Scholars Journal of Engineering and Technology (SJET) **ISSN 2321-435X (Online)**
Sch. J. Eng. Tech., 2015; 3(3B):304-310 **ISSN 2347-9523 (Print)**
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Research Article

Numerical simulation analysis of cone angle effect on the de-sanding performance of hydrocyclone

Zhang Xiaoguang*, Xu Baorui, Zhao Lixin
Northeast Petroleum University, Daqing 163318, China

***Corresponding author**
Zhang Xiaoguang
Email: xiaoguang8424@126.com

Abstract: First, the necessities of produced liquid sand removal in oil-field are introduced, in addition to the structure of the cyclone-desander to study and its basic separation principle are discussed. By using numerical simulation software FLUENT, putting the field produced fluid from certain oilfield as a separate object, we conducted research on numerical simulation of cone angle structure variable for the main diameter value of 56mm cyclone-desander. The distribution and the variation law of the velocity, pressure drop and sand phase volume fraction were obtained. Finally, sand separation efficiency of the different cone angle structure of Hydrocyclones was compared. Research shows that when the cone angle is 5°, the tangential velocity (v_t) in the cyclone is maximum, the sand volume fraction distribution in the bottom outlet is the highest, But also accompanied by a larger pressure drop, the sand separation efficiency is up to 96.3%. The conclusions of this paper can be for oilfield produced liquid cyclone-desander structure optimization design provides guidance.

Keywords: cone angle, hydrocyclone, desanding, separation performance, numerical simulation

INTRODUCTION

The sand content of produced liquid in oil well is increasing with the extension of oil production time, even the problem is existed when oil well started production[1]. Currently, the main removal of sand method of domestic oil gathering and transportation system is mainly through sand natural subsidence in a variety of container (especially large settling tank), then removing sand from time to time. The disadvantage is the difficulty of removal of sand, it needs long period, large one-time investment and area, when it started removal of sand, each container needs to be shut down, it will take a higher cost. This method can not meet the requirements that produced liquid and sand content increased year by year, it needs to find a new removal of sand device urgently. In recent years, the removal of sand technology that does not entering tank, such as hydrocyclone separation technology, is widely used in the petroleum industry.

Removal of sand hydrocyclone is a device that separate sand phase from liquid phase by using the density difference between solid phase and liquid phase. Hydrocyclone has lots of advantages, such as compact device, small footprint, short period of separation, the amount of processing has large adjustment range, a small investment in equipment costs, etc. So the oil worker pay more attention to it. With the rapid development of computer technology, using computational fluid dynamics numerical simulation to study hydrocyclone and conduct aided design for separation device has gradually developed into one of the main method of hydrocyclone. The numerical simulation technology not only has advantages like lower cost, higher speed, providing whole flow field information, but also has the ability to simulate real situation. It can reflect the flow law of fluid inside the hydrocyclone and provide a reference for the structural optimization of hydrocyclone [2].

The requirement to removal of sand of oil well fluid in hydrocyclone is to increase the density of sand-discharge at the outlet of bottom flow, combined with the actual situation of oilfield fluid sand, and by means of numerical simulation of dynamics CFD calculation method, researchers analyzed the influence of the change of cone angle in hydrocyclone velocity, pressure drop, sand concentration of bottom flow and removal of sand efficiency, and given the best cone angle which apply to removal of sand hydrocyclone in produced liquid of oil well.

The structural analysis of hydrocyclone:

The working principle of hydrocyclone is that separating liquid-solid two-phase by application of centrifugal effect, hydrocyclone itself without any moving parts, by solid-liquid two-phase mixture to be separated to some pressure from the inlet of hydrocyclone tangential entry, which lead to a strong rotational motion, because of the density difference between the solid-liquid two-phase, the suffured centrifugal, centripetal buoyancy and fluid drag force are different, most of the heavy phase(solid phase) are discharged via hydrocyclone underflow outlet, the light phase(liquid phase) are discharged via overflow port, so as to achieve the purpose of the separation of solid-liquid two –phase[3, 4].

