IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

The effects of changing coil radius and tube diameter in the simulation of oil-water separation in a coil tube separator.

To cite this article: S Al-Musawi *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **671** 012069

IOP Conf. Series: Materials Science and Engineering **671** (2020) 012069 doi:10.1088/1757-899X/671/1/012069

The effects of changing coil radius and tube diameter in the simulation of oil-water separation in a coil tube separator.

S Al-musawi[1], M S Adnan[2], A S Bded[2], H Jaber[1] and f rashidi[3]

[1]Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

[2]Department of petroleum, Kerbala University, Iraq

[3]Faculty of Chemical Engineering Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

Corresponding author's e-mail address: rashidi@aut.ac.ir

Abstract. Separating oil and water is a frequent task in the oil and gas industry, and new methods and devices are constantly being designed to accomplish this more effectively. One of the most prevalent devices used is the coil tube separator, in which the separation process takes place between the two-phase fluids, each with its own density, utilising eccentricity acceleration and gravity. In this paper, a numerical simulator based on fluid dynamics calculations is used to survey and study the coil tube separator, modelling the two-phase flow using fluent software based on the Eulerian-Eulerian method. The subject variables such as tube diameter and radius of regression are taken as a focus in order to optimise the device's efficiency and function. For such optimisation, two targets were taken into consideration. The first is pressure flow drop and the second is rate of separation. To attain maximum performance, the pressure drop in this device should be low, while a high rate of separation is required. The research results showed that every variable has an optimum value: from this work, a tube with a 50 mm diameter and a coil with a 500 mm radius are defined as the most appropriate and optimum options.

1. Introduction

Developing exploration and production activities in oil-rich countries usually creates multiple environmental problems. One of the most important effects is the polluting water sources and increasing hydrocarbon percentages in it, which can have serious direct and indirect effects on human health. Dealing with oil polluted seafood and its hazardous effects on both the food chain and human health is a clear example of this. Thus, oil and gas production damage minimisation must be emplaced to handle such situations, which, if not controlled, might be the cause of multiple environmental and economical disasters.

In addition, the amount of water produced has a significant impact on oil pipelines and can reduce oil transfer capacity. Separation must be emplaced to send cleaned water to the sea or to return it to the reservoir. The water content of hydrocarbon fluids is often higher than 80%, which increases the burden of production operations, however, a total of about 300 million barrels goes through separation operations in a single year [1,2].

Increases in the recycling capacity will allow oil production to increase; without this, oil production will face problems, however in some cases, the stabilisation of reservoir pressure and increase of production require the re-injection of water into the reservoir, and the presence of excess oil and sand in injected water can damage equipment; consequently, even water reinjected into the reservoir should satisfy specific conditions and quality control standards in terms of oil and other impurities.

IOP Conf. Series: Materials Science and Engineering **671** (2020) 012069 doi:10.1088/1757-899X/671/1/012069

2. Literature Review

Much work has been done on the design of the spiral separator. In 1951, Stairmand presented one of the most famous designs [3] which suggested that the height and cylinder head and vortices should be 1.5 and 5.5 times the length of the cyclone body, respectively, in order to generate a high-efficiency cyclone; the equations for particle separation were later developed by Barth [4].

In the oil industry, NEYRTEC and TOTAL CFP designed rotary cylinder cyclones to remove impurities for the first time in 1984. The defects in these were laid in their complex structure and long vibration of the enclosure, which was both inevitable and destabilising to the oil close to the central axis [5]. Rotating cyclones are therefore not widely used in comparison with LLHCs (liquid-liquid hydro cyclones), although LLHCs also have disadvantages. For example, determining the diameter of an LLHC is very important in terms of separation efficiency; moreover, the tangential fluid inlet can also lead to an asymmetric vortex and, as a result, a high pressure drop [6, 7].

Due to the wide application of these separators in the industry, in order to optimise the designs of this device, modelling and simulation of *Computational fluid dynamics* (CFD) is this often adopted in this field [8]. In one of the first CFD simulations, the model most suitable for simulating torsional flow was identified [9], and today, most of the work done in this area seeks to optimise the geometric dimensions by means of computer simulations, similar to the current research [10, 11].

The main objective of this research is to optimise the problem variables, tube diameter and coil diameter, in a coil separator to separate water and oil most effectively. Two essential variables are effective in optimising device performance: pressure drop and phase separation rate; thus optimum performance conditions are lower pressure drop and higher level of separation. Therefore, the purpose of this study is to provide optimal geometric design values to achieve this goal.

