Development of twin-fluid atomizer for effective solvent/gas contact in CO_2 capture subsystem

Jan JEDELSKÝ

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

INTER-EXCELLENCE

BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING

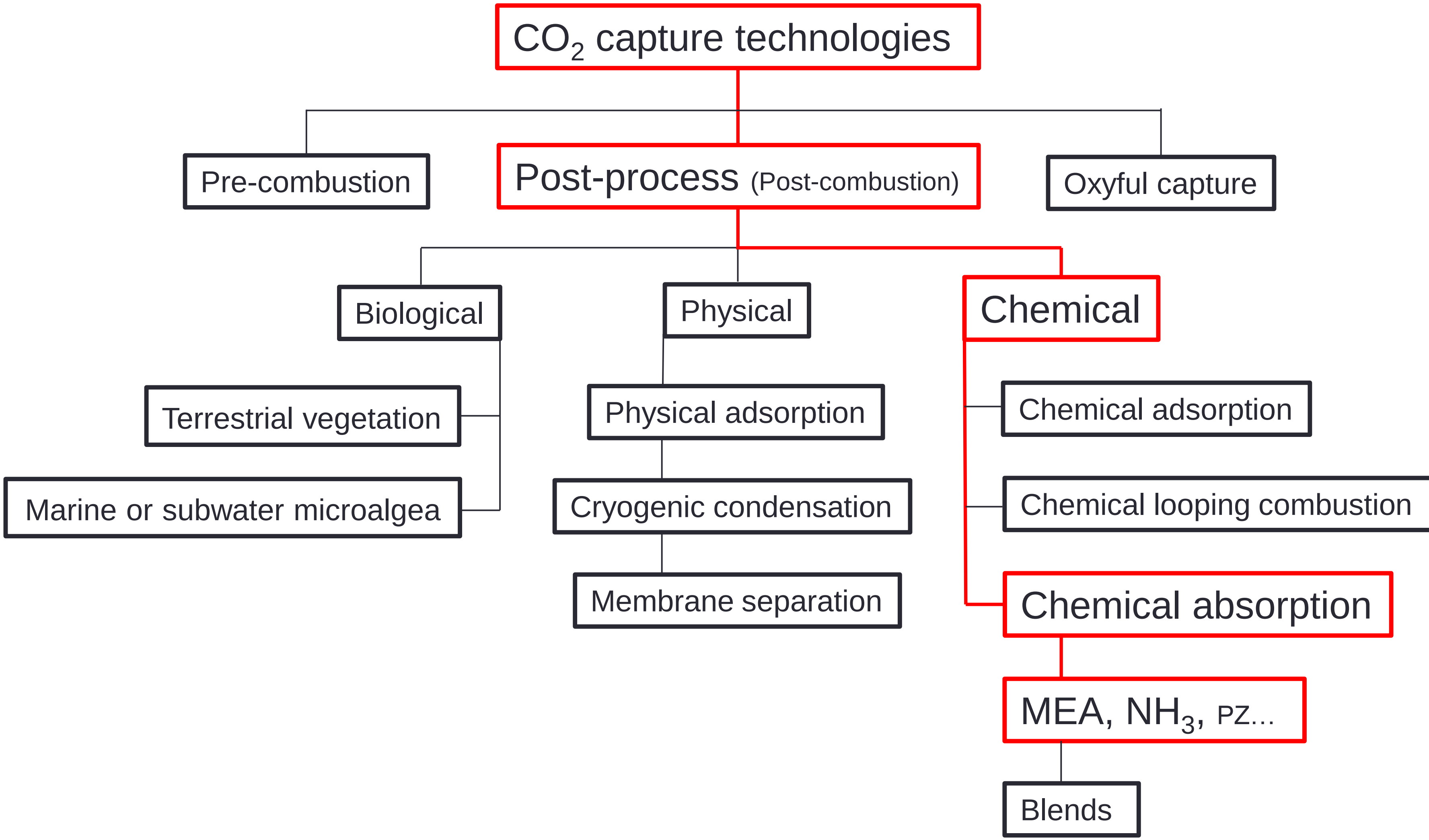
Basic information about the project

Development of energy efficient twin-fluid atomizer for effective post combustion CO_2 and NO_x removal

Vývoj energeticky úsporného dvoumédiového atomizéru pro účinné odstraňování CO_2 a NO_x z produktů spalování

