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Carbon dioxide recovery by means of tsa in a sound assisted fluidized bed of fine activated carbon

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CARBON DIOXIDE RECOVERY BY MEANS OF TSA IN A SOUND ASSISTED FLUIDIZED BED OF FINE ACTIVATED CARBON

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MOTIVATION

CO_2 Emissions and Global Warming

20th century can be regarded as a century of explosive growth in **energy consumption** and rapid increase in population worldwide along with unprecedented speed of inventions of new technologies

All these epochal revolutions have created a new world that has become increasingly **dependent on combustion of hydrocarbon fuels,** which produces **CO_2 as waste**

The concentration of CO_2 in the atmosphere **has risen to a value of 370 ppm** today, from the **preindustrial value of 280 ppm**

A **warming trend is "unequivocal"** and **human activity has "very likely" been the driving force** in that change over the last 50 years (IPCC)

In 1997, the **Kyoto Protocol** was ratified by most of the developed countries setting the stage for an international effort to **reduce CO_2 emissions**

Greenhouse Effect

Increasing anthropogenic greenhouse gas concentrations leads to the warming of the earth surface and lower atmosphere

BAKGROUND – Adsorption by Sound assisted fluidization

Absorption

Membranes

Cryogenics

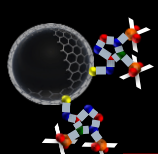
CO_2 separation techniques

Calcium looping

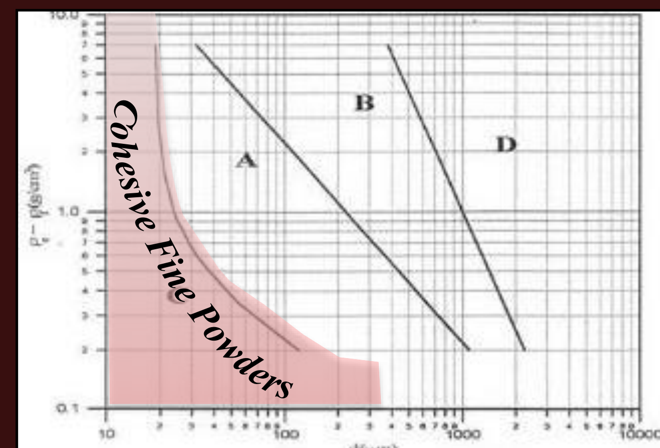
Adsorption

*It has the potential to replace the current absorption technology due to its **lower energy requirement***

- *By means of new materials whose physical and chemical properties can be tuned at the **molecular level***
- *Owing to their special size and shape, nanometric particles are particularly suitable to be easily **tailored and/or functionalized** on the surface with different ligands to induce significant changes in their physical and chemical properties*



SOUND-ASSISTED FLUIDIZATION

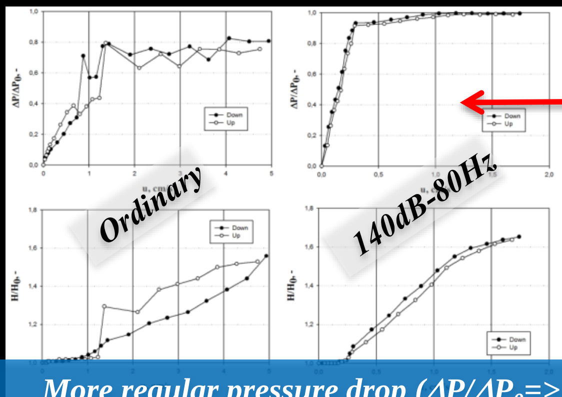


From Large Porous Aggregates (hundreds of μm)

