Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Capture - Membranes

Membrane-Based Hybrid Process to Capture CO_2 from Warm Flue Gas

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Technical Objectives

- To recover >90% CO_2 from a flue gas stream containing 10~15vol% CO_2 and produce a >99 vol% CO_2 product ready for sequestration.
- To maintain long-term stable performance of this membrane hybrid system when dealing with flue gas streams containing SO_x, NO_x, HCl and HF.
- To reduce the capture cost to $10~20/ton CO_2 avoided.

Process Description

- This process is a modified facilitated transport membrane permeation process, i.e., a synergistic integration of simultaneous chemical absorption/stripping in one compact membrane device.

ADVANTAGES compared to conventional alkanolamine-based absorption/stripping

- The energy consumptions from heating, cooling and solvent circulation are drastically reduced
- The footprint of the membrane-based system for CO_2 capture is less than 30% of conventional absorber/stripper

ADVANTAGES compared to membrane-based absorption/stripping (membrane contactors)

- This membrane hybrid process can drastically reduce the steam consumption, while membrane absorption cannot reduce the steam consumption for solvent regeneration
- This membrane-based capturing system has similar footprint as membrane absorber, while use of membrane absorber cannot lead to a drastic reduction of footprint of the entire device since conventional stripping device has to be used

ADVANTAGES compared to conventional physical and chemical membranes

- This membrane process provides both higher CO_2 mass transfer coefficient and CO_2/N_2 selectivity
- The membrane system is stable when the flue gas containing SO_x, NO_x, HCl and HF, when they are bulk-removed by conventional $deNO_x$ and $deSO_x$ technologies
- Furthermore, the proper accumulation of anions such as SO_4^{2-}, SO_3^{2-}, NO_3^-, NO_2^-, Cl^- in the membrane phase will lead to higher CO_2 mass transfer coefficient and CO_2/N_2 selectivity
- Excess accumulated anions can be effectively removed by an online regeneration system

