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GTC Trondheim 2-3 November 2011
Evert van Bokhorst

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Impact of boiling liquid on fluid-vapor-wall interaction in LNG transfer systems

FLUVAWINT: A project of TNO, Delft University, Bluewater and Gutteling -

Evert van Bokhorst
Project Manager – Fluid and Structural Dynamics


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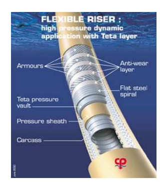
TNO – Independent contract R&D and Consultancy organization (4300 staff – 7 Themes)

Theme Energy: Fluid & Structural Dynamics

- Exploration and production optimisation
- Integrity of gas transport and storage
- Flow-induced pulsations in flexible risers
- Pulsation and vibration analysis on process installations



Partner for LNG Development:

- Cryogenic material behaviour
- Fluid/structural dynamics in transfer systems and process equipment
- Measuring and modelling of heat transfer and boil-off
- Assessing and modelling ship structural integrity
- Industrial and external safety

STATOIL · GUTTELING BV composite hoses · bluewater Power by People · SBM OFFSHORE · Shell

Floating LNG requires qualification of components and systems used in LNG transfer

- Offshore FLNG configurations in STS transfer:
  - Side-by-Side
  - Tandem Aerial
  - Tandem Floating

Production > **liquefaction** > **loading** > **shipping** > **offloading** > **storage** > **regasification**

Qualification program according EN1474:

EN1474-1: Design and testing of transfer arms

E**N1474-2: Design and testing of transfer hoses**

EN1474-3: Offshore transfer systems

Technical challenges in risked-based qualification according EN1474-2 is not a simple check list-:

- EN-1474-2 specifies only the baseline of qualification
- Complex mechanical behaviour of the multi composite hose
- Unknown material properties under cryogenic conditions
- Pressure losses in corrugated hoses
- Impact of possible two-phase flow (LNG + boil-off gas)
- Unknown external loads during transfer
- Definition of allowable levels: vibration, pressure loss, hose permeability

"Not only the test methods need to be developed, but rules need to be interpreted and requirements have to be detailed".

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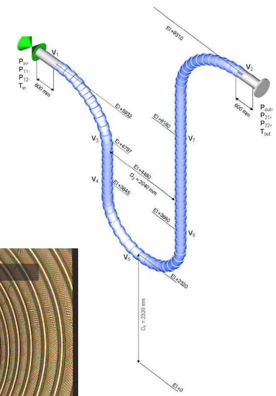
Part of the qualification for Gutteling hose: Ambient and Cryogenic LNG Flow Test in straight and STS configuration

- Inlet-, Outlet pressure
- Pressure loss across the hose
- Pulsations at inlet and outlet
- LNG Temperature at inlet and outlet
- Vibrations along the hose
- Temperatures along the hose
- Modal analysis: natural frequencies, mode shapes
- Methane gas permeability



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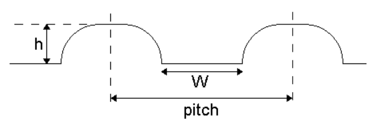
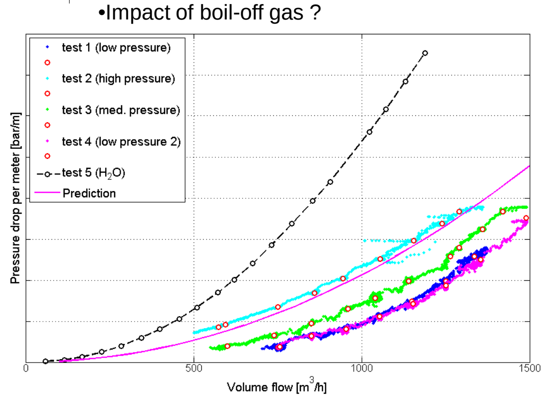
LNG Flow test shows a considerable variation of pressure loss with the inlet pressure of the hose:

- impact of hose elongation
- impact of profile and roughness
- vortex shedding
- Impact of boil-off gas ?





