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Advanced Oxygen Recovery via Series-Bosch Technology

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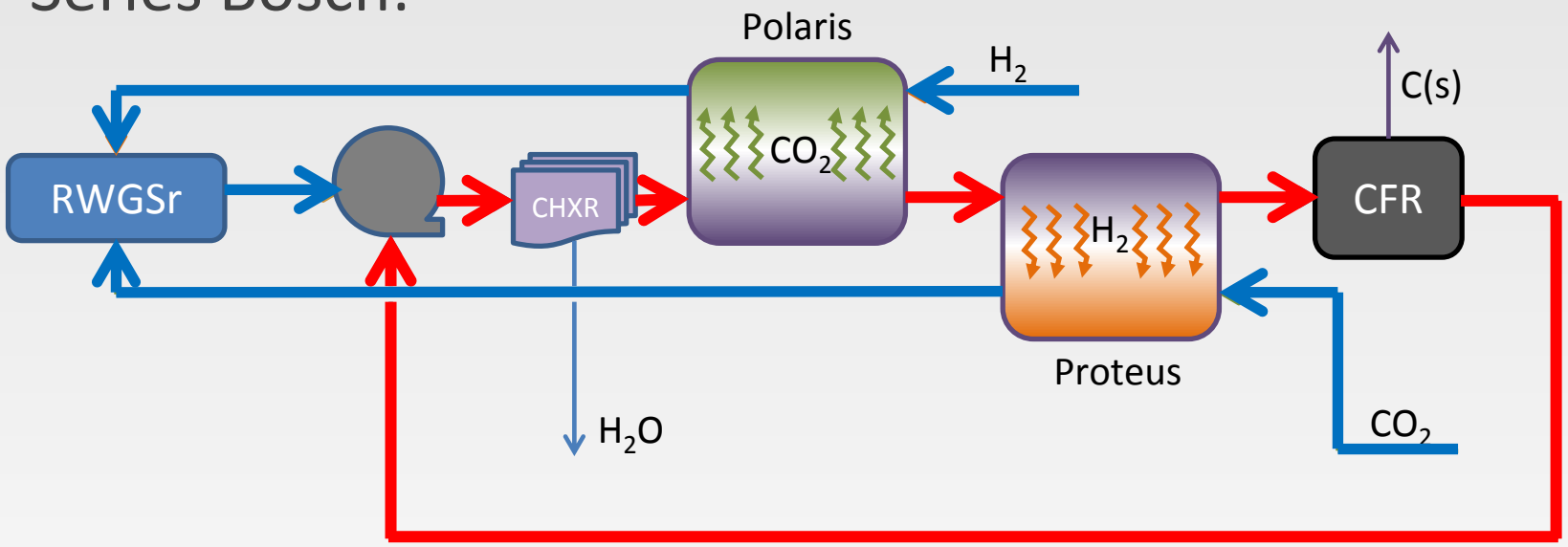
Background

- Bosch Process:

RWGS Rxn	$CO_2 + H_2 \leftrightarrow CO + H_2O$
Boudouard Rxn	$2CO \leftrightarrow CO_2 + C(s)$
CO Hydrogenation	$CO + H_2 \leftrightarrow H_2O + C(s)$
Bosch Process	$CO_2 + 2H_2 \leftrightarrow 2H_2O + C(s)$

- Series Bosch:



- Objective:

  To evaluate the stand-alone performance of each S-Bosch sub-assembly:

  - RWGSr
  - Polaris Membrane (CO_2 Separation)
  - Proteus Membrane (H_2 Separation)
  - CFR

Methods: RWGS Reactor Performance Testing

Parameter	Values
RWGSr Heater Set Points	600°C, 650°C, 700°C
CO_2 Feed Rates	1.41 SLPM, 2.82 SLPM
H_2:CO_2 Ratios	1:1, 2:1, 3:1
RWGSr Inlet Pressure	20.7 kPa (3 psia), 34.5 kPa (5 psia), 55.1 kPa (8 psia)

RWGS IncoFoam Nickel Foam Catalyst

RWGS Reactor (prior to installation of insulation)

RWGS Reactor (following insulation and containment)

