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European Metrology Research Programme
▶ Programme of EURAMET
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

LNG METROLOGY

LNG Flowrate Measurement Using Laser Doppler Velocimetry (LDV)

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CESAME- EXADEBIT

Acknowledgement

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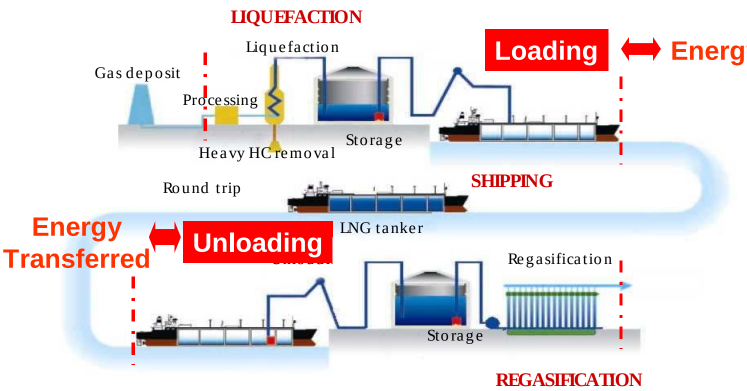
LNG SUPPLY CHAIN

LNG METROLOGY

LNG tankers capacity varies between 95 000 m^3 and 160 000 m^3



LNG Storage Tank 120 000 m^3

LNG ENERGY SALES

Energy Transferred from the loading facilities to the LNG carrier or from the carrier to the unloading facilities

$$E = V_{LNG} \times D_{LNG} \times GCV_{LNG} - E_{gas\ displaced}$$

- Volume of LNG loaded or unloaded
- Density of LNG loaded or unloaded
- Gross calorific Value of LNG loaded or unloaded

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LNG ENERGY SALES

Energy Transferred from the loading facilities to the LNG carrier or from the carrier to the unloading facilities

$U[E_{LNG};k=2]=0.76$

GIIGNL LNG Custody Transfert Handbook 3rd Edition

$$E = V_{LNG} \times D_{LNG} \times GCV_{LNG} - E_{gas\ displaced}$$

Volume of LNG loaded or unloaded

- Level Gauging & Calibration Table
  (level gauges, calibration tables, correction tables, temperature probes distributed in the LNG tanks)

$U[V_{LNG};k=2]=0.21$

- In line flow measurement of LNG
  - Coriolis Flowmeter
  - Differential pressure Flowmeter
  - Ultrasonic Flowmeter

Lack of large scale calibration facilities for LNG

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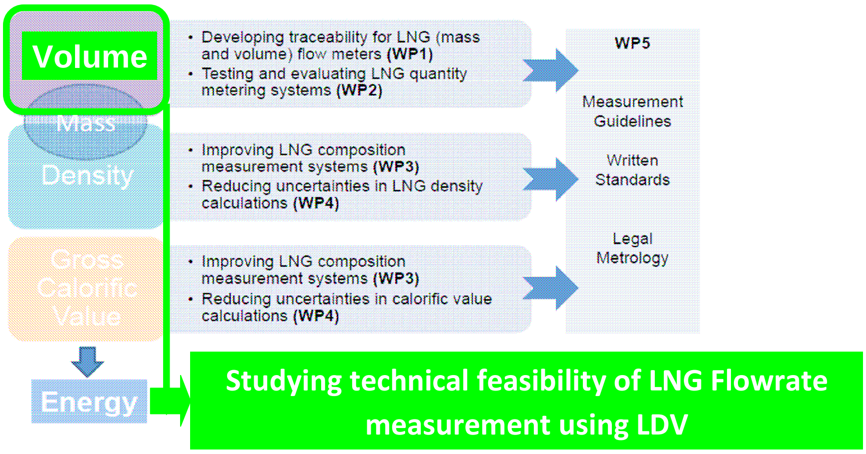
JRP METROLOGY FOR LNG [2010-2013]
Project aims and objectives

contribute to a significant reduction of uncertainty in the determination of transferred energy in LNG custody transfer processes

