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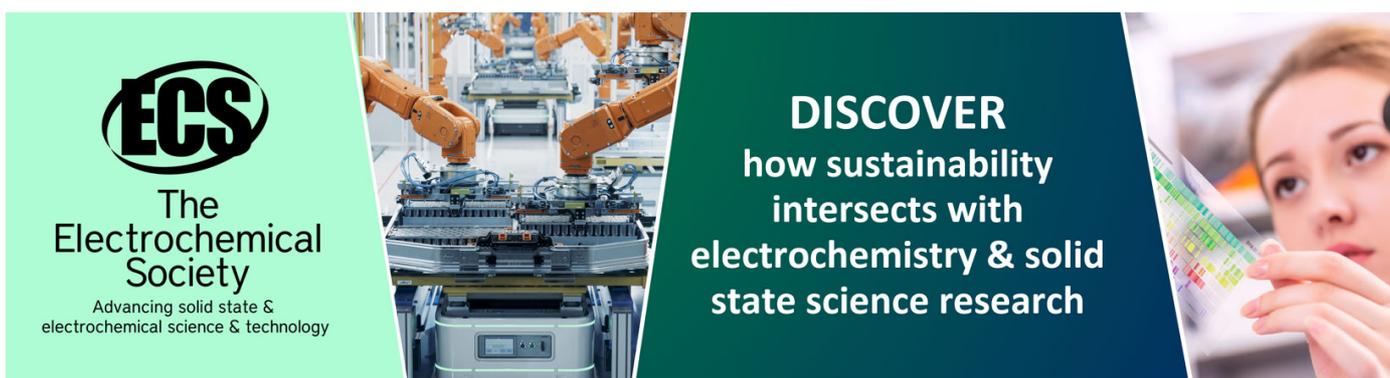
Numerical analysis of cocurrent conical and cylindrical axial cyclone separators

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Numerical analysis of cocurrent conical and cylindrical axial cyclone separators

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Abstract. Axial concurrent liquid-liquid separator is seen as an alternative unit to the traditional tangential counter current cyclone due to lower droplet break ups, turbulence and pressure drop. This paper presents the numerical analysis of a new conical axial cocurrent design along with a comparison to the cylindrical axial cocurrent type. The simulation was carried out using CFD technique in ANSYS-FLUENT software. The simulation results were validated by comparison with experimental data from literature, and mesh independency and quality were performed. The analysis indicates that the conical version achieves better separation performance compared to the cylindrical type. Simulation results indicate tangential velocity with 8% higher and axial velocity with 80% lower recirculation compared to the cylindrical type. Also, the flow visualization counters shows smaller recirculation region relative to the cylindrical unit. The proposed conical design seems more efficient and suits the crude/water separation in O&G industry.

1. Introduction

Liquid-liquid cyclone separator works by inducing centrifugal forces (caused by the swirling fluid) to push denser liquid to the wall while lighter one migrates to the centre. The swirling motion is obtained by injecting the mixture tangentially into the cyclone body through small holes or deflecting the fluid using a swirl generator. The latter does not induce adequate swirling motion and the former is prone to droplet break ups due to high shear stress at the inlet but attains high swirl strength [1, 2]. Regardless of the inlet versions the unit is available as counter current or cocurrent, where the former and latter body shapes are cylindrical-conical and cylinder respectively. Axial cylindrical cocurrent cyclone is postulated to have a stable core, lower pressure drop and can operate at high capacity compared to the counter current version [3]. Though these sound promising, cylindrical cyclone suffers from recirculation region that promotes oil core-water mixing and break ups [4, 5]. It also suffers from swirl decay going downstream [3, 4, 6]. The use of conical body may reduce the recirculation region though this is proven in counter current version and is worth investigating for axial cocurrent [5]. Very little work however has been done on cocurrent cyclone such as by Schummer et al. [1], Dirkzwager [3], Slot [4], Rocha et al. [6] and Murphy et al. [7] in which cylindrical body is employed.

The literature review reveals that the application of axial inlet cocurrent conical cyclone separator using swirl generator is not yet available. The swirl generator could reduce droplet break ups by lowering shear stress and turbulence and produces symmetrical flow [3, 4]. The one suggested and



tested by Slot has a cylindrical separation chamber which suffers from recirculation and lower downstream tangential velocity. This problem motivates us to propose modified technique that is the chamber has conical shape.

