

# Investigation of flow characteristics in helical separator

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**Abstract.** The oil recovery technology of submersible electric pump has the advantages of multi-function and strong adaptability, which has become one of the important lifting methods at present. High gas-liquid ratio and low downhole pressure in oil well will lead to a large amount of natural gas in crude oil. Cavitation and air lock will shorten the pump operation cycle. Therefore, a gas separator is installed at the inlet of the pump to separate the gas from the well fluid, reducing the volume fraction of the gas entering the pump and improving the production efficiency of the pump. In this study, the flow passage of the helical separator is treated as an equal-section pipeline in the research process. Through theoretical analysis and numerical simulation, the separation efficiency and pressure loss in the helical separator are studied and the expression of the total liquid phase drag multiplier applicable to the separator structure is obtained by the method of fitting.

## 1. Introduction

Helical flow is most widely used in separation technology. The gas-liquid separator is used to separate the gas-liquid mixture media in many occasions in petroleum, chemical and other industries. The fluid of the helical gas-liquid separator enters from the lower inlet and flows upward through the fixed screw blade in the spiral separator [1,2]. With the action of centrifugal force, the dense phase moves to the outer wall of the separator, while the low-density phase flows to the central area of the separator.

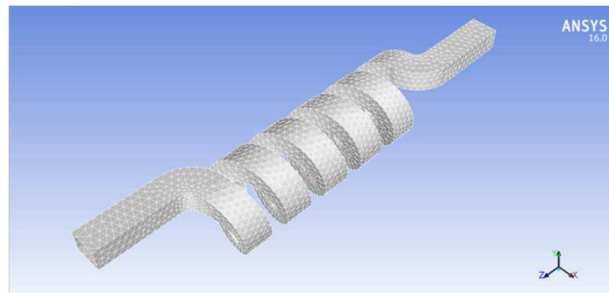
Conventional gas-liquid separator usually adopts the structure form of gravity sedimentation tank, but it has large volume, large area and long processing time. The helical separator was used to remove sand from wellhead in the early days and is now widely used to separate gas-liquid two phases. Compared with gravity separator and other cyclone separator, centrifugal gas-liquid separator has the characteristics of compact structure, small pressure loss and high efficiency [3]. The advantages of the helical separator have attracted wide attention, and the research areas also involve the separation of oil and water in the spiral pipe, the analysis of the movement and deformation process of bubbles in the oil, fluid morphology, pressure drop, etc. [4,5]. In this paper, Fluent is used to simulate the flow characteristics of two-phase flow in the flow channel of the helical separator and study the separation efficiency and pressure loss in the helical separator.



## 2. Simulation method

### 2.1. Solution model

Using ANSYS DM software to model, the grid division module in ANSYS was adopted to complete the grid division. The form of grid division directly affects the quality of the grid, and the quality of the grid will have a direct impact on the calculation results and the stability of the calculation. In this study, the fluid drainage area of helical separator is taken as the calculation model, and the tetrahedron unstructured grid is used to divide. In order to make the calculation more accurate, the grids are encrypted. After the verification of grid independence, the final overall computing grid partition digit is 487294, as shown in Fig. 1. The properties of the fluid used in the simulation are shown in Table 1.



**Figure 1.** Grid division of numerical simulation of helical separator.

**Table 1.** Properties of the fluid used in the simulation study.

Properties	Air	Water
Density	1.225kg/m <sup>3</sup>	1.7894×10 <sup>-5</sup> kg/m·s
Viscosity	998.2kg/m <sup>3</sup>	0.001003 kg/m·s

#### 2.1.1. Continuity equation. gas continuity equation:

$$\frac{\partial}{\partial t}(\alpha_g) + \nabla \cdot (\alpha_g \bar{v}_g) = \frac{1}{\rho_g} \left( m_{gl} - \alpha_g \frac{d\rho_g}{dt} \right) \quad (1)$$

Liquid continuity equation:

$$\frac{\partial}{\partial t}(\alpha_l) + \nabla \cdot (\alpha_l \bar{v}_l) = \frac{1}{\rho_l} \left( m_{lg} - \alpha_l \frac{d\rho_l}{dt} \right) \quad (2)$$

Where  $\alpha_g, \alpha_l$  is the volume fraction of gas phase and liquid phase,  $\bar{v}_g, \bar{v}_l$  is the velocity of gas phase and liquid phase,  $\rho_g, \rho_l$  is the physical density of gas phase and liquid phase,  $m_{lg}$  is the mass transfer from liquid phase to gas phase,  $m_{gl}$  is the mass transfer from gas phase to liquid phase.

