Bench-Scale Development and Testing of Rapid PSA for CO_2 Capture

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catacel™
Driving Reaction Technology

Battelle
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GRACE
Davison

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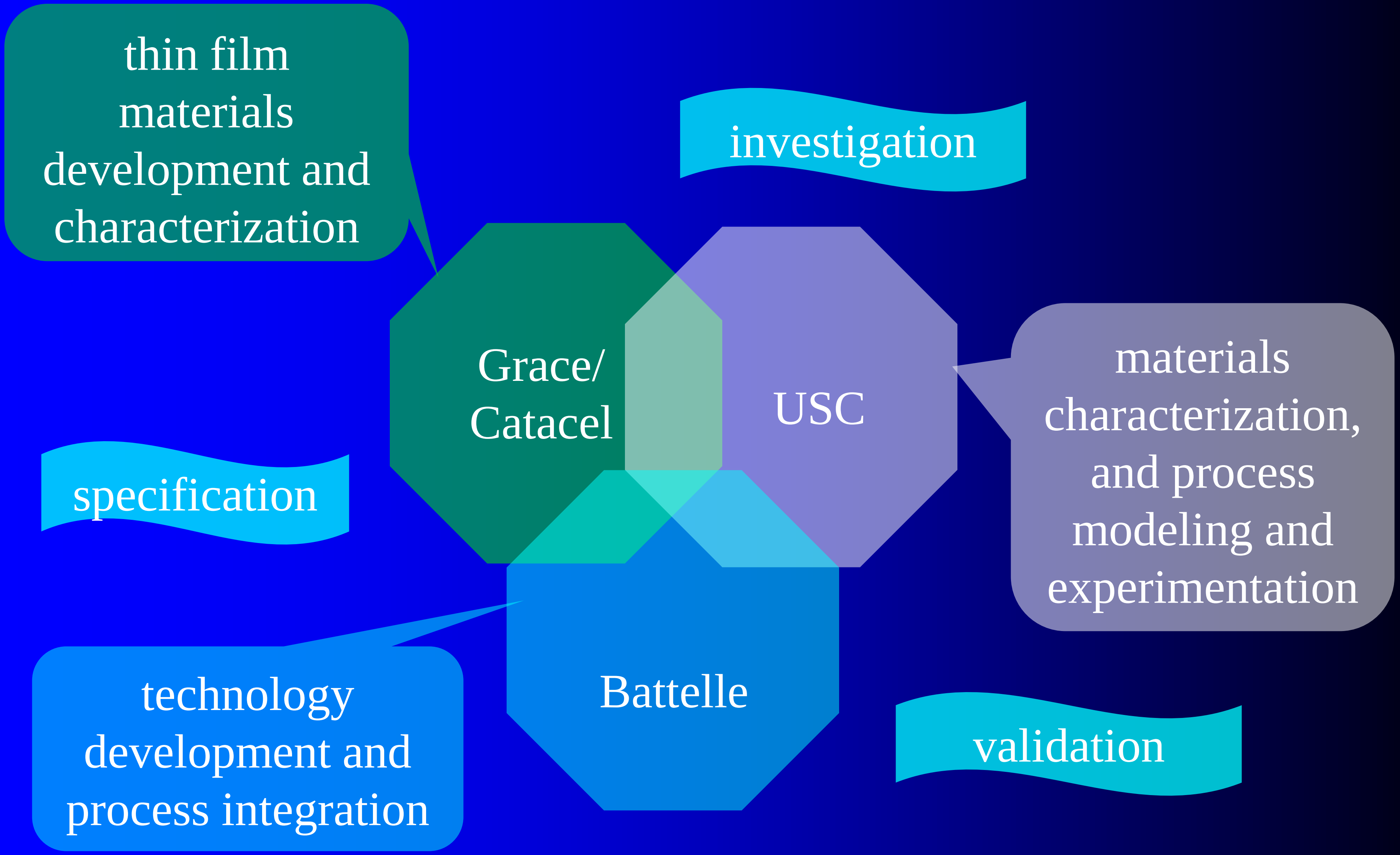
Overall Project Objectives

- **design, develop and demonstrate a bench-scale process for the efficient and cost effective separation of CO_2 from flue gas using Pressure Swing Adsorption (PSA)**
- **goal to reduce energy consumption, capital costs, and environmental burdens with novel PSA cycle/flowsheet designs**
- **applicable to both large (500-1000 MW) and small (5-50 MW) capacity power plants, and industries with 10 to 100 times less CO_2 production**

Process simulations and experiments; structured adsorbent material development, CFDs and experiments; and complete flowsheet analyses being used for demonstrating and validating the concepts.

The Team



thin film materials development and characterization

investigation

Grace/ Catacel

USC

materials characterization, and process modeling and experimentation

specification

Battelle

technology development and process integration

validation

PSA Technology Advantages

- established, very large scale technology for other applications
- needs no steam or water; only electricity
- tolerant to trace contaminants; possibly with use of guard or layered beds
- zeolite adsorbent commercial and widely available
- increase in COE lower than other capture technologies
- beds can be installed under a parking lot

PSA Technology Challenges

- energy intensive, but better than today’s amines; possibly overcome by novel designs
- today, very large beds required → implies large pressure drop → more power; possibly overcome by structured adsorbents and faster cycling
- large footprint; possibly overcome by underground installation and faster cycling → smaller beds
- high capitol cost; possibly overcome by faster cycling → smaller beds

