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Hydrate Flow Performance JIP

JIP Member Slide Copy
Hydrate Risk Management Program

Principal Investigators
Dr. Michael Volk
Emmanuel Delle-Case
600 S. College Ave.
Tulsa, OK 74104

Advisory Board Meeting

March 2008
Confidential

THE UNIVERSITY OF TULSA
Hydrates Flow Performance Project
Advisory Board Meeting

Champion Technologies
3130 FM 521
Fresno, Texas 77545

AGENDA

Wednesday, March 5, 2008

Mike Volk...... …………………………………………..……………..…1:00 p.m. - 1:15 p.m.
Safety Orientation/*Introductory Remarks*

Steady State Studies

Emmanuel Delle-Case......……………………………………..…………..1:15 p.m. - 1:35 p.m.
Steady State Experiments

Ramon Domingues………………………………………………………….1:35 p.m. – 2:00 p.m.
Steady State Simulations

Transient Studies

Angelina Coletta.……………………………………………...……………..2:00 p.m. – 2:30 p.m.
Jumper Study

BREAK ....………………………………..…………..…..………………2:30 p.m. – 2:45 p.m.

Autoclave Studies

Alisher Yunuskhojayev……………………………………………………….2:45 p.m. – 3:15 p.m.
Water Droplet Size and Their Effect on Plugging Tendencies

Plug Characterization Studies

Kieran Barrows…………………………………………..………………...3:15 p.m. – 3:45 p.m.
Status Update

Mike Volk........………………………………………………………………3:45 p.m. – 4:00 p.m.
Open *Discussion/Issue Bin*

Adjourn ……...........……….………………………..…..4:00 p.m.

Tulsa University
Hydrate Risk Management JIP

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Welcome

- 11th Semi-Annual Advisory Board Meeting
- Handouts
  - Slide Copy Book and CD
- Sign-Up List
  - Please leave Business Card at Registration Table

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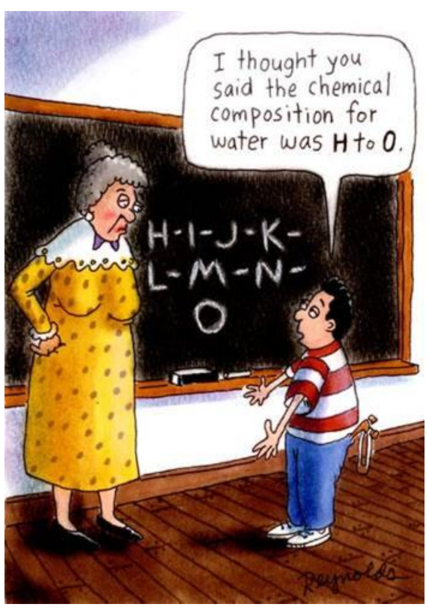
Please Put Your Cell Phone to Silent

Safety Moment



Safety Video

Champion Technologies

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Hydrate Staff

- Mike Volk – PI
- Emmanuel Delle-Case, Co-PI
- Cem Sarica, & Keith Wisecarver, Graduate Student Advisors
- Lissett Barrios – Post Doc
- Jose Aramburu – Operation Engineer
- Garrett Pierce – Technician
- Alisher Yunuskhodzha, Ramon Domingues, Angelina Coletta & Kieran Barrows – Graduate students
- Lori Combs – Project Coordinator
- Justin Horn – Web Site Administrator

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ABM Agenda

Steady State Studies

Emmanuel Delle-Case..1:15 p.m. - 1:35 p.m.
Steady State Experiments

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Open *Discussion/Issue Bin*

Adjourn ....**4:00 p.m.**

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Phase III Studies

Hydrate Risk Management

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Research Participants

JIP Members

- bhpbilliton
- Champion Technologies
- NALCO
- Colorado School of Mines 1874
- calsep
- SCANDPOWER
- MMS

DeepStar Members

- Anadarko Petroleum Corporation
- Eni
- BR PETROBRAS
- STATOIL
- TOTAL
- bp
- Chevron ChevronTexaco
- Marathon Oil Corporation

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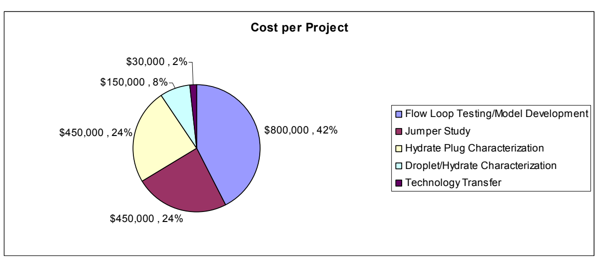
Phase III Studies

- CTR 9202 $620K
- JIP $1.2M
  - MMS $320K
  - Industry $700K
  - Other $180K

- Four parts
  - •Steady-state studies
  - •Transient studies
  - •Plug properties and remediation studies
  - •Dispersion/Hydrate Characterization



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Phase III – Steady State Studies

- Part I: Steady-state conditions
  - Continue evaluation of variables on plugging risk
    - Water cut, salinity, flow patterns (liquid loading & rate), viscosity
  - Slurry flow data generation and modeling
  - Steady-state simulations
    - Find hydrate formation rates and plugging conditions
    - Collaboration with CalSep (FlowAsta)

Phase III - Transient studies

- Part II: Transient conditions
  - Construction of clear jumper facility
  - Understand flow patterns taking place upon restart
    - How is the water being displaced?
    - Is there a range of operating conditions allowing un-inhibited restarts?
  - Comparisons with OLGA predictions
    - Collaboration with ScandPower
  - Extend studies with hydrates (THF)

Phase III studies

- Part III: Plug properties and dissociation
  - Control hydrate plug formation in the flow loop
  - Measure plug porosity, permeability and trapped fluids for different conditions
  - Compare efficiency of dissociation methods for plugs with different properties
    - Gas or Oil-dominated systems
    - Effect of water cut, fluid velocity during plugging
    - Heating, depressurization, inhibitors (MEG/MeOH)

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Steady-State Experiments

Emmanuel Dellecase

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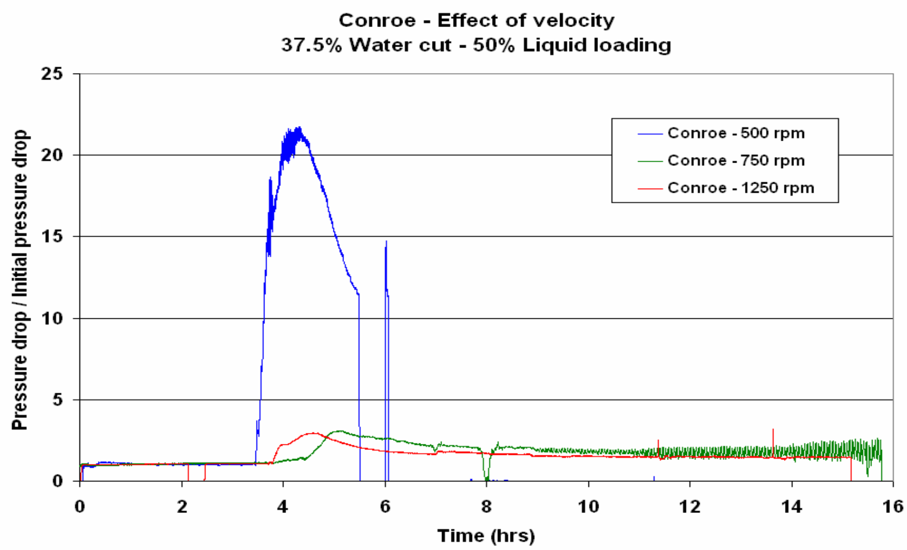
Outline

- Summary of findings
- New plugging classification
- Facility modifications
- Future work

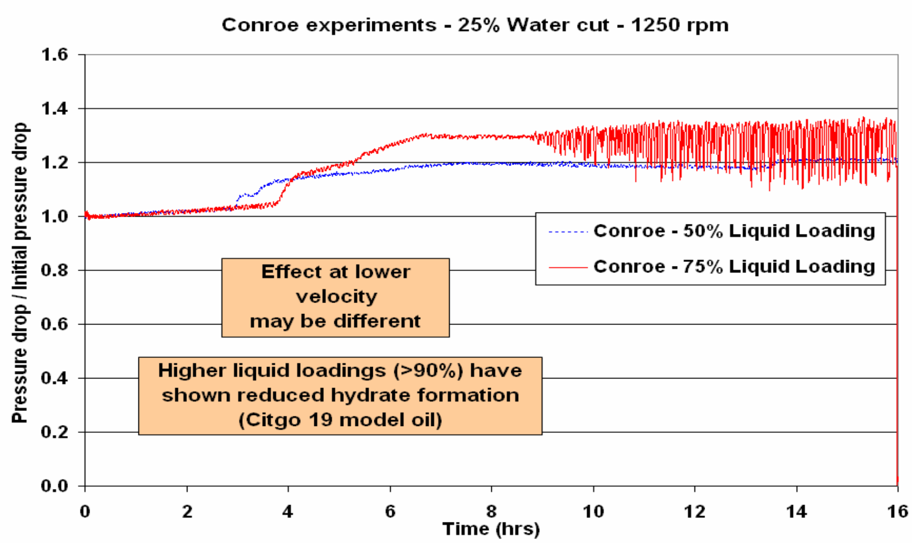
Summary of findings

- Water cut
  - Feasibility of non-inhibited slurry flow above 30% water cut found to be remote
- Velocity
  - Low velocities favor plugging
  - No effect above 4 ft/s
- Effect of liquid loading
  - No measurable effect on plugging from 50% to 75%, possibly up to 100%

Effect of Velocity

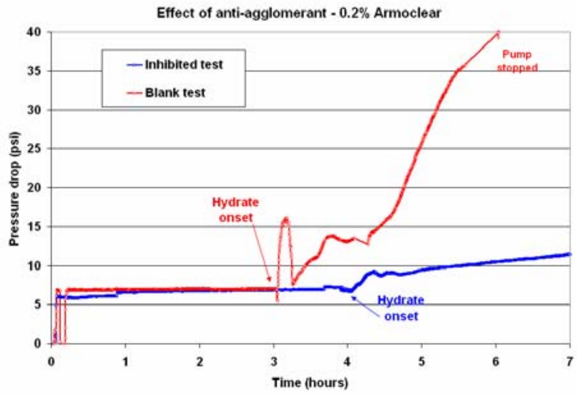


Effect of Liquid Loading



Summary of findings

- Small percentage of AA sufficient to change pressure drop and plugging outcome



New plugging classification

Plugging Classification

- **Type I FAIL**
  - Solid plugs
  - Large increase in pressure drop
- **Type II FAIL** (FALSE PASS)
  - Trace similar to slurry flow
  - Possible partial plugs formed
- **Type III PASS**
  - Slurry flow
  - No agglomeration detected

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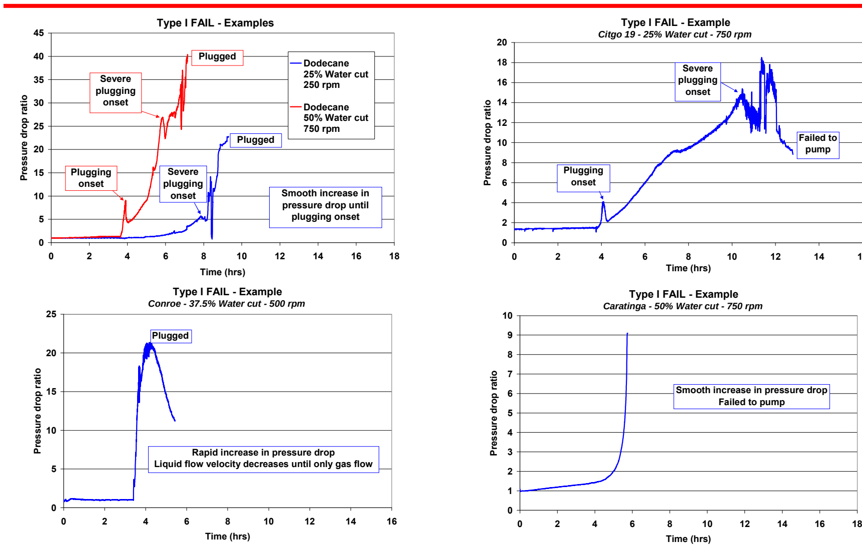
Type I FAIL



