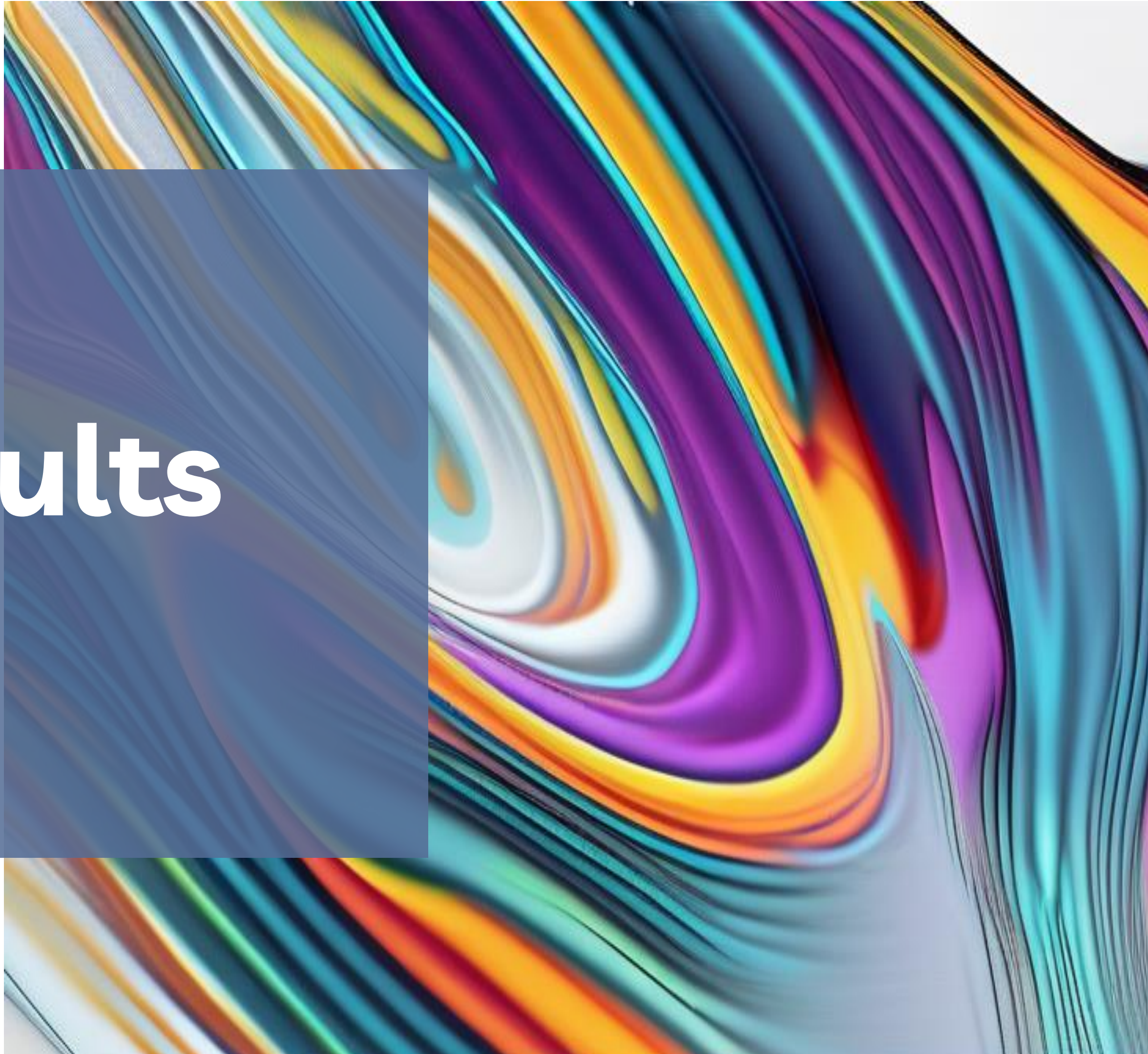
