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The Differential Pressure numerical model

Safest

Webinar

20 February 2023

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The SAFEST consortium

The UNICAS task is related to the investigation of the interaction between the test liquid and the flowmeter's performance through numerical simulations.

Development and validation of a CFD numerical tool to support experimental campaigns, aiming at:

- *investigating different operative conditions (e.g. flow-rate, temperature, pressure);*
- *performing parametric analysis, which is difficult to carry out experimentally;*
- *obtaining detailed information about thermo-fluid dynamic fields (e.g. liquid densities, viscosities, etc.)*

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Computational Fluid Dynamics

Computational Fluid Dynamics is a very effective tool for understanding fluid flow properties and predicting how the flow will respond to different boundary conditions.

The Navier-Stokes equations are turned in CFD application into systems of linear equations:

(1) Conservation of mass equation $$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

(2) Conservation of momentum equation $$\frac{\partial (\rho \mathbf{u})}{\partial t} + \mathbf{u} \cdot \nabla(\rho \mathbf{u}) = \nabla \cdot \sigma + \rho \mathbf{f}$$

(3) Conservation of energy equation $$\frac{\partial E_t}{\partial t} + \nabla \cdot (E_t \mathbf{u}) = \nabla \cdot \sigma \mathbf{u} - \nabla \cdot \mathbf{q}$$

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CFD application within the project

The developed CFD numerical tool allows to :

- *predict fluid behaviour;*
- *calculate detailed pressure and velocity fields;*
- *investigate different boundary conditions and fluid properties.*

The study case is an orifice plate flow meter, whose analysis has been conducted through OpenFOAM which is a Finite-Volume-Method, open-source and completely programmable software.

OpenFOAM®

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Numerical Model

The study case is a three-dimensional, incompressible and time-variant case.
A summary table is presented, containing the numerical simulation details.

Numerical model

Mathematical Model	PISO (Pressure Implicit with Splitting Operators)
Time Step	Adjustable Time Step
Courant Number	2
Residual Control	10^{-6}
Turbulence Model	Realizable $k - \varepsilon$

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Test setup

The case setup has been defined considering the following specifications and evaluating the response of the numerical model varying the inlet boundary conditions:

Test setup

Test liquids	white spirit 180 EA (D 60)
Pipe diameter	DN 50
Flow-rate range:	3 m^3/h -8 m^3/h
Pressure:	ca. 3 bar
Temperature (test liquid):	25, 30 and 40 °C
Temperature (ambient):	room

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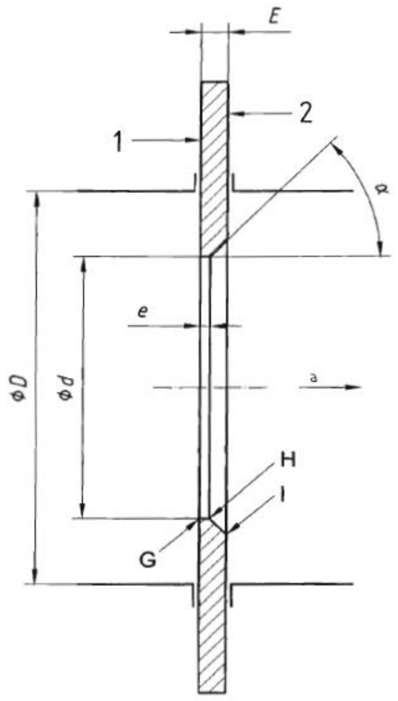
How it has been chosen?



The ISO Standard 5167-2 imposes the geometry of the orifice plate.