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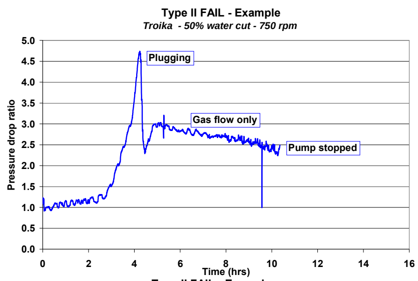
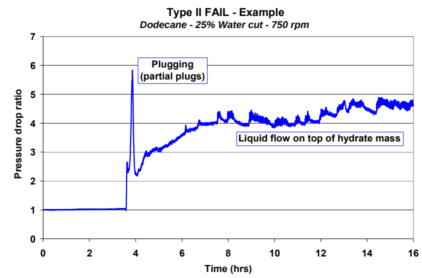
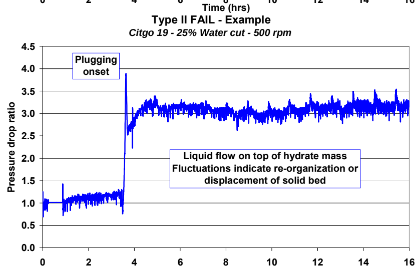
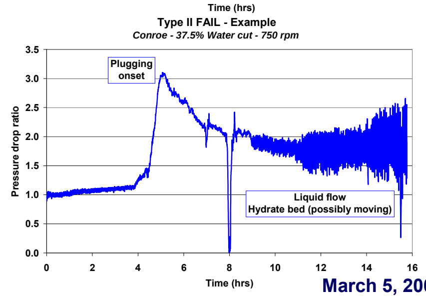
Type II FAIL









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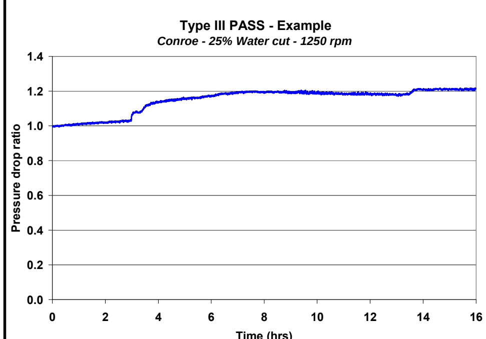
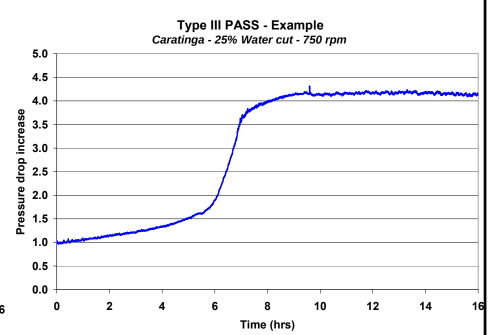
Type III PASS





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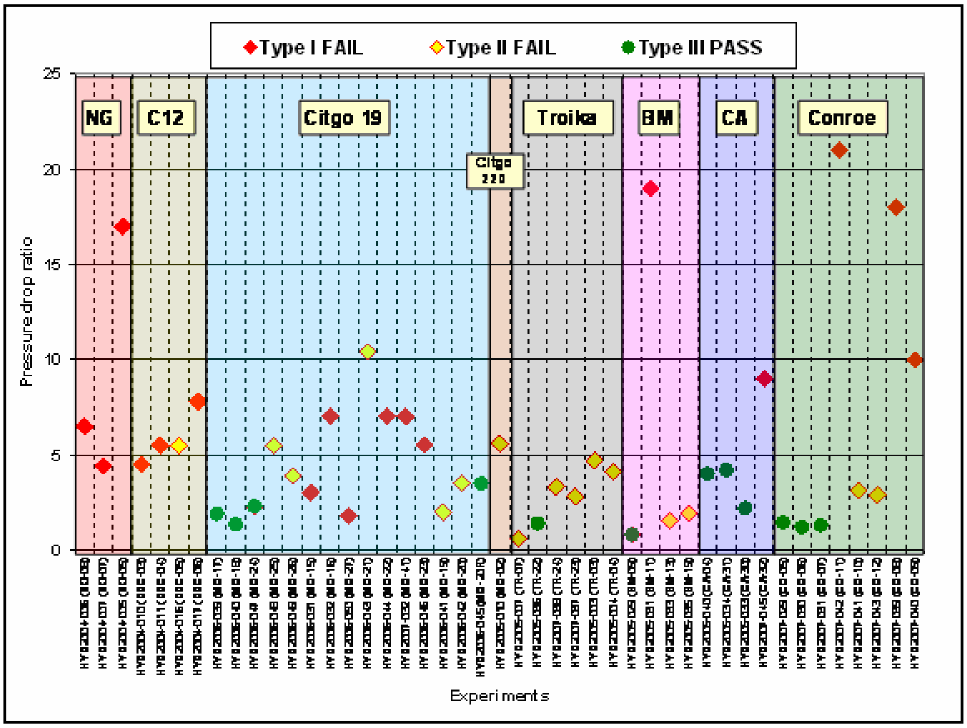
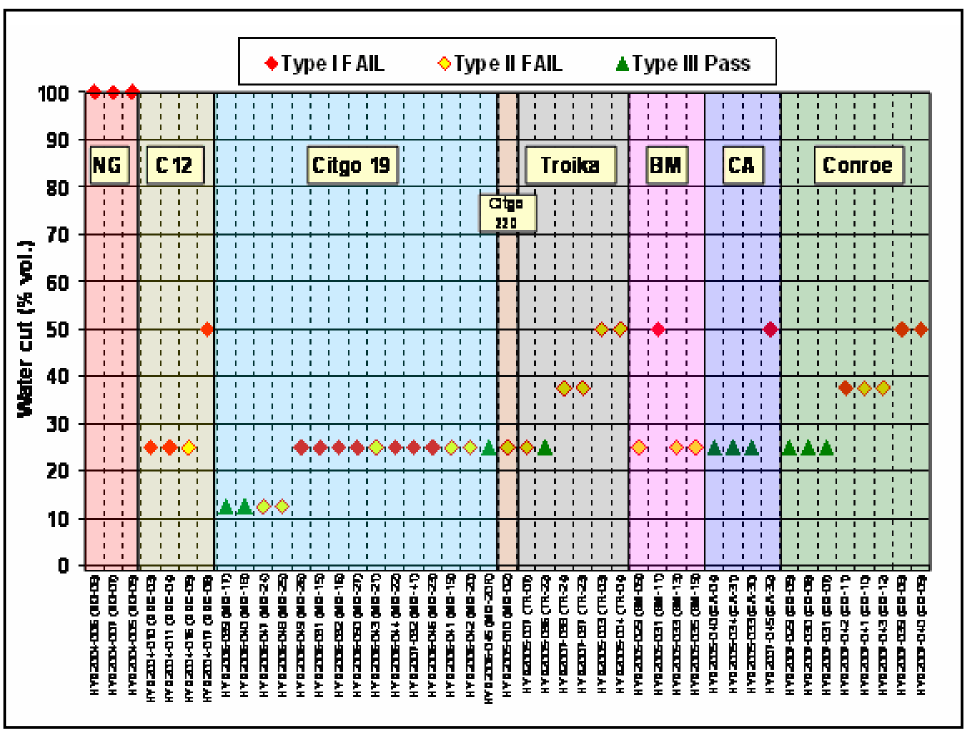

Type I FAIL
Type II FAIL
Type III PASS
NG
C12
Citgo 19
Citgo 220
Troika
BM
CA
Conroe
Pressure drop ratio
Experiments
0
5
10
15
20
25


Type I FAIL
Type II FAIL
Type III Pass
NG
C12
Citgo 19
Citgo 220
Troika
BM
CA
Conroe
Water cut (% vol.)
0
10
20
30
40
50
60
70
80
90
100

Facility modifications

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Facility modifications

- Gas system modifications
  - Faster gas addition rates and pressure maintenance capabilities
  - Inlet gas temperature control for plug permeability studies
  - Outlet gas temperature control to prevent valve freeze up
  - Automatic pressure control of the flow loop (depressurization ramps, drainage)

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Facility modifications

- Differential pressure transducers
  - Replaced with remote seals to prevent plugging of impulse lines
    - Larger pressure drop range (0-100, 0-250 psid)
    - Four transducers @ $2,500 each
  - Existing transducers will be used on the transient jumper facility
  - Eliminates electrical heat trace on impulse lines

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Future Work

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Future experiments

- Verify high liquid loading hypothesis
  - Drain liquids after experiments to visually inspect for plugs (Citgo 19)
- Flow patterns
  - Water cut, liquid loading, velocity, viscosity
- Fluid properties
  - Salinity effects (pumping conditions)
  - Additive effects (DP vs. concentration)
  - Fluid viscosity
- Others…

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Modeling aspects

- Hydrate formation rates
  - In-house simulations using PVTSim open-structure
  - Joint effort with CalSep
- Slurry flow operating envelope
  - Prediction of plug formation
  - Mechanistic modeling too complex
  - Use correlation approach
- Pressure drop calculations
  - Continue slurry flow model development

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Discussion

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Steady State Simulations

Ramon S. Domingues

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Outline

- Objectives
- Scope of Programming
  - Hydrate phase equilibrium curve at constant volume and pressure conditions (conceptual approaches).
  - Block diagrams for both tests (tools - PVTSim/Calsep, VBA).
- Test Results
  - Constant Pressure Tests
    - Different effects comparisons (LL, WC, pump speed)
  - Constant Volume Tests
    - Different effects comparisons (WC, salinity)
- Future Work

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Objectives

- Simulate hydrate formation at equilibrium conditions (no mass transfer, no flow pattern effect) for constant volume and pressure tests.
  - Develop simulation tool based on these two different tests.
- Understand effect of operating parameters in comparison with steady state experimental test conditions
  - Liquid loading, Water cut, Salinity, P, T.
- Improve methods for water conversion calculation.
- Continue effort towards non-equilibrium simulations.

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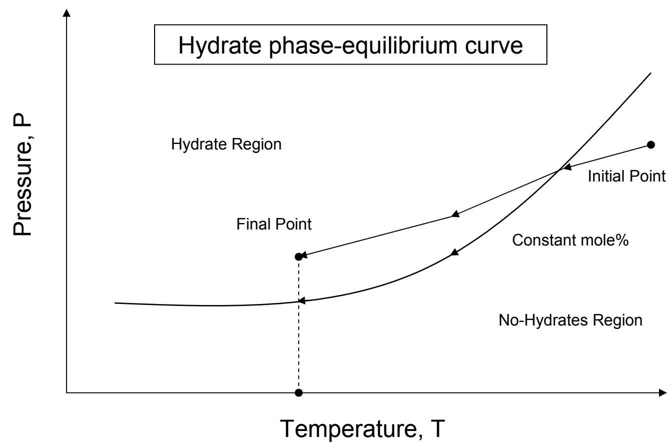
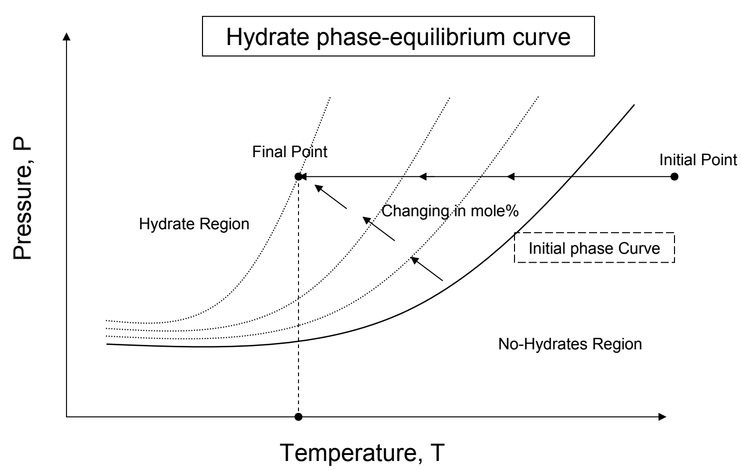
Scope of Programming

Constant Volume Test - Pressure Drop Prediction



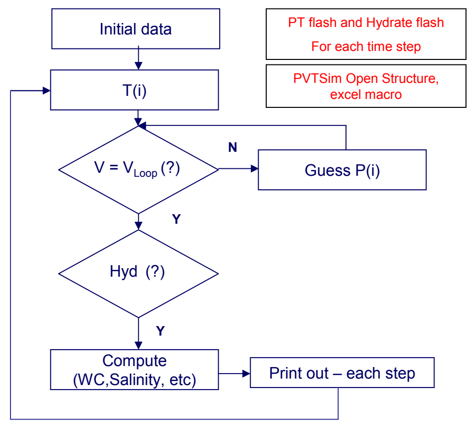
Scope of Programming

Constant Pressure Test – Gas Addition estimation



Scope of Programming

Block diagram - Constant Volume Test

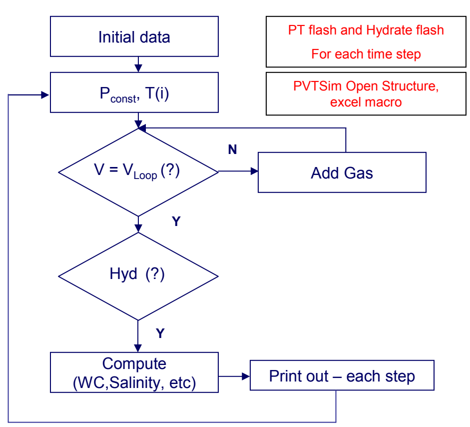


Input data
- Mixture composition – Oil, Gas and Brine
- Temperature profile (cooling description)
- Initial Loop Pressure
- Loop Volume

Output
- Pressure profile
- Water conversion, salinity changes, mass balance (hydrates formation)

Scope of Programming

Block diagram - Constant Pressure Test



Input data
- Mixture composition – Oil, Gas and Brine
- Temperature profile (cooling description)
- Constant Loop Pressure
- Loop Volume

Output
- Gas addition estimation
- Water conversion, salinity changes, mass balance (hydrates formation)

Test Results

- 24 experimental pumping tests simulated considering:
  - Oils: Conroe, Troika, Citgo 19, ButterMilk, Caratinga.
  - Liquid Loading: 50%, 75%, 90%, 100%.
  - Water cut: 12.5%, 25%, 37.5%, 50%
  - Velocity: rocking, 2.3ft/s, 3.9ft/s, 7.2ft/s.
  - Salinity: fresh and 3.5%wt.

