SOCRATCES

ROLE OF ACOUSTIC FIELDS ON THE FLUIDIZED BED CARBONATION FOR TCES IN CSP APPLICATIONS

Paola Ammendola

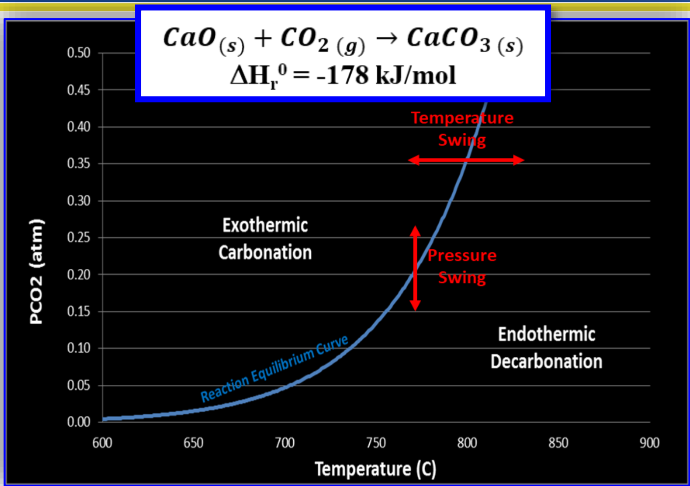
Istituto di Scienze e Tecnologie per l'Energia e la Mobilità Sostenibili (STEMS) - CNR,
P.le V. Tecchio 80-80125 Naples, Italy

SOCRATCES WEBINAR 10 June 2021

SOLAR CALCIUM-LOOPING INTEGRATION FOR THERMO-CHEMICAL ENERGY STORAGE

Politecnico di Torino · Universidad de Sevilla · EKETA · Universidad Zaragoza · CSIC · calix · virtualmech virtual engineering. real results · BIOAZUL · ttz Bremerhaven · Aristotle University of Thessaloniki · spi Sociedade Portuguesa de Inovação · iSiTEC · Consiglio Nazionale delle Ricerche

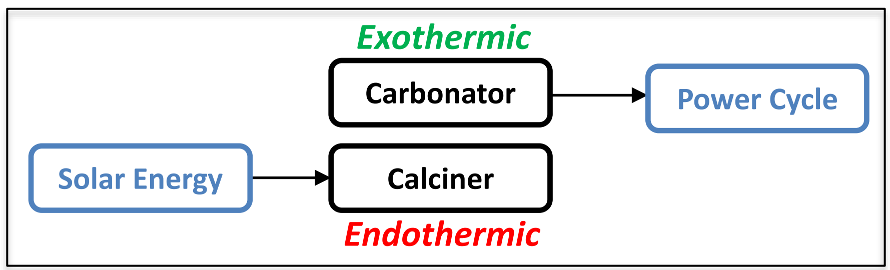
Calcium Looping



- Reaction fully reversed by **temperature and/or pressure swing**
- High heat of reaction (**-178kJ/mol**)
- High energy storage density (**3.26 GJ/m^3**)
- Reaction equilibrium occurs in relevant temperature range of **650-900°C**
- Low cost, non-toxic, abundant storage media (**~$10/ton**)
- **Capacity** and **durability** are key **challenges**

CaL (widely studied for CCS applications) is generally performed in **two interconnected fluidized beds**, one acting as **carbonator** and the other as **calciner**

CaL for CSP



	CaL for CSP	CaL for CCS
Carbonation	~ **850 °C** and **high PCO$_2$** - in order to obtain high thermal to electricity efficiency of the power cycle	~ **650 °C** and **low PCO$_2$** - up to 0.2atm as typical of a combustion flue gas
Calcination	~ **700 °C** and **low PCO$_2$** - a gas easily separable from CO$_2$ (helium) is used to reduce sintering and allowing the use of already available solar receiver	~ **950 °C** and **high PCO$_2$** - pure CO$_2$ is fed to the calciner in order to recover a pure CO$_2$ stream for the storage step

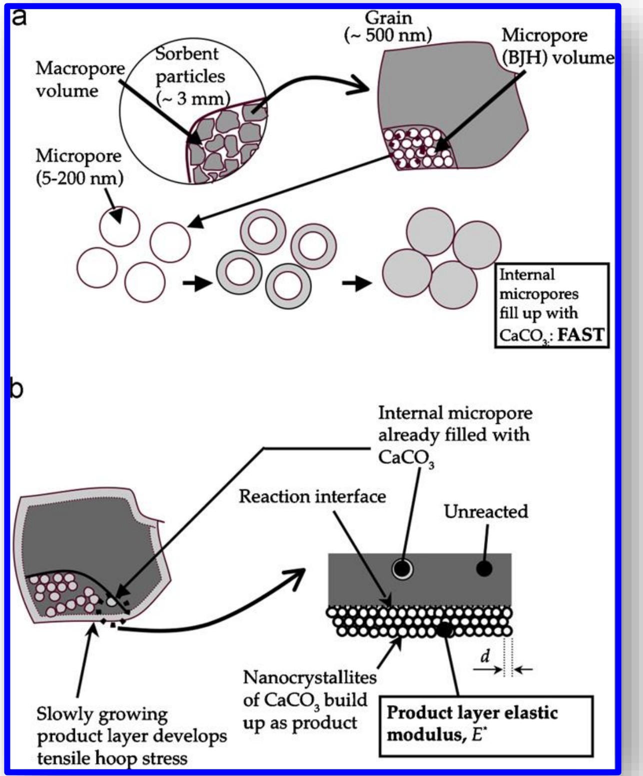
Calcium Looping - Carbonation

Carbonation occurs in two phases

Fast initial rate - sorption of CO_2 on the free surface of the particles

Slow rate - diffusion of CO_2 through the solid $CaCO_3$ layer

The rate of CO_2 capture in a fluidized bed **is not just controlled by the kinetics of the chemical reaction** itself, **but also by the transport of CO_2** to the particles' surface
=> Carbonation can be hindered by poor **gas/solids contact**



Main drawbacks of the $CaO/CaCO_3$ system => **progressive decline in the carbonation conversion** with the number of cycles due to the CaO deactivation caused by **sintering and pore-plugging**