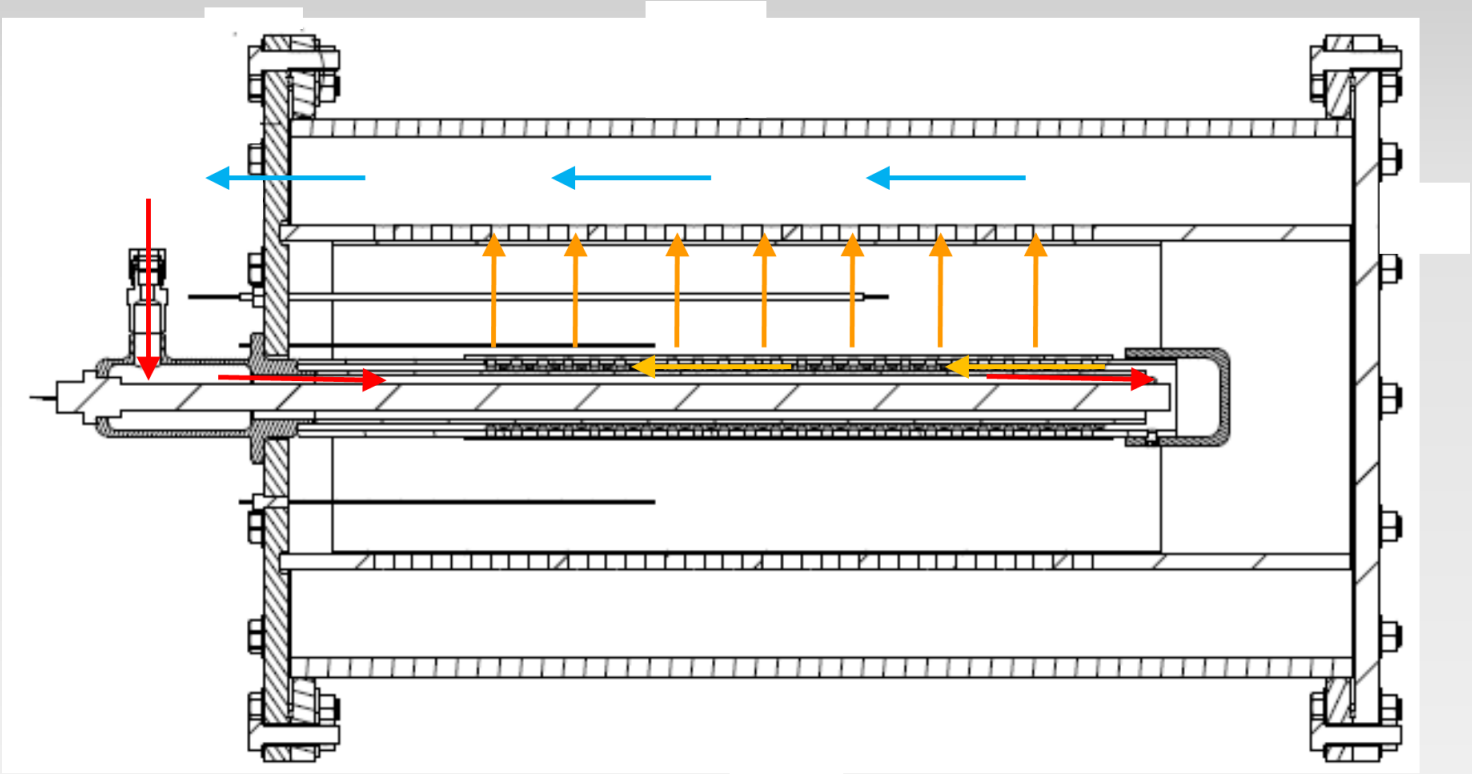
Methods: Membrane Performance Testing

Parameter	Values
Membrane Process Side Pressure	55.1 kPa (8 psia), 68.9 kPa (10 psia), 89.6 kPa (13 psia)
Membrane Temperature	Ambient, 111°C (Proteus only), 130°C (Proteus only)
Sweep Gas "Low Flow" Rate	0.7 SLPM (Proteus), or 1.41 SLPM (Polaris)
Sweep Gas "High Flow" Rate	1.41 SLPM (Proteus), or 2.82 SLPM (Polaris)
Process Feed Composition	
H_2	27-63 mol%
CO_2	16-41 mol%
CO	15-24 mol%
CH_4	0-0.26 mol%

MTR Proteus Membrane
(with special packaging)

MTR Membranes
(in COTS packaging)

Methods: CFR Performance Testing

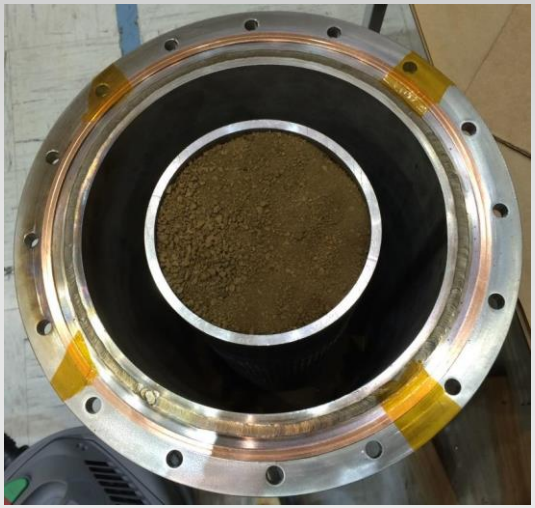


CFR Internal Flow Path

Methods: CFR Performance Testing

Orbitec JSC–Mars 1A Martian Regolith (Surface Catalyst) Testing Parameters:

