The Analysis of heat loss situation on gas-injection wellbore

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Abstract. Heavy oil thermal recovery technology began its industrial test in the early 20th century, since then the technology have been developed greatly. The main forms of thermal recovery of heavy oil are steam stimulation and steam drive. But steam injection would make casing produce thermal stress and cause bad damage to the casing, which restricts heavy oil steam injection technology in a great extent. This paper has built the wellbore-formation temperature model in injection phase of steam injection well by energy conservation, momentum conservation and mass conservation theorem. Also a wellbore temperature change model in soak period have been built. In the calculation of wellbore heat transfer injection stage, we introduced the time step function and make the results more conform to actual situation. After the wellbore-formation temperature model has been built, wellbore thermal stress calculation model was built basing on the basic theory of thermal stress. In the same time, we compiled the calculation software to simulate actual situation of steam injection, studied the casing temperature and thermal stress distribution. The result showed that calculation results were very close to measured values, which means this model has reflected the real situation objectively. This model can be applied to steam injection wells dynamic prediction and simulation and optimized steam injection parameter, as well as analyze the calculation of casing thermal stress at the same time. In the end of this paper, the relationship of casing under force balance in the process of drawing casing is established, and the prestressing force distribute model is deducted. The model have considered friction's influence on the wellhead lift load based on previous studies. And it obtained the thermal stress distribution produced by steam injection after adoption of prestressing force cementing methods.

Keywords: Wellbore Pressure, Heat Transfer Coefficient, Dryness Fraction, Heat Loss.

1. Introduction

Heavy oil reservoir is usually adopting thermo-mechanical drilling, and thermal recovery method mainly include hot water flooding, steam stimulation, steam drive and in-situ combustion. Among them, steam stimulation and steam drive are the most effective mining technologies, and also the main ways to improve recovery factor of heavy oil reservoir. In China heavy oil resources are abundant and widely distributed. In the whole country the heavy oil resource is expected to 300 x108 t, proved geological reserves reach 15.3x108 t, and accumulative exploitation geological reserves reach 8.11x108 t. More than 70 discovered reserves have been found and formed the Liaohe, Shengli, Xinjiang and Henan four heavy oil production base. At present, there is about 1.6x104 heavy oil production wells, heavy oil production keep more than 1100x104t. Heavy oil production accounts for about 9% of the total oil production and has become the most important component in crude oil.

Dynamic monitoring technology of thermal recovery of heavy oil well can provide all kinds of dynamic parameters of producer in the process of thermal recovery, understand vapor conditions in different oil suction vapor condition qualitatively and quantitatively, monitor steam injection quality, steam injection effects, and understand heavy oil timely. Producing performance, thermal recovery plan adjustment and steam injection effect improvement can provide the scientific basis for development effectiveness. Therefore, the application of dynamic monitoring technology in thermal recovery of heavy oil well plays a vital role in the production of heavy oil steam injection. During the process, recording the temperature and pressure data of the thermal recovery wells has become a necessary means of production design. In the heavy oil, there is a sensitive temperature point, which can monitor the temperature and pressure change of reservoir in the producing process and help to analyze reservoir fluid rule, optimize the design lifting design parameters, and improve cycle oil recovery.

In America RPG-3 thermometer and pressure gauge have been applied to the test of temperature, pressure. The testing has reached more than 1000 every year in Karamay oilfield of Xinjiang. The application of thermometer and pressure gauge can also help to obtain good data for Liaohe, Shengli oilfields.

L-GSY high-temperature electronic double parameter tester developed by Liaohe oilfield, can simultaneously measure two curves responding to downhole steam temperature and pressure changes one time. It can replace imported RPG-3 thermometer and pressure gauge and be applied widely. Long-term high temperature electronic pressure gauge is developed by Liaohe oilfield and has obtained the national patent. The instrument can achieve the whole cycle monitoring of heavy oil, ultra heavy oil well production stage. It has been working for 12 consecutive months and completed 200 well field testing task. It has certain guiding significance for admitting dynamic analysis and guide the on-site construction.

