Coatings for Co-sequestration Processes and Pipelines

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Outline

1. Motivation and Scope
2. Introduction
3. Experiments and Discussions
4. Conclusions
5. Future Experiments

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Major Issues of Project

- Treating Materials of SCCO2 Processing as a source of risk and SCCO2 release as well as the storage processes – pipeline failures are inevitable
- Determining approximate range of compositions of dSCCO2 resulting from Co-Sequestration Processes as they effect pipeline corrosions & integrity
  - Weyburn Project will be major source of field data
- Determining Polymers resistant to such compositions, especially the dSCCO2
- Designing prototype interior pipeline organic protective coats for such compositions
- Preliminary performance testing – developing test protocols for dSCCO2 resistance

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Other Issues

- Graduate student Training in CCS Issues
- Development of training modules on protecting CCS Pipelines
- Issues of materials choices for pipeline alloys
  - Analysis of Coatings development, cost & application vs. pipeline substrate costs
  - Co-sequestration gives dSCCO2 of varying quality leading to possibility of corrosion of standard pipeline alloys used for “Kinder-Morgan” quality of CO_2
  - Pipeline maintenance is key safety issue for CO_2 handling and sequestration
  - Coatings may be most economical way of providing protection to pipelines vs. new alloy development

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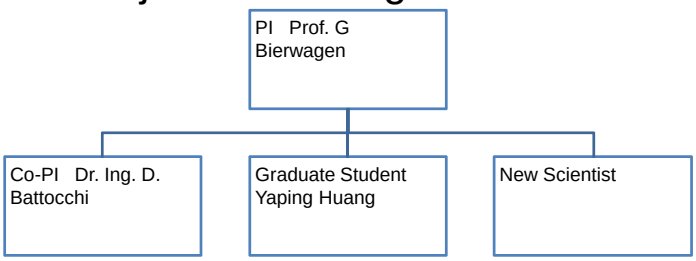
The Scope of Work

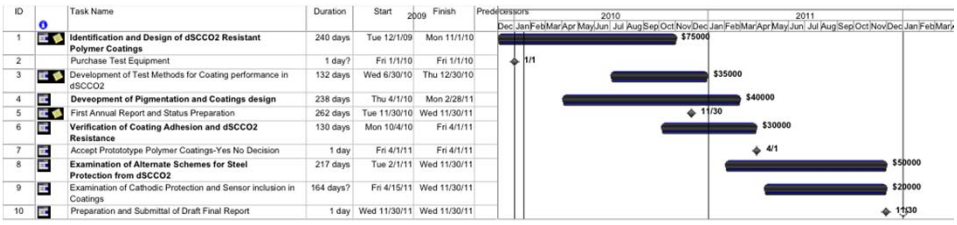
Task 1.0. Project Management and Planning
Task 2.0. Interior Coating Design Specification Studies
Task 3.0. Interior Coating Test Protocol Development
Task 4.0. Study of Cathodic Protection with Exterior Pipeline Coatings for dSCCO2
Task 5.0. Examination of Insulated Exterior Pipeline Coatings
Task 6.0. Multi-layer Interior Coating Design Development
Task 7.0. Hybrid Coating and Hard Coating Layer Development
Task 8.0. Coating Test Development Incorporating dSCCO2 Exposure Results
Task 9.0. Interior Pipeline Coating Test Protocol Development and Choice
Task 10.0.Field Application Studies and Coating Testing
Task 11.0.Preliminary Examination of Special Exterior Protection Needs for Co-Sequestration

Project Team Organization Chart



Total Project Budget
$299,987

Project Schedule



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Scope

- Characterization of pipeline corrosion under d-SCCO2 conditions
- Pipeline corrosion mechanism
- Pipeline coating design

Gas Quality in CO2 Capture

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Table 3
Gas quality and CO_2 capture impacts