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Constant Pressure Tests

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Constant Pressure Tests

- Parameters covered by simulated experiments
  - Velocity, Liquid Loading, Water cut, Salinity
- Findings
  - Pumping conditions approach equilibrium conditions (2.3 ft/s to 7.2 ft/s)
  - Match is better for higher velocities
  - Same trend for different fluids and conditions
    - Buttermilk, 3.5% brine, 25% water cut, 3.9 ft/s, 50% LL
    - Caratinga, fresh water, 25% water cut, 3.9 & 7.2 ft/s, 75% LL
    - Conroe, fresh water, 37.5% water cut, 2.3 to 7.2 ft/s, 50% LL

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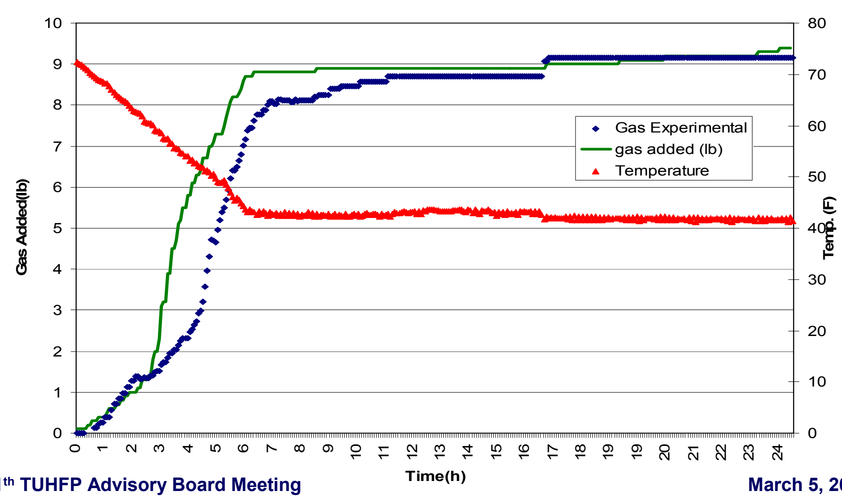
Constant Pressure Tests

ButterMilk: 50% LL, 25% WC, 3.5% wt., 3.9ft/s



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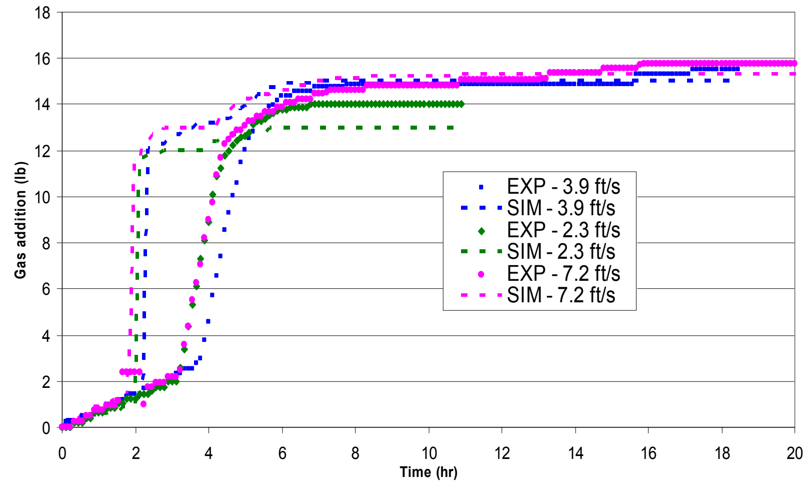
Effect of Velocity

Conroe: 50% LL, 37.5% WC



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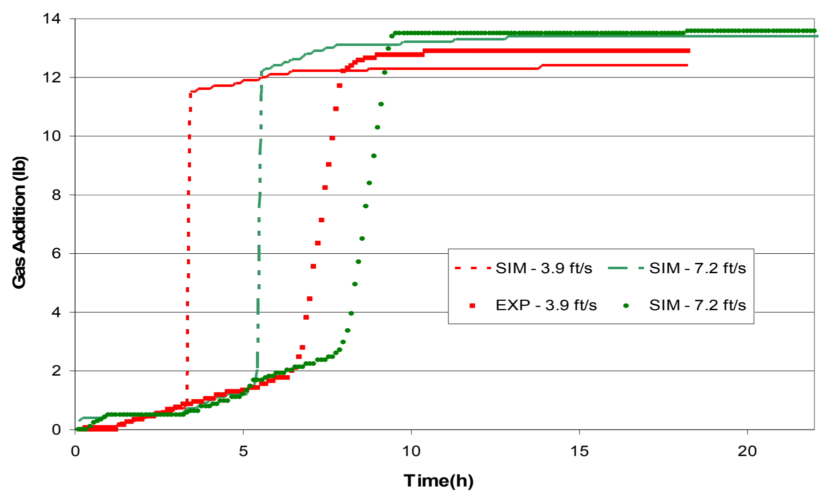
Effect of Velocity

Caratinga: 75% LL, 25% WC



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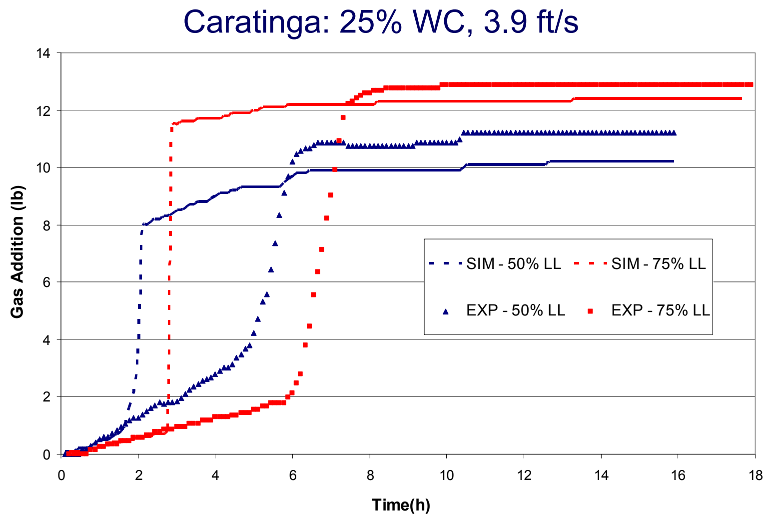
Effect of Liquid Loading



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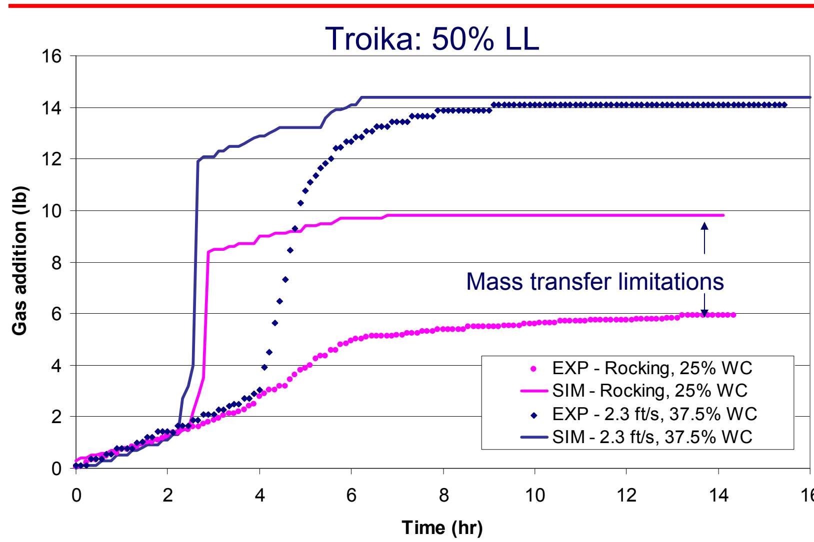
Rocking vs. Flowing



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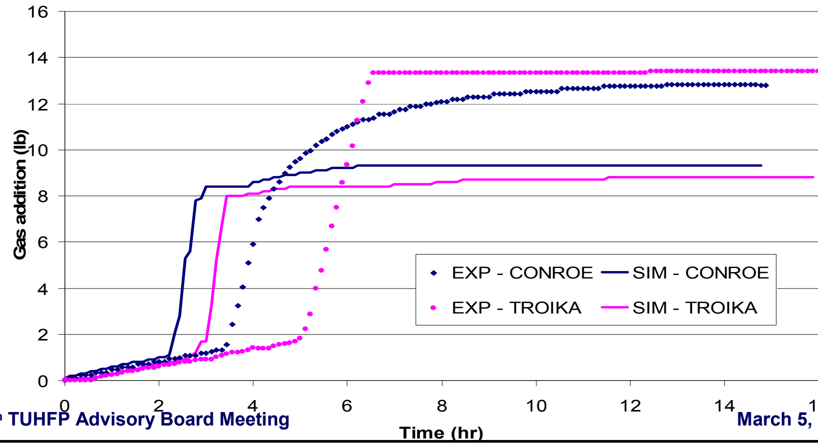
Some issues

- Experimental gas addition higher than simulation
  - Fluid composition analysis? High liquid loading effect (75%)?



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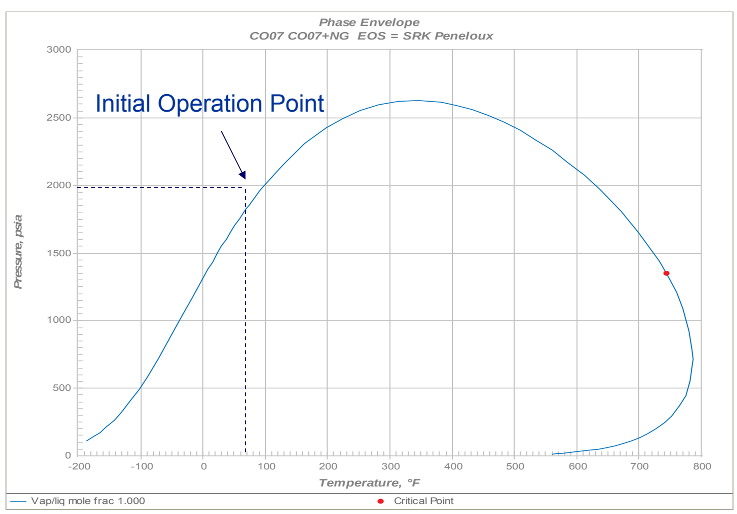
Conroe phase envelope



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High liquid loading cases

- Simulations show hydrate formation is reduced when amount of free gas is reduced
  - Some indication experimentally
  - Must be proven

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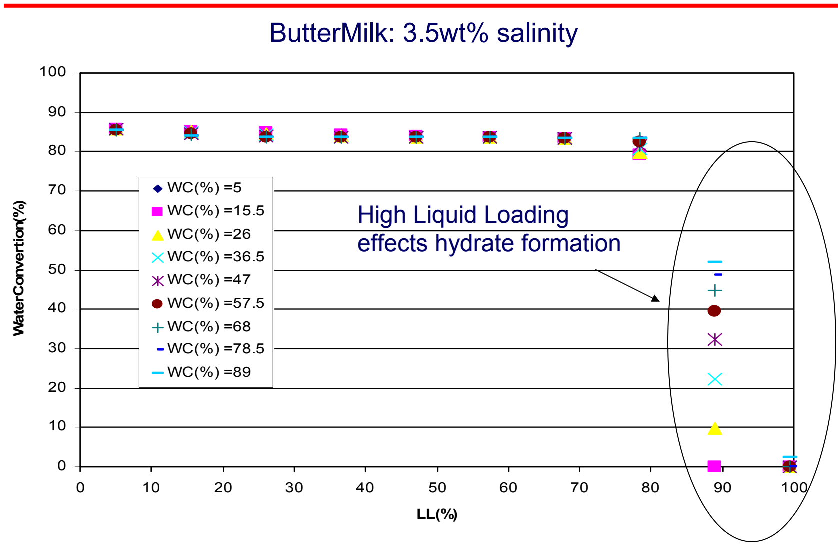
Effect of High Liquid Loading