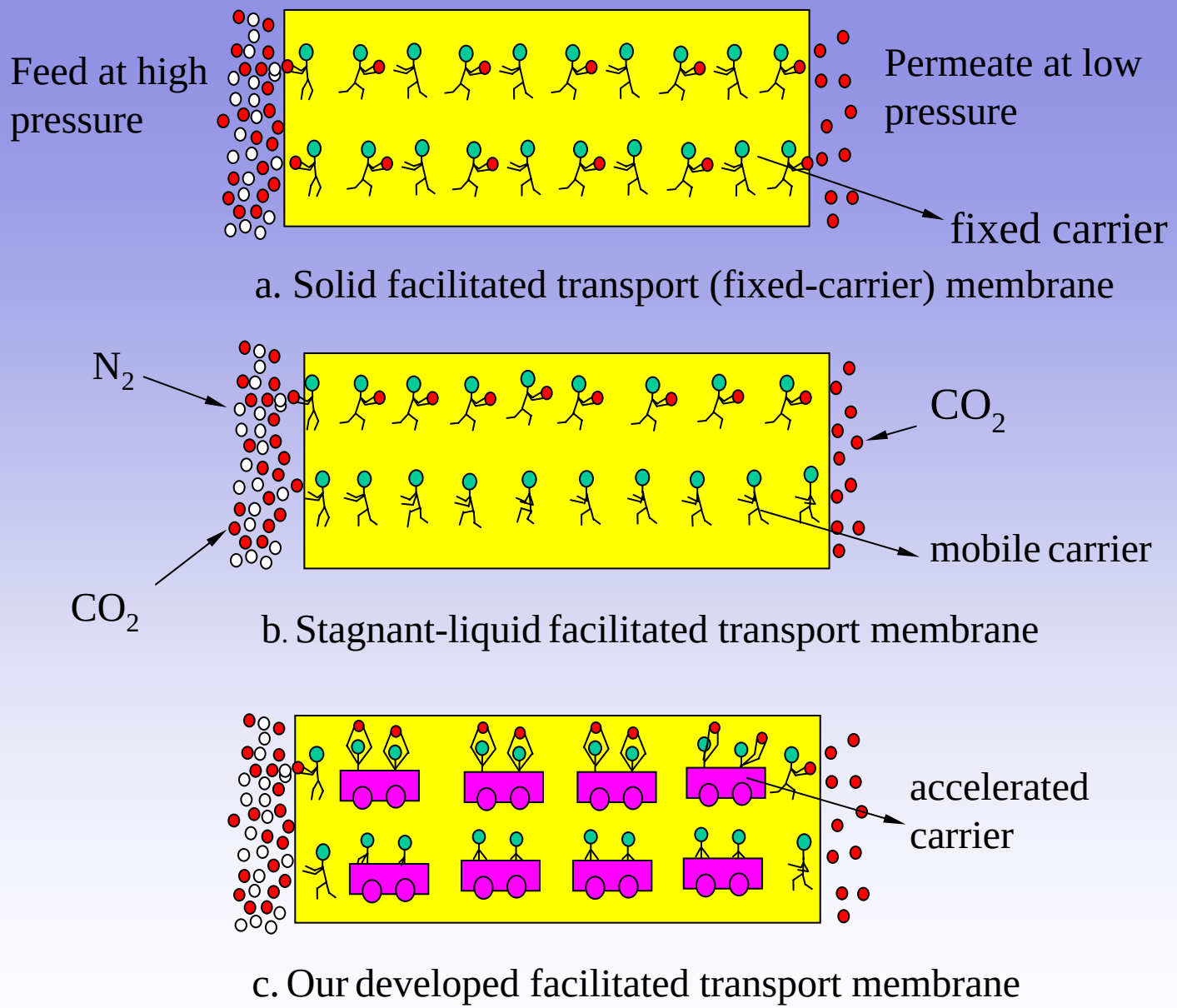

Figure 1. Mechanisms for various facilitated transport membranes

Figure 2. Influence of feed concentrations on the product purity and CO_2 recovery (dry feed containing CO_2 and 3vol% O_2 balanced by N_2; $P_{feed-in}$=1.10 atm, $RH_{feed-in}$ = 40%, $Q_{feed-in}$= 400 cm^3(STP)/min, $P_{sweep-out}$= 0.3 atm, $Q_{sweep-in}$= 80~120 cm_3(STP)/min)