In now days, heavy oil exploitation mainly includes steam stimulation, steam flooding, in-situ combustion, hot water flooding and so on, the total production accounts for about 70% of the total output. Thermal production mainly adopts steam stimulation and steam drive. In the steam injection production, steam flooding production occupies a certain proportion, included a few large steam drive developed oil fields, such as American KernRiver and Belridge, Indonesia Duri, Venezuelan Bare, Canadian ColdLake and PeaeeRive oil fields. Steam stimulation has largest scale in Venezuela, followed by the United States and Colombia.

In the early '60 s, our country had developed team stimulation and steam drive test in karamay oilfield, and also developed experiments on in-situ combustion successively in Shengli, Xinjiang, Jilin. Until the early 80s, industrial tests of hot oil thermal recovery began to develop in Liaohe Gaosheng, district ninth oil fields in Xinjiang Karamay, Shengli Danjisi. On the foundation of advanced technology and equipment imported from abroad, after digestion and absorption, we gradually formed a steam injection mining technology adapted to the characteristics of heavy oil reservoir in our country, which greatly promoted the large-scale industrialized production and production growth in China. In 1995 the national total reached nearly 4101300 tons, which made China become one of the main heavy oil producing countries in the world.

Currently heavy oil thermal recovery in our country is still major in steam stimulation. Steam drive pilot test began in 1987 and have been large-scale industrial tested in district nine of Xinjiang Kalamay oil field. Although the effects are not ideal and oil steam ratio is low, but we have accumulated experience by steam injection tests. After comprehensive adjustment and fortified management, it is expected to improve development effect. While steam stimulation and steam drive technology have been widely used to mining thick oil, but there are many problems to be solved, including the casing damage of steam injection wells, which seriously restricts the development of heavy oil exploitation and affects the production and development of heavy oil. The crucial factor of production efficiency is the thermal stress in the oil well tube produced by high temperature. The thermal stress may make the casing produces yield deformation or fracture and buckling of steam injection tube. Especially in directional well and horizontal well, the existence of bending stress is more likely cause damages.

For serious damages in steam injection wells, we need to study the damage mechanism essentially, analyze thermal stress analysis and take a series of measures to reduce the thermal stress in the casing. So it is necessary to need to analyze the wellbore-stratum temperature in detail. Only by knowing temperature variation caused by steam injection casing, we can calculate formed thermal stress.

At the same time, there are several lifting prestressed methods to prevent casing damage. So far there are still two arguments: one is considered effective and the other is not. More detailed discussion should be taken to decide whether the method is effective or not. If it is effective, how much it should be lifted to satisfy the requirement of reducing the thermal stress but not snap casing?

Considering the steam injection production, if we want to know the dryness and temperature of the vapor when it went through the oil reservoir, we must calculate the wellbore heat loss and conclude the distribution of steam dryness and temperature.

2. Mechanism of pour point depressant technology

2.1 Emulsion wetting mechanism.

Adding certain amount of GNH high pour-point heavy oil displacement solution in reservoir can disperse heavy composition in heavy oil which could stop up the stratum narrow passage. It can demulsify original water-in-oil type emulsion and transform into oil-in-water emulsion, reduce the oil-water interfacial tension and emulsifying dispersion ability, change liquidity of heavy oil. At the same time it can change the wettability of rock surface into hydrophilic, reduce rock adsorption of crude oil and motion resistance, the oil flow throat jams.

2.2 Depressant mechanism.

When the oil outlet flow temperature down to a certain value and wax crystal just form, adding suitable amount of GNH oil displacement agent can work as nucleating agent and precipitate with wax crystal or adsorb on the wax crystal surface, prevent mutual bonding between wax crystal molecular, generate continuous crystallization net, reduce the freezing point of high pour-point heavy oil, and is benefit to oil wax water molecules through the rock pore molecular assembly.

3. Numerical simulation research

Analysis of A31 well concluded that poor production effect was due to formation damages caused by combination of completion fluid and asphalting during production process. It can be relief by steam stimulation and recover wells into normal production. The numerical simulation method can predict the development effects on the basis of steam stimulation.

3.1 Single well history matching.

According to the reservoir model, we analyzed cumulative oil production, water rate, daily oil production and increased rate of water cut and other parameters of A31.The history matching result was near to actual result, and the error is less than 5%. Figure. 1 is the development effect prediction.