The objective of the present paper is to present a simulation procedure of the novel idea of axial cocurrent separator with conical chamber, and to discuss the simulation results. The conical shape separation section is employed to increase the tangential velocity to achieve high separation efficiency and smaller recirculation region. The paper presents and compares a preliminary numerical result of single phase flow of cylindrical and conical axial cocurrent cyclone separators using brine, and compare between the flow field parameters in the cyclone body. Several aspects studied are tangential and axial velocities, pressure distribution and recirculation region. This simulation is meant to visualize the flow field and improve the design of prototype for experimental investigations.

2. Numerical simulation

2.1. Description model

The cylindrical geometry employed is based on the unit used by Slot, figure 1 whom experimented and simulated water only liquid-liquid axial cyclone separator [4]. In the case of the conical geometry, the original cylindrical body tube is constricted 0.3° inwards axially to form a conical frustum but has the same separation length as the original. A small angle alteration is used to investigate the effect of having a conical body without altering too much of the original geometry. The swirl generator is excluded from the simulation and a swirling fluid is imposed at the entry at 62° deflection. The exclusion is found to have little effects on the overall flow properties of the cyclone [4].

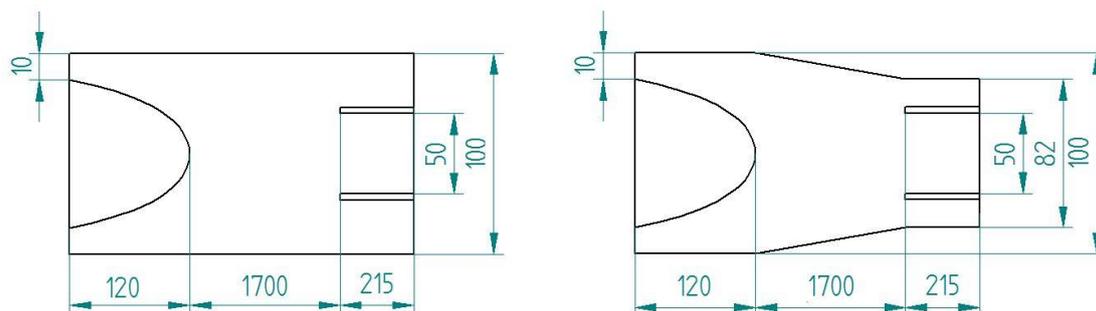


Figure 1. The left and right pictures are the cylindrical and conical cyclone respectively. (Drawn not to scale).

2.2. Mesh generation

Hexahedral mesh in ICEM is used as it is less diffusive than tetrahedral and reduces the cell count without compromising the accuracy. A mesh independent study is carried out for 800,000, 900,000 and 1.4 million elements. It is found that 900,000 produced acceptable results in relation to Slot experimental and simulation with reasonable computation cost as shown in figure 2.

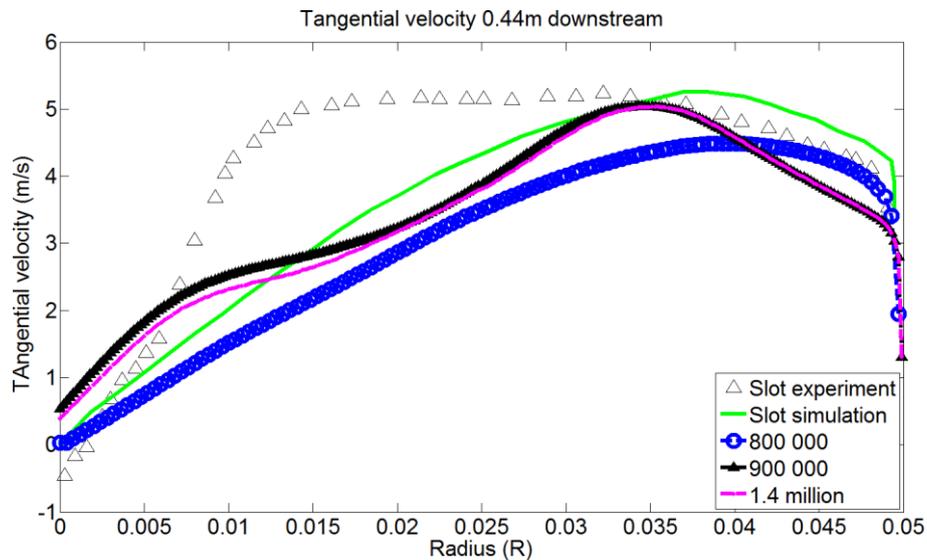


Figure 2. Mesh independence study denotes 900,000 is reasonably acceptable.