CCS technology	CO_2 % v/v (dry) prior to capture	Other gases	Comments on impacts
PCC	5–20	Primarily N_2 from air, O_2 from XS air, NO_x and SO_x from converted fuel N and S	Chemical solvents for CO_2 react irreversibly with SO_x, NO_2 and O_2 with solvent loss. Equipment corrosion
IGCC-CCS	15–60, for O_2 blown gasifier	CO_2 levels from shift reactor, balance being primarily H_2, with impurities	Sulfur removed prior to shift reactor. CO_2 capture at elevated pressure prior to gas turbine, impurities influencing both.
Oxyf	80–95	N_2 from air leakage (~3% typical), O_2 from XS O_2 and air leakage, Ar from ASU supply of O_2. NO_x is reduced by 50–75% due to reactions of recycled NO_x. SO_x is typically 3 × air firing	CO_2 levels determine recovery and energy for compression, NO_x reduction a technology driver in some countries, SO_x levels associated with corrosion and may restrict to low S fuels. SO_2 remains with CO_2 on compression, and may result in avoidance of FGD if CO_2 is sequestered

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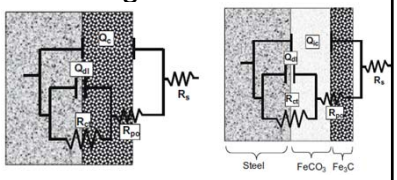
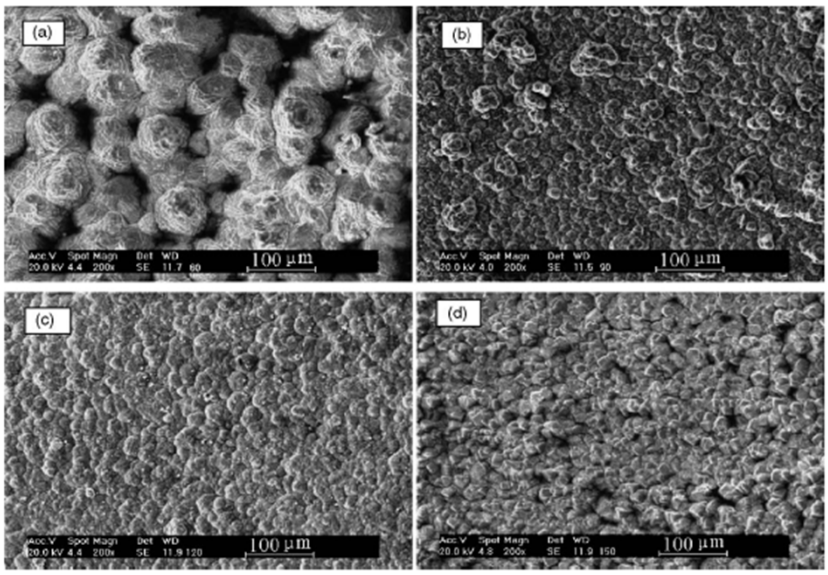
Corrosion In Steel Pipelines

- Corrosion
  - Water/H_2S/Acetic Acid
  - Sweet corrosion mechanism
- Corrosion protection
  - Cathodic protection
  - Plastic lining
  - Entrapping technology
  - Coatings



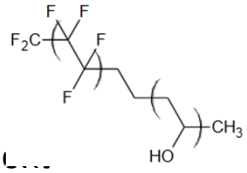
SEM images with a higher magnification of corroded surface of J55 samples immersed in static SPW saturated with SC-CO2 for 96 h at different temperatures: (a) 60 8C; (b) 90 8C; (c) 120 8C; (d) 150 8C.



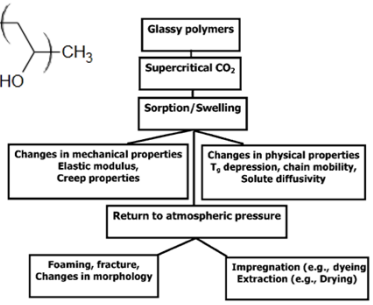
Introduction to Designing SCCO2 Resistant Systems

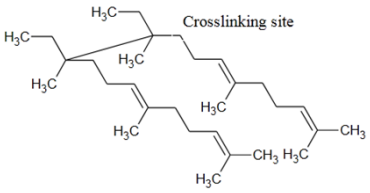
- Solubility
  - Chemical structure
  - External condition
  - Solubility measurem…
  - Solubility mechanism