#### 2.1.2. Momentum equation. gas momentum equation

$$\frac{\partial}{\partial t}(\alpha_g \rho_g v_g) + \nabla \cdot (\alpha_g \rho_g v_g^2) = -\alpha_g \nabla_p + \nabla \cdot \tau_g + \alpha_g \rho_g g + \alpha_g \rho_g F + K_{lg}(\bar{v}_g - \bar{v}_l) + m_{lg} v_{lg} \quad (3)$$

liquid momentum equation:

$$\frac{\partial}{\partial t}(\alpha_l \rho_l v_l) + \nabla \cdot (\alpha_l \rho_l v_l^2) = -\alpha_l \nabla_p + \nabla \cdot \tau_l + \alpha_l \rho_l g + \alpha_l \rho_l F + K_{gl}(\bar{v}_g - \bar{v}_l) + m_{gl} v_{gl} \quad (4)$$

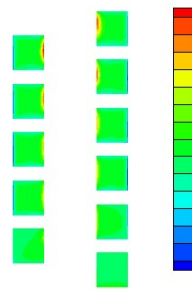
Where  $P$  is the shared pressure of two phase flow,  $\tau_g, \tau_l$  is the shear stress tensor of gas phase and liquid phase,  $K$  is the exchange coefficient of interphase momentum.

According to the characteristics of underground environment, the actual model is simplified and the geometric model of gas-liquid two-phase flow channel is established. In order to calculate conveniently and save computation time and computational space, it is necessary to make some assumptions and simplify treatment of computational fluid. The gas-liquid two-phase fluid is incompressible, the flow is constant turbulent flow, the inlet is velocity inlet, and the outlet is pressure outlet.

### 3. Results discussion

#### 3.1. Separation efficiency in the helical separator

Through the guiding action of the screw plate, the gas-liquid two-phase flow rotates in a spiral form along the inner wall of the separator and flows from the wall to the central pipe in the opposite direction. Gas-liquid two-phase flows from the bottom up to the outlet, forming an external spin flow. Due to the centrifugal influence of strong swirling flow, the relatively light gas flows to the central guide hole, while the liquid flows outward, so as to realize the separation of gas and liquid, as shown in Fig. 2.



**Figure 2.** Distribution of gas phase in the helical separator.

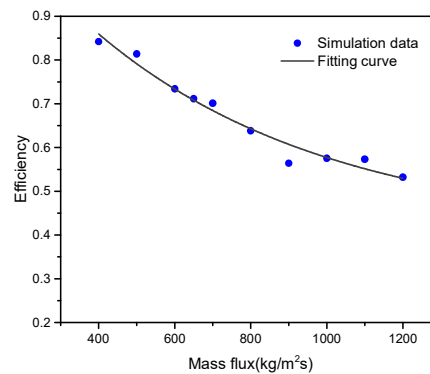
The model based on the mass and momentum balance equations was developed by Alhanati(1993) [6], which was used to predict the natural separation efficiency of two-phase flow. The expression of separation efficiency was expressed as:

$$E = \frac{v_{\infty}(1-\alpha)^n}{v_{sl} + v_{\infty}(1-\alpha)^n} \quad (5)$$

$$v_{\infty} = \sqrt{2 \left( \frac{\sigma(\rho_l - \rho_g)g}{\rho_l^2} \right)^{0.25}} \quad (6)$$

Where  $v_{sl}$  is the superficial velocity of the liquid phase,  $\sigma$  is the surface tension,  $n$  refers to the flow regime.

With the increase of inlet velocity, the swirling strength of the flow field inside the separator also increases, which makes it easier to separate the gas-liquid two phases, thus improving the separation efficiency of the separator. However, the separation efficiency did not increase with the continuous increase of velocity. The flow rate is too high, and the time for the gas-liquid phase to act in the separator decreases. Meanwhile, the carrying capacity of the liquid phase to the gas-liquid phase is enhanced, which is not conducive to the separation of the gas-liquid phase and directly leads to the reduction of the separation efficiency, as shown in Fig. 3. Therefore, in practical application, it is necessary to choose the inlet velocity reasonably to obtain high separation efficiency.



**Figure 3.** Correlation of separation efficiency based on simulation data.

### 3.2. Pressure drop characteristic in helical channel

The state of single-phase flow through spiral pipe is not the same as that in horizontal pipe and vertical pipe. The flow in spiral pipe is affected by centrifugal force, resulting in secondary flow in the radial direction of the fluid, which makes its friction resistance much larger than that in horizontal pipe and straight pipe. The frictional pressure drop of single-phase flow can be calculated by Darcey formula.

$$\Delta P_o = f_o \frac{L}{D_h} \frac{\rho_o \mu_o^2}{2} \quad (7)$$

$$D_h = \frac{2hb}{h+b} \quad (8)$$

$$L = n\sqrt{h^2 + (\pi D_m)^2} \quad (9)$$

Where,  $f_o$  is the frictional resistance coefficient of single-phase fluid,  $L$  is the length of the helical channel,  $D_h$  is the hydraulic diameter of rectangular section,  $\rho_o$  is the density of a single-phase fluid,  $\mu_o$  is the average velocity of a single-phase fluid,  $h$  is hitch,  $b$  is radial length of helical plate,  $n$  is helical number,  $D_m$  is medium diameter of a spiral structure.

A remarkable feature of gas-liquid two-phase fluid flow in helical pipe is that it will generate secondary reflux on the fluid cross section perpendicular to the mainstream direction, and the secondary reflux will increase the flow resistance of the pipe. There are also wall friction and phase interface shear stress between the two phases. Considering the complexity of secondary flow and two-phase flow, the pressure drop of two-phase flow is mainly studied experimentally. According to the test data, the authors have proposed a variety of correlation equations for pressure drop of gas-liquid two-phase flow in helical pipe.

