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A 2 Model of the Flow in Hydrocyclones

B. Chinè[1], F. Concha[2] and M. Meneses[3]

[1] Escuela de Ciencia e Ing. Materiales, Instituto Tecnológico de Costa Rica, Cartago, Costa Rica;
[2] Departamento de Ing. Metalúrgica, Universidad de Concepción, Concepción, Chile;
[3] Escuela de Ing. en Producción Industrial, Instituto Tecnológico de Costa Rica, Cartago,Costa Rica

bchine@itcr.ac.cr

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Presentation overview

- Introduction
- Swirling flows in hydrocyclones
- Geometry and experimental values of the simulated flow
- Physical model and equations
- Numerical results
- Conclusions

Swirling flows in hydrocyclones

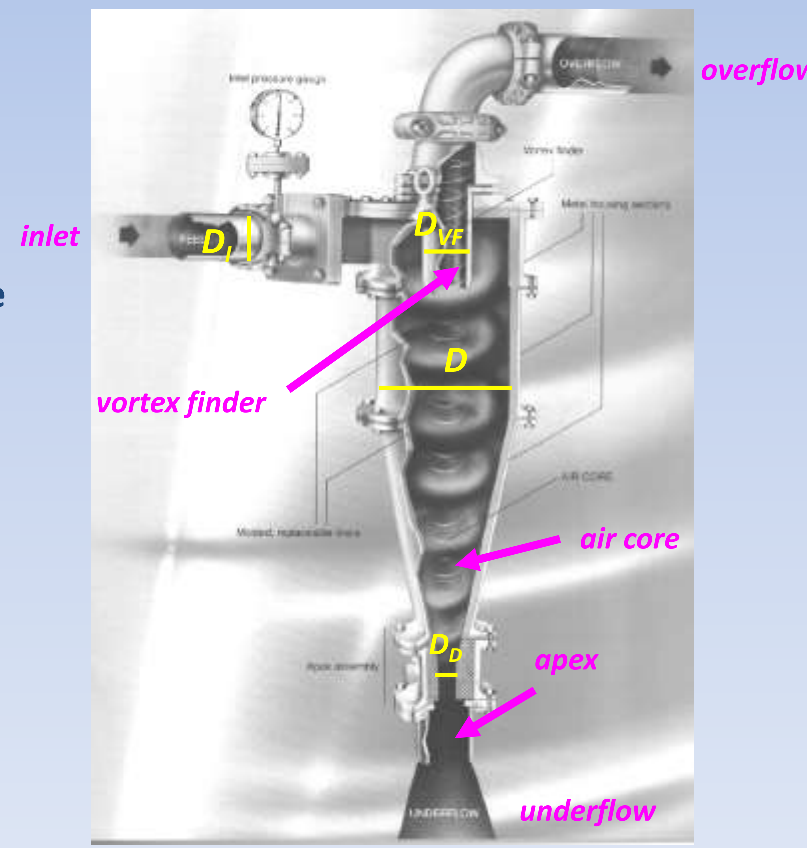
3D swirling flow confined in cylinder-conical geometries [1,2,3,4]

- <u>Tangential velocity v_θ</u> $\rightarrow$ *Rankine vortex*
  $v_\theta = k_1 r$ *forced vortex* (rotation of a rigid body)
  $v_\theta = k_2 / r$ *free vortex* (potential vortex)

- <u>Axial velocity v_z</u> $\rightarrow$ *two opposite flows*
  a flow direct to the apex and a reverse flow direct to the vortex finder

- <u>Radial velocity</u> v_r $\rightarrow$ *small (10^{-2} m/s)*

- <u>Air core</u> $\rightarrow$ controls the liquid splitting to the outlets



Swirling flows in hydrocyclones

From experimental works (LDV) we know that the flow in a hydrocyclone (conical and flat bottom) has the following properties:

- ⇒ **velocity profiles of v_z and v_θ are not completely axisymmetric**
- ⇒ **v_z, v_θ, and their RMS values σ_z and σ_θ, only change their magnitude with pressure Δp**
- ⇒ **v_z changes with z**
- ⇒ **turbulence is neither *homogeneous* nor *isotropic* : σ_z and σ_θ are different and depend on z and r**
- ⇒ **the position of the air core does depend on Δp and the ratio D_{VF}/D_D (vortex finder diameter/apex diameter)**