  Polymer design



Quite a bit of time Spent on literature Searching – much Research already done





Tomasko DI et al., **Ind. Eng. Chem. Res., 42**(2003), 6431-6456.
Bray CL et al., **Journal of Materials Chemistry, 15**(2005), 456-459.
Li YG et al., **Fluid Phase Equilibria, 270**(2008), 15-22.
McCluskey GE et al., **MRS Bulletin, 34**(2009), 108-115.
Chehroudi B, **Combust. Sci. and Tech., 178**(2006), 555-621.

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Effects of Water in SCCO2

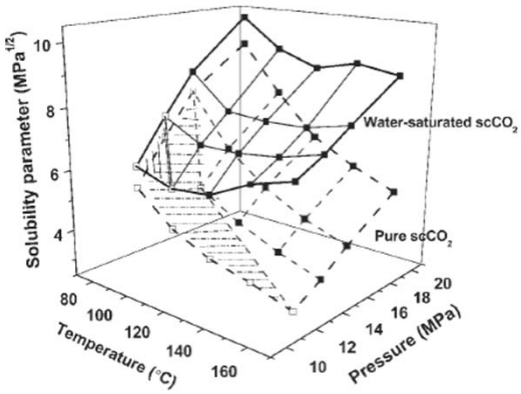


FIG. 7. 3D-diagram of the crystallization of PC vs. temperature, pressure and solubility parameter. The condition with which the treated samples were amorphous is labeled by □, and crystalline labeled by ■.

Polymer Design

Polymer	Experimental conditions	Visual sampling due to exposure to SCCO2	Polymer property related to SCCO2 resistance
Poly(vinyl chloride)	2000/3000psi, 40/70°C	A light dissolution	High dipole C-Cl
Polypropylene	2000/3000psi, 40/70°C	A light yellow	High crystallinity
Polyethylene, Teflon	2000/3000psi, 40/70°C	Some bubbles	High crystallinity
Nylon 66	2000/3000psi, 40/70°C		High crystallinity
Copolymer with poly(methacrylic acid)		SCCO2 insoluble	
High branched phenol		SCCO2 insoluble	
Surface modified polystyrene by carboxylic acid group	1232-2857psi, 40-60 °C	SCCO2 resistant	Static repulsion
Higher fraction of hard segment of poly(urethane)	1000-3000psi, 42 °C	Low sorption of SCCO2	High restriction

- CO2-Phobic
  - No fluorine and no silicone groups
  - No carbonyl and ether groups
  - No aromatic rings
  - No Hydroxyl groups
- Crosslinking
- Crystallinity

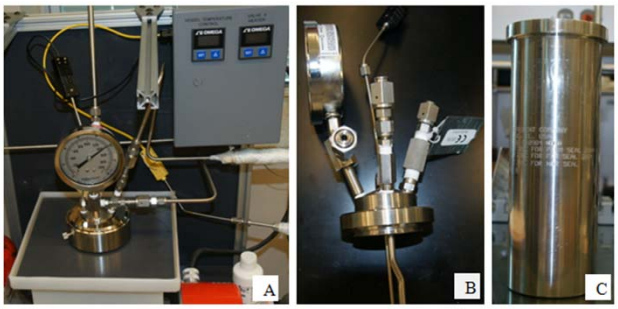
Sawan SP et al., LA-UR-94-2341, (URL: http://www.turi.org/content/view/full/4603).
McCluskey GE et al., **MRS Bulletin, 34**(2009), 108-115.
Cabanas A et al., **Langmuir, 22**(2006), 8966-8974.
Briscoe BJ et al., **Polymer, 37**(1996), 3405-3410.