Key PSA Technology Project Challenge

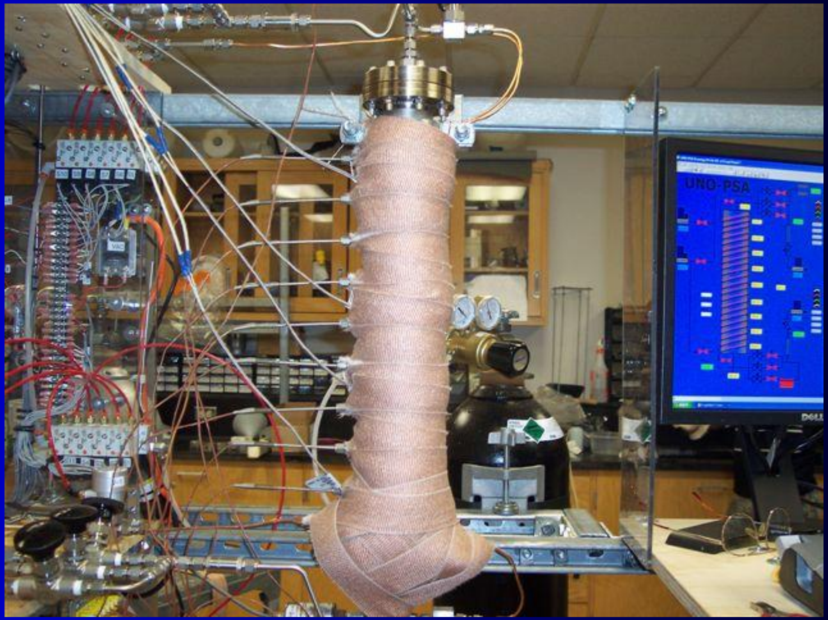
- although a commercial tri-sieve zeolite could be used today in an efficient PSA cycle, it would only minimize to some extent the pressure drop issues, but not the adsorbent attrition and mass transfer issues
- so, the key challenge of this project is to develop a structured adsorbent around an efficient PSA cycle that exhibits a high enough packing density to allow the fastest possible cycling rate (→ smallest possible beds), while improving pressure drop and mass transfer issues and eliminating attrition issues

How did we get to this point?

PSA Process Simulator Validation with 1-Bed PSA Experiment

	CO_2 Feed Concentration in N_2 (%)	Feed Throughput (L STP/hr/kg)	T (^oC)	Cycle Time (sec)	CO_2 Purity (%)	CO_2 Recovery (%)	N_2 Purity (%)	N_2 Recovery (%)
Experiment	15	150	25.2	900	94.1	90.9	93.7	96.0
Model	15	150	25.4	900	93.2	91.5	93.5	97.1

VS



Where are we now?

Low Energy PSA Process for CO_2 Capture Invented using Validated PSA Process Simulator

Process Conditions (70 °C)

Feed & HR @ 120 kPa
P_L @ 5 kPa
LP @ 101.3 kPa
HP @ 138.36 kPa
Feed Composition 15.9% CO_2 in N_2
Cycle Time 180 sec

Energy Penalty

Stream	Energy (kJ/mol CO_2 Captured)	Energy (kJ/mol CO_2 Avoided)
HR	6.72	6.96
HP	11.81	12.59
Total	18.53	19.55

Performance

CO_2 Purity (%)	98.03
CO_2 Recovery (%)	93.01
Throughput (L_{STP}/kg/h)	1,796

- **total separation energy of 25.7 kJ/mol (18.5 kJ/mol for the PSA unit) compared to 39.0 kJ/mol for state-of-the-art amine scrubber**
- **15% of a football field footprint**
- **patent application in preparation**

Scale of PSA System for CO_2 Capture from 500 MW Power Plant

goal: produce 2616 mol/s of CO_2 from stack gas w/15% CO_2 (i.e., 500 MW plant)

PSA Unit[1]	
throughput (L(STP)/h/kg)	1796 (more energy intensive)
material	commercial zeolite
packing	pellets (e.g., UOP Trisep)
number of PSA units	1
number of beds/unit	…
volume per bed (m^3)	…
total volume (m^3)	1048
bed dimensions (m)	…
bed pressure drop (kPa)	7.0

purities > 95 %; recoveries > 90%

imagine a concrete box 36 ft wide, 171 ft long and 6 ft high filling up the space of less than about 15% of a football field

Where are we going?

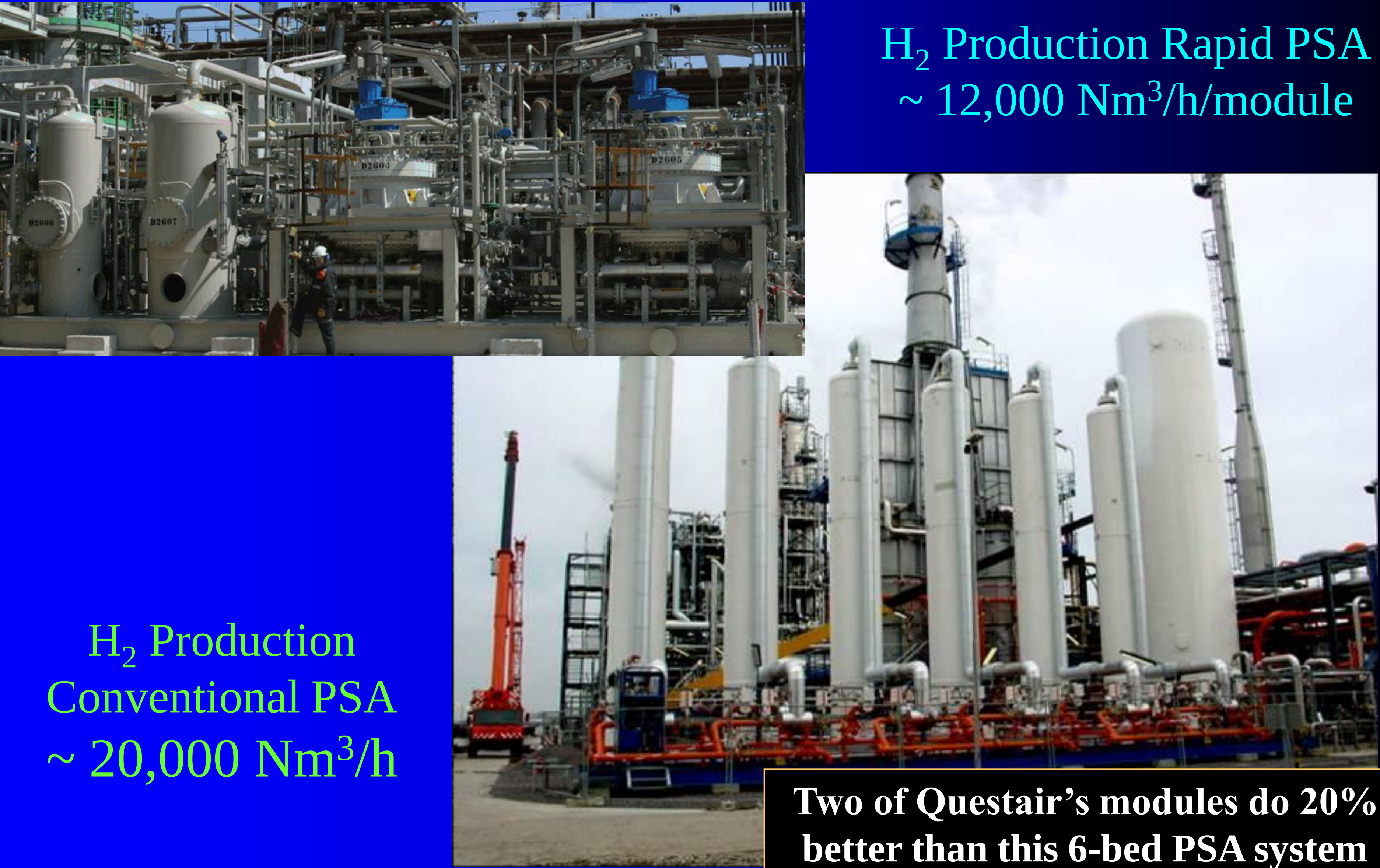
Scale of PSA System for CO_2 Capture from 500 MW Power Plant