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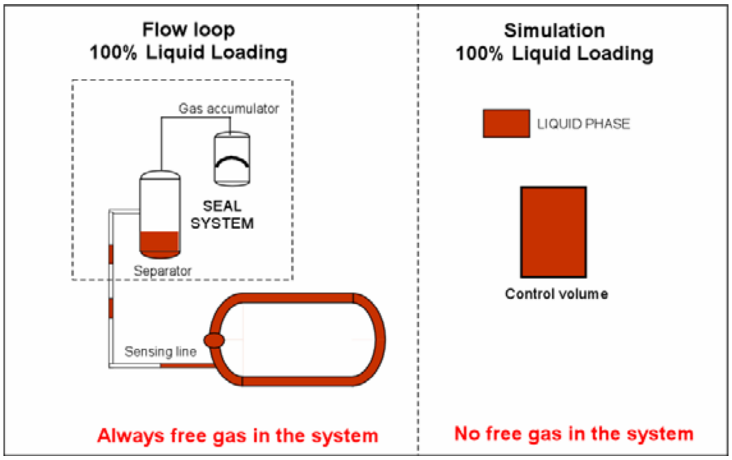
High liquid loading effect



Simulations should account for total system volume

Constant volume tests

Findings

- Parameters considered: water cut, salinity
- Flow loop experiments limited to 14% salinity in constant volume mode

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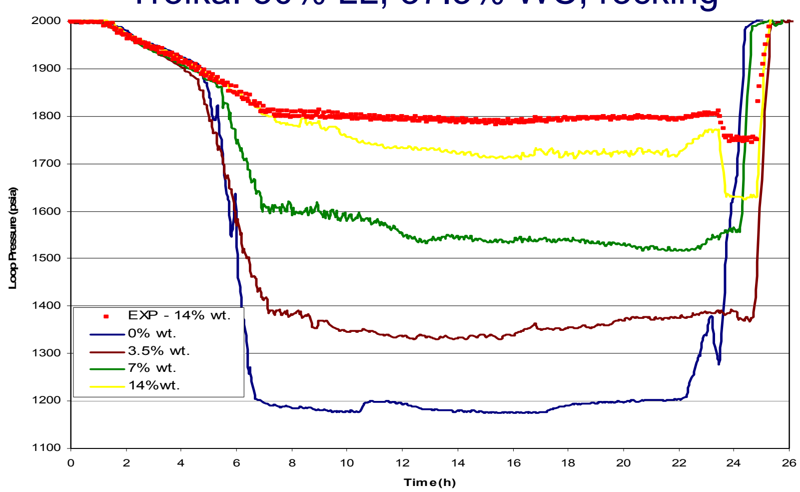
Effect of Salinity

Troika: 50% LL, 37.5% WC, rocking



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Summary of results

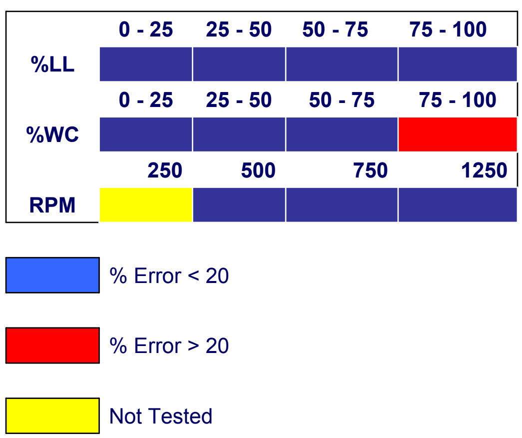
Test #	Pump Speed (rpm)	%LL	%WC	Classification	Gas Addition (lb) EXP	Gas Addition (lb) SIM	%Error
TR-22	1250	75	25	III	13.392	8.8	-34.29
CO-07	1250	75	25	III	12.79	9.3	-27.29
BM-13	750	50	25	II	14.16	11.7	-17.37
BM-09	750	50	25	II	13.756	11.6	-15.67
CA-04	750	50	25	III	11.2	10.2	-8.93
CO-11	500	50	37.5	I	14.011	13	-7.22
MO-17	750	50	12.5	III	7.938	7.6	-4.26
CA-31	750	75	25	III	12.886	12.4	-3.77
CO-12	1250	50	37.5	II	15.752	15.3	-2.87
CO-10	750	50	37.5	II	15.495	15.1	-2.55
MO-24	750	75	12.5	II	9.788	9.6	-1.92
MO-15	750	50	25	I	12.457	12.4	-0.46
CA-30	1250	75	25	III	14.26	14.2	-0.42
MO-21	750	75	25	II	14.016	14	-0.11
CO-06	1250	50	25	III	11.351	11.5	1.31
TR-23	750	50	37.5	II	14.16	14.4	1.69
TR-24	500	50	37.5	II	14.11	14.4	2.06
CO-05	750	50	25	III	11.166	11.4	2.10
BM-19	1250	75	25	II	13.671	14.2	3.87
MO-20	750	100	25	III	4.09	5.2	27.14
TR-20	Rocking	50	25		5.94	9.8	64.98
MO-23	750	90	25	I	8.938	15.7	75.65
CO-08	750	50	50	I	11.957	21.675	81.27
CO-01	Rocking	50	25		5.999	11.5	91.70

Less free gas at earlier times

Rocking test "almost static".

High LL% the amount of free gas is not enough to form hydrates

Match with experimental data



Conclusions

- Simulations at equilibrium are much closer to steady state experimental data, despite not considering any possible non-equilibrium model
- Possible issues with phase envelope
- Issues related to high liquid loadings
- The salinity strongly inhibits hydrate formation and limits loop experiments (constant volume)

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Future Work

- Continue tool development
  - Investigate liquid loading effect
    - Accurately measure flow loop volume
  - Conduct PVT analyses on fluids
  - Perform constant volume tests (pumping)
  - Develop a non-equilibrium simulator
    - Account for sub-cooling at onset conditions
    - Simulate kinetic rates
- Compare simulation results to test data

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Questions

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Jumper Study

Angelina Coletta

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Outline

- Objectives
- Task Management
- Olga Simulations
- Facility Design
- Test Matrix
- Future Work

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Objectives

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Objectives

- Perform transient flow experiments on a jumper like configuration upon restart
- Understand the liquid displacement and flow patterns as a function of different operating parameters (ex. WC, LL, RS, μ_o)
- Validate Olga transient simulations
- Relate study to hydrate plugging risk

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Task Management

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Task Management

- Run Olga simulations to finalize design of transient flow facility:
  - Test section
  - Equipment
  - Instruments
- Conduct experiments in new facility
- Compare Olga simulations with experimental results

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Current Status

- Olga Simulations
  - Attended OLGA training course
  - Simulations have been run
- Facility Design
  - Loop design complete
  - Facility construction in progress

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Olga Simulations

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Simulation Set-up

- Software – OLGA 5.2.1
- 226 simulations completed:
  - Restart phase — Oil/Gas
  - Oil viscosity — 19 cSt / 220 cSt @ 40 ºC
  - Flow rate — From 2 to 30 ft/s, Step: 3 ft/s
  - Liquid loading — Partial / Bridging
  - Water cut — 25, 50, 100%

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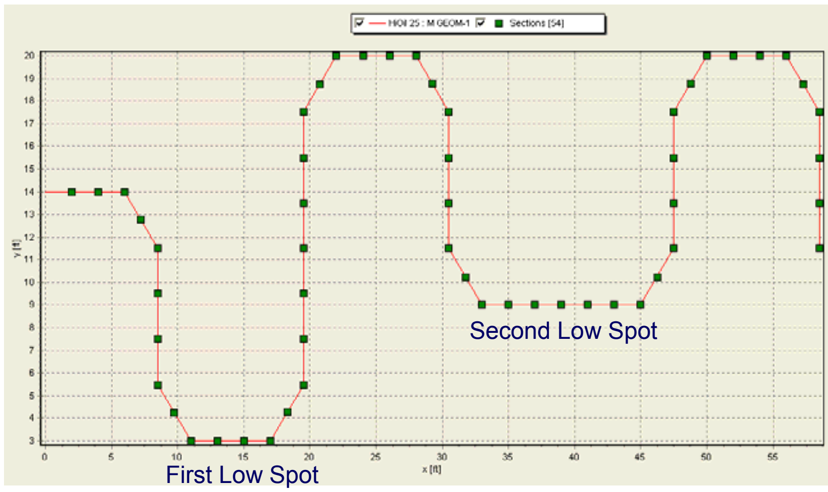
Simulation Geometry



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Simulation Runs

- 25, 50, 75, 100, 125% → Water hold up in low spot
  - 10 Gas Restarts

50 simulations

- 25, 50, 125% → Water hold up in low spot
  - 10 Low Viscosity Oil Restarts
  - 10 High Viscosity Oil Restarts

60 simulations

- 25, 50, 75, 100% → Oil hold up in low spot
  - Two Oil viscosities
  - 7 Gas Restarts

56 simulations

- 25, 50, 100% → 50/50 Oil/Water Mix
  - Two Oil viscosities
  - 10 Gas Restarts

60 simulations

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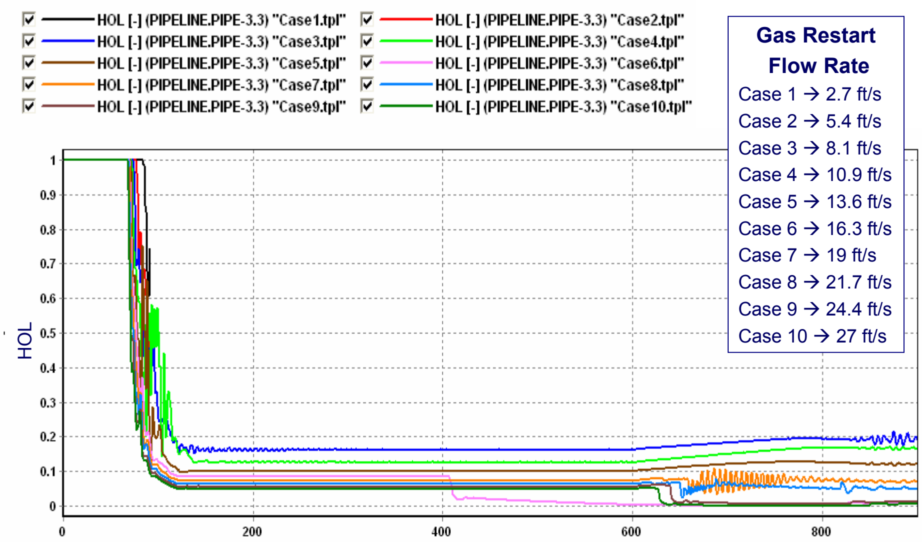
Videos

- Video 1
  - 100% Water in Low Spot – 2.7 ft/s Gas Restart
- Video 2
  - 100% Water in Low Spot – 8.1 ft/s Gas Restart
- Video 3
  - 100% Water in Low Spot – 27 ft/s Gas Restart

125% Water Bridged in 1st low spot trend



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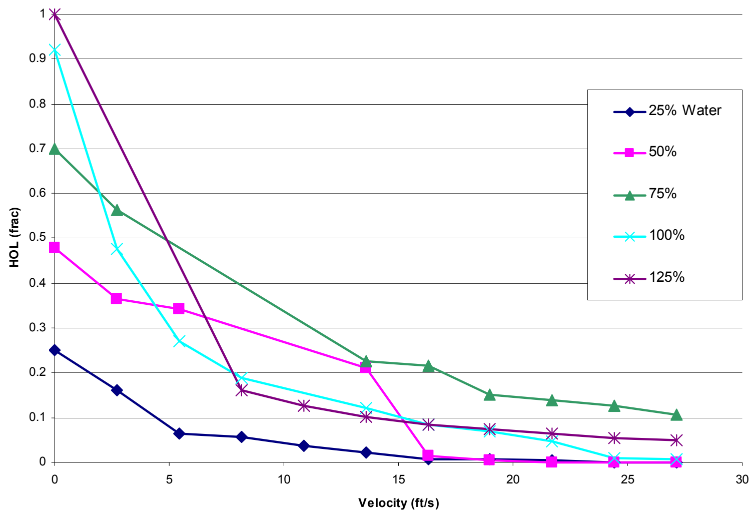
Hold-up on 1st Low Spot



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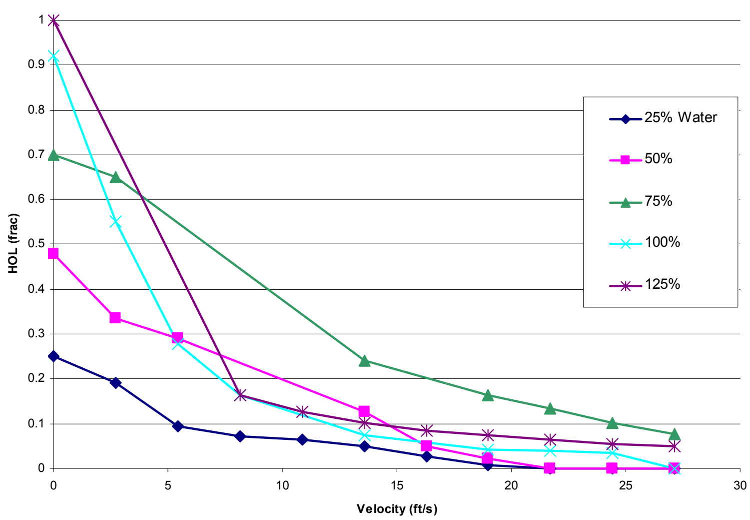
Hold-up on 2nd Low Spot