Parameters	Case study
Pipe Diameter D	$\mathrm{D} = 5.476 \cdot 10^{-2} m$
Orifice Diameter d	$d = 1.847 \cdot 10^{-2} m$
Thickness $\boldsymbol{e}$	$e = 5 \cdot 10^{-4}\mathrm{m}$
Thickness of the plate, $\boldsymbol{E}$	$E = 2 \cdot 10^{-3}\mathrm{m}$
Angle of bevel $\boldsymbol{\alpha}$	$\alpha = 45°$

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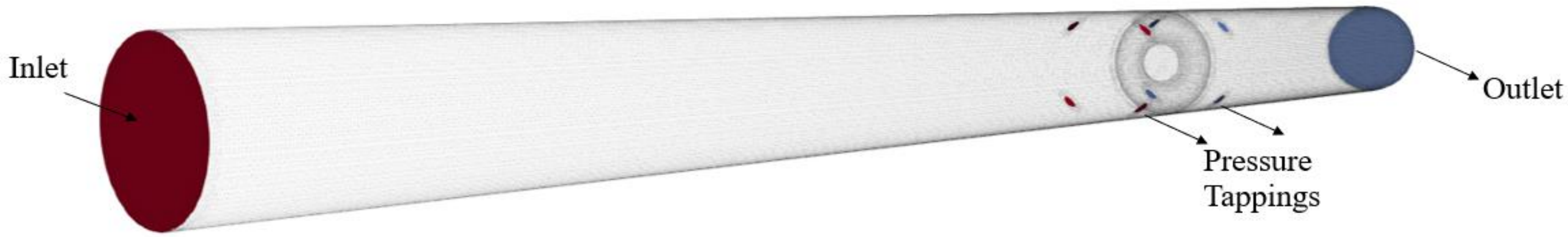
CFD application within the project

The computational domain is presented in the figure below, together with the main boundary conditions:



Boundary conditions	Velocity	Pressure
Inlet	Flow-rate 1.084 [kg/s]	3 [bar]
Outlet	$\nabla u = 0$	0
Pressure Tappings	$\vec{U} = 0$	$\nabla p = 0$

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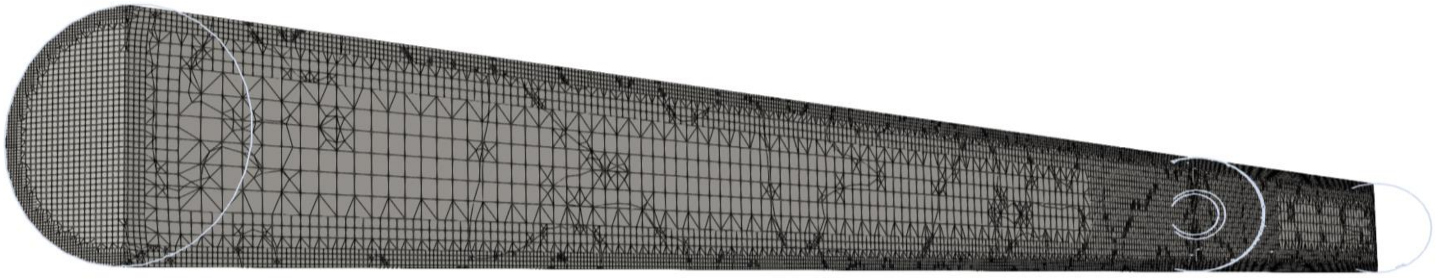
Numerical domain

For the sensitivity analysis a 3.2 million cells reference grid has been adopted, comparing it with two mesh grids of 1.6 million and 800 thousand cells. The chosen grid is presented in the table below:



	Characteristics
Number of Elements	$1.6 \cdot 10^6$ cells
Skewness	2.387
Non-orthogonality	60.01

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Fluid properties

Different fluid operating conditions have been simulated, aiming at evaluating deviation from the reference conditions and at testing the numerical model.