Is it possible to achieve a 1/10th volume reduction?

- increase working capacity 10 fold (herculean)
- operate at 1/10th cycle time (achievable)
- known as rapid PSA

although rapid PSA offers potential for a low-cost solution for CO_2 capture, the extent of size reduction achievable is, at the moment, unknown

QuestAir H-6200 Rapid PSA-Installed at ExxonMobil Facility



H_2 Production Rapid PSA
~ 12,000 Nm^3/h/module

H_2 Production
Conventional PSA
~ 20,000 Nm^3/h

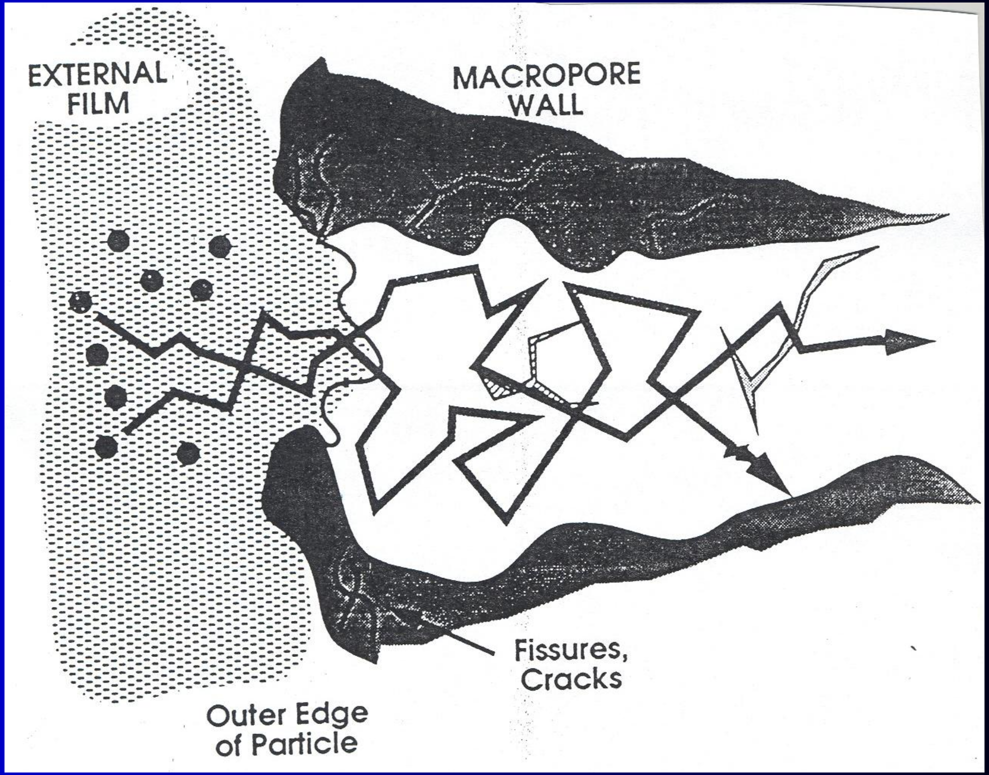
Two of Questair's modules do 20% better than this 6-bed PSA system and are much smaller.

Mass Transfer Resistances in Adsorbents

powders, beads, pellets, extrudates, granules

Goal of Practical Adsorbent

Concentrate a large amount of solid surface area in as small a volume as possible, while still satisfying process constraints.



Leads to Resistances

- external film
- macropore
- micropore

Leads to Increased Pressure Drop

How are we going to get there?

