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Potential of CO_2 separation by adsorption

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Introduction

Adsorption is common industrial process for gas separation.

In my dissertation I dealt with separation of water vapors from natural gas, H_2O-CH_4.

In the department laboratory is adsorption unit separating oxygen from air, O_2-N_2 .
(hospitals, bioreactors, WWT)

CO_2 capture has become a topic of increasing interest (fossil and conventional fuels still represent a majority of energy supplies, global strategies towards cleaner environment, green industrial policies etc..

Research aim and objectives

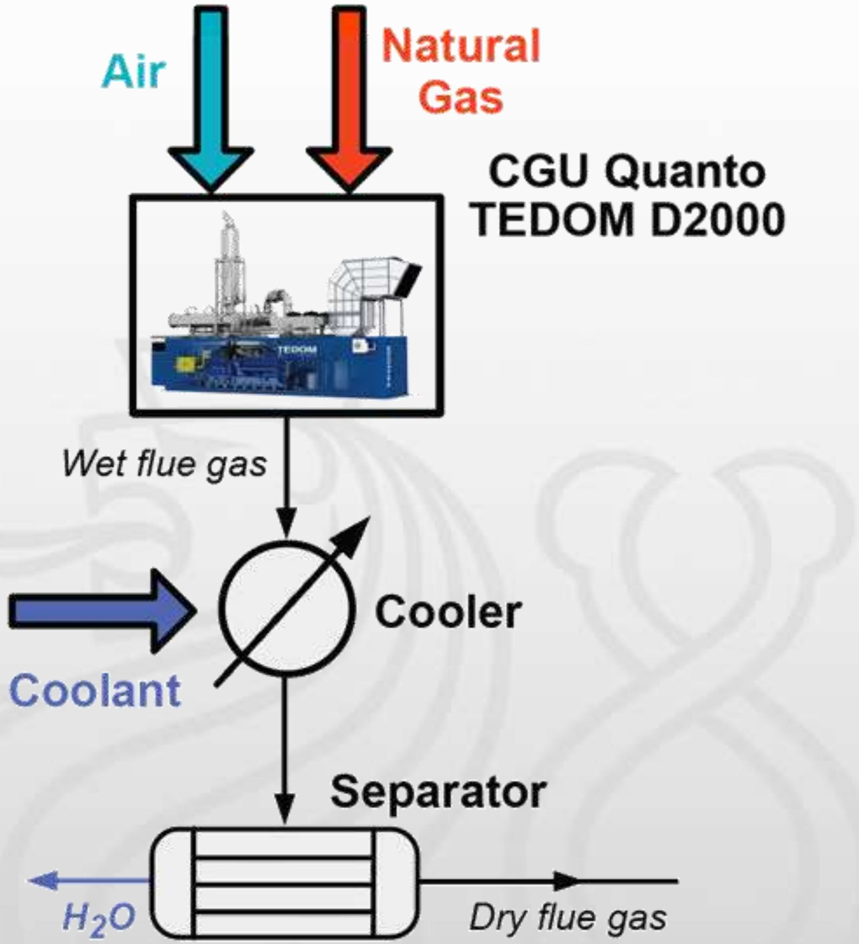
Check the potential of an adsorption process application for post-combustion CO_2 capture from a medium size natural-gas cogeneration (CHP) unit. Real process data, literature data, and mathematical modelling were applied.

Example of high efficiency (92%) energy source. Industrial use, and remote regions with poor infrastructure.

Input data   Major simplification

CHP 2,3 MW_h +2 MW_e.
Flue gas flow: 9,000 Sm^3/h
Flue gas temp.: 82°C.
Wet gas vol. comp.: 73 % N_2
12 % H_2O
8 % O_2
6 % CO_2
1 % Ar

	Emission limit (mg/m^3)	*Averaged concentration (mg/m^3)*
CO	*650*	*34 ± 5*
NO_X	*500*	*326 ± 36*

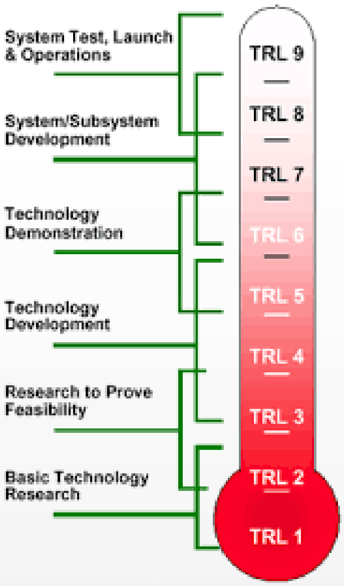


Process selection

Commercialised process for CO_2 capture is amine-based absorption (MEA).

