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Study on closed sampling device for wellhead of heavy oil containing hydrogen sulfide

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Abstract. The development of Liaohe heavy oil field main in the way of steam soak, and during the process will be a high concentration of hydrogen sulfide gas, Conventional hand wheel valve open air sampling method may threaten the personal safety and environment. Researching Liaohe oilfield, Based on the overall grasp of the idea, design of a new type of heavy oil wellhead closed sampling device, it will success in closed sampling without affecting the flow, Sampling is safe and not easy to freeze, establishing the three-dimensional model of closed sampler, compiling UDF process, combined with the field data, dynamically simulating sampling procedure, the effects of sampling rate, hydrogen sulfide gas content and crude oil velocity on the sampling error are analyzed, finally the sampling error range is within 2% and verified the accuracy of the sampler, Providing guidance for the safety of personnel, environment pollution and freeze blockage in the process of sampling in heavy oil field.

Key words. Closed sampling, Hydrogen sulfide , UDF, Error curve, Numerical simulation.

1. Introduction

Generally, in the middle and late period of oilfield development, only when having a precise understanding of the composition and yield of produced fluid in each well can we take corresponding yield-increasing measure, [1-3] It is necessary to take samples of wellhead production fluid, and then conduct chemical analysis

Internationally there are two representative pipeline automatic sampling device manufacturing companies, they are Emerson in the United States and DOEDIJNS in Holland.[4-7] The principles of the sampling devices produced by the two com-

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panies are similar, their common disadvantage is that the internal pipeline of the sampling device is easy to enter the impurities and blocking the pipeline. Sometimes the internal filter needs cleaning once a few hours, and sometimes it also needs second separations and it really waste labor. Therefore, only low viscosity, low density crude oil and less impurity crude oil or refined oil are applicable.[8] Holland DOEDIJNS's products, in some ways, have advantages over other overseas companies, the company's sampler enhanced accuracy, but the equipment price is high, the cleaning cycle is short, and the power consumption is large. [9-10]In addition, in order to obtain the internal flow signals of the oil pipeline, the sampling device should also be equipped with a small flow meter, this also increases the purchase cost. Overall, the development of foreign sampler is faster, but not suitable in our country according to the actual situation of our country's oil field.[11-14]

In China, in 2009, in order to solve the problem of different sampling position data in heavy oil wells, Du Lizhi and others reconstructed the sampling process, the static mixer of the polymer injection station is moved to the sampling point of the inlet pipeline of the separator to make the single well coming liquid fully mixed by static mixer, improving the accuracy of sampling data analysis[15]. In 2011, Shen Jianguo carried out technical improvement on wellhead anti-theft sampling device according to the actual situation of oil field, the improved device is reliable and stable and has ideal anti-theft capability. It solves the problem of frequent oil well sampler stealing oil cases, and plays a positive role in reducing the loss of crude oil and protecting the environment.[16] In 2012, Zhao Faming developed super heavy oil automatic high temperature sampler, realize the automation and high temperature sampling, it can be used to implement high temperature gathering process after the SAGD production wells sampling, guarantee the authenticity and safety of sampling after the gathering and transportation process.[17]

At present, most of the sampling devices used in China are made in China, while the foreign pipeline automatic sampling devices used in China are quite few.[18-20] Wellhead sampling devices used in domestic oilfields are often installed on the sampling branch line of the oil production line. When carried out sampling operation, it needs to open the sampling valve and output liquid is collected for sampling. But for heavy oil fields, hydrogen sulfide with high concentration is often accompanied by steam huff and puff, for example, when monitoring wellhead gas of 488 production wells in SHU-ONE region in Liaohe Oilfield, there are 467 wells, account for 95.7%, having hydrogen sulfide.[21-22]In this moment, in the process of sampling for high hydrogen sulfide content gas, a large number of hydrogen sulfide gas will be discharged together with the produced liquid, not only causing air pollution, but also easy to cause hydrogen sulfide poisoning accident of operators; In addition, because the valve is installed in the external of main oil line, it is also prone to freezing when the temperature is low in winter, it will be unable to sampling, or even lead to crude oil leakage problem caused by froze and burst of pipes.[23] Meanwhile, in order to obtain accurate oil samples, we need to use the method of emptying before sampling, that is, a part of the liquid in the cecum before the valve is released, so the sampling method is very inconvenient.