3. Assumptions and the geometry of the study:

The assumptions used in this simulation are

- Two-phase flow is permanent and turbulent.
- The density of oil is 836 kg/ m^3 and its viscosity is 20 mPa.
- Due to the large quantities of oil fractions, using the Eulerian-Eulerian method is an acceptable way to model the two-phase flow.
- The input rate into the separator unit is constant.
- Water is fed from the bottom of the device and exits from the top.
- Developed motion is considered in the extended outlet.
- The non-slip condition is applied to all walls.

The original geometry was selected according to the work by Guoet al [12]. This prompted consideration of a tube of diameter 40 mm and a coil radius of 400 mm, with the coil step being 100 mm. To attain the most suitable profile when taking the inlet flow into consideration, the inlet tube was elongated. At the end of the simulation, seven loops were designed for the coil. The initial geometry was simulated using Workbench ANSYS software as shown in figure 1.

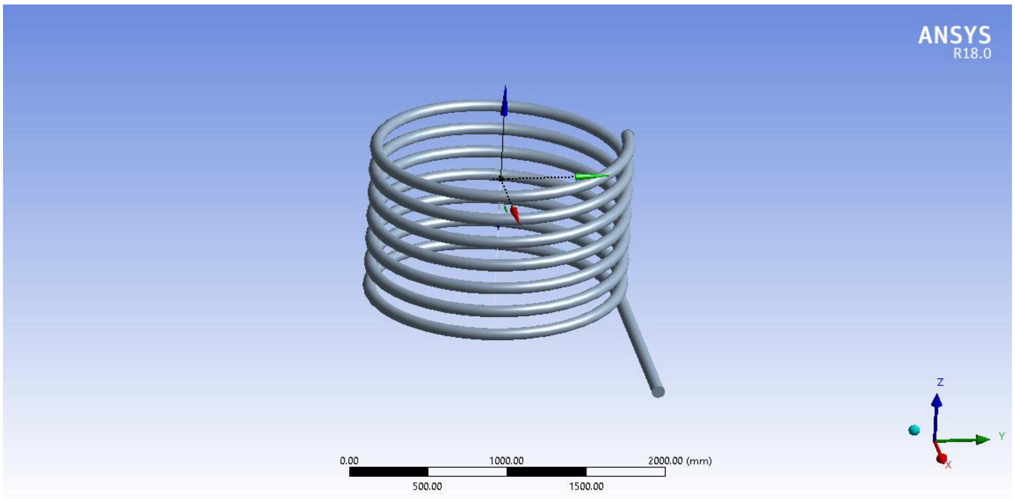

Figure 1:*Initial geometry of the coil with seven loops designed using Workbench ANSYS software.*

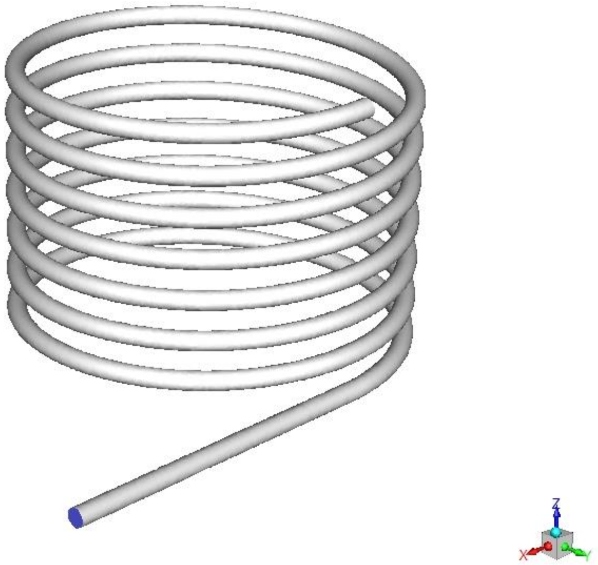

Figure 2: *Final coil with seven loops designed using Fluent software.*

4. Computational grid:

Around 3 million cells were used to solve the limited volume issues using Workbench ANSYS software based on the computational grid method. To check the independency of the results from the grid, several grids with different cell sizes were selected. The first two grids were created with uniform dimensions, and 4 and 2 mm were selected as sizes for the smallest sides of the cells, respectively. Following cells were smaller in the grids nearer to the tube wall.

