Gas Hydrate Testing under Flowing Conditions: Laboratory and Field Cases

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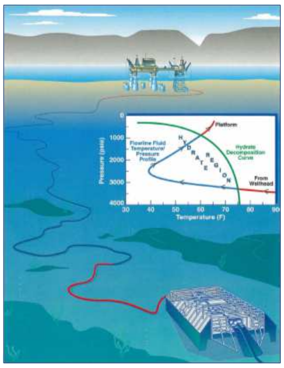
Overview

This presentation will focus on SwRI projects and some results from those studies.

- Why Study Hydrates?
- Field Study
- Flow Loop Tests
- Follow-On Industry Hydrate Projects
- Future Projects

Why Study Hydrates?

- Deepwater projects have generated questions related to hydrate physics for at least 20 years
  - Pipelines in cold environments since the 1930s
- How do operators design for and mitigate the risk of forming hydrate plugs?
- How do they verify their designs?
- How do they alleviate systems if they do form plugs?
- What kind/how much inhibitor is really required?



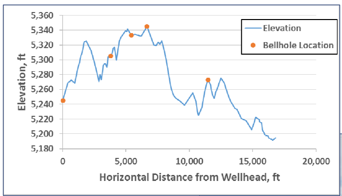
Answers to Hydrate Questions

- Replicating field conditions is challenging
- Field studies are complicated and expensive
  - Plugging a producing asset is not generally ideal
  - Sensing techniques are limited for underground or subsea assets
- Lab and flow loop tests
  - Difficult to determine how to scale the test
  - Autoclave or static tests (with associated agitation)
  - Benchtop/lab-scale flow loops (cyclopentane hydrates)
  - Field-scale flow loops (natural gas, water, oil)

Hydrate Field Study

- DeepStar funded a test in Wyoming to study hydrate blockages and remediation
  - Model verification for "safe" single-sided depressurization
  - Published in two OTC papers (8521 and 8728)
- Pipeline is a 900-psi, 4-inch, 3.3-mile liquid rich gas stream
- Wellhead temperatures above dissociation
- 7 ft/s nominal gas velocity yielded stratified and slug flow

Field Study Measurements



Five Bellhole locations measured pressure and temperature for the plug location

Bellhole 4 had dual gamma units

Field Study Results

- Formed plugs (shut off methanol)
- Plugs dissociated by depressurization
- Line was pigged to remove residual hydrate

Field Study Results

Test No	No. of Blockages	Max DP (psi)	Estimated Length (ft)	Max Velocity (ft/s)	Test Result and Comments
1	2 or more	174	--	--	Single-sided depressurization, permeable and impermeable plugs
2	1	80	--	--	Dual-sided depressurization, unsafe location
3	1	150	25	270	Single-sided depressurization
4	1	357	90 to 175	80	Single-sided depressurization, traveled about 1,200 feet

Hydrate Field Study Conclusions

- Successfully demonstrated that one-sided depressurizations can be performed safely
- Supporting computational simulations and knowledge of the plug location are critical
- Permeability determined by monitoring pressure
  - Directly related to dissociation physics

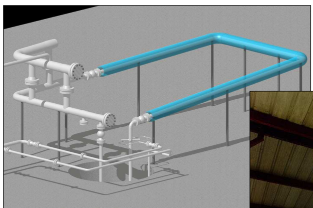
Hydrate Design Considerations

- The Wyoming field study demonstrated the need to better understand the formation and deposition process
- Leads to more questions to be answered:
  - How do you scale the geometry?
  - How long should the test section be?
  - How do you produce and transport these fragile particles?

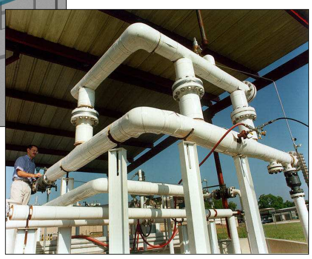
Hydrate Flow Loop Requirements

- An SwRI internal research project was conducted to study hydrate formation, agglomeration, and deposition
- Project goals:
  - Design a flow loop to "pump" hydrate slurry and free gas
  - Develop methods and instrumentation for quantifying deposition and slurry characteristics