According to the actual problems in the field, a new double hole closed sampling

device for wellhead is designed in this paper, Based on the principle of instantly overall grab, avoiding the influence of layered fluid flow, improving the sampling accuracy. It need not emptying before sampling, so the pollution is reduced. When without sampling, there is always a flow of crude oil in the cavity of the lofting valve, so it has no freezing plug problem in winter.

2. The principle of closed sampling device

According to the actual problems existing in the field sampler discussed above, the working principle of the closed sampler is analyzed, the sampling device is rationally designed and the three-dimensional model of the sampler is established.[24]

The closed sampler designed by the paper mainly include Upper clamp head, Tee, Spanner, Sealing ring, Lower clamp head, Main valve body, Turning ball. The sampler model is shown in Figure 1

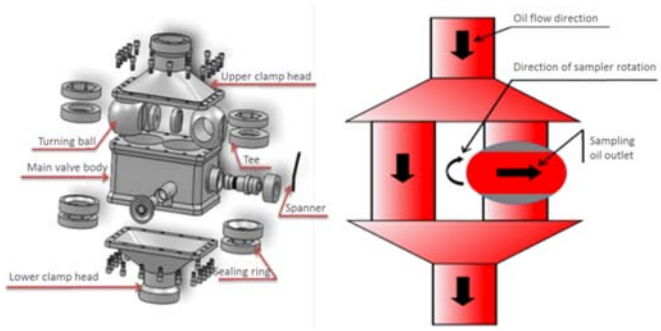

Fig. 1. Sampling device diagram

The sampler installs in the oil production pipeline, in normal production, the direction of both sides of the reversing ball is in accordance with the direction of the incoming liquid, the oil enters both sides through the upper clamp head at the same time, then flowing through the lower clamp head, at this time, the fluid in the through hole of the right reversing ball is completely isolated from the outside, the internal fluid fully represent the wellhead output liquid of the whole process. [25]When sampling, the right reversing ball is pulled to the direction perpendicular to the incoming liquid, the hole and the ball seat forms a closed space to cut out the whole fluid, the subsequent liquid will be switched to the left through hole, so that the pressure of valve will not be increased due to fluid blockage. In the whole sampling process, the harmful gas will be controlled in the through hole of the reserving ball, and will not cause diffusion; The released sample can completely reflect the liquid composition of the oil well and ensure the accuracy of sampling; When the valve is not working, the cavity is empty and the sealing surface is inside the device, so there is no winter freeze blocking problem

3. Multiphase flow equation of oil, gas and water

3.1. Continuity Equation

Liquid phase

$$\frac{\partial(\rho_l \varphi_l A)}{\partial t} + \frac{\partial(\rho_l w_l \varphi_l A)}{\partial z} = -\delta G_{lg}\,. \tag{1}$$

Gas phase

$$\frac{\partial(\rho_g \varphi_g A)}{\partial t} + \frac{\partial(\rho_g w_g \varphi_g A)}{\partial z} = \delta G_{lg}\,. \tag{2}$$

In the type: δGlg—indicate the mass exchange between two phases in the unit length of the control body, kg.

The equation of continuity of oil, gas and water three-phase flow can be obtained by adding the two equations above:

$$\frac{\partial(\rho_m A)}{\partial A} + \frac{\partial(uA)}{\partial z} = 0 \tag{3}$$

When oil and gas water mixture flow steadily in the pipe, type2-77 can be simplified as

$$G = uA = C\text{onstant} \tag{4}$$

3.2. Momentum Equation

Liquid phase

$$\frac{\partial(\rho_l \varphi_l w_l)}{\partial t} + \frac{1}{A}\frac{\partial}{\partial z}(\rho_l \varphi_l A w_l^2) - GF_{lg} = -\varphi_l \frac{\partial p}{\partial z} - \frac{\tau_{lB} S_{lB}}{A} + \frac{\tau_{gl} S_{gl}}{A} \tag{5}$$

Gas phase

$$\frac{\partial(\rho_g \varphi_g w_g)}{\partial t} + \frac{1}{A}\frac{\partial}{\partial z}(\rho_g \varphi_g A w_g^2) - GF_{lg} = -\varphi_g \frac{\partial p}{\partial z} - \frac{\tau_{gB} S_{gB}}{A} + \frac{\tau_{gl} S_{gl}}{A} \tag{6}$$

In the type:

$GFlg$—Momentum exchange rate between gas and liquid phases;

$\tau gBSgB$—The friction between the gas pipe wall;

$\tau lBSlB$—The friction between the liquid pipe wall;

$\tau glSgl$—Shear force between gas and liquid phase.