Minimising the grid near the tube wall was done to examine the fluid conditions in the boundary layer; the part of the tube nearest the wall was thus divided into five grid layers. After comparing the results of the volume fraction at the corresponding points, the difference in the results of the last two grid layers was less than 5%. Thus, the third selected computational grid, in which the smallest side of the standard computing cell was4 mm and the cells near the wall were minimised in five layers, was selected as a suitable grid from the perspective of independency in results and a noticeable reduction in its computational costs. This is shown in figure3.

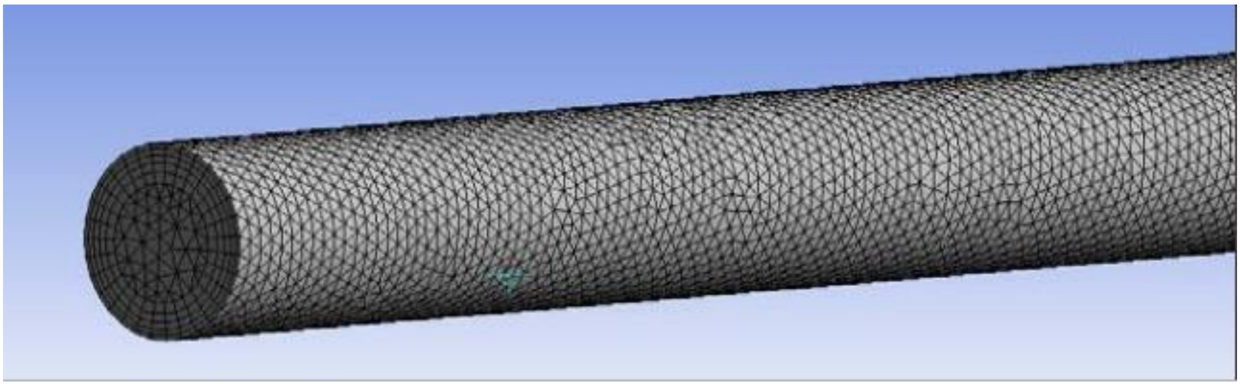

***Figure 3**: Applying mesh on the design to analyse results independency of the grid; 3 million cells were observed to be the optimal cell number.*

5. Boundary conditions:

Using the software, certain inlet flow boundary conditions were defined to allow analysis of the inlet boundaries, while outlet flow boundary conditions were used for the outlet boundaries. For this test, the pressure was set to atmospheric. A totally developed flow was considered in the outlet and the non-slip condition applied on the tube wall as a boundary condition; the volume fraction of the input water was assumed to be 0.7.

To solve the equations in multiphase flow, a new group of mass conservation equations was introduced, and the initial equations (single-phase flow) changed to include the introduction of the volume fraction α_1, α..., α_N or multi-phases, and the momentum transport mechanism between the phases. All these equations were extracted from the Fluent software guide [13].

6. Research and data review method:

6,1 The effect of changing the size of the coil radius on the separation rate:

Several simulations with different coil radii (100, 200, 400, 500, and 600 mm) were used to find the optimal coil radius for maximum water-oil separation. In these simulations, the diameter of the oil droplets was set to 2 mm, the velocity of the fluid to 0.5 m/ s, and the volume fraction of the oil at the inlet to 0.3. The simulation results of the fifth coil loop are shown in figure 4.As the coil radius increases, the centrifugal acceleration decreases, and the separation of oil and water improves.

Theoretically, the acceleration of the centre of gravity is proportional to the inverse of the radius, and thus a lower radius results in greater acceleration and a better phase separation. However, this acceleration causes an emulsion to form, and thus causes the collapse of water and oil separation. Thus, maintaining the coil radius in a limited range improves the degree of separation, as at radii greater than 1,200 mm, the separation of the phases deviates once more from the desired state. Determining the optimal radius of a coil is thus a balancing issue.

