SUPERSONIC POINT SOURCE CAPTURE

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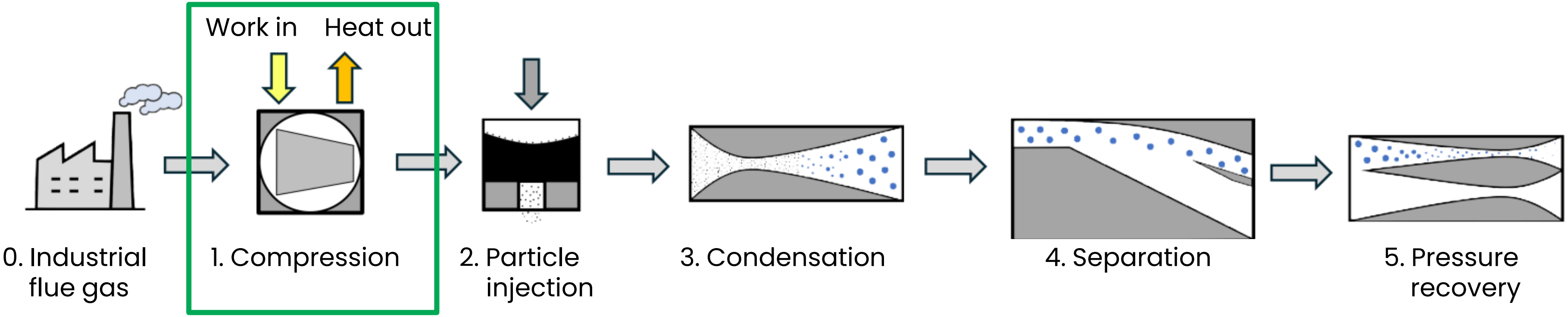
SUPERSONIC CARBON CAPTURE TECHNOLOGY:

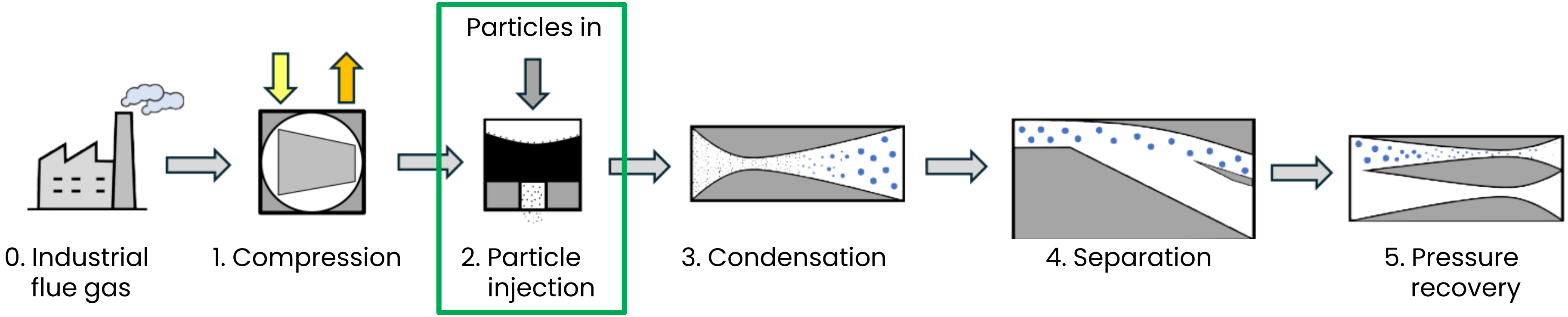
- A novel capture technology using supersonic flows to **condense & separate CO2** from flue gas.
- Technology validated by **lab-scale experiments**.
- Simulations show **competitive performance** at industrial scale.

SYSTEM OVERVIEW:



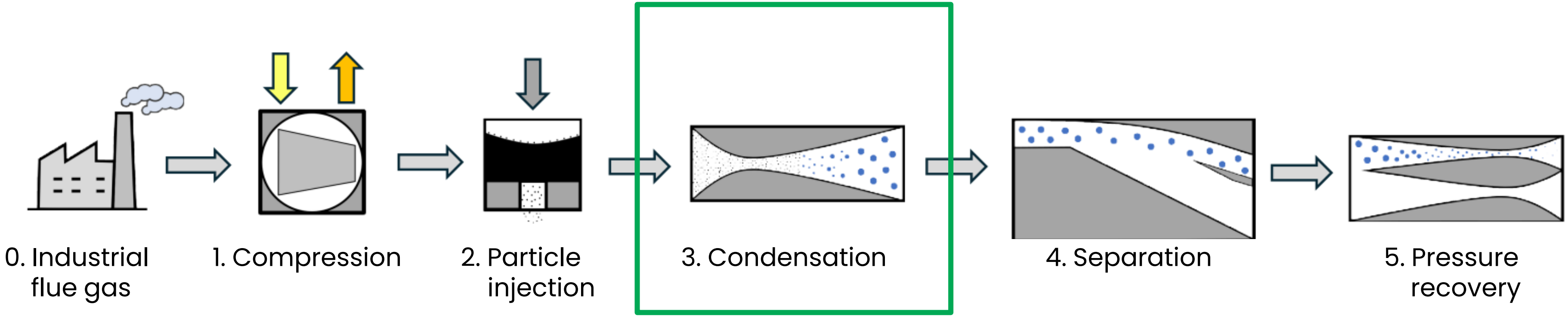
- Flue gases are **compressed to 5–20 bar**, depending on CO2 concentration.
- Heat is recuperated by heat exchangers to reach near ambient temperature.
  - This energy can be used in other processes of the plant.

SYSTEM OVERVIEW:



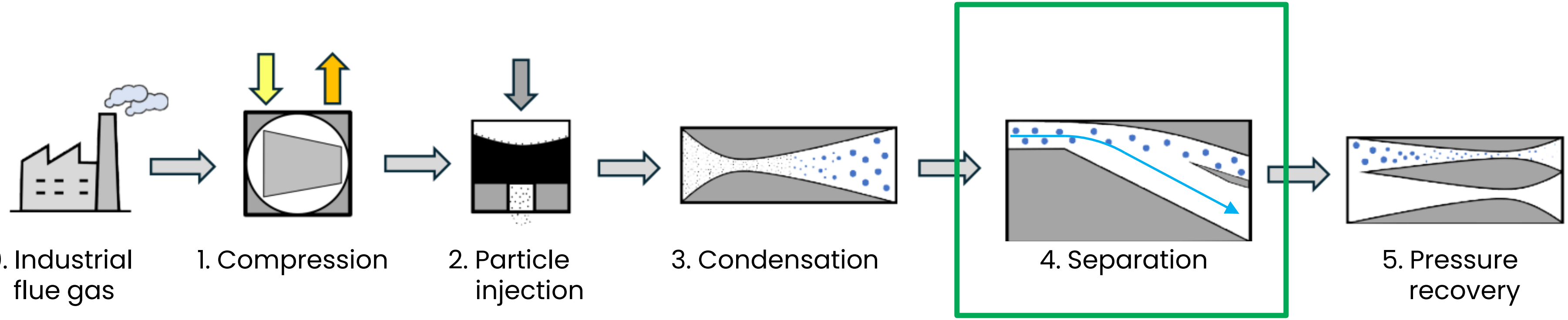
- Inert **solid particles** of known size and density are injected into the flow.

SYSTEM OVERVIEW:



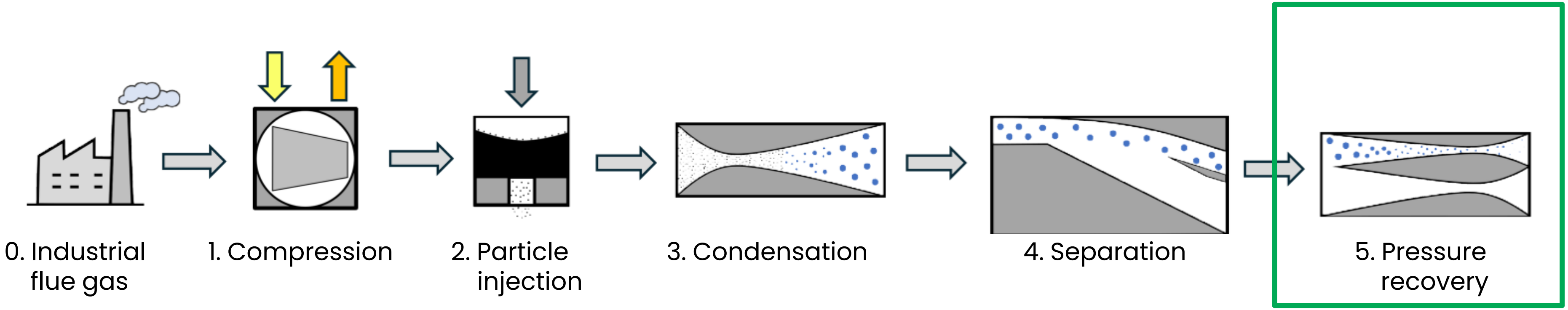
- The nozzle's shape converts the gas's temperature and pressure into kinetic energy accelerating the flow to 3 times the speed of sound.
- The temperature drops below -130 °C, enabling **CO_2 to condense onto the particles**.