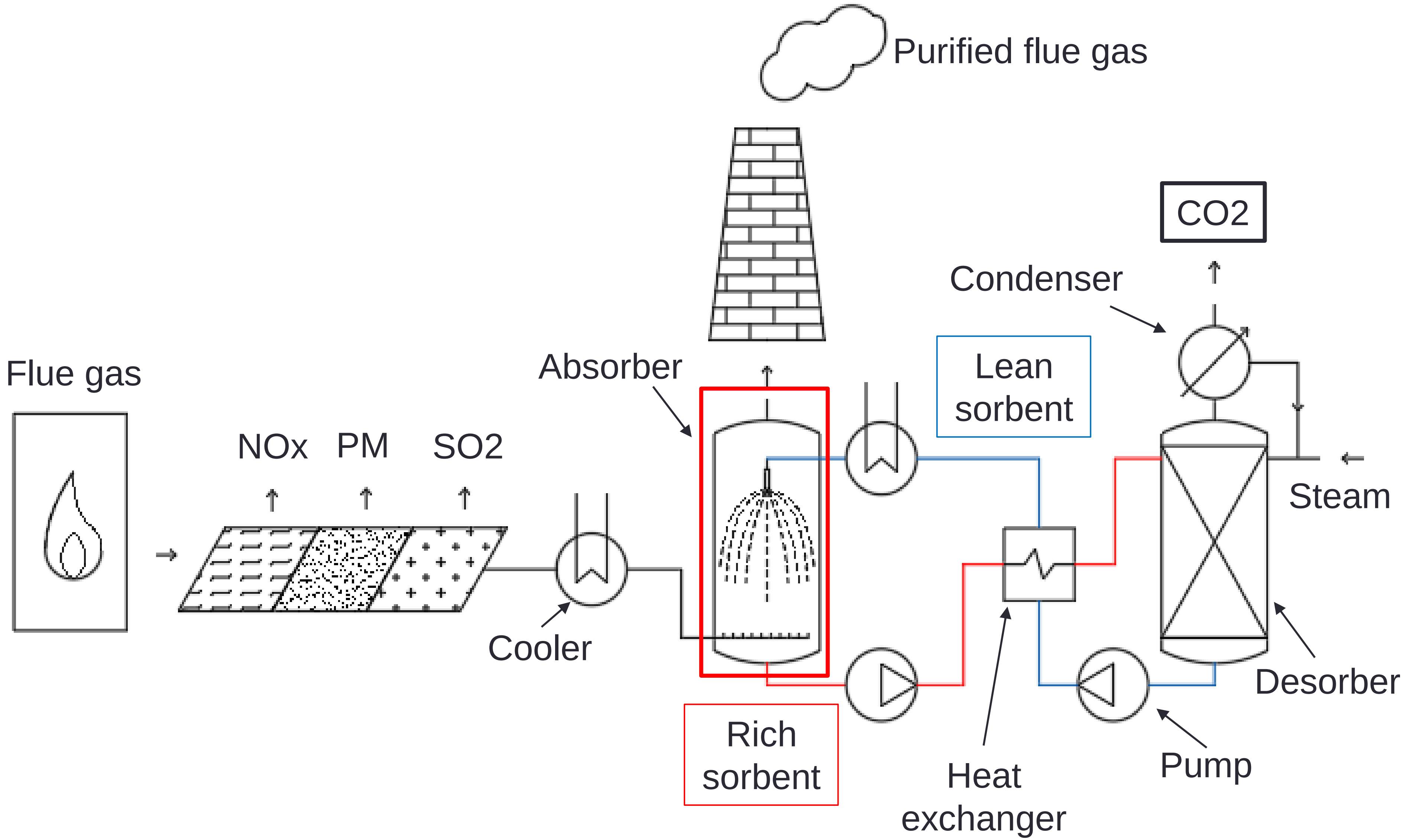
दहनोपरांत CO_2 एवं NO_X के प्रभावी निष्कासन हेतु ऊर्जा दक्ष ट्विन-फ्लूइड एटमाइज़र का विकास

- Program: INTER-EXCELLENCE
  - Subprogram: INTER-ACTION
  - Czech-Indian cooperation between research groups at **Indian Institute of Technology Tirupati** and **BUT Brno**
- Research categories: basic and applied research
- Start date 1.1.2020, solution period (in years) 3