Aluminosilicate A-Zeolite Molecular Sieve Crystals

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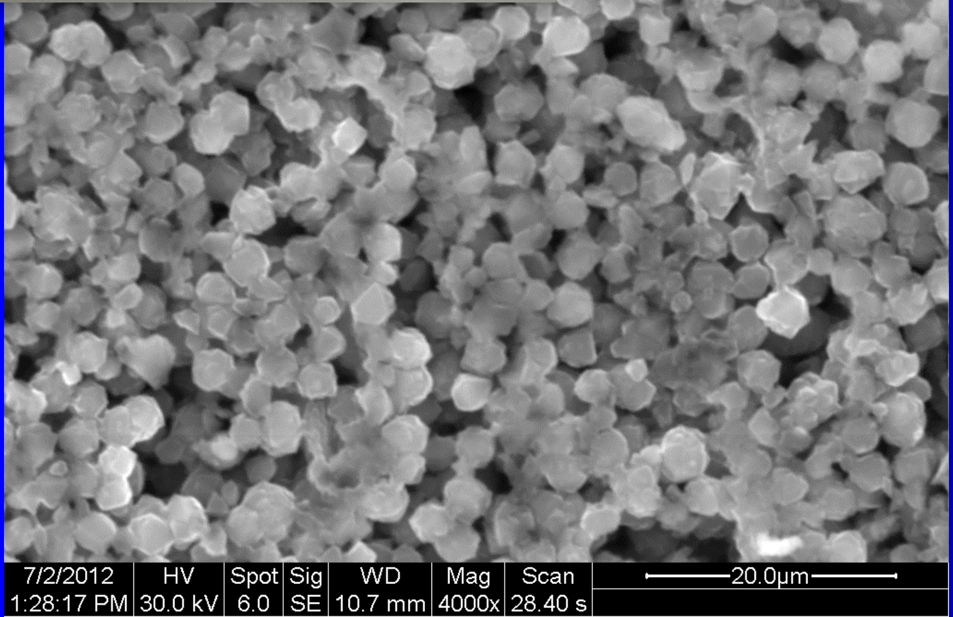
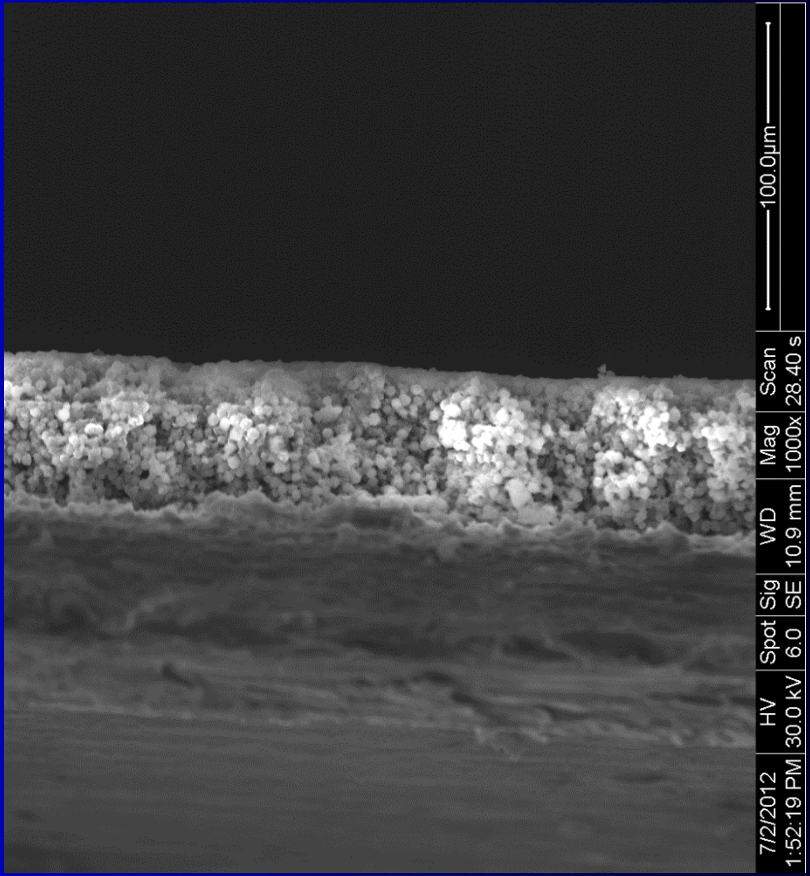
Zeolite Coated Metal Foil

- preliminary fabrication
- coated on flat foil coupon at 30 mg/in^2
- coating passed Catacel adhesion test





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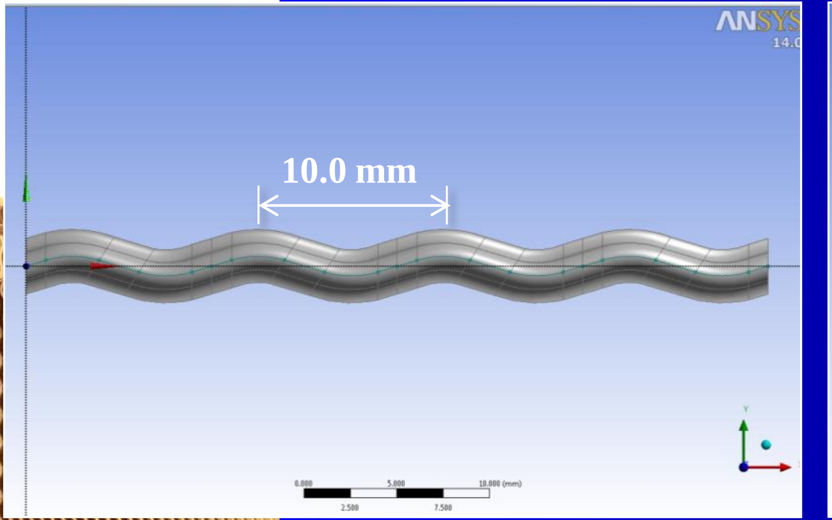
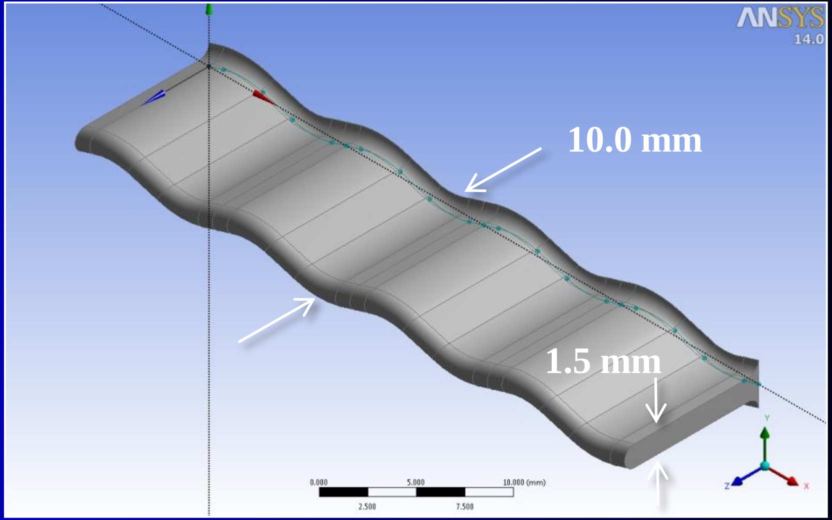
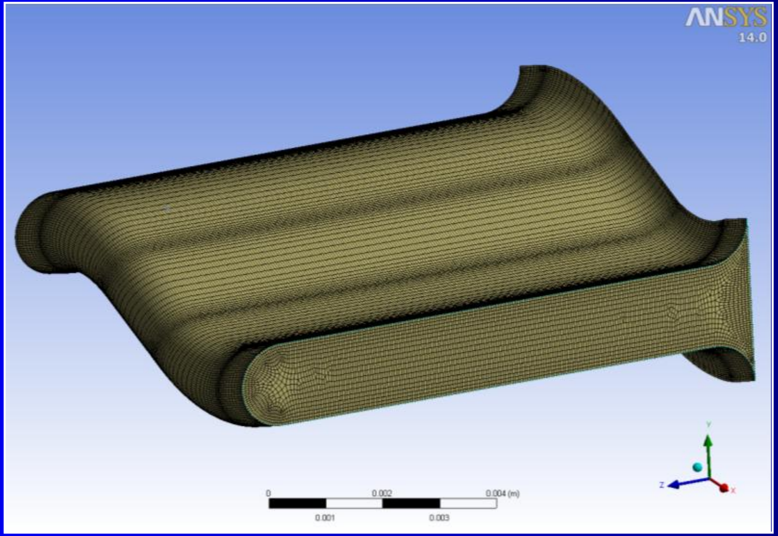
Catacel CFD Geometry

