University of
South-Eastern Norway

Measurements in low temperatures

Preslhy Workshop 07.03.2019

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Measurements in rapid depressurization of liquid CO_2 (Expansion of saturated liquid)

Rapid depressurization and phase transition of CO_2 in a vertical duct – Small scale experiments and Rankine Hugoniot analysis

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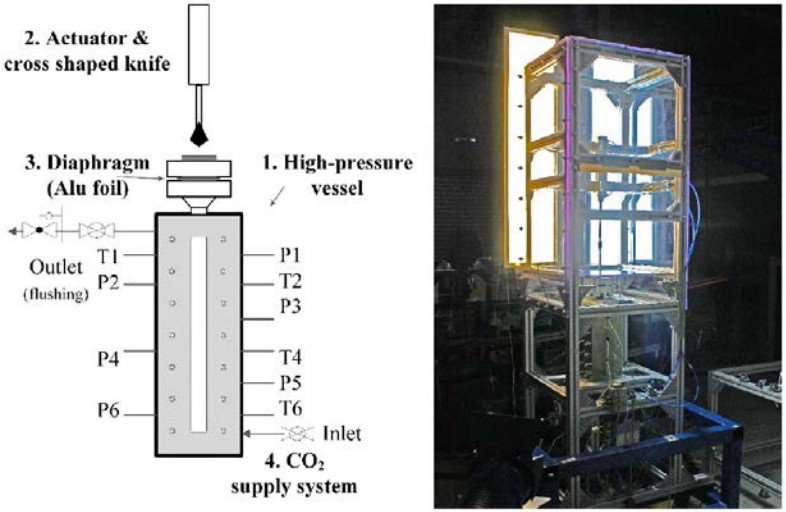


Fig. 1. Left: a sketch of test setup A; right a photograph showing the test setup and the support frame