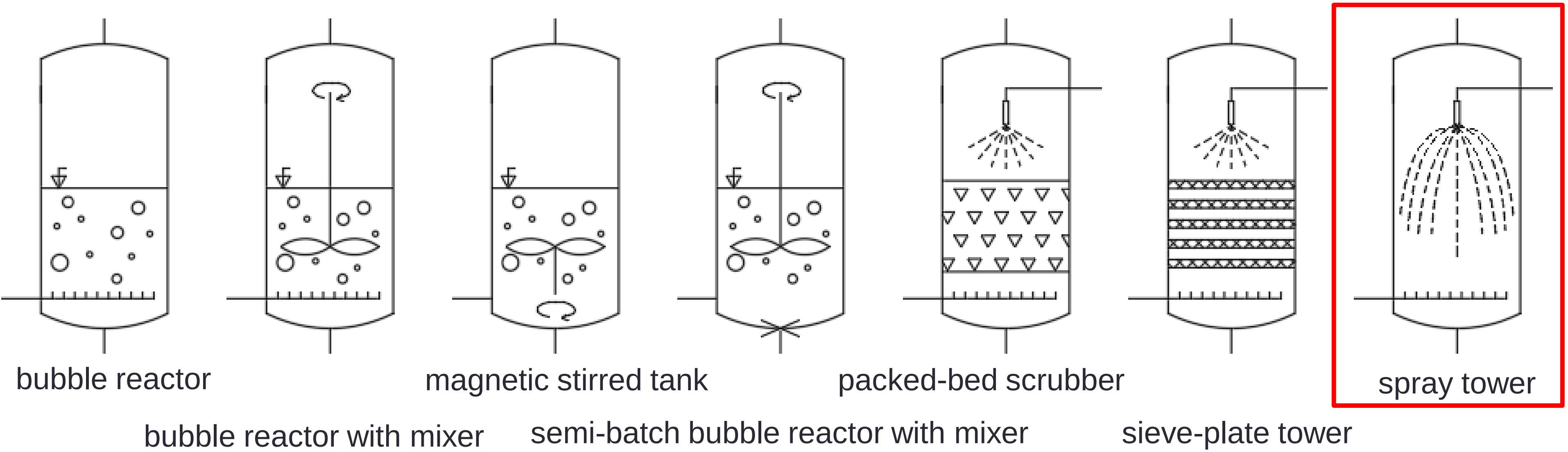
CO2 capture technologies
Pre-combustion
Post-process (Post-combustion)
Oxyful capture
Biological
Physical
Chemical
Terrestrial vegetation
Marine or subwater microalgea
Physical adsorption
Cryogenic condensation
Membrane separation
Chemical adsorption
Chemical looping combustion
Chemical absorption
MEA, NH3, PZ…
Blends

The post-process CO_2 capture



Absorbers

- **Spray column / spray tower (SC)** - a widely used reactor type for removal of substances from (flue) gases
- **Liquid solution sprayed into the gas** to increase the absorbent-gas contact area.
- More advantageous than compact absorption columns; CO_2 uptake by packed and tray columns studied for many years with many types of solvents and builders [2-9], while little data published to use amine-based SCs [10], though SCs implemented successfully in industrial chemical processes.
- Already **applied concept**, but we have competence and potential in advanced exp. a sim. methods = new knowledge



Advantages/drawbacks of the approach

- Simple design and operation - absence of inserts, low investment and operating costs, applicability for gases with solids and precipitants (Bandyopadhyay and Biswas, 2012; Seyboth et al., 2014).
- Applicable when a low pressure drop required on the gas side and a high degree of separation not required [6, Norman and Rochelle, 2003].
- Absorption takes place in three main directions from the gas-liquid interface, the ratio of surface area to volume 6-times greater than in liquid film of the same thickness as the drop diameter. [Cho et al. 2018].

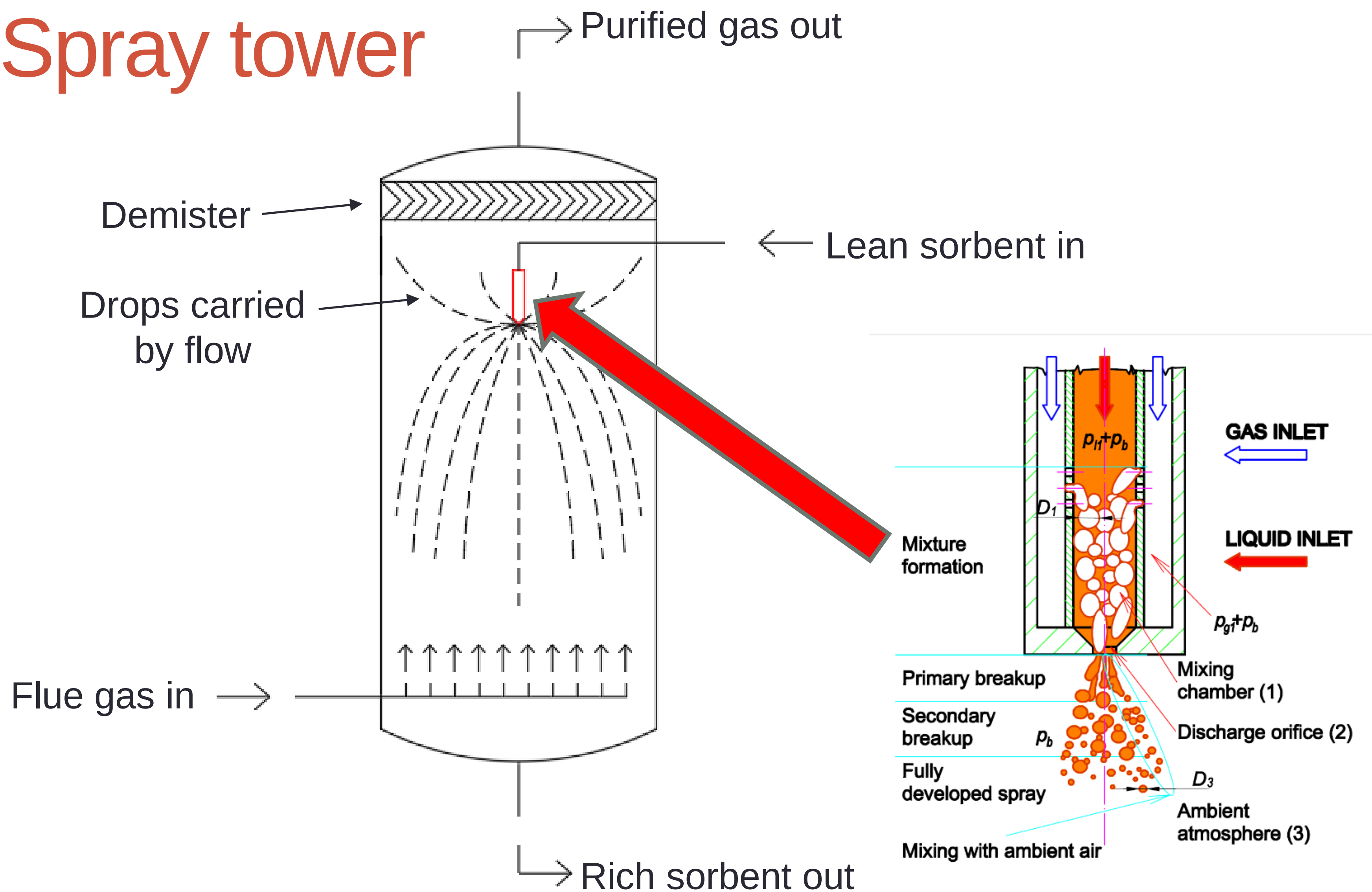
Table 14.1 **Classification of gas–liquid contactors** (Kumar et al., 2002; Stolten and Scherer, 2011; Nguyen et al., 2011)