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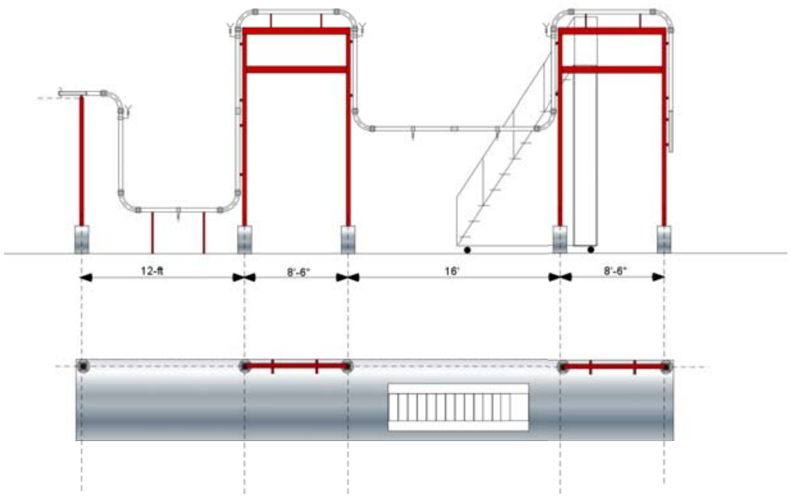
Simulation Use

- With the simulation results it was possible to finalize the design by:
  - Locating instrument positions along test section
  - Calculate instrument's range
  - Size receiver and storage tanks
  - Predict restart working range
  - Establish compressor capacity
  - Efficiently select experiments of interest

Facility Design

Facility Layout



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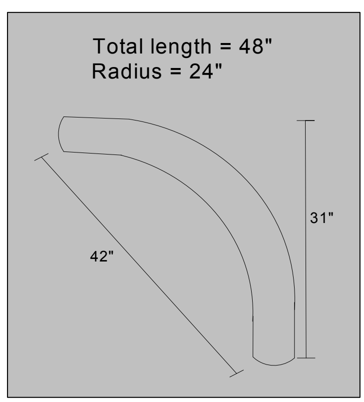
Elbow Dimensions



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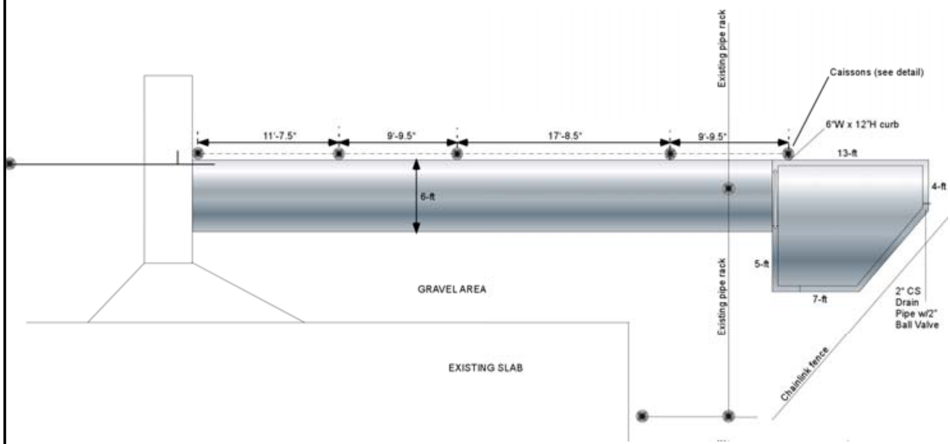
Facility Location



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Jumper Pad

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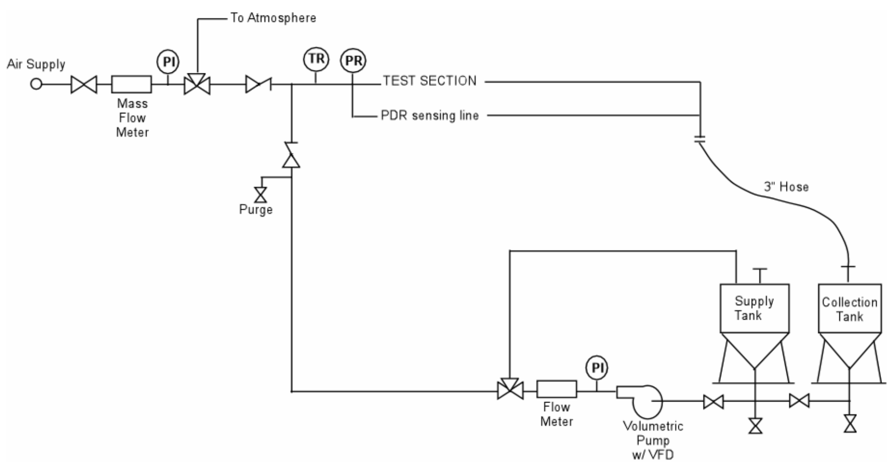
Facility Design



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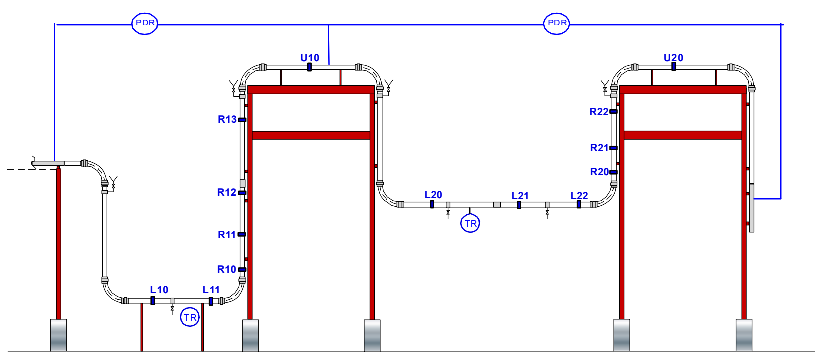
Facility Design - Instrumentation



Drain ports (3)
Fill ports (4)
Capacitance sensors (14)
PDR Differential pressure transducers (2)
TR Temperature transducers (2)

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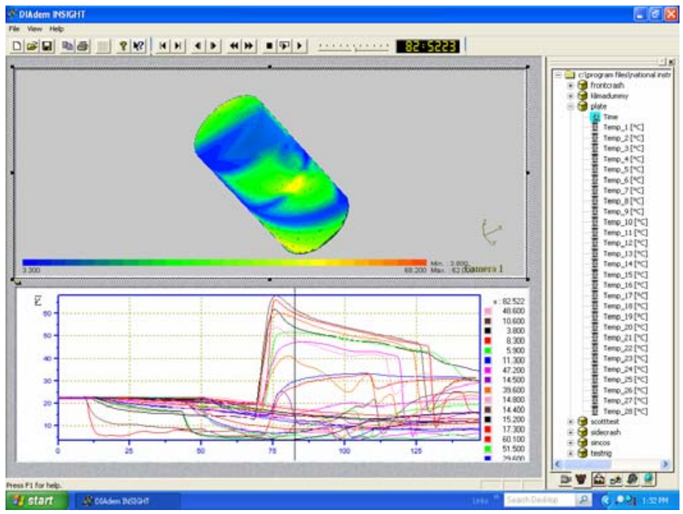
DIAdem Insight

3D flow software



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Instruments Specifications

- Visualization Technique
  - Flow pattern observation at different operational conditions
  - Droplet size measurements
- Regular digital camera

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High Speed Video Technique

OLYMPUS i-SPEED

$20,000

$7,000

$300

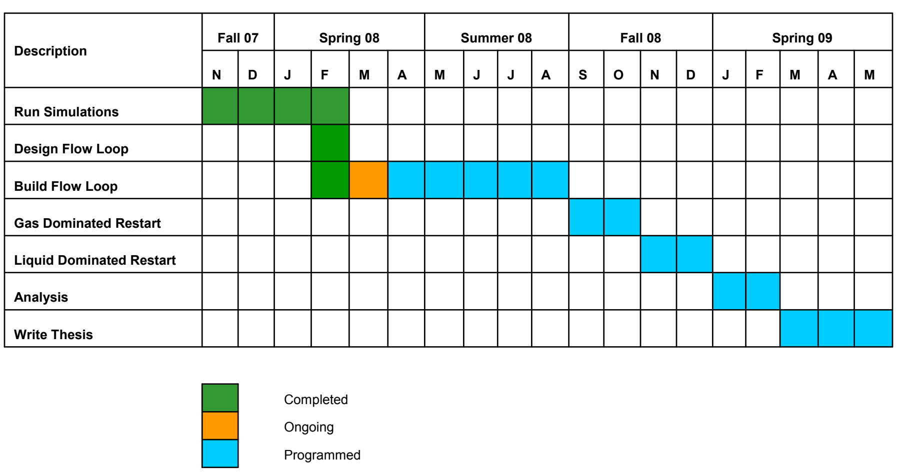
Frame Rate (fps)	Maxima Resolution (pixel)		Record Time (sec)
	H	V	
60 to 1,000	800	600	4.47
2,000	579	432	4.32
3,000	448	336	4.76
33,000	96	72	9.41

Future Work

Future Work

- Finish facility construction
- Carry out about 100 experimental tests in new flow loop
  - Locate the water accumulation zones and the flow conditions that favor it
  - Select cases of interest from simulation runs
- Data analysis
- Make necessary alterations to the facility to run experiments with hydrates

Task Chart



Questions

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15 Minute Break

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Water Droplet Size and Effect on Plugging Tendencies

Alisher Yunuskhojayev

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Outline

- Prior TUHFP Findings
  - Kak's Studies (2007)
  - Sanchez's Studies (2007)
- Phase III Research Objectives
- High Pressure Set Up Improvements
- Current Status
- Future Work

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Prior Findings

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Kak’s Studies

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Current System Set Up

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Kak’s Hypothesis

- At rest, droplets coated with hydrate film
- Under shear conditions
  - Snow-like
  - Non-spherical particles, flakes
- Droplet break-up believed to be a key mechanism in agglomeration

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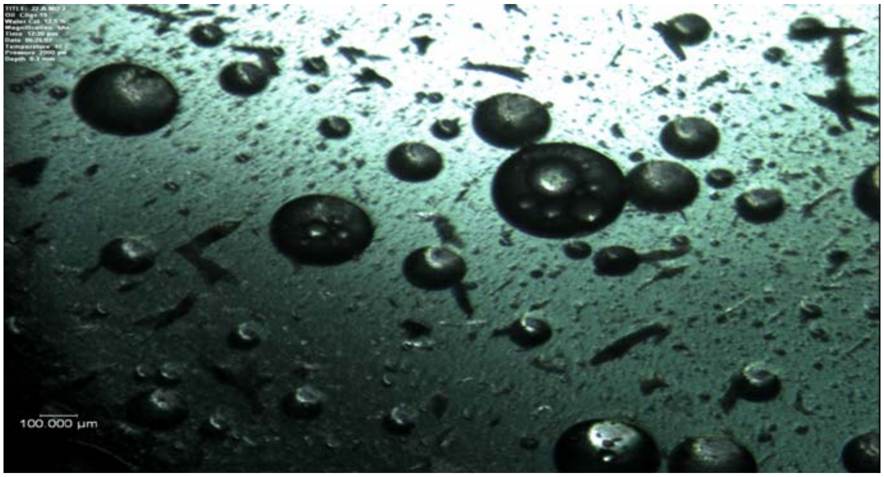
Proposed Hypothesis



Sanchez's Studies

Hypothesis

- Higher IFT will generate larger water droplets. Hence, resulting in solid hydrate plugs.
- Lower IFT will generate smaller water droplets. Hence, resulting in weak hydrate plugs.