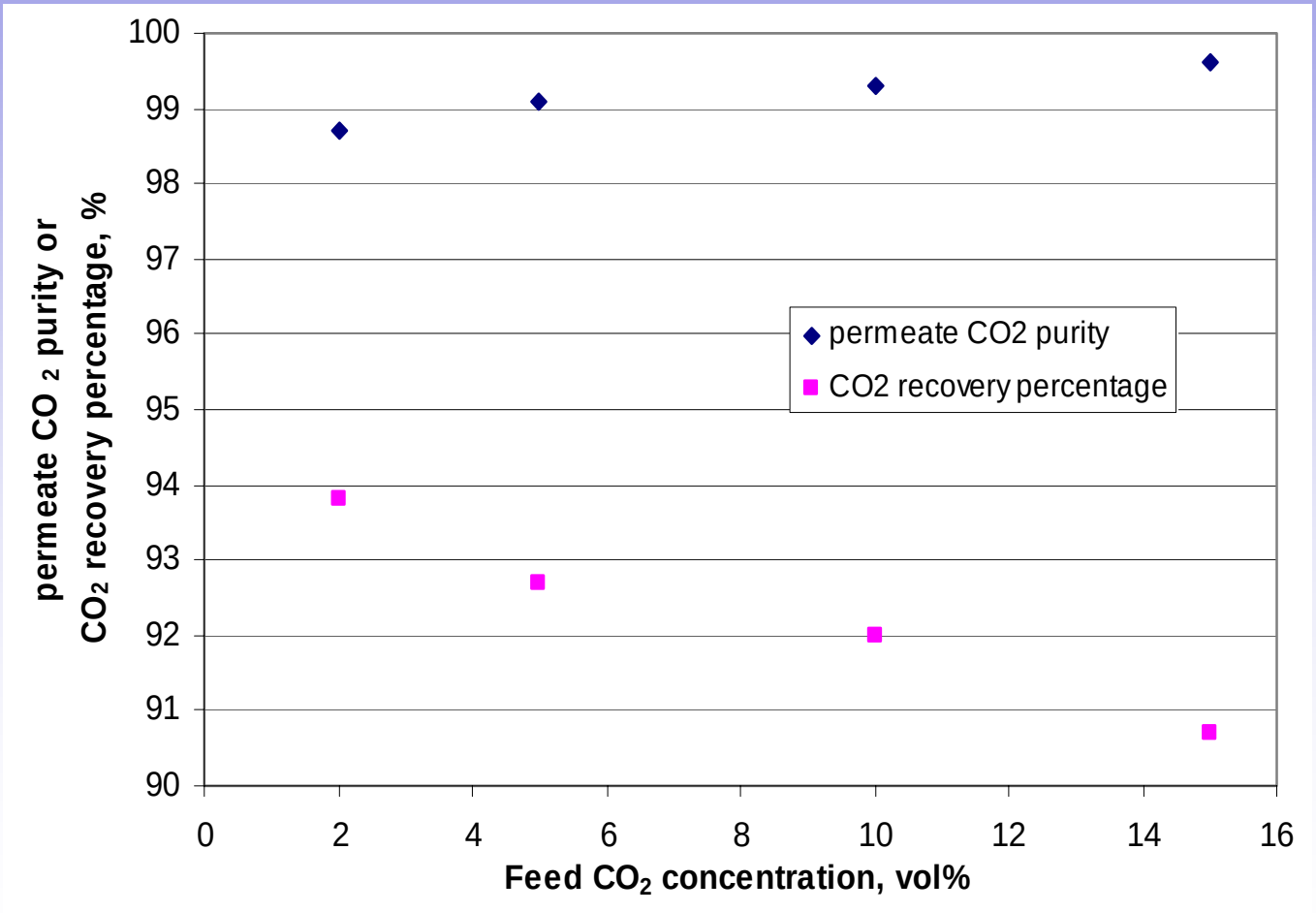

Figure 3. Influence of operating temperature on CO_2 permeance (dry feed composition: 15vol% CO_2, 3vol% O_2 balanced by N_2; $P_{feed\text{-}in}$=1.05 atm, $RH_{feed\text{-}in}$ = 40%, $Q_{feed\text{-}in}$= 100 cm^3(STP)/min, $P_{sweep\text{-}out}$= 0.3 atm, $Q_{sweep\text{-}in}$= 30 cm^3(STP)/min)

