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Preliminary Study on Air Injection in Annuli to Manage Pressure during Cementing

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Abstract

Along with the development of low permeability reservoirs, underbalanced drilling technology is applied more and more widely. During the cementing operation of underbalanced drilling wells, cementing liquid can flow into the reservoir more easily for the absence of the mud cake, which certainly weakens the reservoir protection advantage of underbalanced drilling. Based on the methods of underbalanced drilling and managed pressure drilling, a new method of cement technology, Balanced Pressure Cementing Technology by Air Injection in Annuli, was put forward. The calculation models of the maximum depth of injection point and the maximum start-up pressure were built. Considering the power limitation of the pump, valves of gas lift were introduced and the calculation method of valve location was developed. This technology could effectively control the annulus pressure of wellbore, assure the cementing quality and protect the hydrocarbon reservoir, thus reduces the exploration and development cost.

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Keywords: air injection in annuli; balanced cementing; injection point; start-up pressure; valve for gas lift; hydrocarbon reservoir protection

1. Introduction

One of the future trends of petroleum industry is the exploration and development of high-pressure, low-permeability reservoirs and further development of old oil fields. And underbalanced drilling (UBD) technology is effective for discovery, mining and maximize protection of this kind of reservoirs [1].

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However, the cementing technology matching the UBD is not mature, which restricts the development of UBD technology to some extent.

The difficulties of the cementing technology for UBD mainly include:

- Generally, the formation fracturing pressure of UBD well is low. Therefore, it is easy to fracture the formation and lead to lost circulation in the process of cementing.
- The cementing fluid is more easily to invade the formation because of the absence of mud cake, which would cause serious solid invasion, aqueous phase trapping and water sensitivity damage [2].
- If the leakage occurs, it would not only reduce the cement slurry column pressure, but also cause "pressure instability", thus it makes the formation fluids pollute the slurry.

On the analysis of the present cementing technology for UBD, the main problems of UBD well cementing include:

- The high-strength, low-density cement slurry and foam cementing technique are still inadequate either from operation, performance, or from the cementing quality guarantee and economic view, so they are restrained from deep well;
- The present cementing technology for UBD has high risk. There's no research on the real-time control of annulus pressure in the cementing process.

The main factor of reservoir damage is pressure difference. The key of cementing technology for UBD wells is to control the well pressure strictly. Inspired by the method and thought of bottom hole pressure control in UBD and MPD, according to the balanced cementing technology standard, a new cementing technology is proposed, which called Balanced Pressure Cementing Technology by Air Injection in Annuli.

2. The Basic Principle of Balanced Pressure Cementing Technology by Air Injection in Annuli

2.1. The control method of annular pressure

At present, within all kinds of well bottom pressure control methods [3-5]for UBD and MPD, only the wellhead back pressure control method and the friction resistance control method can be applied to control the wellbore annulus pressure. The wellhead back pressure control method can adjust wellbore pressure through reasonable control of wellhead back pressure without changing the fluid density. The friction resistance control method is mainly dependent on gas injection in the wellbore to form multiphase flow. The multiphase flow pattern can be changed by changing the gas-liquid ratio within a wellbore, which leads to the change of the annulus friction resistance and ultimately brings the annulus pressure into control.

The gas injection methods [6] include ground injection method, concentric casing injection method, coiled tubing injection method and parasitic tube injection method. Concentric casing injection method has high cost, complicated process; and the coiled tubing injection method has a great requirement on down hole tool combination. Only parasitic tube injection method not only overcomes the disadvantages of ground injection method, such as two-phase flow instability, flow pattern variation and serious degasification, but also can conveniently change the gas injection rate.

2.2. The principle design of Balanced Pressure Cementing Technology by Air Injection in Annuli

On the analysis of the bottom hole pressure control method, along with the pros and cons of methods used in gas injection and the characteristics of cementing operation, parasitic tube gas injection in annuli combined with wellhead back pressure adjustment are adopted to control wellbore annulus pressure. One gas injection tube with non-return valve and gas lift valve at the end is run into the annuli between casing and the borehole. Then annular gas-liquid two-phase flow is built up in the annuli above the gas injection point by the gas injection, thereby the fluid column pressure of the annuli above the gas injection point is reduced. At the same time, the designed pad fluid and conventional density cement slurry still applies in the annuli below the gas injection point. The process of gas injection makes the wellbore annular pressure lower than the reservoir pressure, and develops the negative pressure. It's necessary to regulate wellhead back pressure valve in order to maintain wellbore annular pressure between the formation pressure and the fracture pressure and satisfy the requirements of balanced pressure cementing technology [7].

