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Session 12CM Control And Mitigation Technology III 9:45-10:45

"Separation of Aerosols by Localized Vapor Condensation"

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MICS

AEROSOL TECHNOLOGY LAB

MICS
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Circolare e Sostenibile

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Cleaning exhaust fumes

- Many industrial and domestic processes generate fumes containing vapors
- Exhaust fumes must be cleaned to satisfy emissions limits set by environmental protection agencies

Rubber vulcanization: low vapor pressure organic contaminants condense in exhaust ducts of post-vulcanization ovens

Cooking fumes: volatile organic compounds and water vapor from cooking can pollute the indoor environment

Recovering condensable substances

Collecting the condensed vapors may provide useful materials with a market value

Coffee roasting: the fumes are responsible for the aroma; they could be recovered and sold

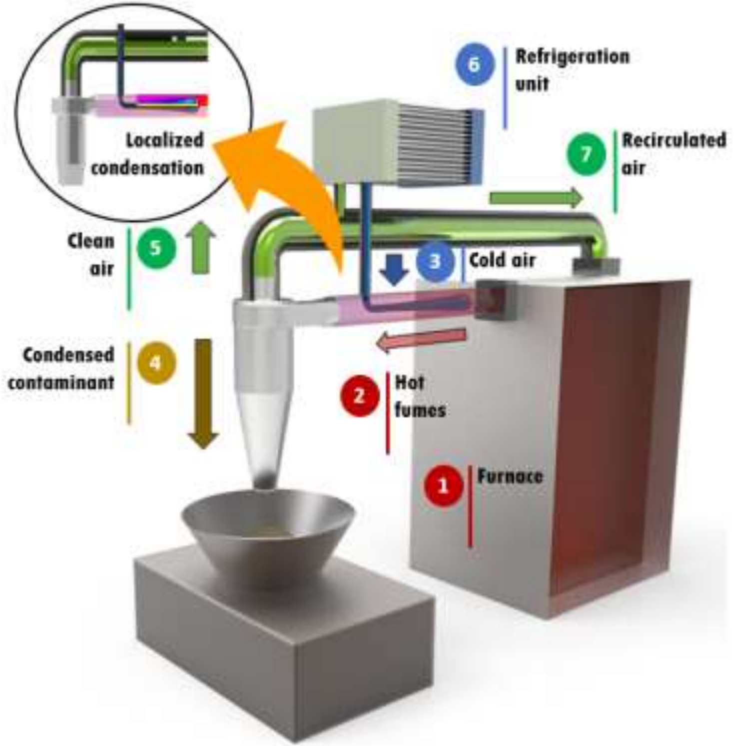
Wood pyrolysis: 40–70% of the initial mass is exhausted in the fumes; bio-oil or pyrolysis vinegar can be collected

Inertial separator for condensable substances

Dual-purpose device purifying exhaust fumes and recovering the pollutants

Closed-loop stand-alone unit adaptable to existing manufacturing lines

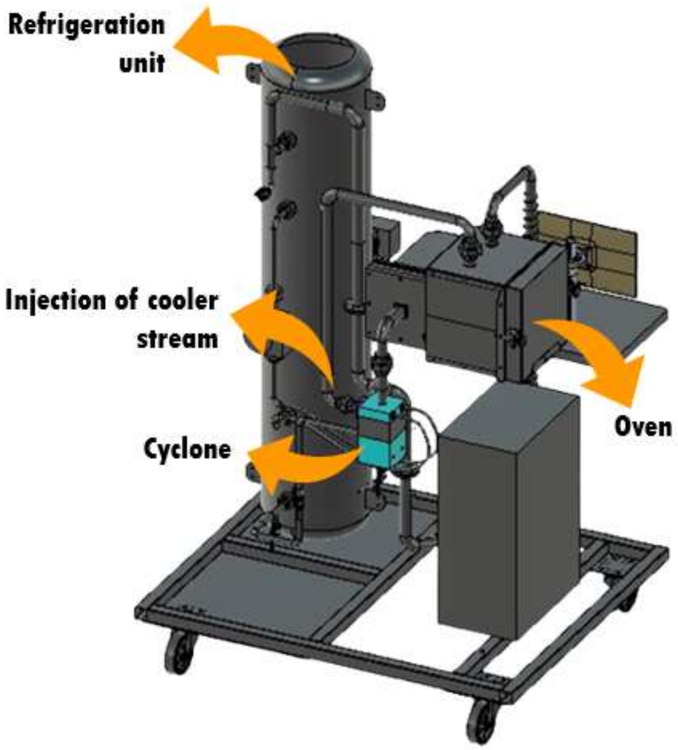
1. A colder flow cools down hot fumes
2. Condensable compounds reach saturation conditions
3. An inertial separator collects the particles generated by the condensation