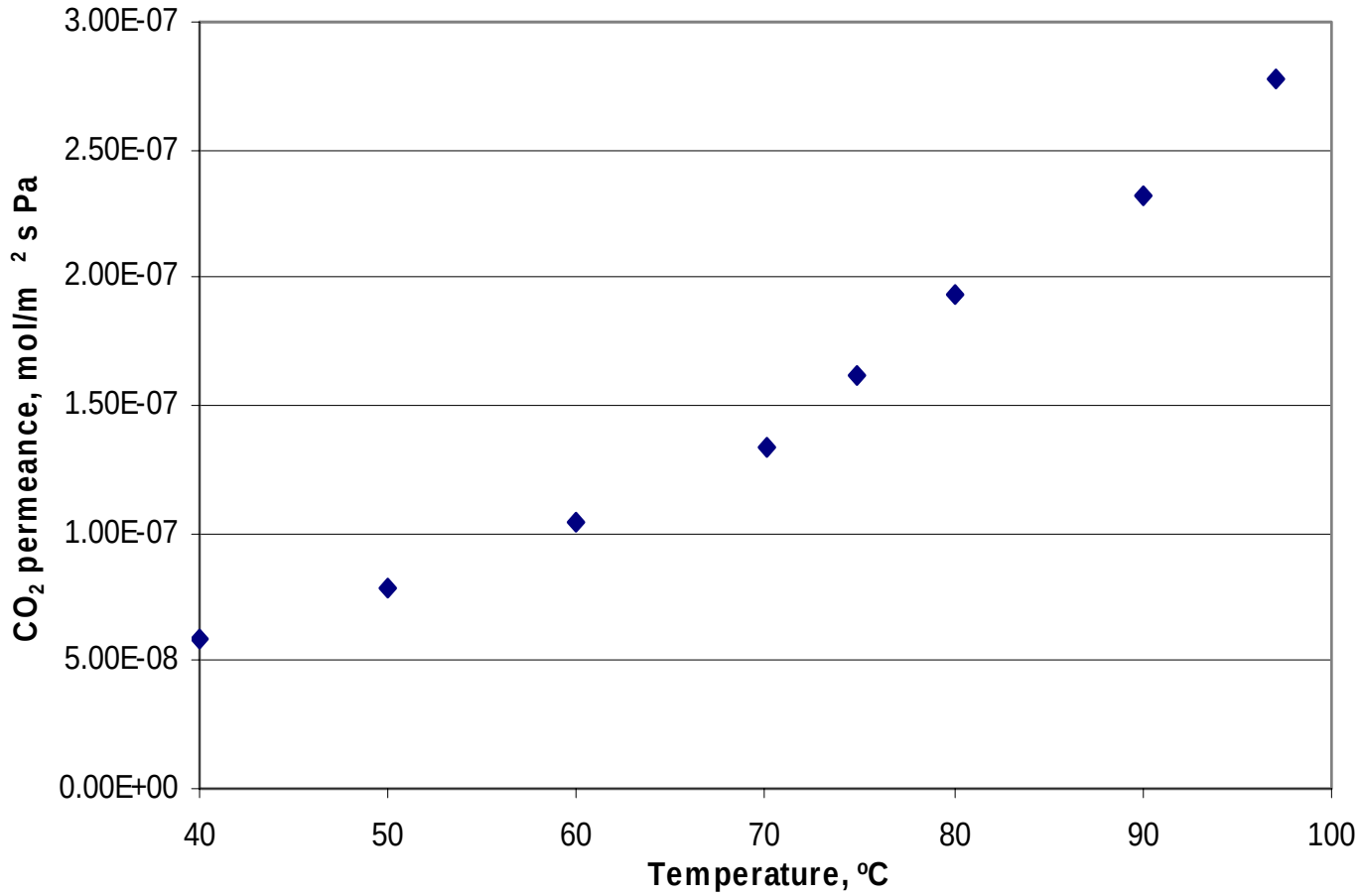

Figure 4. Influence of operating temperature on CO_2 /N_2 and CO_2/O_2 selectivity (See Fig. 3 for experimental conditions)

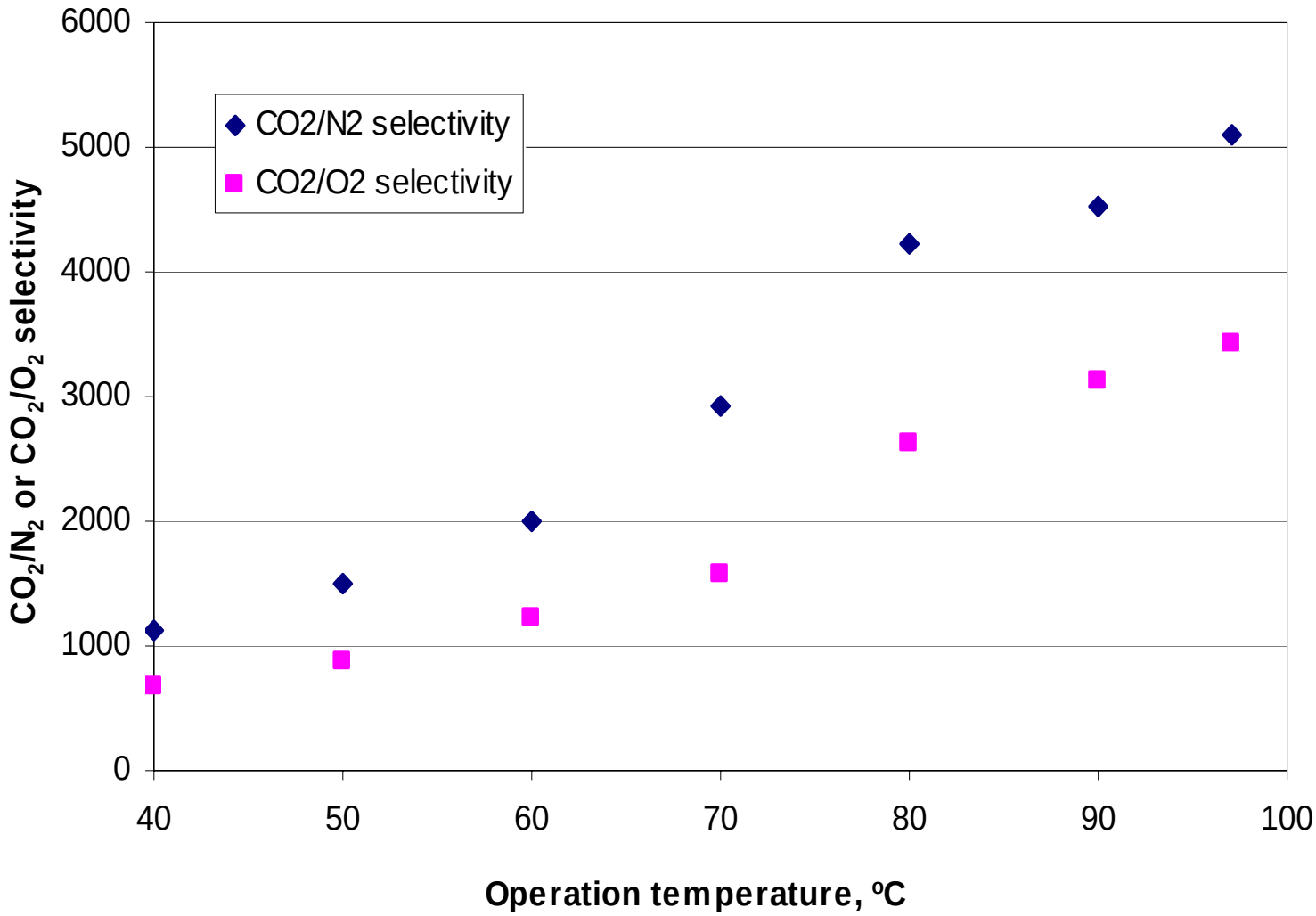

Figure 5. Influence of impurity salts on CO_2 permeance (dry feed composition: 15vol% CO_2 balanced by N_2; $T_{feed\text{-}in}$=$T_{sweep\text{-}in}$=80 ^oC, $P_{feed\text{-}in}$=1.05 atm, $RH_{feed\text{-}in}$ = 40%, $Q_{feed\text{-}in}$= 100 cm^3(STP)/min, $P_{sweep\text{-}out}$= 0.3 atm, $Q_{sweep\text{-}in}$= 30 cm^3(STP)/min)