Adsorption CO_2 capture technology readiness level TRL = 7.

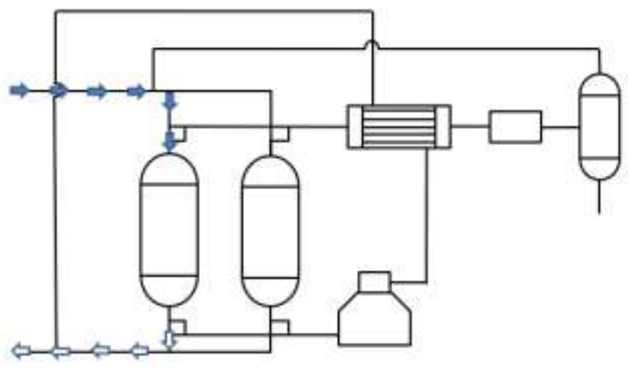
It is promising technology suitable for a high volume of diluted gas processing. Adsorption require less energy for sorbent regeneration and extends the sorbent lifetime, also do not face problems with corrosion.



Industrially applied adsorption methods:

1) Pressure Swing Adsorption (PSA)
   including Vacuum Swing Adsorption (VSA)
2) Temperature Swing Ads. (TSA)

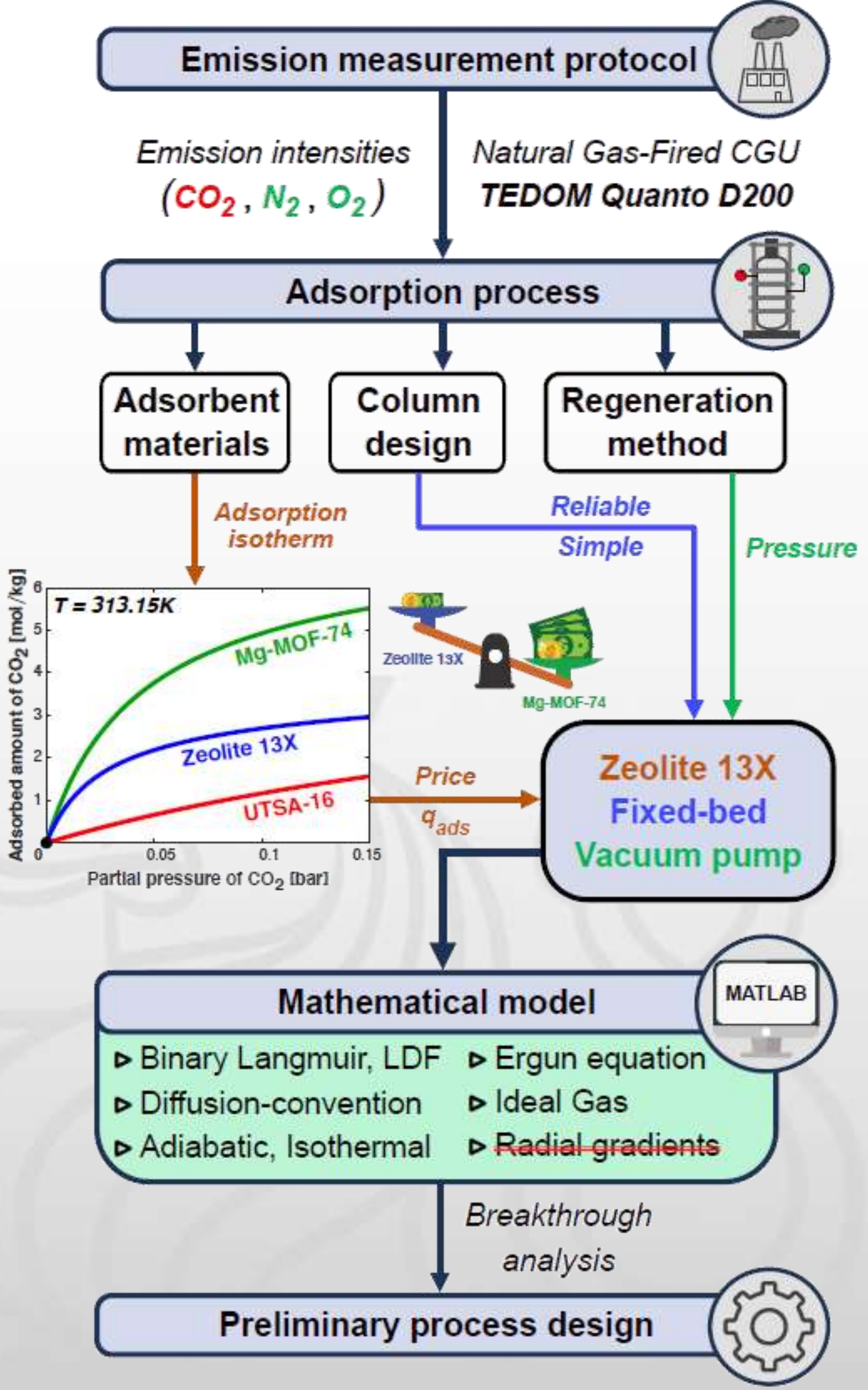
These methods utilize a difference in adsorption equilibrium.



