Process safety of hydrate deposition in orifices during a blowdown of line plugged with hydrate

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SPE Flow Assurance Technical Section

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Outline

Hydrate blockage remediation
Hydrate blockage locations
Example: Teapot oilfield site
Cooling to form hydrate
Hydrate transport model result
Field result
Repeat ஃphase flow model preparation and result
Process safety – depressurization time
Flow shear stress research
Hydrate inhibitor chemical testing with consistent shear
Hydrate blockage restriction
Summary

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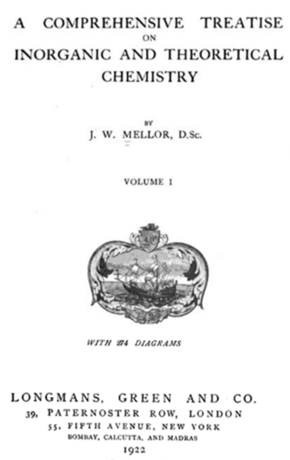
Foreword on hydrate crystals

In crystals, we see one of the many ways of judging the internal world of molecules and atoms, and one of the weapons for conquering the invisible world of molecular mechanics which forms the main object of physical chemistry.—D. I. Mendeléeff.



A COMPREHENSIVE TREATISE ON INORGANIC AND THEORETICAL CHEMISTRY

BY J. W. MELLOR, D.Sc.

VOLUME I

WITH 274 DIAGRAMS

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39, PATERNOSTER ROW, LONDON
55, FIFTH AVENUE, NEW YORK
BOMBAY, CALCUTTA, AND MADRAS
1922
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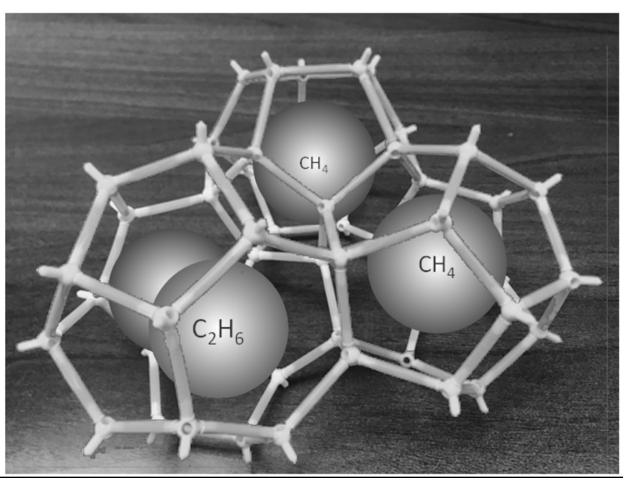

why:
Plugs

Resource
1cf=160scf

more heat
Climate
more gas
from hydrate

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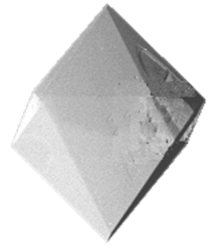
Hydrate blockages

Remediation: majority by **blowdown**



Hydrate collected in scraper receiver on a workover floating platform after a blowdown of gas well flowline, plugged at startup due seawater influx ca.1992, Petrobras
https://engenhariaquimica.files.wordpress.com/2010/04/apostila-ppp.pdf

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Hydrate blockage Locations

Operator seldom cares when did the plug form, but they want to know Where is the plug.

Yuri Makogon in his 1966 book showed locations of hydrate accumulation observed at the Shebelinskoye gas field in the Ukraine (the largest in Europe at the time):

1) at chokes,
2) separator inlet lines
3) separators
4) metering orifices
5) gathering lines near orifices and near line branch connections
6) gas trunk flowline at locations of a sudden change of gas velocity
7) at line endpoint valves

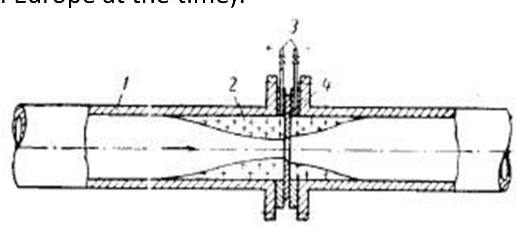

Рис. 26. Схема накопления гидратов на замерной диафрагме.
1 — газопровод; 2 — гидраты; 3 — импульсные трубки; 4 — диафрагма.