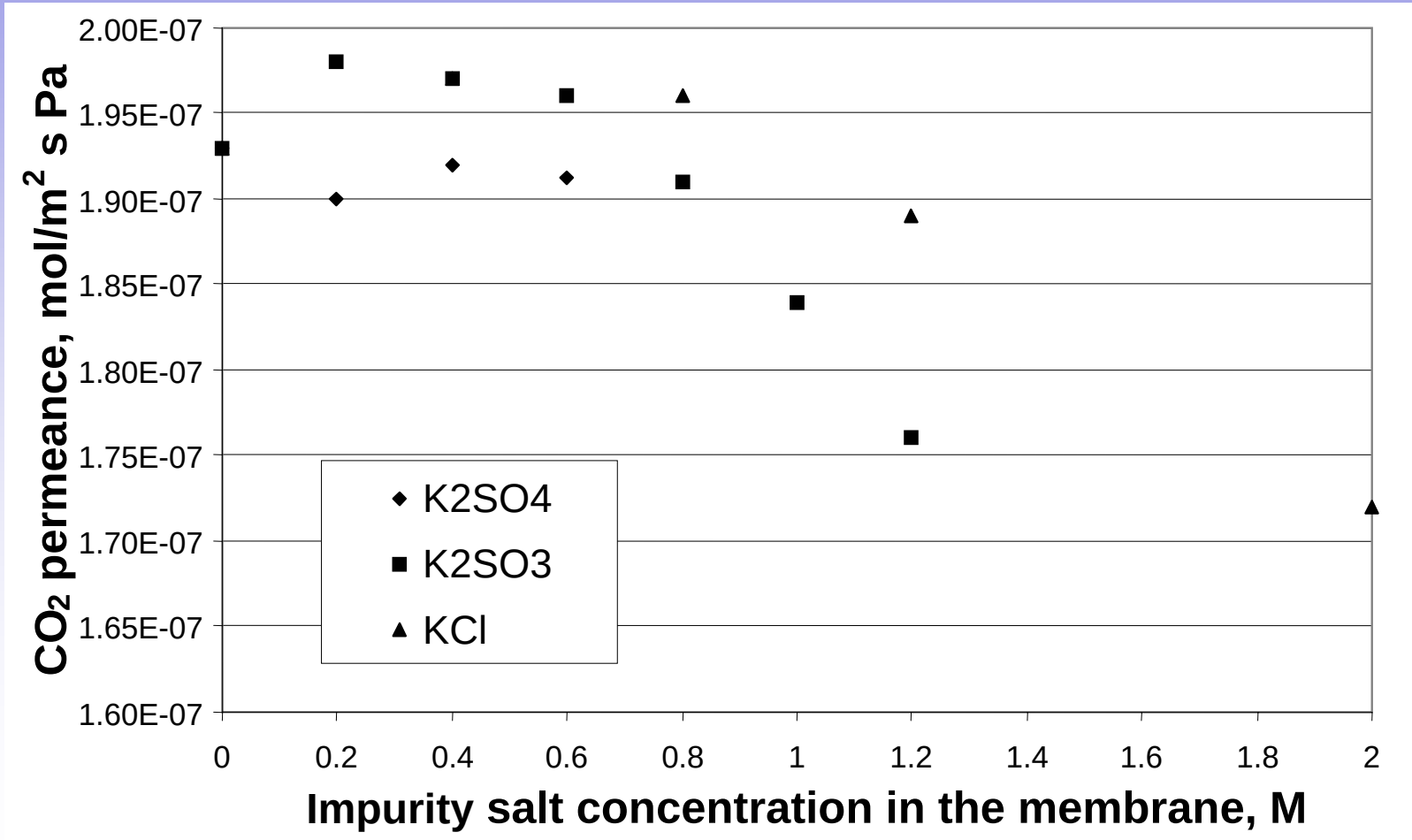

Figure 6. Influence of impurity salts on CO_2 /N_2 and CO_2/O_2 selectivity
(See Fig. 5 for experimental conditions)