The use of **fine particles (< 100 μm)**

- can strongly **limit sintering and pore-plugging**, thus consequently **enhancing the multicyclic CaO conversion** at the conditions to be used for TCES[1,2]
- can provide **better gas-solid contact efficiency** due to the **higher surface to volume ratio** with respect to coarser particles by **maximizing** the **availability** of the **sorbent surface** exposed to the gaseous phase, which **positively affect** the **the fast initial phase** of the carbonation

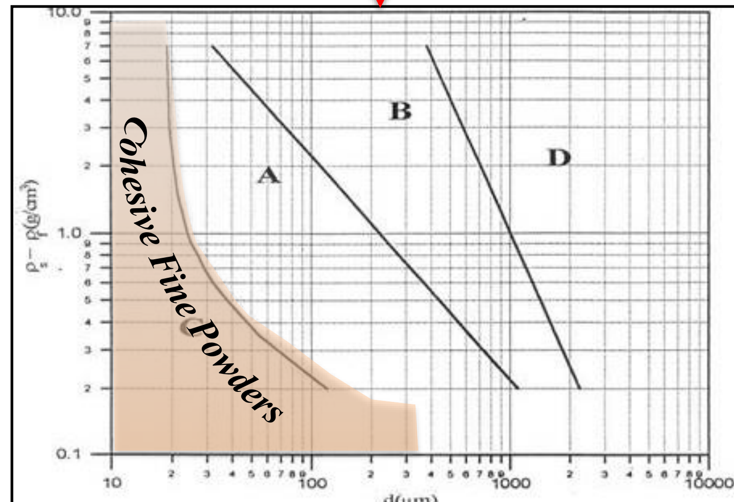
[1] M. Benitez-Guerrero, B. Sarrion, A. Perejon, P.E. Sanchez-Jimenez, L.A. Perez- Maqueda, J. Manuel Valverde, Large-scale high-temperature solar energy storage using natural minerals, Sol. Energy Mater. Sol. Cells 168 (2017) 14–21.
[2] C. Ortiz, J.M. Valverde, R. Chacartegui, L.A. Perez-Maqueda, P. Giménez, The Calcium-Looping (CaCO3/CaO) process for thermochemical energy storage in concentrating solar power plants, Renew. Sustain. Energy Rev. 113 (2019) 109252

Sound-assisted Fluidization

Fine particles cannot be fluidized under ordinary conditions due to their **strong interparticle forces (IPFs)**

Agglomeration and channeling

Hindering of the **reaction efficiency** due to poor and **heterogeneous gas/solid contact**



Sound-assisted Fluidization

Large Aggregates (hundreds of μm) → *Small Fluidizable Aggregates*

- It promotes **gas/solids mixing uniformity** (gas channels disruptions and agglomeration reduction)[1,2]
- It promotes a **continuous break-up** of the fluidizing aggregates, thus continuously **renewing the sorbent surface** exposed to the gaseous phase[1,2]

Aim of the Study

Improvement of the carbonation of fine CaO particles (< 10 μm) at TCES-CSP conditions

- **Comparison between ordinary and sound-assisted conditions**
- **Effect of the acoustic parameters (intensity and frequency)**

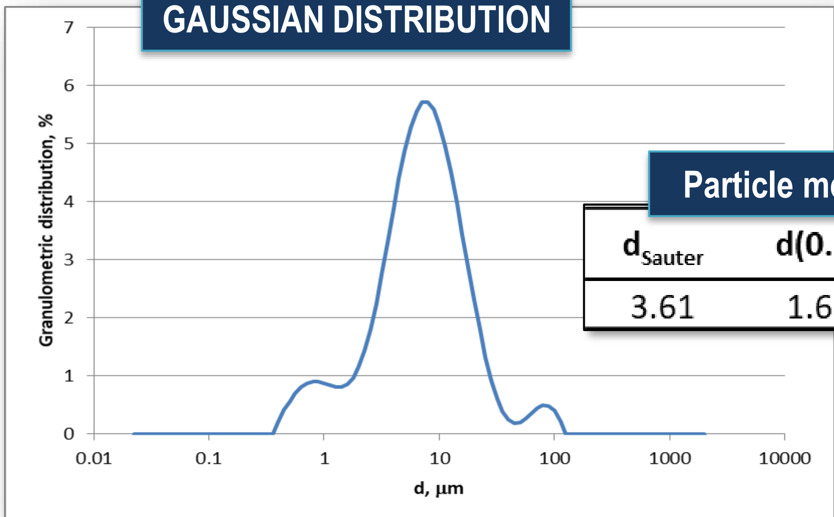
[1] Raganati F., Ammendola P.: Sound-Assisted Fluidization for Temperature Swing Adsorption and Calcium Looping: A Review Materials (Basel). Vol. 14, 2021, pp. 672.
[2] Valverde J.M., Raganati F., Quintanilla M. a. S., Ebri J.M.P., Ammendola P., Chirone R.: Enhancement of CO2 capture at Ca-looping conditions by high-intensity acoustic fields Appl. Energy Vol. 111, 2013, pp. 538–549.

Materials - Characterization

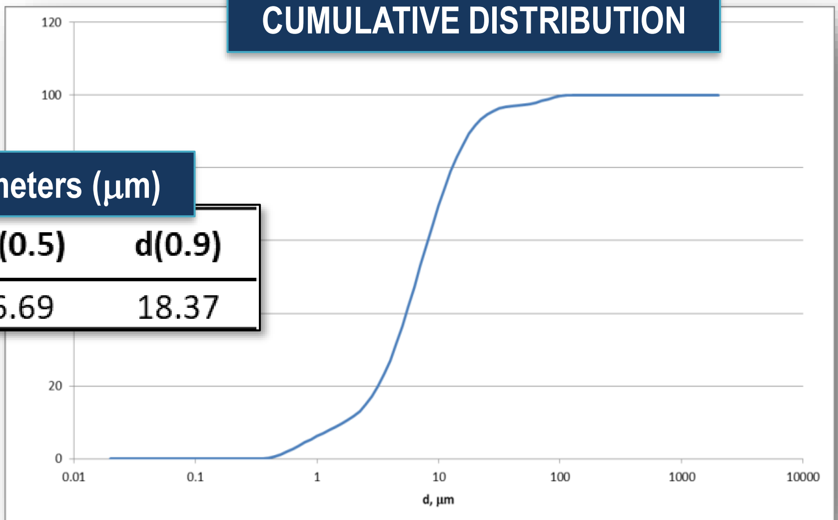
Sorbent:

Fine limestone particles, from Belchite quarries (Spain) supplied by OMYA → it is expected to be **cohesive**

GAUSSIAN DISTRIBUTION



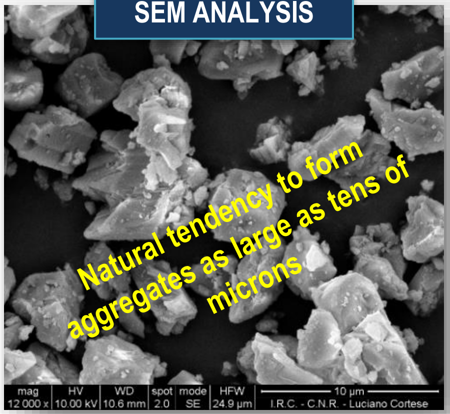
CUMULATIVE DISTRIBUTION



Particle mean diameters (µm)

d_{Sauter}	d(0.1)	d(0.5)	d(0.9)
3.61	1.68	6.69	18.37

SEM ANALYSIS

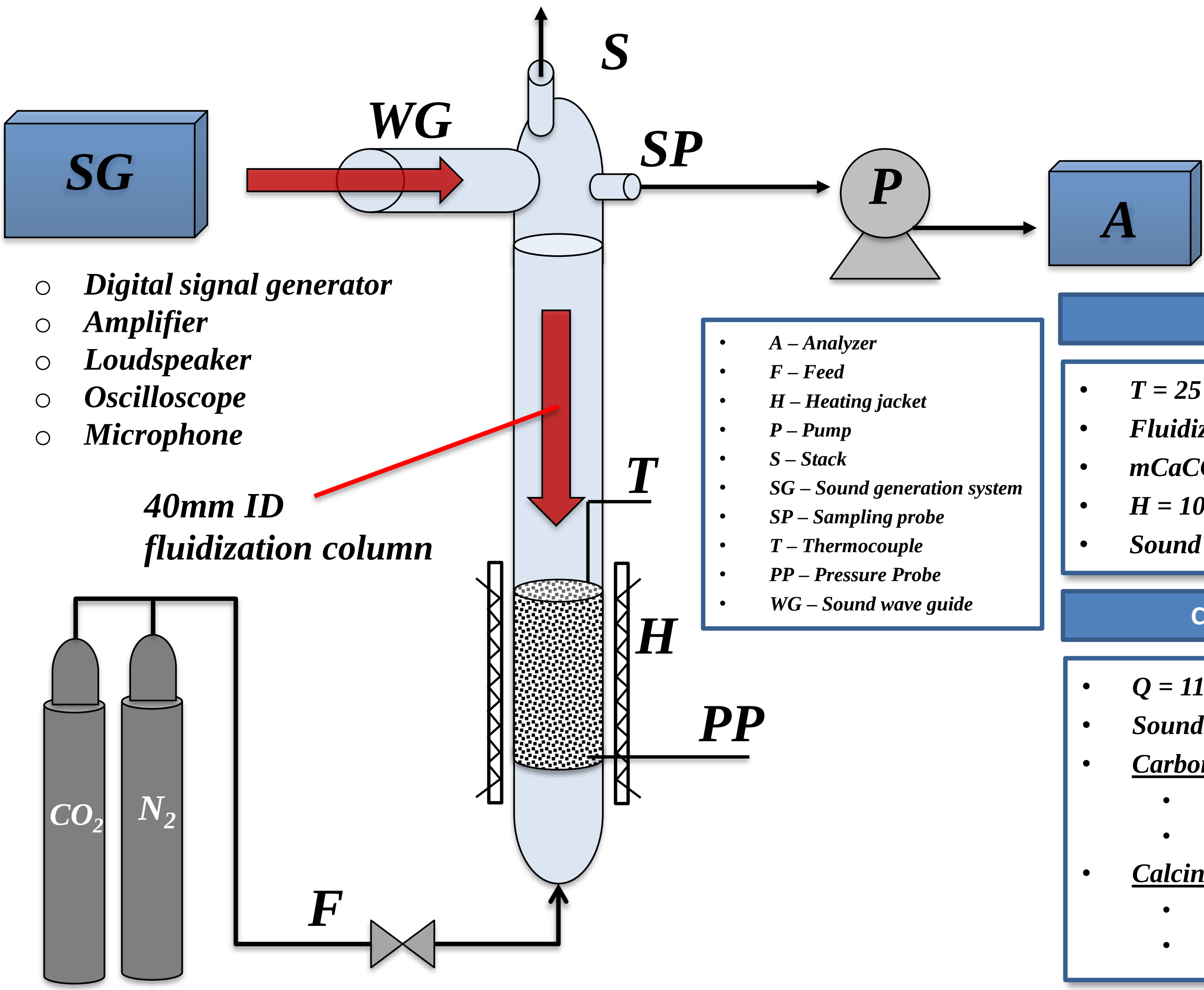


Mean diameter < 30µm, meaning that it is all classifiable as **Highly cohesive powders** (i.e. belonging to the **C group of Geldart's classification**)

↓

Difficulty in fluidization under ordinary conditions

Experimental Apparatus and procedure



- *Digital signal generator*
- *Amplifier*
- *Loudspeaker*
- *Oscilloscope*
- *Microphone*

- *A – Analyzer*
- *F – Feed*
- *H – Heating jacket*
- *P – Pump*
- *S – Stack*
- *SG – Sound generation system*
- *SP – Sampling probe*
- *T – Thermocouple*
- *PP – Pressure Probe*
- *WG – Sound wave guide*