2.3. Boundary conditions

FLUENT with Reynolds stress model (RSM) is used as it is known to simulate swirling flow with acceptable accuracy in cyclonic flow. Linear pressure strain option is utilized and wall reflection terms option is disabled since it is found to acceptably predict the fluid motion [7]. SIMPLE is used for pressure-velocity coupling, PRESTO! for pressure and QUICK for the rest of the spatial discretizations [5]. The brine density and viscosity are 1067.80 kg/m^3 and $1.18 \times 10^{-3} \text{ kg/ms}$, respectively. Velocity inlet is used with tangential and axial velocity components at 5.71 m/s and 10.74 m/s , respectively. The central and annulus outlets are set as pressure outlets, with the central outlet flow split of 30%. The turbulent intensities at the inlet and outlets are set to 5% and 10% respectively. The hydraulic diameters at the inlet, central and annulus outlets are set to distances that define those boundaries. Standard wall function with no slip wall are implemented which could predict the near wall swirling flow properties satisfactorily [7, 8]. The simulation is carried out in transient of 0.5 ms and data sampling is enabled after the simulation has reached statistically steady for time averaged data for 1 s .

2.4. Validation

The time averaged results are validated against Slot experimental and simulated data for the cylindrical version as in figure 3. A small gas core is observed (might lead to flow asymmetries) in Slot's experiment could cause the differences between the simulation and experimental data [4]. The average difference between simulated and experimental data is about 30%. This also might be caused by the fact that RANS models all turbulent length scales. The use of LES could lead to fewer discrepancies. Overall, the simulated axial and tangential velocity profiles have acceptable values in relation to experimental data and close to Slot simulation. The simulated and Slot simulation is close to one another which could be caused by the differences in meshing technique.

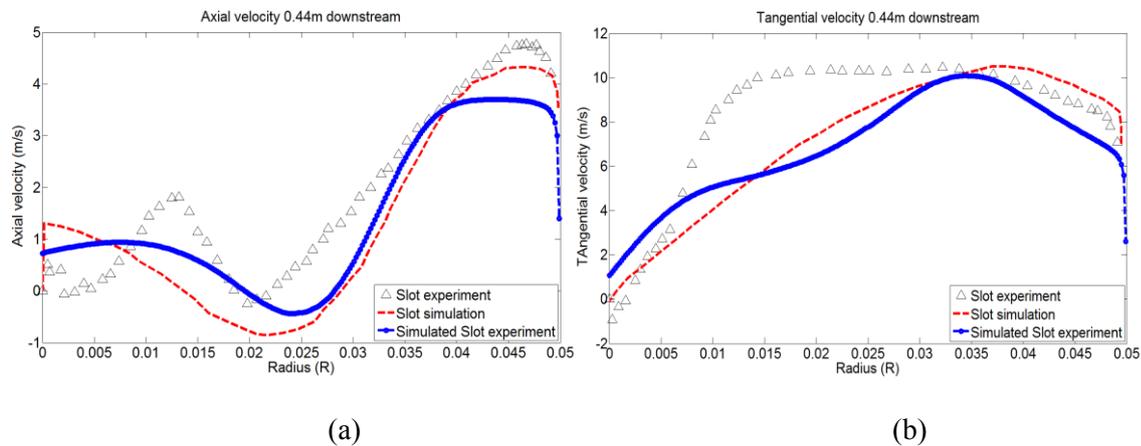


Figure 3. Comparison of experimental and simulated data for the axial cyclone separator of (a) axial velocity and (b) tangential velocity. The sampling location is located 0.44m downstream from the swirl generator tail across the tube radius.

3. Results and discussion

3.1. Tangential velocity

Tangential velocities, V_{tan} at different axial locations are sampled at 0.6 and 1.4m from the swirl generator tail to fully capture the fluid behaviour downstream. The plots depict the formation of the Rankine Vortex in both cyclones which is favourable for efficient separation as in figure 4. The same profile exists regardless of counter current or cocurrent cyclone used [2, 3]. The conical also has 8% higher V_{tan} on average at all radial and axial locations relative to the cylindrical. The maximum V_{tan} at any axial location in a conical cyclone is higher and almost constant in magnitude compared to the cylindrical type. This similar-magnitude-behaviour is typically seen in cylindrical-conical counter current cyclone in the conical part [9] which prompts its beneficial usage in a conical cocurrent cyclone.