Gas–liquid contactor type			Mass transfer parameters (common range of values)		
	Advantages	**Disadvantages**	$k_l\bar{a}$ (1 s^{-1})	$k_g\bar{a}$ (mol s^{-1} kPa^{-1} m^{-3})	$\bar{a}$ (m^2 m^{-3})
Packing	Able to manage foaling liquids, low gas-side pressure drop	Not appropriate for liquids with solid particles	0.005–0.02	0.5–2.0	100–300
Tray	Wide operational gas/liquid range, can accommodate heat exchangers on tray	Less applicable for foaming and corrosive liquids, high gas-side pressure drop, high costs	0.01–0.05	0.5–1.0	100–400
Bubble	Low capital and maintenance cost, simple construction	Bubble coalescence, high gas-side pressure drop	0.005–0.01	0.4–1.0	10–30
Spray	Low gas-side pressure drop, applicable for gases with solid particles	Liquid coalescence, energy demand for spraying the liquid phase	0.007–0.015	0.1–0.8	20–80
Membrane[a]	Flexible, modular, easy scale-up, enables the two phases to be independently controlled	The membrane itself provides additional mass-transfer resistance, prone to fouling	local mass-transfer coefficient in the membrane (m/s) 10^{-4}–10^{-2}	1500–3000	

[a]For commercially available hollow-fiber membrane modules.

Feron P H M, Absorption-Based Post-Combustion Capture of Carbon Dioxide, Woodhead Publishing, 2016.

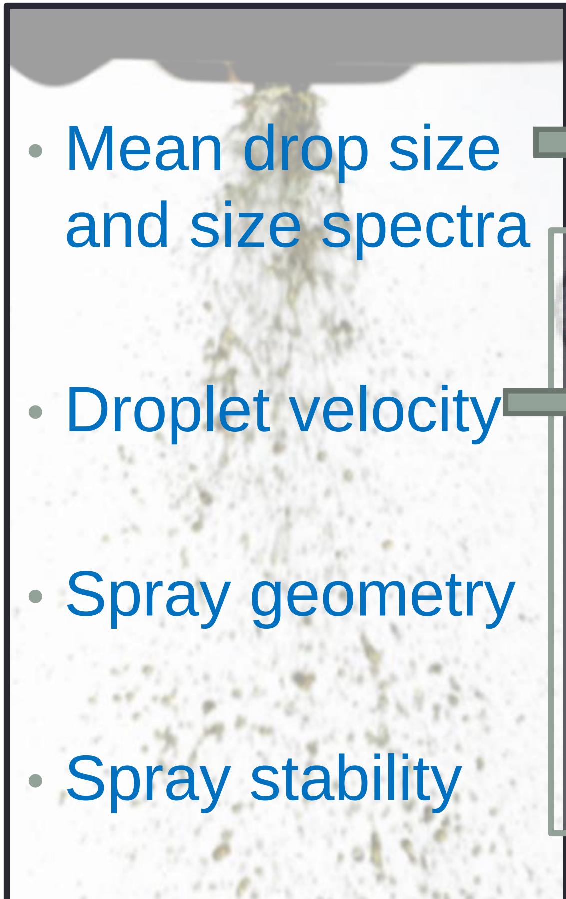
Spray tower


Purified gas out
Demister
Lean sorbent in
Drops carried by flow
Flue gas in
Rich sorbent out
GAS INLET
LIQUID INLET
pl1+pb
D1
Mixture formation
pg1+pb
Mixing chamber (1)
Primary breakup
Secondary breakup
pb
Discharge orifice (2)
Fully developed spray
D3
Ambient atmosphere (3)
Mixing with ambient air