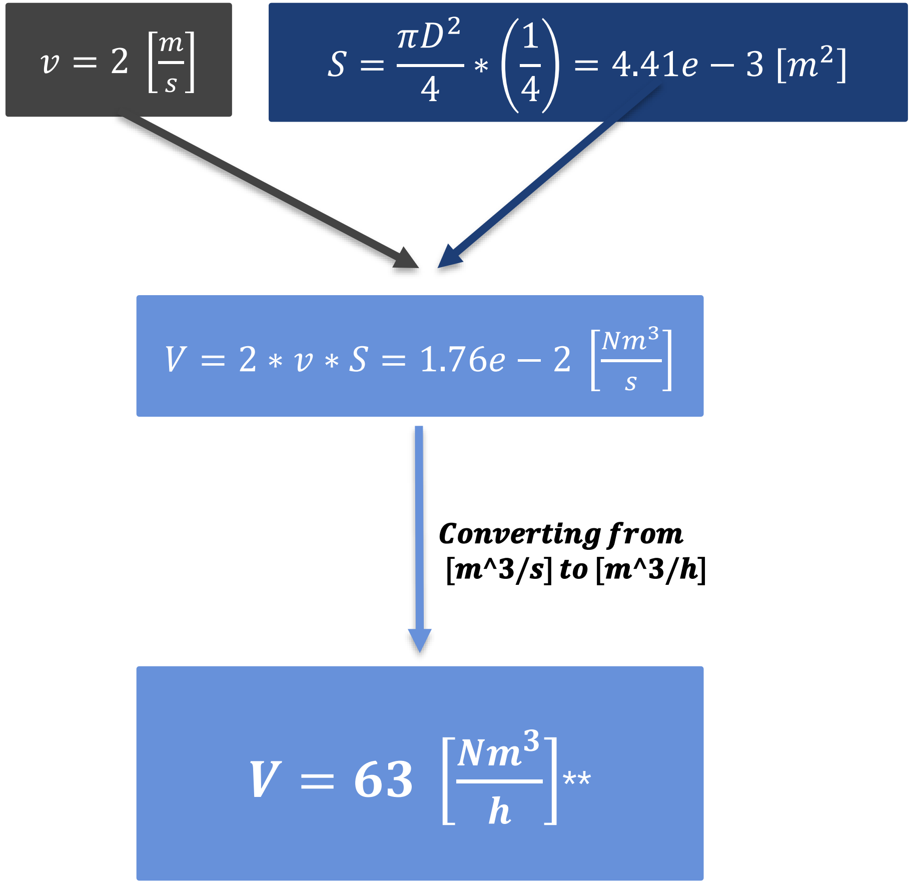