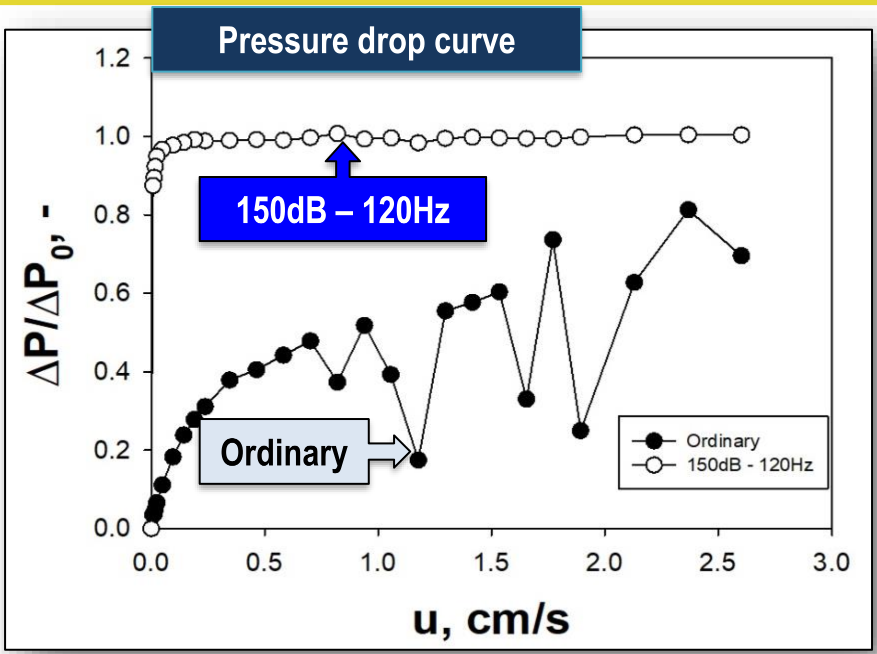
Fluidization tests

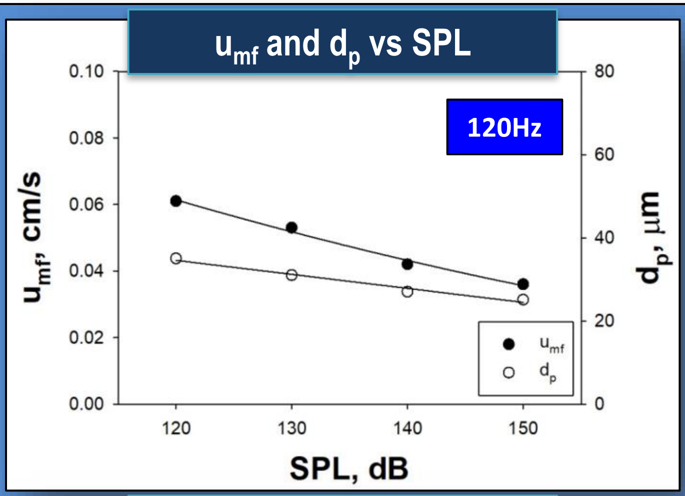
- *T = 25 – 800°C; P = 1atm*
- *Fluidizing gas = N_2*
- *$mCaCO_3$ = 100g*
- *H = 10cm*
- *Sound = 120 - 150dB/50 -300Hz*

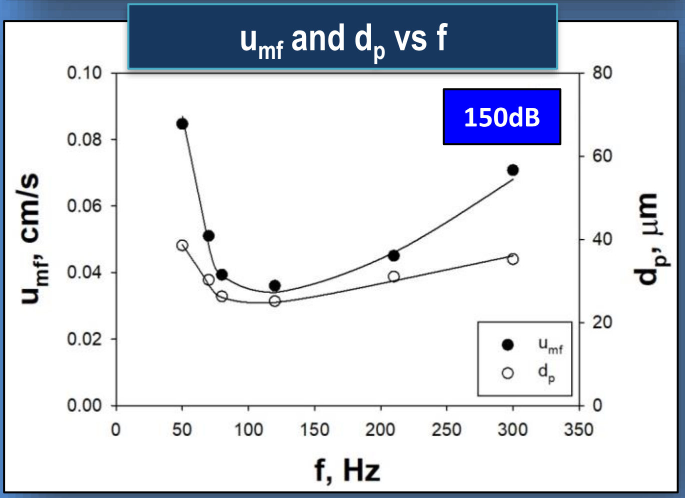
Calcium Looping tests

- *Q = 115 Nl/h; P = 1atm*
- *Sound = 120 - 150dB/50 -300Hz*
- ***Carbonation***
  - *70%CO_2/30%N_2vol/vol*
  - *T = 850°C*
- ***Calcination***
  - *0%CO_2/100%N_2vol/vol*
  - *T = 750°C*

Results - fluid-dynamic characterization (effect of SPL and f)