Proposed Hypothesis

1. Fluid properties measured at ambient conditions
2. Critical water cut has to be found for specific oil and system

Assumptions

- Negligible effect salinity
- No effect of pressure on interfacial tension and oil viscosity
- W/O emulsion

$$HPRI = \frac{\sigma_i \cdot \rho_d}{\eta_c \cdot \rho_c} \cdot \frac{Wc}{\gamma \cdot d_{pipe}} \cdot \frac{1}{Wc_{critical}}$$

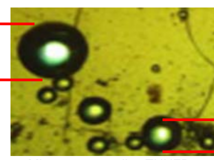
$$HPRI = \frac{[MT^{-2}][ML^{-3}]}{[ML^{-1}T^{-1}][ML^{-3}]} \frac{1}{[T^{-1}][L]} = \frac{T^{-2}}{T^{-2}}$$

Variables Impacting Water Droplet Size

Large water droplet size	Small water droplet size
1. Fluid properties • High interfacial tension • Low oil viscosity and density	1. Fluid properties • Low interfacial tension • High oil viscosity and density
2. Operating parameter • Low shear rate or stirring velocity	2. Operating parameter • High shear rate or stirring velocity
3. Test conditions • High water cut • No surfactants • No salinity	3. Test conditions • Low water cut • Presence of surfactants • Salinity

High Plugging Risk

D_d



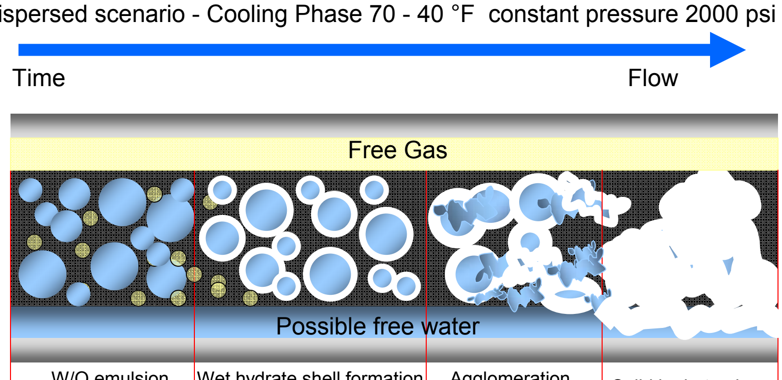
D_d

Microscope studies TUHFP

Low Plugging Risk

Large Water Droplet Size Scenario

Dispersed scenario - Cooling Phase 70 - 40 °F constant pressure 2000 psi



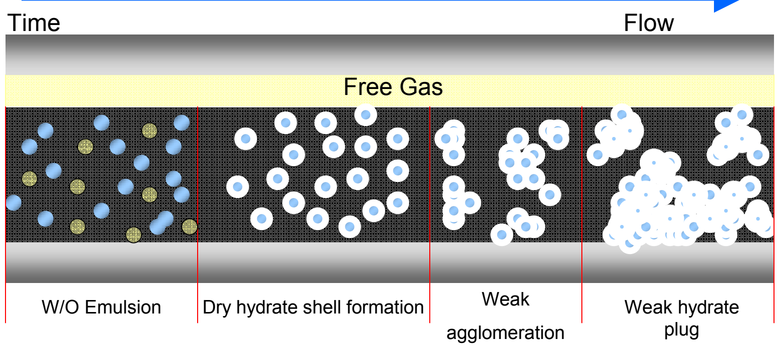
Water release
High wettability
High adhesive forces

High water cut and interfacial tension
Low shear rate, viscosity and density

Gas ○ Water ● Oil ▓

Small Water Droplet Size Scenario

Dispersed scenario - Cooling Phase 70 - 40 °F constant pressure 2000 psi



Low water cut and Interfacial tension
High shear rate, viscosity, and density

Gas ○ Water Oil

Low water release
Low wettability
Low adhesive forces

Research Objectives

Research Objectives

- **Validate and improve the hydrate plugging parameter (high pressure)**
  - Autoclave tests at high pressure with varying water cuts
  - Include a pressure effect on IFT and oil viscosity
  - Experiment with different oils
- **Validate droplet break up hypothesis**
  - NIR camera
  - Lab View system

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Research Objectives

- Study the effect of the following on the water droplet size at high pressure
  - Water cut
  - Hydrate inhibitor and salt concentrations
  - Shear rate/stirring velocity
- Study the effect of water droplet size on the hydrate plugging tendency
  - In the autoclave
  - In the flow loop

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High Pressure Set Up Improvements

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HP Set Up Improvements

- Lab view for P,T data acquisition
  - Hydrate on-set detection
- Viscosity increase/decrease monitoring
- NIR Camera
  - Experiments with dark oils
  - Allows visualization at higher water cuts
    - Up to 45% in a dark heavy oil

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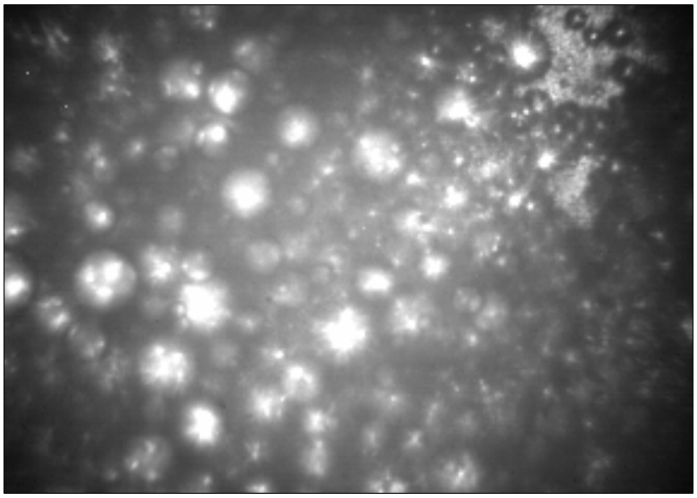
NIR: High WC + Dark Oil



Dark Oil 1
WC: 40%
Depth: 0.3mm
Magn.: 3AX
70 F, 1000psi

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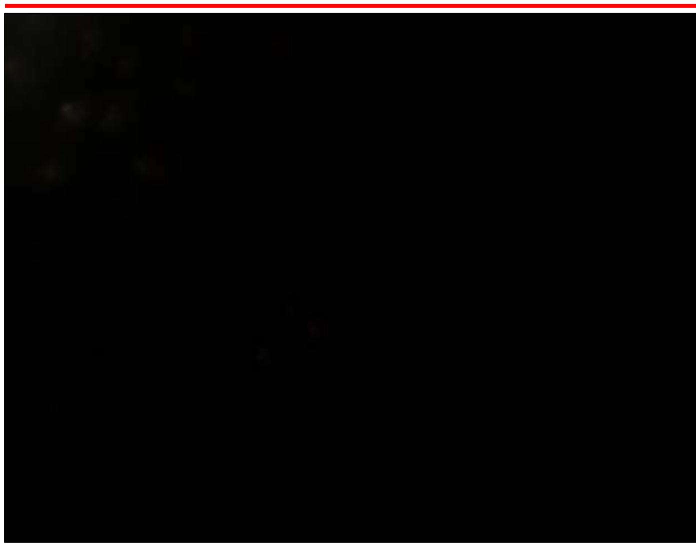
Regular Camera: High WC + Dark Oil



Dark Oil 1
WC: 40%
Depth: 0.3mm
Magn.: 3AX
70 F, 1000psi

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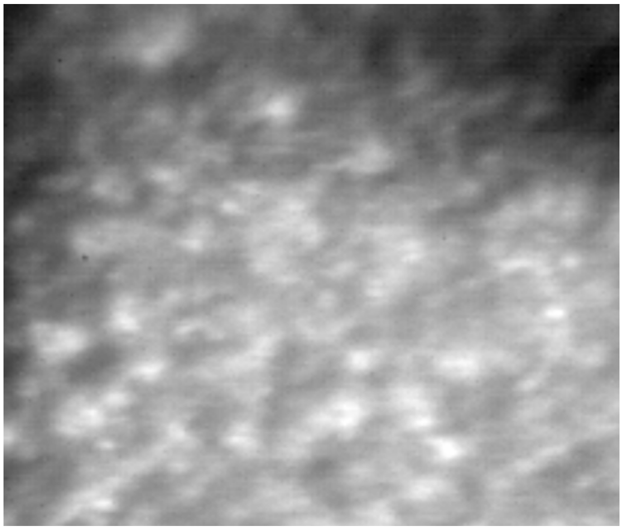
NIR: Hydrate visualization



Dark Oil 1
WC: 40%
Depth: 0.3mm
Magn.: 3AX
35 F, 1000psi

Current Status

Current Status

- Repeatability demonstrated
  - Autoclave sampling validated
    - Two 12.5% WC troika tests - 3 microns apart
    - Two 15.0% WC troika tests - 5 microns apart
- NIR camera is set-up and tested
  - Initial visualization is obtained
    - Dark oil emulsions up to 45% water cut
    - Hydrate agglomerate structure

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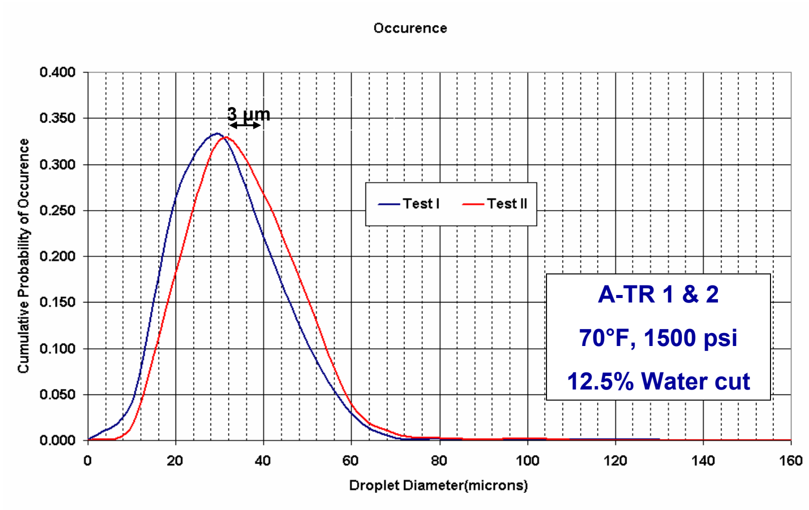
Repeatibility Analysis



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Future Work

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Future work

- ❑ Install data acquisition on autoclave
  - Run tests with NIR microscopy for gaining insights into dark crude oils, different water cuts
  - P,T and torque measurement
- ❑ Model autoclave experiments
  - Ramon's simulation tool

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Questions

¿ ? ? ? ? ? ? ¿ ?

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Plug Characterization Study

Kieran Barrows

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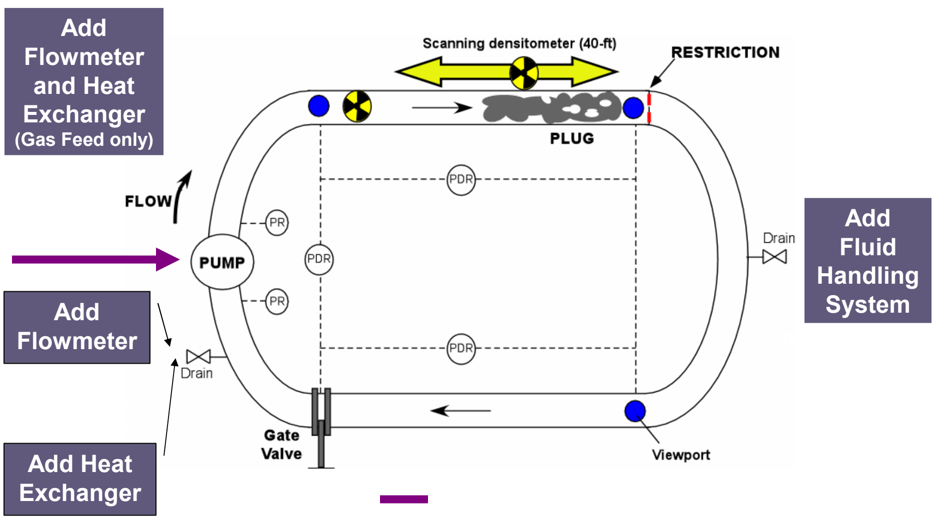
Outline

- Objectives
- Experimental Program
  - **Hydrate Plug Dissociation Methods**
  - **Characterization Examples**
  - **Test Parameters**
- Test Program
- Open Discussion
- Questions and Comments

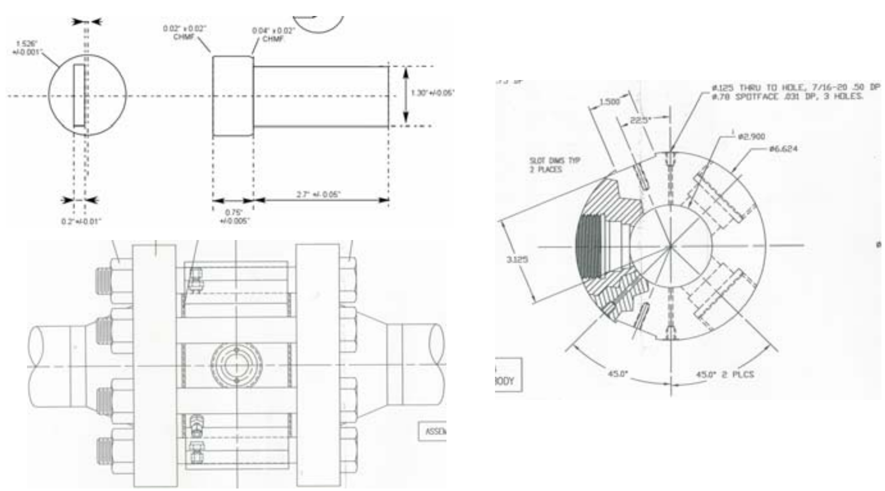
Objectives

- Develop an experimental facility to carry out plug characterization and plug dissociation studies
- Hydrate Plug Characterization
  - Porosity
  - Permeability
- Hydrate Plug Dissociation Methods
  - Heat, Pressure Reduction, MEG
- Relate the impact of porosity and permeability to current dissociation models.