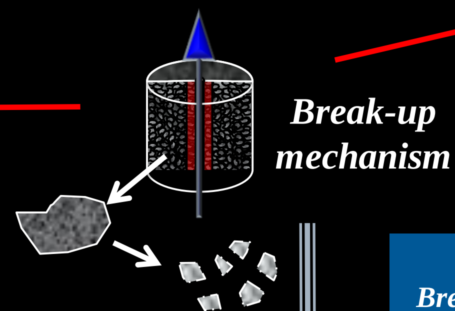
To Small Fluidizable Aggregates

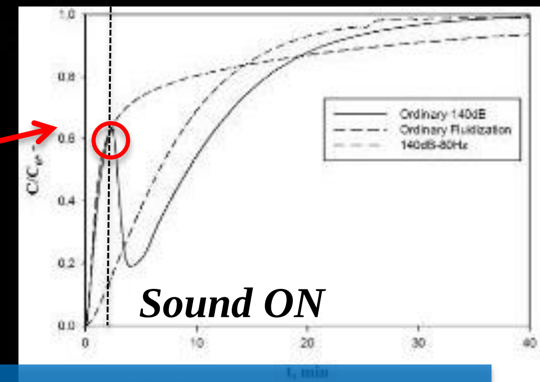
BAKGROUND – Adsorption by Sound assisted fluidization

SOUND ASSISTED FLUIDIZATION



- *More regular pressure drop ($\Delta P/\Delta P_0$=>1)*
- *Higher bed expansion ratios*





SOUND ASSISTED TESTS
Break-up mechanism ➔ Continuous renewing of the exposed surface

***Ordinary fluidization**: poor fluidization quality (channeling), as clearly confirmed by the fact that asymptotic value reached by the pressure drops is lower than 1 (i.e. portions of the bed are not fully fluidized)*[1-3]

***Sound assisted fluidization**: achievement of a proper fluidization regime in terms of both pressure drops and expansion curves, and decrease of the minimum fluidization velocity*[1-3]

[1]Ammendola, P., Chirone, R., & Raganati, F. (2011). Advanced Powder Technol., 22(2), 174–183.
[2]Ammendola, P., Chirone, R., & Raganati, F. (2011). Chem. Eng. Proc. 50(8), 885–891
[3]Raganati, F., Ammendola, P., & Chirone, R. (2015). KONA Powder and Particle Journal, 32(32), 23–40.

*The use of sound-assisted fluidization allows to **maximize the gas–solid contact efficiency** and, in turn, minimize the limitations to the intrinsic adsorption capacity of the sorbents. Acoustic field positively affects adsorption efficiency in terms of remarkably higher*[4-7]

- *Amount of adsorbed CO_2*
- *Breakthrough time*
- *adsorption kinetics*

[4]Raganati, F., Ammendola, P., & Chirone, R. (2014). Applied Energy, 113, 1269–1282.
[5]Raganati, F., Gargiulo, V., Ammendola, P., Alfe, M., & Chirone, R. (2014). Chem. Eng. J., 239, 75–86.
[6]Raganati, F., Ammendola, P., & Chirone, R. (2014). Powder Technol., 268, 347–356.
[7]Alfe, M., Ammendola, P., Gargiulo, V., Raganati, F., & Chirone, R. (2015). P. Combust. Inst. 35, 2801–2809.

Regeneration – Desorption by TSA

For adsorption to be used as CO_2 capture technique, an ***effective regeneration*** *of the spent adsorbents is needed*

Pressure

Pressure swing adsorption

Vacuum swing adsorption

Temperature

Temperature swing adsorption

Electric swing adsorption

Applied to flue gas[1]

PSA:

- *Expensive compression of a large fraction of inert N_2*
- *Decrease of the sorbent selectivity for CO_2*

VSA:

- *Costs of the vacuum pump (more than 70% of the power consumed in VSA)*

Applied to flue gas[2,3]

TSA:

- *Possible dilution effect*
- *Directly/indirectly heating*

ESA:

- *extra consumption of electric energy*
- *depends on the availability of adsorbents with electric conductivity*

It emerges that TSA by indirect heating is one of the best technological alternatives