Prototype design

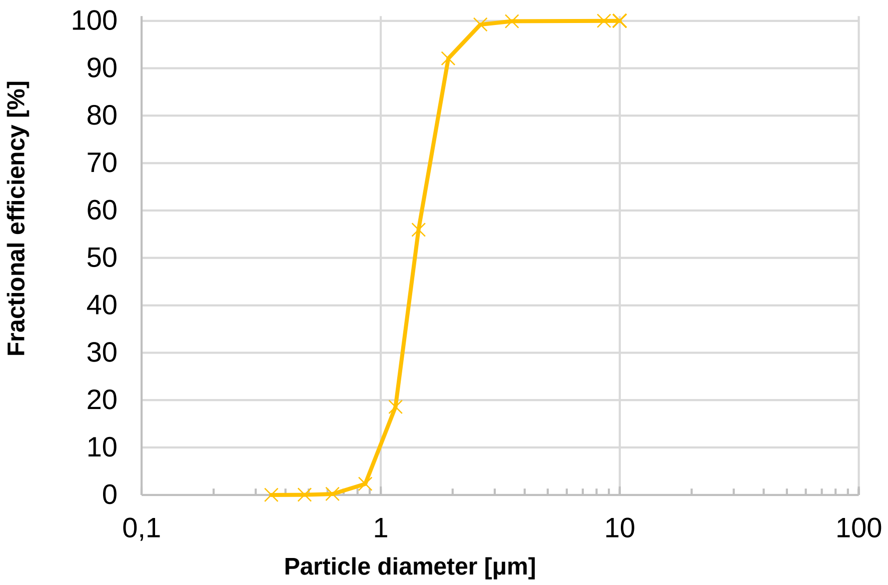
Proof of concept to test the working principle of the separator in a simplified way:

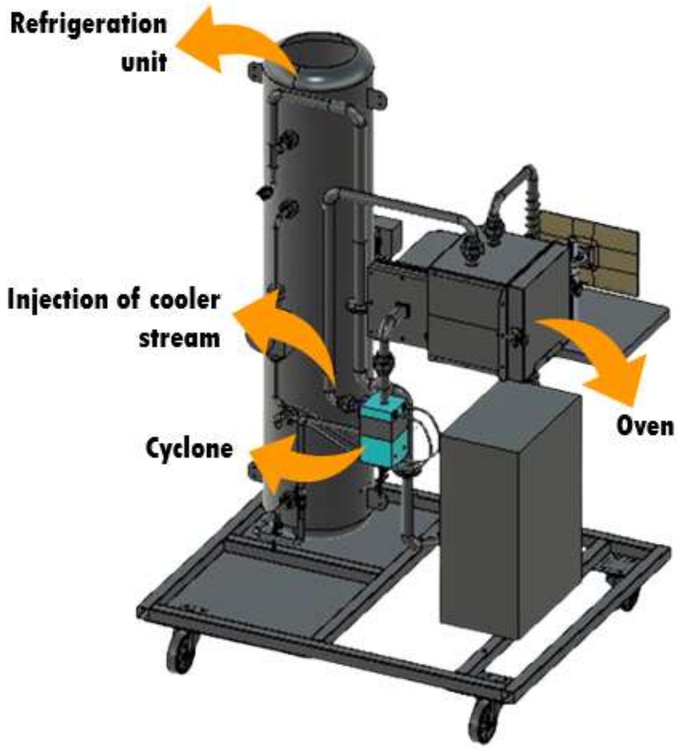
- An oven heats a boiler where the contaminant is generated by evaporation
- The vapors are mixed with a cooler flow in a specific section (nucleation, growth, and coagulation of the liquid particles)
- A cyclone separates the particles downstream
- Part of the cleaner fumes pass through a refrigeration unit (heat exchanger immersed in a refrigeration fluid)