Methodology

How conceptual design adsorption process and set key process parameters?

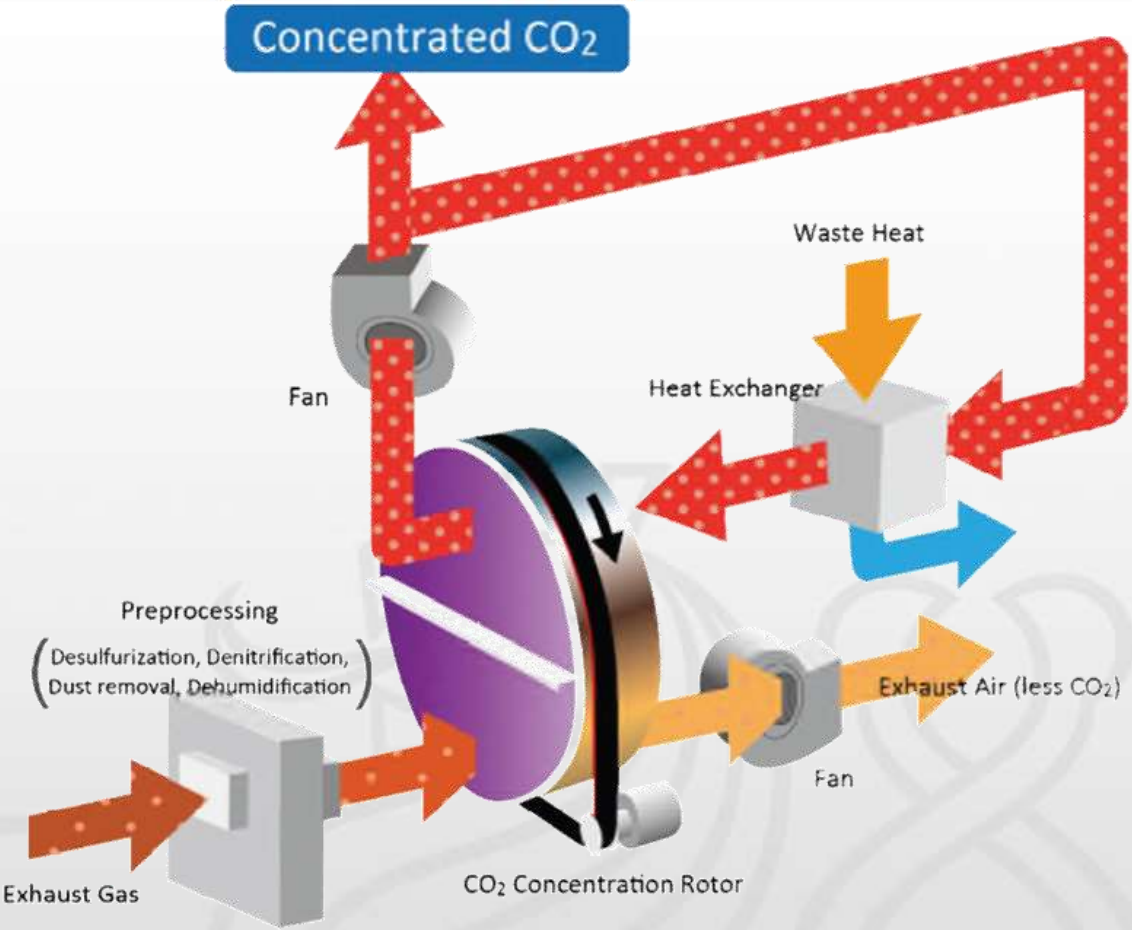
1. Define separation limit
2. Lit. search for similar cases to select:
   A. Regeneration method
   B. Adsorbent
   C. Equipment setup
3. Create a model
4. Tune the process



Regeneration methods

TSA – problem with time demanding regeneration. Further studies on concepts of rapid TSA → (TRL is low).