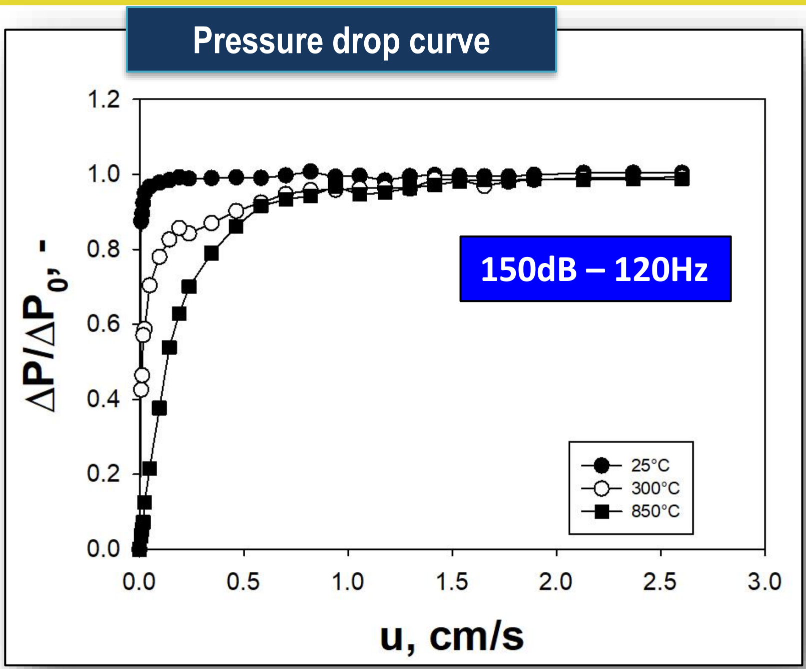


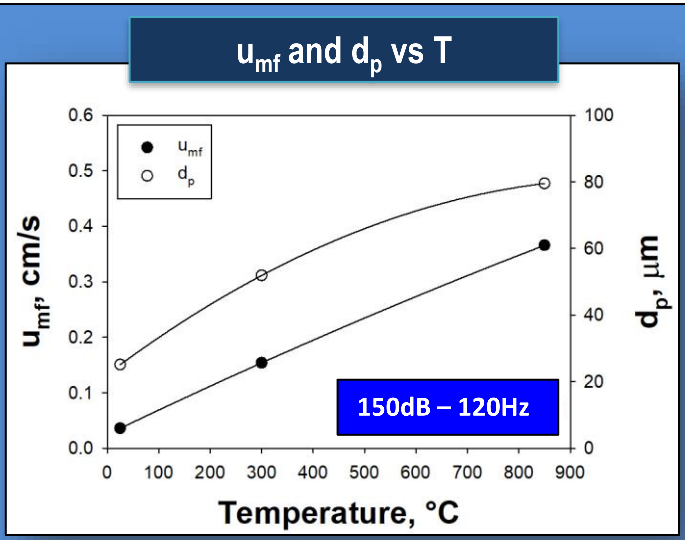
- **Ordinary conditions** : **Poor fluidization quality** - quite irregular pressure drop curve due to **agglomeration and channeling**)
- **Sound-assisted conditions**: **Good fluidization quality** - regular pressure drops curve due to the **continuous break-up mechanism** of the large aggregates into smaller fluidizable ones

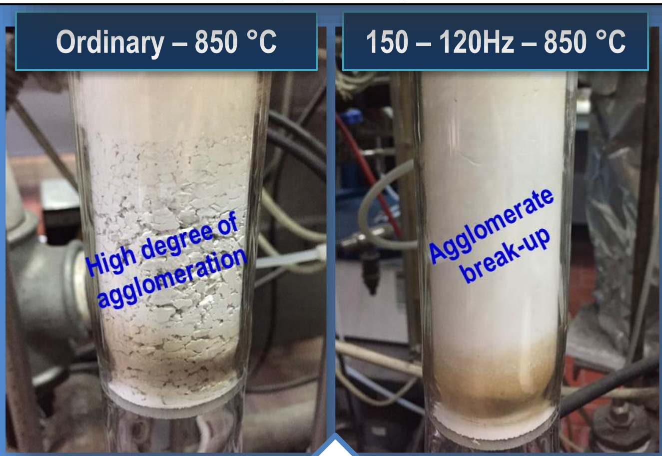
❖ **SPL**: **beneficial effect** on the fluidization quality - dp and umf are always decreased by passing from 120 to 150 dB

❖ **Frequency**: **non-monotonic effect** on the fluidization quality - umf and dp exhibit a nonlinear relationship with f with minimum values at 120 Hz

Results - fluid-dynamic characterization (effect of T)





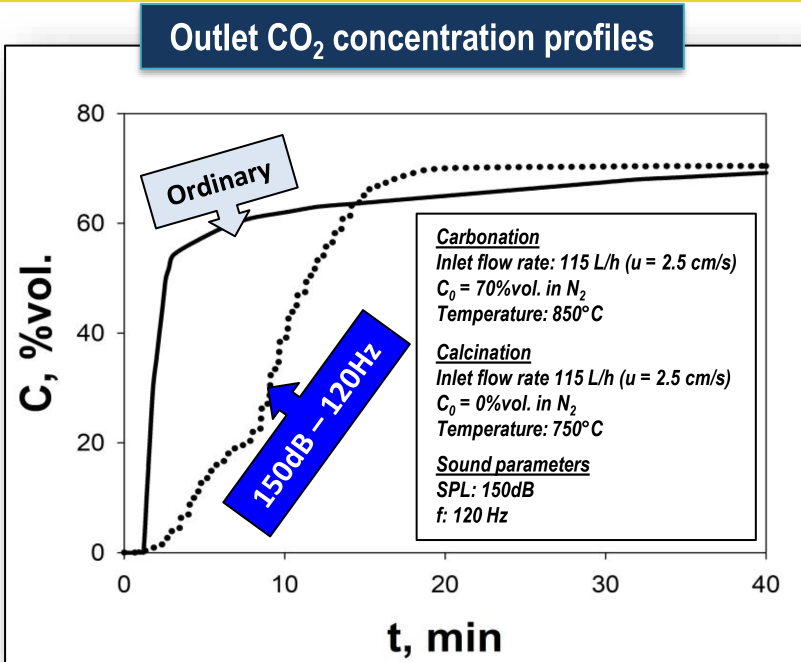


- Increasing temperatures lead to **increased fluidization difficulty**, as confirmed by the pressure drop curves shifting to the right
- **Interparticle forces** become **more and more intense** as temperature is increased

- ❖ Increasing T values lead to the intensification of the interparticle forces - formation of larger fluidizing structures, i.e. higher values of dp
- ❖ As a consequence of the increased size of the fluidizing aggregates, umf is also increased when temperature is increased from 25 to 850 °C

Even though the acoustic field becomes less effective as T is increased, its break-up mechanism is still remarkable