SYSTEM OVERVIEW:



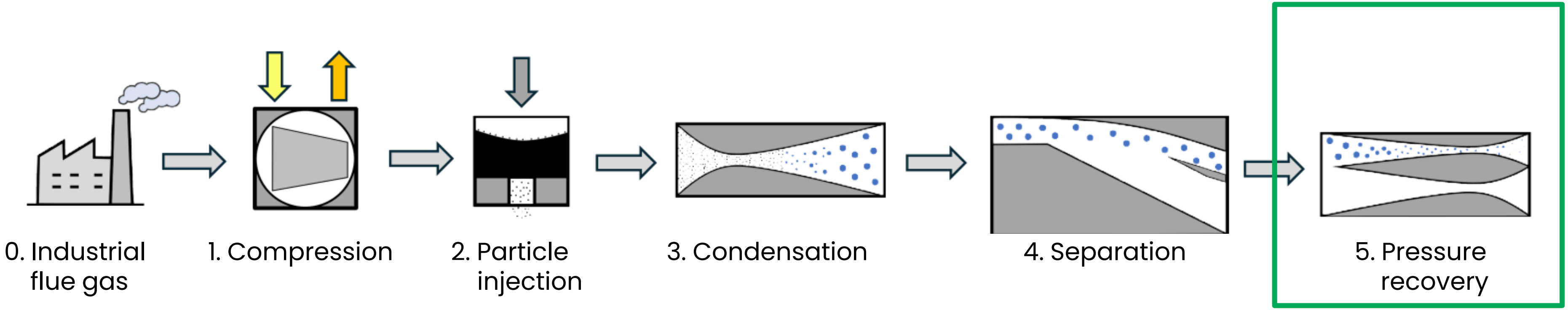
- A sharp convex corner creates expansion waves, turning the flow and further cooling the gas.
- Due to their inertia, **the particles** do not follow the gas and **are removed** by a separator plate that divides the flow.
- The flow must remain supersonic until the particles are separated from the gas to prevent CO2 from sublimating.

SYSTEM OVERVIEW:



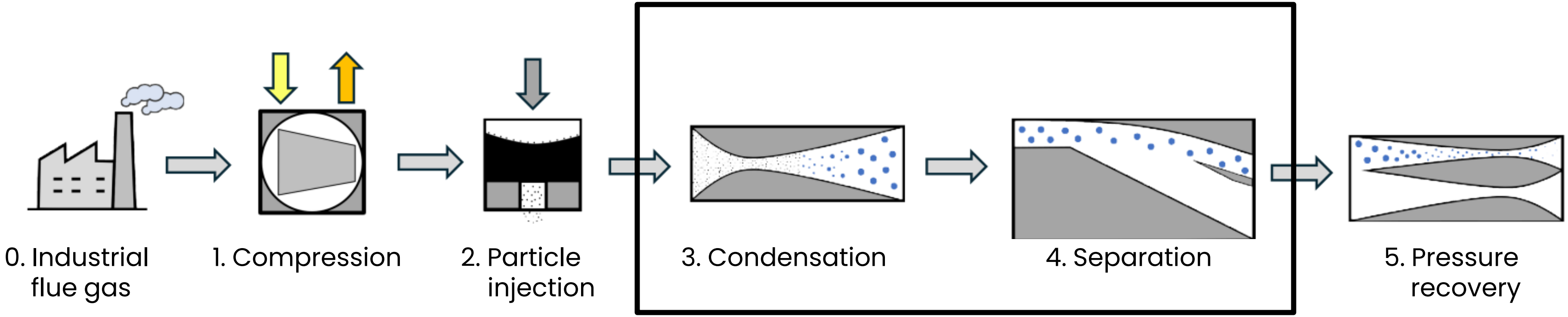
- A gradual deceleration of both flows raises the temperature and the pressure to ambient conditions in the most efficient way, minimizing the compression required in step 1.
- The gas must return to atmospheric pressure from the partial vacuum in step 4 before exiting the system.

SYSTEM OVERVIEW:



- In the **CO2-rich stream**, as the flow is slowed, CO2 sublimates to be sent to compression and storage.
- The particles are separated from the CO2-rich stream and reinjected into the system.
- The **CO2-lean stream** exits the system into the atmosphere.

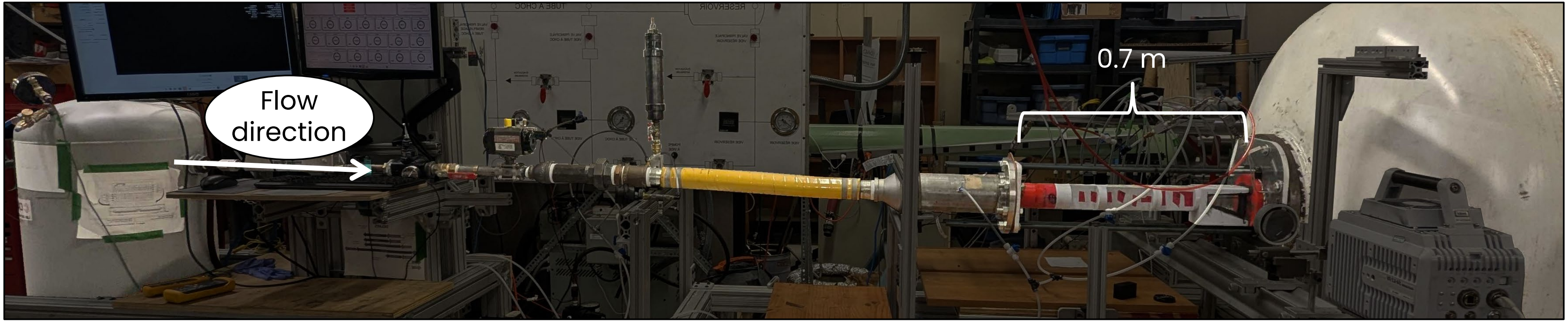
SYSTEM OVERVIEW:



The presentation will focus on the experimental results related to condensation and separation.

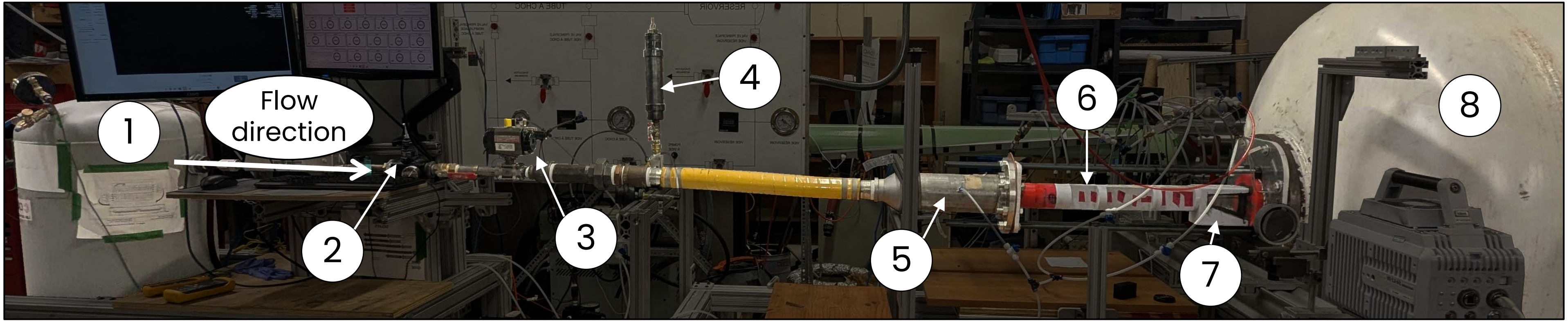
SUPERSONIC TEST BENCH:

The laboratory test bench is a blowdown-type system operating at flow rates equivalent to **1 tonne of CO2 per day at a concentration of 10 % CO2**.



SUPERSONIC TEST BENCH:

A blowdown system works for a few seconds by releasing the pressure from the pressure vessel (1) towards the vacuum vessel (8) when the valve (3) is open.