The Lockhart and Martinelli relation of two-phase friction pressure drop using two-phase friction factor  $\phi_{lo}^2$  is as follows:

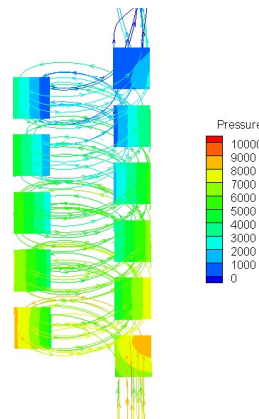
$$\left( \frac{\Delta P_f}{\Delta Z} \right)_{TP} = \phi_{lo}^2 \left( \frac{\Delta P_f}{\Delta Z} \right)_L \quad (10)$$

Bi (1994) et.al.[7] studied the two-phase pressure drop characteristics of the spiral channel. Considering the influence of mass gas content and channel size on the friction pressure drop, the relationship of full-liquid phase friction multiplier coefficient was obtained.

$$f_{lo}^2 = 1 + \left( \frac{\rho_l}{\rho_g} - 1 \right) \left[ 0.1469x^{1.3297} (1-x)^{0.59884} \left( \frac{D}{d} \right)^{1.2864} + x^2 \right] \quad (11)$$

Where  $x$  is dryness,  $d$  is the equivalent diameter of section,  $D$  is pitch diameter.

Fig. 4 shows the pressure cloud diagram in the helical separator. Energy consumption of separator is an important index to evaluate separation performance. Separator is carried out at the cost of loss of pressure, the lower the pressure drop, the lower the loss of energy. Through the color of the pressure profiles at different sections, we can see the change trend of pressure intuitively. In the pressure cloud diagram, red represents the maximum pressure, blue represents the minimum pressure, and other colors represent the middle pressure. As can be seen, the flow pressure in the flow passage of each layer of threaded vane decreases in a step-shaped manner after entering the spiral section. The reason of pressure drop is usually divided into static pressure and dynamic pressure in separator. After the air flow into the separator, the flow field and pressure distribution within the separator are determined by the static pressure and dynamic pressure in the separator. As a result of the sudden increase in the volume ratio at the inlet screw, the partial energy loss and partial dynamic pressure will be reduced. After entering the separator, the gas spirals along the wall surface. Because of the effect of fluid viscous, the gas will definitely have friction with the wall surface, thus resulting in friction loss [8]. In addition, the resistance generated by the gas flow to the blade will change into an internal spin flow and then into a backward motion. This is a static pressure rotational pressure process, which will also lead to the loss of rotational kinetic energy. This is where the secondary flow is generated. The gas eventually leaves the separator from the spillway, where the energy loss is also due to the rapid contraction of the spillway and the friction of the spillway wall. This is the end of the separation process of the two phases. During the whole process, due to the lack of static pressure, the loss of dynamic pressure will lead to pressure drop in the helical separator.

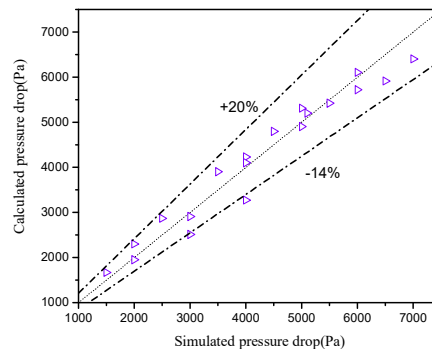


**Figure 4.** The pressure profiles at different sections.

The full-liquid phase friction multiplier of gas-liquid two-phase flow in the spiral channel was obtained by software Origin2016 fitting, and its expression is as follows:

$$f_{lo}^2 = 1 + \left( \frac{\rho_l}{\rho_g} - 1 \right) \left[ 0.316x^{0.981} (1-x)^{2.487} De_{lo}^{-0.854} + x^2 \right] \quad (12)$$

The comparison between the numerical simulation results and the results calculated by the formula is shown in Fig. 5. The calculated relationship obtained by fitting has good accuracy and can well predict the pressure drop of two-phase flow in the helical channel.



**Figure 5.** Comparison between pressure drop results and calculated relational results.

#### 4. Conclusion

In summary, the gas-liquid two-phase flow characteristics in the helical channel of the helical separator are studied by theoretical analysis and numerical simulation. The separation efficiency of helical separator increases first and then decreases with the increase of inlet velocity. From the diagram of pressure profiles at different sections, it can be seen that after entering the helical segment, the flow pressure in the flow passage of each layer of threaded blade decreases in a step-shaped manner, mainly because the volume ratio at the inlet screw suddenly increases, which will lead to local energy loss, and secondary flow and energy loss will occur after the fluid flows through the spiral blade, increasing energy loss. The two-phase flow friction pressure drop multiplier of the helical separator is calculated by fitting method.

#### Acknowledgments

This work was supported by Rapid Development of Mold based on RE/TDP Technology (Grant No.Z18051) and by Natural Science Foundation of China (Grant No.51574161).

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