Experiments

- Materials
  - TZ-904: A modified epoxy coating from Chevron Phillips Chemical Company and an outstanding resistance for steel structures in corrosive environments.
    - 1:1 volume ratio, Toluene adjust, Curing more than 1 day
  - DevChem 253: A two-component epoxy novolac coating from International Paints and a protective coating for highly corrosive environments.
    - 4:1 volume ratio, Xylene adjust, Curing more than 5 days
  - S 36: Steel panel from Q-Lab
    - Sand blasted, Hexane degreased

Experiments

Facilities



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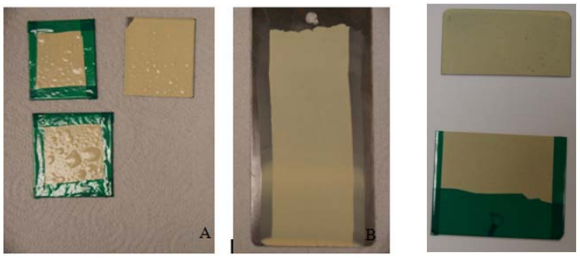
Experiments: TZ 904

❿Drawdown (8mils) and Spray



Materials	Thickness/μm	Color	Appearance
Drawdown	***107 to 145***	***Pale to dark***	***Smooth to Blister***
Spray	***145 to 131***	***Similar***	***Similar***

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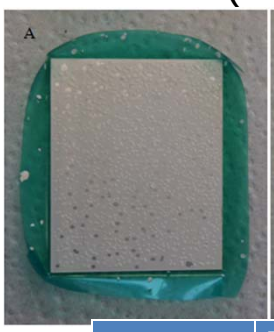
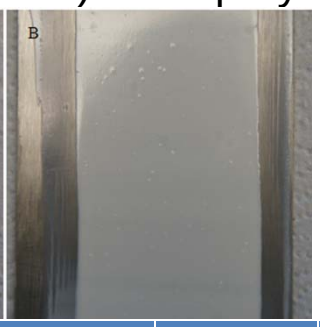
Experiments: DevChem 253

Drawdown(8mils) and Spray





Materials	Thickness/μm	Color	Appearance
Drawdown	***74 to 79***	***Similar***	***Smooth to Blister and porous***
Spray	***52 to 58***	***Similar***	***Similar***

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Conclusions

- Blister formed for the thicker coatings.
  - Barrier property is significant higher for CO2 than SCCO2
  - Possible pores formed in the thinner coatings
- To confirm the hypothesis, diffusion coefficient measurement and surface characterization should be considered.

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Conclusion

- Good adhesion is required to protect coatings.
- Resilient coating to withstand blistering.
- Blister formation proposed mechanism

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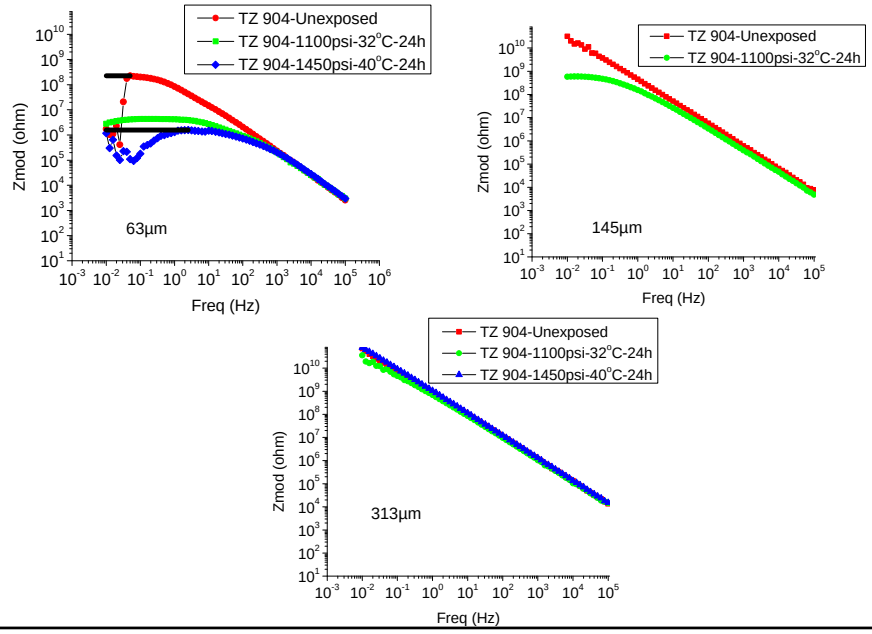
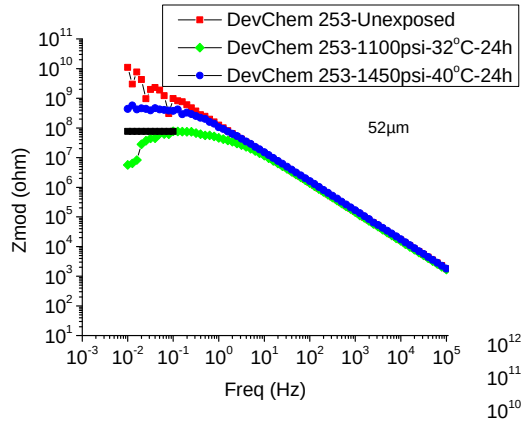
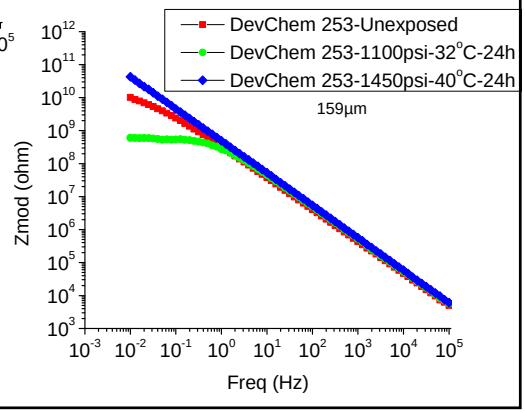
EIS Results for TZ-904