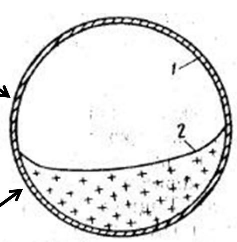

Рис. 27. Схема заполнения гидратами горизонтальной трубы.
1 — газопровод; 2 — гидраты.

A dense spiral-shaped hydrate blockage of approx. 5 m length was observed with a sample cross-section shown here

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Example of Hydrate plug blowdown: onshore field

Hydrate slush collected in pipeline after a blowdown from a plug 2-sided depressurization

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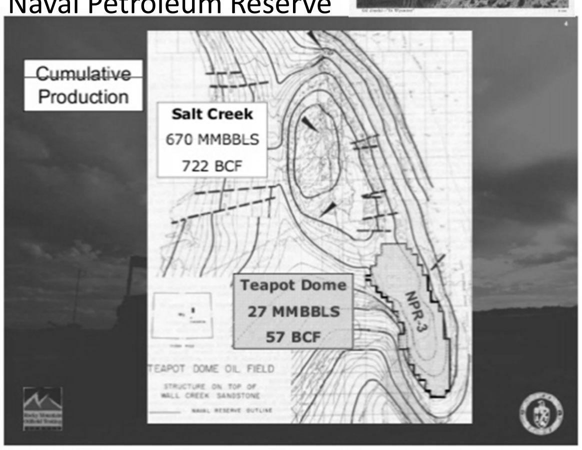
Plug formation at NPR-3

Securing energy for the country

Naval Petroleum Reserve



http://wyoarchives.state.wy.us/Archives/Photo.aspx

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This is not Tatooine

NPR-3 offers topography and temperature regimes similar to deep water sea floor

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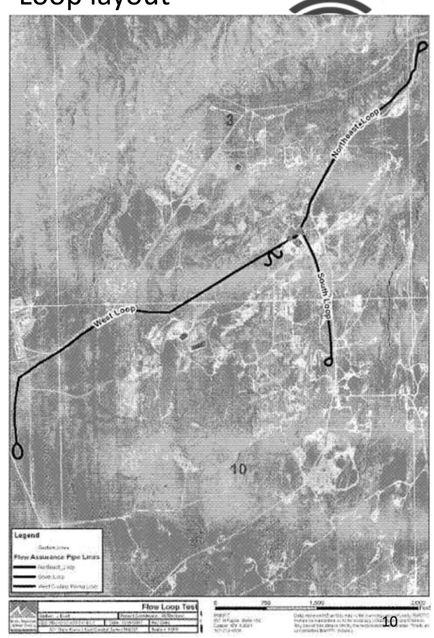
Using natural cooling

Typical winter, not during the test.

Loop layout



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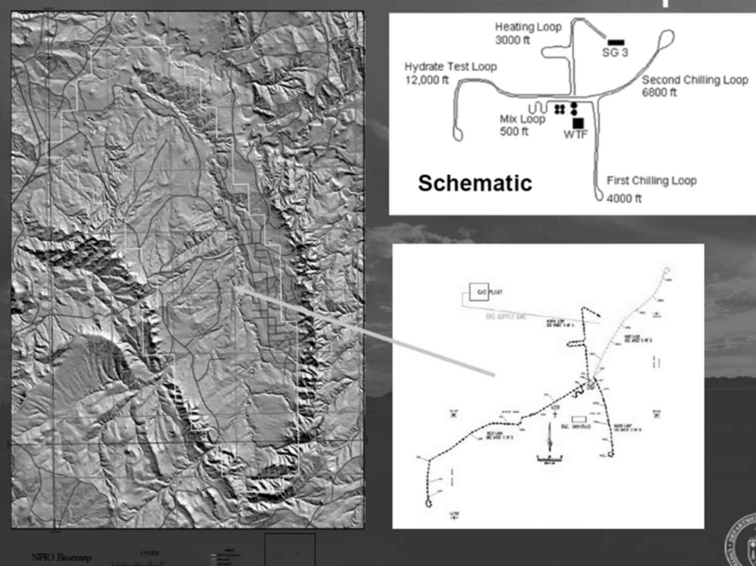
DOE public domain info

Flow Assurance Test Loop



An overview of tests at RMOTC www.rmotc.doe.gov/PDFs/TechPres_TechTested8.pdf
A full-scale facility for flow assurance testing www.rmotc.doe.gov/PDFs/flow_loop.pdf