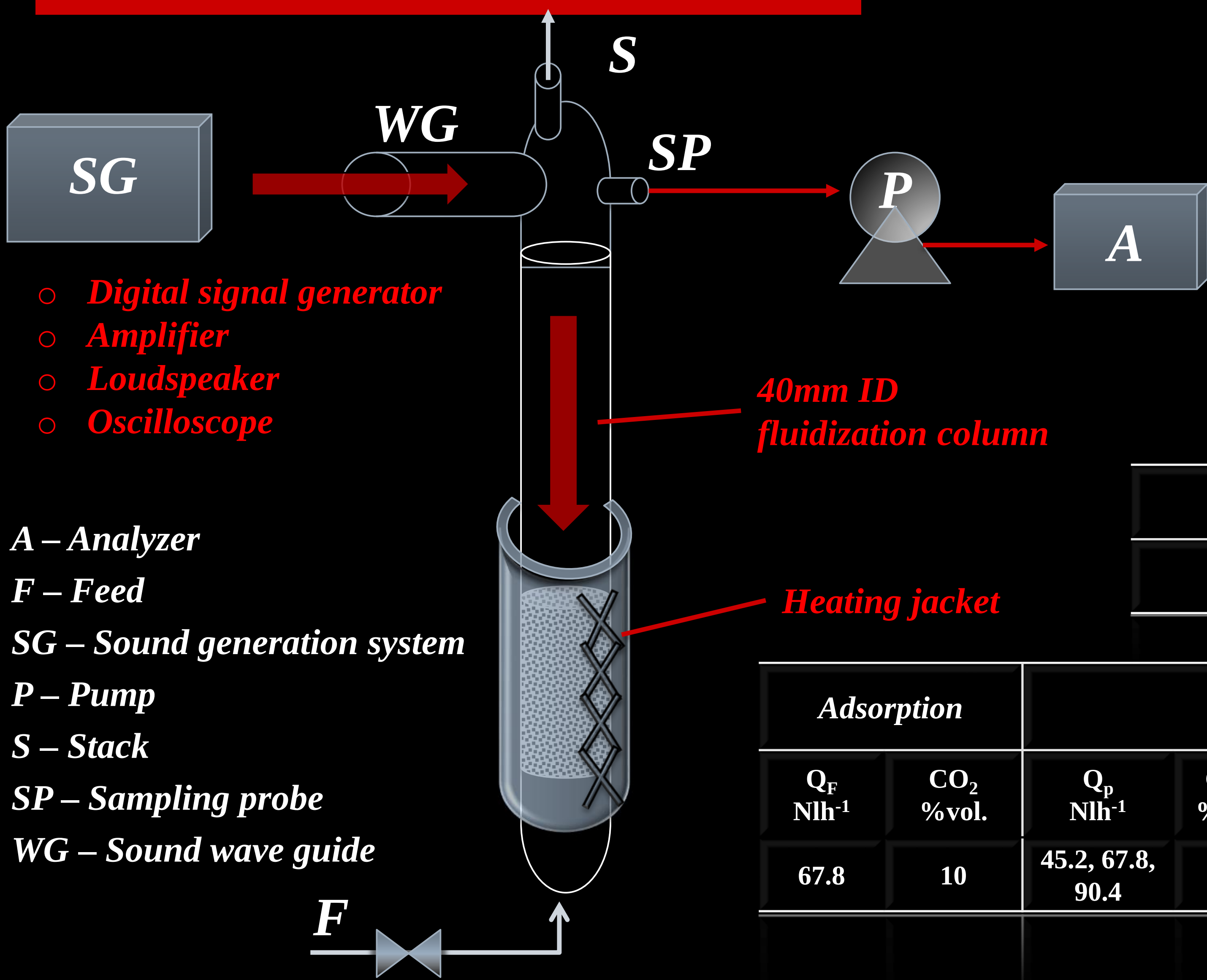
[1]Xiao et al., 2008, Adsorption 14, 575–582
[2]Plaza et al. 2010, Chemical Engineering Journal 163, 41–47
[3]Yu et al. 2012, Aerosol and Air Quality Research 12, 745–769

In this work

TSA in a sound assisted fluidized bed of fine activated carbon to recover the captured Carbon dioxide

- **Experimental Campaign**
  - *Desorption tests under* ***ordinary*** *and* ***sound assisted*** *fluidization conditions*
  - *Evaluation of the* ***desorption efficiency***
  - *Study of the main* ***operating variables****, i.e.* ***desorption temperature*** *and* ***N_2 purge flow rate***

Experimental Apparatus



- *A – Analyzer*
- *F – Feed*
- *SG – Sound generation system*
- *P – Pump*
- *S – Stack*
- *SP – Sampling probe*
- *WG – Sound wave guide*