PSA – pressurize the entire flow is energy demanding.
VSA evacuates only volume of column.



Seibu Giken, C-SAVE

Adsorbent

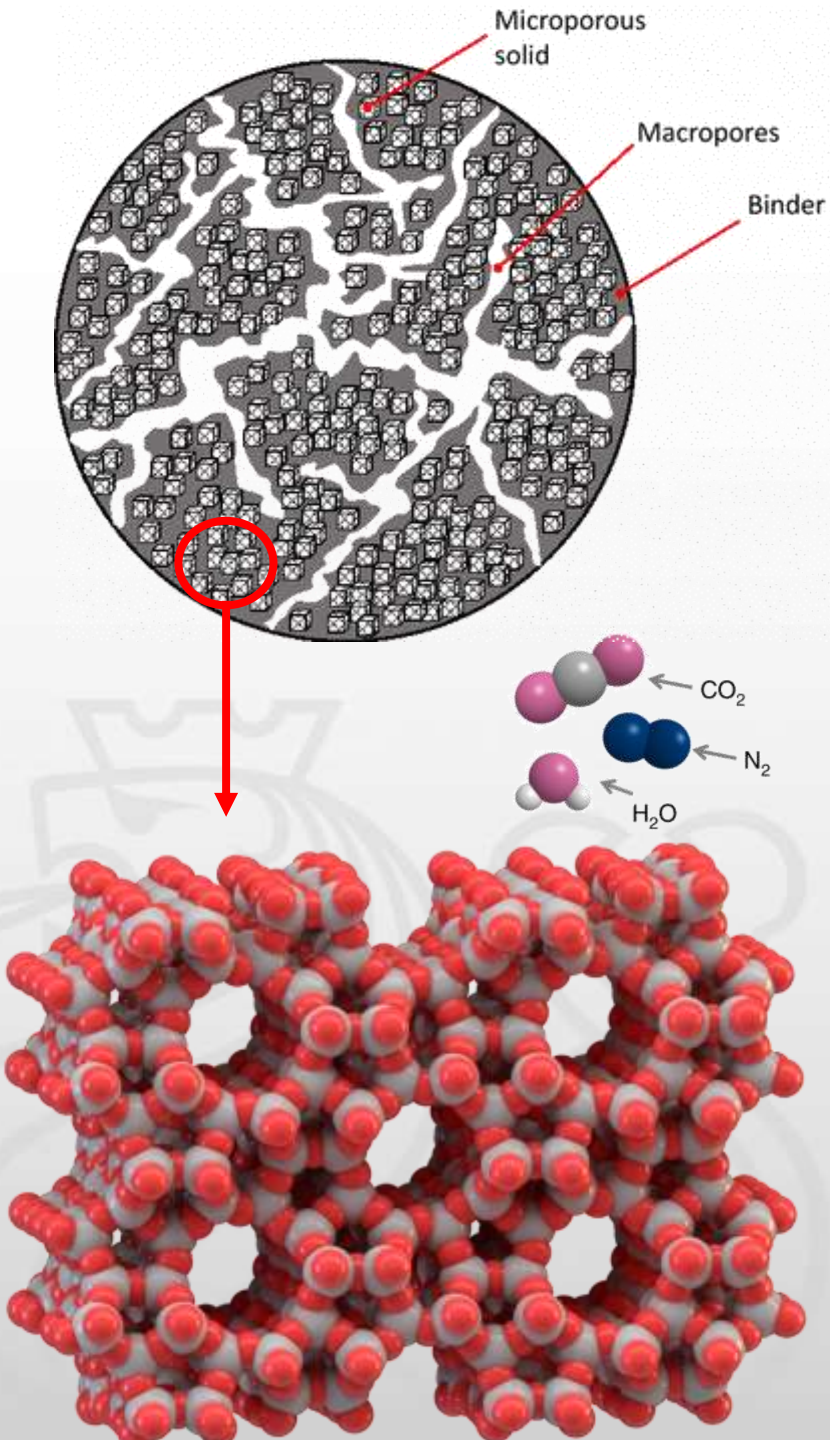
Adsorption is a consequence of surface energy of adsorbent and charge of gas molecules.

Ads. rate/extend is affected by internal structure of the adsorbent.