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Concentric Pipe Jacketed Section

6 inch, 3600 psi rated, inside of 10 inch, to enable heating and cooling fluid circulation; 190° F produced water available

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6 inch pipe

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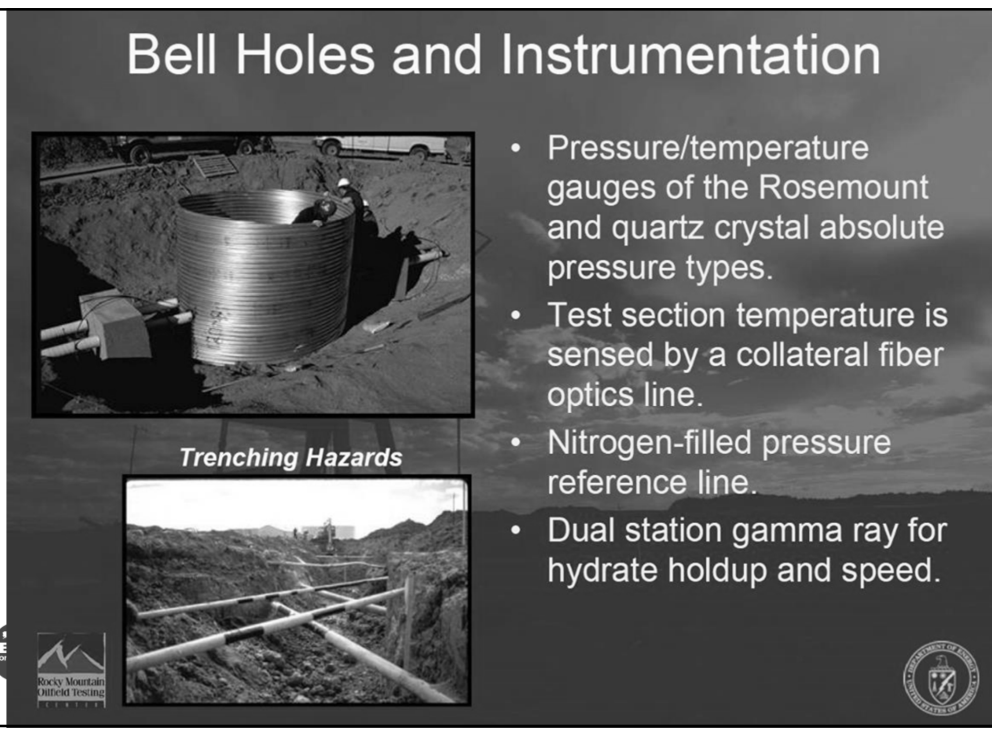

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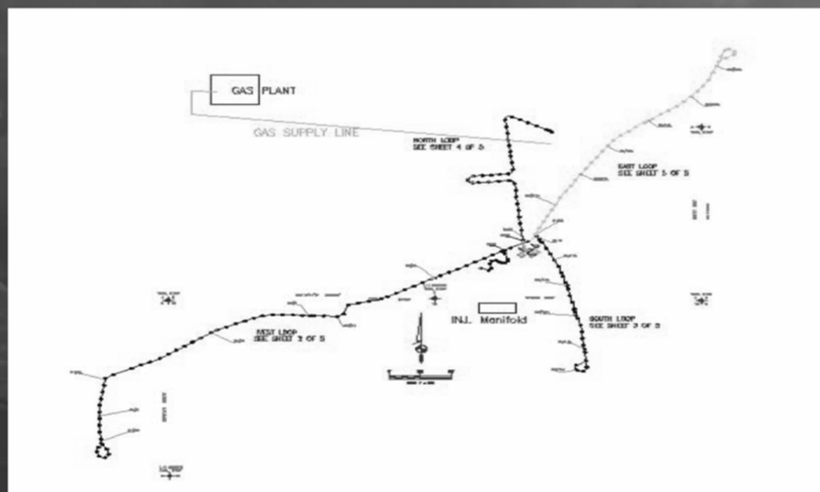
Setup for Generating Hydrate Plug



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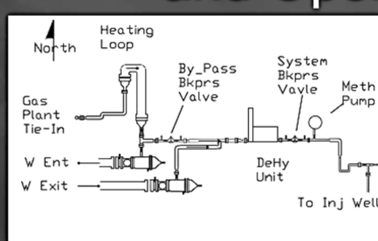
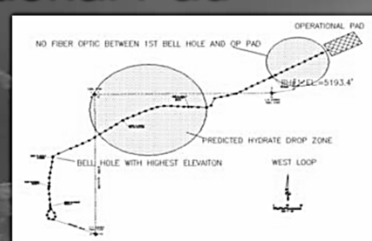
Gas Supply, Dehydrator, and Operational Pad





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Success!