After completion of history matching, we predicted huff and puff production. There are two ways: 1 cycle huff and puff to break down the jam and achieve normal production for 3 years; 3 cycles' huff and puff, one year for each cycle. Compare the development effect of huff-puff production and routine production.

During the two production process, fluid volumes were controlled under 150 t/d. Figure 1 shows that three times huff and puff is no better than one time because large bottom water energy made production water cut rise fast. So we suggested one cycle huff and puff is best for A31 well to achieve regular production after breaking down.

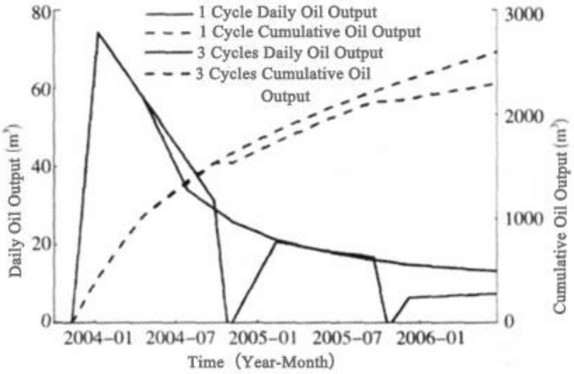

Figure 1: Comparison of two methods

3.2 Analysis of wellbore heat loss in steam injection development of heavy oil reservoir.

Analysis of wellbore heat loss is a very important content during heavy oil thermal recovery. It is the foundation of analysis and prediction on steam temperature, dryness and steam pressure distribution. During steam injection phase, the flowing wet steam in the wellbore is gas-liquid two phase flow. During the process of establishing temperature distribution model, there were following basic assumptions: (1) Wet steam steady flow down the tubing and not an isothermal;(2) Concentric pipe, insulation pipe and casing;(3) Using heat packer, no steam into the oil casing annulus;(4) Do not consider the effect of coupling, centralizer, etc;(5) Initial formation temperature distributed according to geothermal gradient (6) Wellbore was a one-dimensional stable radial heat transfer, formation was a one-dimensional stable heat transfer.

4. Analysis process of wellbore heat loss in wellbore of gas-injection well

In steam injection of thermal recovery, the severity of the wellbore heat loss is very important, it directly relates what was injected to shaft bottom-steam or water, and decides the condition of final mining. Therefore, we need to get thermodynamic parameters according to the steam injection rate, dryness and pressure situation, which can be used to select reasonable injection-production parameters according to physical and chemical properties of bottom reservoir.

Before establish a mathematical model for wellbore heat loss, we must be close to the actual oil field production situation as much as possible. Therefore, consider the following assumptions:

(1) Wellhead injection rate, pressure and dryness of steam remain unchanged;

(2) Well tubing, thermal barrier, casing structure as shown in figure 2.

(3) Use downhole packer, oil casing annulus do not contain steam and be filled with low pressure air;

(4) One dimensional steady heat transfer between reservoir and cement ring flange, one-dimensional unsteady heat transfer between cement ring flange and formation, do not consider heat transfer along depth direction;

(5) Ignore thermal conductivity coefficient of formation along depth direction, and consider it as constant;

(6) Consider wellbore pressure changes (due to pressure changes, temperature of saturated steam-sT, enthalpy- swhh, latent heat of vaporization-vL both change).

4.1 Analysis thought.

Known wellhead injection pressure, steam injection rate and dryness at initial moment, and consider it as the starting point;

From the wellhead, calculate pressure changes of every Z Δ . During the calculation, every parameter related to pressure should use the pressure in last length, or choose ZZ- Δ and average pressure of Z, but because of unknown Z, we need to assume a pressure to calculate by iteration method.

Calculate heat loss Q Δ on tube Z Δ ;

Calculate steam dryness of wellbore Ztx,;

Calculate wellbore heat loss percentage of a certain depth;

After calculate to shaft bottom, calculate pressure, dryness and heat loss percentage along the wellbore dring the time tt+ Δ , until maxtt > (the whole injection time).