The total friction between oil, gas, water, three-phase fluid and pipe wall can be defined as:

$$\tau_B S_B = \tau_{gB} S_{gB} + \tau_{lB} S_{lB}\,. \tag{7}$$

In the type: SB—pipe circumference, m.

3.3. Bernoulli equation for the total flow of real fluids

$$z_1 + \frac{p_1}{\rho g} + \frac{\alpha_1 v_1^2}{2g} = z_2 + \frac{p_2}{\rho g} + \frac{\alpha_2 v_2^2}{2g} + h_{w_{1-2}}\,. \tag{8}$$

In the type:
$z1, z2$—elevation of entry and exit, m;
$p1$, $p2$—Inlet and outlet pressure, m;
$\alpha 1$, $\alpha 2$—Correction coefficient of kinetic energy for 1 Section and 2 Section;
ρ—fluid density, kg/m3;
g—Gravitational acceleration; m/s2;
$h_{w_{1-2}}$−Head loss of unit gravity fluid from 1 cross section to 2 cross section, m.

The Bernoulli equation and the continuity equation of the total flow of the actual fluid can solve many practical engineering problems, such as oil and water pipeline system, hydraulic transmission system, mechanical lubrication system, pump suction height, head and power calculation, jet pump and throttle flowmeter hydraulic principle, etc.

The above three equations are the basis of numerical simulation of fluid flow inside the sampler, and then the paper will simulate and compute three-dimensional sampler.

4. computational model

The simplified model of the sampler is drawn by Solidworks, and the unstructured mesh is partitioned by ICEM, because the analysis of the composition of fluid in the reversing ball is our focus, so the local grid refinement are used to the sphere, and the other parts are treated by the rough grid. In the joint of reversing ball and ball seat, there is a link of from roughness to dense mesh so that to reduce the truncation error in the flow simulation process, At the same time, interface connection is used for the ball and the ball seat to easily load UDF to realize 90 degree rotation of the ball valve. Finally, the number of meshes is 651211, and the quality reaches 0.6, which meets the calculation standard.

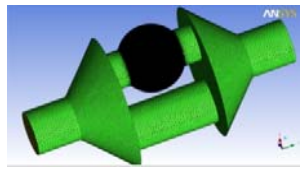

Fig. 2. The grid of sampling device

Using the Mixture model, the solution of Transient, k-epsilon (2 eqn) turbulence model, choosing hydrogen-sulfide(H2S) and water-liquid (H2O) in Database, and define new material as oil phase, Density 930kg/m3, Viscosity 0.00645mPa·s. Then dynamic simulation of sampling device under different working conditions can be realized by changing inlet flow rate, hydrogen sulfide content and adjusting UDF program.

5. dynamic results analysis

Taking the actual wellhead oil sample of a block in Liaohe heavy oil field as the basic data, The moisture content is 90%, the hydrogen sulfide content is 0.02%, the oil content is 9.98%, the temperature is 120 DEG C, the crude oil viscosity is 0.00645mPa·s, and the density is 930kg/m3. The influence of sampling speed, crude oil flow rate and hydrogen sulfide gas content on sampling error will be analyzed respectively.

5.1. sampling speed influence on sampling error

The inlet oil velocity is 0.09m/s, the pressure outlet is 0.4MPa, changing the ball valve rotation angle speed and the sampling time is controlled. Firstly, studying the flow state of the sampling ball in different angles when the ball valve rotates from 0 to 90 degrees, we take the zero, 45 and 90 degrees respectively as the observation angle.

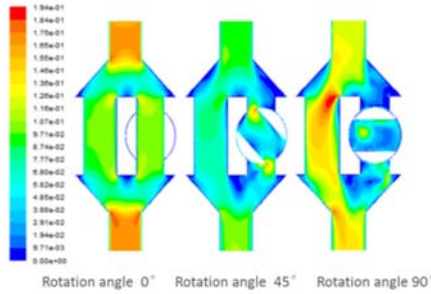

Fig. 3. Velocity field of different rotation angle

As shown in Figure 3, the velocity at the tangency of sampling hole and liquid increases obviously with the rotation of the sample ball; With the increase of the rotating angle of the sample ball, the flow rate is getting bigger and bigger at the tangency of sampling hole and liquid. The velocity of the liquid changes to zero gradually, until the sampling hole is completely closed. When sampling valve goes to 90 degree, the velocity of the liquid in the upper part and lower part of the ball and the inside of the sample ball are almost zero. Though the inlet velocity variation is not obvious, it still shows an increasing trend. The flow velocity of the inner liquid on the left side of the sampler increases gradually from top to bottom, and the flow velocity changes more and more obviously. In addition the sampler velocity increases slightly.