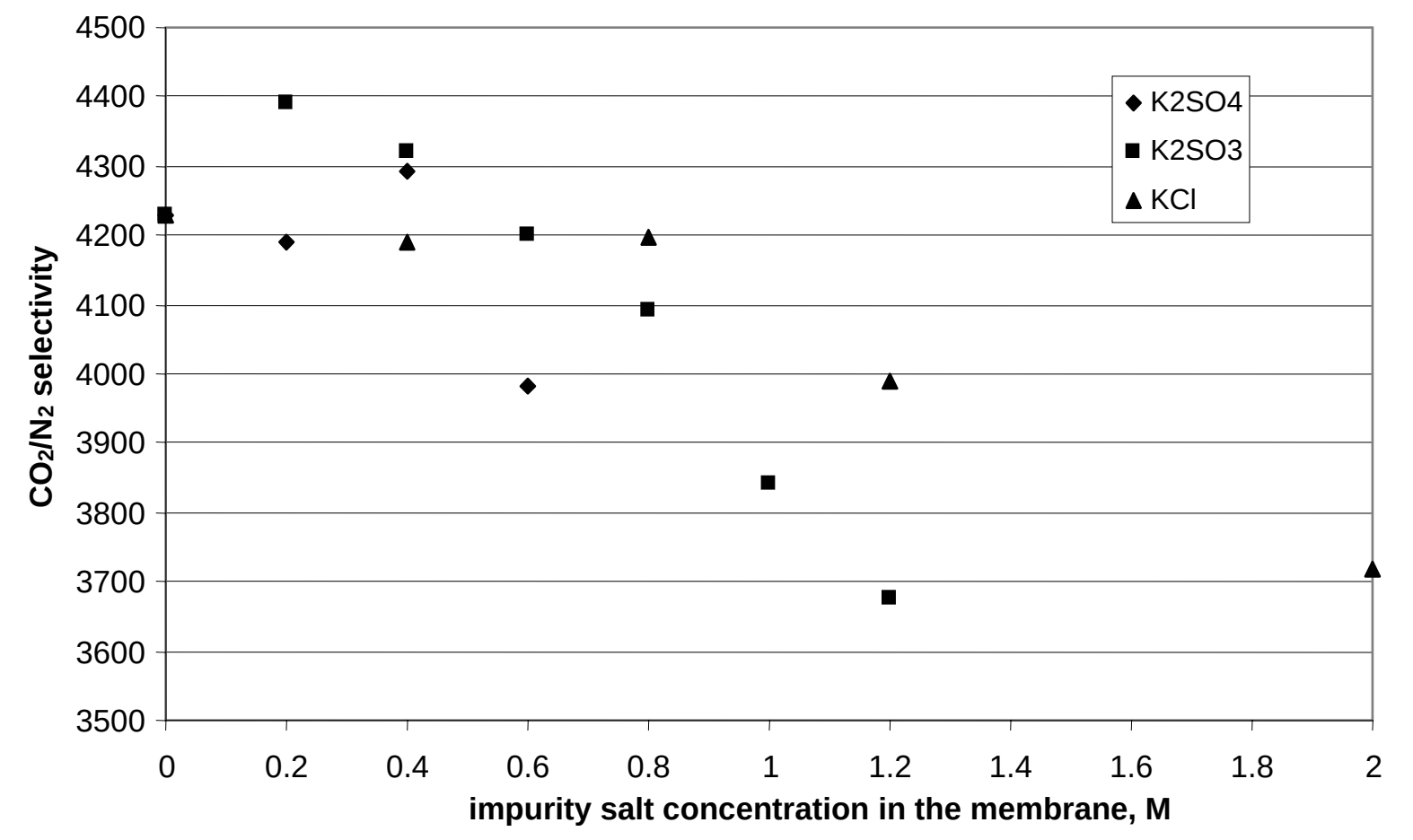

Figure 7. Variation of CO_2 permeance with operation time (dry feed composition: 15vol% CO_2, 1 - 3vol% O_2 balanced by N_2; $T_{feed-in}$=$T_{sweep-in}$=80 ^oC, $P_{feed-in}$=1.05 atm, $RH_{feed-in}$ = 40%, $Q_{feed-in}$= 100 cm^3(STP)/min, $P_{sweep-out}$= 0.3 atm, $Q_{sweep-in}$= 30 cm_3(STP)/min)