Saturated steam will become a water two phase flow when injected into well, therefore, we can adopt the calculation method of gas-liquid two phase flow to calculate pressure change. According to the pressure balance equation, its pressure drop is the sum of friction energy loss, potential energy and kinetic energy changes. For vertical injection well, the pressure drop formula is:

Type:

P - Pressure of a point on wellbor, 110MPa-

$$\frac{dP}{dZ}=\rho_m g-\tau_f-\frac{\rho_m v dv}{dZ}$$

Z - Depth, m;

m ρ - Saturated vapor mixture density, 3/kgm;

g - Gravity acceleration, 2/ms;

f ζ -- Friction loss gradient, 110MPa-;

v - Saturated vapor mixture velocity, /ms.

In fact only under the condition of mist flow kinetic energy change has obvious significance. To mist flow, gas volume flow is much larger than liquid volume flow, so ideal gas law can be used.

Because

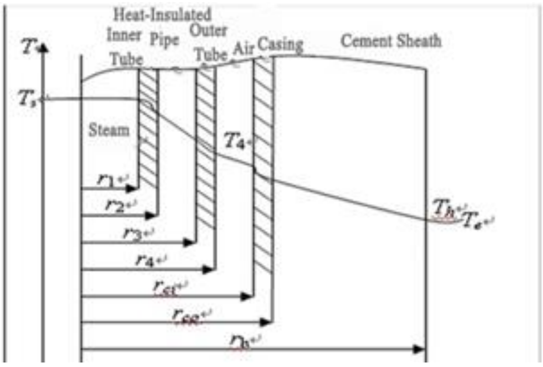

Figure 2: Wellbore structure diagram

$$v=\frac{i_s}{\rho_m A_P},\quad \rho_m v dv=\rho_m\cdot\frac{i_s}{\rho_m A_p}\cdot d\left(\frac{i_s}{\rho_m A_p}\right)=\frac{i_s^2}{A_p^2}d\left(\frac{1}{\rho_m}\right)$$

And

$$PV=RT,\ \rho=\frac{M}{V},\ \frac{1}{\rho}=\frac{RT}{PM}$$

$$d\left(\frac{1}{\rho_m}\right)=\frac{RT}{M}d\left(\frac{1}{P}\right)=-\frac{RT}{MP^2}dP=-\frac{1}{\rho_m P}dP$$

So

$$\rho_m v dv=-\frac{i_s^2}{A_p^2\cdot\rho_m\cdot P}dP$$

$$\frac{\rho_m v dv}{dZ}=-\frac{i_s q_g}{A_p^2\cdot P}\frac{dP}{dZ}$$

Type:

si - Steam mass flow, / kgh;

gq - steam volume flow, 3/mh;

PA - Pipe cross-sectional area, 2m;

Substitute Type 2 into Type 1, finishing

$$\Delta P=\frac{\rho_m g-\tau_f}{1-\frac{i_s q_g}{A_p^2 P}}\cdot\Delta Z$$

Analysis of heat loss condition.

According to above assumptions and the methods of Ramey and Setter, we considered the heat transfer along the radius direction between the outer and tubing center as a one-dimensional steady, the heat transfer between cement ring outer border and the formation as one dimensional unsteady. Thermal energy losses changed along with the change of time, and constantly changed toward well bottom. So, calculation process must adopt a phased way in specific depth and specific time. In assumed time, heat loss in infinitesimal dZ is the dQ.

5. Conclusion

Apply thermodynamics, heat transfer science, fluid mechanics and other disciplines theory to analyze heat loss in wellbore heat transfer process, and establish a foundation of comprehensive analysis model.

Specific to characteristics of system thermal equilibrium and energy balance, apply the combination of wellbore radial and longitudinal calculation, unify the longitudinal heat loss, longitudinal enthalpy changes of steam and pressure changes, and make the calculation results more accurate.

Replace single heat balance with comprehensive energy in the wellbore, replace steam parameters with variable function instead of hypothesis on constant steam parameters, built a more comprehensive model, reflect the heat transfer in the wellbore accurately.

Comply a general calculation software, to establish foundation on further analysis heat transfer losses economically and technologically.

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