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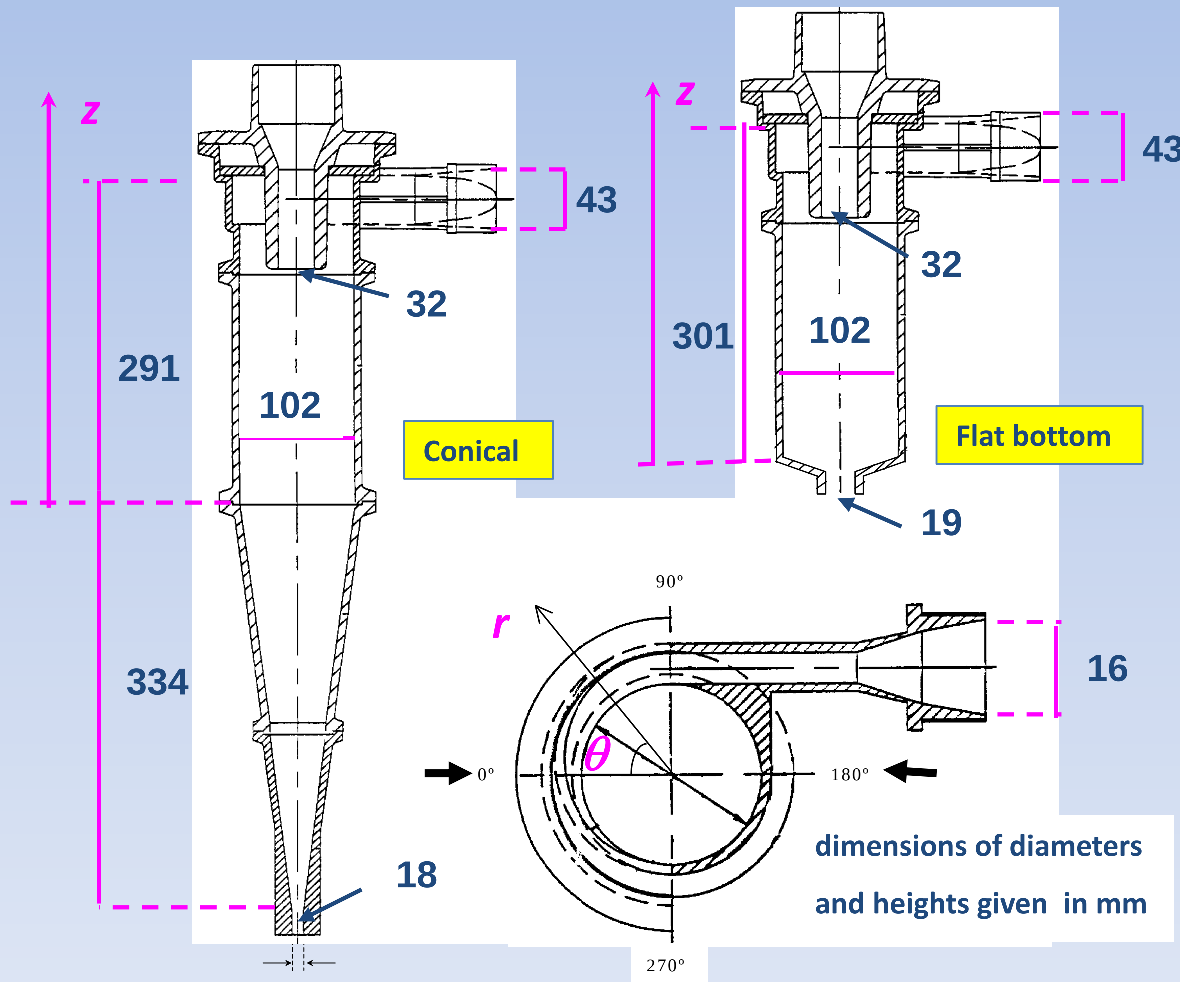
Geometry and experimental values