Subsequent mitigation tests conducted with a major oil company (still confidential) were also successful at proving their clean-out technology.

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phase Model setup: Distance & Elevation profile

Distance Measurement Tool https://maps.google.com/maps
Elevation measurement tool http://www.freemaptools.com/elevation-finder.htm

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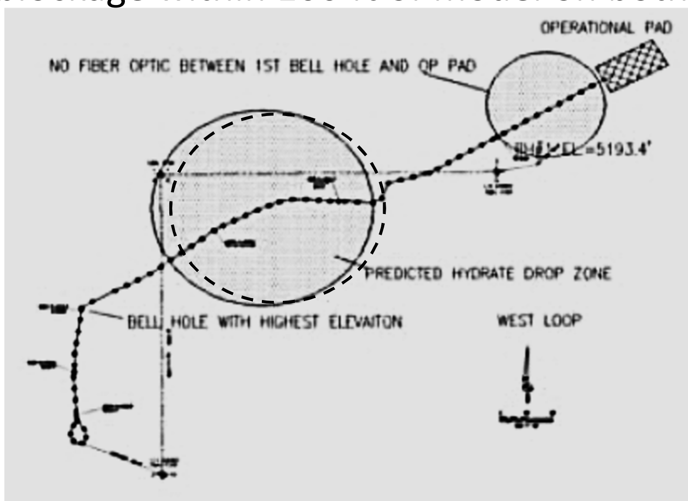
Model prediction was matched by field data

Actual solid blockage within 100 ft of model on both ends



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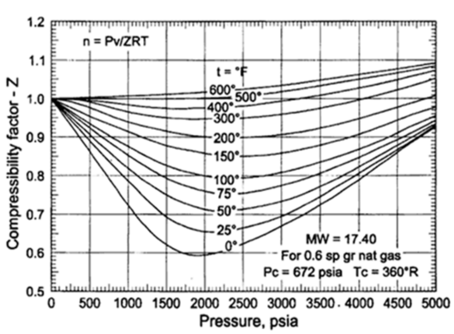
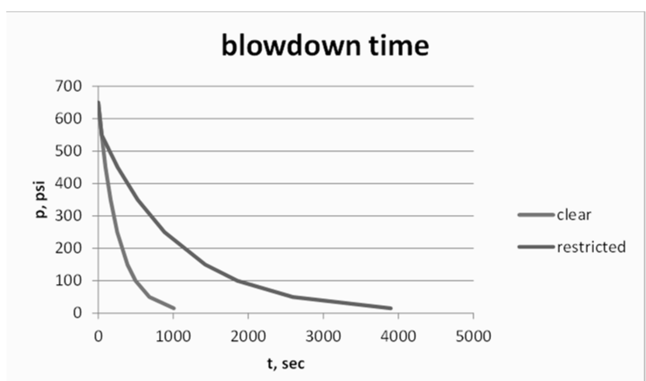
Main interest is Line depressurization

- Hydrate can deposit in orifices
- This affects time to blowdown

$$t\ (\text{sec}) \simeq \frac{5.5\ V}{A}\left(\ell n\ \frac{Pa}{Patm}\right)\sqrt{\frac{SG}{ZTa}}$$





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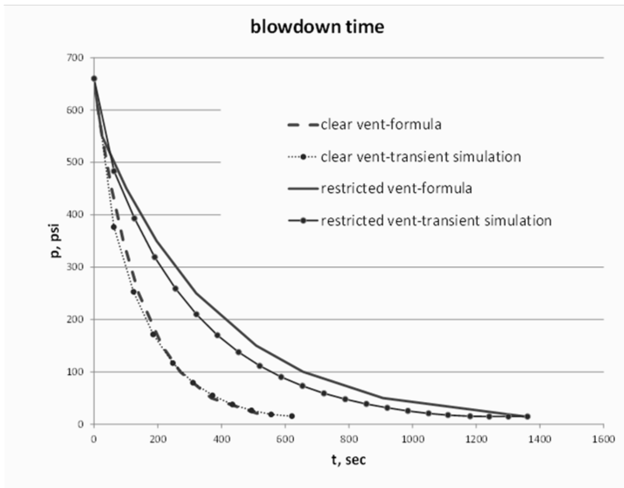
Blowdown formula matched transient simulation