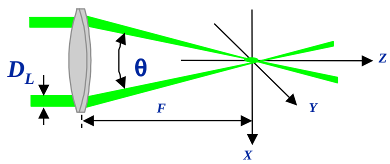


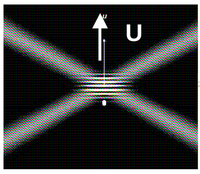
OUTLINE

- Introduction
- Technical feasability
- Experimental Means
- Results & discussion
- Conclusion & perspectives

Principle of the volume flow rate measurement with a LDV

Laser wavelength λ_0





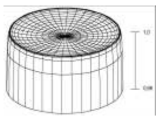
Δi interfringe

Measurement volume

Doppler Frequency f_D

$$\Delta i = \frac{\lambda_0}{2 \cdot \sin\left(\frac{\theta}{2}\right)}$$

$$U = \Delta i \cdot f_D$$



$$Q_v = 2\pi \int_0^R U(r)\,r\,dr$$

The volume flow rate measurement Qv based upon the measurement of velocity profiles at a nozzle exit plane is directly traced back to SI units of Length and Time

Studying technical feasibility of LNG Flowrate measurement using LDV

The flowrate measurements using a LDV technique is not new

PTB (Germany) developped an Optical Primary National standard based on LDV measurement for Natural Gas of High Pressure (50 bar). Accuracy U(Qv; k=2)= 0.13% [→ 0.10%]

D. Vieth, H.M Hinze, B. Mickan, R. Kramer, H. Müller, & V. Strunck, IGRC Conférence 2008, Paris

WHAT is Challenging in this study?

- **handle the cryogenic conditions with the LDV system & no flashing**
- **design the optical access for the LDV at low temperature (-266°C)**
  (avoid the icing, reduce the stresses in the optical windows)
- **develop an adapted & clean seeding for LDV Measurements**
  (particles naturally present in the LNG or injected)
- **accuracy less than 0.20 %**

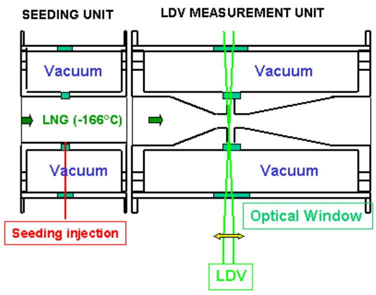
Studying technical feasibility of LNG Flowrate measurement using LDV

LNG METROLOGY

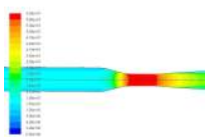
Conditions for In-line flow measurements of LNG

- Pipe diameter DN 900 (36'')
- Temperature = - 166℃
- Pressure < 10 bar
- Flowrate of LNG = 5000 to 15 000 m^3/h
- Mean pipe velocity = 2 to 7 m /s
- Pipe Reynolds number = 9×10^6 to 3×10^7
- Extended accuracy better than 0.20 %

LNG Measurement system: technical feasabilty

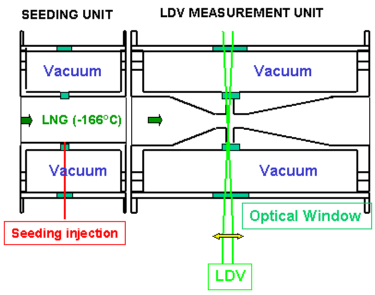


- **Flow conditions in the pipe**
  - LNG Unloading conditions (P,T,Qv, D)
  - Fluid= LNG; P<10 Bar ;T= - 166℃



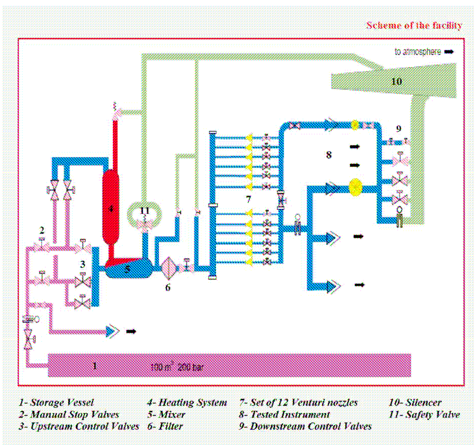
- **Measurement System**
  - Seeding unit
  - Conditionning the flow with a convergent (optimization → Flow simulation)
  - Local velocity measurement by means of the LDV
  - Vacuum insulated to avoid icing of the optical windows
  - Optical access (temperature gradient) for laser beams & flow visualization