Structure based on Catacel Corp. Patenet (US 7,906,079 B2)







Repeat Unit Details:

Length: 10.0 mm

Width: 10.0 mm

Height: 1.5 mm

Dh: 2.6 mm

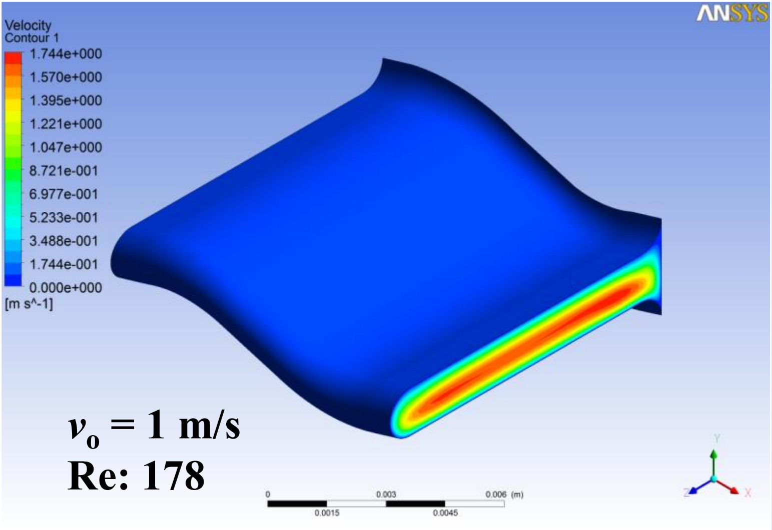
Velocity: 10-30 m/s

Reynolds No.: 1780-5340

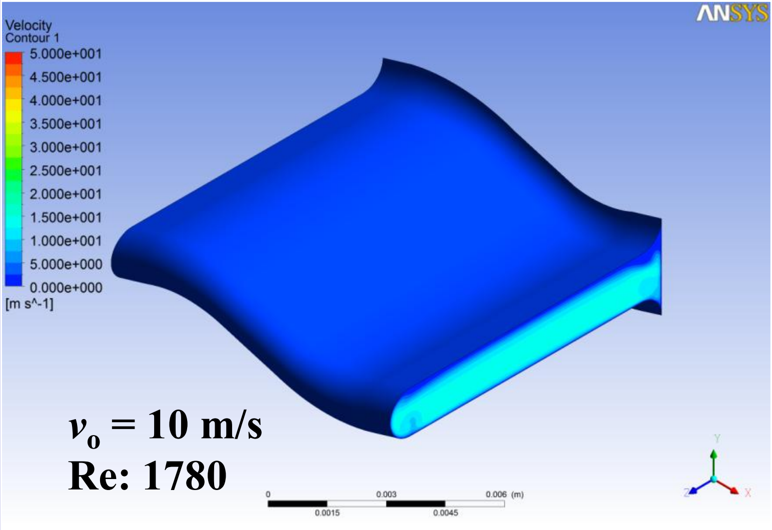