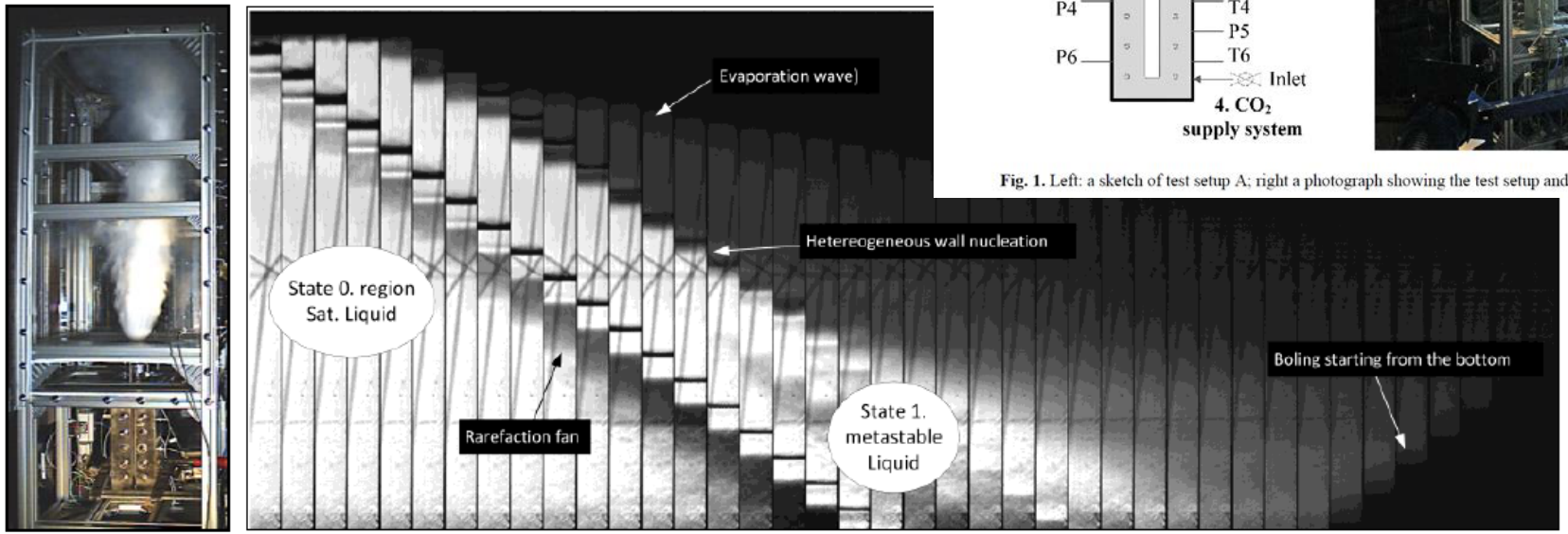
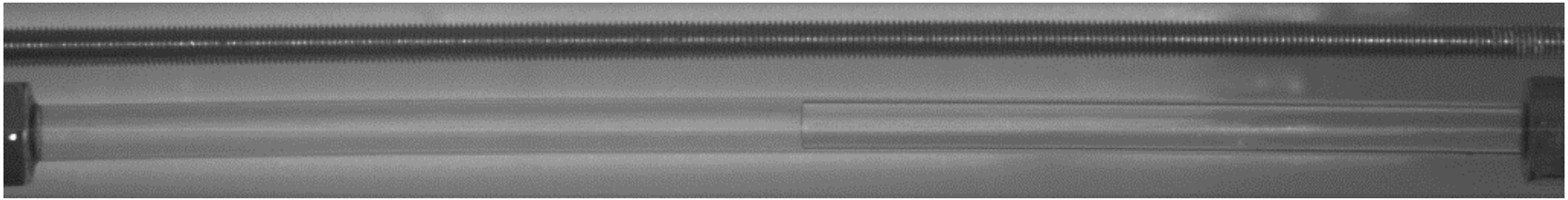
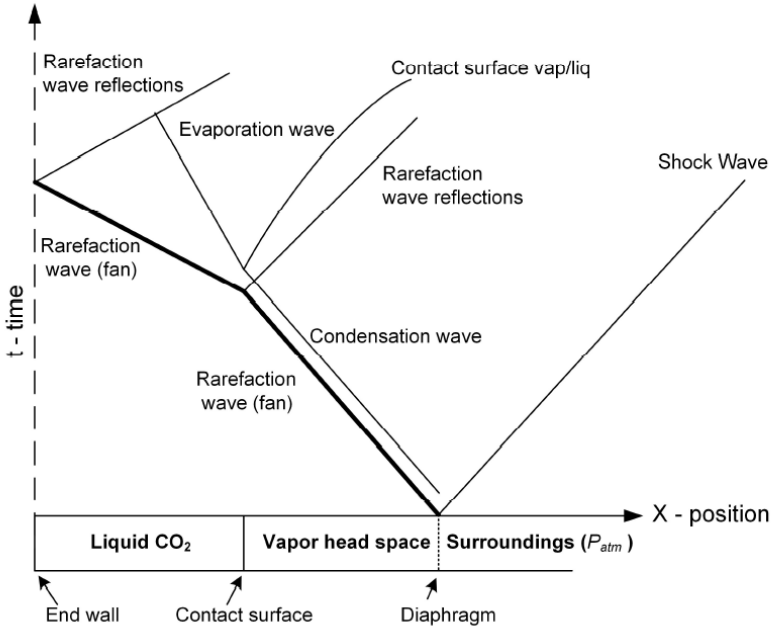
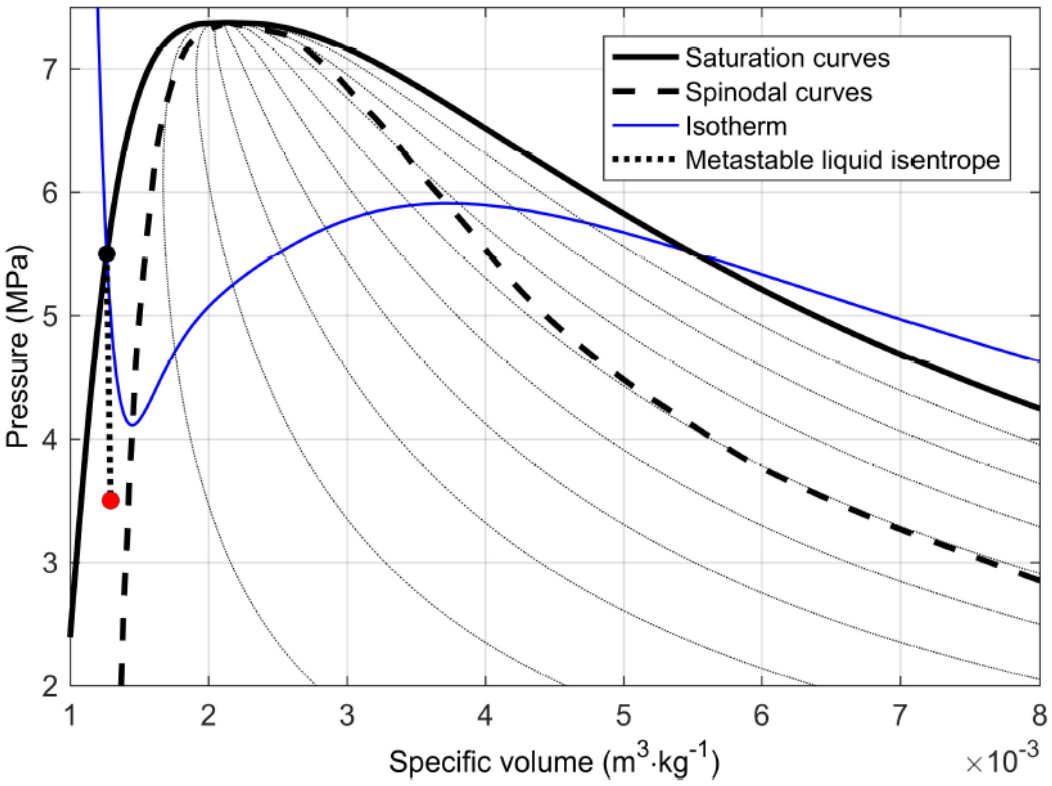
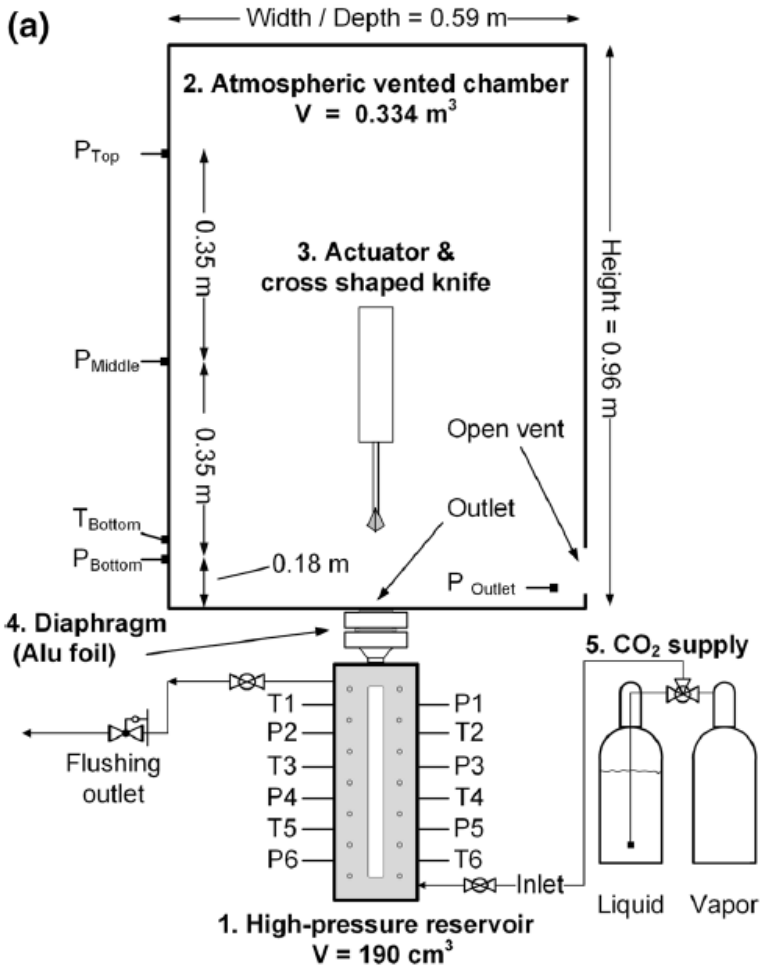