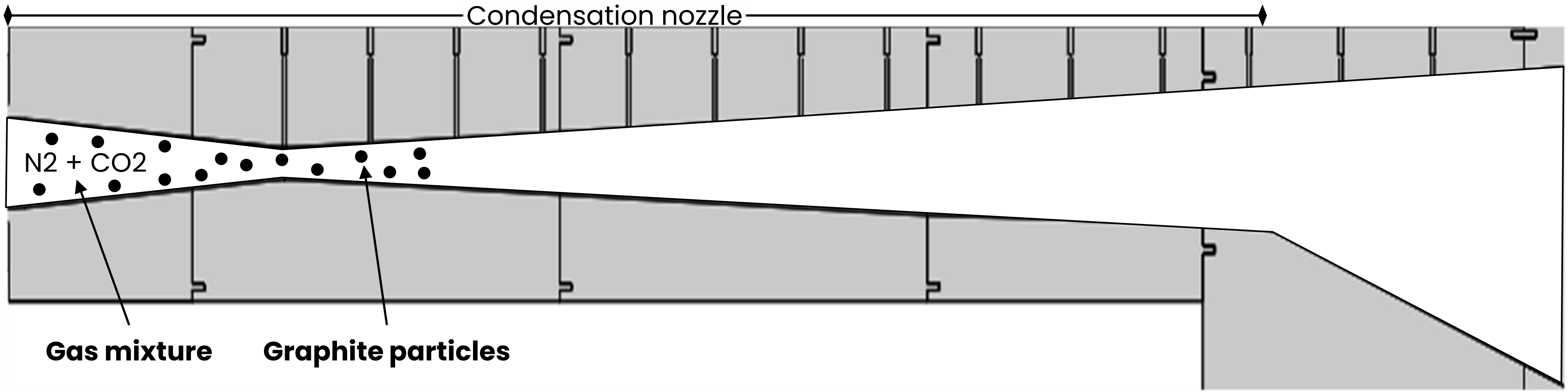


Composed of:

1. Pressure vessel,
2. Pressure regulator,
3. Pneumatic ball valve,
4. Particle injector,
5. Plenum,
6. Condensation nozzle,
7. Simple separator,
8. Vacuum vessel.

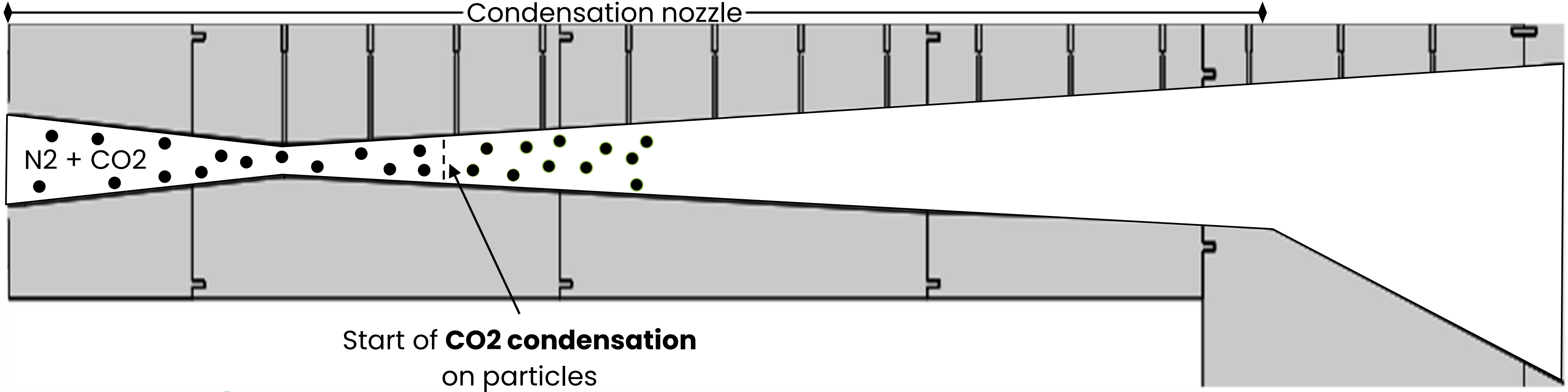
SUPERSONIC TEST BENCH – CONDENSATION:

1. CO_2 and particles accelerate together in the condensation nozzle.



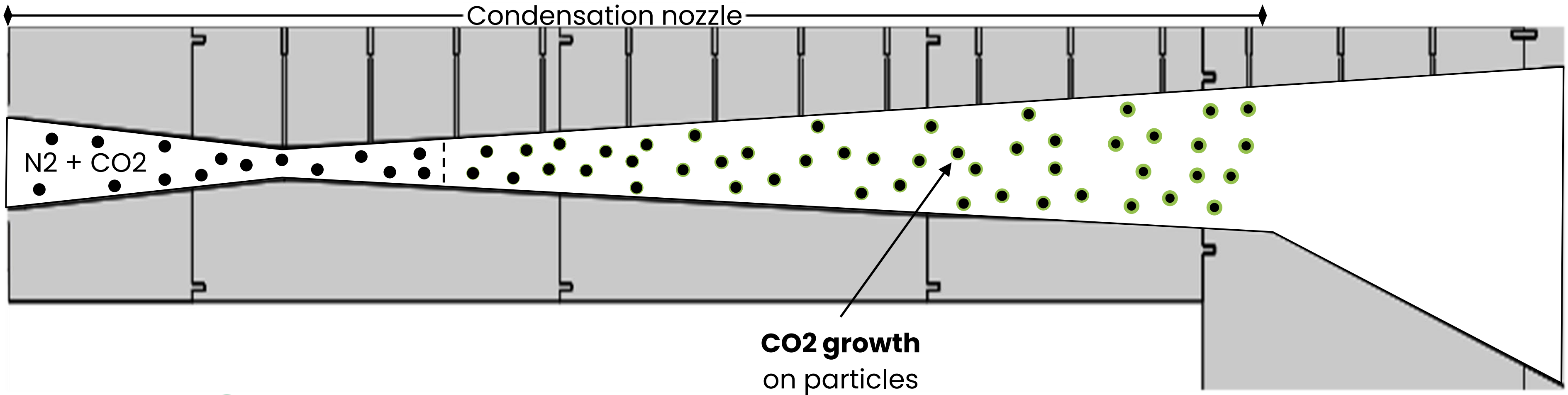
SUPERSONIC TEST BENCH – CONDENSATION:

1. CO2 and particles accelerate together in the condensation nozzle.
2. Shortly after the throat, CO2 begins to condense.



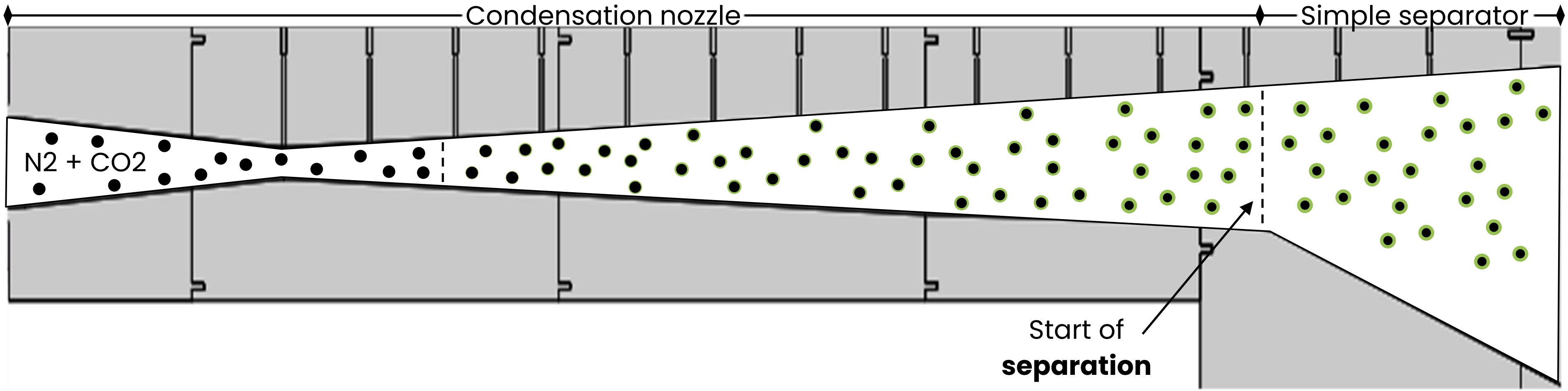
SUPERSONIC TEST BENCH – CONDENSATION:

1. CO_2 and particles accelerate together in the condensation nozzle.
2. Shortly after the throat, CO_2 begins to condense.
3. CO_2 continues to accumulate on the particles.