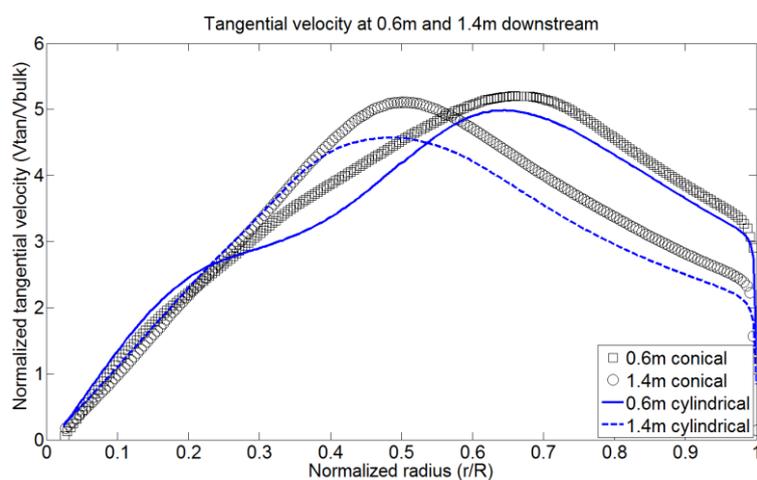


Figure 4. Tangential velocity plots for both cyclones at various downstream locations. The values are normalized against 2 m/s bulk velocity.

The maximas for both cyclones also appear to shift to the centre pipe due to swirl decay [7]. From the maximum V_{tan} to the wall, the conical has higher velocity which could be caused by the fact that the conical annulus outlet is smaller than the cylindrical's; also seen in a counter current cyclone as the underflow diameter is reduced [10]. Such event is favoured as higher centrifugal force can be imposed on the particle for better separation even at the downstream before exiting. In figure 5, both cyclones portray velocity decay downstream due to swirl decay caused by wall friction [7], but conical cyclone still attain higher V_{tan} (from the max V_{tan} to the wall) than cylindrical. It is evident that having a conical body can increase the V_{tan} along the axis for higher performance. The plot shows that conical cyclone can attain higher tangential velocity radially downstream than cylindrical version. The values are normalized against 2 m/s bulk velocity.

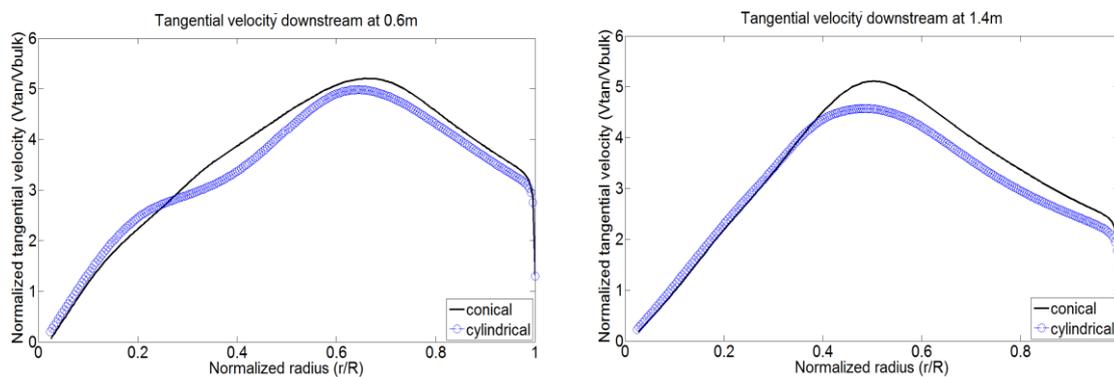


Figure 5. Normalized tangential velocity predicted by the simulation for the conical and the cylindrical types of the hydrocyclone, at 0.6 and 1.4m downstream of the swirl generator.