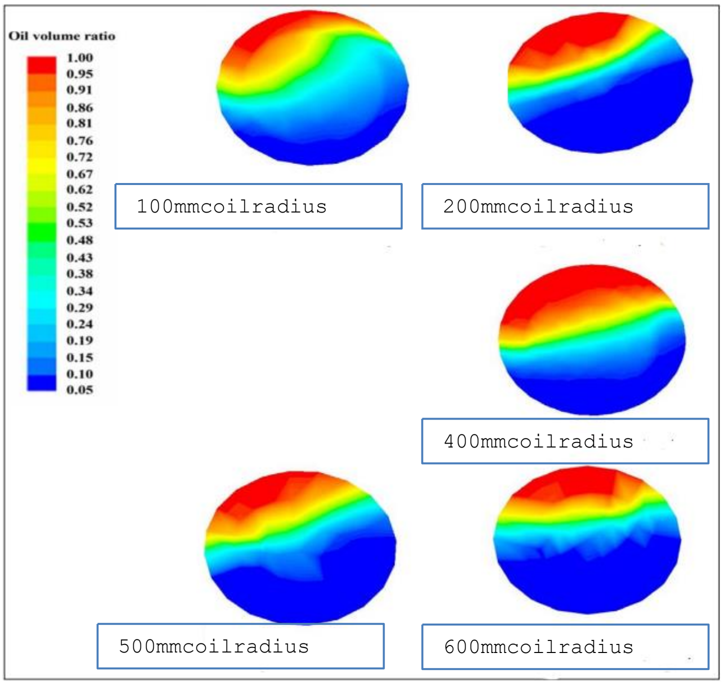

Figure 4*: Horizontal section view of the fifth coil loop showing volumetric fraction of the oil-water mixture as considered by taking different coil radii in the inlet. The red indicates that the volumetric fraction is 1, while the blue indicates that it is zero. The optimal selection criterion occurs when the maximum separation of the two phases is achieved.*

6.2Effect of tube diameter change on the separation rate

Several simulations with different diameters (20, 30, 40, 50 and 60 mm) with droplets of 2 mm diameter, fluid velocity of 0.5 m/s, and a volume fraction of oil of 0.3 in the inlet were considered. Infigure5, the simulation results after the fifth coil are shown as a summary. By increasing the tube diameter from 20 to 50 mm, the separation improves, but from that point on, due to the increase in Reynolds number and the formation of turbulent flow, mixing occurred. Thus, better results were achieved by choosing the 50 mm diameter tubes.

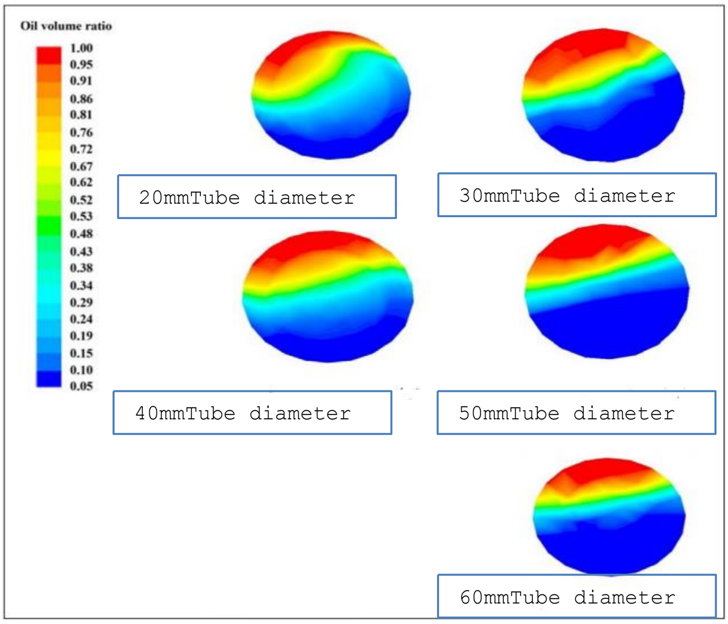

***Figure 5**: Horizontal section view of the fifth coil loop showing the volumetric fraction of oil in the oil-water mixture is considered by taking different tube radii, with coil diameter of 400 mm. The red indicates that the volumetric fraction is 1, while the blue indicates that it is zero. The optimal selection criterion occurs when maximum separation of the two phases is achieved.*

6,3 Investigating the effect of pressure difference

To examine the role of pressure difference in phase separation, the pressure differences in the coil tube separator within different cases were compared. The scenario studied relied on multiple assumptions: the diameter of the tube was 40 mm, the oil droplets were2 mm, the fluid flow speed was 0.5 m/s, and the volume fraction of the oil at the inlet was 0.3. Taking in consideration that in all these simulations there are 7 loop periods and considering different coil radii taken throughout the pathway needed to be covered, no much useful information was detected from pressure difference measured. In order to make a better comparison, the pressure difference was expressed over the unit length by dividing the total pressure drop by R14π to determine the unit pressure drop per millimetre.