Cryogenic Flow Test

Inlet pressure:

High 9.0 Bar

Medium 6.0 Bar

Low 2.7 Bar

ID = 8”
L = 15.0 m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Lessons learned:

- Close cooperation of supplier, certifying authority, possibly the end user and the independent research contractor is recommended because of the non-prescriptive character of the EN1474-2;
- Specification of the requirements and allowable levels is needed: vibrations, pressure loss, permeability;
- Combine testing with modelling to reduce amount of testing;
- Flow tests should be carried out with LNG **over the complete operating envelope** regarding flow rates and pressure range involved in the actual operation;
- Further fundamental investigation of flow phenomena is recommended to understand impact of internal pressure and boil-off gas on pressure loss and friction coefficient of the hoses;


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FLUVAWINT: Impact of boiling liquid on FLUid-VApor-Wall INTeraction in LNG transfer systems:

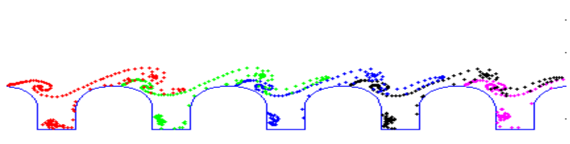
- MIP project 4 years
- Approved July 2010, started January 2011
- Participants:
  - **TNO** project manager: project co-ordination, progress reports to AgentschapNL, knowledge from qualification/experimental work LNG hoses, vortex shedding in corrugated piping (gas risers), test facilities
  - **Delft University** - Aero and Hydrodynamics -Prof. Westerweel -PhD students: experimental and numerical work, modeling
  - **Gutteling**: supply of samples, knowledge of product and materials, valorisation , economic perspective
  - **Bluewater**: knowledge of applications/configurations, valorisation, economic perspective

Objectives :

- To gain a better understanding of fluid-vapor-wall interaction of a liquid in near boiling conditions
- To develop a prediction model for impact of boil-off gas on pressure loss in multi-composite hoses and others
- To predict and avoid cavitation (implosion of gas bubbles) by appropriate models

Fundamental questions are:

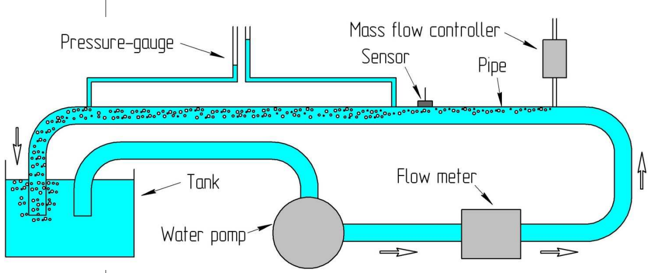
- When do vapour bubbles occur and at which location in corrugated hose or pipe ?
- What is the impact of internal corrugation and wall roughness on vapour bubble occurrence ?
- What are the physical properties of vapour bubbles, like size, distribution and deformability depending on local flow conditions ?
- What is the impact of vapour bubbles on flow resistance ?
- What are the local flow conditions to stimulate bubble formation ?

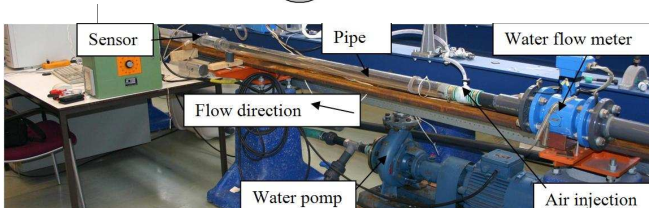


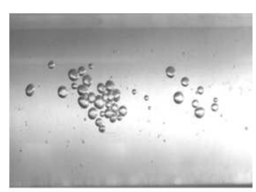
Project combines numerical and experimental investigation:

- Observing gas bubbles in wall turbulence (experience obtained from drag reduction experiments for ships and multiphase flow in pipes)
- Effect of gas bubbles on flow in smooth and corrugated pipes
- Onset of boiling in flow under depressurized conditions
- Flow visualisation studies in transparent pipes with inner corrugations similar to LNG hoses
- Results available as function of:
  - operating conditions (flow, pressure, temperature, LNG comp.)
  - hose/pipe geometry (inner diameter, spiral wire diameter, roughness, pitch)
  - physical properties of gas bubbles (size, distribution, deformation)

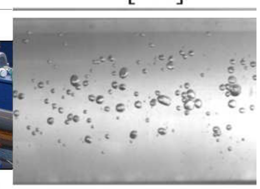
Test loop in a pilot study TUD:







V=1 [m/s]



V=1.5 [m/s]

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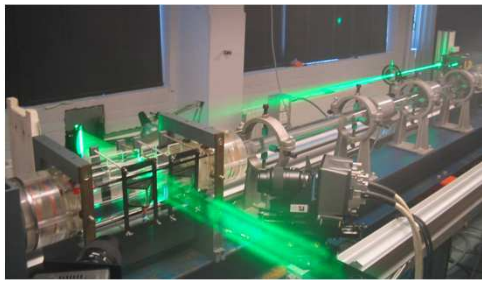
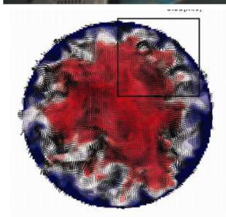
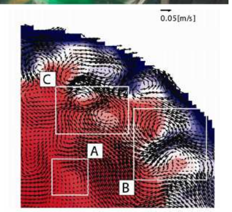
High speed stereoscopic PIV system at test section to visualize flow structures





Instantaneous flow field at Re_b=20,000
(only every second vector is displayed)



Close-up of the highlighted flow field
(every vector displayed)

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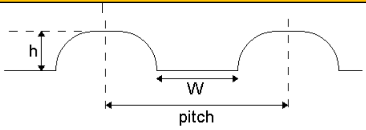
State of the art: friction factor versus Reynolds number for corrugated piping/hoses based on models:

Impact of hose profile/surface roughness



1. Nikuradse:

$$\lambda = 1/\left(2\log\left(ID_m/h\right)+1.14\right)^2$$

2. Moody:

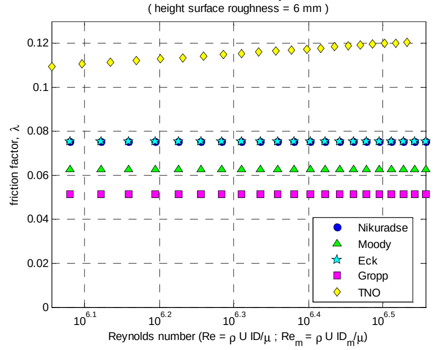
$$\lambda = 0.0055 + 0.15\left(h/ID_m\right)^{(1/3)}$$

3. Eck:

$$\lambda = 0.25/\left(\log\left(3.71\cdot ID_m/h\right)\right)^2$$

4. Gropp:

$$\lambda = 0.25/\left(\log\left(f_p\sqrt{ID_m\cdot pitch/h\cdot W}\right)\right)^2$$



5. TNO:

$$\lambda = p_1\cdot\log(RE) - p_2$$

$$p_1 = F(f) \text{ and } p_2 = F(f, alfa, beta)$$

$$f,\ alfa,\ beta = F(geometry)$$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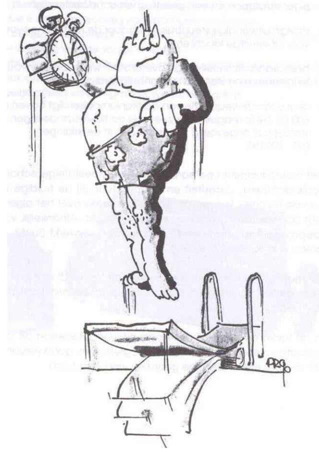
Thanks for your attention
Questions?



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