Main aims/challenges:

- To maximize the capture efficiency and output at compact size and cheap design,
- To reduce the solvent loses and washout
- The CO_2 absorption capacity in SC is influenced by process parameters:
  - 1) physical properties of the fluids,
  - 2) the relative gas-liquid velocity, mass and energy ratio
  - 3) the concentration of CO_2 molecules and sorbent in the reactor,
  - 4) the distribution of liquid mass, droplet size spectrum i.e. directly affected by **the atomizer specification**.

Important characteristics and requirements for the atomizer



- Mean drop size and size spectra
- Droplet velocity
- Spray geometry
- Spray stability

- Droplet collisions +coalescence
- Droplet density (concentration)

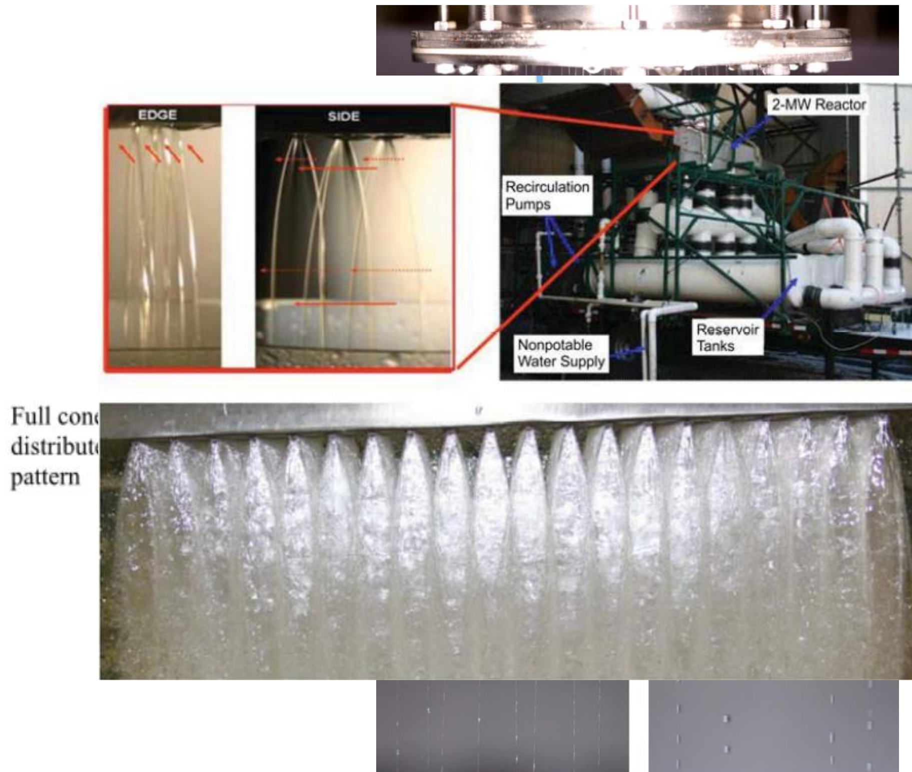
- Momentum exchange, mixing, gas entrainment
- Droplet washout
- Gas-liquid contact area
- Impact of drops on the wall
- Residence time
- Atomization efficiency

CO_2 capture efficiency

Inconsistency, inadequacy and unsystematic references regarding nozzle requirements: SMD = 50 µm (Chen et al.) vs. 1-2 mm (Seyboth et al. (2014)) !!!