LNG MEASUREMENT SYSTEM



- DN 80
- Beta Ratio = 0.5
- Total length 12 D
- Vacuum insulated 10^{-3} - 10^{-5} mb
- Quartz windows for LN2 or LNG measurements (- 160°C)
- Convergent & Nozzle optimisation for the Reynolds Number Range
- Use the Delta P for flowrate measurement

CESAME EXADEBIT FLOW LOOP



- **Flow rate** : Qm = 4.10^{-4} to 30 kg/s , Qv= 1 à 80 000 m^3/h (normal conditions)
- **Pressure** : 1 to 45 bar (depending on the flowrate)
- **Reference flowrate uncertainties** : 0.20 to 0.25 % depending on the flowrate

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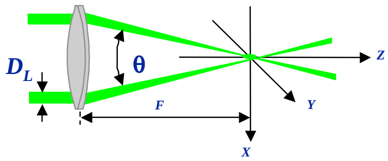
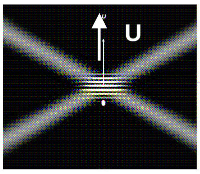
LASER DOPPLER VELOCIMETRY

Laser wavelength λ_0





Δi interfringe

Measurement volume

- LDV DANTEC
- Laser power = 40 mW
- λ = 532 nm (green light)
- Back scattering mode
- Focal length = 160 mm
- Measurement volume l=0.05 & L=0.4 mm
- Interfringe spacing = 2.2 μm

Doppler Frequency f_D

$$\Delta i = \frac{\lambda_0}{2 \cdot \sin\left(\frac{\theta}{2}\right)}$$

$$U = \Delta i \cdot f_D$$

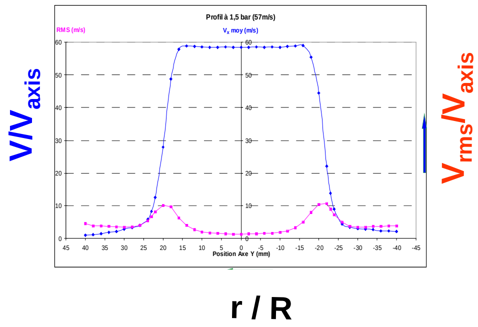
AIR BASED EXPERIMENTS: MEASUREMENT CONDITIONS

- **Fuid = Compressed AIR**
- **Pipe Diameter** = 0.080 m

Pressure (abs.) [Bar]	Throat Velocity [m/s]	Pipe Reynolds Number
1.5	5; 20; 57	1.0E+4 to 1.1E+5
5	5; 20; 57	3.3E+4 to 3.8E+5
10	5; 20; 57	6.5E+4 to 7.2E+5