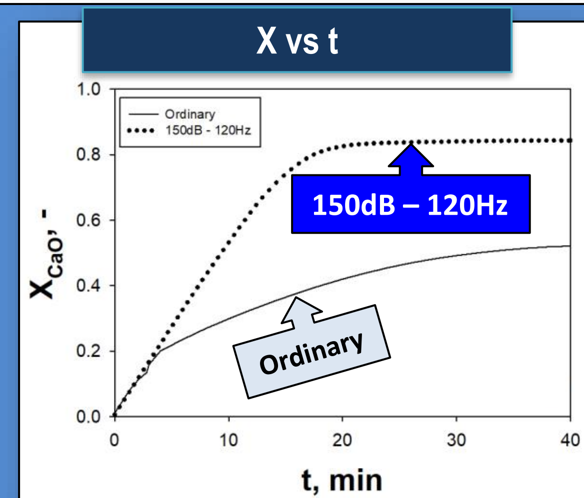
Results – Carbonation

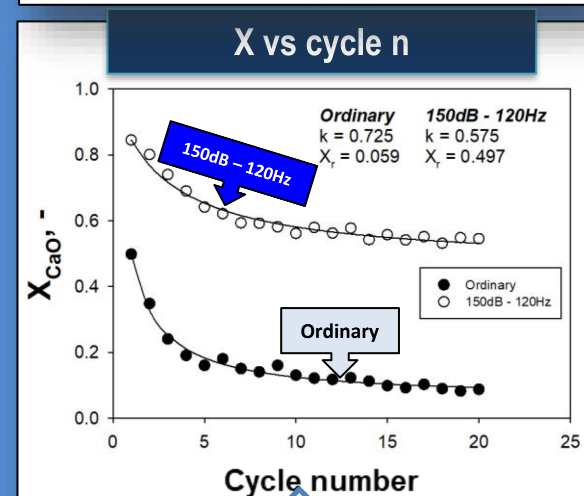


Sound application causes a **remarkable enhancement of carbonation performances**, as consequence of the improved fluidization quality and acoustic streaming

- the carbonation reaction occurs **globally faster**;
- the **exploitation of the sorbent reactivity is maximized**;

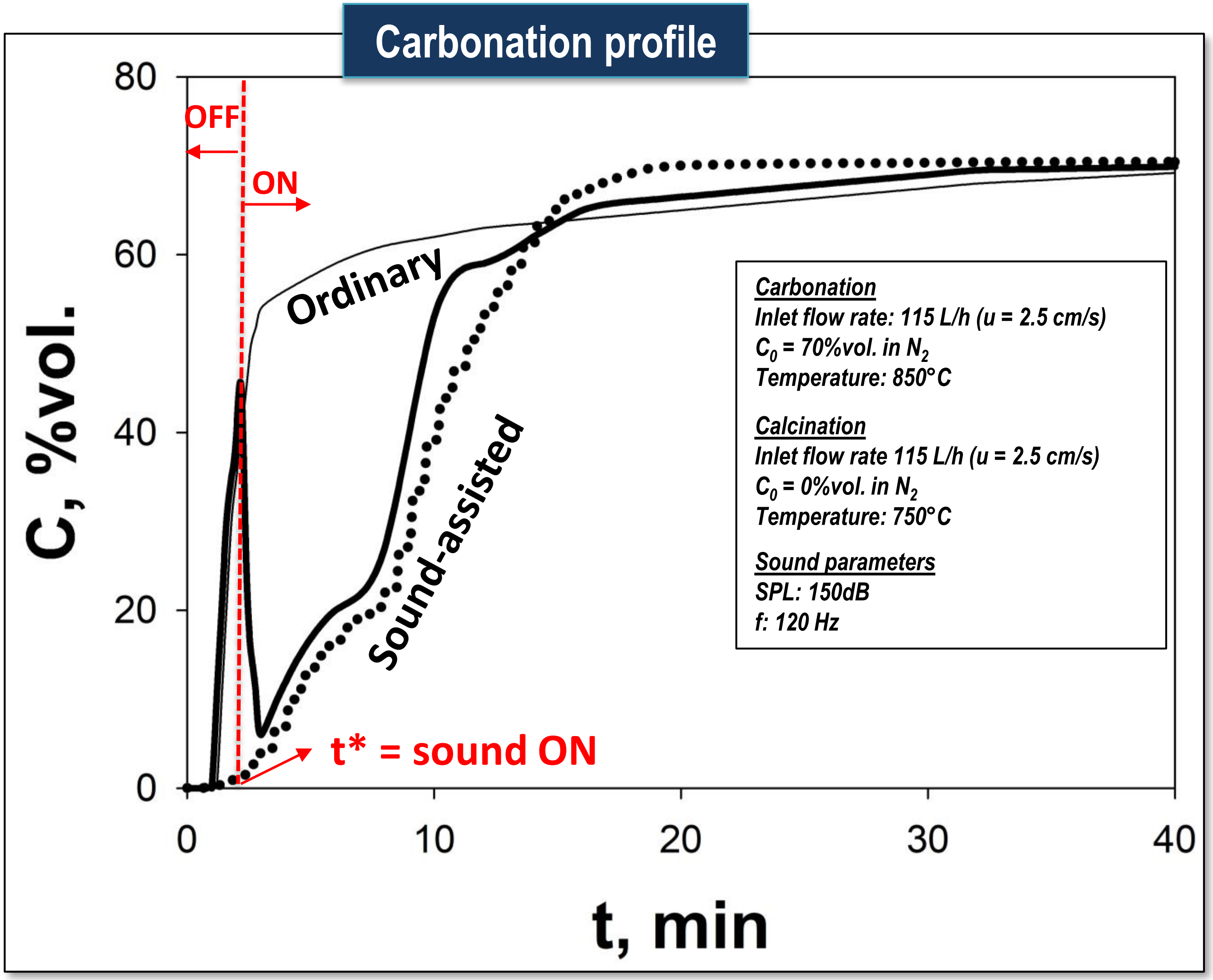
- **Agglomeration is hindered and channels are destabilized** - a higher surface can enter into direct contact with the fluidizing gas (CaO surface is continuously exposed and renewed), thus yielding **higher values of carbonation conversion**
- Differences between the ordinary and sound-assisted tests are more evident in the initial kinetically controlled stage





The deactivation rate is reduced and the residual conversion is increased when sound is applied due to the hindrance of the agglomeration phenomena

Carbonation tests – Sound OFF/ON



Sound was switched on at t = t*

- **t < t***

  the CO_2 concentration profile is the same as that obtained in ordinary conditions (i.e. the **bypassing gas makes the CO_2 concentration abruptly rise**)