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Flow velocity, deposition & shear

- Flow velocity in <u>gas system</u> reached at least an estimated 74 ft/s

time of flight	4 sec
time up t	2 sec
acceleration a	9.8 m/s^2
vertical velocity = a t	20 m/s
vertical distance = v t	39 m
angle from horizontal	60 deg
sine of angle	0.87
velocity	22.6 m/s
	74 ft/s

Shear of gas at 74 ft/s is **78 Pa**

τ_{w}_tur [Pa] = 0.5 f dens[kg/m^3] V^2 [m^2/s^2]
= $0.5*0.009*34.6*22.7^2=78$

- Shear should be a common parameter reported by researchers in hydrate deposition

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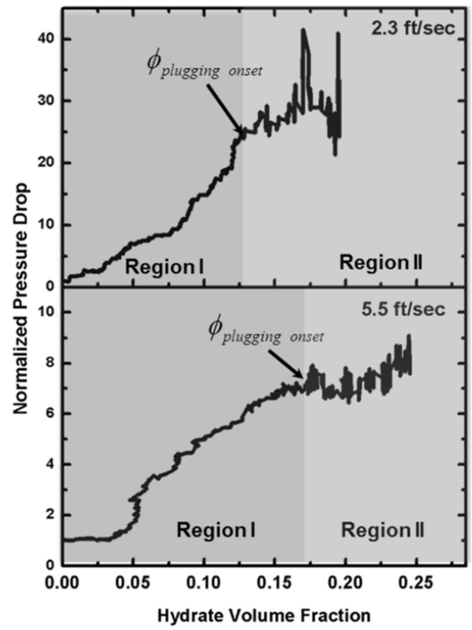
Plugging onset

- Vijayamohan (CSM) data for <u>liquid system</u> at 1-2 m/s:

  Effect of mixture velocity (2.3 and 5.5 ft/sec) on transportability of hydrates (experimental conditions: 80% WC, 90% LL, 1500 psia, 3.5 wt.% salt, Mineral Oil 350T), 2015 dissertation

- I estimate shear of water at 5.5 ft/s was **24 Pa**



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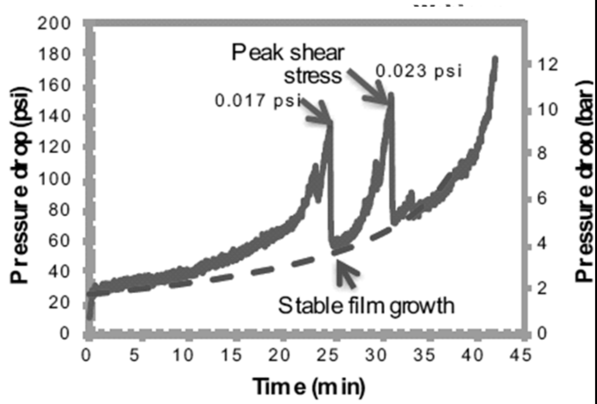
Plugging onset

- Di Lorenzo and Charlton (UWA) data for <u>Gas system</u>:

  Effect of gas velocity on deposition of hydrates 2015 workshop

- Peak shear of gas (sloughing) is 158 Pa
- Flow shear of gas (growth) is ~1/2 = **79 Pa**



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Shear is also relevant to LDHI

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- We presume shear affects performance in two ways:

1. it breaks up water droplets into size of few microns (see size estimate in Autoclave section)
2. it keeps hydrate agglomerates dispersed (shear-degraded).
   Hence shear stress should be consistent across test methods.