Cyclone design

The cyclone worked at a flow rate of 10 m^3/h to provide a removal efficiency of 50% at 1.44 µm



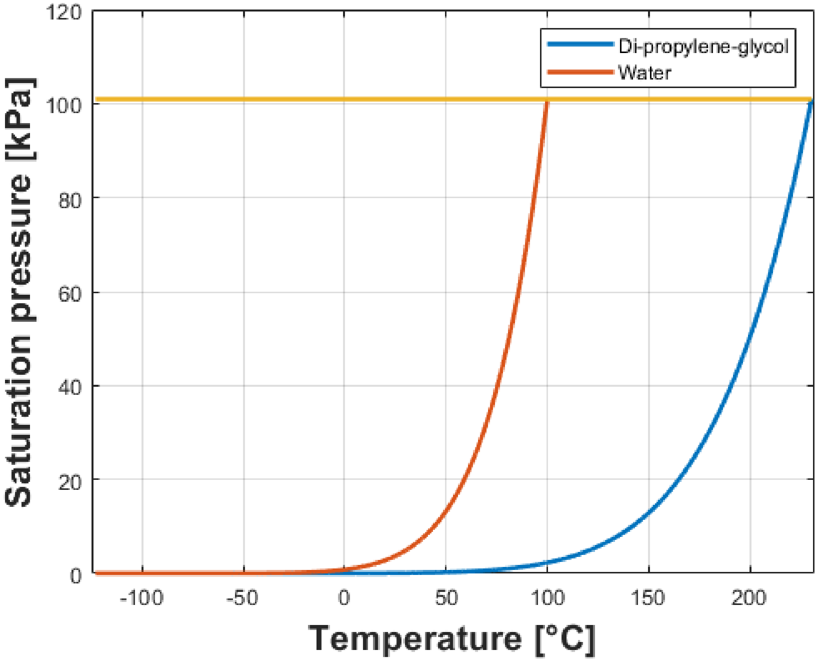


Test contaminant

To test the prototype's performance, we chose **dipropylene glycol**.

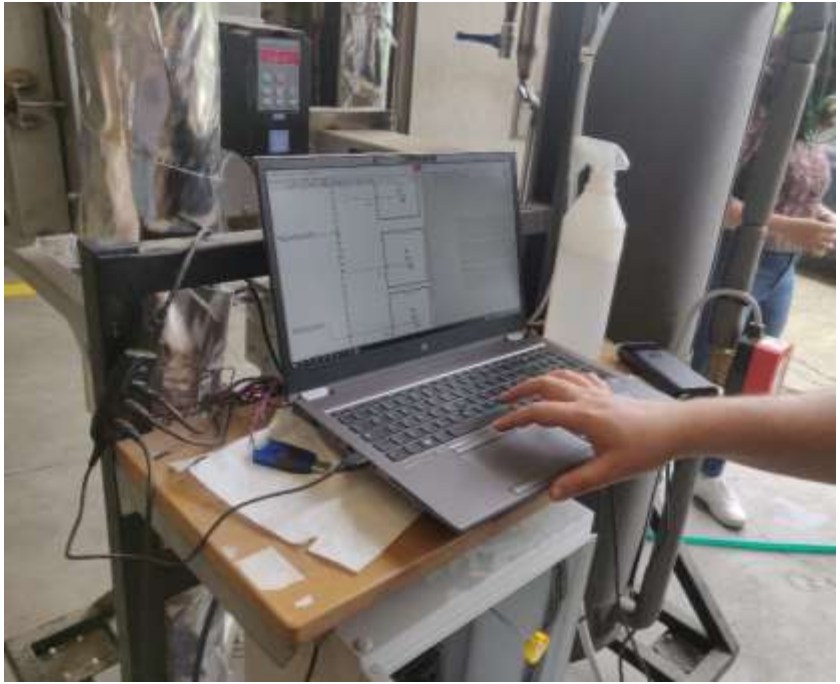
Edible **oils** or similar substances are made up of several organic chains, different in length and chemical nature