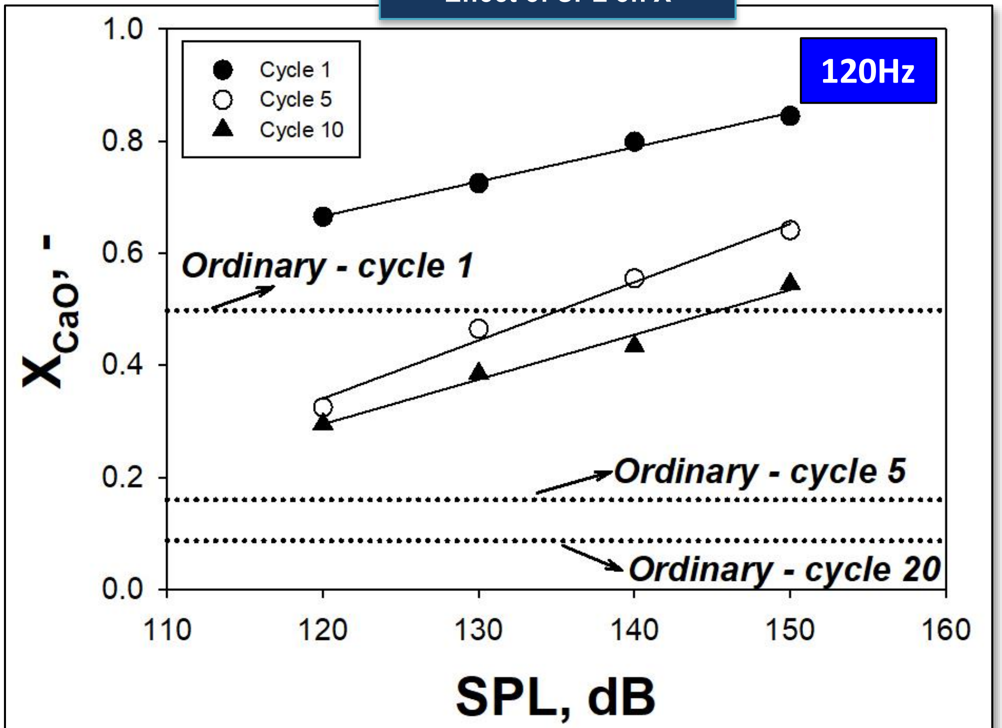
- **t ≥ t***

  the CO_2 concentration **suddenly drops down** before rising up again following now the **typical trend of the sound assisted test**

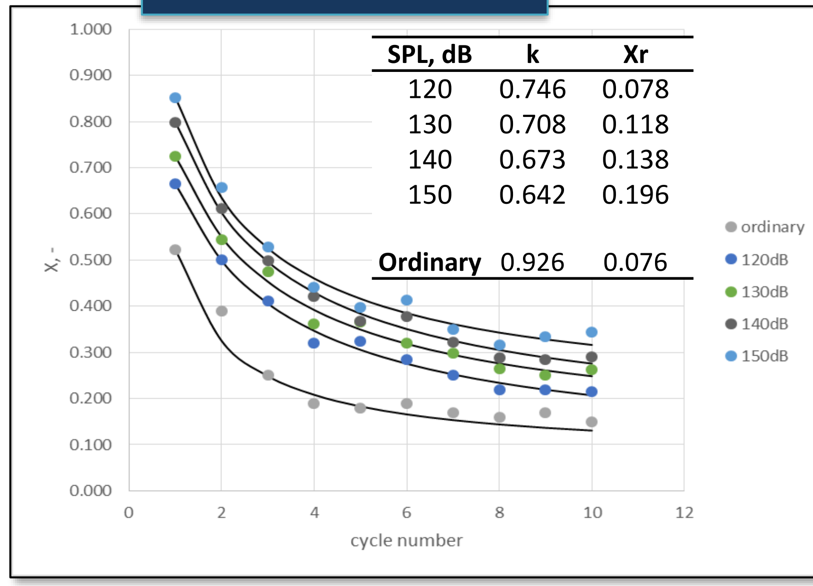
This result confirms the **ability of the sound to better exploit the sorbent**. As soon as the sound has been switched on, that specific surface, precluded to the fluid under ordinary conditions, suddenly becomes available causing CO_2 concentration to drop down because of the **renewed sorbent reactivity**