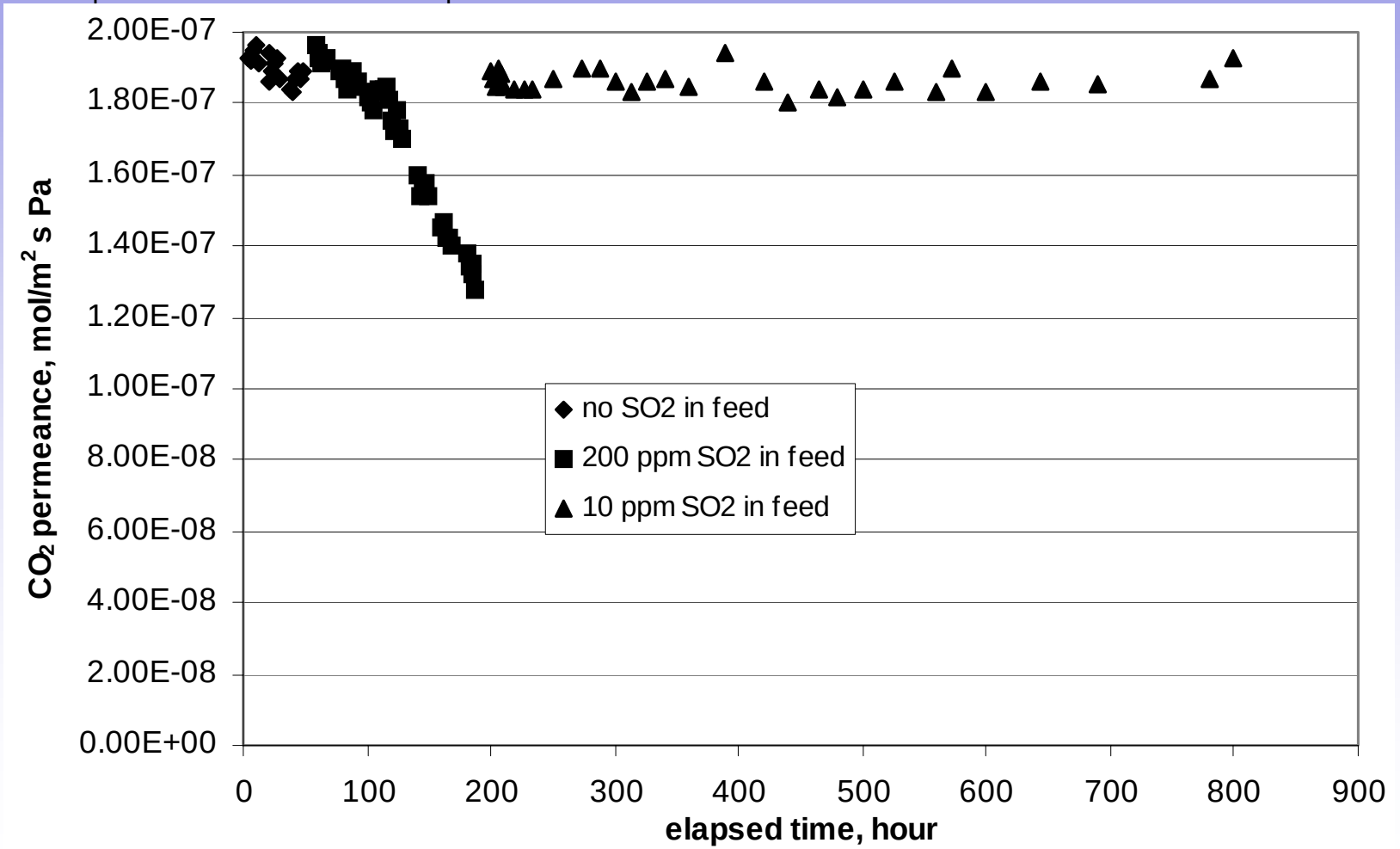

Figure 8. Variation of CO_2/N_2 and CO_2/O_2 selectivities with operation time (See Fig. 7 for experimental conditions)