Then, in order to observe the influence of sampling speed of 1s, 1.5s and 2S on sampling error, the field plots of three sampling velocities are analyzed when the rotation angle is 22.5 degrees. It can be seen from Figure 4, the faster the sampling rate is, the greater the velocity at which the sampling hole is tangent to the liquid. Because the sampling entrance is far away from the sampling sphere, the faster of the sampling rate is, the slower the flow velocity at the entrance and the faster of the

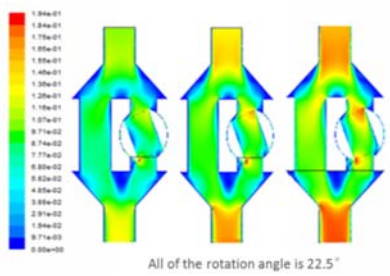

Fig. 4. Velocity field at different sampling velocities

sampling rate is, the slower of the velocity variation at the left side and the outlet.

The error curve is obtained by comparing the calculated gas content and oil content with the actual value, and we can analyze the sampling accuracy of the closed sampler.

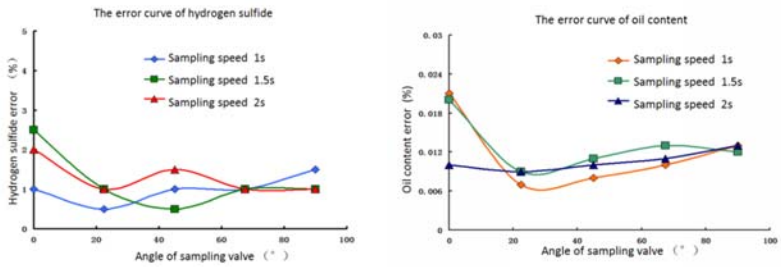

Fig. 5. Error curve at different sampling rates

It can be seen from figure 5, when the sampling valve is just beginning to rotate, different sampling speed has great influence on the fluctuation of error curve. This shows that the valve body begins to rotate, the liquid is still in continuous flow state. When the fluid is suddenly subjected to the transverse force of the ball valve, the content of the components in the sample varies violently. With the increase of rotation angle, the error of oil content and gas content gradually stabilized, and the error values of different sampling rates are approximately equal at 90 degrees. Finally, the hydrogen sulfide error is between 1% and 1.5%, and the error of oil content is between 0.012% and 0.015%.

5.2. Influence of oil sample velocity on sampling error

Taking the actual wellhead oil sample of a block in Liaohe heavy oil field as the basic data, the inlet speed of oil sample change from 0.09m/s, 0.18m/s to 0.27m/s respectively; the outlet pressure is 0.4MPa; the sampling speed is assumed to be 1s.

Through the internal flow chart, the fluid flow in the sampler under different flow rates can be clearly observed, It is helpful to thoroughly analyze the cause of error in the process of sampler rotation. Since the 0.09m/s is already included in the (1) section, the following is the field map at the entrance speed of 0.18m/s and 0.27m/s.

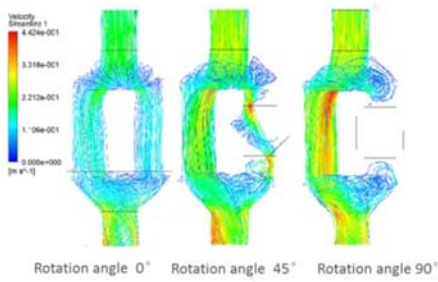

Fig. 6. Oil sample velocity is 0.18m/s

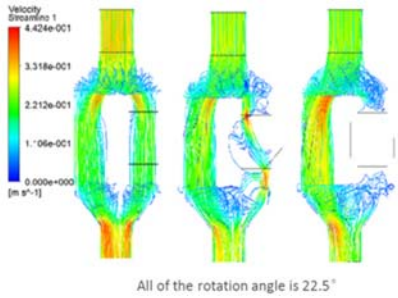

Fig. 7. Oil sample velocity is 0.27m/s

As shown in figures 6 and 7, it can be seen from the streamlines within the sampling valve at different inlet velocities that in the absence of sampling the liquid flow lines on the left and right sides are basically the same, it is shown that both sides of the through hole can work simultaneously to share the wellhead fluid without sampling operation; the blue line in the diagram is part of the liquid that is close to zero after the entry fluid hits the top plane of the sampling valve; At the beginning of sampling, the color of the flow line in the sampling hole and the lower part of the ball which tangent to the liquid gradually change to red, indicating the liquid velocity is increasing. The color of the streamline in the left hole gradually turns red which indicates that part of the liquid in the through hole of the right sampling valve begins to flow through the left; The color of the inlet streamline in the sampler changes little, but the color at the exit becomes red, indicating that the outlet velocity increases.