Infigure6, the unit pressure drop variations for different coil radii (100, 200, 400, 500, and 600 mm)are observed, as given in table 1. For the 400 mm radius, the unit pressure drop was increased due to a slight computational error; overall, the unit pressure drop is approximately the same for all diameters greater than 200 mm. Examining figure4, as the spiral radius decreases to 100 mm, the pressure drop increases, showing that increase in the coil radius does not negatively affect the efficiency of the separation of water and oil. Considering a constant 400 mm coil radius, another comparison was made to show the pressure difference between different tube diameters. The diameter of oil droplets was2 mm, the fluid flow rate 0.5 m/ s, and the volume fraction of the oil at the inlet was 0.3 again.

The unit pressure drop variations can be seen for different tube diameters (20, 30, 40, 50, and 60 mm) in figure7 and are laid out in table 2; these indicate that an increase in the pressure drop can be seen when there is a decrease in the size of the tube diameter. Therefore, the tube diameter should be increased as much as possible in order to obtain the most appropriate pressure drop, to the extent that this has no negative effect on water-oil separation efficiency.

IOP Conf. Series: Materials Science and Engineering **671** (2020) 012069 doi:10.1088/1757-899X/671/1/012069

Table 1:*Comparison of pressure drop for different coil radii*

Coil radius(mm)	Unit pressure drop (Pascals)	Total pressure drop (Pascals)
20	0.463	8147.3
30	0.242	4263.4
40	0.213	3740.6
50	0.105	1857.4
60	0.079	1385.2

Table 2: *Comparison of pressure drop for different diameters*

Tube diameter (mm)	Unit pressure drop (Pascals)	Total pressure drop (Pascals)
100	0.493	2168.6
200	0.142	1252.2
400	0.213	3740.3
500	0.145	3196.9
600	0.141	3737.4

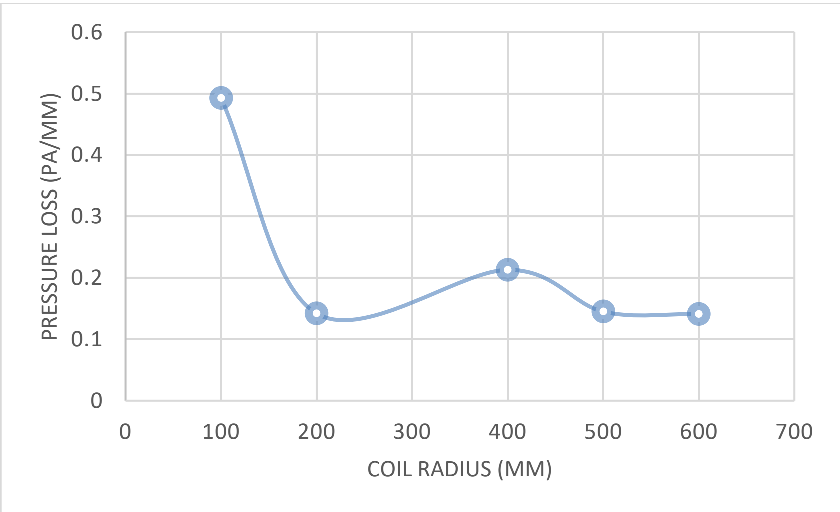

Figure 6:*Comparison of unit pressure drop in different coil radii*

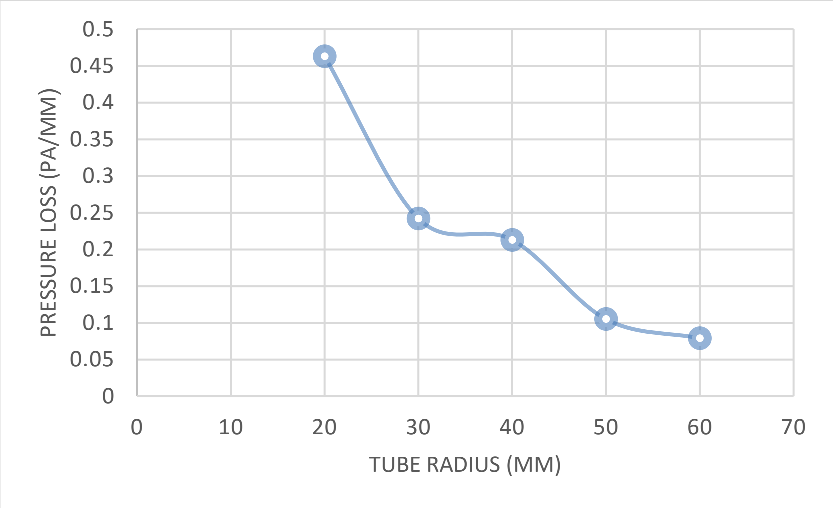

Figure 7:*Comparison of unit pressure drop for different diameters*

7. Optimal variables

Based on the simulations, the effects of geometric variables such as coil radius, number of coil loops, tube diameter, and other physical variables such as inlet fluid velocity and the size oil droplets of oil were investigated and thus allowing the selection of proper values in order to create an optimal state.