EIS Results for Dev-Chem 253





Conclusions

- Good adhesion necessary in protective coatings
- Blister formation resulted from ingress of SCCO2 & expansion of CO_2 before egress
- Thicker coatings caused blister formation, but gave better corrosion protection
- High pressure and high temperature increased the rate of corrosion processes
- TZ 904 performed better than DevChem 253
- New Industrial Samples will be examined

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Future work

- Synthesize the polymer designed to prepare pigmented primer internal to pipe
  - Polymer for SCCO2 resistance
  - Pigment for corrosion/metal protection
- Test more commercial coatings under SCCO2 treatment to investigate the corrosion process and range of polymers available

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Status

- Project Approximately on Budget
- Equipment acquisition for Enhanced Electrochemical Characterization to be purchased shortly
- New Co-PI Will be added to fill in for departure
- Materials Issues Continue in Importance as Little work on these issues ongoing in industry

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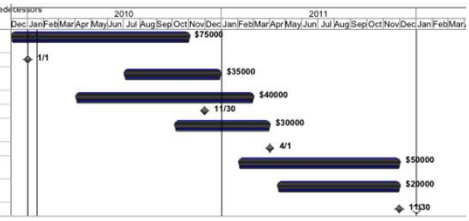

Total Project Budget
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Summary

- Research Program underway at NDSU examining protective coatings for Co-sequestration pipelines (dSCCO2)
- Initial thrust will be to determine range of conditions for dSCCO2 that are possible from CoCCS processes
- Examining internal pipeline coatings emphasizing SCCO2 resistant polymers
- Emphasis on graduate student training
- Later Emphasis on possible monitoring sensors embedded in coatings

Further Issues

- Developing understanding of the corrosivity and impact of contaminants in liquid to SCCO2 on standard piping
- Examining pipe alloy composition sensitivity to contaminants in liquid to SCCO2 with respect to corrosivity and other safety related variables
- Studying modifications to piping composition and/or interior coatings that would make co-sequestration technically and economically feasible
- Characterizing phase behavior of mixtures of CO_2, SO_X, NO_X and its corrosivity, solvent nature, and sensitivity to admixture of small amounts of H_2O
- Development of pipeline corrosion sensors and RFID data acquisition methods with capabilities to monitor pipes used in handling co-sequestration fluids. These sensors could be an important technique to monitor a pipeline carrying a not-so known fluid
- Development of corrosion inhibitors that could be added to the CO_2 stream periodically.

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