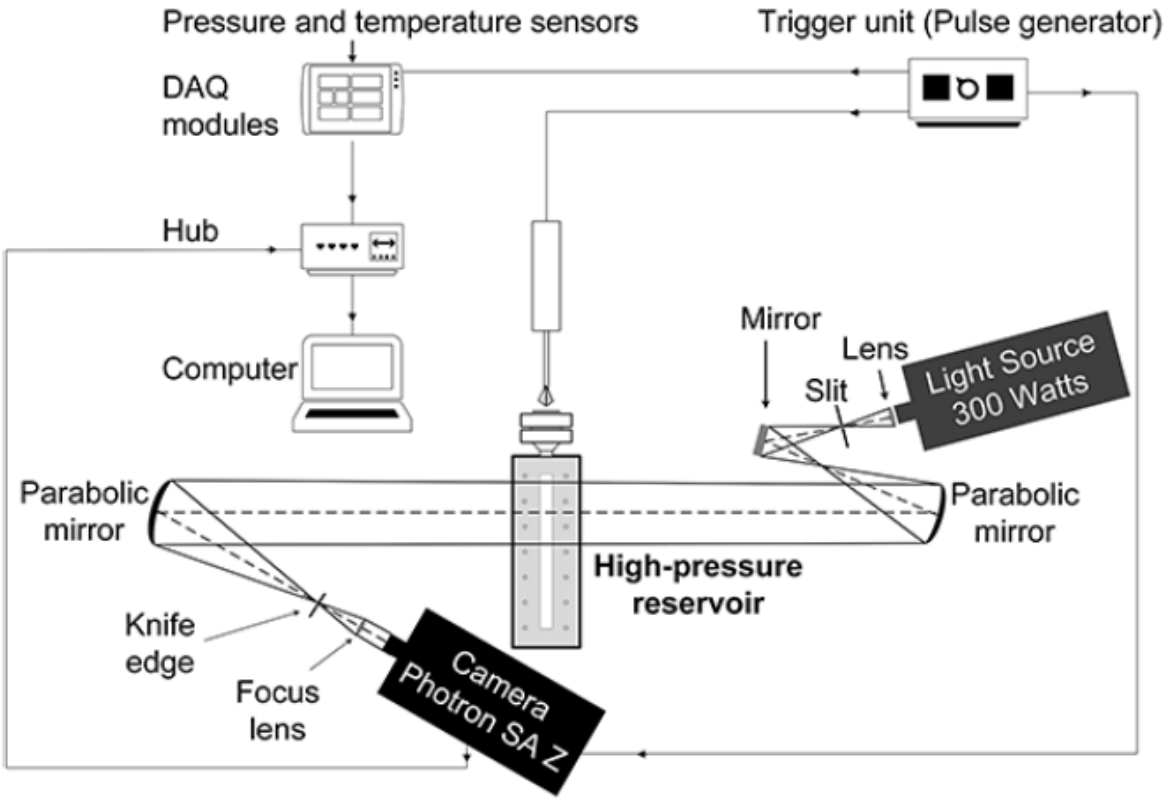
Fig. 4. Left: (a) Jet-flow of the vessel contents; right (b) Image series (schlieren setup) showing 1.5 ms of the rapid expansion and boiling process.




Rarefaction
wave reflections
Contact surface vap/liq
Evaporation wave
Rarefaction
wave reflections
Shock Wave
Rarefaction
wave (fan)
t - time
Condensation wave
Rarefaction
wave (fan)
X - position
Liquid CO_2
Vapor head space
Surroundings (P_{atm})
End wall
Contact surface
Diaphragm


Saturation curves
Spinodal curves
Isotherm
Metastable liquid isentrope
Pressure (MPa)
Specific volume (m^3·kg^{-1})
×10^{-3}
1
2
3
4
5
6
7
8


(a)
Width / Depth = 0.59 m
2. Atmospheric vented chamber
V = 0.334 m³
P Top
0.35 m
3. Actuator &
cross shaped knife
Height = 0.96 m
P Middle
0.35 m
Open vent
Outlet
T Bottom
P Bottom
0.18 m
P Outlet
4. Diaphragm
(Alu foil)
5. CO₂ supply
T1
P2
T3
P4
T5
P6
P1
T2
P3
T4
P5
T6
Flushing
outlet
Inlet
Liquid
Vapor
1. High-pressure reservoir
V = 190 cm³