CO_2 capture benchmark aluminosilicate minerals e.g., Zeolite 13X. Research on metal organic frameworks MOFs.

Adsorbent selection criteria:

A. Price & availability
B. Ads. capacity & Selectivity
C. Durability

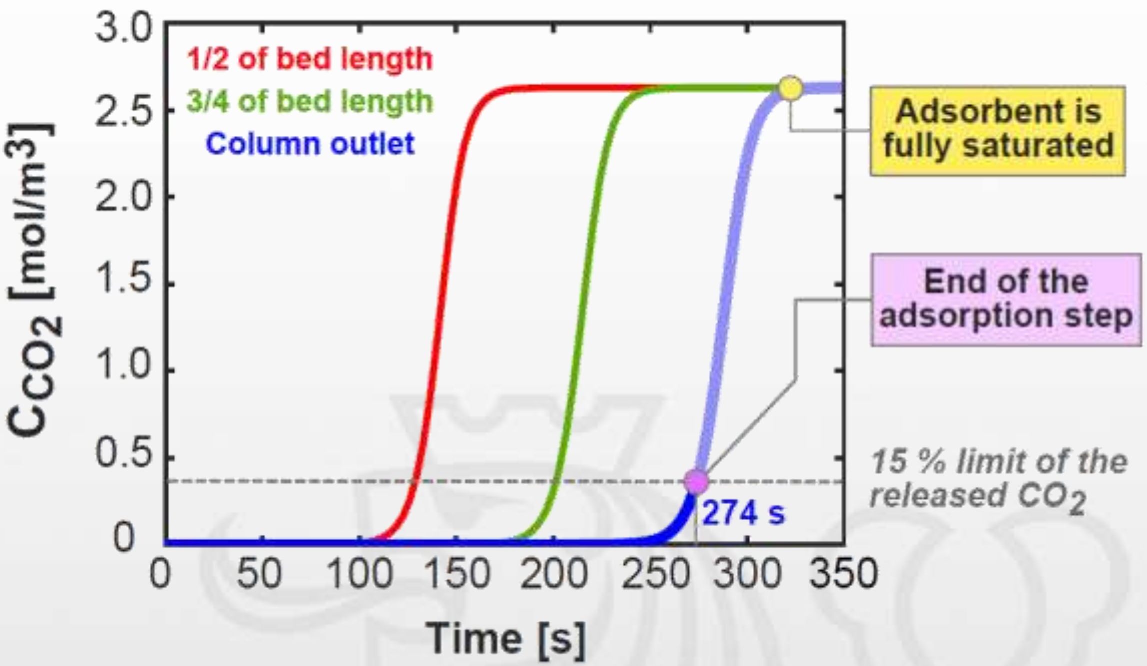


Mathematic modelling

Analysis by dimensionless criteria to tune parameters.

Favorable shape of breakthrough curve as the target.

Outcome is the adsorption cycle duration.



Biot – *sufficient transport to surface.*

$$Bi = \frac{\beta R_p}{D_{ef}} \qquad \frac{\text{transport to particle surface}}{\text{difussion into particle}}$$

π₁ *- significant intraparticle diffusion.*

$$\pi_1 = \frac{u}{4H}\frac{R_p^{\,2}}{D_{ef}}\frac{\varepsilon_p}{1-\varepsilon_p} \qquad \frac{\text{convection through column}}{\text{difussion into particle}}$$