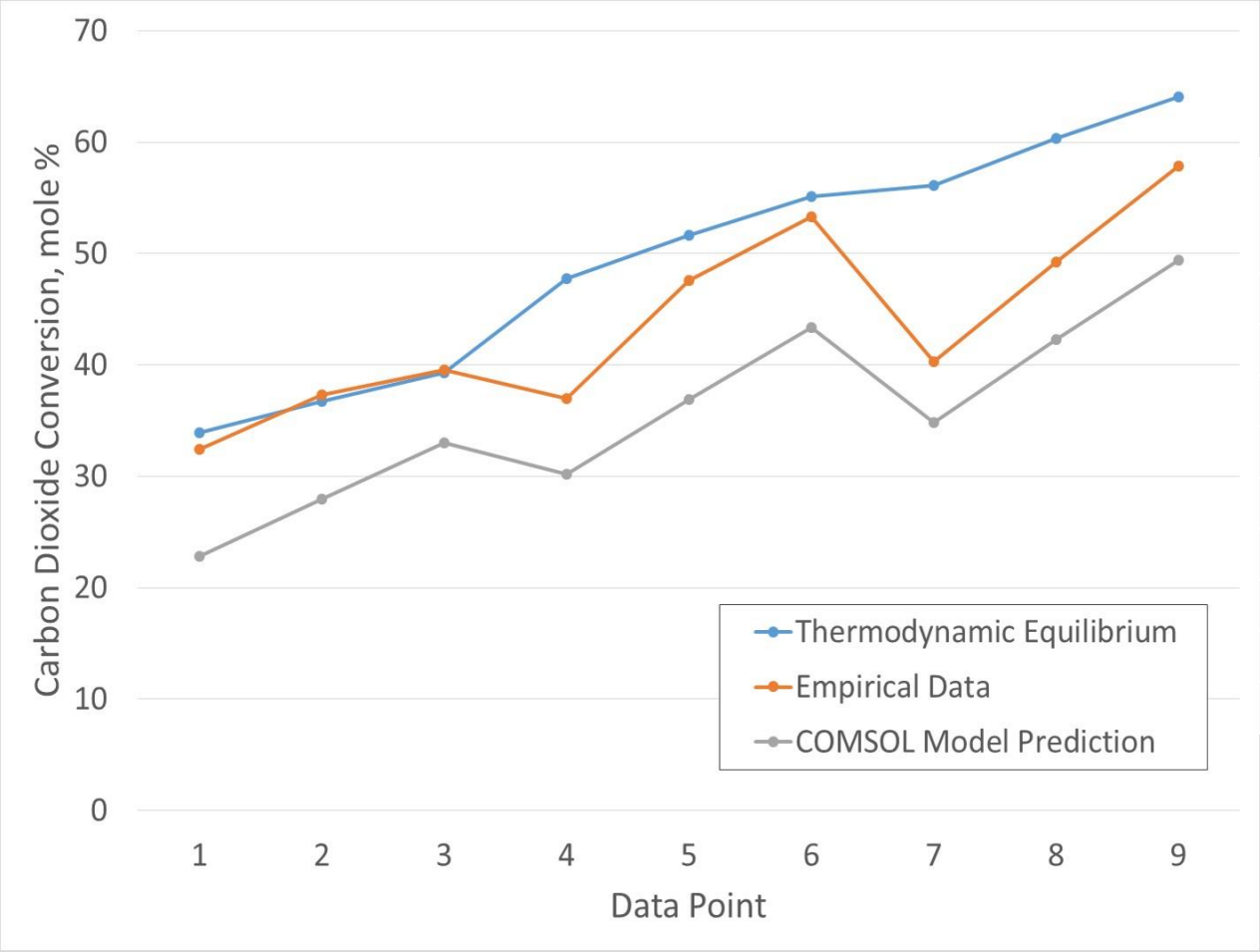
Parameter	Values
CFR Heater Temperatures	700°C, 750°C
CFR Pre-Heater Temperatures	0°C, 150°C, 400°C
CO Feed Rates	0.195-1.000 SLPM
H_2 Feed Rates	0.195-1.000 SLPM



Amasteel S-660 Steel Bead (Transit Catalyst) Testing

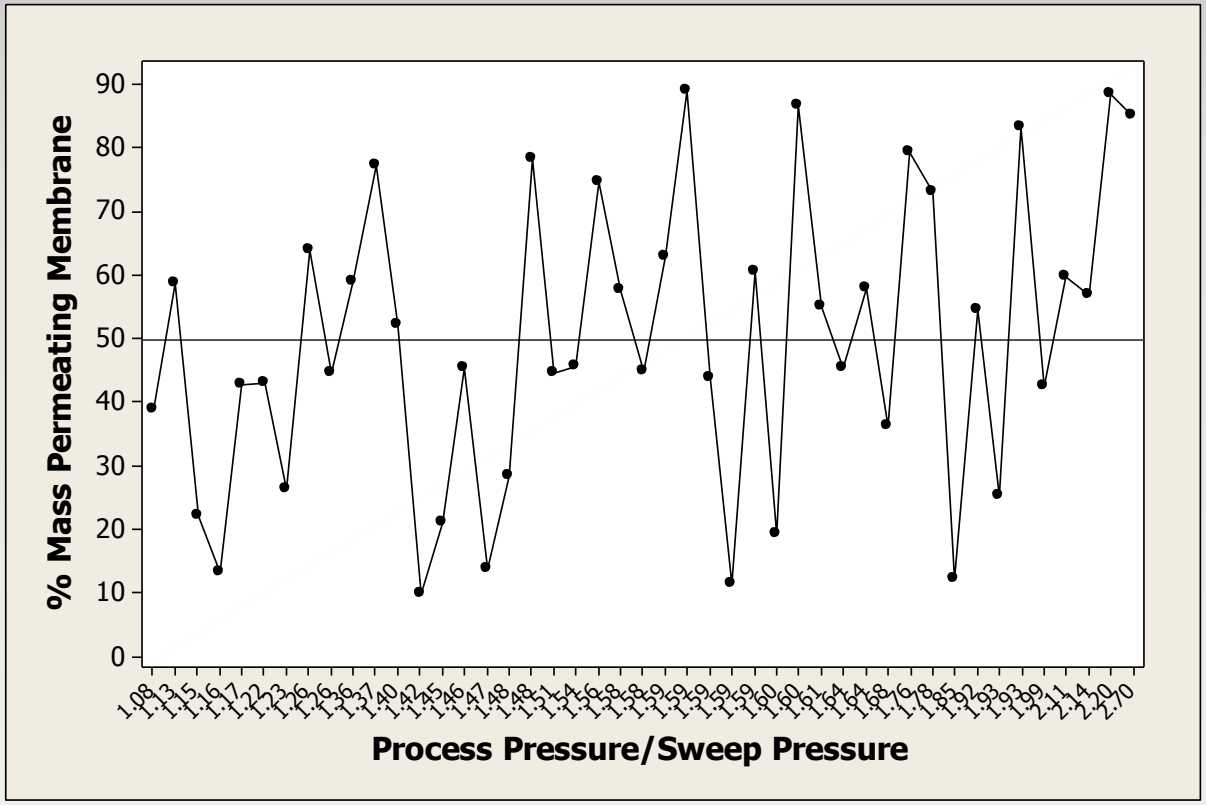
Parameter	Values
CFR Heater Temperature	750°C
CFR Pre-Heater Temperatures	400°C
CO Feed Rates	0.195-2.000 SLPM
H_2 Feed Rates	0.195-2.080 SLPM