Carbonation tests – Effect of SPL

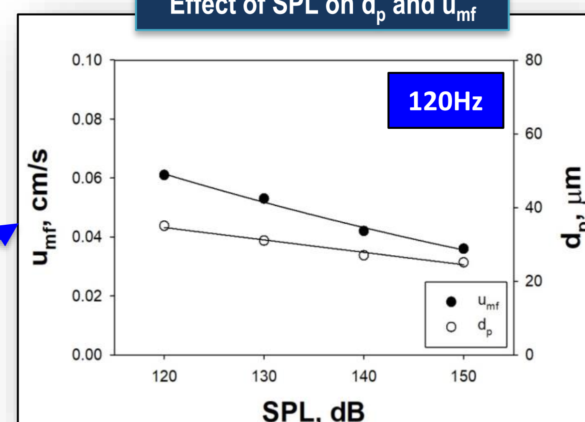
Effect of SPL on X



Effect of SPL on X decline



Effect of SPL on d_p and u_{mf}



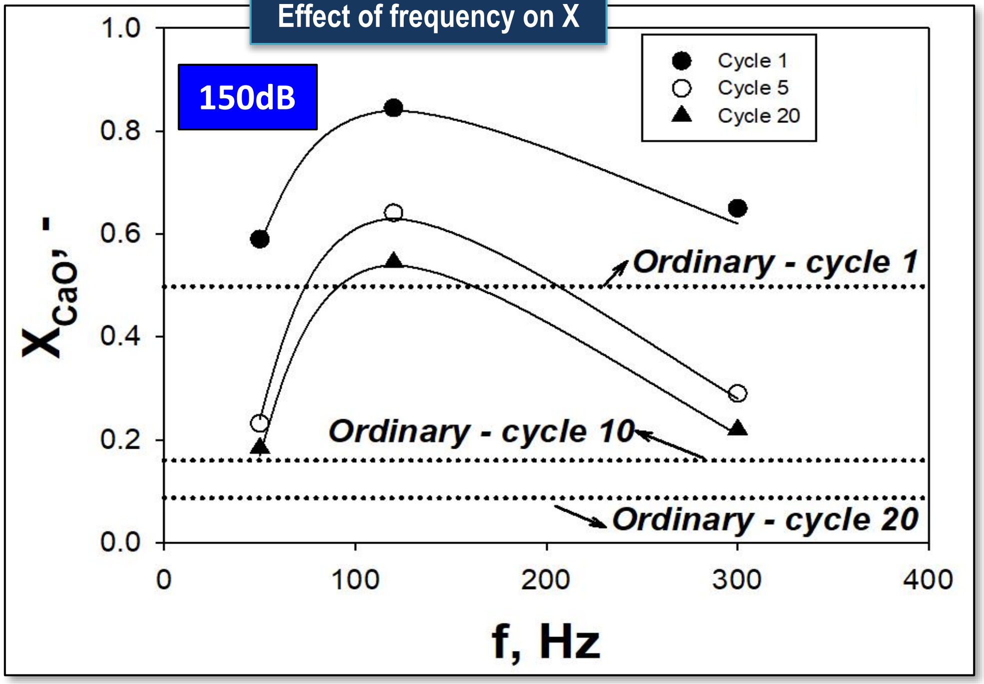
SPL has a **monotonic effect** on the **carbonation performances**:

- the **strength of the acoustic wave is proportional to SPL** (higher SPL means **larger energy** introduced inside the bed)

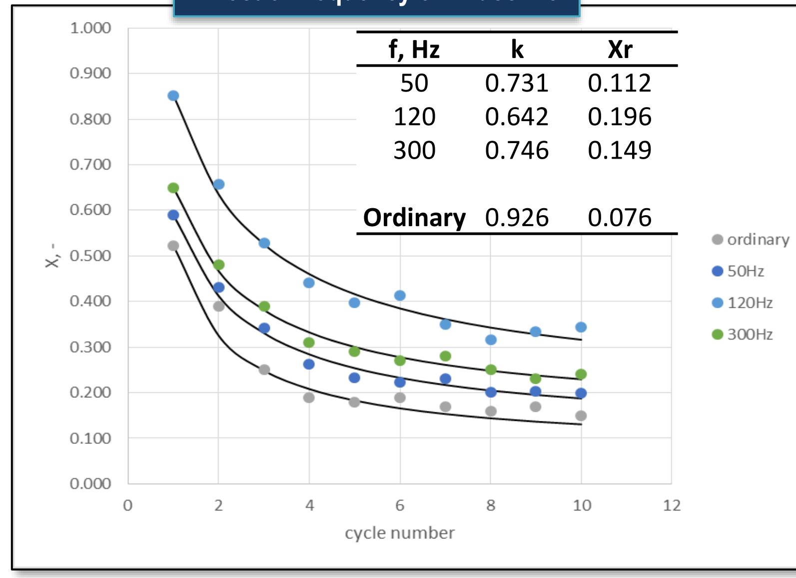
❖ In line with the effect of SPL obtained on the fluidization quality: there is a **tight link** between **the fluidization quality** (i.e. **agglomeration entity**) and the **carbonation performances**

Carbonation tests – Effect of frequency

Effect of frequency on X



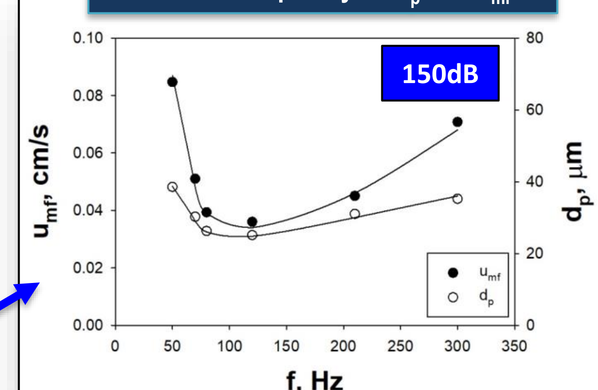
Effect of frequency on X decline



Sound frequency has a **non-monotonic effect** on the **Carbonation performances**:

- **Too low frequency** - **absence of relative motion** between smaller and larger clusters (**no break-up of aggregates**)
- **Too high frequency** - the sound wave is **not able to properly propagate** inside the bed

Effect of frequency on d_p and u_{mf}



❖ In line with the effect of frequency obtained on the fluidization quality: there is a **tight link** between **the fluidization quality** (i.e. **agglomeration entity**) and the **carbonation performances**

Conclusions

A fine carbonate powder (**d = 3.61μm**) has been selected as sorbent to be used in the CaL experiments under operating conditions optimized for TCES in CSP applications in order to study the effect of the **acoustic perturbation** on the **agglomeration** phenomena

- ***Preliminary fluid-dynamic characterization***
  - The fluidization quality is quite a poor under **ordinary conditions**, i.e. particles adhere to each other leading to **agglomeration**, **channeling** and **plugging**
  - The application of the **sound** makes it possible to obtain a **proper fluidization regime** due to a **continuous break-up** and **reaggregation mechanism**
- ***CaL tests***
  - The application of the **acoustic perturbation remarkably enhances the carbonation performances** in terms of carbonation conversion and kinetics of the fast carbonation stage
  - The **acoustic perturbation** can **hinder** the **agglomeration** phenomena due to the **enhanced fluidization quality**, which involves **better gas–solid contact**
  - The application of the sound results in a **remarkable decrease** of the **deactivation rate** and **increase** of the **residual conversion**
  - Both SPL and frequency exhibit on the carbonation performances the same effect as that obtained from the fluidization experiments, i.e. **increasing SPL are advantageous** and the same **optimum range of frequency** has been found

SOCRATCES

ROLE OF ACOUSTIC FIELDS ON THE FLUIDIZED BED CARBONATION FOR TCES IN CSP APPLICATIONS

Paola Ammendola

Istituto di Scienze e Tecnologie per l'Energia e la Mobilità Sostenibili (STEMS) - CNR, P.le V. Tecchio 80-80125 Naples, Italy

Thanks for your attention

This Project has received funding from European Commission by means of Horizon 2020,
the EU Framework Programme for Research & Innovation, under Grant Agreement no.727348.