Water does not mimic organic substances generated from industrial processes



Pictures of the prototype

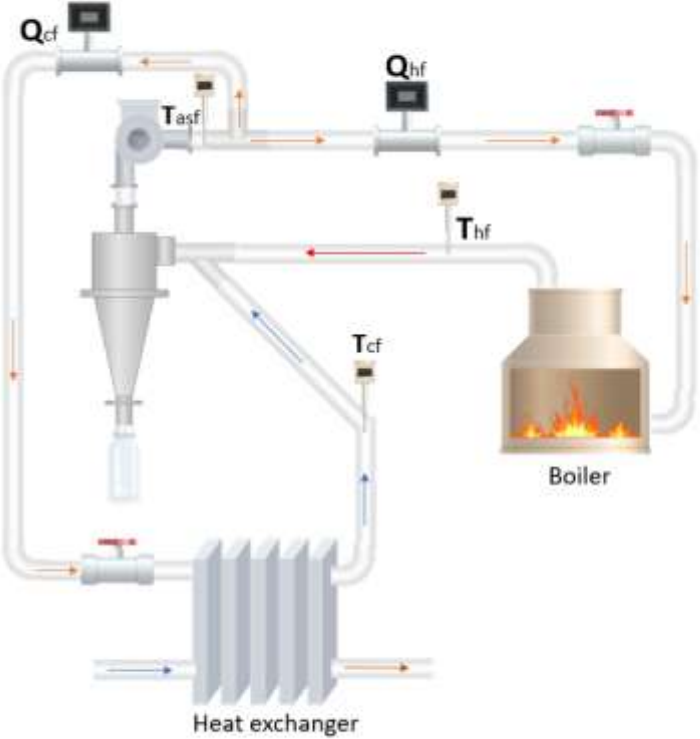
Vapor generation



Prototype testing

- Two mass flow meters, valves, and a centrifugal fan controlled the flow rate
- Two tests at different cold fumes temperature (T_{cf})

Test	Time [min]	Temperature of hot fumes out of boiler (T_{hf}) [°C]	Hot fumes temperature after separation (T_{asf}) [°C]	Temperature cold flow (T_{cf}) [°C]
1	56	139	46	1
2	73	130	54	-3



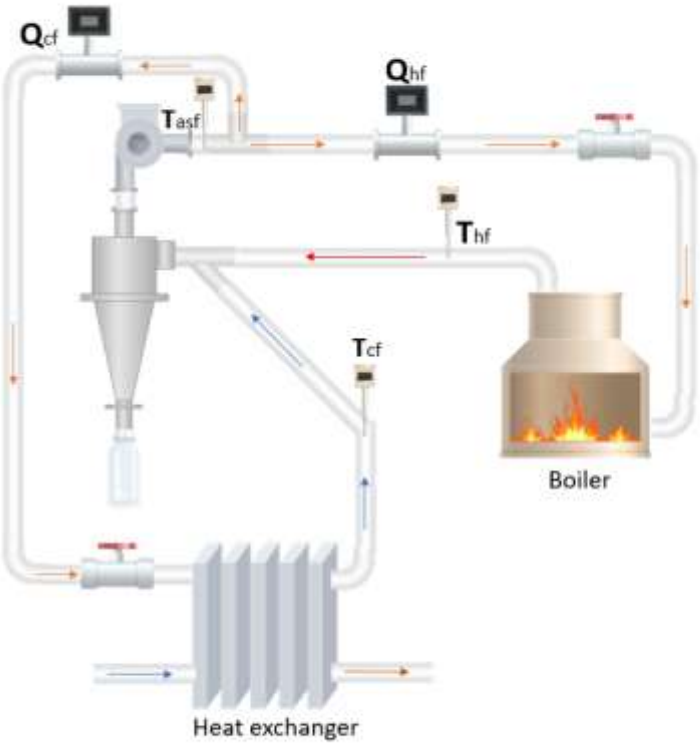
Removal efficiency

- Mass of contaminant evaporated: the difference between the amount of liquid in the boiler at the beginning and the end of each test
- Mass of liquid collected after the cyclone
- Removal efficiency:

$$\%CE = \frac{mass\ of\ contaminant_{collected\ after\ cyclone}}{mass\ of\ contaminant_{evaporated}}$$