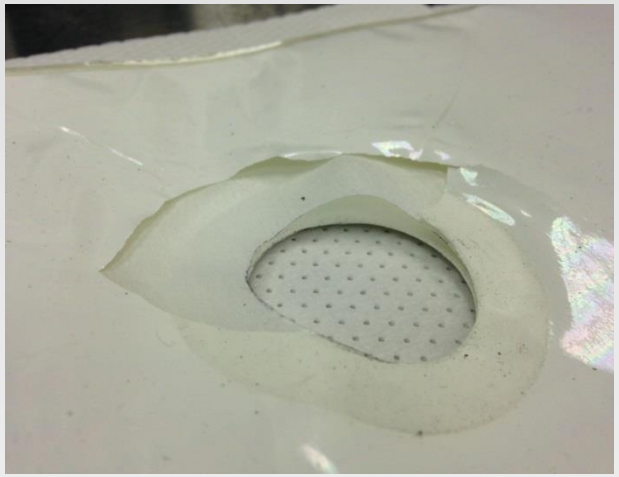
Results: RWGS Performance Testing



Test Point	Ratio of H_2:CO_2	Temp (°C)
1	0.81	600
2	0.81	650
3	0.81	700
4	1.66	600
5	1.66	650
6	1.66	700
7	2.51	600
8	2.51	650
9	2.51	700

