24th COBEM - 2017

24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017- 2270
CHARACTERIZATION OF PRESSURE DROP AND VELOCITY FIELD IN A GAS-LIQUID CYCLONE SEPARATOR

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Abstract. *An experimental study of a gas-liquid cyclonic separator is presented. The equipment has a tangential inlet, a cylindrical body and two inner fixed components: a section of guiding vanes near the inlet and a static element near the liquid outlet, intended to break the rotation of the downward liquid flow and minimize contact between the two phases inside the main body. Particle Image Velocimetry (PIV) is used to characterize the velocity field along the cylindrical body. Pressure drop is measured between the inlet flow and the gas outlet with the aid of a differential pressure transducer. The objective of the present investigation is to assess the influence of the internal components on pressure drop, on velocity field and on the general performance of the separator.*

Keywords: *cyclonic separator, pressure drop, Particle Image Velocimetry*

1. INTRODUCTION

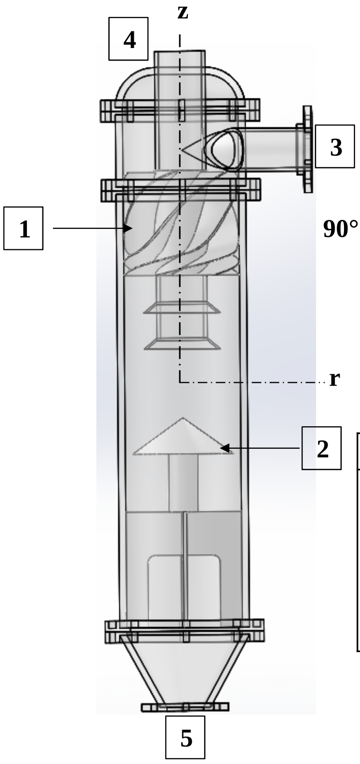
Phase separation process in petroleum industry is a compulsory activity. Given the oil flow rates and the high water content observed in production fields, new technologies have been developed to increase flow separation efficiency, reducing processing time and footprint. Indeed, the classical method of phase separation by gravitational force requires large facilities and long residence time; resulting in increased production cost, even more in offshore facilities. A widely used alternative solution to separation vessels is a compact separators technology (Hannisdal *et al.*, 2012), based mainly on pipe and cyclone separators. The gas-liquid cyclone cylinder (GLCC), for example, is a compact separator designed to remove liquids from natural gas taking advantage of centrifugal forces and density difference among the phases. The cyclonic separator investigated in the present work has a tangential inlet, a cylindrical body and two inner fixed components: a section of guiding vanes near the inlet and a static element near the liquid outlet, intended to break the rotation of the downward liquid flow and minimize contact between the two phases inside the main body. This element is called chinese hat due to its geometry. The equipment operates as a scrubber, where liquid is the dispersed phase on gas-liquid mixture, and its operational conditions are limited by the Gas Liquid Ratio (GLR), not overpassing a value of $GLR < 0.03$.

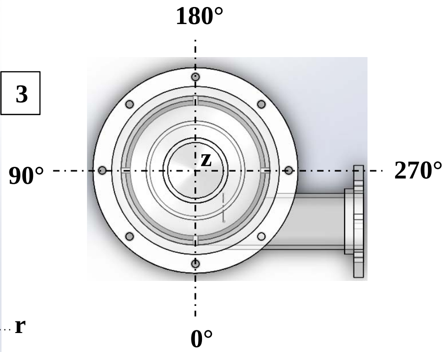
Inside the cyclone, the swirling flow creates two vortex structures. The first one is a downward external vortex structure, where mainly occurred the separation process due the centrifugal force and the difference in density on the continuous and dispersed phases. The another structure is an internal upward vortex, where the cleaned gas reach at the top of the separator a concentric exit pipe named vortex finder. The resulting velocity field is usually divided into three components for studying purposes. Tangential component is the most important on separation process, and its magnitude is bigger than the other components (Peng *et al.*, 2002). The axial component is responsible for the residence flow time on cyclone, and radial direction is the smallest component.

The separator geometry to be analysed in present work, most of the related studies have been focused on global assessments performance without studying flow behaviour inside the separator (Oranje, 1990). Particle Image Velocimetry (PIV) is used to characterize the velocity field along the cylindrical body. This approach is important since the PIV will allow to understand the influence of internals on flow. Pressure drop is measured between the flow inlet and the gas outlet (*vortex finder*) with the aid of a differential pressure transducer. The objective of the present investigation is to assess the influence of the internal components on pressure drop, on velocity field and on the general performance of the separator.