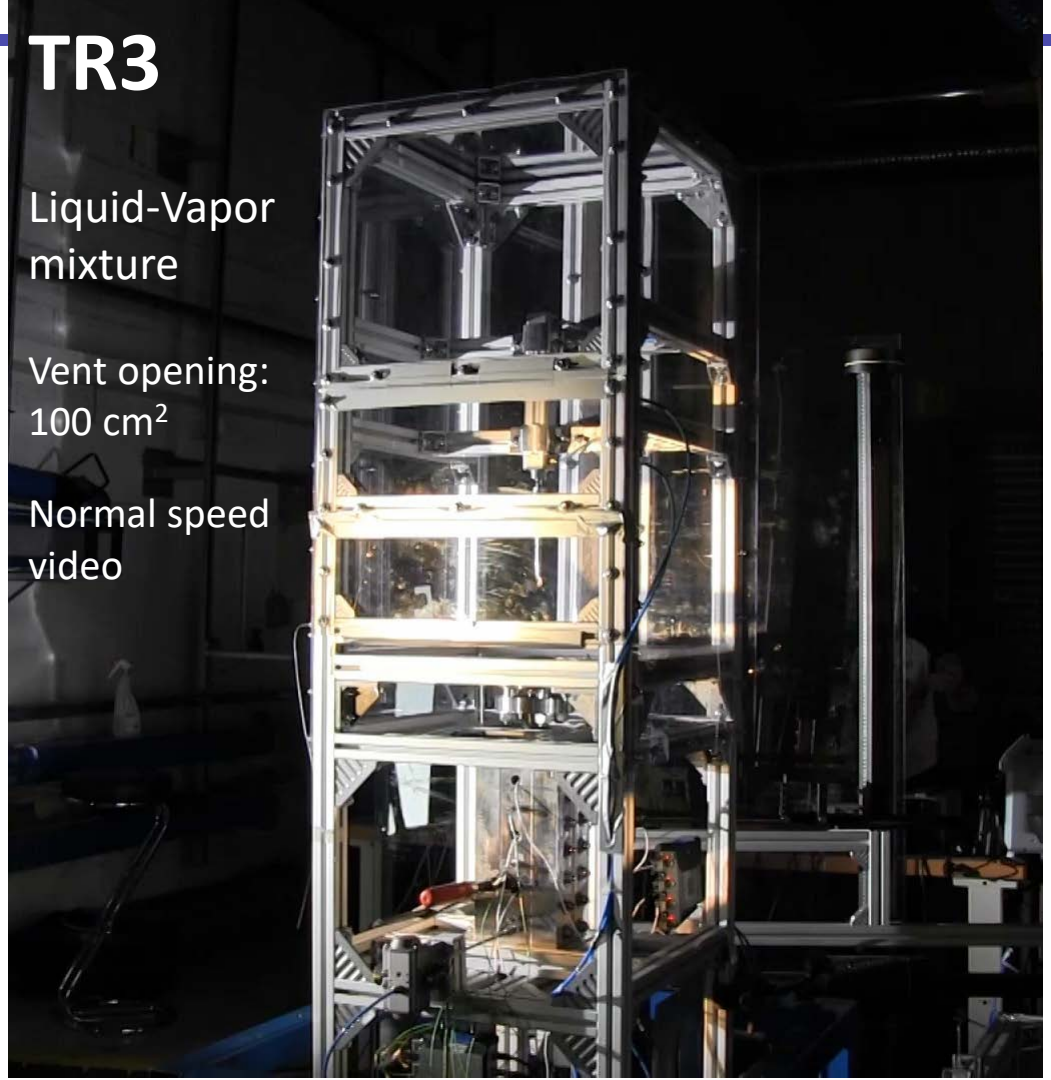

Pressure and temperature sensors
Trigger unit (Pulse generator)
DAQ modules
Hub
Computer
Mirror
Lens
Slit
Light Source 300 Watts
Parabolic mirror
Parabolic mirror
High-pressure reservoir
Knife edge
Focus lens
Camera Photron SA Z