π₂ *- convection dominant*

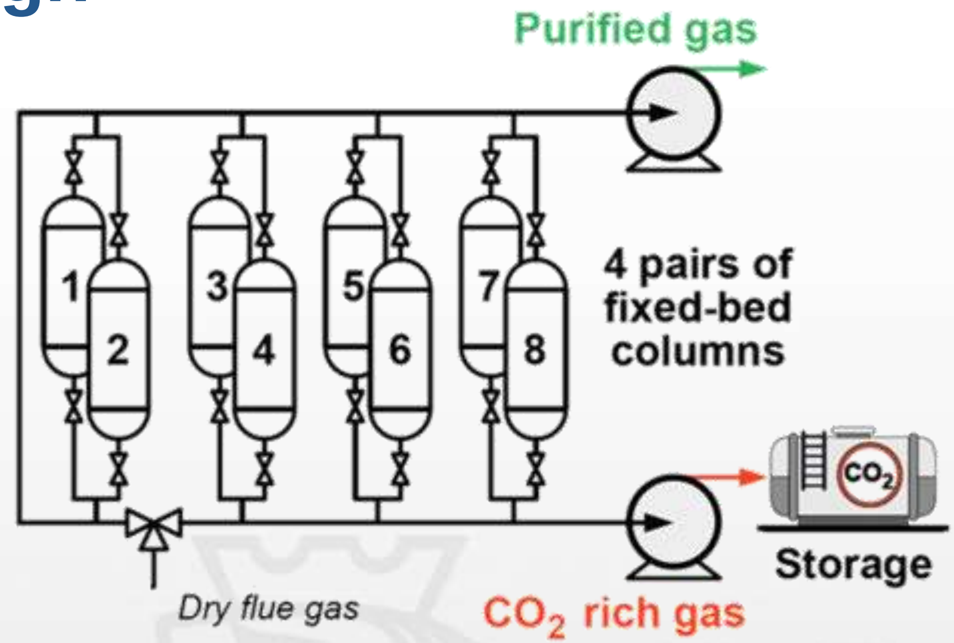
$$\pi_2 = \frac{D_{AX}}{v \cdot H} \cong \frac{\beta \cdot R_p}{H} \qquad \frac{\text{axial dispersion}}{\text{convection through column}}$$

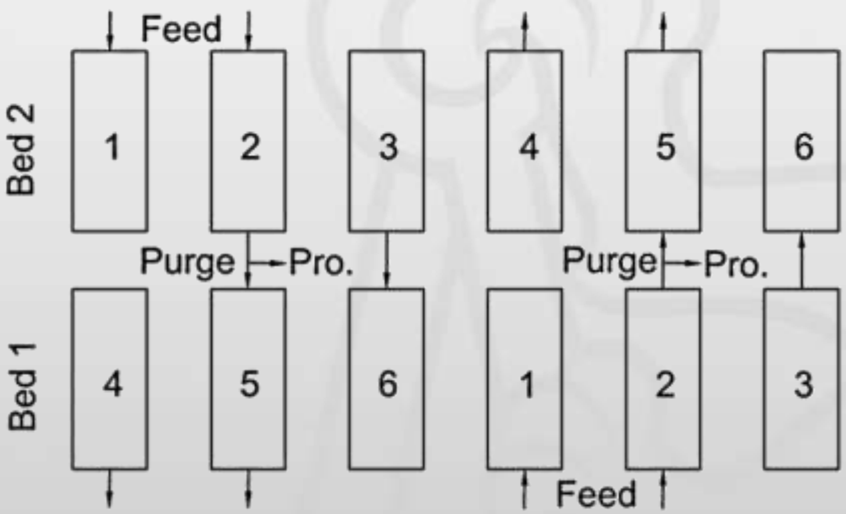
Process design

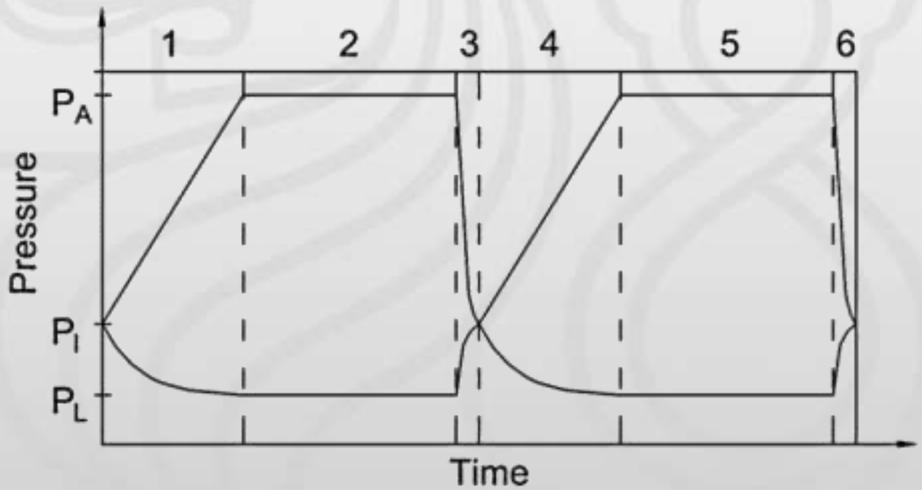
1 stage train design selection (4x2col., col.: L=2m, ∅=1m).

to assure performance (mass transfer/superficial velocity)

Continuous separation in train requires at least two columns system and cycle scheduling.