2.3. The advantages of Balanced Pressure Cementing Technology by Air Injection in Annuli

Balanced Pressure Cementing Technology by Air Injection in Annuli adopts the conventional drilling fluid as the base fluid, then continuously injects certain amount of gas into the base fluid, thereby effectively reduces annulus fluid column pressure in the process of cementing. This technology mainly has the following advantages:

- effectively control the annulus fluid column pressure, prevent leakage, and fully protect reservoir;
- ensure the cement strength by using conventional density cement slurry to seal production formation;
- the injected gas is air, thereby it has lower risk of environmental pollution;
- The range of suitable formation is broad, especially for leakage reservoirs and low pressure reservoirs.

3. The Equipment Technologies of Balanced Pressure Cementing Technology by Air Injection in Annuli

3.1. The main equipment of Balanced Pressure Cementing Technology by Air Injection in Annuli

In mid-deep wells, especially deep and ultra-deep wells, the injection tube has to run down deeply, and the air pump must provide enough power to inject the gas into the annuli at a predetermined depth. As the air is injected into the annuli, the fluid density would decrease. The maximum value of wellhead injection pressure is called the maximum start-up pressure. If the rated pressure of air compressor cannot reach the maximum start-up pressure, the gas lift valve should be installed on the gas injection tube to reduce the start-up pressure. The location and the number of gas lift valves are closely related to pressure distribution of the annular wellbore and the pressure provided by the air compressor.

3.2. The location design of gas lift valves

According to the basic principle of Balanced Pressure Cementing Technology by Air Injection in Annuli, in order to prevent the breakthrough of gas, so the gas injection point must be set in the drilling fluid above the pad fluid in annuli. The maximum depth of gas injection point can be determined by the returning position of the cement slurry and the length of pad fluid. And 10 meters are reserved to prevent gas entering into the lower position of the pad fluid. It could be calculated by the following formulae:

$$L_{max} = h_l - \Delta h - 10 \qquad (1)$$

Here L_{max} is the maximum depth of annulus gas injection, m; h_l is the return position of the cement slurry, m; and Δh is the length of pad fluid in annuli, m.

The maximum start-up pressure is correlated with the depth of gas injection point. By referring to the process of gas lift [8-9], when the gas is injected into the annulus, the density of the mixed fluid in annuli is reduced and the hydrostatic fluid column pressure in the point of gas injection is also reduced. Finally, the pressure would reach a stable state. According to the principle of tachometer, the gas injection tube could be considered a rigid body. When the drilling fluid reached to it, the drilling fluid streamline is bent and divided into two stocks on the front of the tube (as shown in Fig 1), so the fluid velocity is zero at the gas injection point, and the pressure is called the standing pressure. Taking the fluid between section A and B as the study object, the Bernoulli equation is as the following:

$$\frac{p_b}{\gamma}+\frac{u_0^2}{2g}=(Z-Z_1)+\frac{p_a}{\gamma} \tag{2}$$

Here p_b is the pressure of section B, Pa; γ is the gravity density of mud fluid, N/m^3; u_0 is the velocity of mud fluid, m/s; g is the gravitational constant, m/s^2; Z is the depth of the section B, m; Z_1 is the depth of gas injection point, m; and p_a is pressure of section A, Pa.