hydrocyclone diameter D =102 mm

liquid = water

dynamic viscosity $\mu = 10^{-3}$ Pa•s

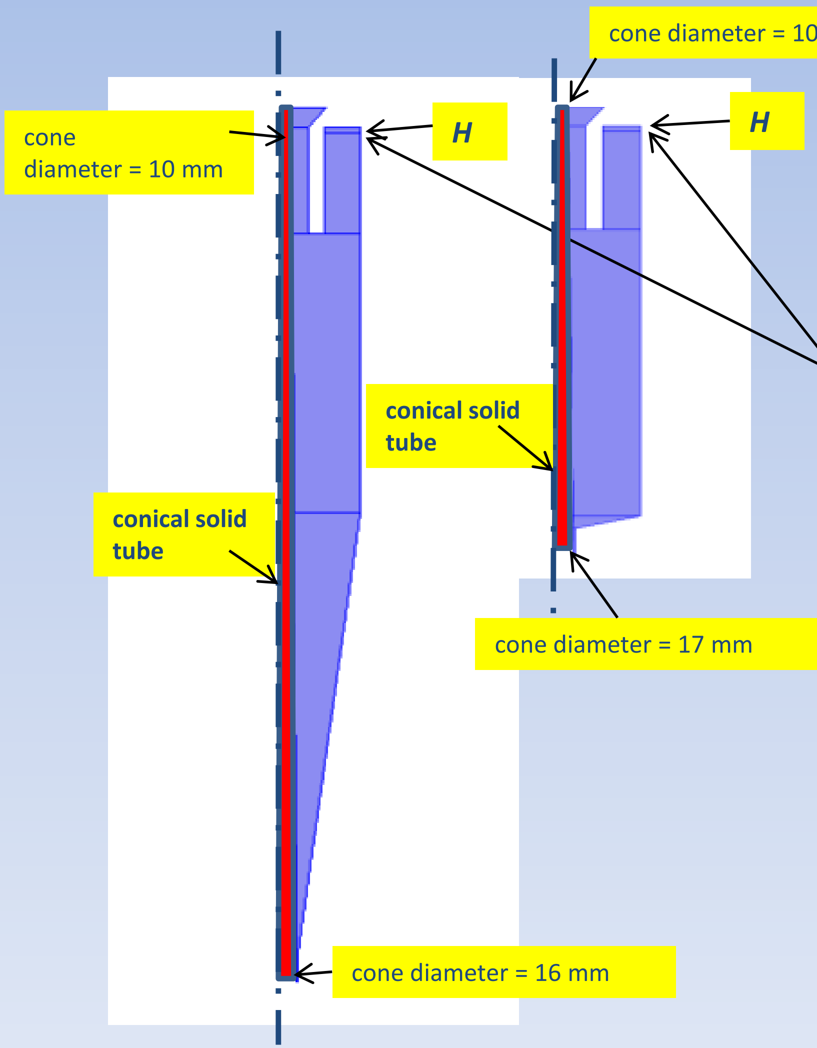
density $\rho = 10^{3}$ kg/m^{3}

	Δp(psi)	*Q(l/s)*	*Re*
Conical	*4*	*1,65*	*2,06x10* ^{4}
Flat bottom	*4*	*1,42*	*1,77x10* ^{4}

where $Re = \rho V D / \mu$

and $V = 4Q/\pi D^{4}$ *(mean axial velocity inside the hydrocyclone)*

Physical model



- **Model is 2D**

  (*the flow is assumed axisymmetric*)

- The flow is **stationary**, **turbulent, incompressible** and **Newtonian**

- The radial and tangential components of the velocity are specified on the inlet, which is modeled as a circumferential ring of height ***H***

- **Air core** is modeled as a **conical solid tube** with known (by LDV) diameters (*water is the only phase in the system*)

- **Turbulence** is modeled by the RANS equations (***k-ω model***): default values are used for turbulence intensity and turbulence length scale at the inlet

- **Slip** conditions are set on the solid tube walls (air core)

- **Wall functions** are considered on the other walls

- **Pressure, no viscous stress** is the boundary condition at the outlets

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Equations: RANS and *k*-ω

$$\rho\frac{\partial \mathbf{U}}{\partial t} + \rho\mathbf{U}\cdot\nabla\mathbf{U} + \nabla\cdot\overline{(\rho\mathbf{u}'\otimes\mathbf{u}')} = -\nabla P + \nabla\cdot\mu(\nabla\mathbf{U} + (\nabla\mathbf{U})^T) + \mathbf{F}$$

$$\rho\nabla\cdot\mathbf{U} = 0$$

Reynolds-averaged Navier-Stokes (RANS) equations [5]

$$\rho\frac{\partial k}{\partial t} + \rho\mathbf{u}\cdot\nabla k = P_k - \rho\beta^* k\omega + \nabla\cdot((\mu + \sigma^*\mu_T)\nabla k)$$