Acoustic field

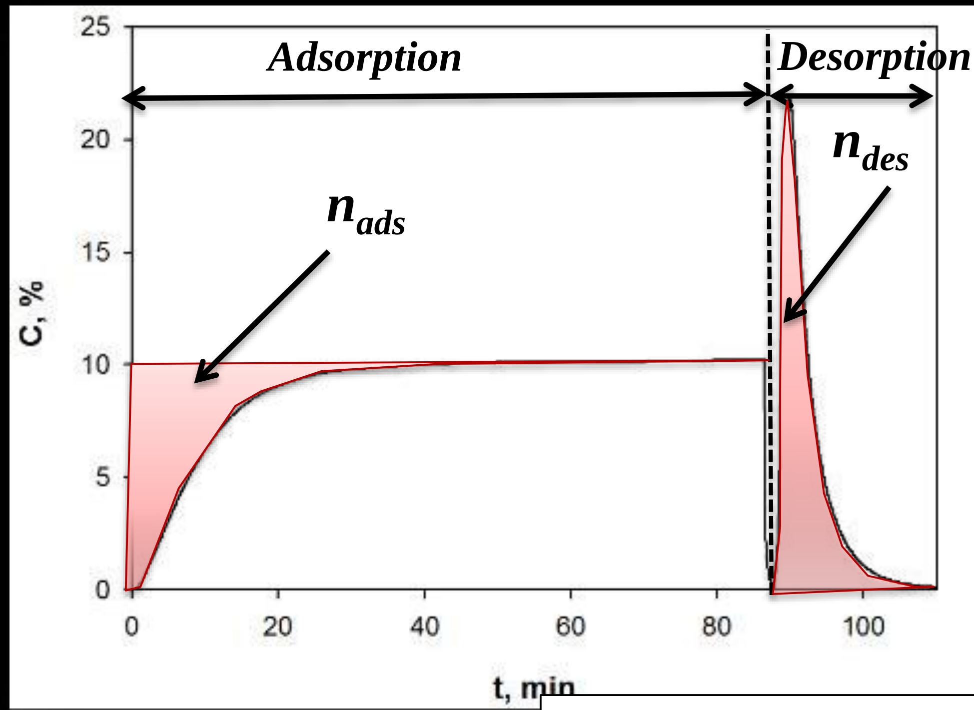
SPL dB	f Hz
140	80

Adsorption		*Desorption*		
Q_F Nlh^{-1}	CO_2 %vol.	Q_p Nlh^{-1}	CO_2 %vol.	T_{des} °C
67.8	10	45.2, 67.8, 90.4	0	25, 40, 70, 100, 130, 150

Results

Key Parameters

- *CO_2 Recovery - R*
- *Desorption time - t_d*
- *CO_2 purity - C_m*



AC Norit – 140dB-80Hz
Adsorb. → $Q = 67.8 Nlh^{-1}$
$C_0 = 10\%vol$
Desorb. → $Q_p = 67.8 Nlh^{-1}$
$T_{des} = 70°C$

$$C_i = \frac{V_i^{CO_2}}{V_i^{CO_2} + V_i^{N_2}} = \frac{\int_0^{t_i} Q_{CO_2}^{out}(t)dt}{\left(\int_0^{t_i} Q_{CO_2}^{out}(t)dt\right) + \left(Q_{N_2}^{p} \cdot t_i\right)}$$