The fluid properties at different temperatures are reported in the table:

WHITE SPIRIT 180

Fluid Temperature [°C]	25	30	40
Density $[\mathrm{kg/m^3}]$	781.13	777.453	750.08
Dynamic Viscosity [Pa*s]	$1.24 \cdot 10^{-3}$	$1.14 \cdot 10^{-3}$	$1.02 \cdot 10^{-3}$
Kinematic Viscosity $[\mathrm{m^2/s}]$	$1.59 \cdot 10^{-6}$	$1.47 \cdot 10^{-6}$	$1.36 \cdot 10^{-6}$

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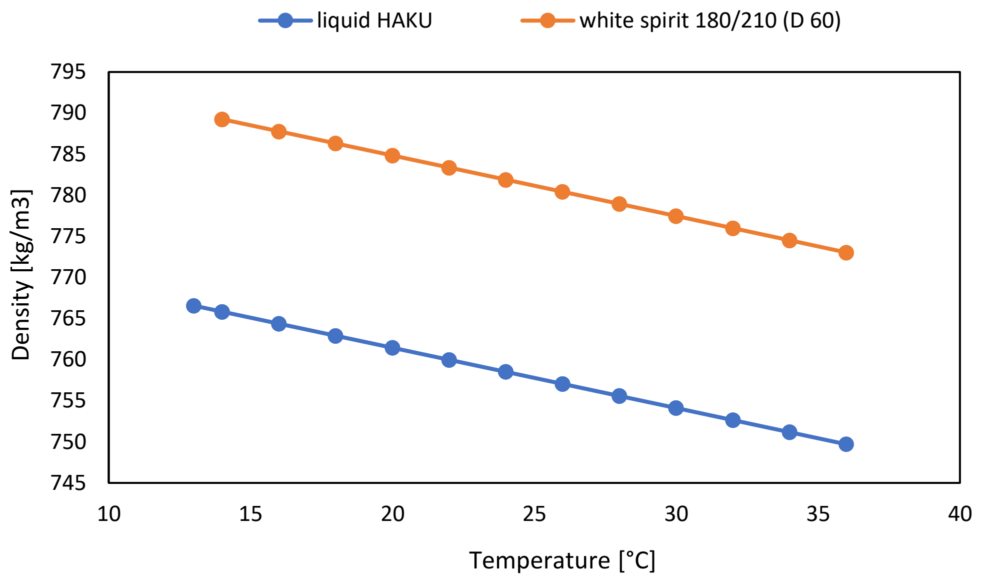
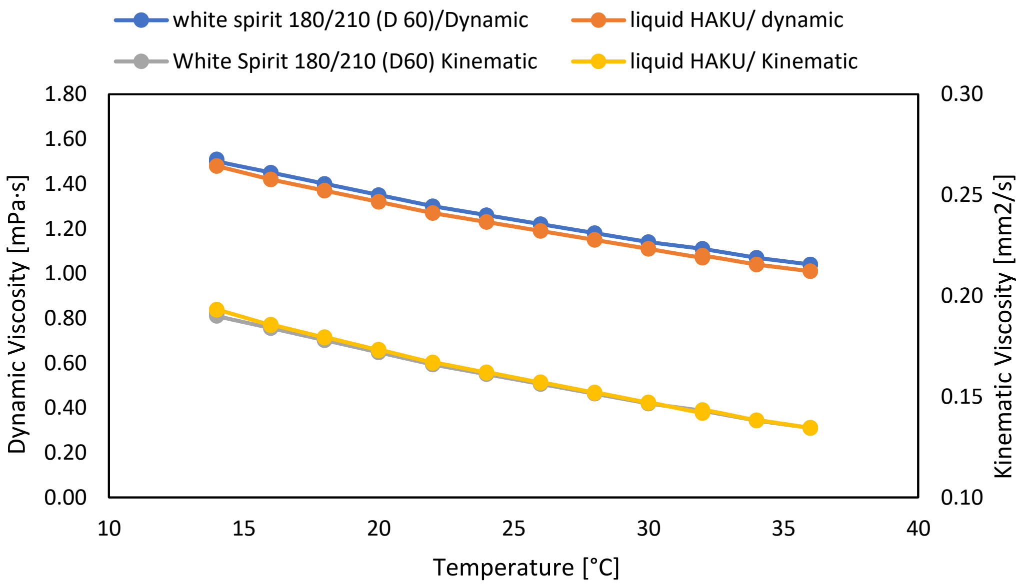
Fluid properties





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Turbulence Model

The three different turbulence models below have been considered to evaluate the performance of the numerical model.