Hydrocyclone usually consists of inlet, whirl cavity, cone segment, overflow port and underflow outlet, its structure sketch as shown in figure 1[5], the main structural parameters including the main diameter D_1, cone angle α , equivalent diameter of inlet d_i , the length of cavity L_1, diameter of overflow pipe D_0, the stretching length of overflow tube L_0 and the diameter of underflow tube D_u, etc. The main diameter and cone angle are the most important parameters, because the length of whirl cavity is determined by D_1 and α, other structural parameters are related to D_1[3, 6, 7]. Select the cut entry forms to the form of rectangular structure with double entrance, its quivalent hydraulic diameter of 0.22 times the main diameter D_1. Rectangular entrance section tangent to the whirl cavity wall, eliminating the liquid short circuit dead zone, weaking possible circulation flow, making the liquid flow of inlet more stable. Other main parameters are L_o=0.714 D_1, D_o=0.357 D_1 and L_1= D_1.

As shown in figure 2 the structure of cone angle of hydrocyclone for different stucture comparison chart, the transform of cone angle major impact on the length of cone segment of hydrocyclone, whirl cavity, overflow pipe and stuctural parameters of flow at the end of the pipe segment unchanged, the main diameter of hydrocyclone D_1=56mm which is determined by simulated structure, using Hy-α5, Hy-α8, and Hy-α10 to represent the cylone's structure of cone angle of 5°,8°,10°, its calculated length of cone segment are 5.71D_1, 3.58D_1 and 2.86D_1.

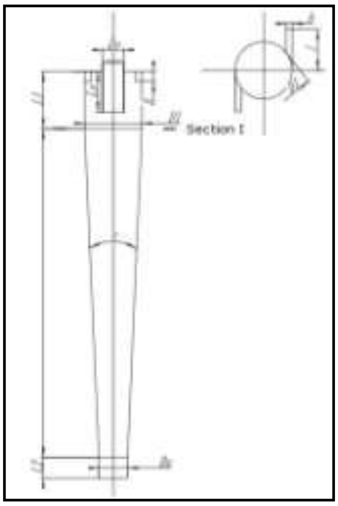
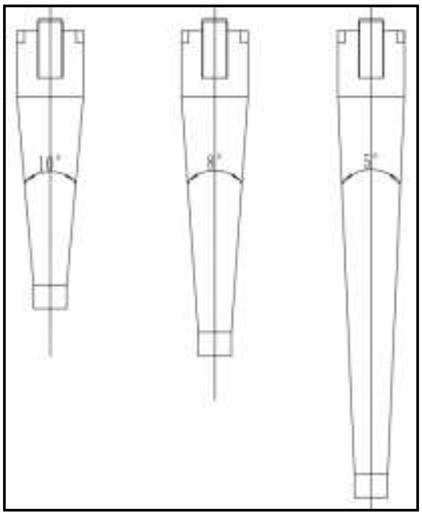


Fig-1: The structure sketch of hydrocyclone



Hy-α5 Hy-α8 Hy-α10

Fig-2: The comparison chart structure sketch of hydrocyclone

Parameter setting and mesh generation

The medium physical parameters and initial condition setting

The corresponding physical parameters when conducting simulated calculation as follows: the density of oil phase is 870kg/m^3, dynamic viscosity is 0.0461kg/m·s, the particle size of oil phase is 0.09mm; the density of water is 0.9982×10^3 kg/m^3, dynamic viscosity is 1.003×10^{-3} kg/m·s, the density of sand is 2500 kg/m^3, dynamic viscosity is , the average particle size of sand is 0.09mm.

According to the actual situation of station in oil field, the boundary conditions of initial simulated calculation as follows: the inlet flowrate is 4m^3/h, the oil volume fraction of inlet is 7.9%, the sand content of inlet is 1.5%, the split ratio of overflow is 80%, the velocity component along normol direction of inlet is 9.26m/s, the speed of the other two directions component is zero; overflow outlet and underflow outlet are set to free outlet.

Mesh generation

We can use Gambit, a CFD's processing software, to build model and mesh generation, the mesh as shown in figure 3, using hexahedral structural mesh form to build mesh, mesh generation of inlet, whirl cavity, overflow outlet and underflow outlet of hydrocyclone of different forms of cone angle are consistent. Using the method of equal interval to divide the mesh of cone section, making the density of different mesh generation of differenr cone angle of hydrocyclone are consistent. Meanwhile conducting a test of mesh are divided into different levels[8], comparison of different levels of mesh generation on the bottom of sand effect of the change of volume fraction, the volume fraction of sand phase of the underflow does not change with the increase in number of mesh when the number of mesh are 281200.