Experimental Facility

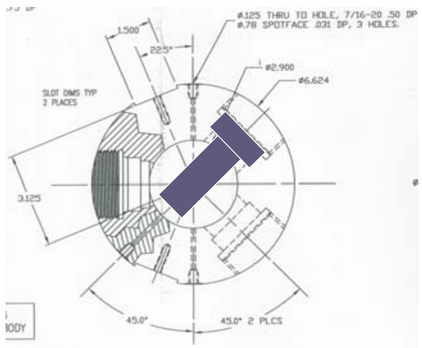


Restriction Design

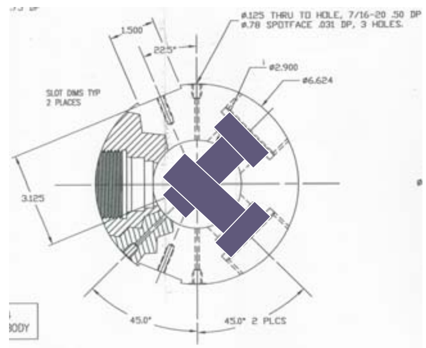


Blockage Options

- Annular Flow Area: 6.6 in^2
- Flow Impedance Area: 3.7 in^2
- Blockage Percent: 44 %



- Annular Flow Area: 6.6 in^2
- Flow Impedance Area: 5.7 in^2
- Blockage Percent: 87 %



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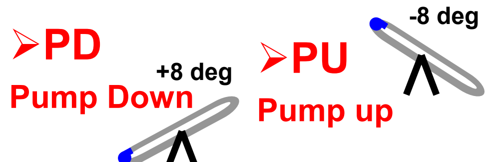
Test Procedure

- ❑ Hydrate Plug Formation
- ❑ Drain Free Liquids (tilt to PU and PD)
  - Density scans (porosity, plug length)
  - Record the Volume of the Drained Oil, Water and Gas
- ❑ Measure ΔP of the Plug (gas at PD)
  - Collect liquids from effective porosity
- ❑ Density Scans of the Plug (PU, 0 °, PD)
  - Porosity calculation
- ❑ Dissociation



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Test Parameters

- Formation of a REPLICABLE Solid Hydrate Plug
  - Replication Criteria: Permeability and porosity are within ± 20% difference for COMPACT/TIGHT plugs and LOOSE plugs
    - Compact/Tight Plugs: Low Φ and Low Permeability
    - Loose Plugs: High Φ and High Permeability

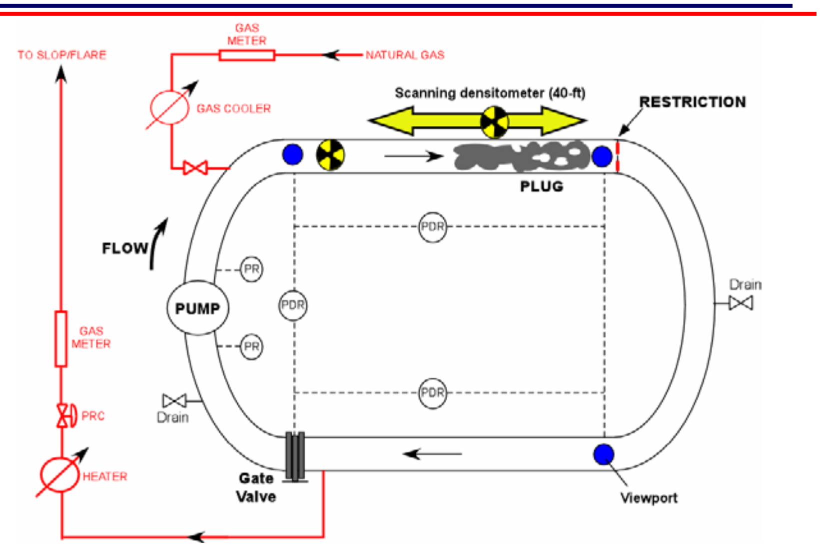
Testing Parameters

TEST CONSTANTS:		
Temperature:	40.0	°F
Pressure:	1500	psi
Fluid Velocity:	3.9	ft/s
TEST VARIABLES:		
Water Cut:	Low	High
Brine Water:	3.5%	12.0%
Viscosity:	Low	High
Shut-In:	4 Hours	3 Days
AA Effects:	Low Viscosity	High Viscosity

Testing Step Program

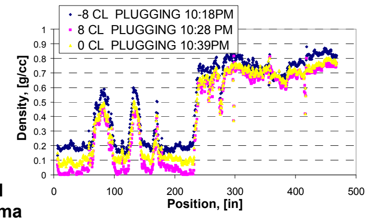
- Step 1:
  - Hydrate Plug Formation
- Step 2:
  - Plug Characterization
    - Permeability (*k*)
    - Porosity (Φ_{TRAP} & Φ_{EFF})
- Step 3:
  - Dissociation
    - Heat Treatment
    - Pressure Reduction
    - MEG

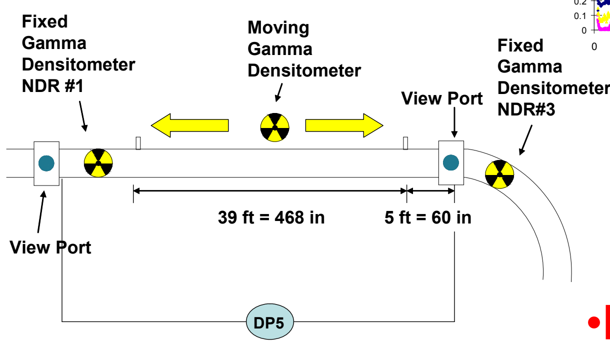
Permeability Scan PFD



Plug Characterization Example

- Estanga (2006)





$$k = v\mu \frac{dl}{dp}$$

- Darcy's Law

Plug Porosity Model

- Barrios (2007)

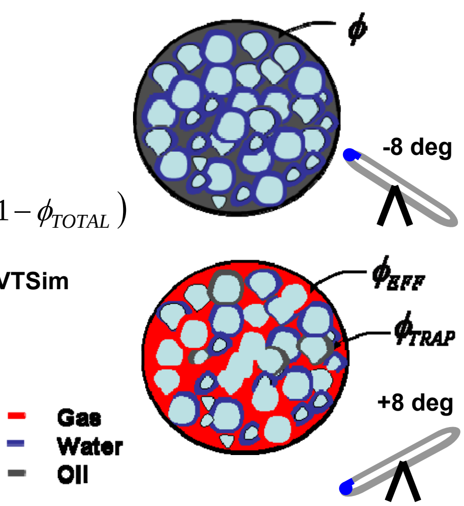
$$\phi = \frac{V_p}{V_{BULK}}$$

$$\rho_{BULK} = \rho_{MIX}\,\phi_{TOTAL} + \rho_{HYD}\left(1-\phi_{TOTAL}\right)$$

Moving Gamma → ρ_{BULK}; PVTSim → ρ_{HYD}

$$\phi_{TOTAL} = \frac{\rho_{BULK} - \rho_{HYD}}{\rho_{MIX} - \rho_{HYD}}$$

$$\phi_{TOTAL} = \phi_{EFF} + \phi_{TRAP}$$



Plug Characterization Example

(Barrios 2007)

Steady-State Test

- ❑ Pressure: **2000 psi**
- ❑ Temperature: **40 °F**
- ❑ Gas: **Tulsa NG**
- ❑ Fluids: **Conroe**
- ❑ Water Cut: **50%**
- ❑ Liq. Loading: **50%**
- ❑ Velocity: **3.9 ft/s**
- ❑ Inclination Angle: **0°**
- ❑ Cooling Rate: **5 °F/hr (6 hours)**

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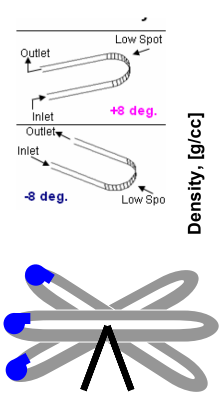
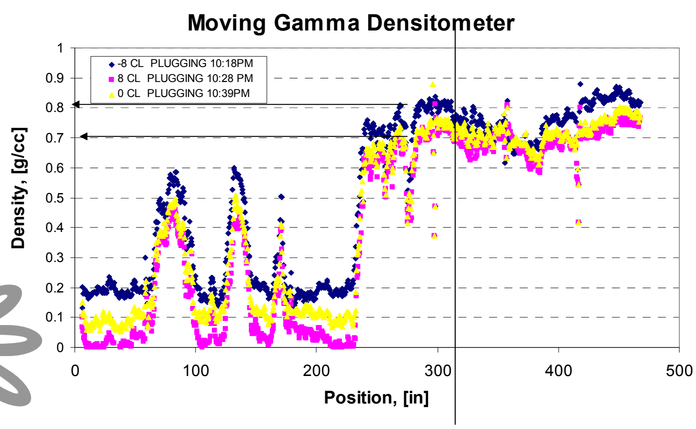
Plug Characterization Example

(Barrios 2007)

- ❑ Conroe-NG-Water (50% LL, 50% WC, 3.9 ft/s)





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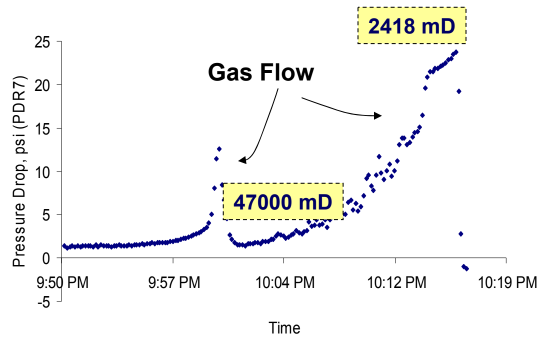
Plug Characterization Example

(Barrios 2007)

- Permeability
  - Conroe-NG-Water (50% LL, 50% WC, 3.9 ft/s)

$$k = v\mu \frac{dl}{dp}$$



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Plug Characterization Example

(Barrios 2007)

- Conroe-NG-Water (50% LL, 50% WC, 3.9 ft/s)
  - ✓ **- 8 deg**

$$\rho_{BULK} = \rho_{HYD}(1-\phi_{TOTAL}) + \rho_{MIX}\phi_{TOTAL}$$

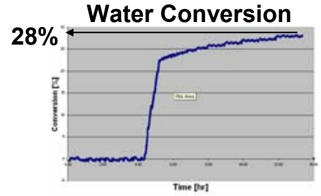
$$\rho_{BULK} = 0.8g/cc$$

$$\rho_{MIX} = 0.63g/cc \times 0.64 + 1.00g/cc \times 0.36$$

$$\rho_{MIX} = 0.77g/cc$$

$$\phi_{TOTAL} = 0.78 = \phi_{EFF} + \phi_{TRAP}$$

Water Conversion



$\rho_{OIL} = 0.63g/cc$ ➡ $\phi_{TOTAL} = 0.44 = \phi_{EFF} + \phi_{TRAP}$

$\rho_{MIX} = 1g/cc$ ➡ **Negative Values**

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Plug Characterization Example

(Barrios 2007)

- Conroe-NG-Water (50% LL, 50% WC, 3.9 ft/s)
  - ✓ **+ 8 deg**

$$\rho_{BULK} = \rho_{HYD}(1-\phi_{EFF} - \phi_{TRAP}) + \rho_{GAS}\phi_{EFF} + \rho_{MIX}\phi_{TRAP}$$

$$\rho_{BULK} = 0.71 g/cc$$

$$\rho_{G} = 0.12 g/cc$$

Mix=Oil + Water	Mix=Oil
$\phi_{TOTAL} = 0.78$	$\phi_{TOTAL} = 0.44$
$\rho_{MIX} = 0.77 g/cc$	$\rho_{OIL} = 0.63 g/cc$
$\phi_{EFF} = 0.14$	$\phi_{EFF} = 0.17$
$\phi_{TRAP} = 0.64$	$\phi_{TRAP} = 0.26$

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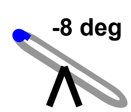
Dissociation Approaches

- Heat Treatment: Circulating warm glycol (70 °F) in the glycol jacket (at 0°).
- Pressure Reduction: Reduce the pressure on both ends of the hydrate plug (at 0°).
- MEG: Chemical injection system added to the south end of the loop (at PU).