	Realizable k-ε	k-ω SST	k-ε
$\Delta p_{Transient}$[mbar]	223.41	222.25	219.82
Δp_{Theory}*[mbar]		223.17	
Error %	0.19%	1.64%	2.71%

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Results

The averaged field approach is considered to evaluate the performance of the orifice flow meter. A maximum fluctuation of 3% from the average value is considered to set the average time.

The results are expressed in terms of:

- *Pressure and velocity fields at different temperatures;*
- *Velocity profiles at 25°C;*
- *Comparison of pressure drops at different temperatures with the ISO 5167-2;*

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Results

The results of the numerical simulations for three different temperature tests are presented, all other factors held constant. Two comparison are reported:

- *Velocity field comparison for 25°C, 30°C and 40°C;*
- *Pressure Field Comparison for 25°C, 30°C and 40°C.*

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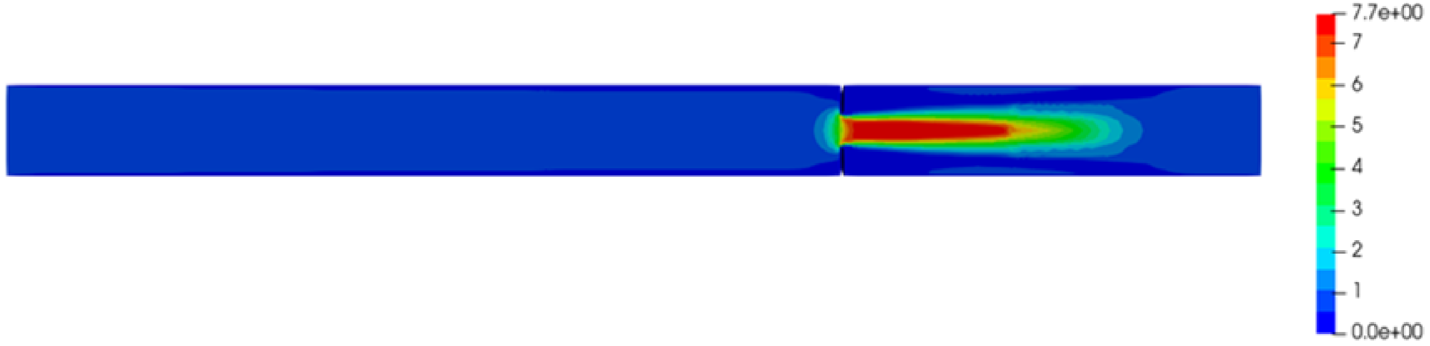
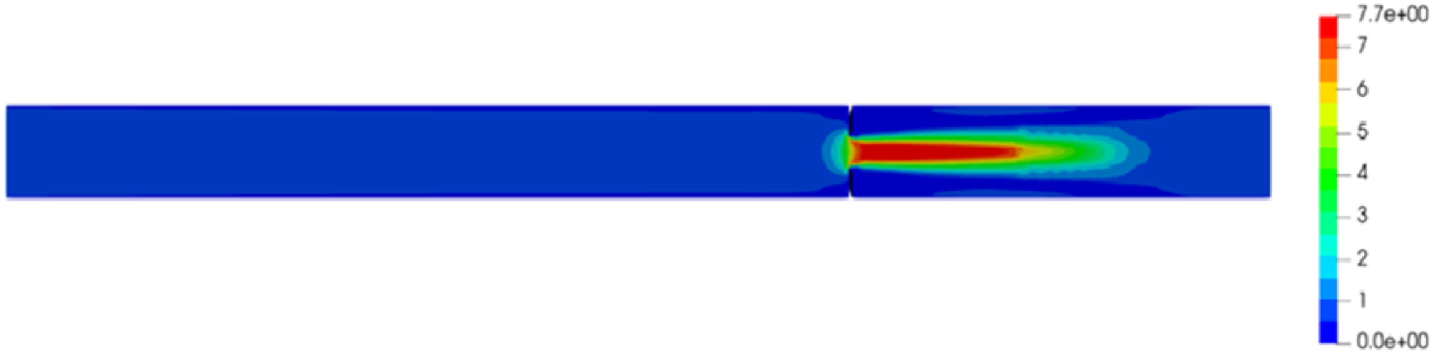
Velocity field