$V_i^{CO_2}$ *CO_2 total volume desorbed at t_i*

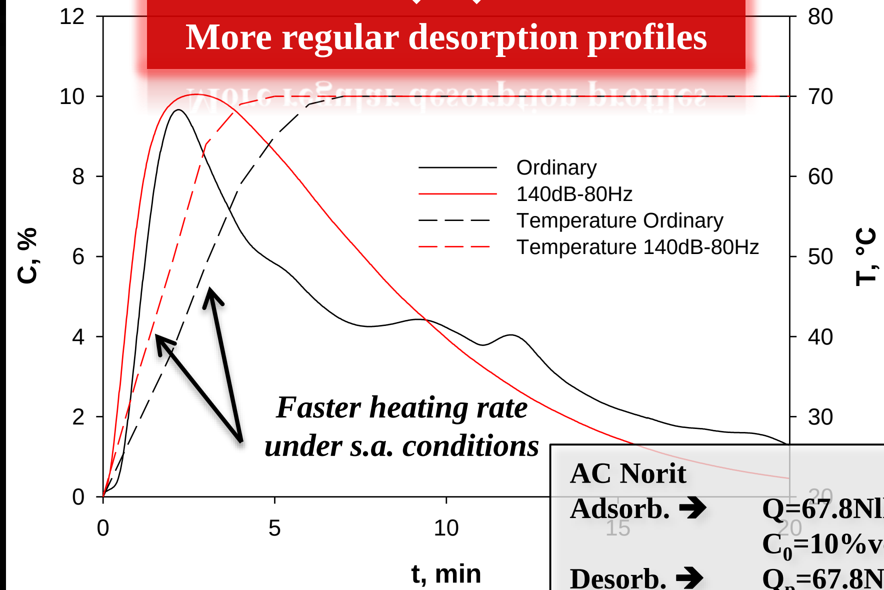
$V_i^{N_2}$ *N_2 purge gas volume fed to the column up to time t_i*

$Q_{CO_2}^{out}(t)$ *CO_2 outlet flow rate*

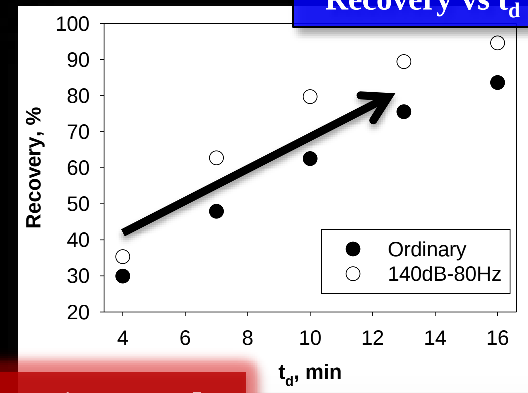
$Q_{N_2}^{p}$ *N_2 purge gas flow rate fed to the column*

Results – Effect of sound application

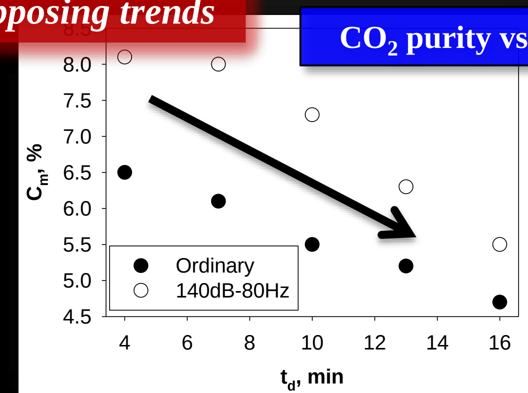
Sound assisted conditions
↓ ↓
More regular desorption profiles



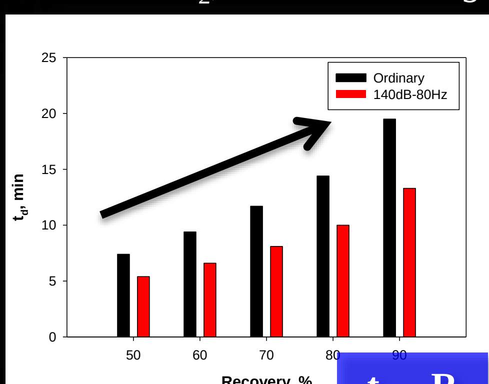
AC Norit
Adsorb. → $Q=67.8 Nlh^{-1}$, $C_0=10\%vol$
Desorb. → $Q_p=67.8 Nlh^{-1}$

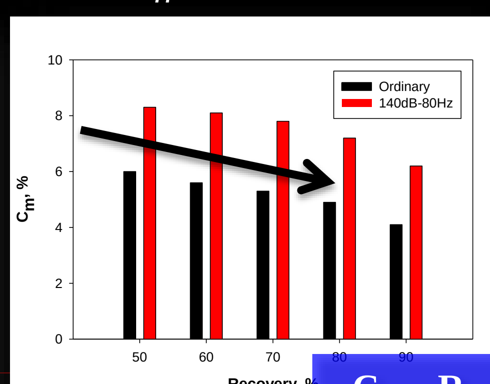


Opposing trends



Both CO_2 recovery and purity depends on the desorption time:
Higher t_d leads to a decrease of desorption rate due to a lower driving force, and, consequently, a larger purge volume is required to remove the residual adsorbed CO_2, thus determining a dilution effect