CFD Results Update

Damiano 13/06/24



$$v = 2 \left[\frac{m}{s}\right]$$

$$S = \frac{\pi D^2}{4} * \left(\frac{1}{4}\right) = 4.41e - 3\ [m^2]$$

$$V = 2 * v * S = 1.76e - 2 \left[\frac{Nm^3}{s}\right]$$

Converting from **$[m^\wedge 3/s]$ to $[m^\wedge 3/h]$**

$$\boldsymbol{V = 63 \left[\frac{Nm^3}{h}\right]^{**}}$$

Last Week Results

- The flowrate (V) to ensure a homogeneous composition in around 60 seconds is just above 60 Nm3/h.
- The steady-state is reached.

Next Goals

- Find the minimum flow rate at which a homogeneous steady-state is reached.
- Increase the flow rate to guarantee homogeneity in a fixed (and reasonable) time.

** The flowrate is calculated for a mixture
50%CO2 - 50%C4F10

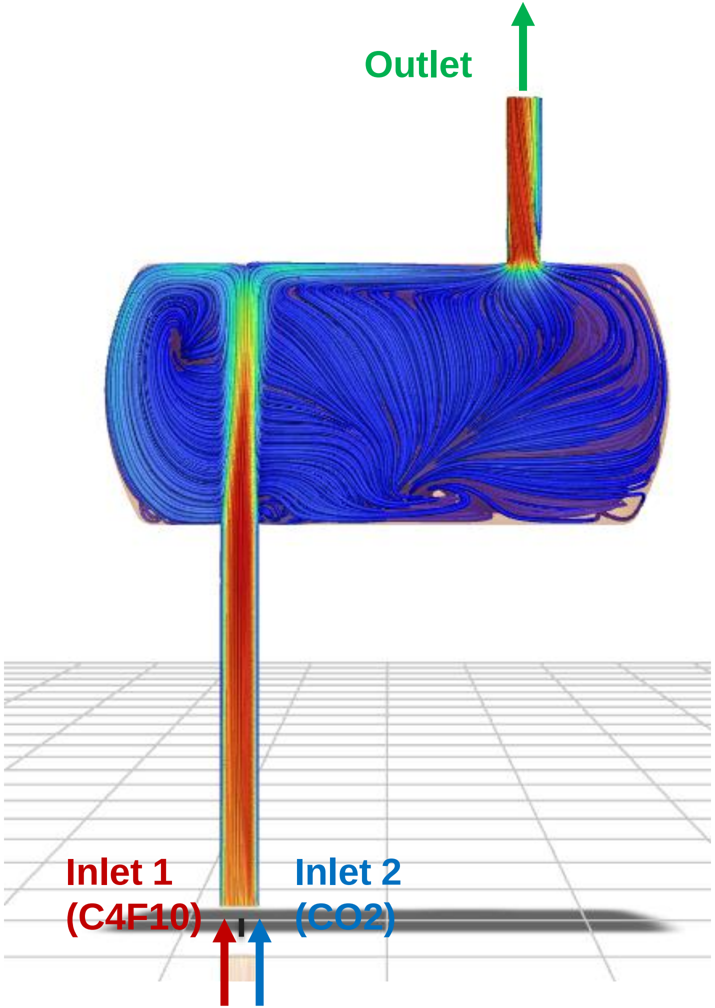
Minimum Inlet Velocity

The first step consists in finding which is the minimum inlet velocity to guarantee homogeneity of the composition at the outlet.

To achieve this goal a set of steady-state simulations has been run.

The parameters varying along the different simulations are the inlet velocities.

The following velocities have been tested:
- 2.0 m/s
- 0.5 m/s
- 0.3 m/s
- 0.2 m/s
- 0.1 m/s



$$MFA(\Phi) = \frac{\left[\sum_{i=1}^{N} \Phi_i \dot{m}_i \right]}{\left[\sum_{i=1}^{N} \dot{m}_i \right]}$$

VS

$$AA(\Phi) = \frac{\left[\sum_{i=1}^{N} A_i \dot{m}_i \right]}{\left[\sum_{i=1}^{N} \dot{A}_i \right]}$$

Used for total quantities such as:
- Composition
- Temperature

This is the best averaging method when dealing with quantities strongly influenced by the velocity fields.

Used for static variables such as:
- Static Pressure
- Density

- N is the number of discrete segments or elements in the flow.
- $\dot{m}_i$ is the mass flow rate through the i-th segment.
- ϕ_i is the value of the scalar quantity in the i-th segment.
- A_i is the area of the i-th segment.

In this case, the scalar quantity of interest is the molar fraction of CO2!!!

Key Variables

The key variable to take under control is the molar fraction of CO2.

If we start with a tank full of CO2 and start sending an equimolar mixture, we expect that, at infinite time (steady-state), the composition inside the tank will asymptotically tend to the inlet composition.

We will focus on:

1. Molar composition of CO2 on the symmetry plane.
2. Molar composition of CO2 at the outlet.
3. Mass Flow Averaged molar composition of CO2 through the outlet*.

