A new submarine oil-water separation system

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Abstract. In order to solve the oil field losses of environmental problems and economic benefit caused by the separation of lifting production liquid to offshore platforms in the current offshore oil production, from the most basic separation principle, a new oil-water separation system has been processed of adsorption and desorption on related materials, achieving high efficiency and separation of oil and water phases. And the submarine oil-water separation device has been designed. The main structure of the device consists of gas-solid phase separation device, period separating device and adsorption device that completed high efficiency separation of oil, gas and water under the adsorption and desorption principle, and the processing capacity of the device is calculated.

1. Introduction

According to the division of the World Petroleum Congress in 2002 on the depth of offshore exploration and development, water depth less than 400m is conventional, 400 ~ 1500m is deep and more than 1500m is ultra deep water. Offshore and onshore oil production has great difference. Comparing with the land, the low real gas-liquid ratio in deep-water, the high pressure of oil-water separation and low environment temperature are the problems to oil production[1-3].

For the most conventional offshore oil and gas development project, the treatment measures including that separation of oil and water, oil and gas separation, crude oil dehydration, produced water treatment standards discharge is always behind lifting crude oil to the surface production device. Research shows that the sea water-oil-gas separation effect is not very obvious when the water mass fraction is less than 15% in oil output[4]. With the mining time extended, water mass fraction in oil output is higher and higher. As to ensure qualified crude oil production, the work of treatment measures is increasing and the separation device also needs greater volume. Because production platform or FPSO space are overwhelmed, the device needs to deal with the implementation of reconstruction. It has a good economic value to put the separation device on the seabed surface for deep-water and ultra-deep-water development.

The restriction of the design is the flow area in the traditional underground oil-water separation device. It is very difficult to efficiently process output liquid in the narrow well bore area, and the common Hydrocyclone separation device have the high energy consumption problem[5]. Because it is restricted by separation principle of density difference, small molecule organic fraction cannot be separated. It leads to the existence of organic fraction in the water in a certain proportion of the total.

Using the principle of oil-water separation technology of adsorption and separation, the device begins from the fluid inflow to the oil, gas and water three-phase flow out of the device[6]. The basic structure is firstly separating gas phase and solid phase from the production liquid in traditional way, then the rest of the oil-water mixture separate into oil and water through adsorption separation device.
And the separated oil and gas are lifted to offshore development platform, the separated water was used to reinjection.

Compared with the gravity type oil-water separation and oil-water hydrocyclone water-oil separation, the technology has a certain advantage[7]. But due to the development of current materials and technology, there still have has some shortcomings in this technology, and the specific comparison are given in Table 1:

| Separation method                      | Principle                                                                 | Separation effect | Energy consumption | Life of the device | Device scale |
|----------------------------------------|---------------------------------------------------------------------------|-------------------|-------------------|--------------------|--------------|
| Conventional gravity separation        | Density difference between oil and water, separated by gravity             | Common            | Low               | Long               | Big          |
| Electrostatic coalescence enhanced gravity separation | Oil-water separation by electric field                                    | Better            | High              | Common             | Smaller      |
| Tube type separation                   | accelerated the separation of water emulsion layer, achieving rapid oil-water separation | Better            | Less              | Common             | Smaller      |
| Hydrocyclone separation                | Using the high speed of liquid rotating in the cyclone tube will produce different centrifugal force that separate oil from water | Better            | High              | Long               | Smaller      |
| Adsorption separation                  | Using the technology of the adsorption and separation, oil and water are separated by adsorption and desorption technology | Good              | Less              | Common             | Small        |

2. Device Operation Principle

Due to the high pressure of submarine and the device vertical height is low, the device is placed in the horizon, the general principle is shown in Figure 1. As shown in Figure 2, well production flows into the gas-solid separation device through the liquid pipe. And gas and a small amount of residual solid phase will be separated isolated from production liquid. When separated oil-water flows into period separating device, in the period separating device, oil-water mixture is evenly divided into two periods to inject into adsorption device for oil-water separation. In the adsorption process of the device, water, through the adsorption device and liquid separating device, is injected by pump. In the desorption process, oil, through liquid separating device, is fed into the platform by pump.
Fig. 1 A simplified flow diagram of submarine oil-water separation system

Fig. 2 A sketch of submarine oil-water separation system
3. Estimation of device handling capacity
In order to easy calculation, a few hypotheses are proposed: Once the crude oil is exposed to the adsorption coating, the adsorption will be instantaneous. The surface is uniform and the adsorption efficiency is 100%. During the desorption process, the crude oil will be completely desorbed from the adsorption coating. An adsorption cell as shown in figure 3, $\delta$ is the distance between the outer surface and the outer surface.