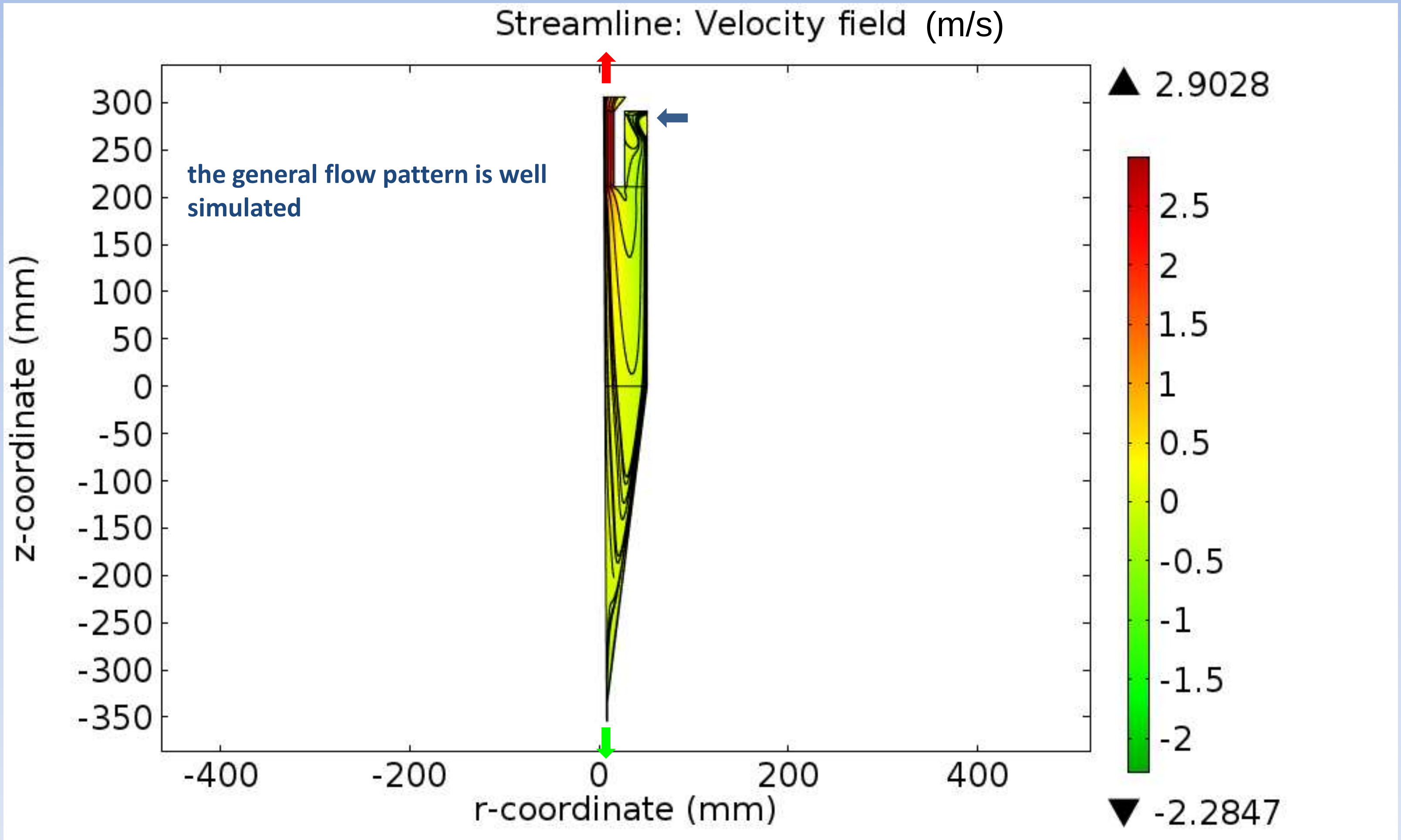
$$\rho\frac{\partial \omega}{\partial t} + \rho\mathbf{u}\cdot\nabla\omega = \alpha\frac{\omega}{k}P_k - \rho\beta\omega^2 + \nabla\cdot((\mu + \sigma\mu_T)\nabla\omega)$$

Transport equations for the turbulent kinetic energy κ and the specific dissipation rate ω [5]

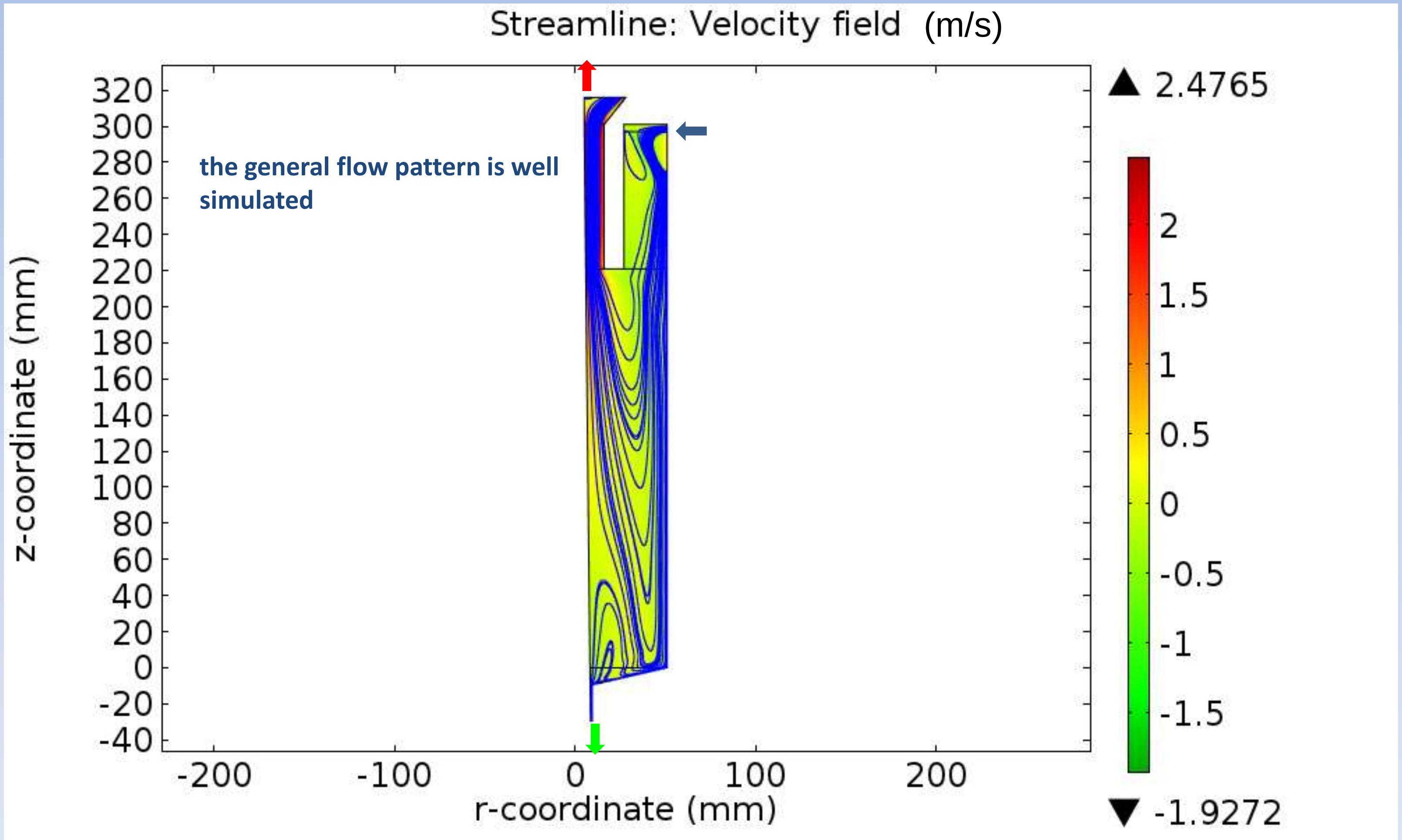
In Comsol, for modeling the turbulence of this swirling flow we use the ***k***-ω turbulence model.