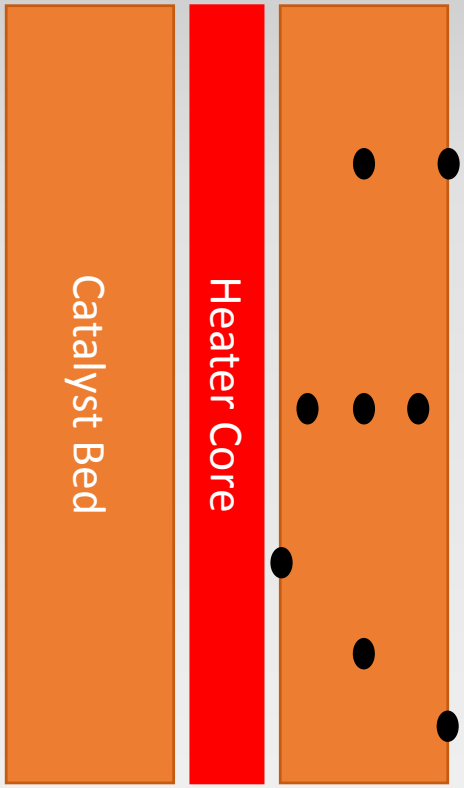
Results: Membrane Performance Testing



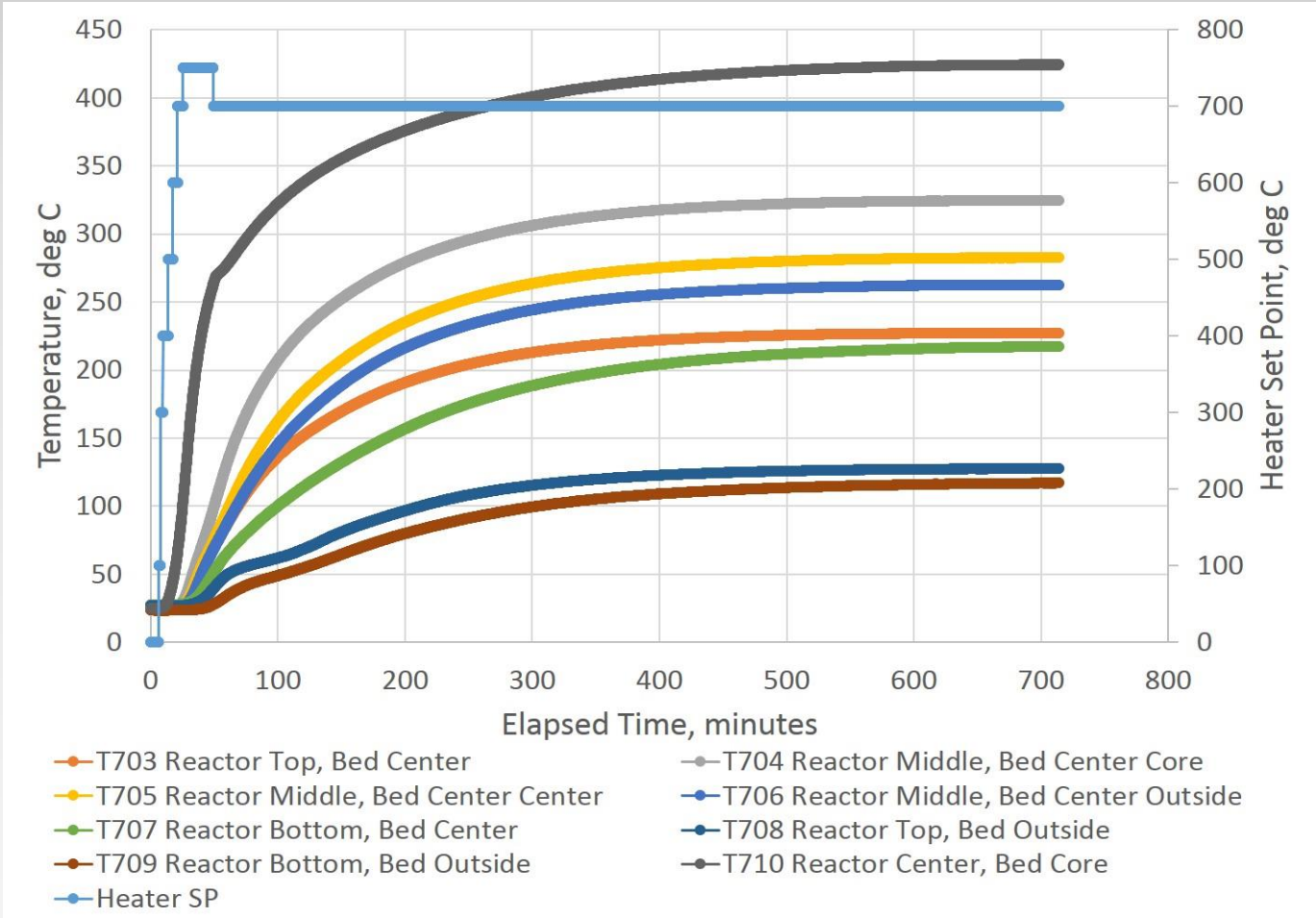


- No effect of dP across the membrane
- No effect of concentration gradient across the membrane
- Indicative of damage to the membrane