Virtual-Long Flow Loop



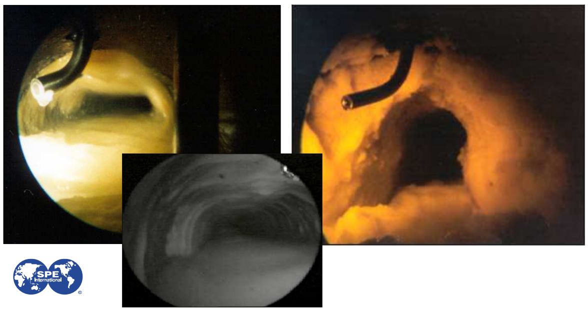
- 3-inch pipe
- 1,440 psig



- Natural gas and water
- Ports for visual access

Hydrate Deposition

Experiments suggest that blockages are a result of deposition



Hydrate Video Data

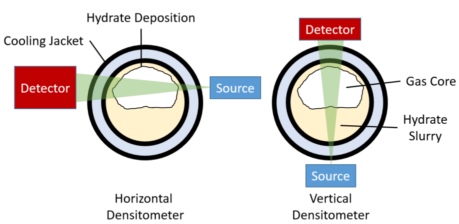
Stratified Flow

Slug Flow

Deposition Measurements

- Hydrate deposition measured with a gamma densitometer
  - Horizontal unit was offset from centerline
  - Vertical unit monitored liquid/slurry holdup

Deposition Measurement



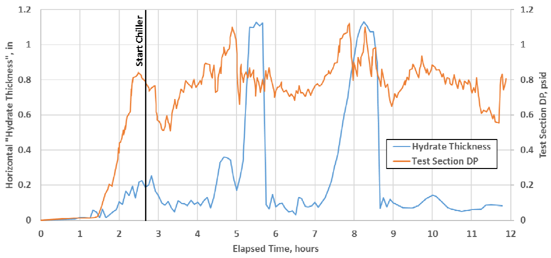
Hydrate Deposition

- Deposition rates between 0.2 in/hr and 1.9 in/hr
- Maximum deposition measured 1.1 inches

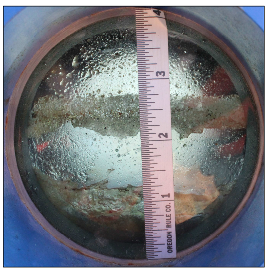
Test No.	Test pressure (psig)	Blockage Achieved?	Max DP Across Blockage (psid)	Max Deposition Measured (inch)	Max Deposition Rate (in/hr)
1	700	Yes	150	0.8	0.5
2	700	Yes	155	1.1	1.4
3	700	No	--	1.1	1.9
4	400	No	--	0.2	0.3
5	700	No	--	1.2	1.1
6	700	No	--	0.8	0.4
7	700	No	--	0.2	0.2
8	700	No	--	1.1	1.3

Hydrate Deposition

- DP data and deposition not necessarily correlated
  - Slurry viscosity
  - Liquid loading
  - Deposition



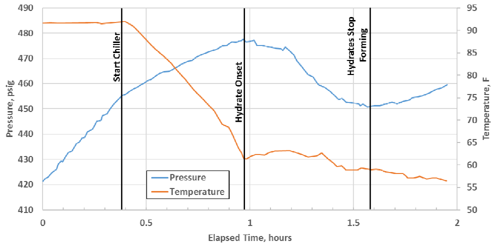
Hydrate Onset Monitoring



- Visual observations
- Pressure, temperature measurements
- Acoustic monitoring

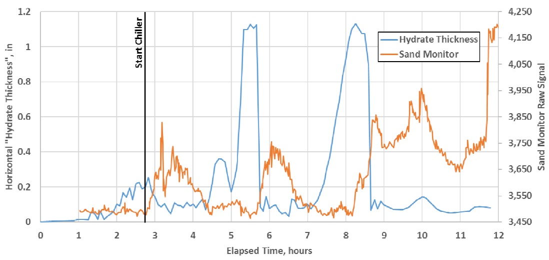
Hydrate Onset Monitoring

- Pressure and temperature measurements are useful for detecting onset
  - No information on transport
  - Plugging in ports



Hydrate Acoustic Monitoring

- Sand monitor signal strongly associated with solid particle impingement
  - Sand monitor signal out of phase with deposition