Average velocity field for 25°C [m/s]



Average velocity field for 30°C [m/s]

Average velocity field for 40°C [m/s]



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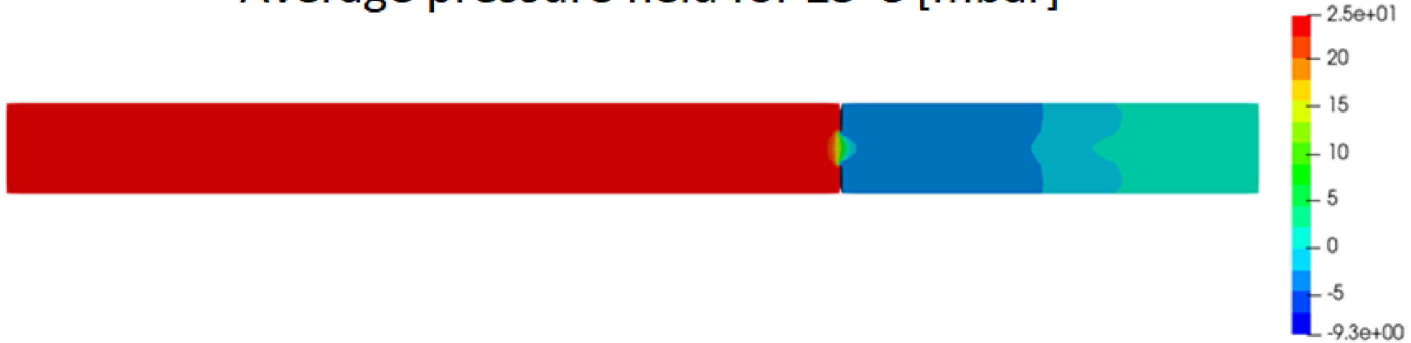
Pressure field

Average pressure field for 25°C [mbar]



Average pressure field for 30°C [mbar]

Average pressure field for 40°C [mbar]