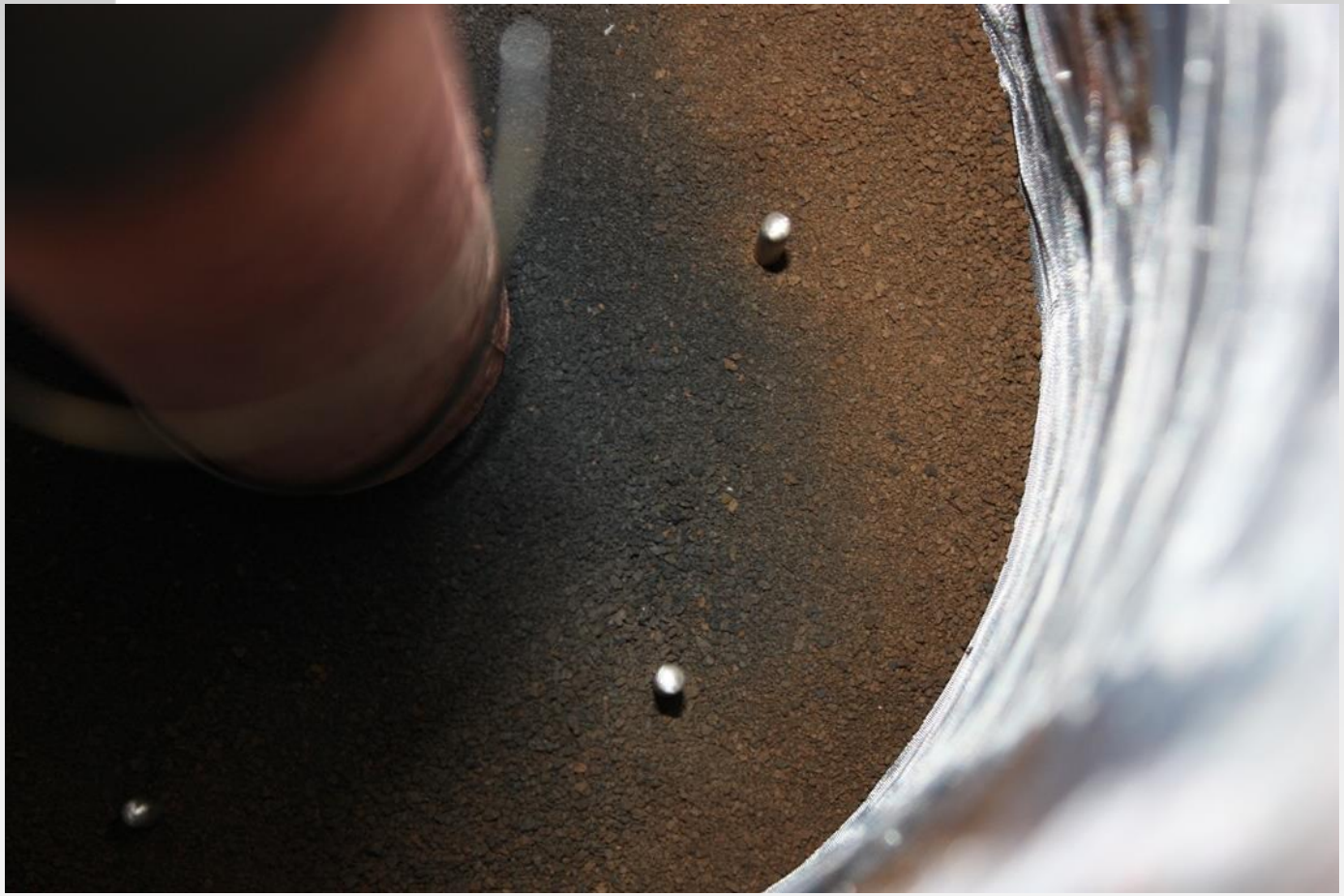
Results: CFR Performance Testing



CFR Thermocouple Placement

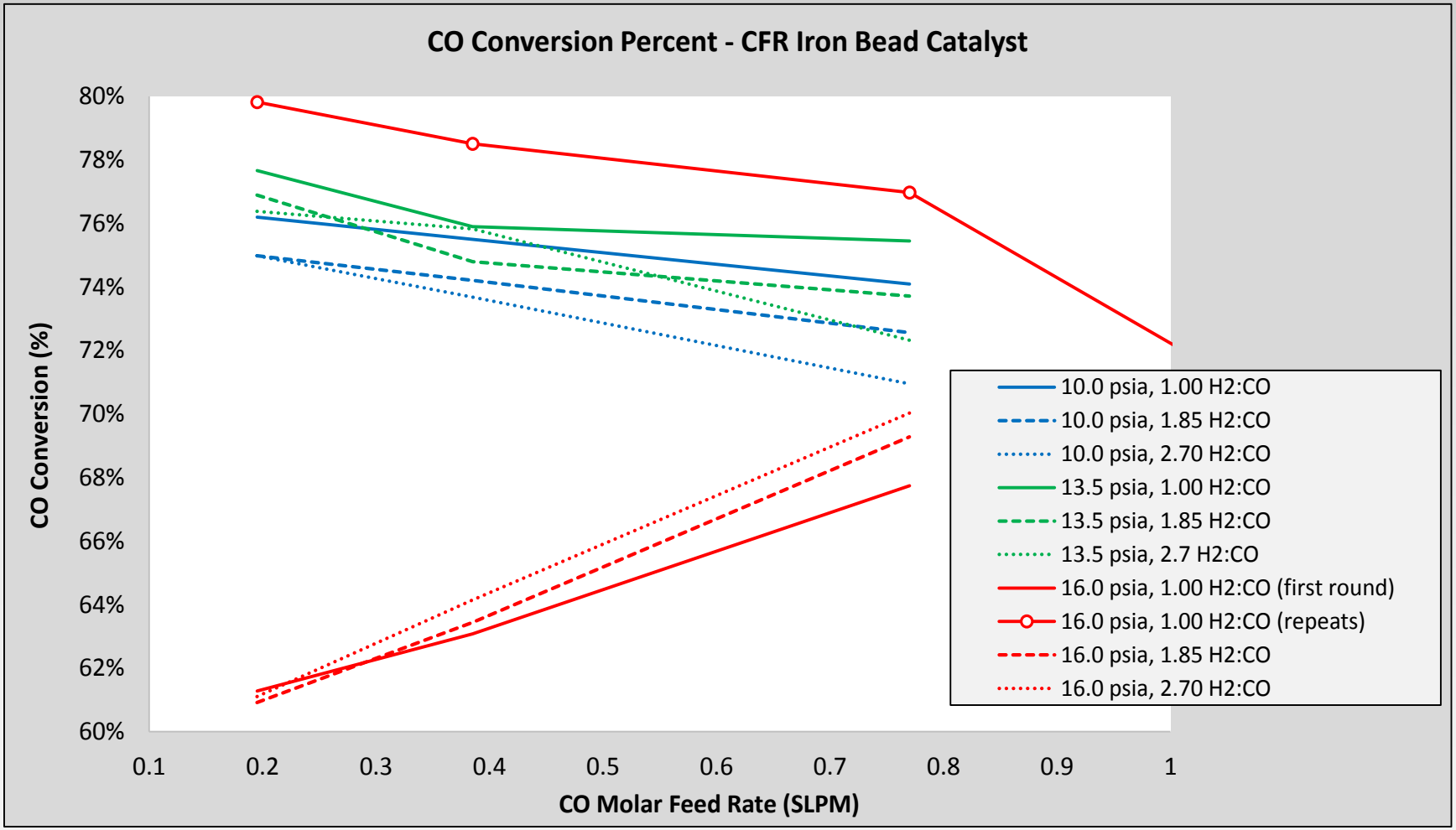


Results: CFR Performance Testing