Transitional flow

k-omega SST used

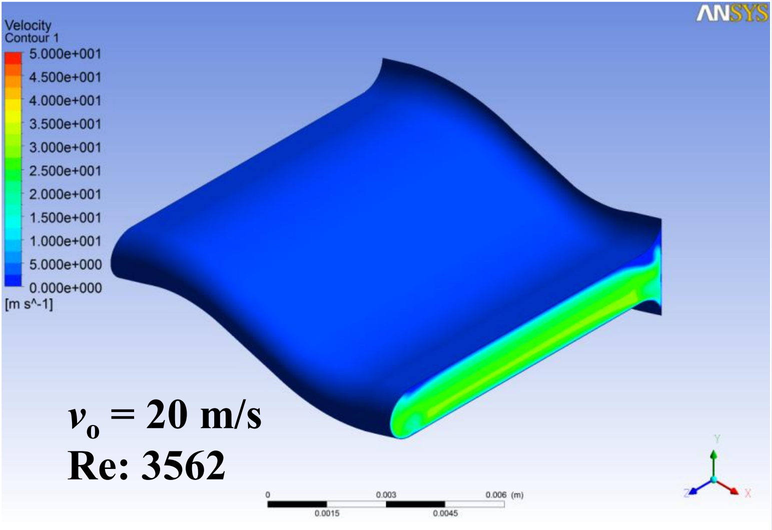
Preliminary CFD Results



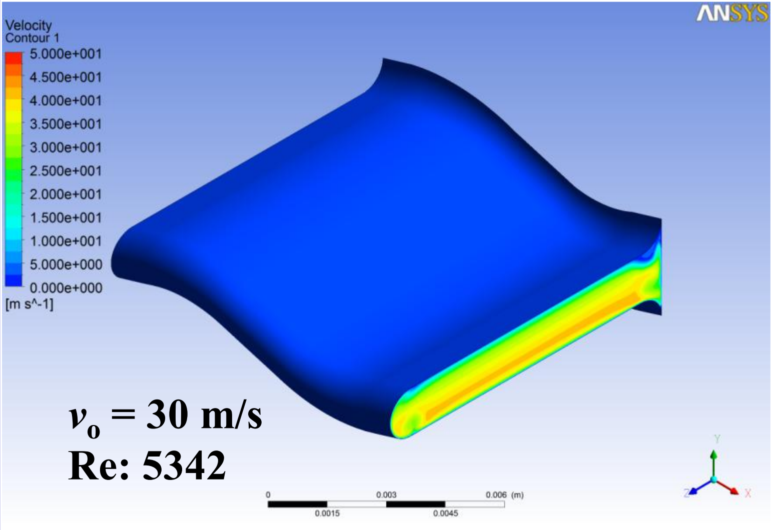
v_o = 1 m/s
Re: 178



v_o = 10 m/s
Re: 1780



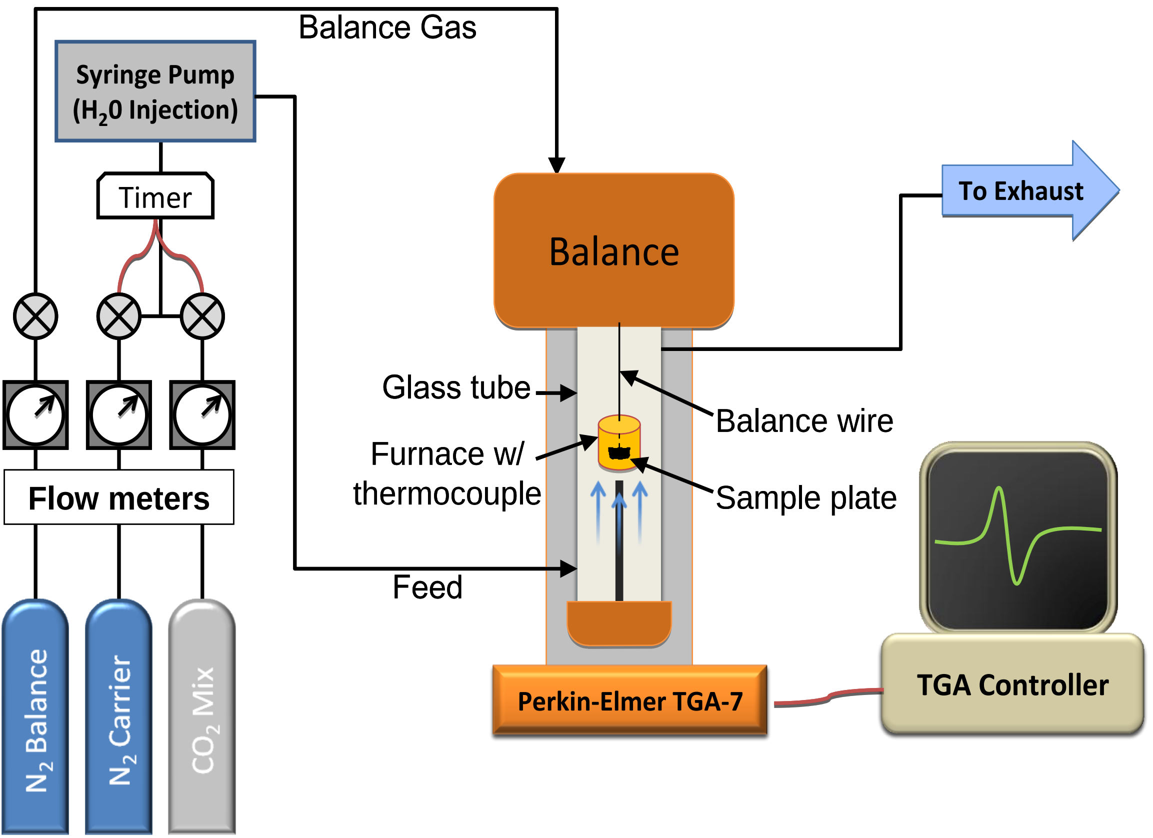
v_o = 20 m/s
Re: 3562



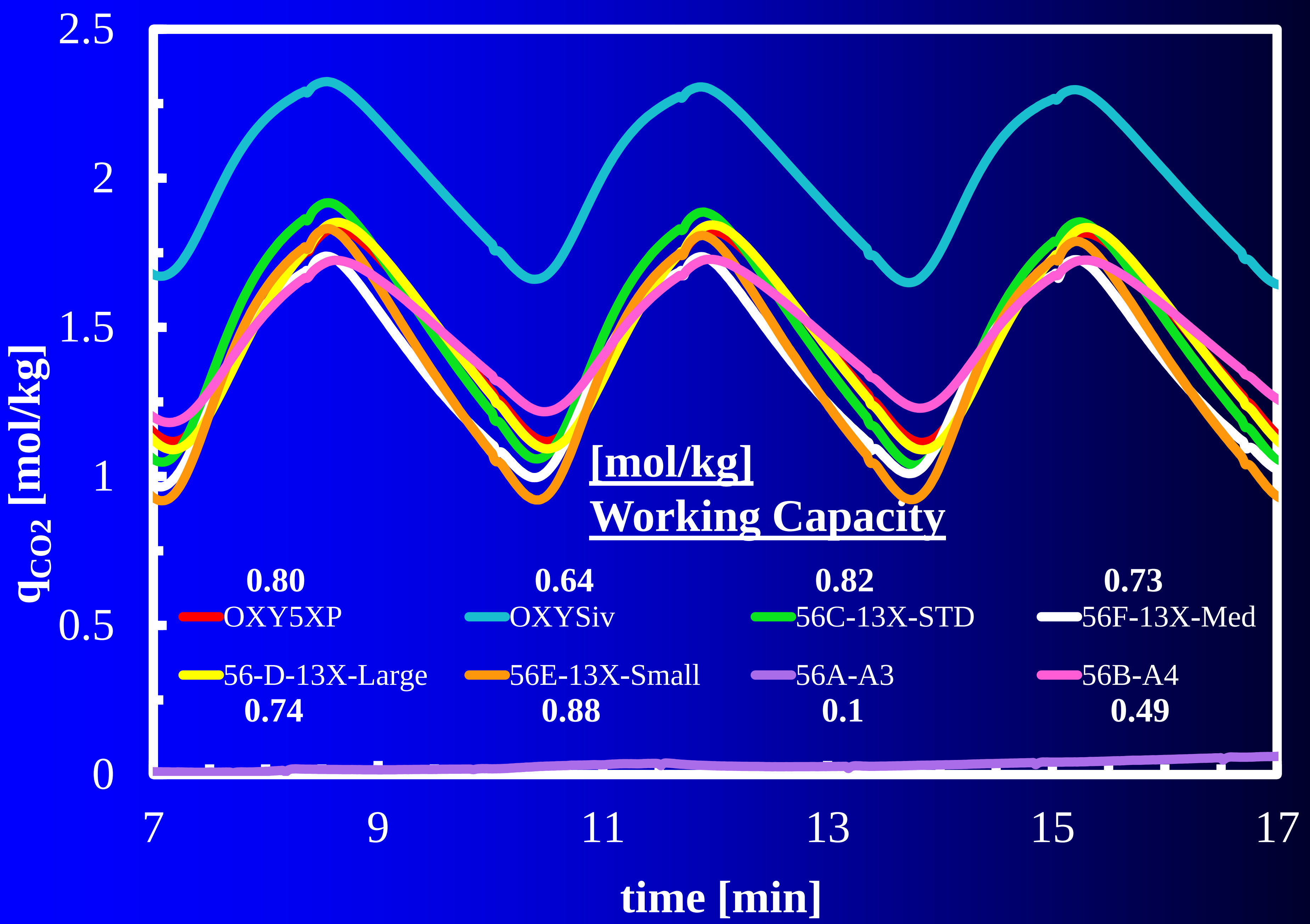