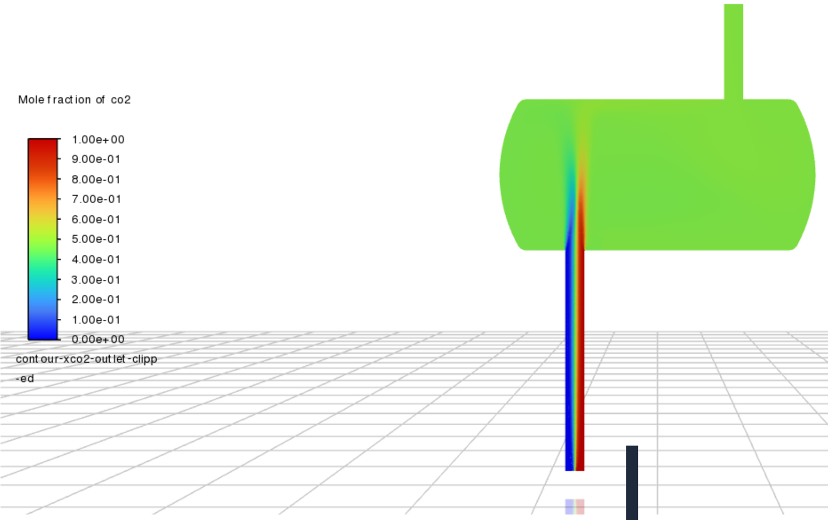
Mass Flow Average? Why?

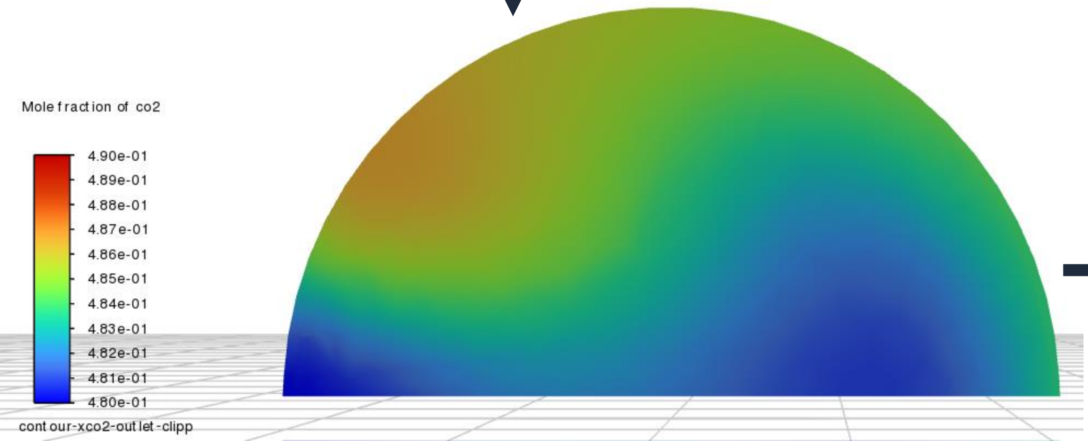
* The MWA

STEADY-STATE: 2.0 m/s (63 Nm3/h)

Here and in the next slides we report:

- CO2 molar fraction (from 0 to 1) along the symmetry plane.
- CO2 molar fraction (clipped between 0.48 and 0.49) along the outlet pipe’s cross-section.

