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# Are membrane gas separation processes able to meet the product specifications of post combustion $CO_2$ capture?

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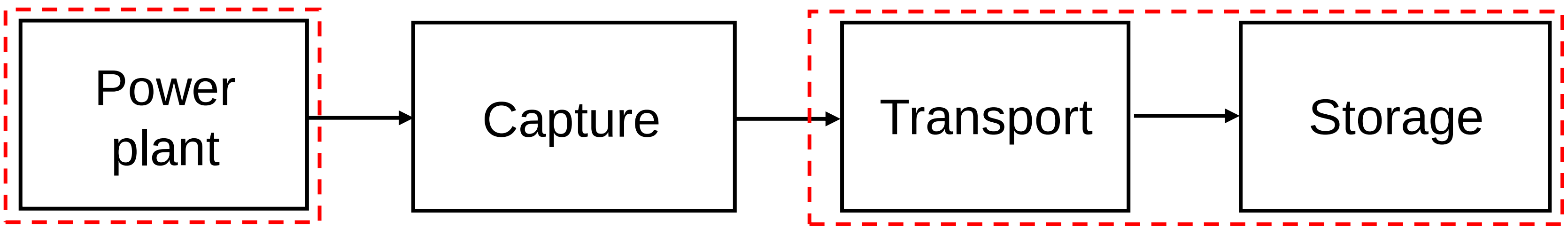
# Introduction

- CCS is considered an important option to reduce $CO_2$ emissions
- Large $CO_2$ emission sources are particularly attractive for CCS
- More than 30% of the global $CO_2$ emissions result from coal fired power plants
- Only post combustion capture enables retrofitting of existing power plants and industrial units


RWE Power

# Definition of boundary conditions (I)

- Power plant
  - 560 kg/s flue gas
  - 1 bar, 50°C, saturated in water
  - $CO_2$ 13.6%, $N_2$ 71.2%, $O_2$ 3.2%
  - Contaminants ($SO_x$, $NO_x$)




- How much to be captured?

- $CO_2$ requirements?
  - $CO_2$ concentration
  - Trace components

# Definition of boundary conditions (II)

- Delivery to pipeline at 130 bar and 30°C
- Composition
  - > 95.5 mole-% $CO_2$
  - max. 4 mole-% of air gases ($N_2$, Ar, $O_2$)
- 2 scenarios for $O_2$ content
  - High purity (only 100 ppm allowed)
  - Up to 4 mole-% $O_2$
- $SO_x$ and $NO_x$ (max. 0.5 mole-% in worst case)
- Residual water content: not specified
- Optimal capture rate: 90% assumed as optimal

# Membrane separation materials

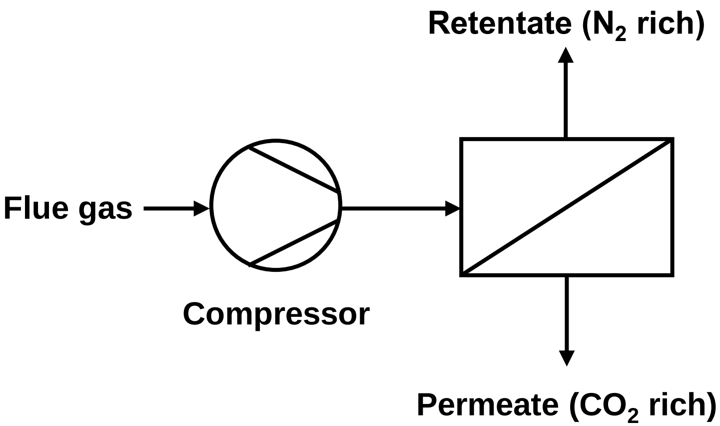
- Ceramic membranes seem inadequate for post combustion $CO_2$ capture
- State-of-the-art polymers appear most suitable

| | $CO_2$ Permeance | $CO_2/N_2$ Selectivity | $CO_2/O_2$ Selectivity | $CO_2/SO_2$ Selectivity |
|---|---|---|---|---|
| PPO | 4.1 | 20 | 4,5 | 5 |
| PEO | 1.25 | 45 | 15 | 0.2 |