v_o = 30 m/s
Re: 5342

Rapid Adsorbent Characterization

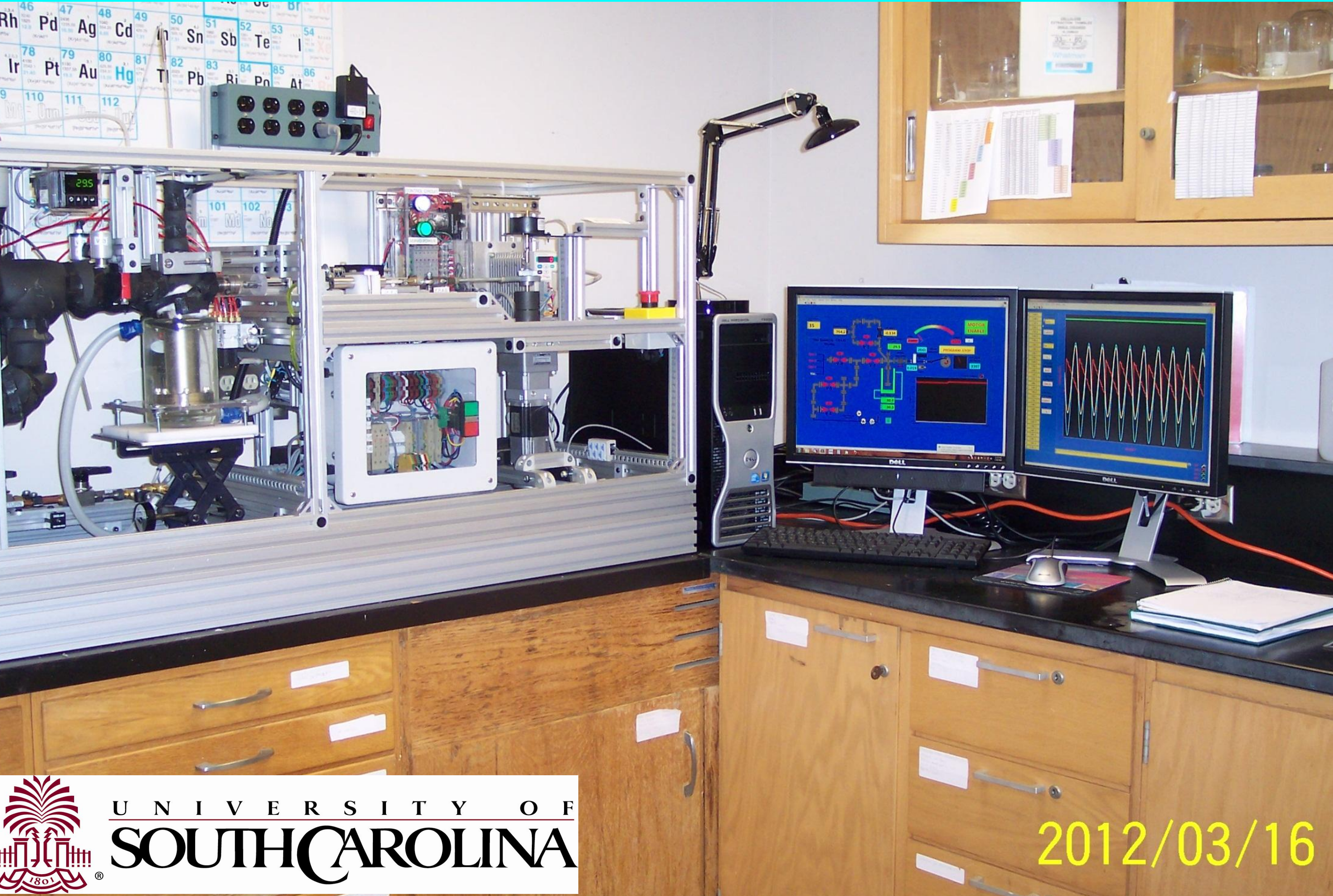
- commercial zeolites
  - activation at 350 ^oC overnight in N_2
  - cycling at 90 ^oC
    - 2 min adsorption in 15% CO_2-N_2
    - 2 min desorption in 100% N_2
  - P_T=1 atm