Conclusions

- CO_2 capture from medium size emission source by adsorption is possible
- VSA for CO_2 capture is favourable from energy point of view.
- Zeolit 13X is attractive adsorbent for industrial VSA CO_2 sep.
- Train configuration of VSA units can benefit from a simple technical solution and provide continuous CO_2 removal.
- Mathematical modeling provides possibility to tune process parameters (no. of columns, cycle time).
- Light product pressurization cycle is recommended for VSA. It reduces the energy consumption of vacuum pumps and improves product recovery.
- As the next step techno/economical evaluation of the proposed solution shall be performed.

THANK YOU FOR THE ATTENTION!

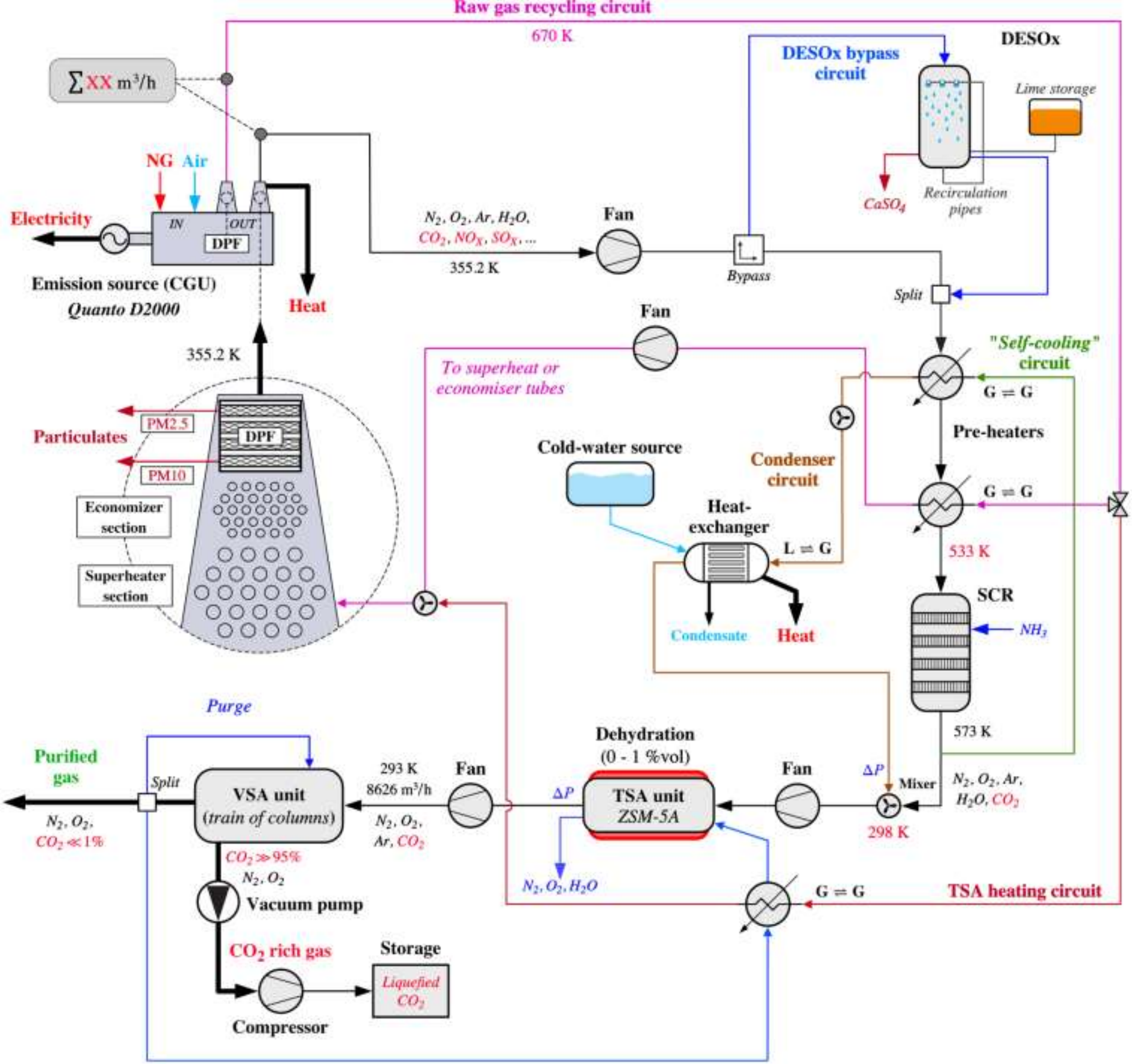
QUESTIONS?

Visegrad Fund

The project is supported by The International Visegrad Fund, project ID22120032.