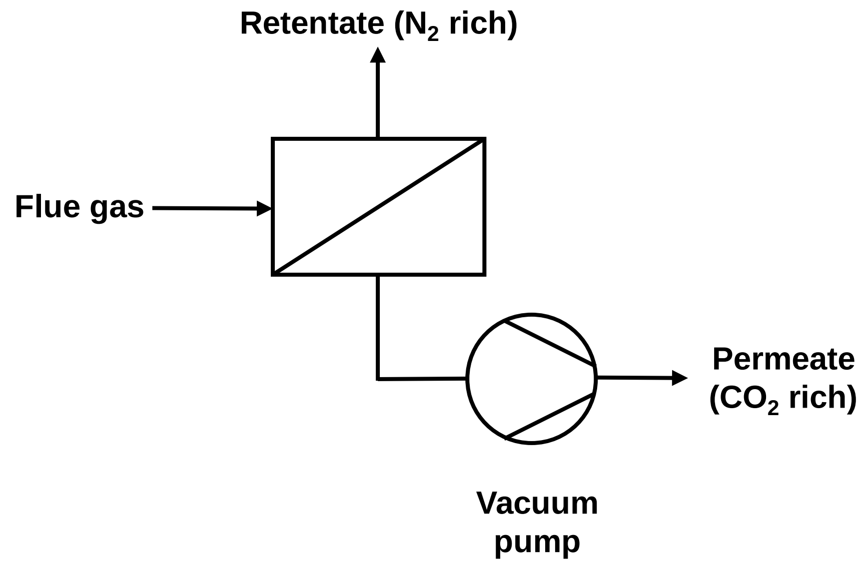
- Permeability $H_2O$ >> permeability $CO_2$
- Permeability $SO_2$ ≥ permeability $CO_2$
- Mass transfer across membrane: $n_i = Q_i A_{Mem} (x_i p_F - y_i p_P)$