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Heat Treatment Approach

- Open gate valve
- Start circulating 40°F glycol (for 30 min)
  - Take a scan
- Change glycol temperature to 70°F
  - Take a scan every 10 minutes
    - Until no additional gas release
- Drain and collect fluids

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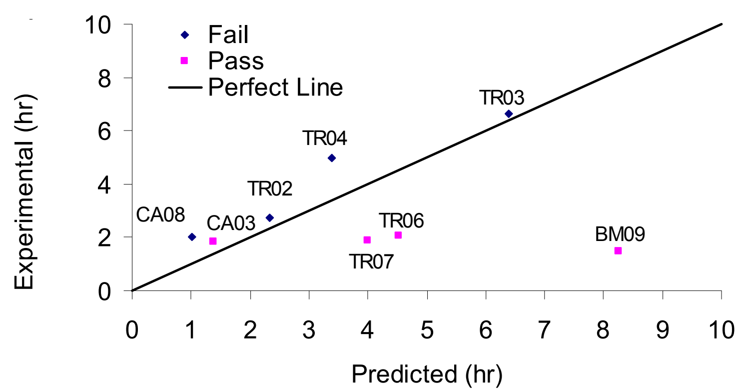
Heat Treatment Approach

•Dissociation Simulator (Ivanic 2006)



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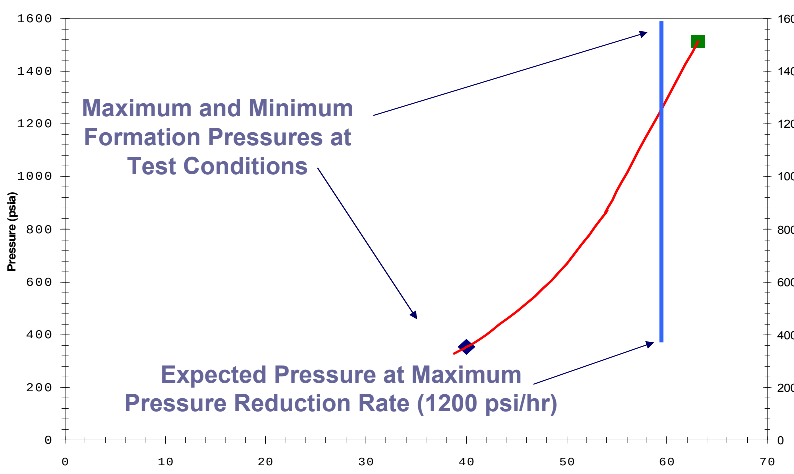
Pressure Reduction Approach

- Open gate valve
- Bleed pressure at both drainage points on the loop
  - Maximum Pressure Reduction Rate:
    - 1200 psi/hr (pump seal limitation)
      - Discussion Topic 1:
        - » Rate used in the field?
- Scan every 10 minutes
  - Until no additional gas release

Pressure Reduction Approach

Pressure Reduction P-T Diagram



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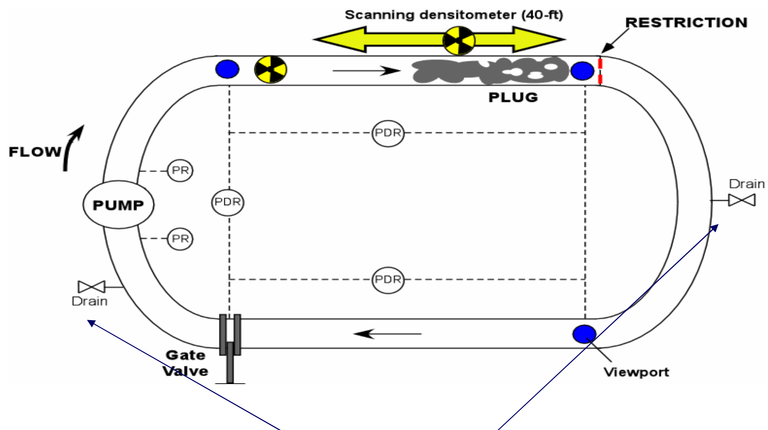
Pressure Reduction Approach



Drain and Bleed Pressure

MEG Treatment Approach

- Discussion Topic 2
  - Batch System
    - Pump in and let it sit on top of the plug
    - Scan every 10 min
  - Pump Through the Plug with Piston Pump
    - Pump at 6 gal/hr
    - Scan every 10 min
  - Simulated Coiled Tubing Entry
    - Install a Lubricator (Allow entry under pressure)
    - Scan every 10 min

MEG Treatment Approach

- Issues
  - Batch System
    - Dilution of MEG
    - Constant rocking/draining to ensure fresh supply
  - Pump Through the Plug with Piston Pump
    - Delivery rate
  - Simulated Coiled Tubing
    - Safety Concern
    - Cost not budgeted

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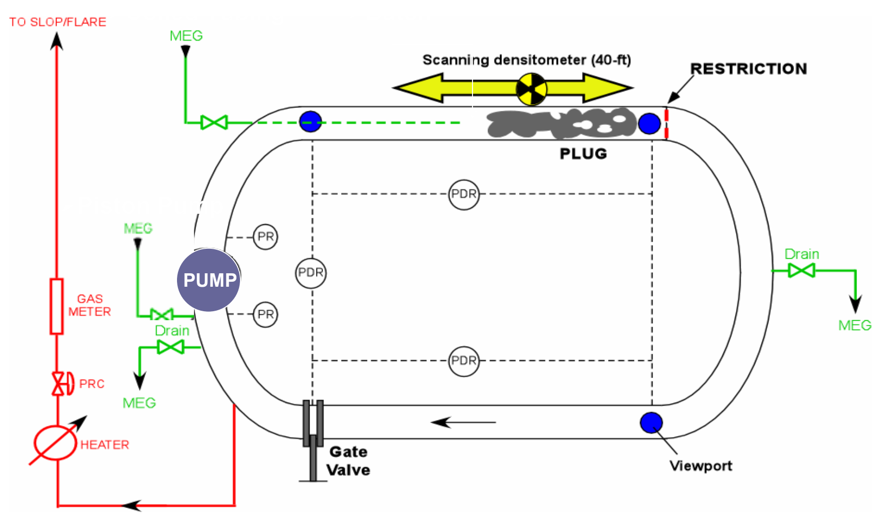
MEG Treatment Approach PFD



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Proposed Test Matrix

- Discussion Topic 3

City Gas & Water Only (2Φ System)				
COMMENTS:			Liquid Loading (Water Cut)	Dissociation Method
Base Case	Test	1	70.0 % (100 %)	Heat
Validation	Test	2	70.0 % (100 %)	Heat
Dissociation	Test	3	70.0 % (100 %)	Pressure Reduction
Dissociation	Test	4	70.0 % (100 %)	MEG
Water Cut Effects	Test	5	30.0 % (100 %)	Heat
Validation	Test	6	30.0 % (100 %)	MEG
Brine Effects	Test	7	70.0% (100%) 3.5% Brine	Heat
Validation	Test	8	70.0% (100%) 3.5% Brine	MEG
Dissociation	Test	9	70.0% (100%) 3.5% Brine	Pressure Reduction
Brine Effects	Test	10	70.0% (100%) 12.0% Brine	Heat
Validation	Test	11	70.0% (100%) 12.0% Brine	MEG
Shut-In Effects	Test	12	70.0 % (100%) 3 Days	Heat
Validation	Test	13	70.0 % (100%) 3 Days	MEG

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Proposed Testing Matrix

- **Discussion Topic 3**

City Gas, Oil & Water (3Φ System)				
COMMENTS:		Liquid Loading (Water Cut)	Oil	Dissociation Method
Base Case	Test 14	80.0 % (40.0 %)	Citgo 19	Heat
Validation	Test 15	80.0 % (40.0 %)	Citgo 19	Heat
Dissociation	Test 16	80.0 % (40.0 %)	Citgo 19	Pressure Reduction
Dissociation	Test 17	80.0 % (40.0 %)	Citgo 19	MEG
Water Cut Effects	Test 18	80.0 % (20.0 %)	Citgo 19	Heat
Validation	Test 19	80.0 % (20.0 %)	Citgo 19	MEG
Brine Effects	Test 20	80.0% (40.0%) 3.5% Brine	Citgo 19	Heat
Validation	Test 21	80.0% (40.0%) 3.5% Brine	Citgo 19	MEG
Dissociation	Test 22	80.0% (40.0%) 3.5% Brine	Citgo 19	Pressure Reduction
Brine Effects	Test 23	80.0% (40.0%) 12.0% Brine	Citgo 19	Heat
Validation	Test 24	80.0% (40.0%) 12.0% Brine	Citgo 19	MEG

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Proposed Testing Matrix

- Discussion Topic 3

City Gas, Oil & Water (3Φ System)				
COMMENTS:		Liquid Loading (Water Cut)	Oil	Dissociation Method
Viscosity Effects	Test 25	80.0 % (40.0 %)	Caratinga	Heat
Validation	Test 26	80.0 % (40.0 %)	Caratinga	MEG
Shut-In Effects	Test 27	80.0 % (40.0%) 3 Days	Citgo 19	Heat
Validation	Test 28	80.0 % (40.0%) 3 Days	Citgo 19	MEG
Shut-In Effects	Test 29	80.0 % (40.0%) 3 Days	Caratinga	Heat
Validation	Test 30	80.0 % (40.0%) 3 Days	Caratinga	MEG
AA Effects	Test 31	80.0 % (40.0%) 1.0 % AA	Citgo 19	Heat
Validation	Test 32	80.0 % (40.0%) 1.0 % AA	Citgo 19	MEG
Disassociation	Test 33	80.0 % (40.0%) 1.0 % AA	Citgo 19	Pressure Reduction
AA Effects	Test 34	80.0 % (40.0%) 1.0 % AA	Caratinga	Heat
Validation	Test 35	80.0 % (40.0%) 1.0 % AA	Caratinga	MEG
Disassociation	Test 36	80.0 % (40.0%) 1.0 % AA	Caratinga	Pressure Reduction

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Test Schedule

Task	Description	2008											2009				
		F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
Project Title: Hydrate Plug Characterization and Dissociation Strategies																	
1	Facility Modification	■	■	■													
2	Plug formation and characterization				6	6	6	3	4	3	3	3	3	3			
	Technology Development			■	■												
3	Evaluation of dissociation methods	■	■														
	Wall heating					■	■										
	Depressurization							■	■								
	MEG Injection									■	■						
4	Data analysis and processing							■	■	■	■	■	■				
	Comparision with Previous Disassociation Models													■	■		
	Thesis writing and defense											■	■	■	■	■	■

- 36 Total Tests

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Work Status

- Completed Work
  - Ordered parts for fluid loading and draining systems
- Current Work
  - Develop dissociation model
  - Select/Design MEG injection system
- Future Work
  - Modification of the flow loop
  - Plug characterization test
  - Plug dissociation test

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Discussion Points

- Depressurization Rate
- Suggested Test Matrix
- MEG Delivery System
  - MEG vs. Methanol

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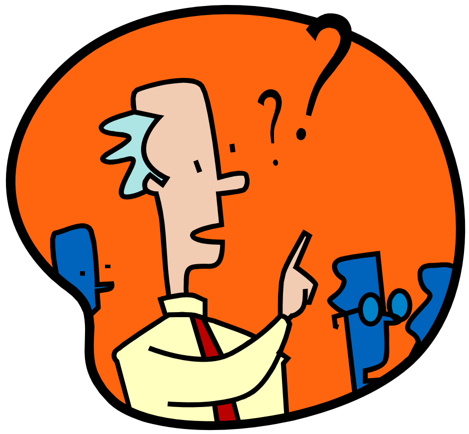
Questions and Suggestions



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Closing Remarks

Mike Volk

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HYDRATE FLOW PERFORMANCE JIP

THE UNIVERSITY OF TULSA RESEARCH PROGRAM

http://www.tuhfp.utulsa.edu

- Research
- Facilities
- Meetings
- Personnel

THE UNIVERSITY of TULSA

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Future Meetings

- DeepStar Meetings
  - March 6, 2008
  - June 5, 2008
- TUHFP Advisory Board Meeting
  - Held in Tulsa
  - September 16, 2008
  - 8:30 – 3:00 PM
  - Tour of Facilities

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Future project
Riser facility

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TUHFP Strengths

- ❑ Address hydrate flow assurance issues with multiple approaches
  - Bench top and large scale experiments
  - Macroscopic/microscopic aspects
  - Steady-state/transient/dissociation
  - Multiple fluids and conditions
  - Simulations of results – slurry flow modeling
- ❑ 180 flow loop experiments

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Riser facility

- Range of operating conditions limited with current flow loops
  - Short flow paths – pump or bends effects?
  - No vertical sections
    - No vertical slurry flow data
    - Segregation / settling effects on shut-in
  - Better facilities required
- Phase III Studies providing input for design

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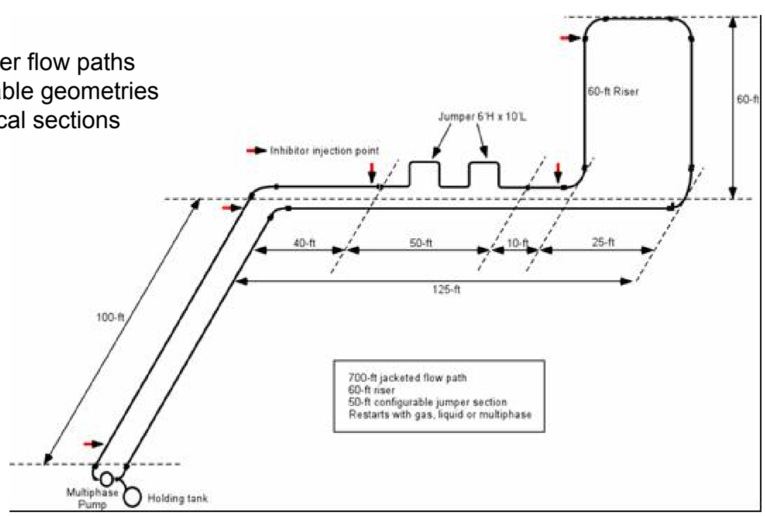
Riser facility

- Longer flow paths
- Variable geometries
- Vertical sections



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Riser facility

- Plan on submitting project for 2009 Ultra Deep water Call
- Project cost: $4.0M - 3 years

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Hope you Enjoyed the Show!