Amount Adsorbed and Working Capacity at 90 ºC



Volumetric Frequency Response Apparatus



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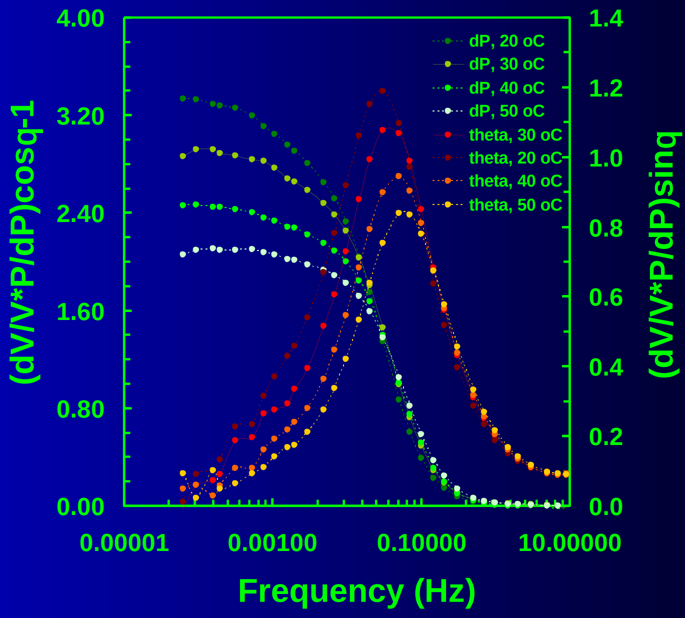
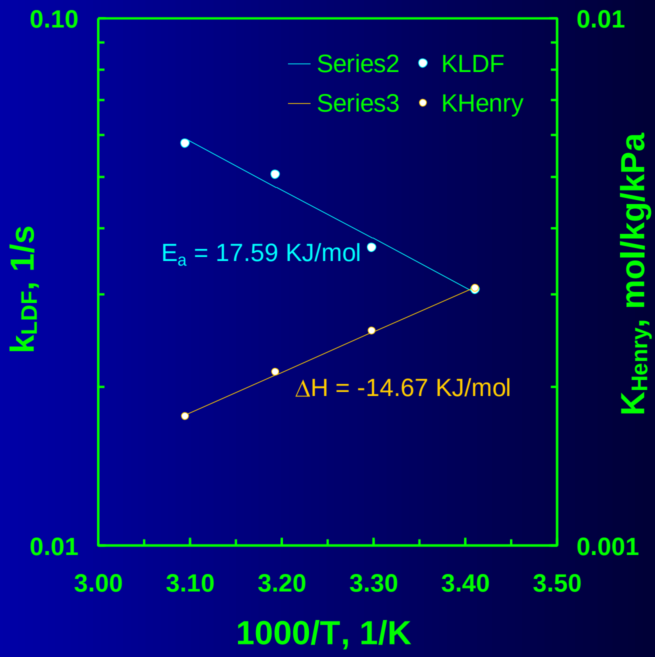
Dynamic Characterization of Adsorbents via Volumetric Frequency Response

- For LDF coeff. determination and understanding of transport processes in adsorbents
- 0 – 1atm; 10 – 60 ^{o}C
- Comsol multipore transport process model for fitting

O_2 on Shirasagi CMS 172 3K





1-Bed Rapid PSA System

Complex PSA Cycle Schedule Analysis

Construction Almost Complete

5-Bed CO_2 Capture PSA System

Under Construction

Suitable for Power Plant Demonstration

Deliverables at End of Each Budget Period

Budget Period 1: Proof-of-concept that zeolite crystals can be coated onto a basic metal structure; 1-bed RPSA and pressure drop (PD) experimental systems constructed; refinements of PSA cycle and process flow sheet toward meeting 35% limit of COE increase; selection of commercial zeolite adsorbent to focus on

Budget Period 2: Improved coated metal structure in terms of cost and performance, based on CFD simulations and PD experiments; RPSA proof-of-concept based on 1-bed RPSA experiments and modeling; 5-bed RPSA experimental system construction initiated.

Budget Period 3: Optimized coated metal structure; RPSA proof-of-concept based on 5-bed RPSA experiments and modeling; final refinements in RPSA cycle and process flow sheet; complete flow sheet analysis, scale-up, comparison against targets, and preliminary pilot-scale design.

Budget

Project Team Member	**Budget Period 1 10/2011 – 9/2012**		**Budget Period 2 10/2012 – 9/2013**		**Budget Period 3 10/2013 – 9/2014**		**Total**
	Gov. Share	Cost Share	Gov. Share	Cost Share	Gov. Share	Cost Share	
Grace	139441	34860	75084	18772	145089	36272	449518
USC	670000	167500	490000	122500	490000	122500	2062500
Battelle	239115	59978	191791	47930	159744	39998	738556
Catacel	125592	31398	172187	43047	100662	25166	498052
TOTAL	1174148	293736	929062	232249	895495	223936	3748626

Breakdown in % of Total Budget

USC	55.0%
Battelle	19.7%
Catacel	13.3%
Grace	12.0%

Conclusions

- commercial zeolite showing much promise as effective adsorbent for CO_2 capture from flue gas
- 1-bed PSA experiments showing possibility to achieve 95% CO_2 purity and 90% CO_2 recovery
- validated DAPS showing PSA energy requirements better than amine scrubbing
- rapid PSA showing potential to significantly reduce PSA column size and thus plant footprint

A major outcome of this work will be proof-of-concept at the bench-scale and the RPSA process design utilizing a structured adsorbent and flowsheet that will enable the successful design and development of a pilot-scale demonstration.

Acknowledgements

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DOE/NETL
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Thank You!

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