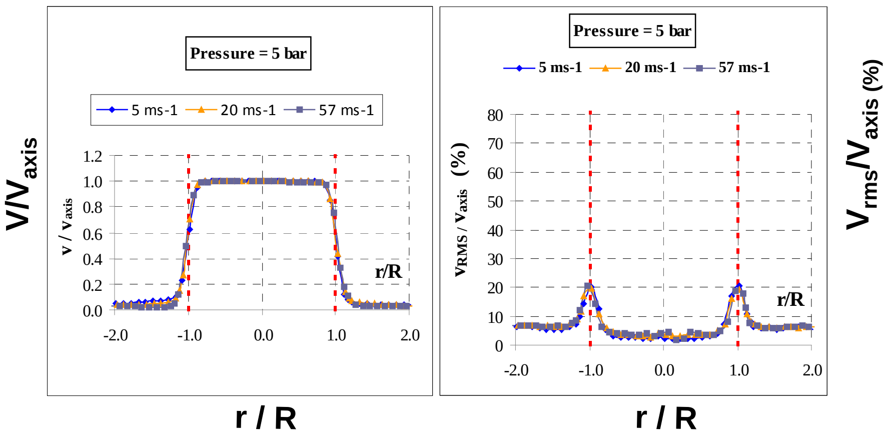
AIR BASED EXPERIMENTS WITH REYNOLD NUMBER SIMULATING LNG CONDITIONS

- Pressure 1 to 10 bar; Reynolds Number = 10^4 to 10^6



AIR BASED EXPERIMENTS WITH REYNOLD NUMBER SIMULATING LNG CONDITIONS

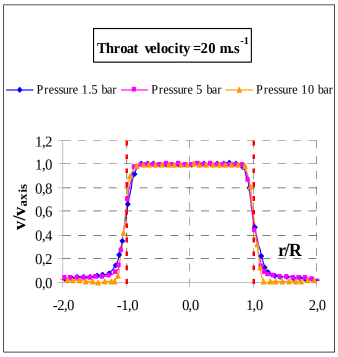
P= 5 bar ; Influence of the Throat Velocity [5, 20 & 57 m/s] on the Mean& RMS Velocity 16 mm dowstream the throat



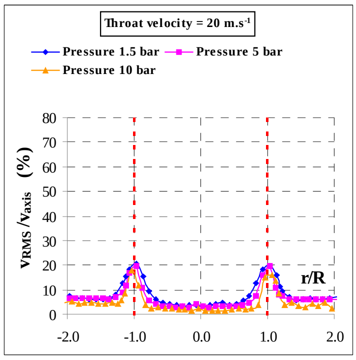
AIR BASED EXPERIMENTS WITH REYNOLD NUMBER SIMULATING LNG CONDITIONS

Throat Velocity= 20 m/s; Influence of the Pressure [1.5, 5 & 10 bar] on the Mean & RMS Velocity 16 mm dowstream the throat

V/V_{axis}



r / R



V_{rms}/V_{axis}

r / R

FLOWRATE MEASUREMENT WITH THE CRYOGENIC MEASUREMENT SYSTEM

$Q_v = \pi R^2 \overline{v} = \pi R^2 \frac{v_{axis}}{A(Re_d)}$ **with** $\frac{v_{axis}}{\overline{v}} = A(Re_d)$ **&** $Re_d = \frac{\overline{v}\, d\, \rho}{\mu} = \frac{4\, Q_m}{\pi\, \mu\, d}$

- V_{axis} — **Axis Mean Velocity 16 mm downstream the throat**
- **R** — **Throat Radius**
- $\overline{V}$ — **Mean Velocity at the throat**
- Re_d — **Ranging from 5 E+04 to 1.5 E+06**

$\overline{A} = 1.01$

FLOWRATE UNCERTAINTY $U_{relative}[Qv\ ;\ k=2] = 0.6\ \%$

Needs to Improve the accuracy of the total flowrate measurement [$Q_{total} = Q_{\ Air\ flow} + Qv_{\ seeding}$] & the uncertainty $U(V_{LDV})$

IMPROVEMENT OF THE FLOWRATE ACCURACY WITH THE CRYOGENIC MEASUREMENT SYSTEM

- needs to reduce ΔA (shift on $A[R_D]$)
- reduce the Reynolds Number Influence

target ⇨ LNG Flowrate uncertainty < 0.2 %

- improvement of the design of the measurement system
- the V_{axis} measures closer to the throat outlet
- industrial conditions (Tanker Unloading) Re_d= 1E+07
- confirmed by means of Flow simulations

LNG Flowrate measurement using LDV

- Pipe diameter DN 900 (36'')
- Length = 6 - 8 D
- Pressure < 10 bar
- Flowrate of LNG = 5000 to 15 000 m^3/h
- Pressure Loss < 500 mb (K= 0.26)
- Mean pipe velocity = 2 to 7 m /s
- Pipe Reynolds number = $9x10^6$ to $3x10^7$
- With a Reynolds Number = 10^7 an accuracy better than 0.20 % seems realistic
- measurement of the flowrate with the Delta P

CONCLUSION

- feasibility to realize a measurement system to measure the flowrate of LNG
- achieved expanded Uncertainty 0.6% on the volume flow rate with the LDV measurement system (air based experiments)
- proposal to improve the accuracy
- objective of an accuracy on the volume flowrate better than 0.2% seems realistic

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PERSPECTIVES

- improve the design of the LDV cryogenic Measurement system
- validation of the measurement system in cryogenic conditions (Liquid Nitrogen and LNG) (LN2 @NIST- LNG@VSL & LNG Terminal GDF Suez/ELENGY)
- assessment of an accuracy better than 0.2% to measure LNG flowrates

THANKS FOR YOUR ATTENTION

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