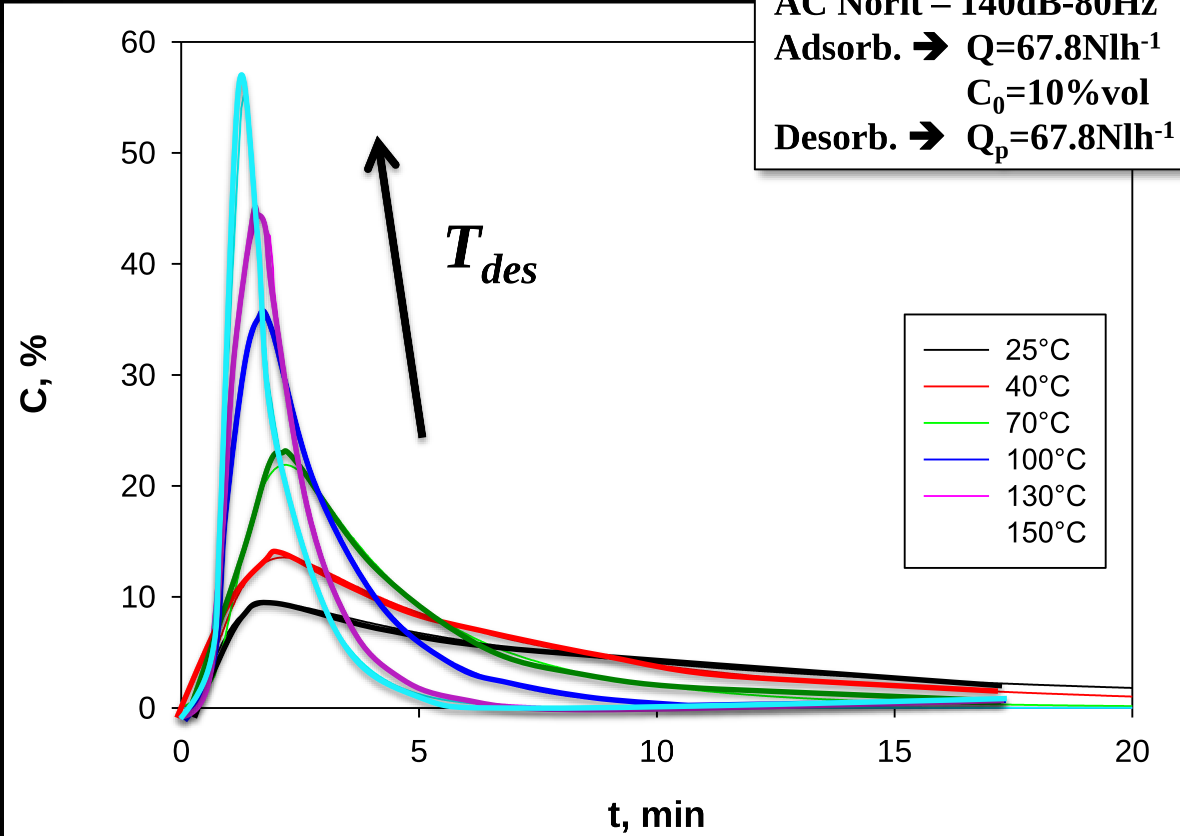


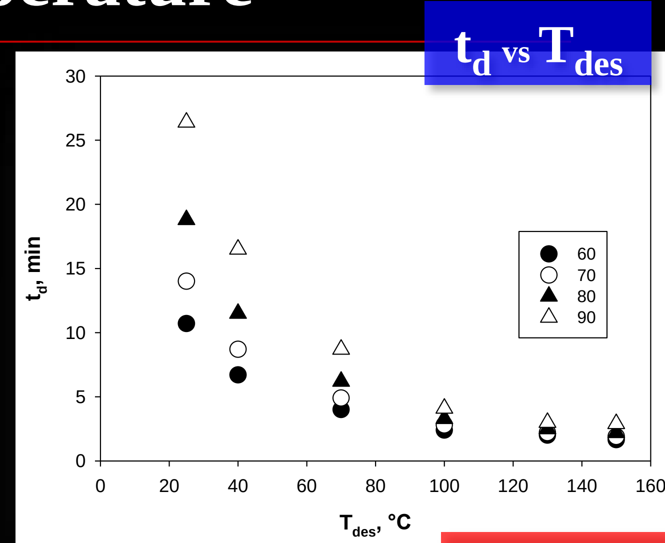


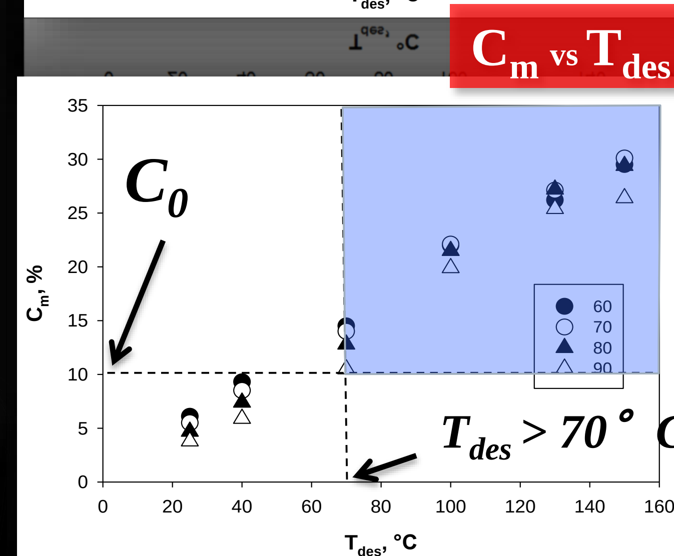
The application of the sound yields:
- ***Faster desorption kinetics***
- ***CO_2 enrichment***

Results - Effect of desorption temperature

AC Norit – 140dB-80Hz
Adsorb. ➔ $Q=67.8 Nlh^{-1}$
$C_0=10\%vol$
Desorb. ➔ $Q_p=67.8 Nlh^{-1}$