k-ω represents the turbulence as isotropic (anisotropic in hydrocyclones) : anyway it should give a better description of the turbulence compared to the available ones.

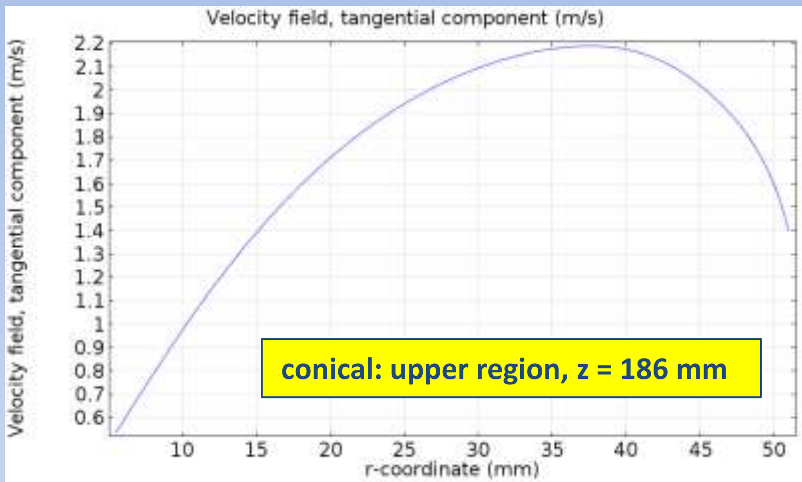
Numerical computations: streamlines in the conical hydrocyclone