Actual work

CO_2 capture shall be the latest in a series of flue gas cleaning processes because the flue gas must be free of particulate matter, reactive components (sulfur and nitrogen oxides), and moisture. Water negatively affects the shape of the adsorption isotherm and condenses, leading to degradation of adsorbents (collapse of pores) and damage to equipment, for example, corrosion


Raw gas recycling circuit
670 K
∑XX m³/h
DESOx bypass circuit
DESOx
Lime storage
$CaSO_4$
Recirculation pipes
NG
Air
Electricity
IN
OUT
DPF
Emission source (CGU)
Quanto D2000
Heat
N_2, O_2, Ar, H_2O, CO_2, NO_X, SO_X, ...
355.2 K
Fan
Bypass
Split
Fan
355.2 K
To superheat or economiser tubes
"Self-cooling" circuit
G = G
Pre-heaters
PM2.5
Particulates
DPF
PM10
Economizer section
Superheater section
Cold-water source
Condenser circuit
Heat-exchanger
G = G
533 K
L = G
SCR
NH_3
Condensate
Heat
Purge
Purified gas
Split
VSA unit
(train of columns)
293 K
8626 m³/h
Fan
Dehydration
(0 - 1 %vol)
TSA unit
ZSM-5A
ΔP
Fan
ΔP
Mixer
573 K
N_2, O_2, Ar, H_2O, CO_2
298 K
N_2, O_2, $CO_2 \ll 1\%$
N_2, O_2, Ar, CO_2
$CO_2 \gg 95\%$
N_2, O_2
Vacuum pump
N_2, O_2, H_2O
G = G
TSA heating circuit
CO_2 rich gas
Storage
Liquefied CO_2
Compressor

Adsorption process selection

Ref	Adsorption technology	Flue gas: Composition	Flue gas: Parameters	Power plant	CO_2 purity
[38]	1-stage 4-step VSA zeolite 13X, UTSA-16 IISERP, MOF2	20 % CO_2 80 % N_2	100 kPa, 25 °C, various: 23,000 m³/h	450 TPD steam-methane reforming hydrogen plant	95.0 % (process constraint)
[39]	1-stage 4-step TSA activated carbon	9 % CO_2 79 % N_2 12 % O_2	100 kPa, 30 °C, 13 t/h	20 MW coal-fired power plant	99.1 %
[40]	1-stage 4-step TSA activated carbon	3.72 % CO_2 75.29 % N_2 12.57 % O_2 8.41 % H_2O	100 kPa, 20 °C, 2,380 t/h	411 MW natural gas combined cycle power plant	-
[41]	2-stage 5-step VPSA zeolite 5A activated carbon	14.3 % CO_2 77.8 % N_2 4.6 % O_2 0.94 % Ar 0.002 % SO_2 2.3 % H_2O	100 kPa, 20 °C, 304.3 mol/s (200 kPa at 360 mol/s before 2nd stage)	1666 MW advanced super-critical pulverized coal-fired plant	95.1 %
[42]	Moving-bed TSA, zeolite 13X (1-stage with circulating adsorbent)	5.15 % CO_2 94.85 % N_2	105 kPa, 30 °C, 3,298 t/h	802 MW NG combined cycle power plant	95.1 - 95.8 %
	4-stage TSA with fluidised bed (steam regeneration) amine-grafted ion-exchange resin	15.0 % CO_2 76.5 % N_2 8.5 % O_2 < 1 ppmv SO_2	50-53 kPa, 40 °C, 612 - 2718 m³/h (plant study: 3,060 m³/h)	1 MW_e sub-bituminous coal-fired power plant	93.0 % (process constraint: 90.0 %)
[43]	1-stage 3-step VSA zeolite 13X	11.4 % CO_2 88.6 % N_2	100 kPa, 30 - 50 °C, 1.670 t/h	20 MW coal-fired power plant	99.1 %
[44]	1-stage 4-step PTSA (solar-assisted) zeolite 13X	14.98 % CO_2 85.02 % N_2	150 kPa, 30 °C, 590 t/h of CO_2	800 MW_e coal-fired power plant	99.9 %
[45]	1-stage 8-step VPSA 2-stage 4-bed 9-step DR-VPSA activated carbon	13.4 - 13.8 % CO_2 86.2 - 86.6 % N_2	160 kPa, 18 °C, 60 - 100 m³/h (bypass)	460 MW pilot plant	75.2 % (VPSA), 87.5 % (DR-VPSA)