# Driving force generation (I)

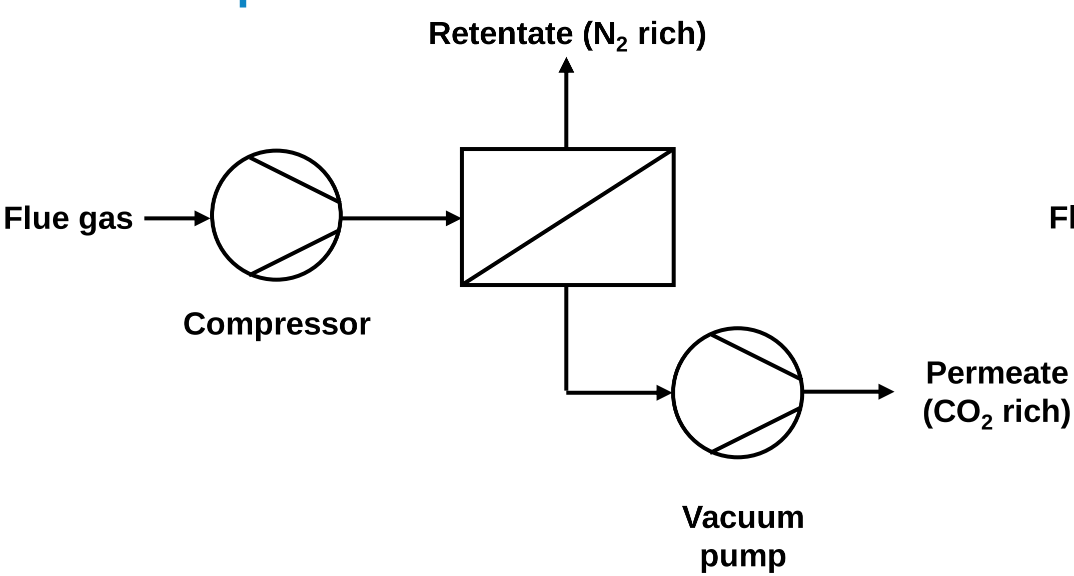
## Feed compression



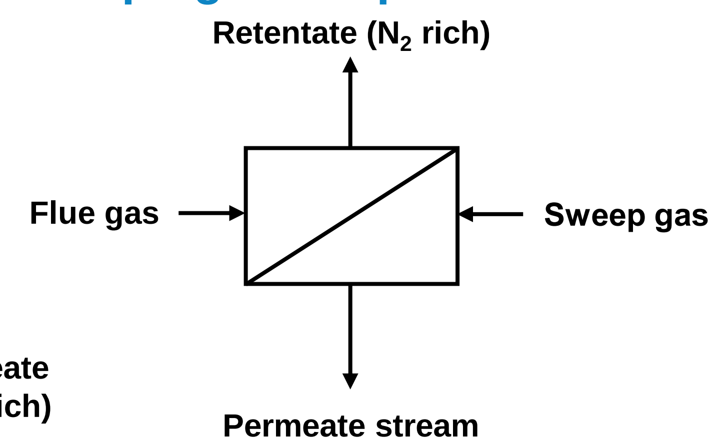

## Low pressure at permeate side




## Feed compression and suction



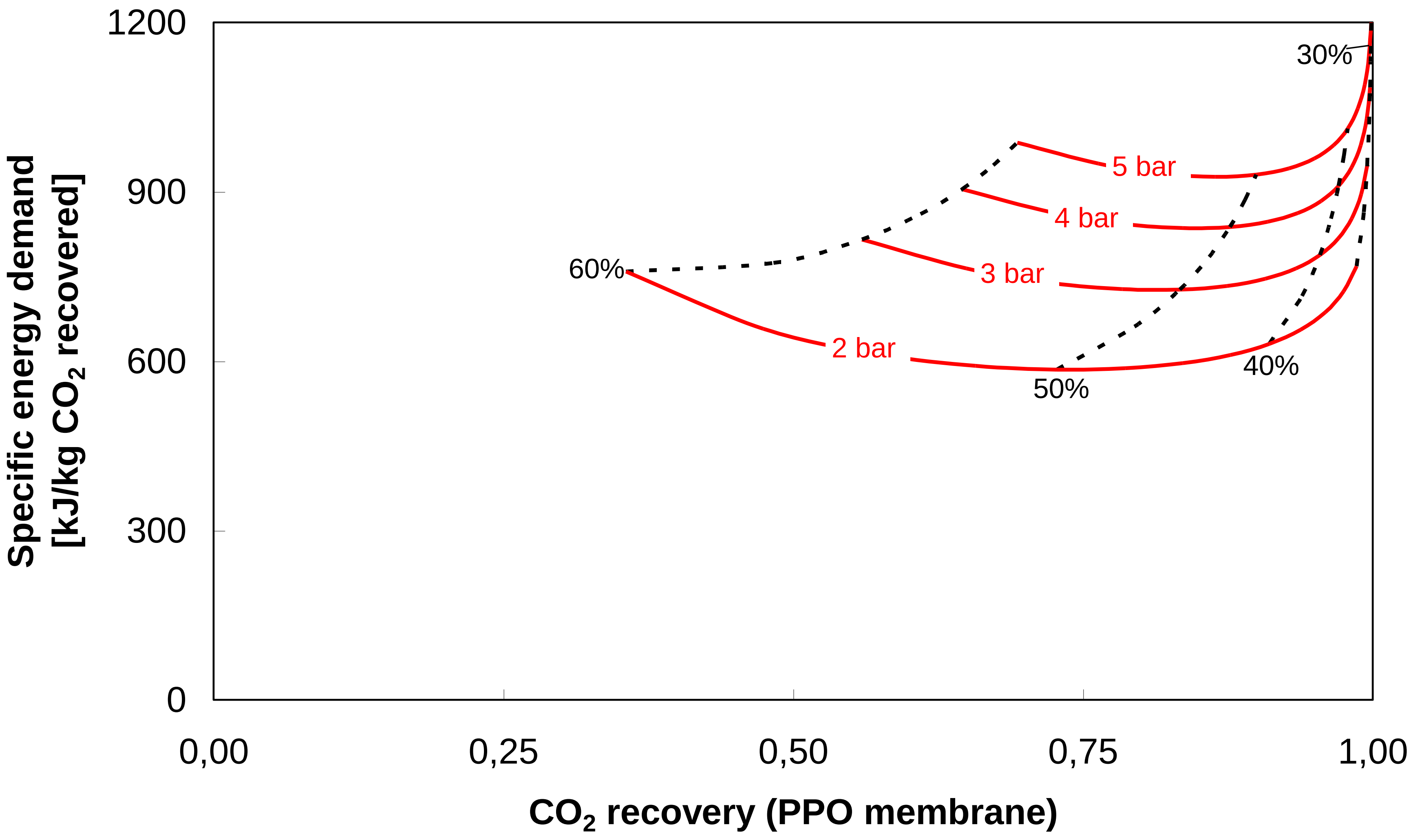

## Sweeping at the permeate side



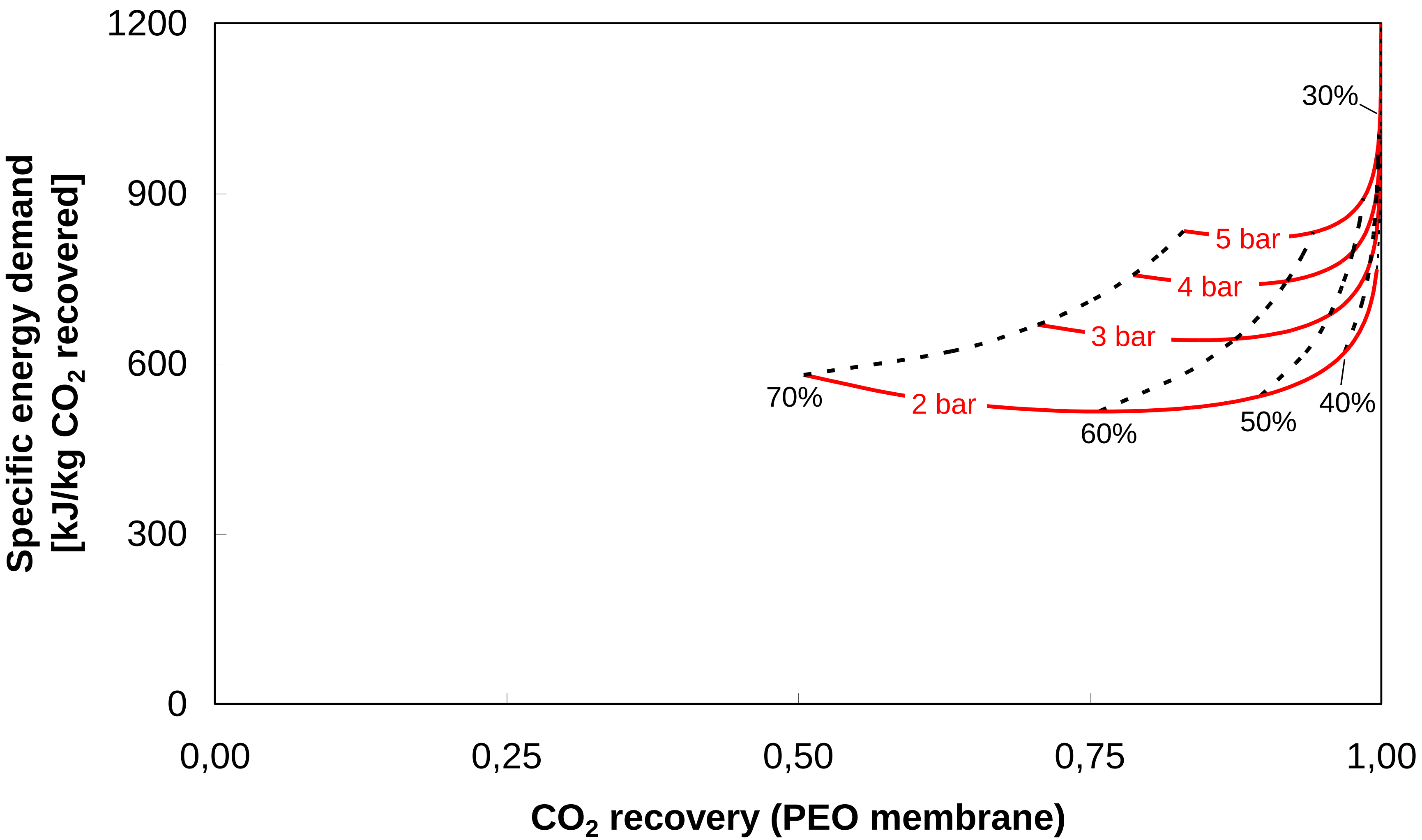
# Driving force generation (II)

- Feed compression
  - Low membrane area, high energy consumption
  - No pressure limitation
- Suction at the permeate side
  - Large membrane area, lower energy consumption
  - Pressure limit at about 200 mbar
- Feed compression in conjunction with suction
  - Combines advantages of feed compression and suction
  - Most likely concept to generate driving force
- Sweeping
  - Only applicable in combination with vacuum on the permeate side
  - Process steam no option for sweeping at the permeate side