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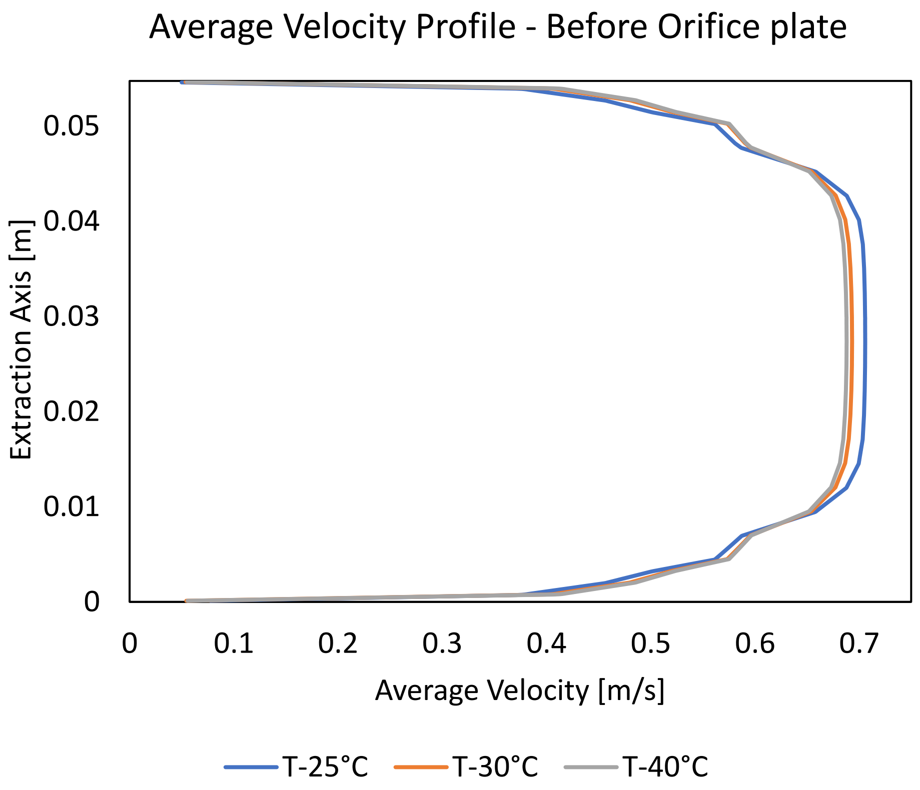
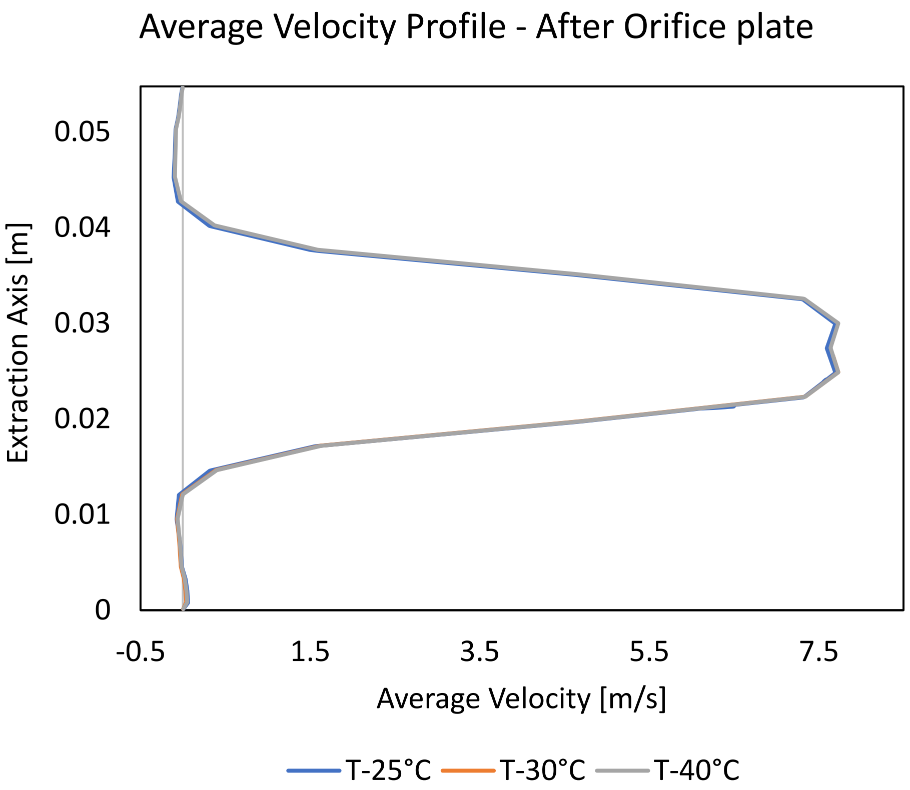
Velocity profiles

The velocity profiles have been extracted in correspondence of pressure tappings. The pressure taps section are located:

- One diameter before the orifice plate;
- Half diameter after the orifice plate;





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Numerical tool validation

The pressure drop calculated through the numerical analysis has been compared with the theoretical pressure drop of the ISO standard 5167-2.

	Test 25°C	Test 30°C	Test 40°C
$\Delta p_{Numerical\ Analysis}$[mbar]	223.41	225.73	217.94
Δp_{Theory}* [mbar]	223.17	222.33	214.50
Error %	0.19%	1.53%	1.60%

*Theoretical Differential pressure ISO 5167-2

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Conclusions and future developments

A numerical model of the orifice flow meter has been developed, following the ISO standard 5167-2.
The mesh and turbulence sensitivity analysis have been conducted to provide the best model possible and reduce the average error from the reference.
A numerical validation has been conducted against the pressure drop obtained through the iterative calculation of ISO standard 5167-2.

Future Developments of this research:

- *Experimental validation of the numerical model, through an experimental campaign;*
- *Variable flow-rate profile to inlet section;*

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