Thermal power required to promote the condensation of the vapor:

$$\dot{Q} = \dot{m}\, c_p \left(T_{asf} - T_{cf}\right)$$



Impact of cold flow temperature

- Two percentages of dry ice in the refrigerant mix (at 30%, the mixture temperature was 0.5 ^{o}C, while at 70%, it was -10^{o}C)
- The collection efficiency increases by decreasing the temperature of the cold flow because the particle size distribution shifts towards larger particles
- It would be nice to measure it

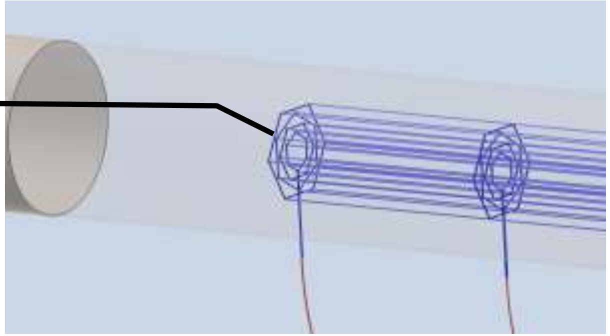
	30% Dry Ice	**70% Dry Ice**
Mass inside the boiler at the beginning of the test [g]	922	1265
Mass inside the boiler at the end of the test [g]	401	734
Mass of di-propylene glycol evaporated [g]	521	531
Mass collected after the cyclone [g]	255	271
Collection efficiency [%]	49	51

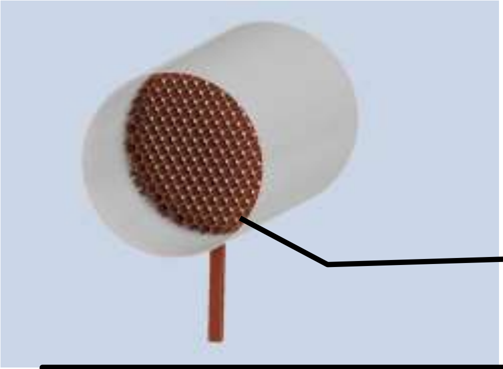
Heat conduction plus heat exchange inside the duct

Reintroducing cleaner and cooler fluid into the stream can be bulky or complex for some applications

Cooling the fumes using a conductive material introduced into the exhaust duct is simpler and provides interesting opportunities

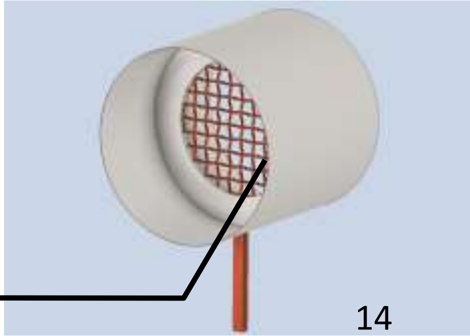
“Squirrel-cage” structure
Heat exchange without high turbulence and compatible with high viscosity fluids





“Honeycomb” structure
Enhances the heat exchange due to the high surface of heat exchange

“Wire-mesh” structure
Enhances the heat exchange and maximizes heat exchange while collecting particles of volatile compounds



Conclusions

- The prototype condenses a pure substance and effectively captures the condensed particles
- Industrial processes, e.g., the vulcanization of the rubber, release less volatile compounds than di-propylene glycol hence higher collection efficiencies can be achieved regardless of future improvements
- Knowing the correct temperature to bring the contaminants to saturation conditions is vital to avoid the extra cost of thermal energy
- Increasing the residence time of the contaminants in the nucleation phase could improve the cyclone operation and result in higher collection efficiencies

Questions?