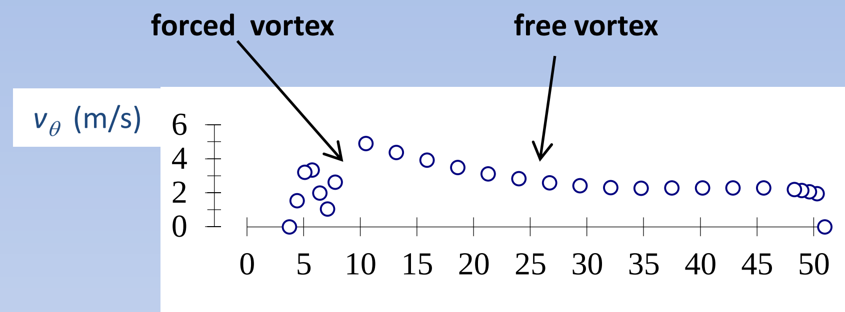


Numerical computations: streamlines in the flat bottom hydrocyclone

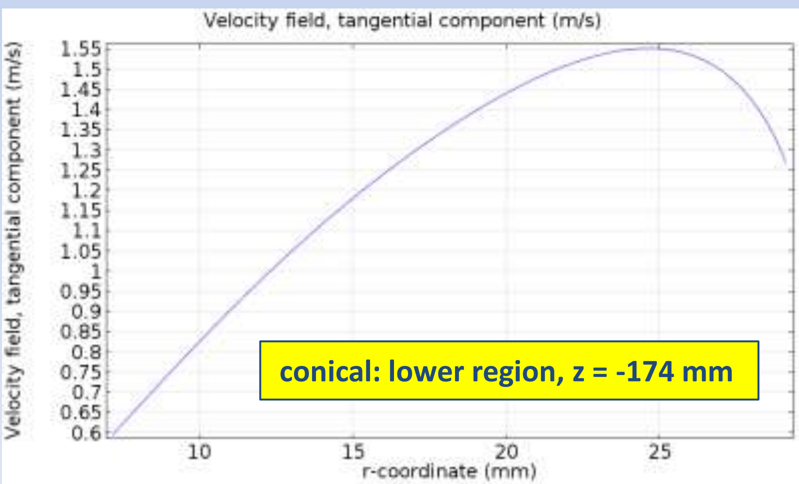


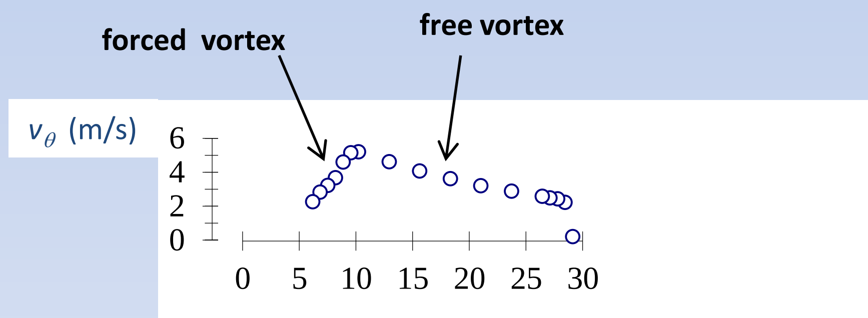
Conical: numerical results of v_θ and LDV measurements





LDV

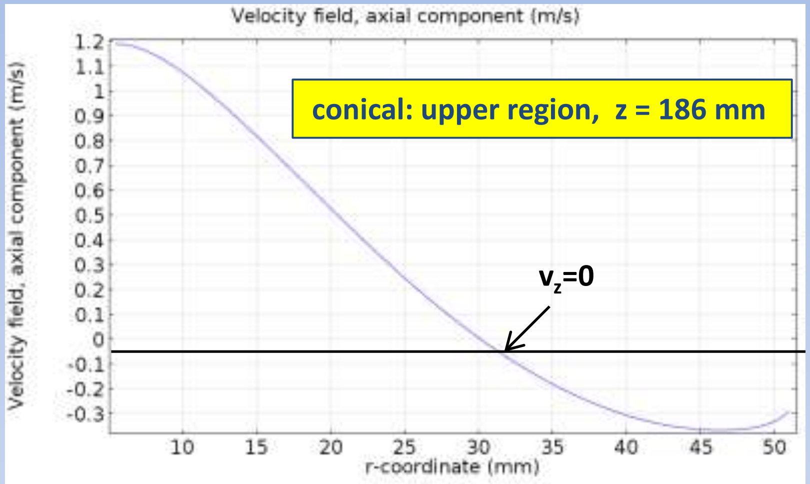


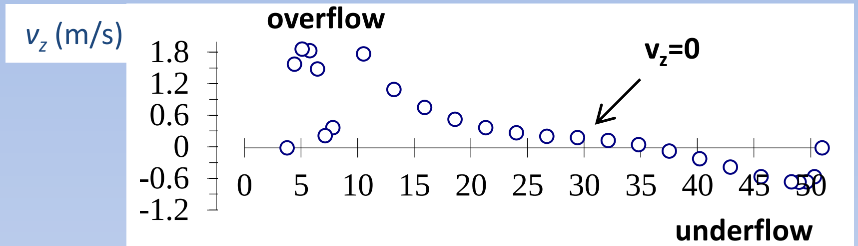


LDV

➡ **numerical results are not satisfactory in the free vortex flow region: the velocity profiles could be very dependent on the turbulence model used in the simulations [6,7]**

Conical: numerical results of v_z and LDV measurements





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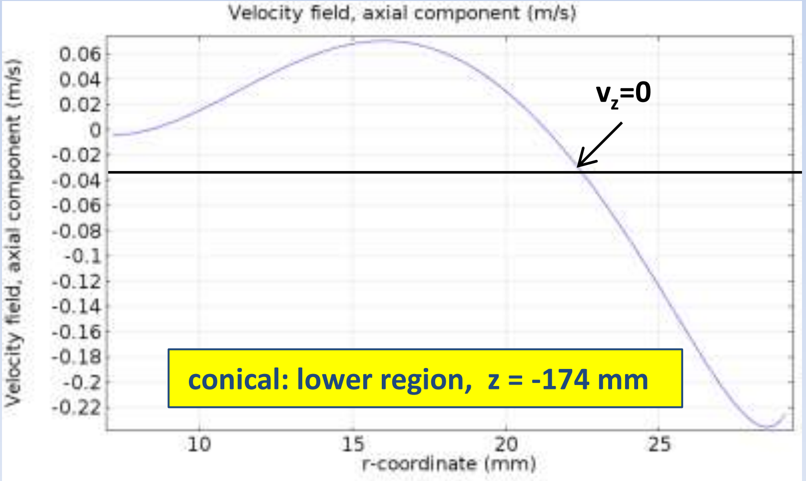
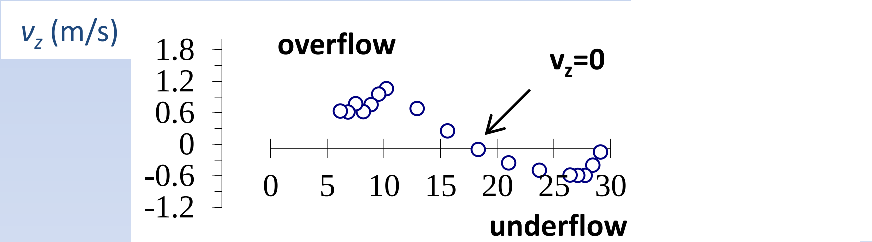
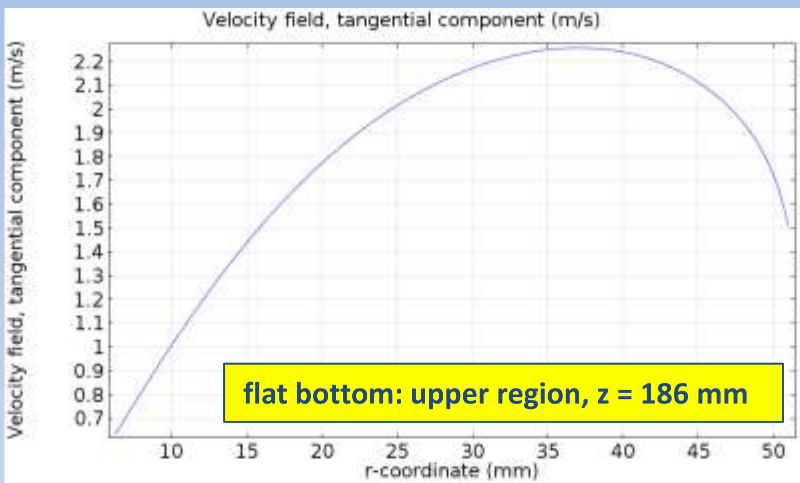