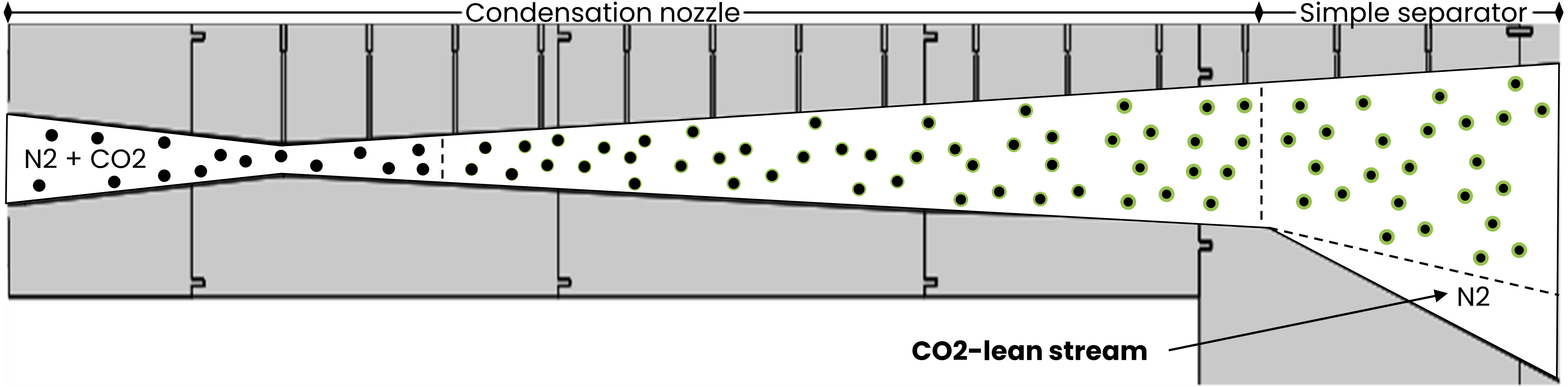
SUPERSONIC TEST BENCH – CONDENSATION:

1. CO_2 and particles accelerate together in the condensation nozzle.
2. Shortly after the throat, CO_2 begins to condense.
3. CO_2 continues to accumulate on the particles.
4. After the sharp corner, particles maintain their trajectory.



SUPERSONIC TEST BENCH – CONDENSATION:

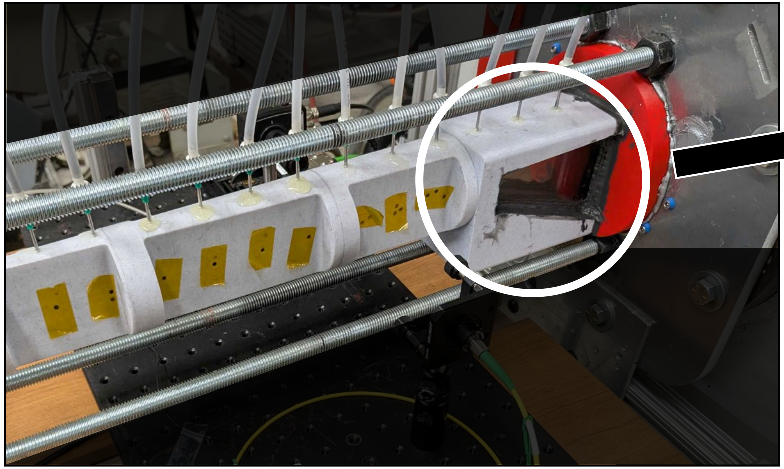
1. CO_2 and particles accelerate together in the condensation nozzle.
2. Shortly after the throat, CO_2 begins to condense.
3. CO_2 continues to accumulate on the particles.
4. After the sharp corner, particles maintain their trajectory.
5. The supersonic flow has to turn, resulting in a CO_2-lean stream at the bottom.

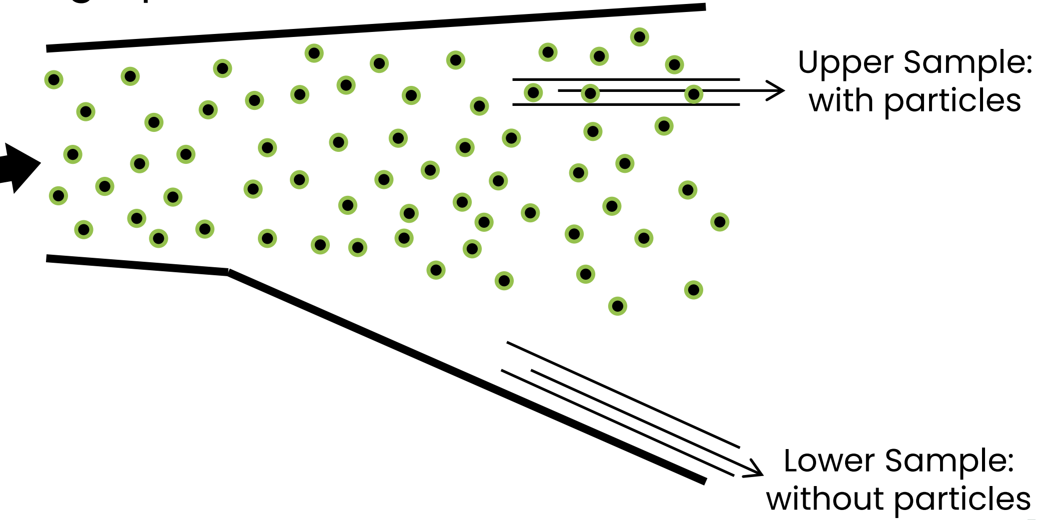


SUPERSONIC TEST BENCH – CONDENSATION:

The simple separator allows us to sample gas from a condensation test with and without particles. It is composed of two tubes connected to 500 ml syringes.

Example of test conditions: CO_2 concentration = 5 %, Initial pressure = 5 bar, Temperature = 23 °C, Particles = 1 µm graphite.

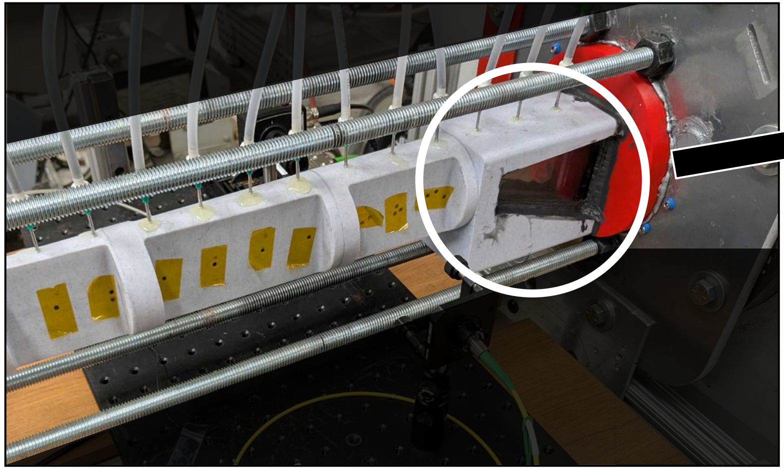


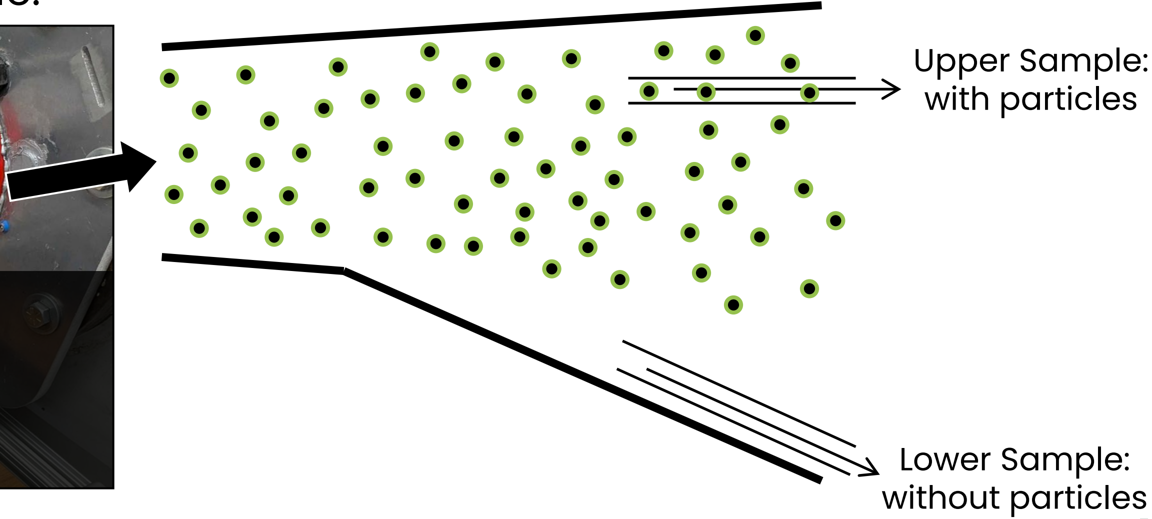


SUPERSONIC TEST BENCH – CONDENSATION:

Three possible outcomes:

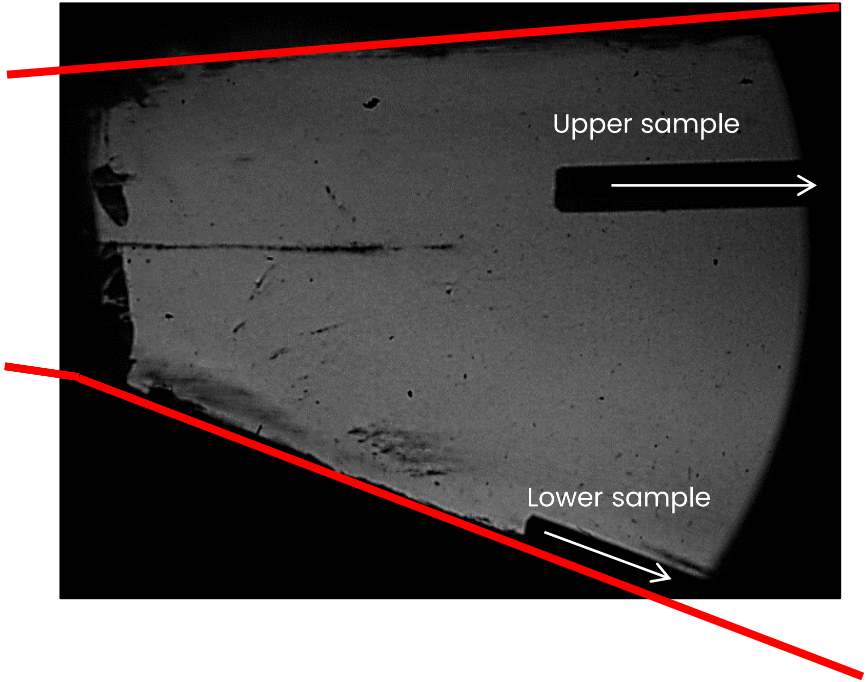
- No condensation → Same CO2 concentration in both samples.
- Condensation without separation → Same CO2 concentration in both samples.
- Condensation with separation → Lower concentration of CO2 in lower sample compared to upper sample.



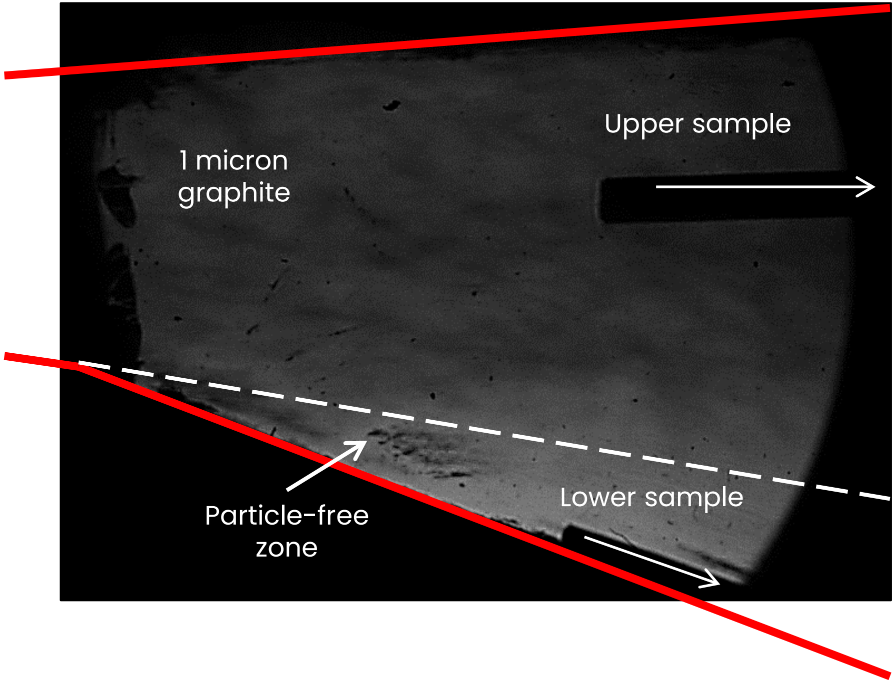


EXPERIMENTAL RESULTS – CONDENSATION:

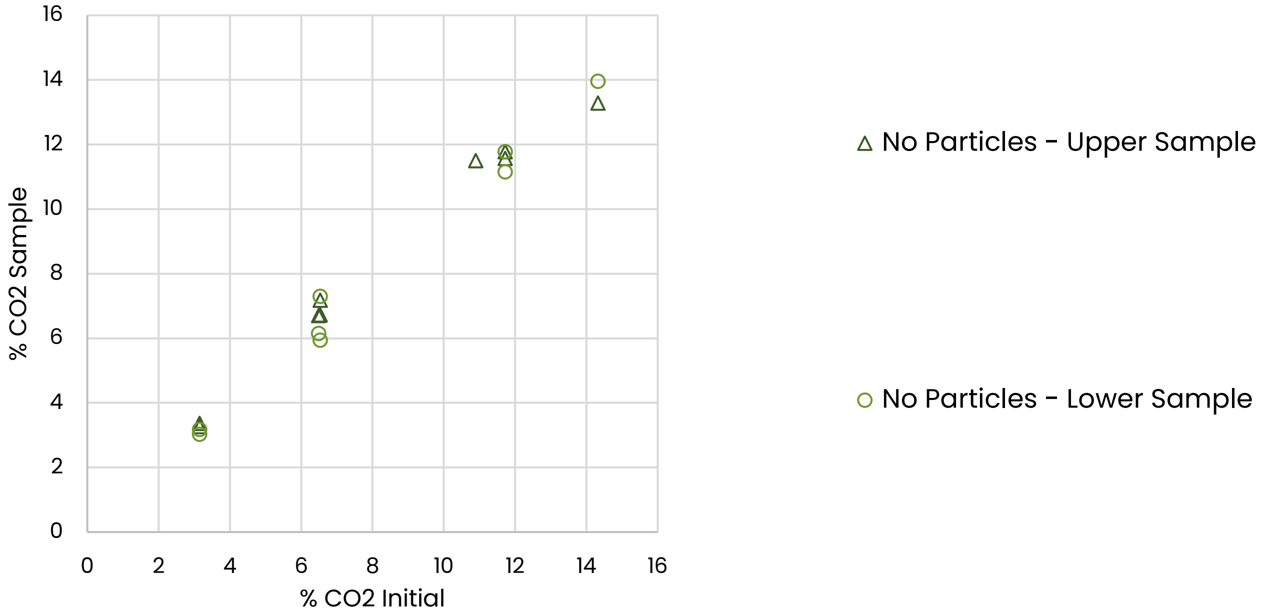
Reference image – No flow:



Test image – Particle laden flow:

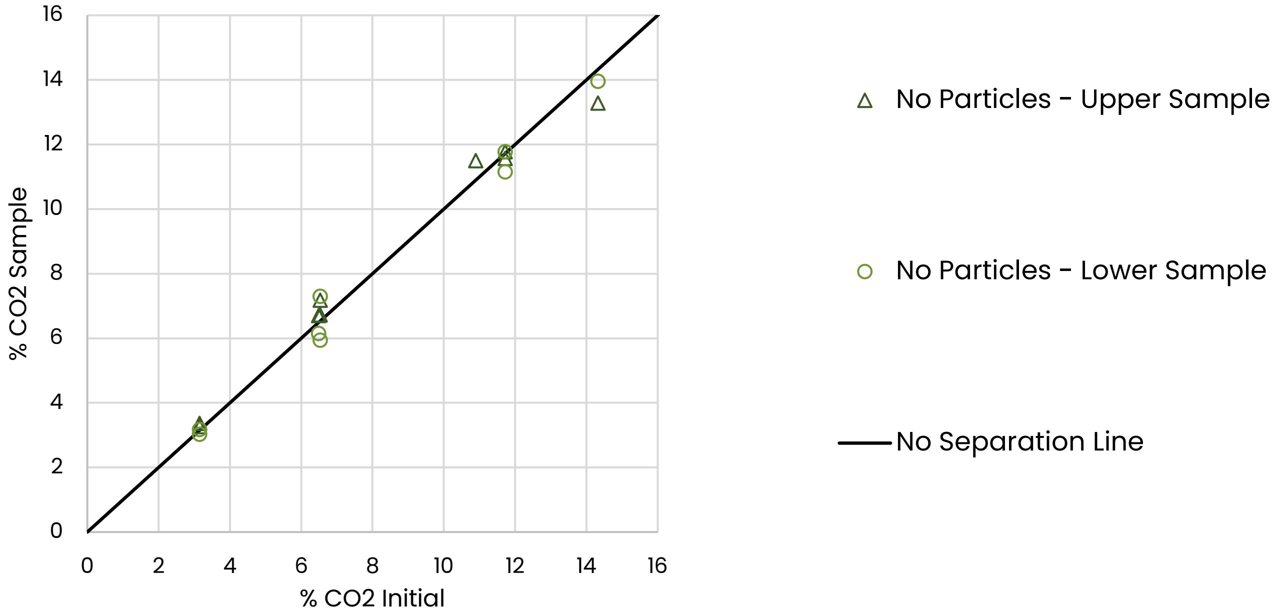


EXPERIMENTAL RESULTS – CONDENSATION:



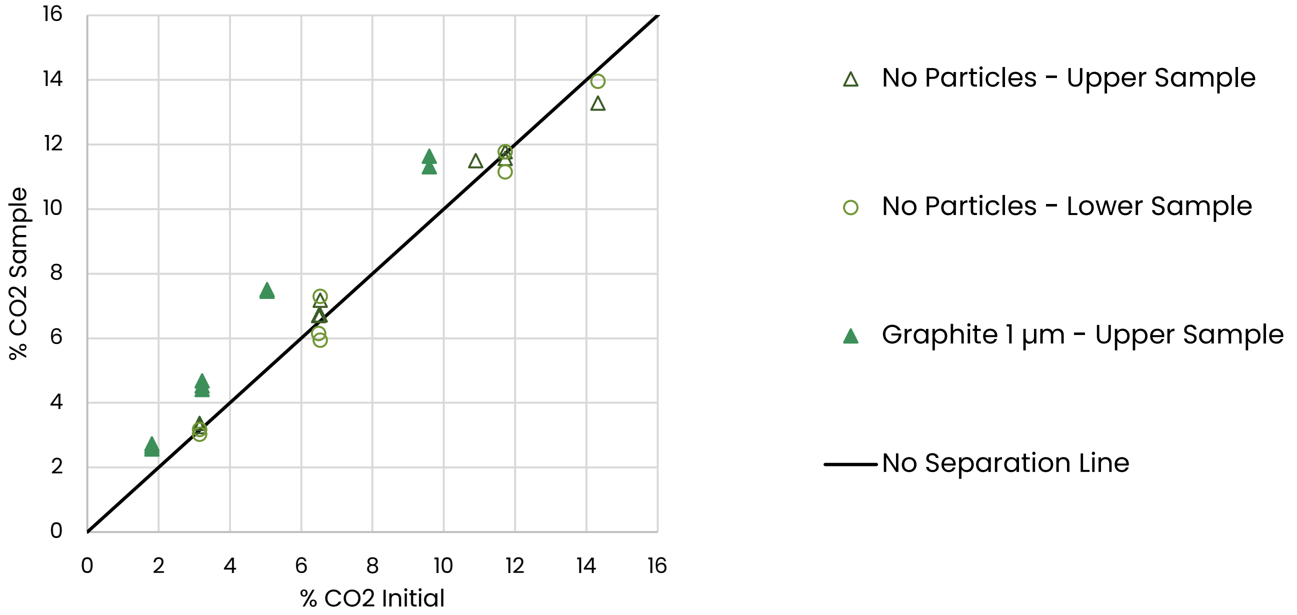
These are the CO_2 concentrations measured at the upper and lower sampling points, depending on the initial concentration.

EXPERIMENTAL RESULTS – CONDENSATION:



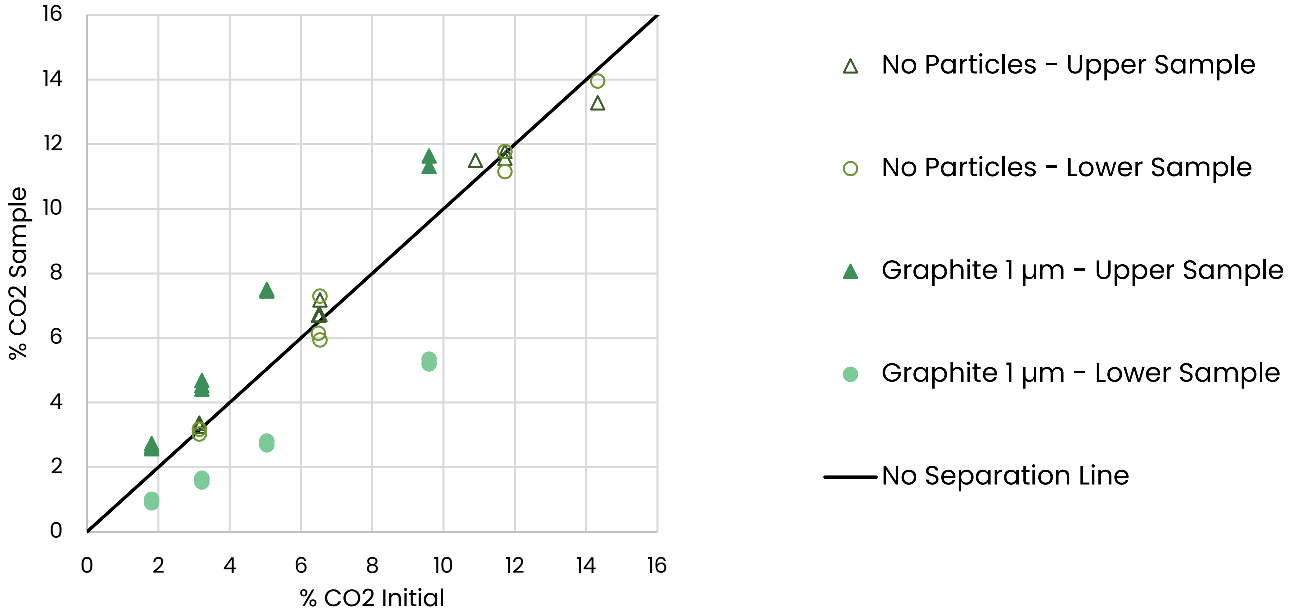
Tests without particles show no separation in both the upper and lower samples.

EXPERIMENTAL RESULTS – CONDENSATION:



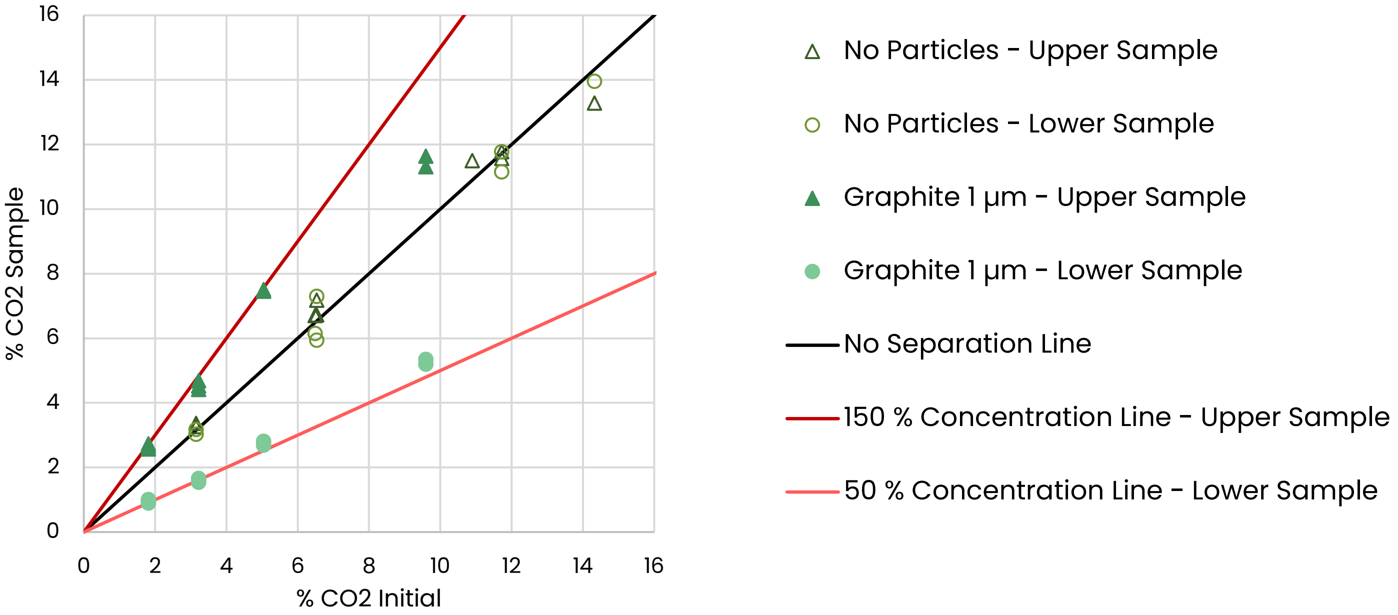
When 1 micron graphite is injected into the flow, an increase is observed in the CO_2 concentration in the upper sample (concentrated particles).