3.2. Axial velocity

Positive velocity in Figure 6 denotes favorable fluid flow towards the exits whereas negative dictates recirculation towards the inlet. The figure depicts the half W shaped profile (sampled across the radius) and clearly portrays the annulus recirculation denoted by the line plots below the blue line. This region has also been noticed by Kegge [8], Mattner et al. [11] and Ko [12]. Conical cyclone possesses better axial velocity, V_{axial} profile than its cousin notably by having smaller recirculation flow magnitude at all axial lengths (80% average improvement). The reverse flow region is critical and must be minimized as it prevents droplets from migrating to the inner vortex for separation [5]. The lowered recirculation region also leads to higher V_{tan} and V_{axial} which is evident from plots in figure 5 and figure 6. The iso-surface of -0.1m/s is generated for better visualisation of such region. Various iso-surface values are tested and the recirculation region is indeed thinner and shorter in conical cyclone than in cylindrical's which is continuous (figure 7).

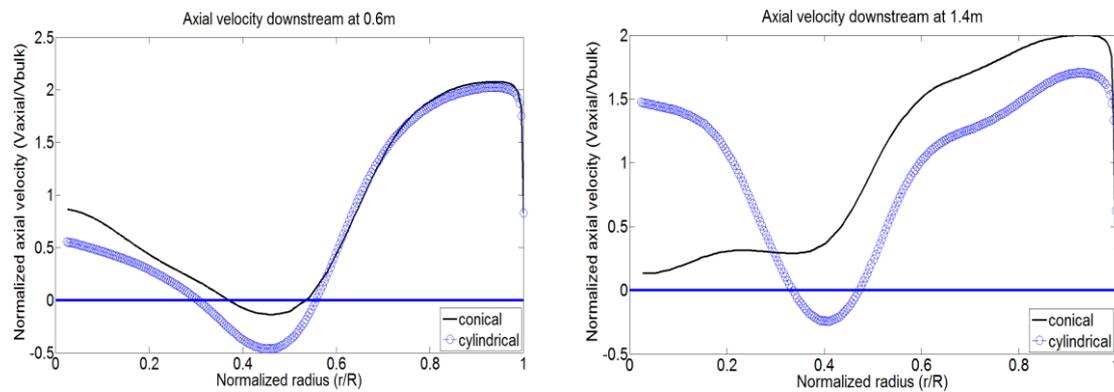


Figure 6. Axial velocity plots at various downstream locations between conical and cylindrical cyclones. The values are normalized against 2 m/s bulk velocity.

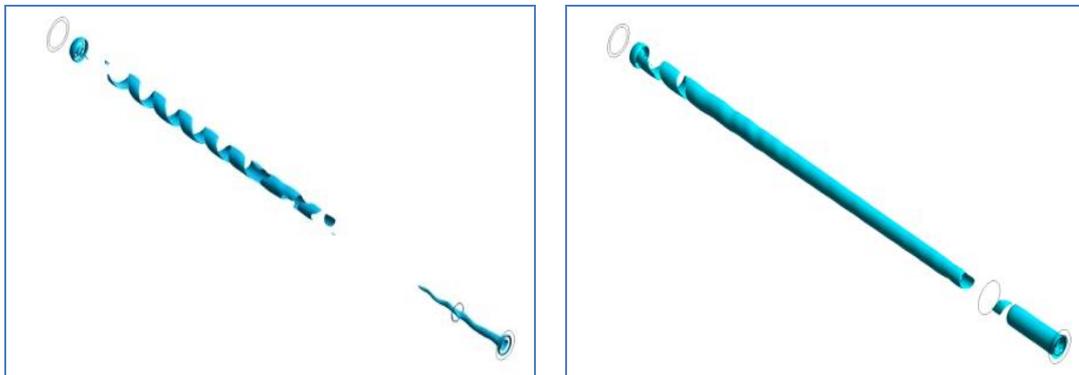


Figure 7. Iso-surface of $V_{axial} -0.1$ m/s. The left and right are the conical and cylindrical units, respectively.

4. Conclusions

Numerical analyses of a single phase conical and cylindrical cocurrent cyclones have been carried out based on an experiment conducted by Slot. Based on the preliminary findings, it can be concluded that the conical cocurrent cyclone can achieve greater separation efficiency in comparison to the cylindrical type. This is achieved by having greater tangential velocity (8% maximum V_{tan} on average), lower reverse axial velocity (80% lower on average) and smaller recirculation region through the use of conical body. The next step is to carry out parametric study in search of the optimal design.

Acknowledgements

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