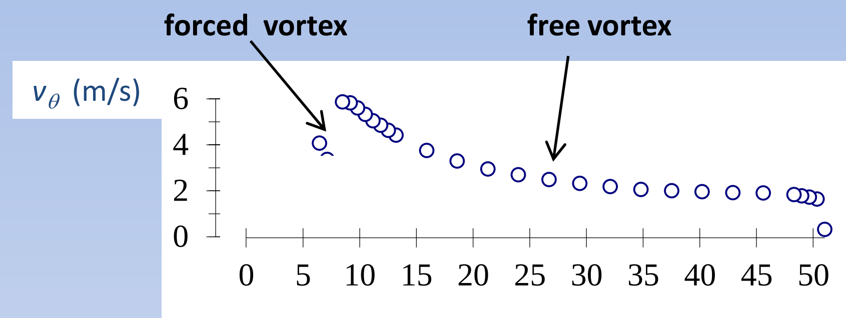


LDV

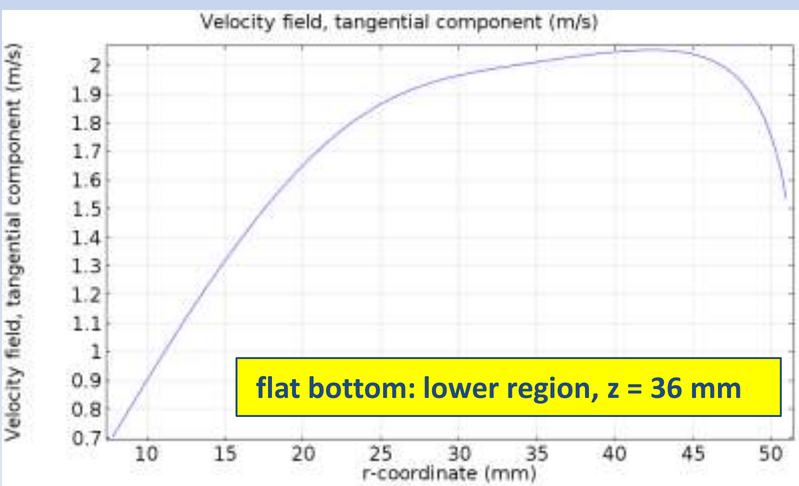
➡ Numerical results are quite satisfactory: two opposite flows are obtained and the real locus of v_z=0 is simulated. The numerical results could depend on other factors, e.g the air core precession, not considered in the model.

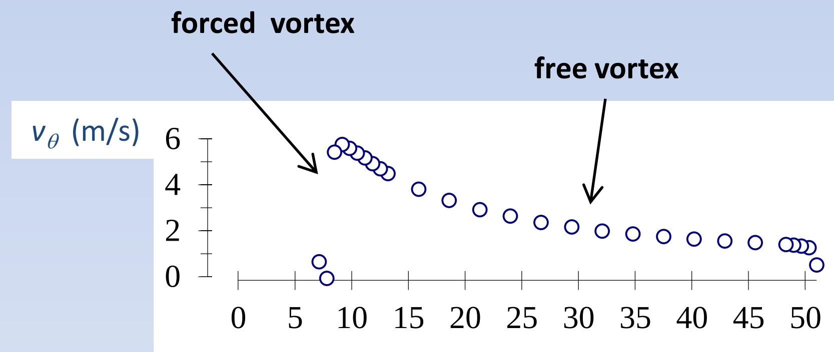
Flat bottom: numerical results of v_θ and LDV measurements