Fig.3 Cyclone model and meshing

Analysis of the effects of velocity field

Mainly in the hydrocyclone velocity field, the pressure decreasing and the solid phase volume fraction distribution is analysis.

Within three - dimensional turbulent flow hydrocyclone flow, its velocity field is represented by a cylindrical coordinate system is divided into three sub-Speed: tangential velocity(v_t)）, axial velocity(v_a)and radial velocity(v_r), Since tangential velocity is much larger than the axial velocity and radial velocity component in numerical, so the analysis temporarily ignore both the axial and radial velocity components, mainly for focusing on researching for tangential velocity[9-12].

v_t is the most important velocity component in velocity profile of hydracyclone,the magnitude of v^t determines the magnitude of centrifugal acceleration and centrifugal force which produced in hydracyclone,it is also the precondition for solid particles to segregated from liquid[9,12]. Hydracyclone is axisymmetric structure, and its entrances is symmetrical so we select intersecting surface I which is the joint of the Swirl chamber and the cone to compare with the velocity profile in interior of different cone angle hydracyclones, the velocity magnitude of intersecting surface is effected by the changes of cone section of hydrocyclone, this can reflect the influence rule of the change of cone angle in hydracyclone effects the fluid flow in the hydrocyclone interior.

Comparison of section I, v_t distribution comparison of different cone angle curve structure of hydrocyclone as shown in Figure 4, the figure shows, section I of the tangential velocity into the circumferential symmetrical distribution, v_t changes of three kinds of cone angle structure of hydrocyclone is consistent: the center velocity are zero; as the radius increases, the tangential velocity increases gradually, and there is a maximum tangential velocity v_t-max, at that point with the further increase of the radius of the hydrocyclone, v_t decreased gradually, in the side wall of the tangential velocity decreases to zero, therefore to the maximum tangential velocity for the sector, making the hydrocyclone is divided into two within the area of eddy current region and the outer vortex area, due to overflow the split ratio is set to 80%, significantly higher than the bottom flow diversion ratio, can be seen within the eddy zone is also obviously larger than outer vortex area.

By figure 4, we can see the difference of tangential velocity variation of three types of cone angel structure hydrocyclone: in the radial position within the scope(0 ~3mm),the variation gradient of Hy-α5 hydrocyclone,with the increase of the cone angel,the area of the tangential velocity variation gradient decrea ses gradually, and the difference of tangential velocity c hanges is small in the Hy-α8 and Hy-α10 two kinds of cone angel structure hydrocyclone; In the radial position within the scope(3~20), the tangentia l velocity of Hy -α 5 hydrocyclone basically unchanged within a certain r ange,and then continue to increase to a maximum, the ta ngential velocity changes of Hy -α 8 and Hy -α10 hydrocyclone with a linearly increasing trend, also gradually increases to the maximum. With the increase of the cone Angle, the maximum tangential velocity poi nt value decreases gradually in the hydrocycloe internal, maximum tangential velocity is the highest of the Hy -α5 hydrocyclone. Therefore, in the case of other param eters is consistent, increasing the cone angle of the hydr ocyclone has little effect on the interface Inside and out side eddy, but will change the rotation strength, rotation strength of internal flow field Hy -α5 hydrocyclone is the largest.