TR3

Liquid-Vapor mixture

Vent opening: 100 cm^2

Normal speed video

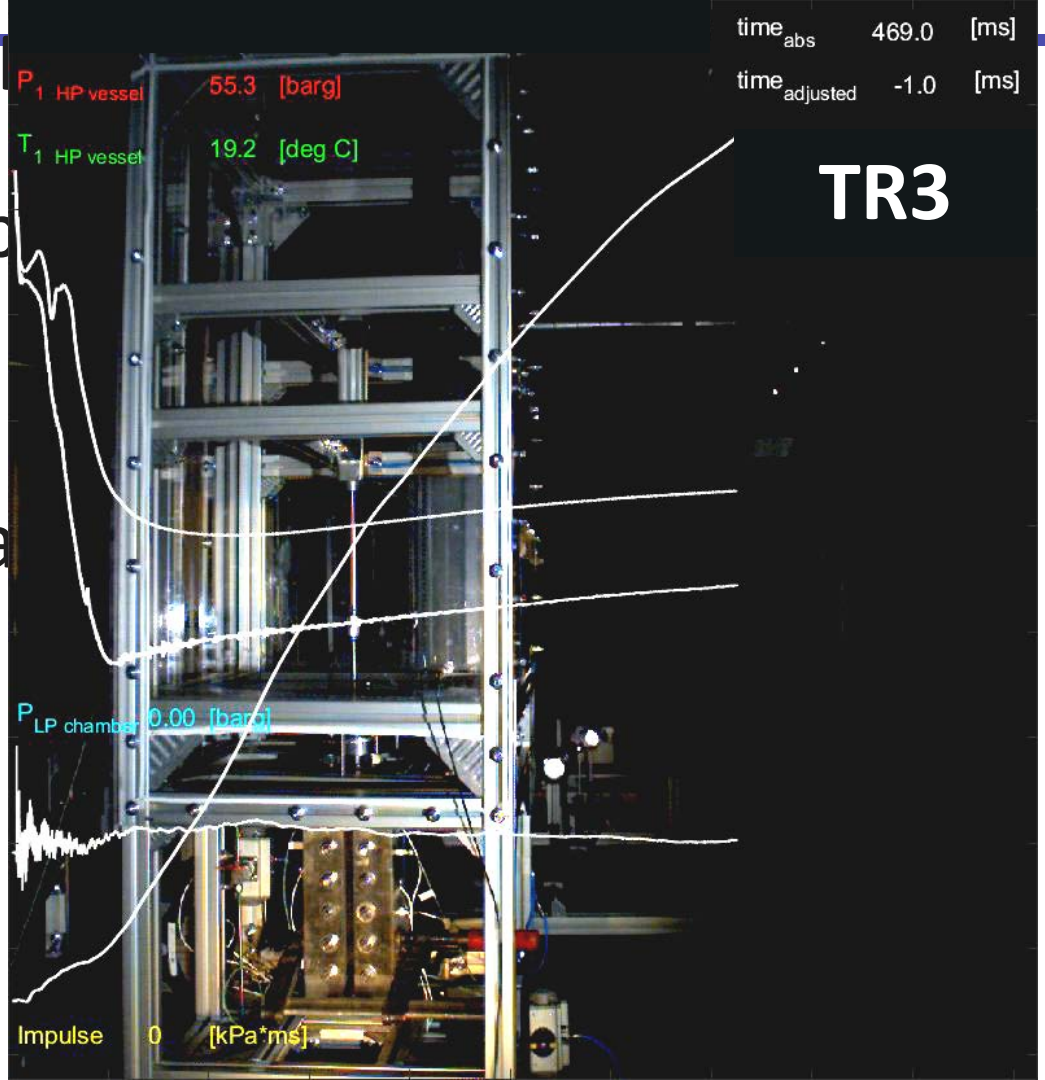


TR

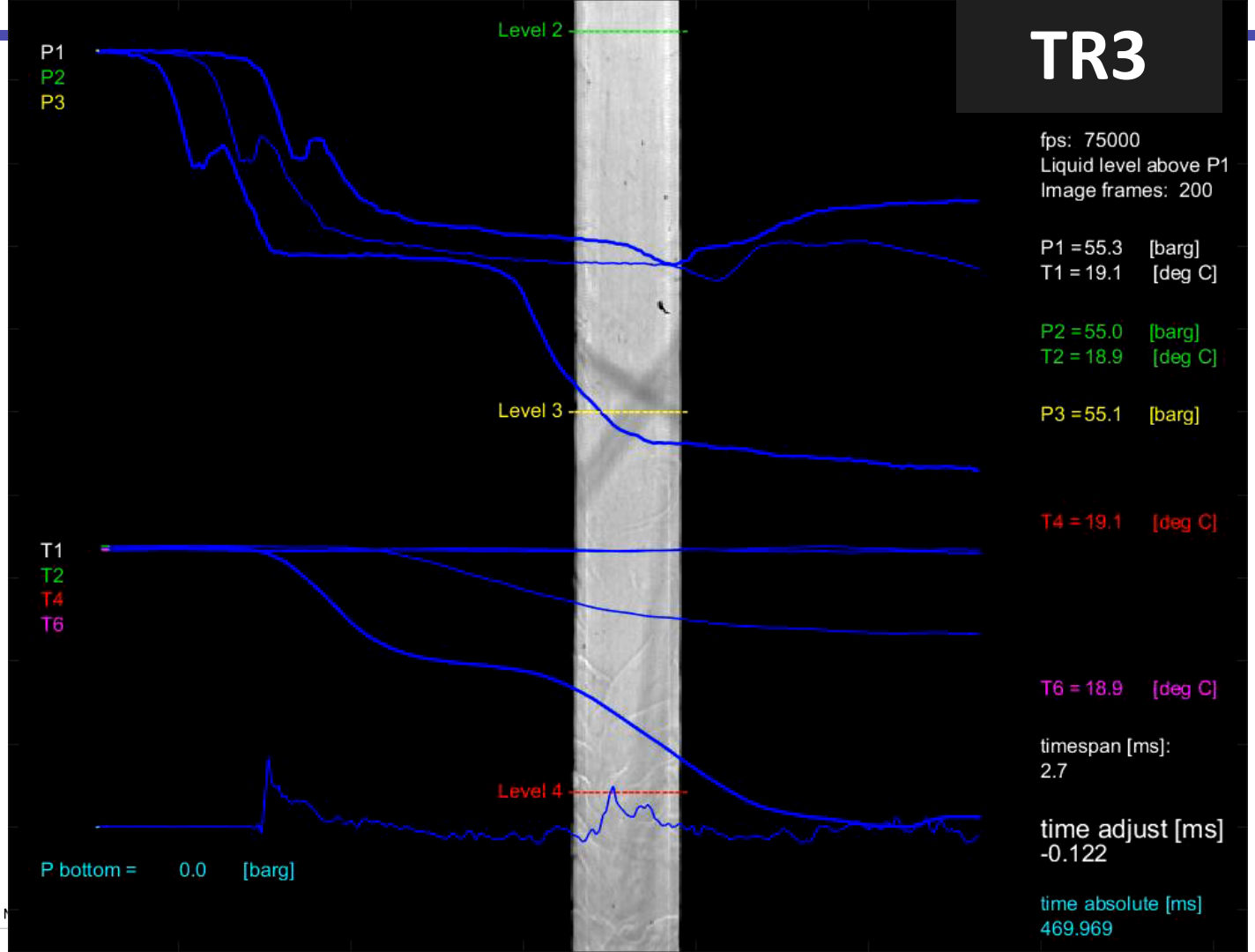
Liquid-Vap

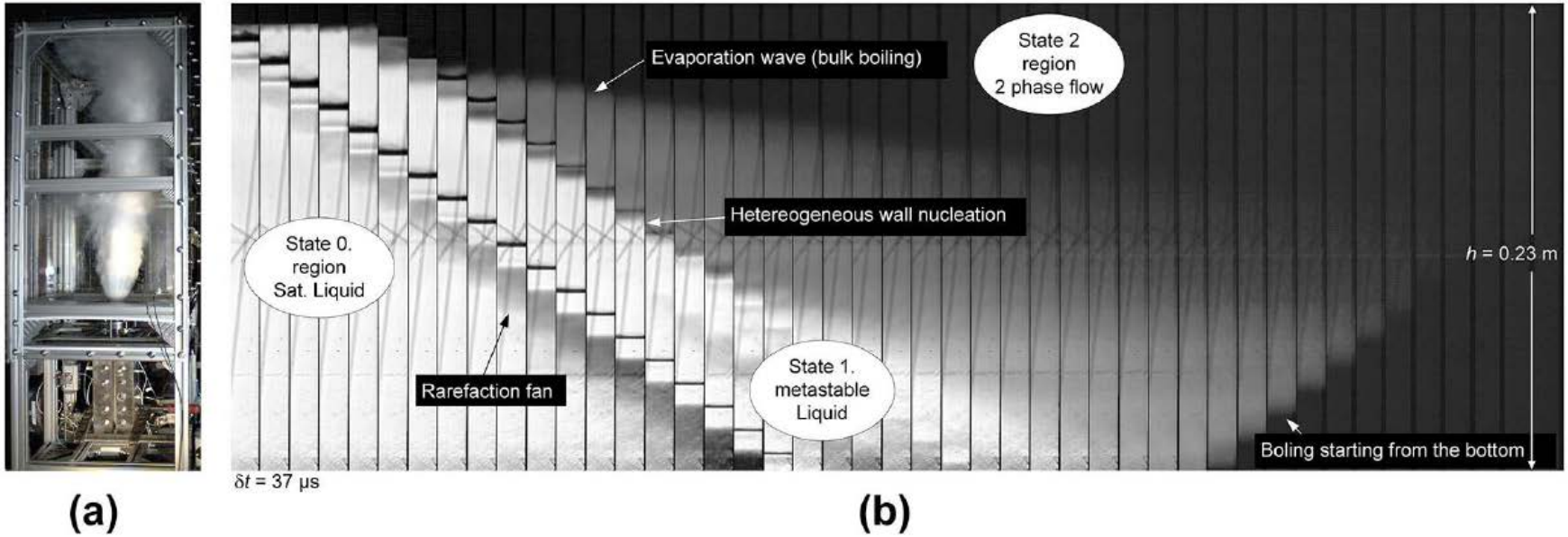
Vent openi

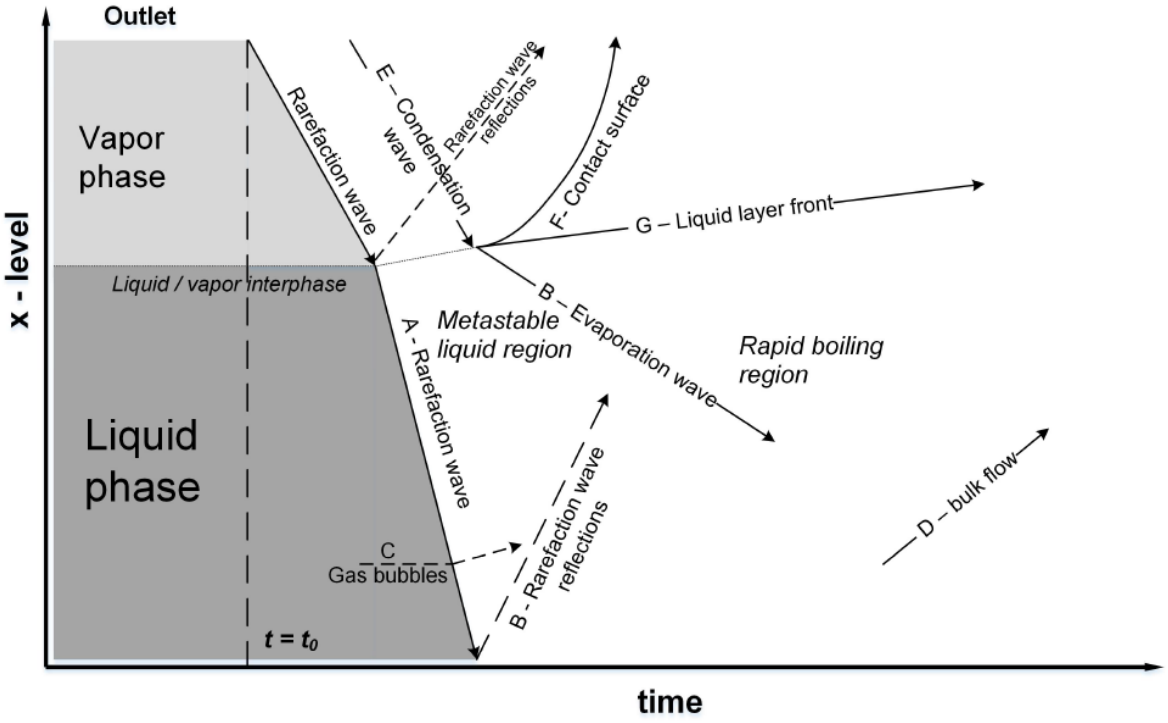
HS camera



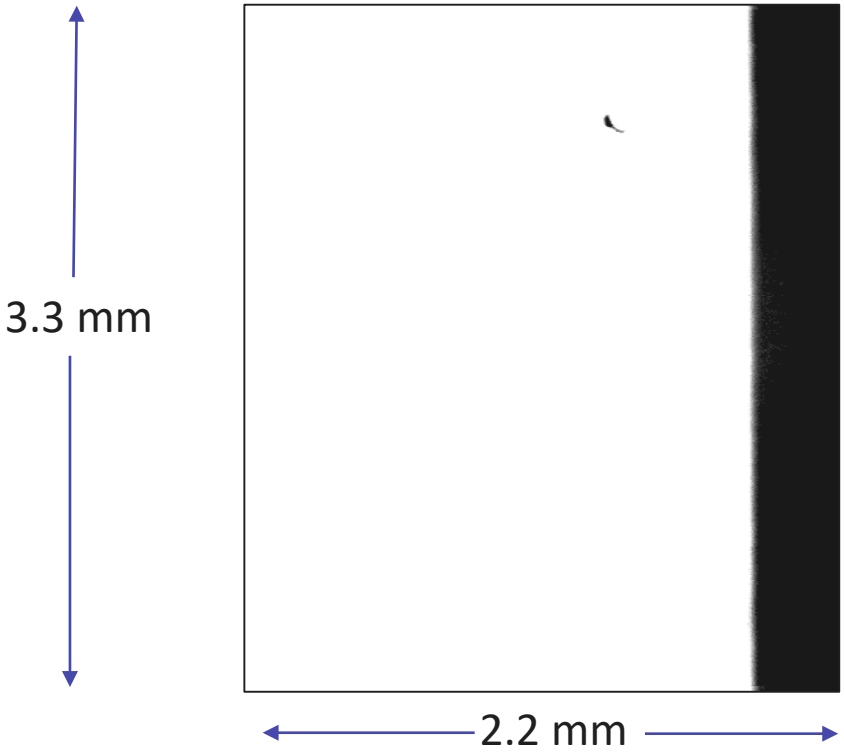
TR3

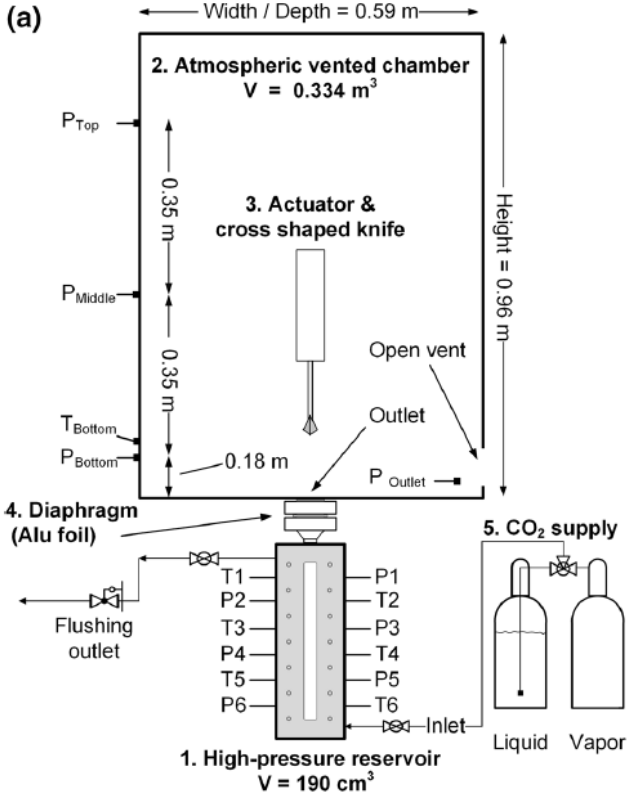

Level 2
P1
P2
P3
Level 3
T1
T2
T4
T6
Level 4
P bottom = 0.0 [barg]
fps: 75000
Liquid level above P1
Image frames: 200
P1 = 55.3 [barg]
T1 = 19.1 [deg C]
P2 = 55.0 [barg]
T2 = 18.9 [deg C]
P3 = 55.1 [barg]
T4 = 19.1 [deg C]