Pipeline

Input	D	8	inch
	u	1	cP
	Q	18000	BPD
	dens	1000	kg/m3
Unit Conversion			
	D	0.2032	m
	u	0.001	Pa•s
	Q	0.033122	m3/s
	Flow velo	1.021373	m/s
Calculation			
	τ_{w_lam}	0.040	Pa
	τ_{w_turb}	7.7	Pa
	Re	207648	
	f	0.014803	

Flowloop

Input	D	0.5	inch
	u	1	cP
	Q	1.4	GPM
	dens	1000	kg/m3
Unit Conversion			
	D	0.0127	m
	u	0.001	Pa•s
	Q	8.83E-05	m3/s
	Flow velo	0.697257	m/s
Calculation			
	τ_{w_lam}	0.439	Pa
	τ_{w_turb}	7.9	Pa
	Re	8860	
	f	0.032571	

Flowwheel

Input	D	2	inch
	wheel dia	2	m
	u	1	cP
	RPM	8	rev/min
	dens	1000	kg/m3
Unit Conversion			
	D	0.0508	m
	u	0.001	Pa•s
	Q_eff	0.001698	m3/s
	Flow velo	0.837757	m/s
Calculation			
	τ_{w_lam}	0.132	Pa
	τ_{w_turb}	7.7	Pa
	Re	42580	
	f	0.021998	

Rocking Cell

Input	D_tube	0.5	inch
	D_ball	0.45	inch
	u	1	cP
	V_liq	15	mL
	Oscil.peri	2	sec
	dens	1000	kg/m3
Unit Conversion			
	V	0.000015	m3
	Q	0.000015	m3/s
	D_tube	0.0127	m
	D_ball	0.01143	m
	A_annulu	2.407E-05	m²
	Flow velo	0.623219	m/s
	u	0.001	Pa•s
	D_eff	0.005536	m
Calculation			
	τ_{w_lam}	0.901	Pa
	τ_{w_turb}	8.0	Pa
	Re	3450	
	f	0.041232	

Autoclave

Input	V_liq	150	cm3
	Motor cur	1	A
	Motor Vol	110	V
	dens	1000	kg/m3
	u	1	cP
	D	2	inch
	D_impelle	1.8	inch
	RPM	300	rev/mi
Unit Conversion			
	Vel.impel	0.718167	m/s
	V_liq	0.00015	m3
	Power	110	W
	u	0.001	Pa•s
	D	0.0508	m
	D_impelle	0.04572	m
Calculation			
	kinem vis	0.000001	m²/s
	dissip.ene	733.3333	m²/s3
	turb.micro	6.08E-06	m
	τ_{w_lam}	0.113	Pa
	τ_{w_turb}	6.1	Pa
	Re	32835	
	f	0.023475	

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Blowdown to zero

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- Hear the hydrate
- Several waves

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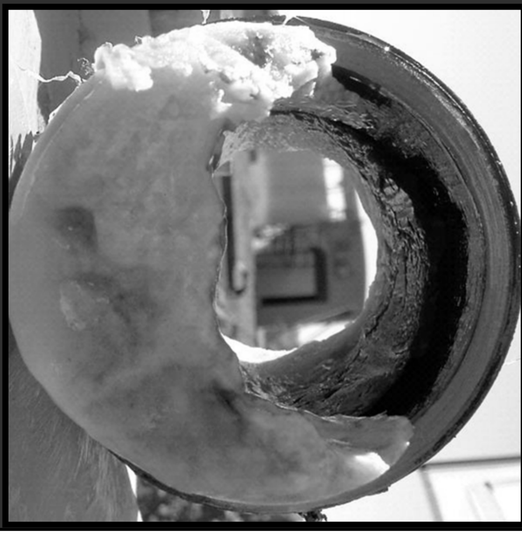
Orifice deposit

- Hydrate reduced vent area approximately by half

Stereo image of deposit



Stereo image of deposit

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Orifice deposit

- Hydrate reduced vent area approximately by half

Stereo image of deposit

Stereo image of deposit

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Summary

- Hydrate plugged the pipeline with gas flow through water at elevated pressure, low ambient temperature, treated with a hydrate promoter and spiked with propane.
- Predictive methods can accurately show where the dominant blockage formed.
- Hydrate deposited in vent orifice during blowdown from 660 to 12 psia.
- Blowdown time formula matched state-of-the-art phase transient simulation.
- Flow velocity reached 74 ft/s, wall shear reached 78 Pa.
- Shear should be a common parameter reported by researchers in hydrate deposition. Paper proposes a common method to report shear.
- Hydrate deposited at that flow velocity reduced orifice area approximately by half.