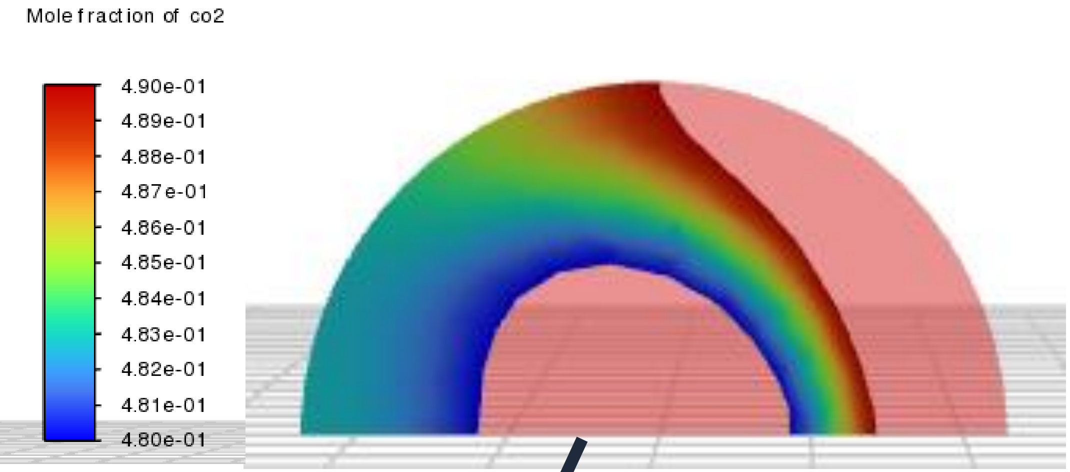




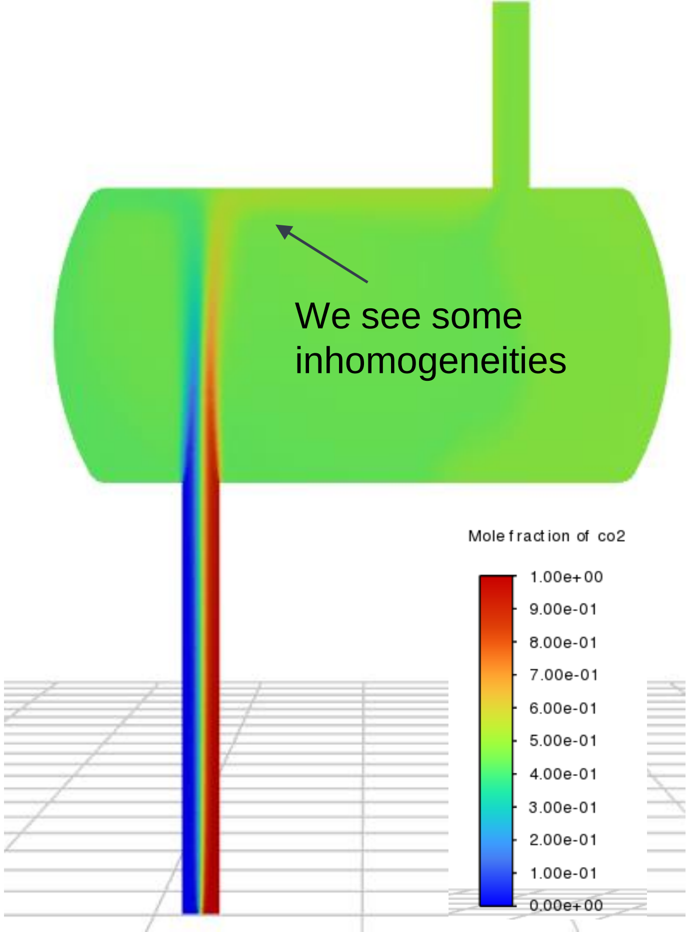
We can notice that both the plots report a homogeneous steady state condition.

Even at the outlet’s cross-section the variation is smaller than 1%.