T6 = 18.9 [deg C]
timespan [ms]:
2.7
time adjust [ms]
-0.122
time absolute [ms]
469.969


Evaporation wave (bulk boiling)
State 2
region
2 phase flow
Hetereogeneous wall nucleation
State 0.
region
Sat. Liquid
h = 0.23 m
Rarefaction fan
State 1.
metastable
Liquid
Boling starting from the bottom
δt = 37 μs
(a)
(b)


Outlet
Vapor phase
Liquid phase
Liquid / vapor interphase
x - level
time
Rarefaction wave
E – Condensation wave
Rarefaction wave reflections
F- Contact surface
G – Liquid layer front
B – Evaporation wave
Metastable liquid region
Rapid boiling region
A - Rarefaction wave
B - Rarefaction wave reflections
C
Gas bubbles
D – bulk flow
t = t0

Heterogenous nucleation - front glass

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P_Bottom
0.18 m
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4. Diaphragm
(Alu foil)
5. CO₂ supply
T1
P2
T3
P4
T5
P6
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Flushing
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Vapor
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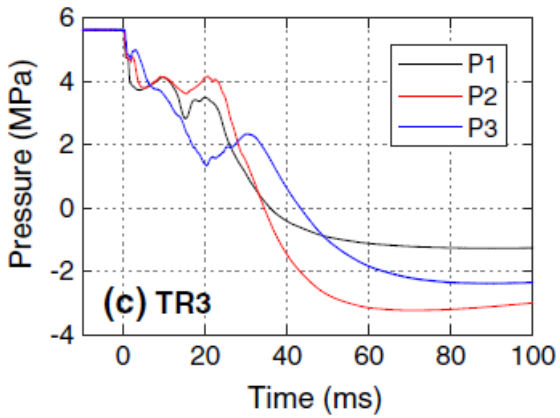
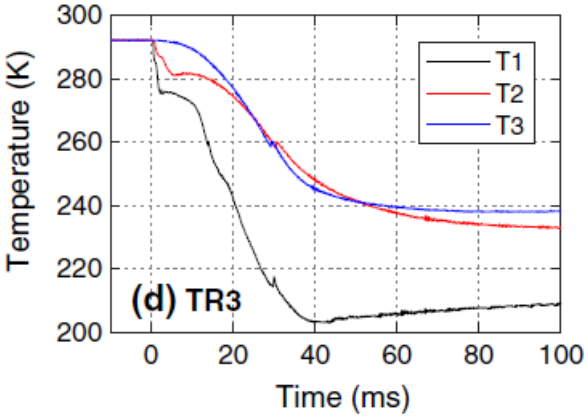
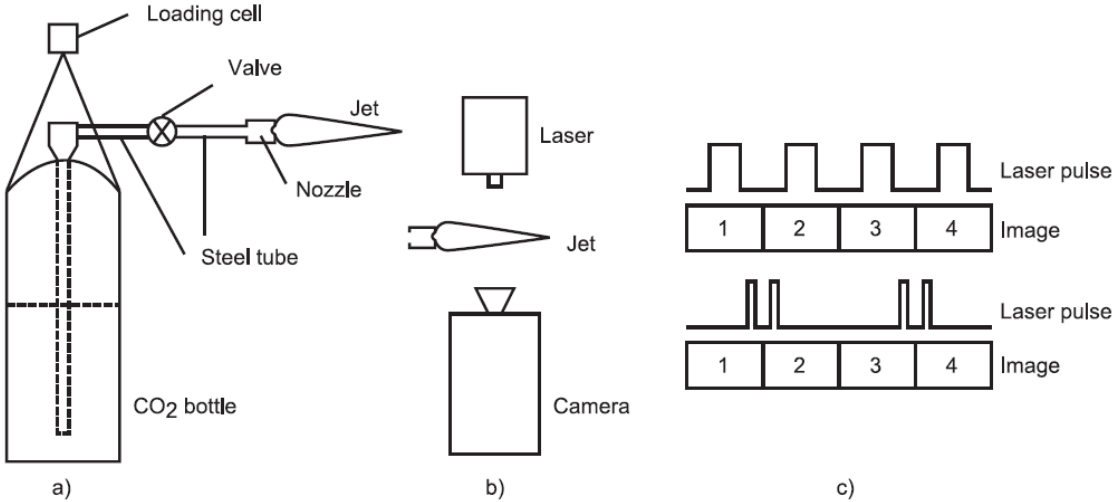