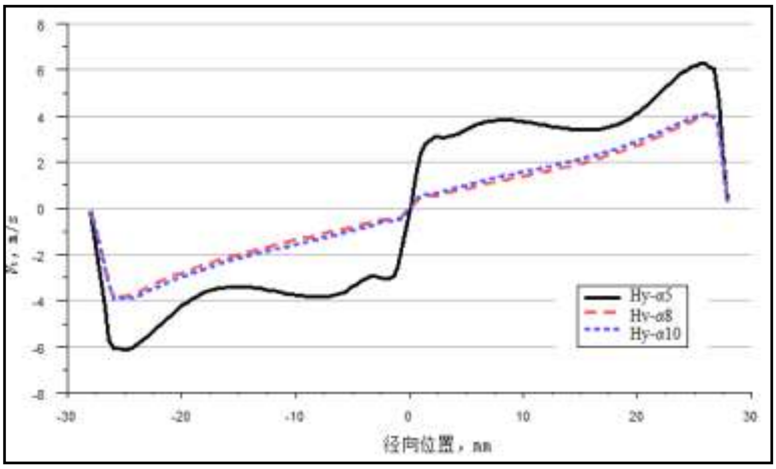
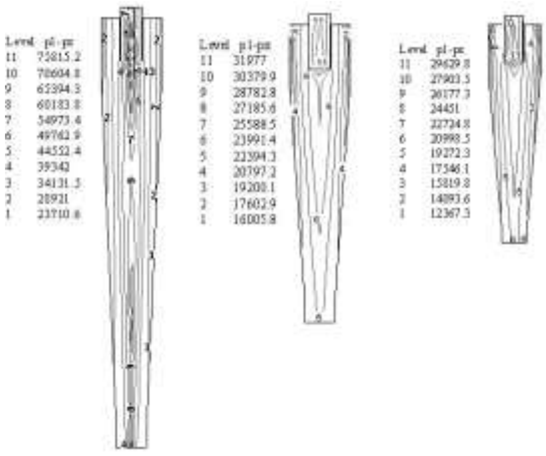


Fig-4: The distribution contrast of the tangential velocity

Analysis of pressure drop influence

15 The pressure drop of hydrocyclone is the pressure difference between inlet pressure and the overflow outlet pipe (or underflow outlet) pressure. Fig.5 shows different cone angle cyclone structure distribution contrast figure of the internal pressure drop, which longitudinal cross section of cyclone z = 0 is contrast section, the figure shows on the cross section of z = 0, the internal pressure drop of cyclone increases gradually from the cyclone wall to center, which reaches the maximum value at the center of cyclone, along the wall of cyclone to the bottom outflow direction the pressure drop into a trend of gradually increasing. In the whirl cavity internal, the cyclone center and the bottom of the overflow outlet intersection position occur the maximum pressure drop values, and from the position along the central axis of cyclone up to the overflow outlet and down to the underflow outlet section, pressure drop showing a decreasing trend, that is, three kinds of maximum pressure drop of different cone angle cyclone inside occurred in the bottom of overflow outlet extends parts. Three different cone angle cyclone reach different maximum pressure drop, the smaller the cone angle, the greater the pressure drop, as the cone section of Hy-α5 cyclone is longest, the underflow pressure drop compared to overflow outlet that other cone angle structure of cyclone pressure drop is higher; the Hy-α8 and Hy-α10 cyclone, due to cone section decrease, bottom outlet pressure drop is obviously lower than the pressure of the overflow outlet drop. So when the other parameters unchanged, the cyclone cone angle change only the influence of internal pressure drop of cyclone is more obvious.



Hy-α5 Hy-α8 Hy-α10

Fig-5: The comparison of the different cone angle of internal z=0 section of cyclone pressure drop distribution

By figure 5 shows the internal main pressure drop of cyclone distribution including the overflow outlet pressure drop Δpo, underflow outlet pressure drop Δpu and overflow extend part maximum pressure drop $\Delta pmax$, comparing the different cone angle structure of cyclone pressure drop distribution is shown in Fig. 6. As is shown in figure, with the increase of corn angle pressure drop to a gradually decreasing trend, the smaller the corn angle, the greater the pressure drop, and the overflow pressure drop increasing extent is more than the bottom flow pressure drop, the largest, when the corn angle change from 8° to 10 ° the pressure drop changes smaller; The overflow pressure drop is lowest, because the highest pressure drop distribution into the bottom of the overflow pipe extend part, near the overflow outlet, the overflow pressure drop is lower not too much than he highest pressure value.

