pm}	specific heat at constant pressure, J/(kg K)
c_{Jm}	Joule–Thomson coefficient, K/Pa
c_f	speed of mixture, m/s
D	caliber, m
E	mechanical energy, J/kg
f	flow resistance
g	acceleration of gravity, m/s^2
G	mass flow of mixture, kg/s
h	heat transfer coefficient, $W/(m^2\ K)$
H	entropy
H_u	liquid holdup
I	cable current, A
L	depth
P	pressure, MPa
q	heat, J/kg
r	radius, *m*
R	cable resistance, Ω/m
T	temperature, K
U_{to}	heat transfer coefficient of exterior surface area, $W/(m^2\ K)$
v	average velocity of gas–oil mixture, m/s
w_i	internal work of mixture, J
w	mass flow rate, kg/s

Greek symbols

ρ	density, kg/m^3
θ	angle, deg
Δ	temperature rise
λ	conductivity, W/(m K)

Subscripts

e	formation
r	radioactive
g	gas
L	liquid
f	fluid in the well bore
fo	outlet of ESP
fl	inlet temperature of fluid
n	surface of seawater
out	output
ti	inside of tube
bi	inside of surface casing
bo	outside of surface
hi	inside of conductor
ho	outside of conductor
to	external of oil tube
i	inner
c	natural convective

3. Flow and heat transfer model in ESP-well

The oil, gas and water mixture flows from the bottom of wellbore, and the flow of mixture belong to the phenomenon of gas–liquid two-phase flow. During the flow of mixture, heat keeps losing to strata, pressure and temperature keep changing, meanwhile dissolved gas emits and expands, which make the volumetric rate and flow rate of mixture increase all the time (Brown, 2006; Zhang, 2006; Izgec et al., 2007). Therefore, the process of oil–gas–water lifting in wellbore is variable and complex.

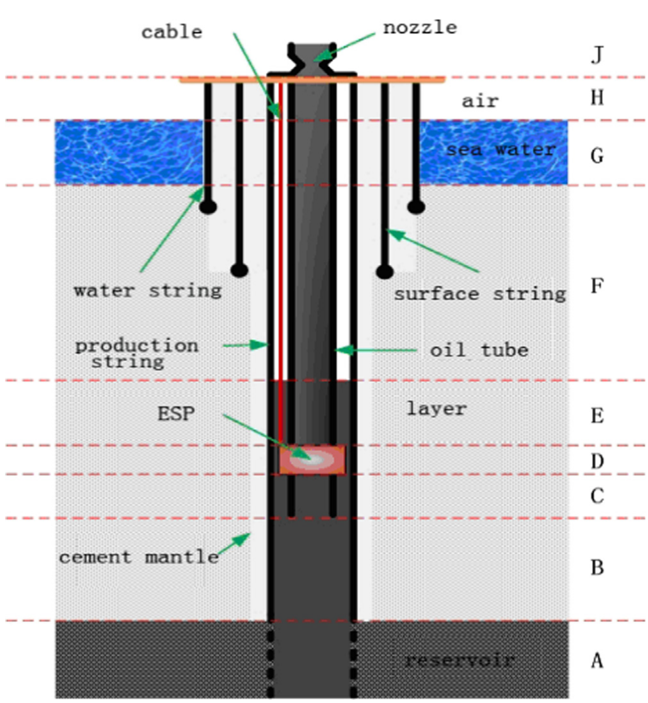

Fig. 1. Pump well calculation physical model.

3.1. Analysis of pressure field

When a two-phase fluid flows in the wellbore, the following equation can be obtained based on the energy equation (Benjamin, 2012)

$$-\frac{dp}{dz}=\rho g\ \sin\ \theta+\rho\frac{dE}{dz}+\rho v\frac{dv}{dz} \tag{1}$$

The right-hand side of the upper equation is constructed by the parts of pressure drops of gas–liquid two-phase flow in the pipe: pressure drop for potential difference, frictional pressure drop, and pressure drop for acceleration:

$$-\frac{dP}{dz}=\left(\frac{dP}{dz}\right)_{position}+\left(\frac{dP}{dz}\right)_{friction}+\left(\frac{dP}{dz}\right)_{acceleration} \tag{2}$$

(1) Pressure gradient of potential difference: pressure drop to overcome the difference of height.

$$\left(\frac{dp}{dz}\right)_{position}=\rho g\ \sin\ \theta=[\rho_L H_U+\rho_g(1-H_U)]g\ \sin\ \theta \tag{3}$$

(2) Friction pressure gradient: pressure drop to overcome the flow resistance.

$$\left(\frac{dp}{dz}\right)_{friction}=f\frac{v^2L}{2D}\rho \tag{4}$$