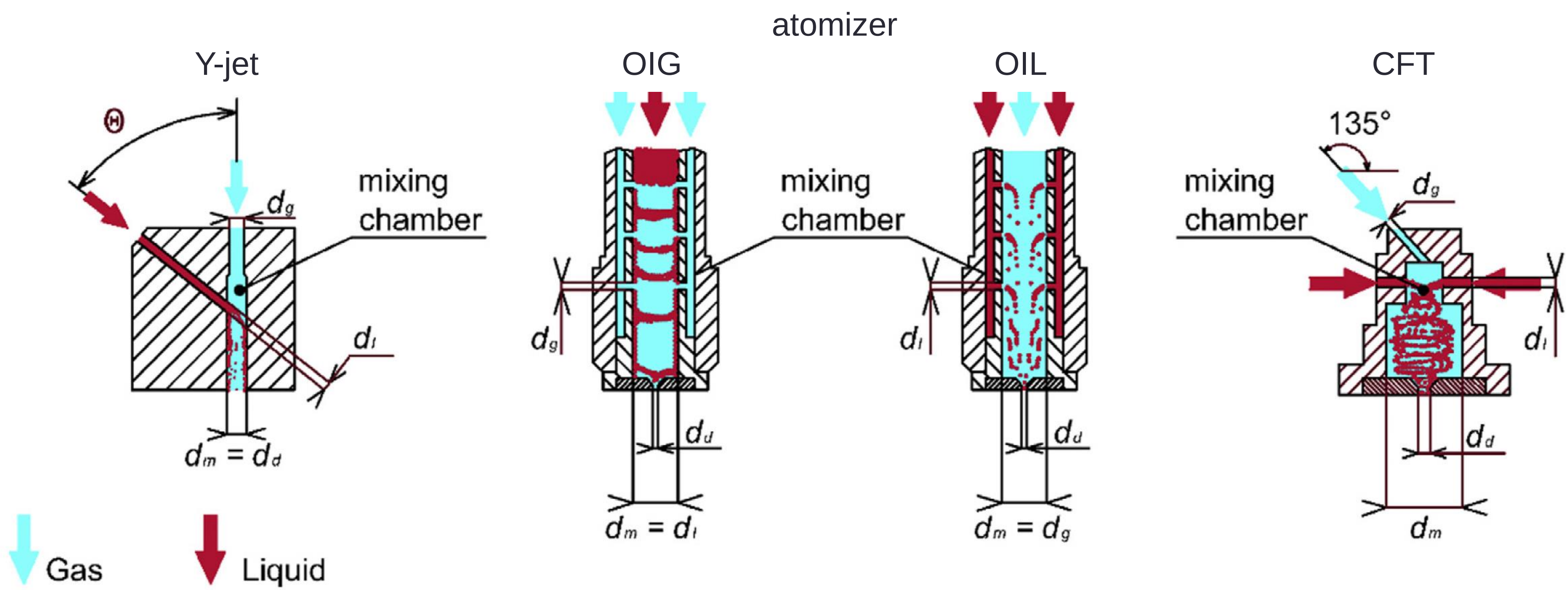
Published solutions – „sprays“

- Uniform Spray of Monosized Absorbent Droplets [1]
- Pressure swirl nozzles
  - Full cone spray nozzles with a spray angle of 90° [2]
  - Nozzle BETE 1/8 MPL 0.30 N; Full cone; 60º [6]
  - Model TGO.3, Teejet Spraying Systems) Do = 0.5 mm. SCA = 50° - 61° [7]
- flat-jet array (NSG NeuStream-C system), an advanced solvent/gas contactor for CO_2 capture [4]
- pressure driven injector vs. air-assisted injector [3]
- two-phase critical flow atomizer [5]



So far no systematic approach to the atomization concepts

Twin-fluid atomizers



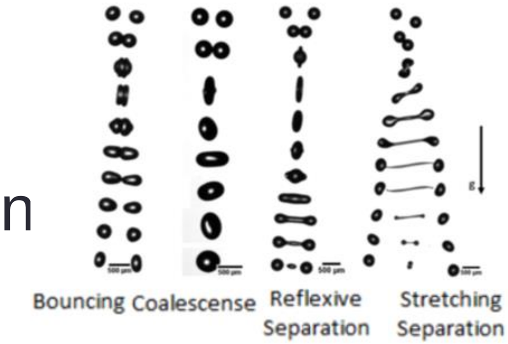
International Journal of Multiphase Flow 77 (2015) 19–31

effervescent atomizer: Types A, B, and C.

Energy Fuels 2009, 23, 6121–6130 DOI:10.1021/ef900670g

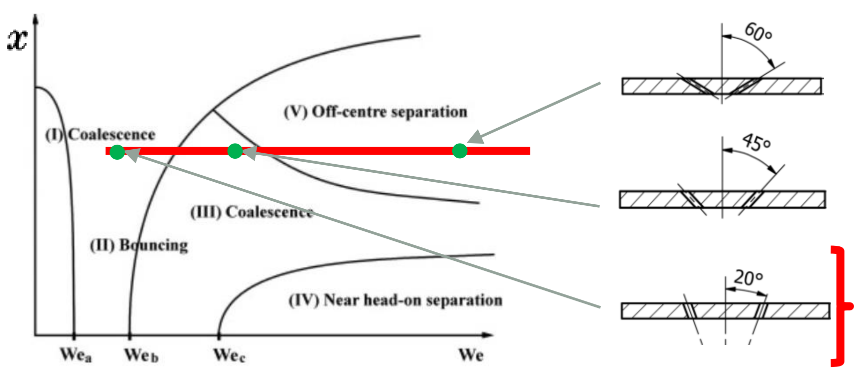
Impinging effervescent atomizer

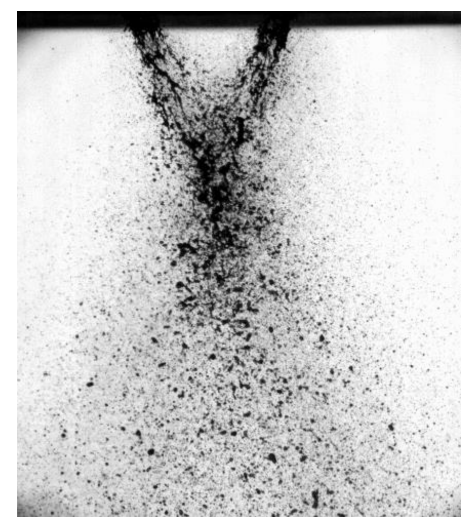
- Collisions of two or more effervescent jets
- Collisions enhance the droplet/jet interaction
- Aims
  - Narrow droplet size distribution
  - Wider spray angle
  - Reduced droplet momentum