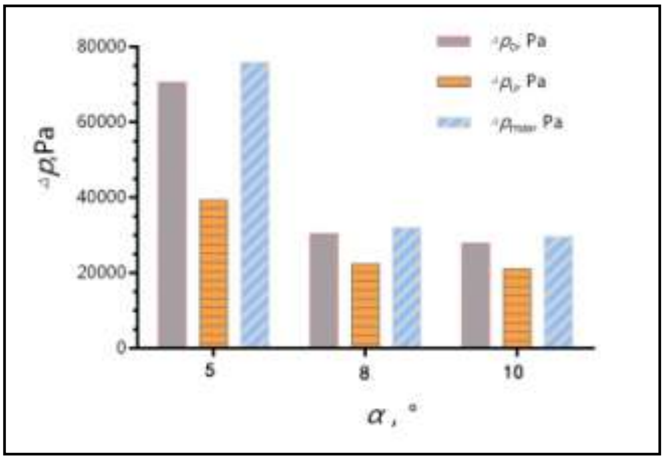
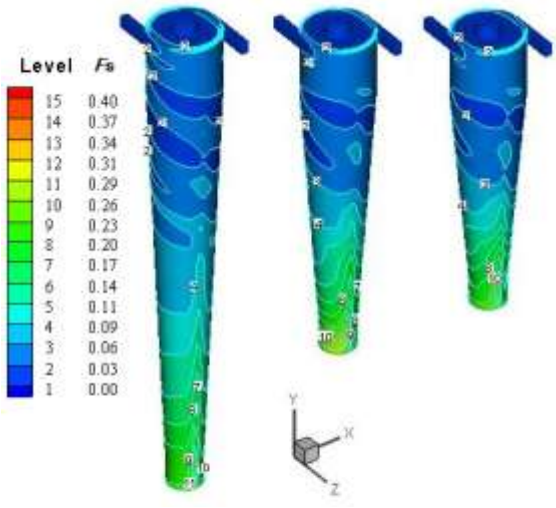


Fig-6: The comparison of the different cone angle structure of cyclone pressure drop distribution

Impact analysis of sand phase volume fraction *F*s

Sand phase basically distributes on near hydro cyclone wall by centrifugal separation . So, volume fraction distributing of sand phase in different cone angle cyclone is compared in the wall region. The volume fraction gradient distributing of solid phase in different cone angle of cyclone under the condition of the same operation parameters are shown in figure 7. By contrast, sand phase separated by whirl cavity and cone parts basically flow to underflow outlet along inner wall, on the whole, underflow gets the maximum enrichment in concentration of sand. Hy-α5、Hy-α8 and Hy-α10 hydro cyclone max volume fraction of solid phase are 29.9%、20% and 17.5% in underflow ,respectively.



Hy-α5 Hy-α8 Hy-α10

Fig-7: Fractional gradient distribution of different cone cyclone sand volume

In order to further compare the effect by the change of cone angle change in underflow containing sand concentration, the volume fraction distributing of solid phase in underflow is compared, as shown in Fig 8. As shown, solid phase volume fraction at different radial positions of underflow is varied. The volume fraction is basically axisymmetric and decreases as the diminished in the radius. Within 7 mm of the wall, hydro cyclone sand volume fraction in underflow peaks. In the region, larger cone angle result in smaller sand volume fraction. Hy-α5 hydro cyclone possesses the biggest sand volume fraction in underflow. In the center and adjacent center parts, sand volume fraction is minimum, less than 0.1%.And sand concentration at hydro cyclone underflow is less affected by the distribution. In general, Hy-α5 hydro cyclone has the highest sand concentration in underflow.

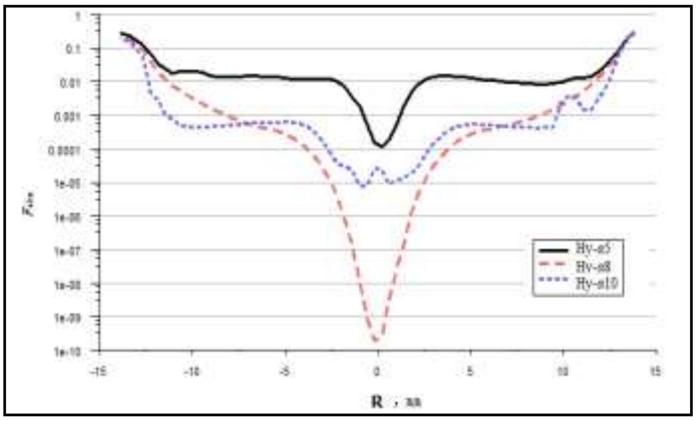


Fig-8: The distribution curves of sand phase volume fraction of different cone cyclone underflow outlet section

IMPACT ANALYSIS OF SOLID-LIQUID SEPARATION EFFECT:

The efficiency of desanding separation is sand phase mass flow rate of coming liquid in underflow divide by inlet`s (Formula 1), "M" as stated in the formula shall refer to sand phase mass flow rate, expressed as kg/s, "u" stand for underflow and "i" stand for inlet.

$$E_s = \frac{M_u}{M_i} \times 100\%$$

The efficiency change of desanding separation in different cone angle of cyclone is calculated and is shown in Fig 9. As shown, change of cone angle of cyclone has great consequences for desanding separation efficiency of oilfield production fluid. In this study, smaller cone angle of cyclone result in larger desanding separate effectiveness, and when the cone angle is 5°, the highest cyclone desanding separation efficiency is gained, 96.3%.

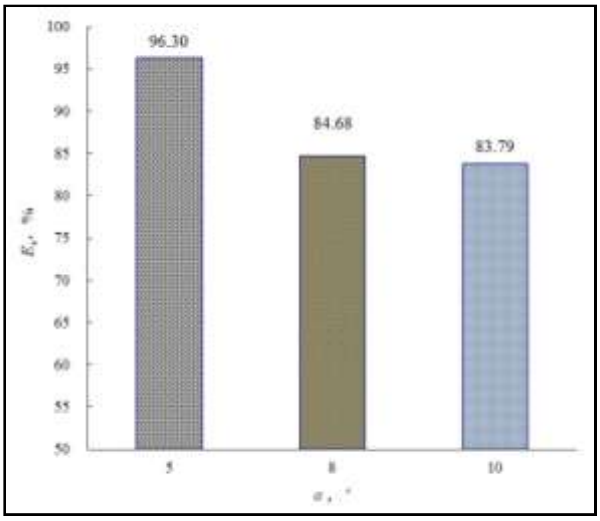


Fig-9: The curve of sand separation efficiency of different cone cyclone

CONCLUSIONS

(1) The tangential velocity on section I distributed symmetrically along the circumferential direction, different tangential velocity structure of the cone angle of hydrocyclone have same trend, the velocity is zero in central part, the tangential velocity is increasing with the increase of radius, and there is a point of maximum tangential velocity, the tangential velocity of hydrocyclone is gradually decreasing with the increase of radius on this point, the tangential velocity is zero in the side wall, maximum tangential velocity is bounded, the interval velocity field of hydrocyclone is divided into inter vortex and outer vortex area, the maximum tangential velocity in the inter of hydrocyclone is gradually decreasing with the increase of cone angle. The tangential velocity is highest when the cone angle is 5°. The change of cone angle of hydrocyclone has a little effect on the radial position of boundary surface of inner and outer vortex in velocity field, but has a strong effect on its rotational strength, the rotational strength is highest of inter flow field of hydrocyclone when the cone angle is 5°.

(2) The main pressure drop inside the hydrocyclone includes the following three typical pressure drop: the pressure drop of overflow outlet,

underflow outlet and stretching pipe of overflow, the pressure drop of stretching pipe is highest, followed by the overflow outlet, the lowest is underflow outlet, the pressure drop is increasing with the decrease of cone angle.

(3) The sand volume fraction of underflow outlet is largest when the cone angle is 5°, and sand phase mainly in the hydrocyclone wall adjacent areas, the separation efficiency of sand phase is highest with this kind of structural simulated calculation.

In summary, the separation efficiency of sand phase can be improved by decreasing cone angle within a certain range, but the pressure drop will be increased. In practical case, we should consider the separation efficiency of sand phase and energy consumption to choose suitable parameters.

Nomenclature

v_t tangential velocity(m/s)
v_a axial velocity(m/s)
v_r radial velocity(m/s)
Δp_o overflow outlet pressure drop (Pa)
Δp_u underflow outlet pressure drop (Pa)
Δp_{max} the maximum pressure drop at stretching pipe of overflow (Pa)
F_s sand volume fraction (%)
M mass flow rate of sand (kg/s)
E_s removal of sand separation efficiency (%)

ACKNOWLEDGEMENT:

This research was sponsored by State 863 projects of China (2012AA061303), national Ministry of education supported by the specialized research fund for the doctoral program of Higher Education (Doctoral category, 20132322110002) and the province of Heilongjiang provincial science and technology cooperation project (HZ201205)

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