STEADY-STATE: 0.2 m/s (6 Nm3/h)

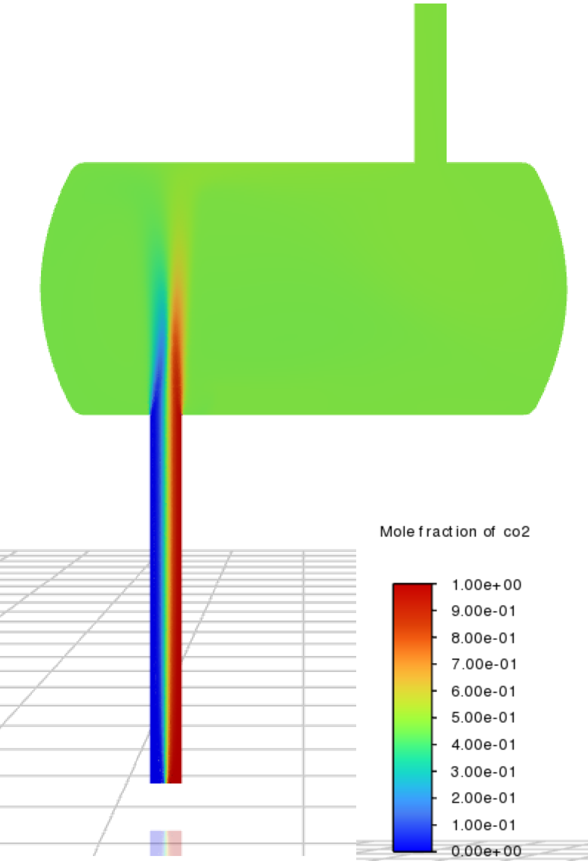


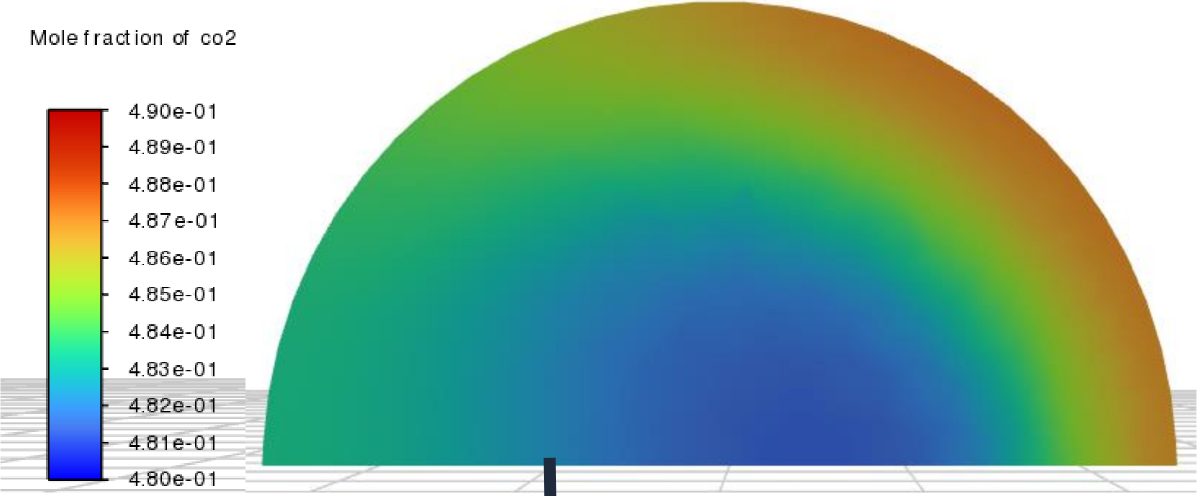
Reducing the inlet velocity of one order of magnitude results in a strong inhomogeneity. The empty zones (light red) represent sub-areas where the molar fraction is outside of the desired range.



We see some inhomogeneities

STEADY-STATE: 0.5 m/s (16 Nm3/h)





In this case, when a 4-fold reduction of the inlet velocity has been applied we can’t notice huge differences.

This tells us that the solution (minimum velocity) lives in the range between [0.2-0.5] m/s.