Then formulate the Bernoulli equation aimed at the fluid between B and C (assuming no energy loss):

$$\frac{p_b}{\gamma}+\frac{u_0^2}{2g}=Z+\frac{u_0^2}{2g} \tag{3}$$

Combining the equation *(2)* and equation *(3)* could obtain:

$$p_a=\gamma(Z_1+\frac{u_0^2}{2g}) \tag{4}$$

Injecting gas into the annulus need to overcome the pressure of section A and the start-up pressure is equal to the standing pressure, that is:

$$p_e=\gamma(Z_1+\frac{u_0^2}{2g}) \tag{5}$$

Here p_e is the start-up pressure, Pa. It's assumed that the gas lift valves are installed in different depths. The gas with high pressure is injected into the annulus, and reduces the density of mixing fluid above the valve. The valve will be closed when the upper annulus pressure decreases to a switch-off value, and the second valve will be opened at the same time. On the analogy of this, the start-up pressure will be greatly reduced. The location design methods of gas lift valves are as follows:

- Assume 0.2MPa differential pressure between inside and outside of the valve could ensure the gas to flow into the valve. The depth of the first valve could be calculated as the following formulae:

$$L_1=\frac{p_{max}}{\rho g}\times 10^5-20 \tag{6}$$

Here is the depth of the first valve, m; p_{max} is the maximum rated pressure of the air compressor, MPa; and ρ is the density of mud fluid, kg/m3.

- When the pressure reaches the switch-off pressure of the first valve, the valve would automatically shut down, and the gas flows into the annuli only through the second valve, as shown in Fig 2. According to the pressure balance at the second valve, it is obtained as the following:

$$p_2=p_1+\rho g(L_2'-L_1)\times 10^{-5} \tag{7}$$

Here p_2 is the annular pressure of the second valve, MPa; p_1 is the annular pressure of the first valve, MPa; and L_2' is the balanced depth of the second valve, m. Assuming L_2 is the depth of second valve, m. Also considering the 0.2MPa differential pressure of the valve, L_2 could be calculated as the following formula:

$$L_2 = L_2' - 20 \tag{8}$$

Similarly, the depth of each valve could be calculated by following the same way, until the maximum depth of annulus gas injection is reached.

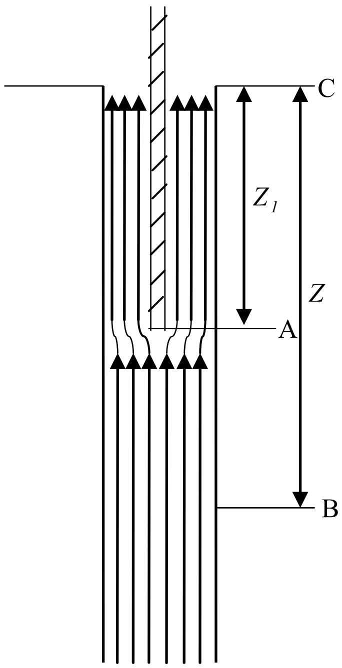

Fig. 1. The drilling fluid is divided into two stocks

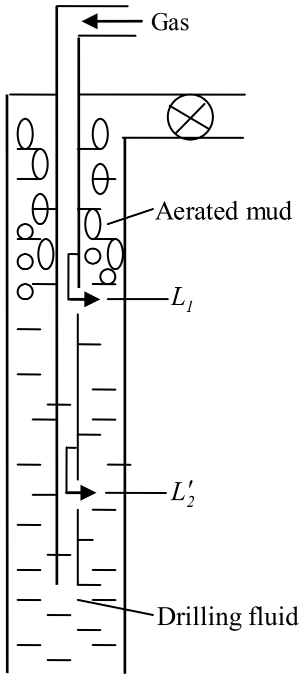

Fig. 2. The principle of gas lift valve

4. Conclusions

(1)The existing cementing technologies for UBD have some defects. In this paper, Balanced Pressure Cementing Technology by Air Injection in Annuli is proposed based on the annulus pressure control. This cementing technology not only could protect the reservoir, but also assure the cementing quality.

(2)The calculation models of the maximum depth of injection point and the maximum start-up pressure were built; it's concluded the maximum depth of gas injection point can be determined by the returning position of the cement slurry and the length of pad fluid. The maximum startup pressure of annulus gas injection is closely related with its maximum depth.

(3)The calculation methods of location and quantity of the gas lift valves are developed. They can help with the selection of air compressor.

Nomenclature

UBD	underbalanced drilling
A	the location of gas injection point
B	the location of Z meters distance from the wellhead
C	the location of the wellhead

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