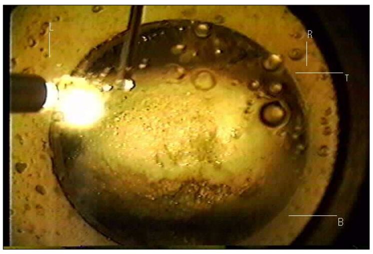


Flow Patterns Affect Deposition

- Flow loop testing indicated that slug flow will “knock-off” deposition leading to sloughing
- Deposition was highest during stratified flow with free gas
  - Likely opposite when oil is present

Flow Loop Hydrate Plug

- Sight window shows a solid hydrate cylinder that could become a projectile in a flow line
- Plug held 70 psid



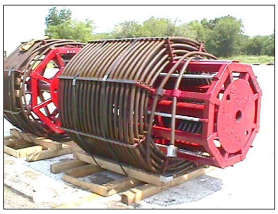
"Virtual-Long" Flow Loop Summary

- Gas lift was successful at driving flow to deposit hydrates, eventually resulting in plugging
- Acoustic monitoring can be used to detect onset of formation
- Hydrate deposition and deposition rates were measured
- Flow patterns affect deposition and eventual blockages
- Results suggest that blockages occur from deposition
  - Potential deposition "sloughing"

HYDRATE BLOCKAGE TESTS

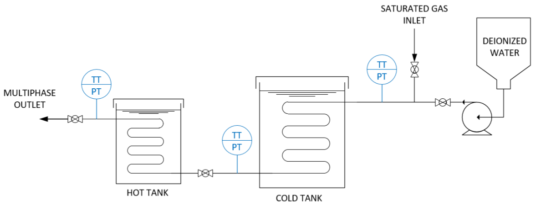
High-Pressure Hydrate Blockage "Single Pass" Flow Test

- The goal was to form and safely dissociate a hydrate blockage in a flow loop
  - Simulate a water-ingress scenario
  - Scaled flow rates to match field conditions of a 24" pipeline
- Documented in OTC Paper 14013
- Utilized coil tubing with hot and cold baths
- Pressures up to 200 bar (2,900 psi)



Hydrate Blockage Test Loop

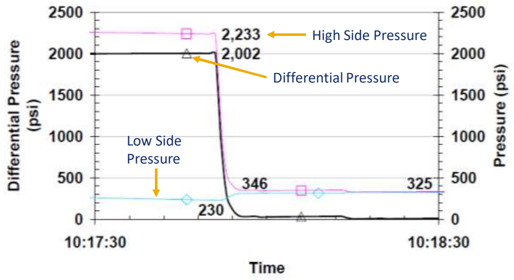
- Pressure measurements used to locate plugs
- External gas injection used to calculate permeability



Hydrate Blockage Test Summary

- Formed several plugs near the water injection location
- Plug pressure differential was 2,000 psi
- Plug permeability was very low
  - Years would be required to equalize the pressure
- Plug moved about 300 feet over about four seconds

Hydrate Blockage Pressure Profiles



Hydrate Blockage Flow Loop Test Conclusions

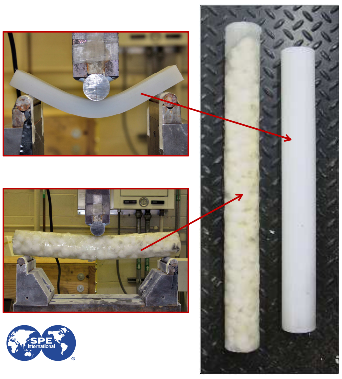
- The permeability was successfully calculated
- Single-sided depressurization was done safely
  - Supporting calculations and locating the plug
- Test likely had multiple plugs
  - Dual-sided depressurization may not be safe
  - Steps should be taken similar to single-sided depressurization

EXPERIMENTAL INVESTIGATION OF PLUG DYNAMICS

Simulated Hydrate Plug Tests

- Calculate the loads and dynamics associated with a hydrate plug traversing pipe bends
- Scale the geometry to a practical experiment
- Launch simulated plugs through a jumper test section
- The challenge was to determine what simulated hydrate material to use