2. EXPERIMENTAL SET-UP

At the Laboratory of Compact Separators of the Interdisciplinary Centre for Fluid Dynamics (NIDF/UFRJ) a prototype of the compact separator was built in Plexiglas material by Nogueira (2013) . Figure 1 shows a sketch of the prototype, highlighting the two static internals to be investigated. The facilities allow to carry out measurements in single and two-phase flows.





Dimension	Symbol	[mm]
Cyclone radius	R	80
Inlet diameter	d_{in}	50
Vortex finder diameter	d_{vf}	50
Cyclone height	H	920
Chinese hat height	h	300

Figure 1: Sketch of separator: **1**. swirl blades, **2**. chinese hat, **3**. inlet flow, **4**. gas outlet – vortex finder, **5**. liquid outlet.

Typically, the separator receives a gas-liquid flow in the tangential inlet, which promotes a rotational movement. Flow path is downward along the region near to the wall of the separator body. The denser fluid forms a liquid film on the wall and flows to the lower liquid outlet, where the cross located below the chinese hat prevents the rotational movement and avoids air entrainment. The lighter fluid rotates in the center part of the separator and finally reaches the upper outlet flowing through the vortex finder.

In the present work, in order to perform a thorough characterization of the velocity field inside the cylindrical body, only single phase flow results will be shown. The air supply is given by an air compressor, dryer and storage tank system, adjusted at maximum pressure of $10\ bar$. A digital vortex flow meter and manometer were installed at the air line. To control the flow rate, a needle valve is located upstream of the separator inlet, at about fifty diameters. For an accurate gas flow rate measure at the inlet of the separator, it was necessary to apply a correction formula, since the pressure and temperature conditions of the flow meter and the inlet conditions are different.

High pressure and low pressure taps points selected to measure pressure drop were located at the inlet flow, and outlet of vortex finder, respectively as show in Fig1. A differential pressure transducer of $0 - 100\ mbar$ in range was used, together with a digital acquisition system. Table 2 shows the four different configurations and the flow rates in which the experiments were made.

A two dimensional velocity fields were obtained at the $0° - 180°$ plane, and the corresponding area, among the vortex finder bottom and the tip of chinese hat, according with Fig.1. A $2D$ Dantec Particle Imaging Velocimetry system was used. The system includes a laser power supply with an arrange of lens in order to create a light-sheet, an image capture component (cameras and frame grabbers), a synchronizer (timer box), and an acquisition and processing software. Tab.1 summarized the main characteristics of the system.

In order to inject particle tracers in flow, a pneumatic atomizing system was used. A $2\text{wt}\%$ sugar solution and air are pressurized and mixing at the annular region of an atomizer as shown in Fig.2. The result is a mist pattern with an average particle size of $10\mu m$. Seeding is critical for measurements in PIV, even more with swirling flows, since the rotation may cause segregation on particles, as occurs in cyclones. Particles are required to follow the centrifugal airflow strictly. A widely used criteria to know if particles will follow the flow in all domain is the Stokes number (St), defined as shown in

Table 1: 2D-PIV system specifications

Device	Characteristics
Laser Nd:YAG	BigSky Laser Power 150 mJ Light-sheet thickness, 1 mm Wave length 532 nm Maximum trigger rate 15Hz
CCD Camera	Resolution 1600x1200 Px Acquired mode, single and double frame
Lens	AF Micro-Nikkor 600 f/2,8D
Acquired and processing software	DynamicStudio 2015a

Eq. 1

$$St = \frac{t_p}{t_f} = \frac{(2\rho_p + \rho_f)\left(\frac{d_p^2}{36\mu_f}\right)}{\frac{D}{2v_\theta}} \tag{1}$$

where t_p and t_f are the characteristic times from particles and continuity phase respectively. Acceleration effects on particles with respect the flow may be neglected if $St < 0.1$, so the particle will have the ability to follow the flow strictly (Brandon and Aggarwal, 2001). During the PIV measurements, Stokes number was 0.0245, indicating the particle tracers may follow the flow without additional inertial effects.