$$x = \frac{2X}{d_l + d_s}$$

$$We = \frac{\rho d_s u^2}{\sigma}$$





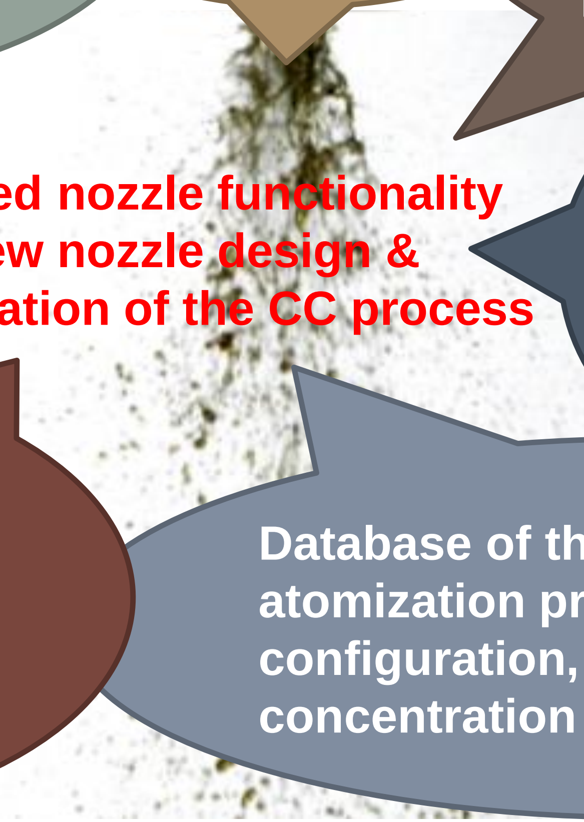
2 colliding jets, 20 ° angle, inlet pressure 1bar, GLR = 2.5

Project aims/goals

Analysis and comparative tests of different air-assisted spraying methods

Development of twin-fluid atomizer with optimized spray

Analysis of 1) gas-liquid in-nozzle mixing, 2) droplet transport and 3) gas entrainment into spray.



Improved nozzle functionality with new nozzle design & optimization of the CC process

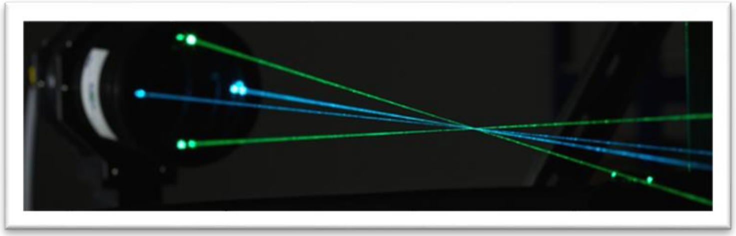
Spray and gas entrainment characteristics, droplet/gas interaction, evaporation, CC efficiency

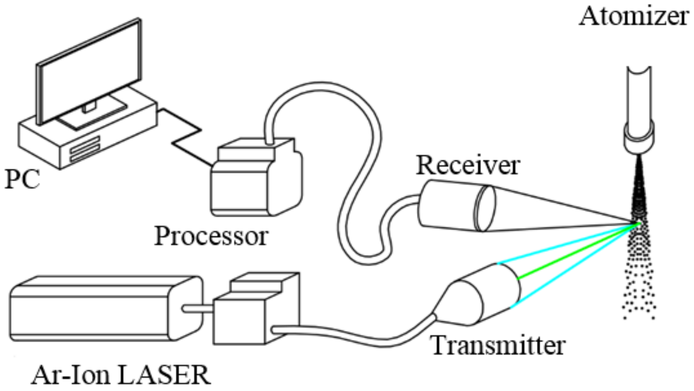
Determination of the range of suitable atomizer operation parameters in the CC capture application

Database of the influence of the atomization process, SC configuration, and sorbent concentration on the CC efficiency.