The results of this paper appear to be in line with reality, the target of any kind of simulation; however, to prove the results, the device must be designed and tested.

Table 3:*Optimal geometric and physical variables*

Optimum amount(mm)	Variables
500	Coil radius
50	Tube diameter

8. Conclusion

In this study, the separation interval and the power required for pumping a coil tube type separator as proportional to variations in the diameter and the radius of the coil were deduced; the following results were obtained:

- As the coil radius increases in an acceptable range, oil-water separation effect improves. At radii of more than 1,200 mm, the separation efficiency decreases, therefore an optimal radius of 1,000 mm is suggested for the coil.
- As the tube diameter rises from 20 to 50 mm, the efficiency of the separation is improved. However, for larger diameters, efficiency is reduced; better results are obtained by choosing a diameter of 50 mm.

Suggestions for future research

One of the most important things to be checked in terms of rate of separation is the coil step, which should thus be the criterion for reviewing this subject in future scenarios and separation methods. In addition, the effect of the internal roughness of the tube on the flow pattern may play an important role in the separation efficiency of the phases, and this has not been investigated here. The verification of the volume fraction method in the separation examination and phase analysis using the Lagrangian method may also be considered as another aspect of further research.

Reference

[1] M. C. S. Souza, A. L. S.figueiredo, M. W. Kuchpil, C. Bezerra and C. A. A. G (2005) Furtado "Water management in Petrobras: Developments and challenges," offshore technol. Conf. help Houston. otc17258.

[2] D. R. Simmons, M. J. H.Komonibo, E.; Azzopardi, B. J.; Dick, (2004) "RESIDENCE TIME distributions and well-head fluids," Chem. Eng. Res. Des., vol. 82, no. 10, pp. 1383-1390.

[3] J. Q. Zhao, J. Abrahamson, (1999) " the flow in conical cyclones", second international conference on CFD in the mineral and process industries CSIRO, Melbourne, Australia 6-8 December.

[4] W. Barth, (1998) "Design and layout of the cyclone separator on the basis of new investigations" Aerosol technolog(2nd ed.). New York,Wiley.

[5] G. Triony, J. Woillez, and C. Bezard. November (1992) "The rotating de-oiling cyclone: Recent Development and Operating Experience. Spe25034.," Eur. Pet. Conf. Held Cannes. 1618.

[6] D. A. Colman and M. T. Thew, (1983) "Correlation of separator result from lightdispersionhydrocyclone," Chem. Eng. Res. Des., vol. 61, pp. 233–240.

[7] A. Gupta and R. Kumar. (2007), Three-dimensional turbulent swirling flow in a cylinder: Experiment and computations., Int. J. Heat fluid flow, vol. 28, no. 2, pp. 249-261.

[8] K.W.Chu, B. Wang, D.L. Xu, (2011) "CFD-DEM simulation of the gas-solid flow in a cyclone separator", Chemical Engineering Science, 66, 834-847N

[9] A.J.Hoekstra, J.J.Derksen, H.E.A.Van Den Akker, (1999) "An experimental and numerical study of turbulent swirling flow in gas cyclones", Chemical Engineering Science, 54 ,2555–2556.

[10] M. Azadi, A. Mohebbi, (2010), "A CFD study of the effect of cyclone size on its performance parameters", Journal of Hazardous Materials,182, 835–841.

[11] B.Zhao, (2006)."Effect of flow parameters and inlet geometry on cyclone efficiency", The Chinese Journal of Process Engineering,6, 458-465

[12] Z. J. j. Guo, D. T.Gong, L.-Y.Wang, C. Tang, and Z C Zheng, July (2006), "AN INVESTIGATION ON OIL/WATER SEPARATION MECHANISM INSIDE HELICAL PIPES" Conf, Global Chinese Scholars on Hydrodynamics, 100080

[13] "Fluent manual, Chapter 20. (2013) "General Multiphase Models".