The combination of Figure 6 and Figure 7 shows that the greater the entrance velocity is, the deeper the streamline color is at the tangent of the sampling hole to the liquid; When the sampling valve goes to 90 degrees, the streamline value on the top and bottom of the sampling sphere is almost zero, and there is no more fluid entering the sampling hole space;

Next, the error curves of gas content and oil content are compared with the true values, as shown in Figure 8.

The error curves in figure 8 shows that when the ball begins to rotate to sample, the composition of the fluid in the valve varies greatly under the action of sudden shear force, which lead to the error of oil and gas is not consistent at different

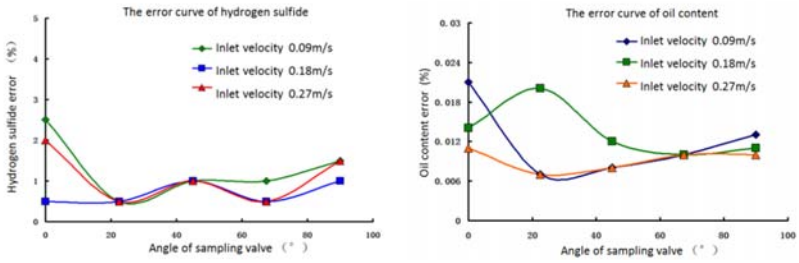

Fig. 8. Error curves at different inlet velocities

flow rates. With the rotation angle increases, the error is decreasing gradually, the error curve tends to be stable and consistent, shows that the composition of the fluid sampling valve gradually stabilized. At the end of the 90 degree, the hydrogen sulfide error range is between 0.5% and 1%, and the oil content error range is between 0.011% and 0.014%.

5.3. Influence of hydrogen sulfide content on sampling error

The other basic data of oil samples are consistent with the above, changing the hydrogen sulfide content, analyzing the error curve when hydrogen sulfide content is 0.02% and 0.1% respectively, shown in figure 9 below.

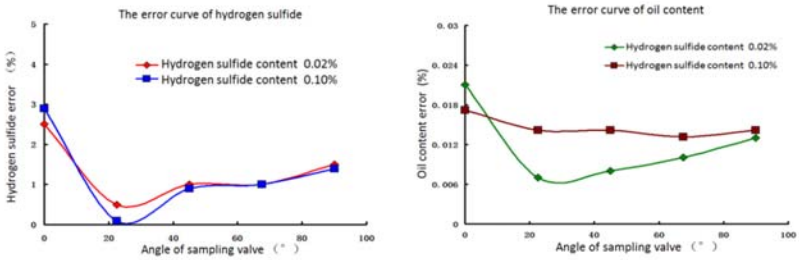

Fig. 9. Error curves of different sulfide content

Under different hydrogen sulfide content, the error curves of H2S and oil content decrease with the increase of sampling valve angle, indicating that the composition of sample in the valve tends to be true in the process of rotation. Finally, at 90 degrees, the error of the liquid with different hydrogen sulfide content is small and relatively low. The error range of hydrogen sulfide is between 1% and 1.4%, and the oil content is between 0.01% and 0.013%.

6. Conclusion

(1) In Liaohe Oilfield, in order to solve the problem of leakage of hydrogen sulfide in the wellhead when sampling and the problem of easy to freeze in winter and inconvenient to sample, this paper designed a sealed sampling device which is dif-

ferent from conventional sampler, The device is installed on the production line of the oil well, and it can realize closed integral sampling when the normal production is carried out, and the operation is convenient without the need of emptying before sampling.

(2) Based on the actual data of wellhead in Liaohe Oilfield, the influence of sampling speed, inlet velocity and hydrogen sulfide content on sampling error is analyzed, it shows that in the rotating process of sampling valve, the error is very large because of the effect of rotation and shearing force, but when the sample is rotated at 90 degrees, the content of oil samples has little difference with the true value, and the error is within 2%.

(3) The new sampling device has the characteristics of tightness, flexibility and high efficiency. It is not only suitable for heavy oil fields containing hydrogen sulfide but also can be used in other heavy oil or non-heavy oil fields containing toxic gas. The design of this closed sampler has important application value and prospect.

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