Simulated Hydrate Plug Tests



- Two plug materials were selected
  - Ice containing cotton balls (experience from aviation industry)
  - Low-density polyethylene
- Mechanical properties were measured
  - LDPE had 4x strength versus ice+cotton balls

Simulated Hydrate Plug Tests

- 2-inch Sch. 10 pipe
- Plug was driven by compressed gas (1,900 psi) from 166 ft/s to 500 ft/s
- High-speed and conventional videos
- Strain and force sensors
- Displacement measured from video
- Calculated velocities

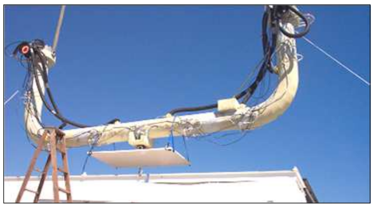
Simulated Hydrate Plug Test Results

- Pipe plastically deformed at the anchors
  - Elbows subjected to elastic stress only
- LDPE and ice results yielded similar displacements and strains
- Loads and displacements verified against simulations and models

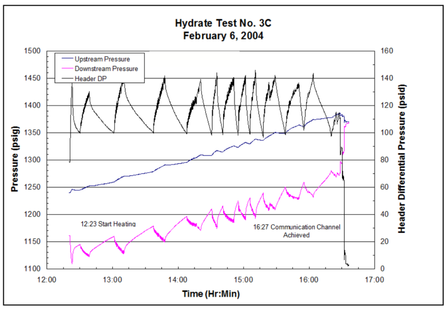
HYDRATE REMEDIATION BY EXTERNAL HEATING

Hydrate Dissociation by Heating

- Safely create a pressure communication path
- 10-inch full-scale model of a jumper
- Hydrate plug formed by "rocking" the pipe section



Hydrate Dissociation by Heating



HYDRATE TRANSPORT TESTS

Hydrate Transport Tests in Pipelines

- Flow through a bare pipeline in subsea conditions without plugging
  - Form a cold hydrate slurry prior to entering the cold section
  - Reduce the amount of free water prior to entering a cold pipeline
  - JT cooling through a choke and water injection upstream

Producing Hydrates for Storage in Vessels

- Investigate nozzles and injection techniques
- Measure the efficiency of hydrate production

HYDRATE MONITORING IN TEST FACILITIES

Use of Sensing Technologies for Field-Scale Applications

- Tomography (EM, Nuclear)
- Acoustic (Guided Wave and Ultrasonic)
- EM/Permittivity Measurements
- Nuclear Densitometers (Gamma, et al.)
- Spectroscopy (NMR, Microwave)
- Fiber-optic Sensing (DTS, DAS)
- Imaging Methods (FBRM, PVM)

Visual Monitoring Capabilities

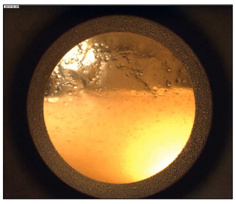
Borescope and Insertion Mechanism

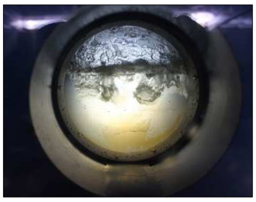
4-Inch Sight Glass

3-Inch Sight Glass

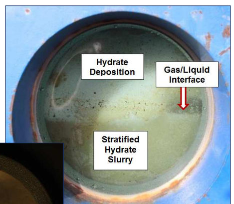
Viewing Hydrates in Bulk Flow

- 3-inch and 4-inch windows monitored the onset of hydrate formation, liquid levels, and the flow regime
- Gamma densitometer was also utilized



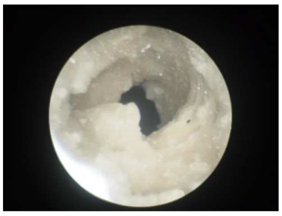


Viewing Hydrates in Bulk Flow



Radial View of Hydrates for Reference Measurements

- Borescope used to look inside the test section elbows
- Difficult to capture a flowing process



Hydrate Monitoring Video

FUTURE HYDRATE RESEARCH

Future Research Areas

- Gas-dominated restarts
  - Investigate methanol/LDHI dosing in jumpers
- Test advanced/novel sensors
  - Quantify hydrate thickness beyond a few millimeters
  - Real-time tomography solutions for hydrate monitoring

QUESTIONS?

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