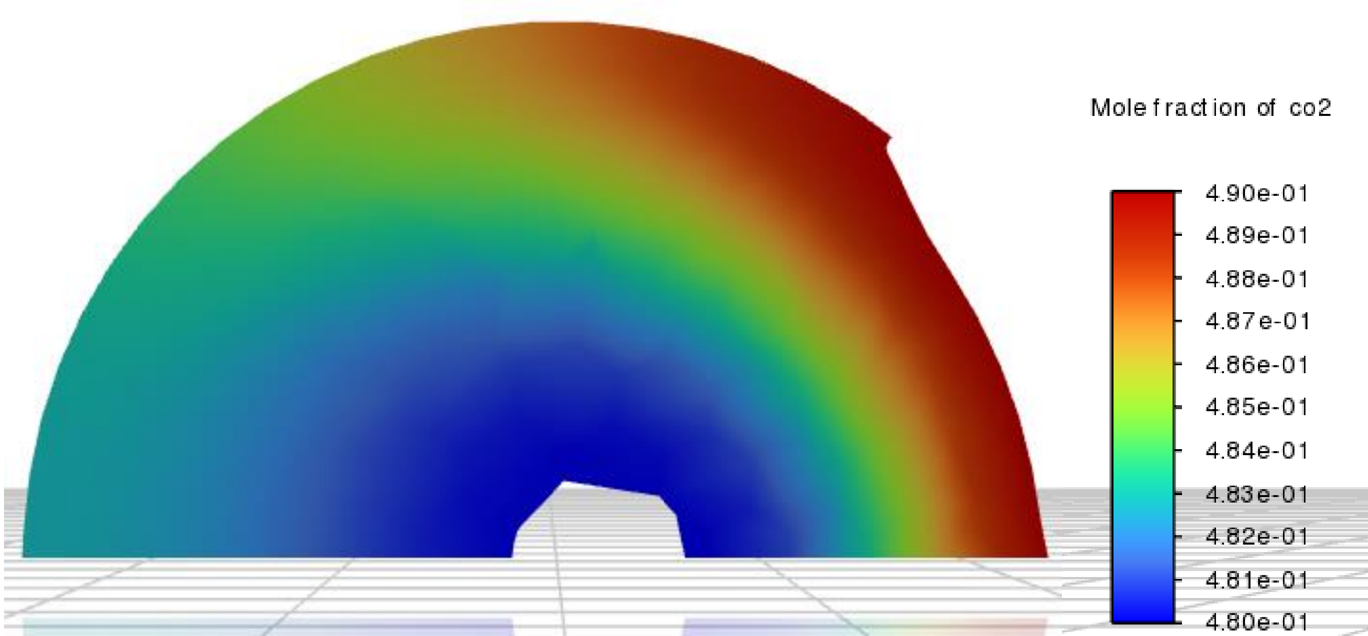
STEADY-STATE: 0.3 m/s (9.5 Nm3/h)

The steady-state solution is achieved with an inlet flow rate of 0.3 m/s!

This solution is a trade-off between:
1. The need to minimize the flow rate
2. The necessity to have homogeneous conditions

With respect to the old solution, the flow rate has been reduced almost 7-fold

The occupancy of the surface area of the cross-section where the mole fraction varies by more than 1% is > 95%



Transient Approach

Once a steady-state solution has been found we look for the following information:

1. What is the characteristic time to reach steady-state conditions? In other words, how long does it take before the variation of composition at the outlet's cross-section is smaller than 1% (given a fixed occupancy)?

2. What is the influence of the velocity (turbulence) on the characteristic time? Is this time just proportional to the volume/flow rate ratio? Is the relationship non-linear?

1. Simulate a steady state and wait for steady-state conditions to be established. In other words, we proceed with the simulation until the Mass Flow Average of the CO2 mole fraction reaches a constant value (expected to be ~ 0.5).
2. Compare two different transient solutions (at different inlet velocities) to highlight the relationship between the mixture homogeneity and the velocity fields.

The transient simulation is computationally heavy!

The run has been started on Tuesday and is still going!

Results will be available (hopefully) next week!