LDV





LDV

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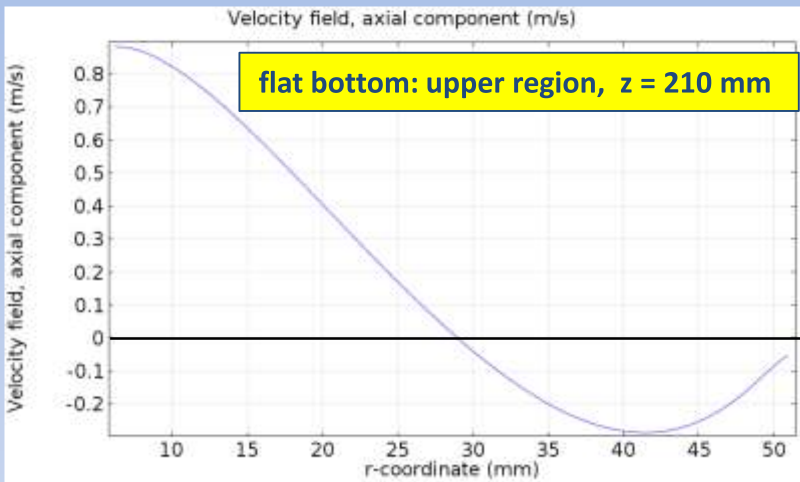
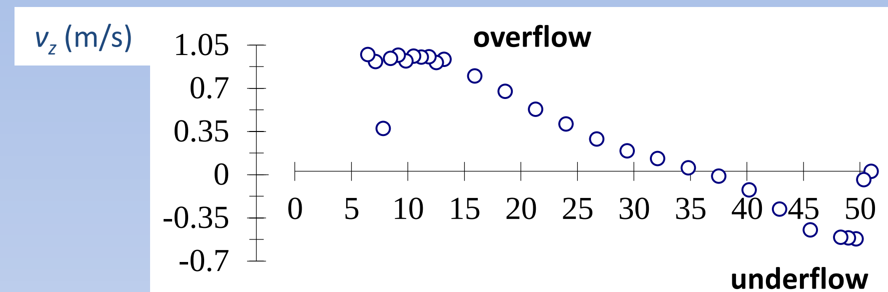
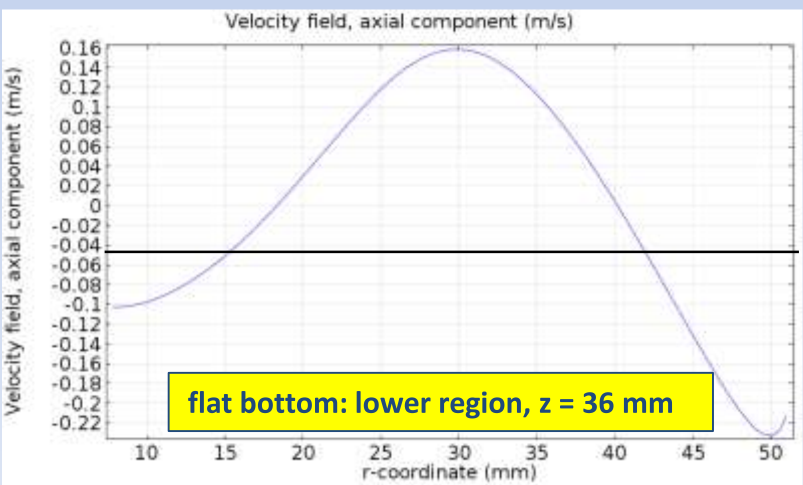
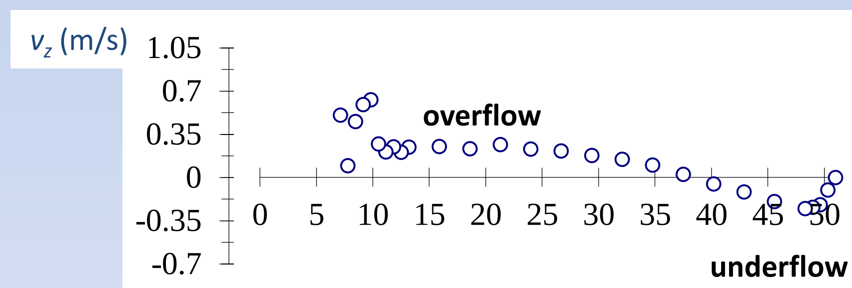
Flat bottom: numerical results of v_z and LDV measurements





LDV





LDV

Numerical results are quite satisfactory: two opposite flows are obtained and the real locus of v_z=0 is simulated. The numerical results could depend on other factors, e.g the air core precession, not considered in the model.

Conclusions

- Swirling flows in 2D hydrocyclones have been simulated by developing an axisymmetric model of the flow
- The general flow pattern is quite well reproduced
- Tangential velocity profiles differ from LDV measurements, they give a poor description of the free vortex: the k-ω turbulence model doesn't assume anisotropy , which is present in the flow
- Axial velocity profiles are quite satisfactory: some difference with LDV measurements could also be dependent on other factors, e.g. the air core precession , not considered here
- Although more complete models might be developed, e.g. 3D, including the modeling of the air core, the anisotropy of the turbulence, etc., computational requirements and computing times have to be considered.

References

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