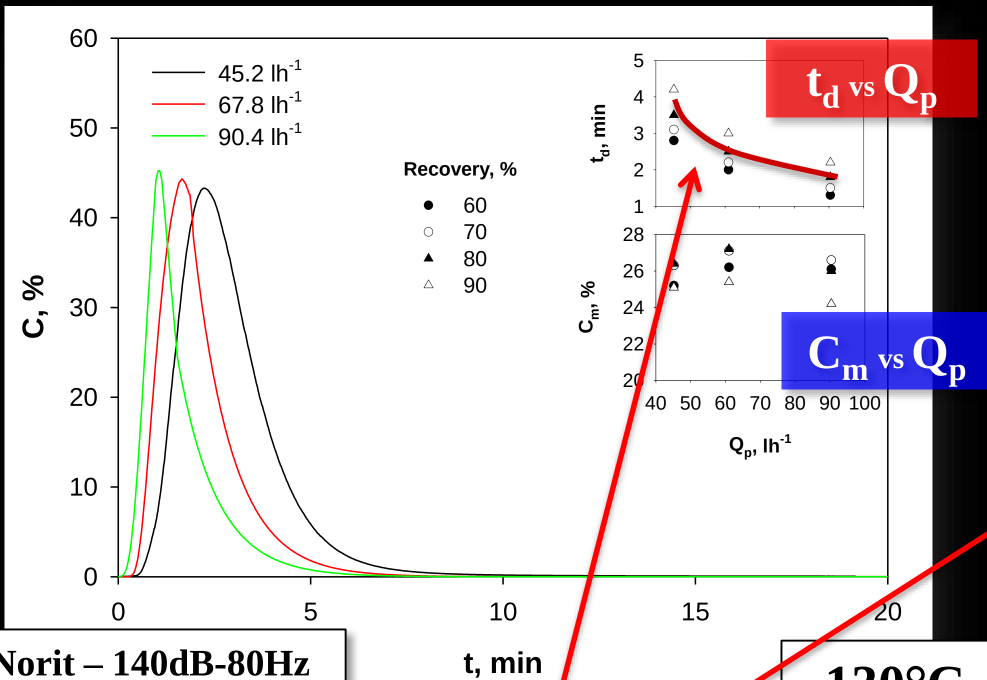
T_{des}

Enhancement of the regeneration kinetics

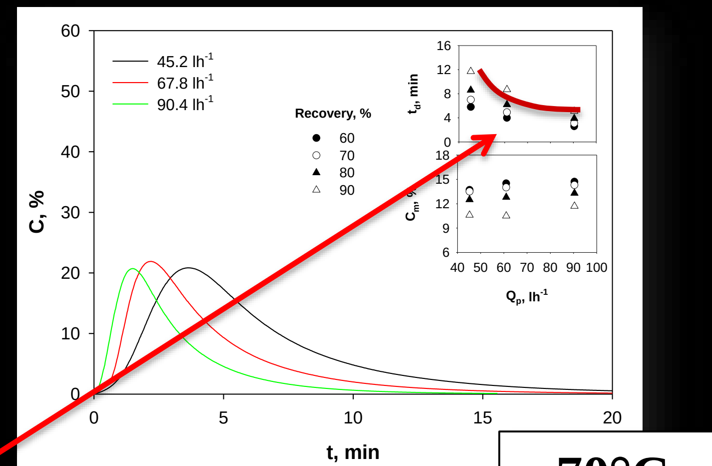
- *decrease in CO_2 adsorption capacity (i.e. enhancing the desorption)*
- *increase in both N_2 and CO_2 molecular diffusivities*

$T_{des} > 70°C$ are enough to obtain an enrichment of the recovered CO_2 stream (i.e. Ci > 10%vol.).

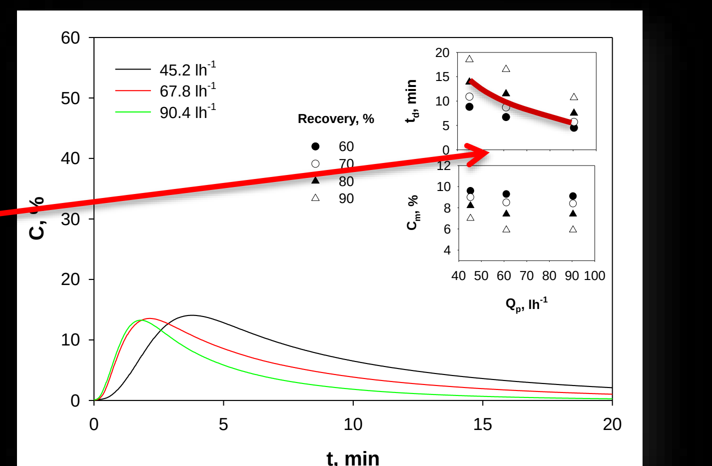
Results - Effect of purge flow rate



130°C



70°C



40°C

AC Norit – 140dB-80Hz
Adsorb. ➔ Q=67.8Nlh^{-1}
C_0=10%vol

- *Increase of Q_p has a positive effect on desorption kinetics: the time needed to obtain a desired CO_2 recovery monotonically decreases with Q_p*
- *For each T_{des} and for each R, Q_p has no influence on both the maximum and mean CO_2 concentration, which are mainly affected by the T_{des}*

Conclusions

- *The capability of sound assisted fluidization to enhance the CO_2 desorption on fine powders has been proved. The application of the sound makes it possible to obtain:*
  - *more **regular** desorption profile,*
  - *to remarkably **increase the desorption rate***
  - *to **enrich** the recovered CO_2 stream*
- *The main aspects influencing the CO_2 adsorption process have been analyzed*
  - ***Desorption Temperature**: increasing temperatures yield **faster desorption kinetics** and **more concentrated streams**; desorption temperature higher than 70° C are enough to obtain streams more concentrated than the inlet stream*
  - ***Purge flow rate**: increasing N_2 purge flow rates yield **faster desorption kinetics**; on the contrary, it has **no influence** on the mean CO_2 concentration*

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Thanks for your kind attention