# Single-stage membrane system (PPO membrane)



# Single-stage membrane system (PEO membrane)



# Summary single-stage membrane processes

- Trade-offs
  - $CO_2$ enrichment, $CO_2$ recovery and energy requirement

- $O_2$ and $SO_2$ enrich in $CO_2$

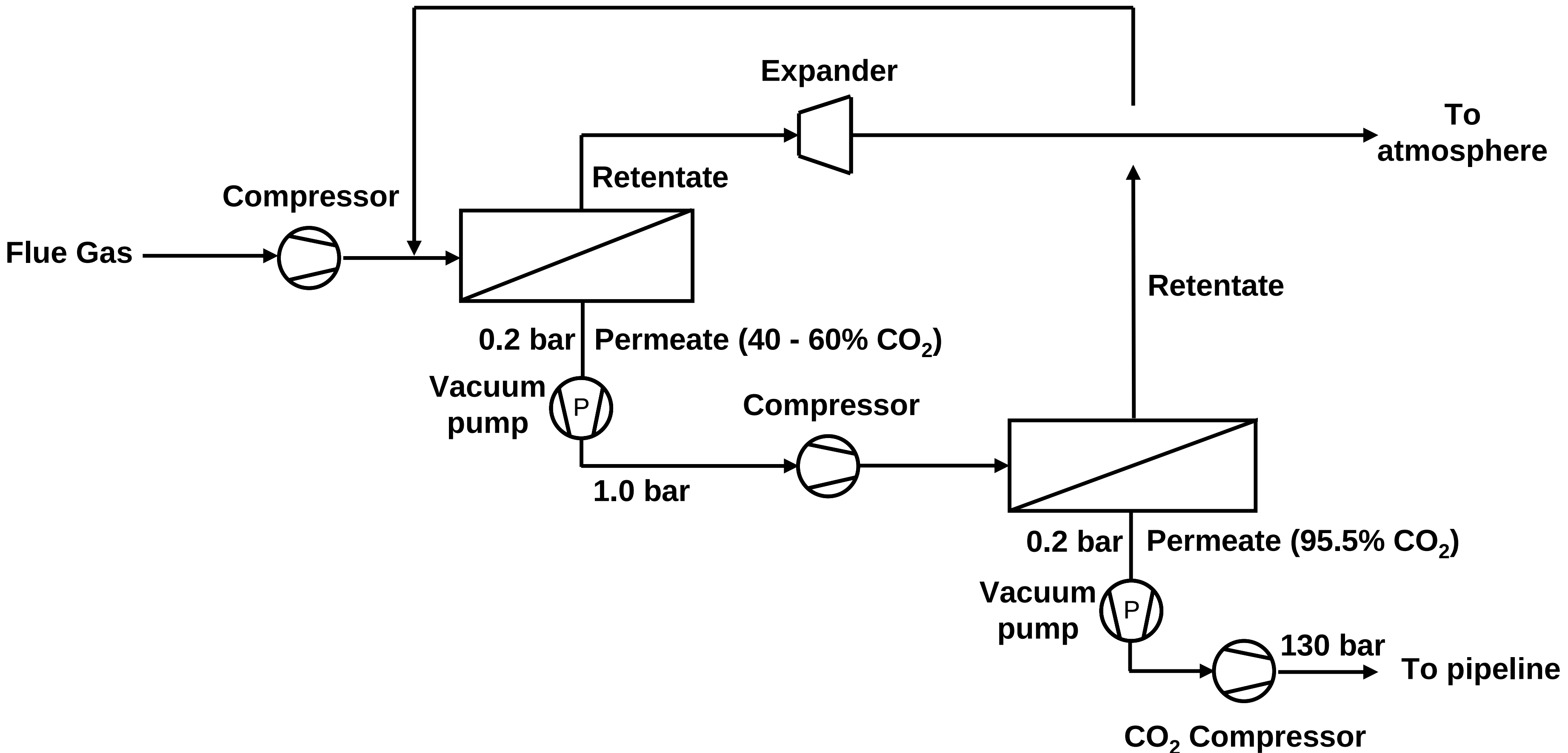
  => additional treatment to achieve low $SO_2$ and $O_2$ content

- Single-stage process works for enrichment

=> Further enrichment / purification by 2nd membrane stage

# Two-stage membrane processes

- Process flowsheet



# Two-stage membrane processes

- Results two-stage processes
  - PPO membrane in 1st stage / PEO membrane in 2nd stage
  - 95.5% $CO_2$
  - 90% $CO_2$ recovery from the flue gas

| Feed pres. 1st/2nd stage | Energy [kJ/kg] | Area [$10^5$ $m^2$] | $O_2$ [%] | $SO_2$ [ppm] |
|---|---|---|---|---|
| 3 bar / 4 bar | 1910 | 7 | 1.8 | 510 |
| 4 bar / 4bar | 1940 | 5 | 1.8 | 510 |

=> Impossible to reach low $O_2$ residual content

# Summary and conclusions

- Membrane gas separation for post combustion $CO_2$ capture is an emerging technology
- Polymer membranes are presently the best choice
- Feed compression in conjunction with suction at the permeate side appears the best option to generate the driving force
- Single-stage processes are unable to achieve 95.5% $CO_2$ in conjunction with reasonable $CO_2$ recoveries
- Two-stage processes reach 95.5% $CO_2$, but fail to meet strict concentration limits of co-captured species
- Membrane-hybrid processes may achieve low residual contents of co-captured species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