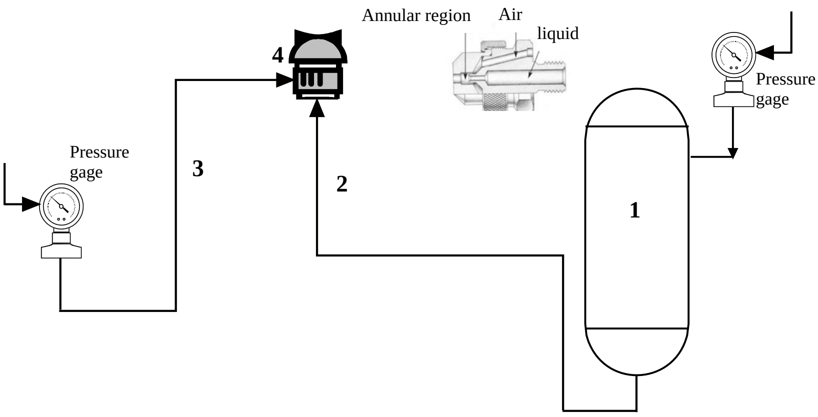


Figure 2: particle tracer system: **1**. pressure liquid vessel, **2**. liquid feed line, **3**. air feed line, **4**. atomizer.

Inside the cyclone, particles are illuminated by a laser light-sheet. Wavelength emitted by particles is captured by the Charge Coupled Device (CCD) camera on double frame mode. This operation mode allows image processing with cross correlation method. Adjustment of time between pulses for acquisition process is a critical parameter, even more for swirling flows in axial plane measurements, since the prominent tangential velocity component is out-of-plane. For the present measurements this parameter was varied in the range of 10 to $20\mu s$. The maximum peak height observed on cross correlation was obtained for $14\mu s$.

Table 2: Experimental flow conditions

Configurations	**Inlet gas flow rates** $[\mathbf{m^3/h}]$	
(A) - Empty	34.7	91.83
(B) - Chinese hat		
(C) - Swirl blades and chinese hat		
(D) - Swirl blades		

3. RESULTS AND DISCUSSION

According to the arrangements showed in Tab.2, a brief description of the influence caused by the internals in the separator is discussed next.

3.1 Pressure drop

For configuration **(B)** and **(C)**, the chinese hat divide the cylindrical body in two regions, to prevent recirculation of liquid from the bottom to the separation area. The swirl blades increase the rotational speed and helps to stabilize the flow.

Figure 3 show the pressure drop measurements for the flow conditions at Tab.2. As expected, pressure drop increases with the gas flow rate. Results show that the pressure drop behaves similarly for all internal arrangements, independently of the flow rates.

Chinese hat on case **(B)**, presented the highest pressure drop value, while the swirl blades on case **(D)**, the lowest one. The effect of swirl blades on the flow is to organized and promote the inlet flow in the axial direction, attenuating the turbulence effects produced due to the sudden change of direction on flow.

It seems that the best configuration for the separator would be the swirl blades internal only, due to the lowest pressure drop. However, as previously discussed, the chinese hat plays an important role in avoiding liquid re-entrainment to the separation area. Therefore, the combination of chinese hat and swirl blades internals is the best configuration, once the pressure drop decreases without compromising separation efficiency.

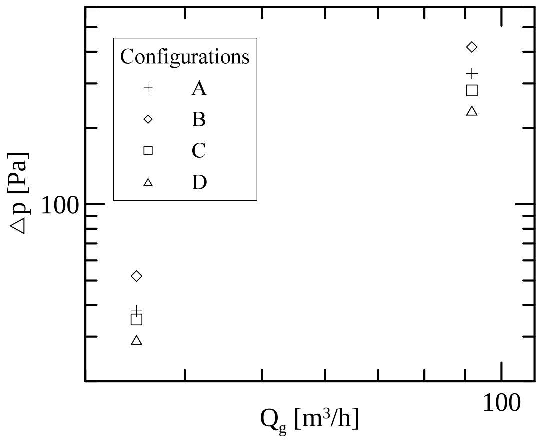


Figure 3: Pressure drop behaviour for different internal arrangements.