Pressure (MPa)
Time (ms)
P1
P2
P3
(c) TR3


Temperature (K)
Time (ms)
T1
T2
T3
(d) TR3

Measurements in jet release of liquid CO_2

Release of liquid CO_2



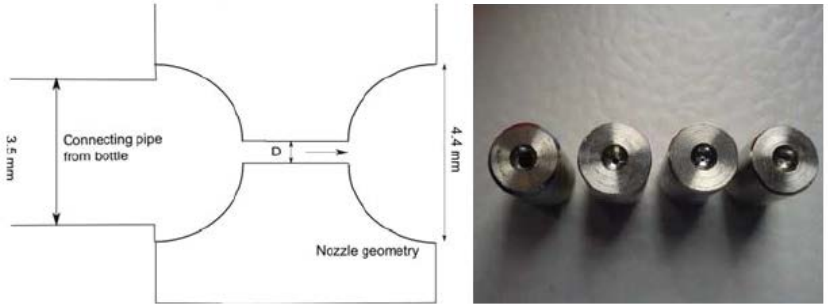
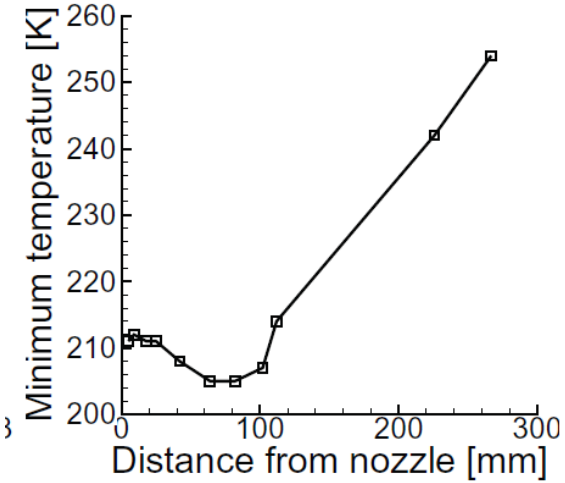


Fig. 2. (a) Schematic view of the nozzle geometry; (b) Photograph of the four nozzles used in the experiments. Throat sizes (D) from left are: 2.5mm, 1mm, 0.5mm, 0.25mm



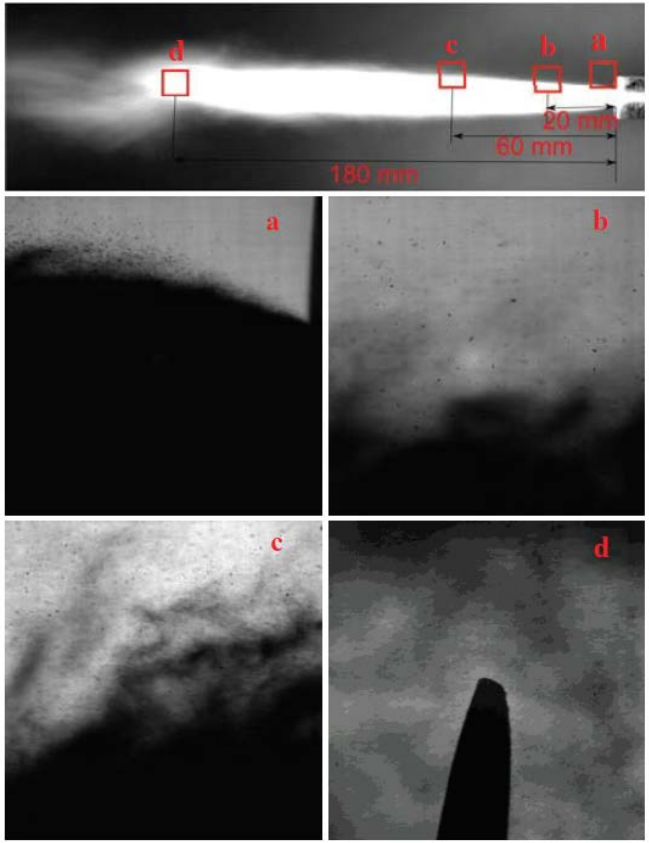


Fig. 5. Close-up images of the jet from the 1 mm nozzle; (a) Nozzle opening; (b) 20 mm from nozzle opening; (c) 60 mm from nozzle opening; (d) 180 mm from nozzle opening. The large object in d) is a needle used for positioning and camera focus. All four images are 5.3 x 5.3 mm in the focus plane. This corresponds to a pixel size of 5.22 µm.

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