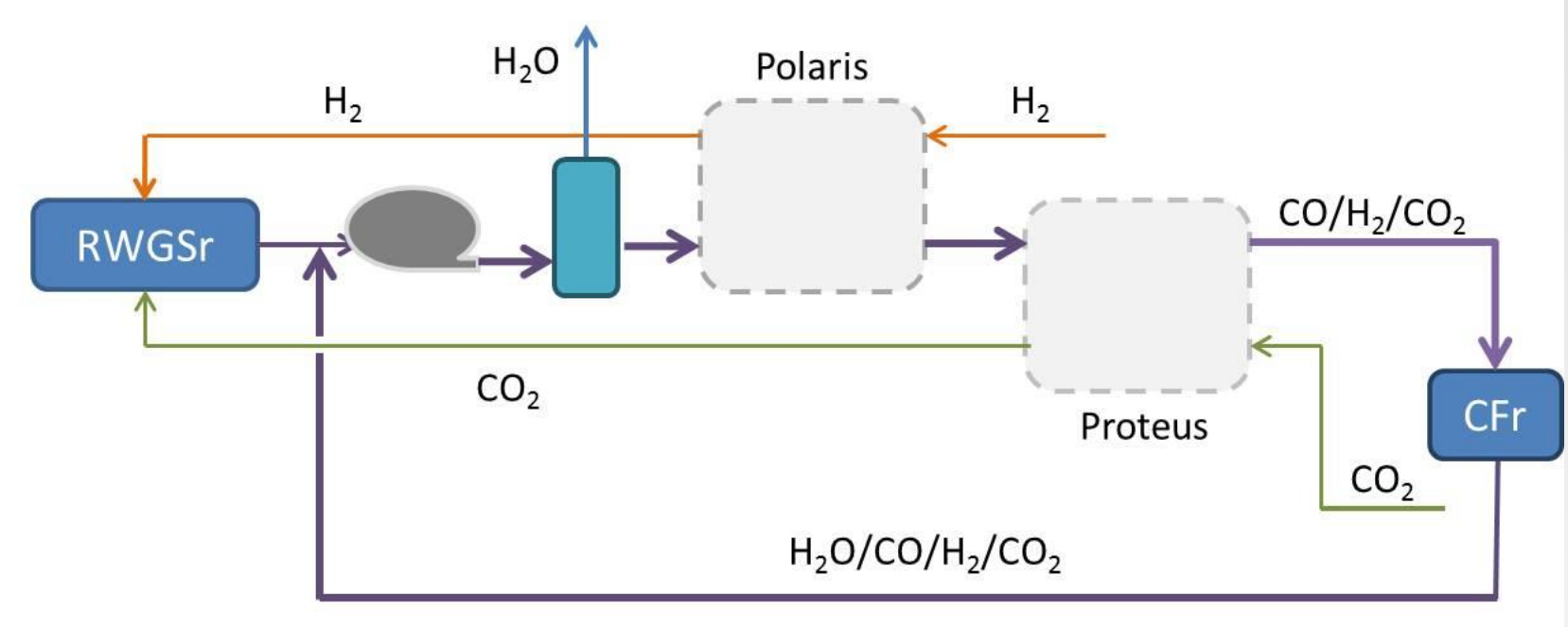
CFR Performance with Martian Regolith Stimulant

Results: CFR Performance Testing



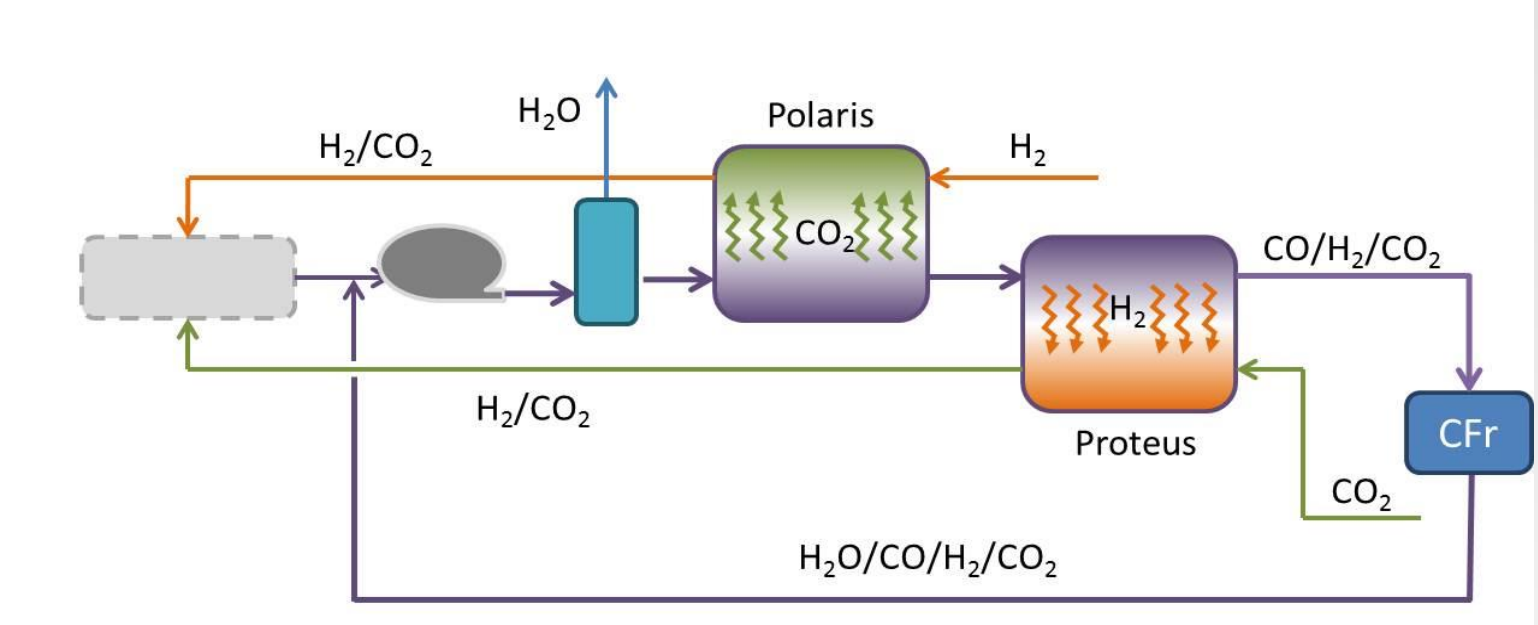
Discussion: Advantage of Architecture: Robustness