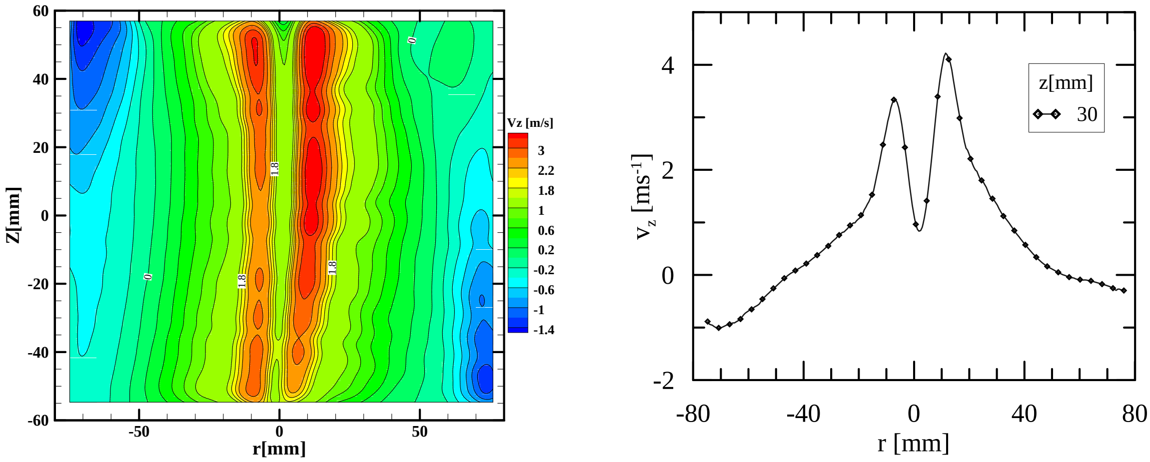
3.2 Velocity field

In order to better understand the increase in pressure drop when the chinese hat internal installed, the velocity field for configurations **(A)** and **(B)** from Tab.2 are analysed via PIV.

The lowest gas flow rate condition on Tab.2 was selected to carry out the measurements. The origin of the reference coordinate system is located 60 mm below the vortex finder border as shown in Fig.1. Axial mean velocity field and axial mean velocity profile at position $z = 30\ mm$ are shown in Figs.4a and 4b respectively. The axial mean velocity in a cyclone separator is negative close to the wall and positive in the center. The negative sign denotes the flow that escapes through the underflow; positive velocity is related to the flow that leaves through the overflow. Around the vertical symmetry axis, two peaks of maximum velocity are observed, creating in between them a decelerating core. The velocity field shows an apparent axial symmetry, but the geometry of the inlet section creates a high turbulence region and end up distorting the velocity field. Maximum values of axial velocity corresponding to $r/R = \pm 0.125$, while the zero axial velocity is around $r/R = -0.56$ on the left side, and $r/R = 0.66$ on the right, as show Fig.4b. These values are in accordance to the ranges of data reported in the literature by Leith and Jones (1984).

The morphology of the velocity field change significantly for configuration **(B)**, when comparing with configuration **(A)** from Tab.2. Even though the structure of the downward flow close to the walls remains, the values of zero axial velocity changes and the flow core is not any more a decelerating region, and turned to be a reverse flow region as show Figs.5. This characteristic may explain the highest pressure drop when the chinese hat is installed on the separator. Flow reversal is associated to a vortex confinement effect, when the local pressure at the core is less than the vortex finder downstream pressure, besides instabilities due to turbulence. When chinese hat is installed, the separation area decreases, increasing the confinement vortex phenomena even more. This condition and additional wall friction effects, may contribute to the increased pressure drop, and so the changes on velocity field as well.

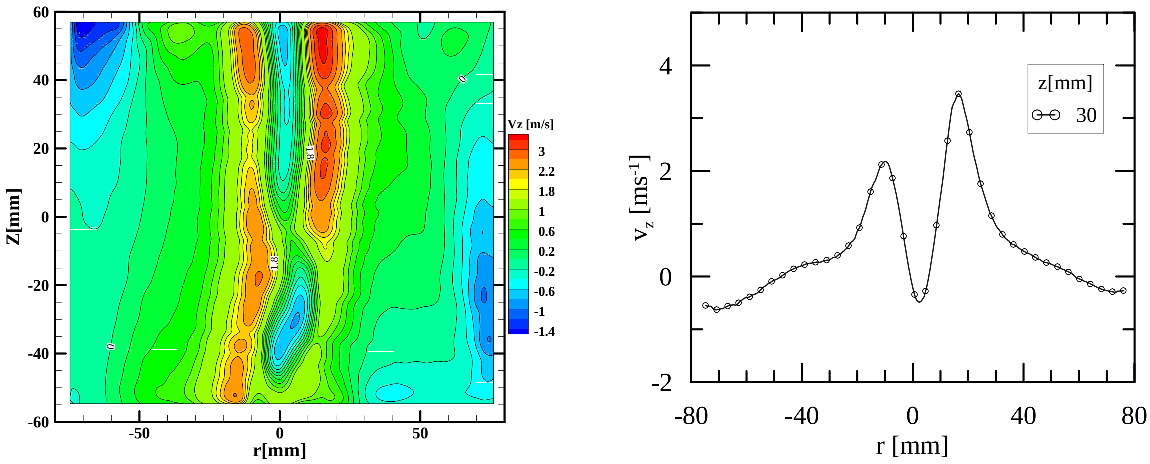
As a consequence of flow reversal and instabilities due to turbulence effects, the flow core presents another phenomena