Working instruments

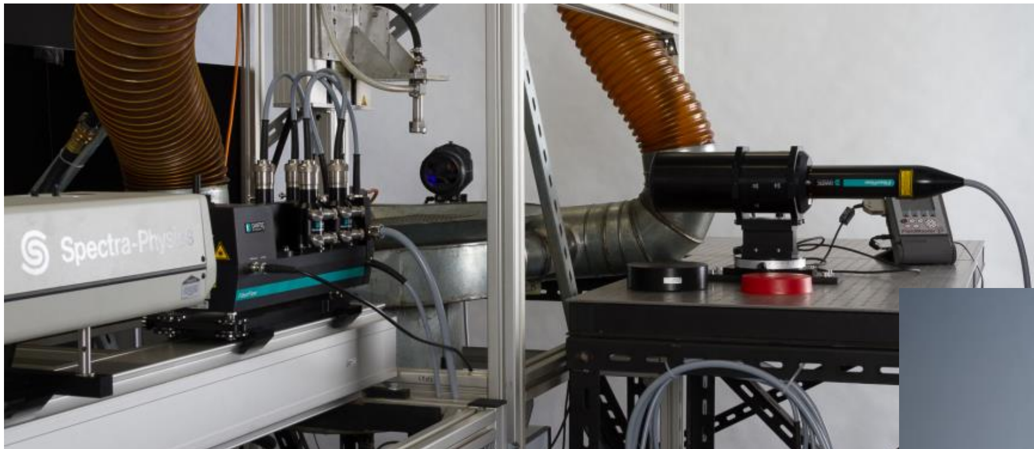
- Spray laboratory + 2× test bench
- Laser Doppler anemometry:
  - particle size & velocity & time
- HS camera Photron FASTCAM SA-Z
  - structures, sizes
- PIV
  - planar imaging, velocity vectors



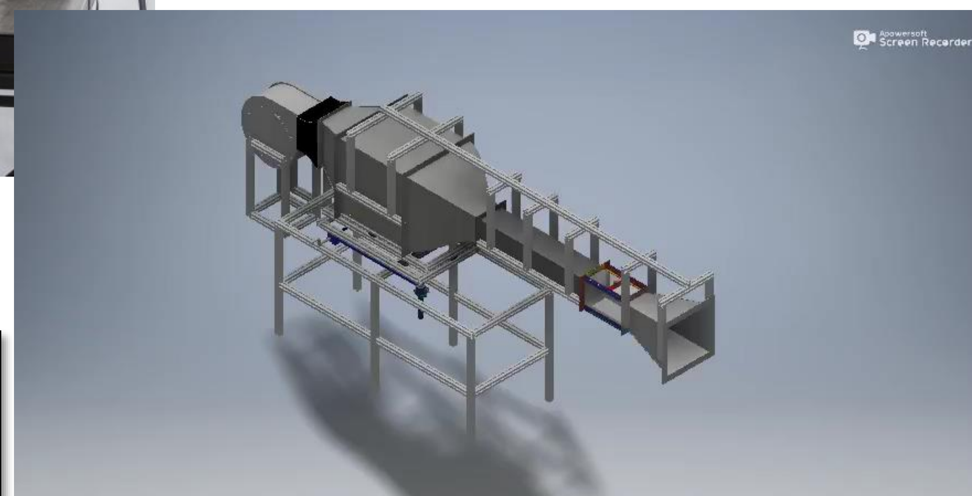


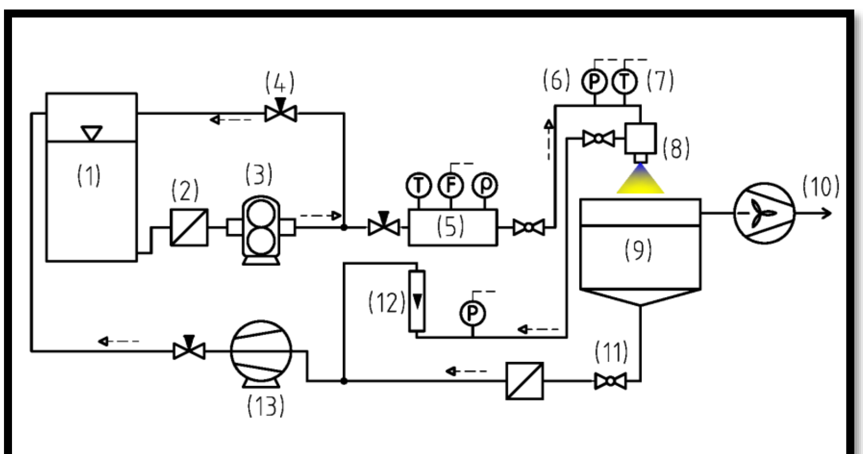
- Computational fluid dynamics:
  - Autodesk Inventor 2016, Rhinoceros
  - COMSOL Multiphysics 5.1, CCM+. (StarCD)
  - A powerful computer cluster (50×PC)
- Data analysis and visualization:
  - Matlab, Origin, Tecplot

Test bench



- Cold/hot testing
- Ambient atmospheric pressure
- Spraying into still/flowing air





- Various atomizers, pressure, twin-fluid, three-fluid, …
- Flowrate, temperature and pressure control of the fluids

Thank you for your attention

Authors greatly acknowledge financial support from project LTAIN19044 funded from the program INTER-EXCELLENCE by the Ministry of Education, Youth and Sports of the Czech Republic.

Phone: (+420) 541 143 266
(+420) 604 300 164
E-mail: jedelsky@fme.vutbr.cz