Area of the cell:

$$s = \frac{3\sqrt{3}a^2}{2}$$ (1)

Recorded the number of small columns as $n$, then

$$\frac{s}{6} \cdot n = \frac{\pi D^2}{4}$$ (2)

$$n = \frac{\sqrt{3}\pi}{3} \left(\frac{D}{2\delta + d + l}\right)^2$$ (3)

The outer surface area of a single cylinder:

$$A = \pi(d + 2\delta)L$$ (4)

The total internal surface area is:
\[ S = A \cdot n = \frac{\sqrt{3} \pi^2 (d + 2\delta)L D^2}{3(2\delta + d + L)^2} \]  

(5)

Maximum crude oil adsorption:

\[ V = S \cdot h = \frac{\sqrt{3} \pi^2 (d + 2\delta)L D^2 h}{3(2\delta + d + L)^2} \]  

(6)

The time required to remember the adsorption saturation is \( t_0 \), the unit is s; The time required to take off the desorption is \( t_1 \), the unit is s.

\[ t_0 = \frac{V}{Q(1-f_w)} \]  

(7)

The rate of desorption \( u = Kt^{-\alpha} \), and the constant \( K \) is related to the properties of the material, \( m \) is constant.

\[ t_1 = \left( \frac{V(1-m)}{K} \right)^{\frac{1}{\alpha-m}} \]  

(8)

The time of device single separation

\[ T = t_0 + t_1 \]  

(9)

The processing capacity of the unit time device:

\[ q = \frac{V}{T} = \frac{1}{Q(1-f_w)} + \left( \frac{V^\alpha(1-m)}{K} \right)^{\frac{1}{\alpha-m}} \]  

(10)

Q is oil production rate, m³/s; \( f_w \) is moisture content; \( d \) is wire diameter, m; \( a \) is the thickness of the adsorption materials, m. \( \delta \) is the distance between the outer surface and the outer surface, m; \( D \) is the inner diameter of the outer barrel, m; \( L \) is the outer barrel length, m; \( h \) is oil film thickness, m.

It can be found that the main parameters affecting the amount of processing are fluid volume, moisture content, desorption rate parameter \( K \) and \( m \), and device parameters. In addition, it is found that the time of desorption is usually greater than the adsorption time. The main factors that affect the operating period of the device are the desorption time. If it can improve the properties of adsorption materials and shorten the time of desorption, the separation efficiency of the device can be greatly improved.

In view of time and experiment device problems, the desorption time of this design has not been accurately calculated and quantified. In order to know the influence of the time on the desorption of device, the liquid output of oil as 500m³/d; Water cut as 90%; The diameter of wire as \( d = 1 \)mm; The thickness of the adsorption material as \( a = 0.5 \)mm; The distance between the adjacent outer surface as \( = 1.5 \)mm; The inner diameter of the outer barrel of the adsorption device as \( D = 500 \)mm; The outer barrel length of the adsorption device as \( L = 400 \)mm; The thickness of the coating surface oil film as \( h = 0.01 \) mm (ideal value).
Taking these data into the above equation, the maximum adsorption capacity is \( V = 0.000929378 \) m³ and the adsorption time is \( t_0 = 1.60 \) s, it can be obtained to the relationship between the time of desorption time and unit time:

\[
q = \frac{0.000929378}{1.606 + t_i}
\]  

(11)

It can be seen that shorten desorption time can improve the unit time of the device processing capacity and improve the efficiency of separation.

4. Conclusions
The adsorption oil and water separator is better than other underwater oil-water separation technology, which has the advantages of high efficiency, low energy consumption and small device. However, there are also shortcomings with adsorption oil-water separator: high performance requirements of adsorption material (adsorption material cost is relatively high), and the process is mainly aimed at the high of oil-water separation (water cut is more than 90%).

Adsorption separation process, although currently under the development stage, may have some imperfections and difficult to meet the demand of industrial application, the technology of research and development for current undersea oil-water separation technology is a revolutionary reform. It is not the improvement of current technology, or deep processing and perfection, but a new idea depend on different principles to achieve oil-water separation. The development of the technology is a great significance to the development of oil-water separation technology.

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