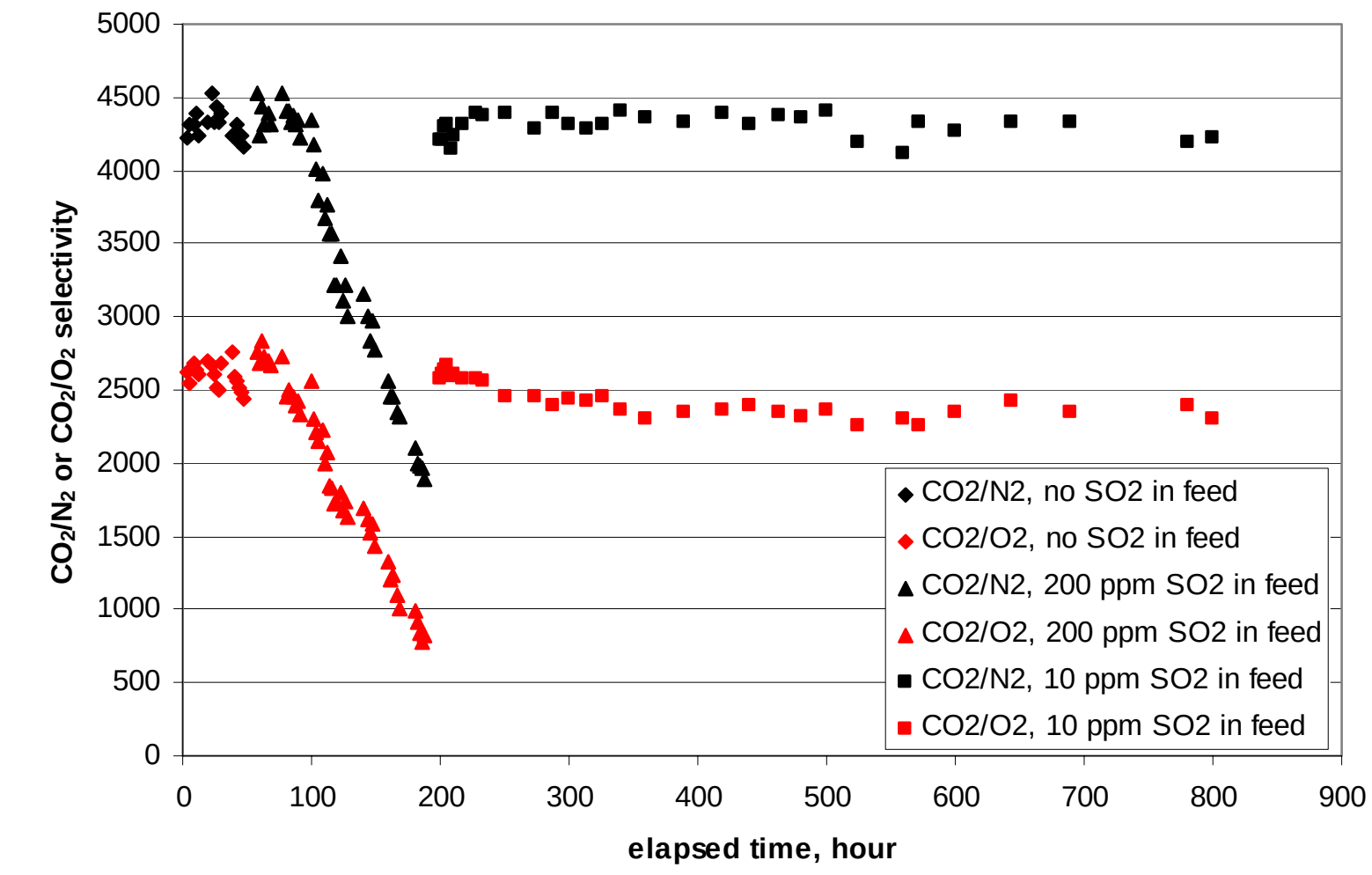

Table 1. Use of utilities in conventional absorption/stripping and our membrane hybrid process

	Conventional absorption/stripping	Chembrane membrane permeation process
Thermal energy	2.4 - 4.6 GJ/tonne CO_2 (reboiler heat)	1.22 – 2.0 GJ/tonne CO_2 (waste heat)
Cooling water	41 - 160 m^3/tonne CO_2	32 - 46 m^3/tonne CO_2
Electricity used in separation section	45 -76 KWh/tonne CO_2	27 KWh/tonne CO_2
Electricity used in compression section (from 1 atm to 150 atm)	90 KWh/tonne CO_2	90 KWh/tonne CO_2

Table 2. Comparison of CO_2 capture cost by chemical absorption/ stripping and Chembrane membrane hybrid process

	Conventional absorption/stripping	Chembrane membrane process
Energy penalty for PC plant, %	22 ~ 29%	12.2%
Capture cost ($/t CO_2 avoided)	$42 ~ 55	$13.5 ~ 20
Capture cost (cent/kWh)	3.7 ~ 5.2 cent/kWh	1.27 ~ 1.80 cent/kWh
Increase in cost of electricity with CO_2 capture	64 ~ 87%	34.3%

Summary

- **Chembrane membrane-based hybrid process can produce a >99 vol% CO_2 stream from a flue gas stream containing 10 to 15vol% CO_2, with a recovery of >90%**
- **This process potentially provides high long-term operational stability when dealing with flue gas streams containing SO_x, NO_x, HCl and HF**
- **This process can drastically reduce the capture cost to $10~20/ton CO_2 avoided.**