EXPERIMENTAL RESULTS – CONDENSATION:



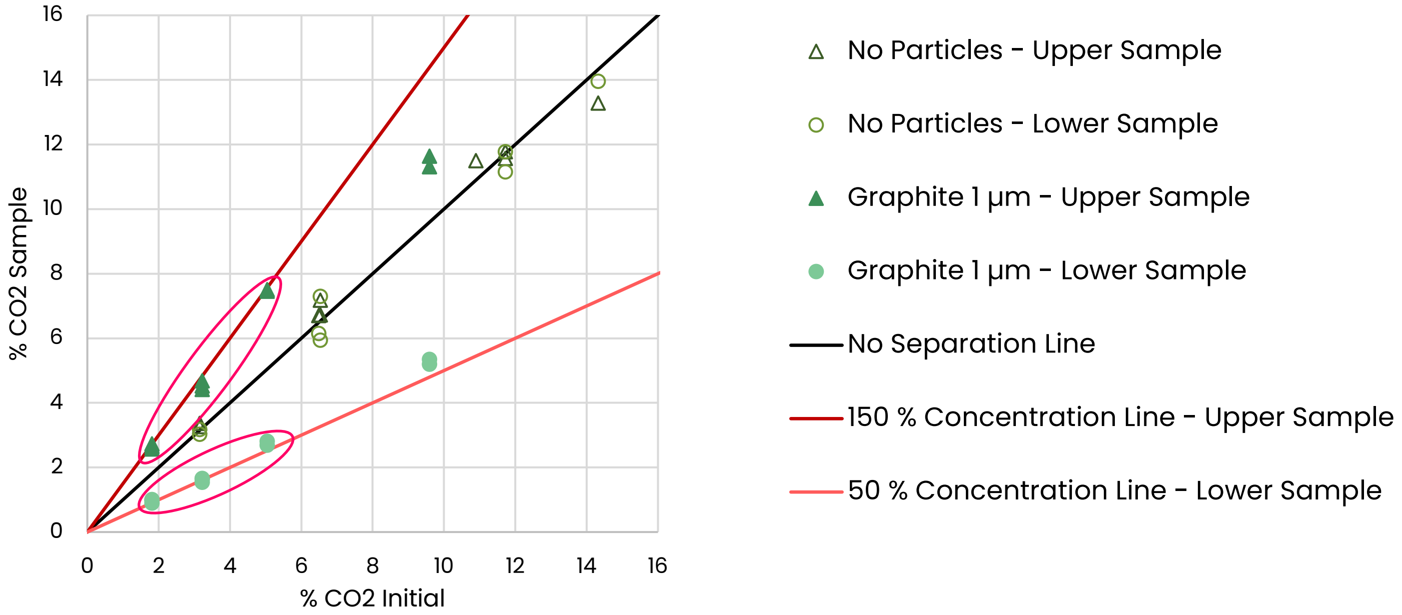
In these same tests, a decrease in CO_2 concentration is observed in the lower sample (without particles).

EXPERIMENTAL RESULTS – CONDENSATION:



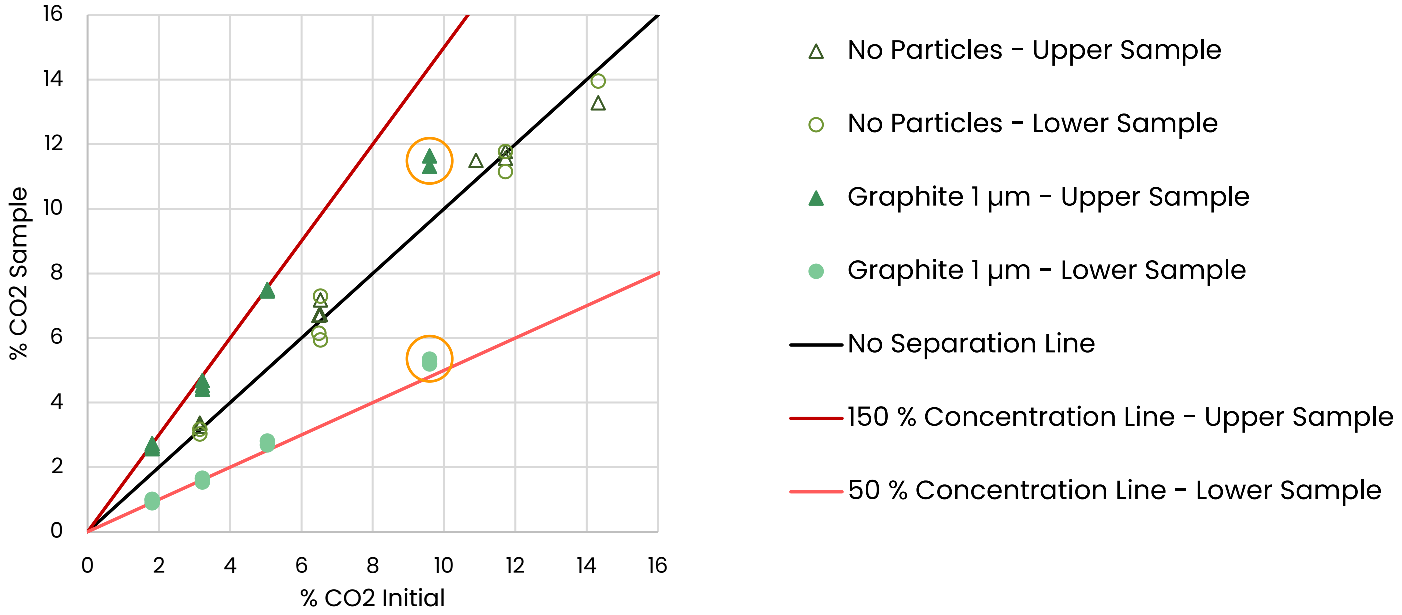
Two distinct trends are observed depending on the initial CO_2 concentration.

EXPERIMENTAL RESULTS – CONDENSATION:



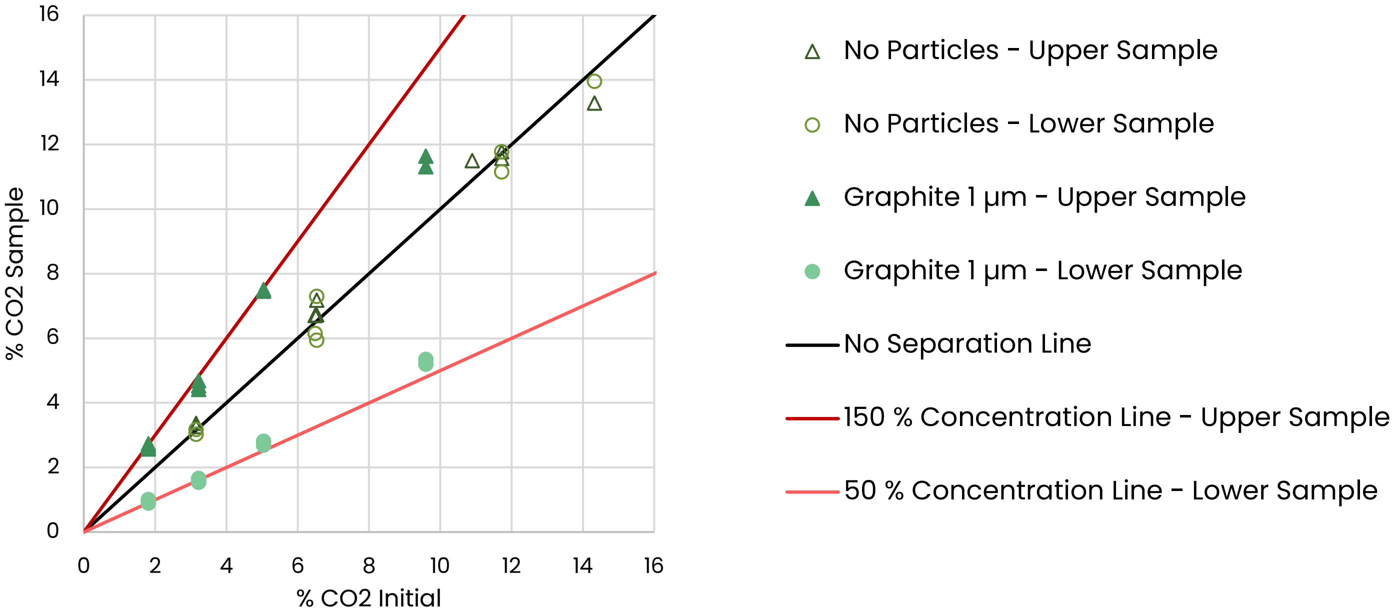
At low initial CO_2 concentrations, we observe a linear relationship between the initial and sample concentrations for both the upper and lower samples.