(a) Axial mean velocity field (b) Axial mean velocity profile

Figure 4: PIV measurements for configuration (A)

called Precessing Vortex Core (PVC), where the flow core is not aligned any more with the geometrical axis, giving origin to a coherent precessing movement, and helical shape on core along all the axis as shown in Fig.5a (Syred, 2006).



(a) Axial mean velocity field (b) Axial mean velocity profile

Figure 5: PIV measurements for configuration (B)

Table 3 summarizes the values of highest axial velocities for both configurations.

Table 3: Peaks of maximum axial velocities

Configuration	r/R		$V_{zmax}[m/s]$	
	left	right	left	right
A	0.125	0.125	3.4	4.2
B	0.125	0.225	2.2	3.5

4. CONCLUSIONS

This work provides an experimental characterization of the single phase flow velocity field and pressure drop measurements for a gas-liquid cyclone separator. The present work is focused on studying the influence of the internal components on pressure drop, on velocity field and on the general performance of the separator. Results have shown that the highest pressure drop values are observed for the configuration that has only the chinese hat. PIV measurements shown how the chinese hat internal modify the velocity field in relation to the separator without it. Additional effects as the precessing vortex core and the flow reversal were characterized via PIV, allowing to understand the flow behaviour and the effects exerted on the pressure drop. An unexpected result is that the addition of the guiding vanes promotes a decrease in pressure drop.

5. ACKNOWLEDGEMENTS

GEOC is grateful to the CNPq for the award of a DSc scholarship. In the course of the research, JBRL benefited from a CNPq Research Fellowship (Grant No 308445/2013-9) and from further financial support through Grants CNPq 458249/2014-9, FAPERJ E-26/102.212/2013 and FAPERJ E-26/010.002857/2014. APSF is grateful to the Brazilian National Research Council (CNPq) for the award of a Research Fellowship (Grant No 305338/2014-5). The work was financially supported by CNPq through Grants No 477293/2011-5 and by the Rio de Janeiro Research Foundation (FAPERJ) through Grant E-26/102.937/2011.

6. REFERENCES

Brandon, D.J. and Aggarwal, S.K., 2001. "A numerical investigation of particle deposition on a square cylinder placed in a channel flow". *Aerosol Science and Technology*, Vol. 34, No. 4, pp. 340–352. doi:10.1080/02786820121279. URL `http://www.tandfonline.com/doi/abs/10.1080/02786820121279`.

Hannisdal, A., Westra, R., Akdim, M.R., Bymaster, A., Grave, E. and Teng, D.T., 2012. "Compact Separation Technologies and Their Applicability for Subsea Field Development in Deep Water". *Offshore Technology Conference*, p. 12. doi:10.4043/23223-MS. URL `http://www.onepetro.org/doi/10.4043/23223-MS`.

Leith, D. and Jones, D.L., 1984. "Handbook of powder science & technology". Chapman & Hall, New York, chapter 15. ISBN 0412-99621-9.

Nogueira, C., 2013. *Análise experimental de um separador gás-líquido ciclônico*. Master's thesis, Universidade Federal do Rio de Janeiro.

Oranje, L., 1990. "Cyclone-type separators score high in comparative tests." *Oil & Gas Journal*, pp. 54–57. ISSN 00301388.

Peng, W., Hoffmann, A.C., Boot, P.J.A.J., Udding, A., Dries, H.W.A., Ekker, A. and Kater, J., 2002. "Flow pattern in reverse-flow centrifugal separators". *Powder Technology*, Vol. 127, No. 3, pp. 212–222. ISSN 00325910. doi: 10.1016/S0032-5910(02)00148-1.

Syred, N., 2006. "A review of oscillation mechanisms and the role of the precessing vortex core (PVC) in swirl combustion systems". *Progress in Energy and Combustion Science*, Vol. 32, No. 2, pp. 93–161. ISSN 03601285. doi: 10.1016/j.pecs.2005.10.002.

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