- Potential Failure 1: Membranes
  - Potential fouling
  - Potential tearing



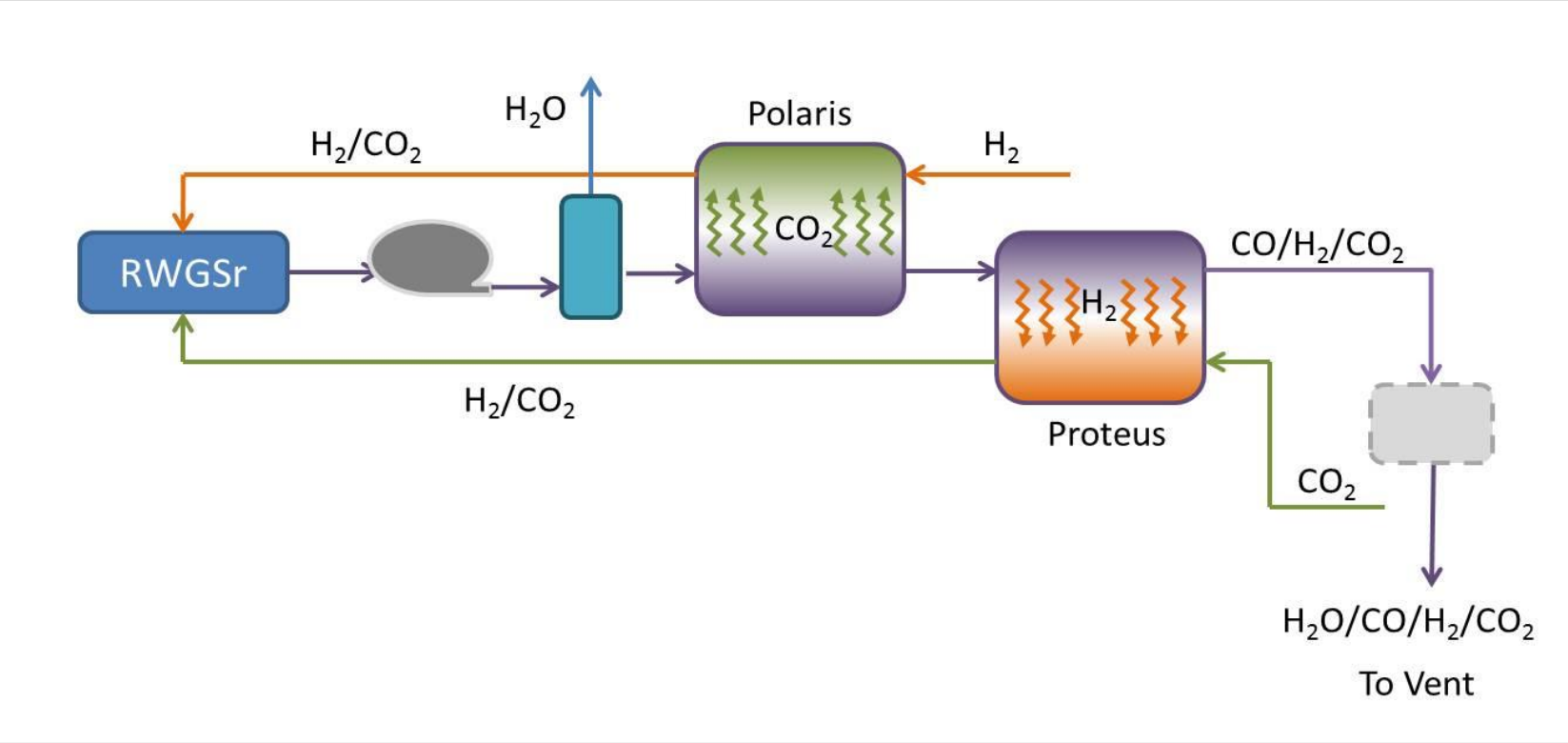
Discussion: Advantages of Architecture

- Potential Failure 2: RWGS
  - RWGS fouled with carbon



Discussion: Advantages of Architecture

- Potential Failure 3: CFR



Summary

- Demonstrated near-equilibrium performance of the RWGS reactor
- Membranes damaged due to special packaging
  - Long-duration performance and reliability proven in industry
- CFR shown to have thermal challenges
- CFR with Martian Regolith simulant performed significantly below target due to inadequate temperature
- CFR with steel beads performed near equilibrium despite low temperature
- S-Bosch architecture designed to be robust against failures

ICES 302: Physio-chemical Life Support- Air Revitalization Systems - Technology and Process Development