EXPERIMENTAL RESULTS – CONDENSATION:



At higher initial CO_2 concentrations, both upper and lower samples start to approach the No Separation Line.

EXPERIMENTAL RESULTS – CONDENSATION:

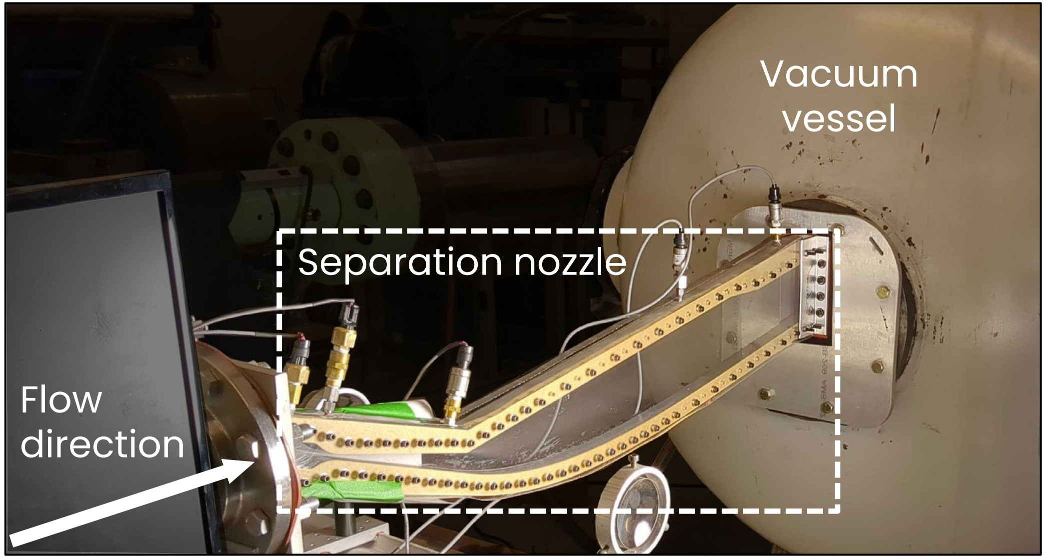


We suspect the deviation observed in both samples at higher initial CO_2 concentrations is due to incomplete condensation in the nozzle.

This could be mitigated by lengthening the condensation nozzle.

SUPERSONIC TEST BENCH – SEPARATION:

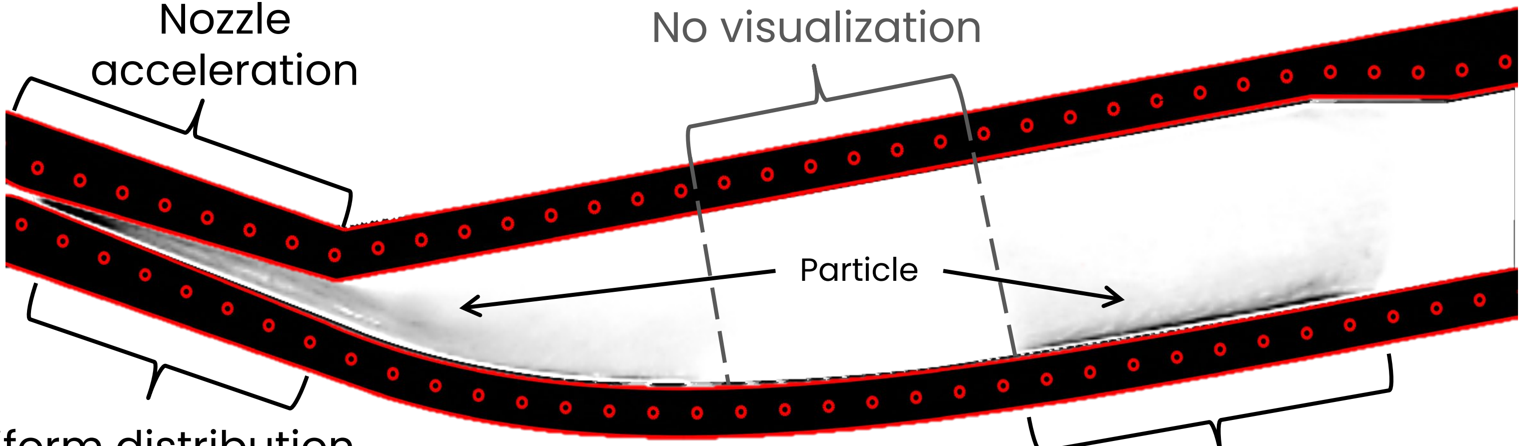
An optimized separation nozzle was tested separately, without condensation.



Example of test conditions: CO_2 concentration = 0 %, Initial pressure = 5 bar, Temperature = 23 °C, Particles = 5 µm graphite

EXPERIMENTAL RESULTS – SEPARATION:

Initially, particles are uniformly distributed within the nozzle. By the end of the nozzle, they are concentrated along the bottom wall.



INDUSTRIAL APPLICATION:

The table presents the simulated performance of a small industrial-scale system:

Industrial case for 10 % CO_2 emitting 70 $ktCO_2$/year		
Effluent flow rate	15	kg/s
Work in	4.3	MW
Heat out	5.3	MW
CO_2 separated	95	%
Energy consumption	700	kWh/tCO_2 *
Levelized cost of CO_2 avoided	55	USD/tCO_2 **

* Does not include potential savings generated by usage of waste heat.

** The cost is 60% OPEX with 0.035USD/kWh & 40% CAPEX with 5% interest for 20 years.

CONCLUSION:

- The results from the integrated nozzle allow us to confirm the **condensation of CO2 onto the injected particles**.
- These **particles can be effectively separated** from the gas by a well-optimized separator.
- This compact and simple design has been **validated through experiments** and **numerical simulations**.

FINANCIAL PARTNERS:

axelys

Économie
Innovation et Énergie
Québec

Natural Resources
Canada

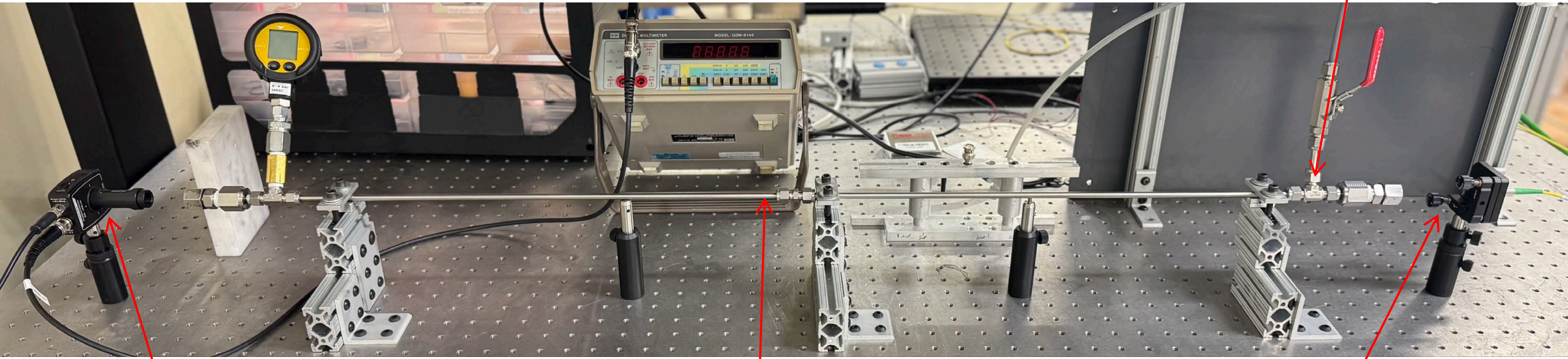
CARBOSONIC

THANKS TO ALL OF THEM!

CO2 MEASUREMENT ASSEMBLY:

The CO_2 from the syringes is measured using a tunable diode laser absorption spectroscopy (TDLAS) system.

Sample in



Detector

Sample cell

Laser in