ASME ORC 2013
2nd International Seminar on ORC Power Systems
October 7th & 8th, 2013 De Doelen, Rotterdam, The Netherlands





Start-up of a Test Rig for Organic Vapors

A. Spinelli, V. Dossena, P. Gaetani

FLUID-DYNAMICS OF TURBOMACHINES

POLITECNICO DI MILANO
ENERGY DEPARTMENT

in collaboration with

clean energy ahead
TURBODEN
a group company of MITSUBISHI HEAVY INDUSTRIES, LTD.

Motivation

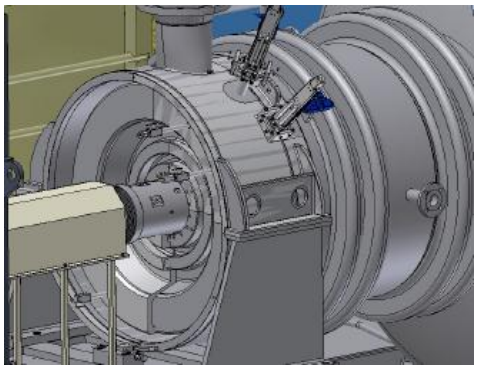
Experimental Investigation of ORC turbine passage flows (NO DATA)

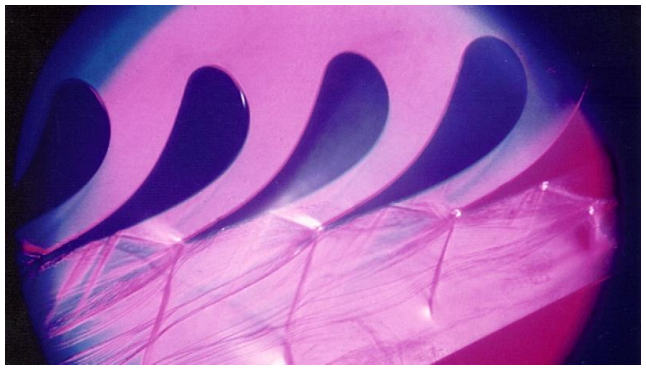
- **Properties** T_T, P_T, P, u, α, ψ independent measurement of P & $\boldsymbol{u}$
- **Techniques** pressure probes & taps *(P_T, P)*, thermocouples *(T_T)*, LDV *(u)*, Schlieren *(shock waves)*

Limits in industrial plants → **TROVA** (**T**est **R**ig for **O**rganic **VA**pors)

Start-up

- **Main sub-systems tests** dry air
- **Instrumentation set up** experiment *(P, T)*





Summary

→ The TROVA

→ Start-up tests

→ Test section

→ Instrumentation

→ Conclusions

→ The TROVA

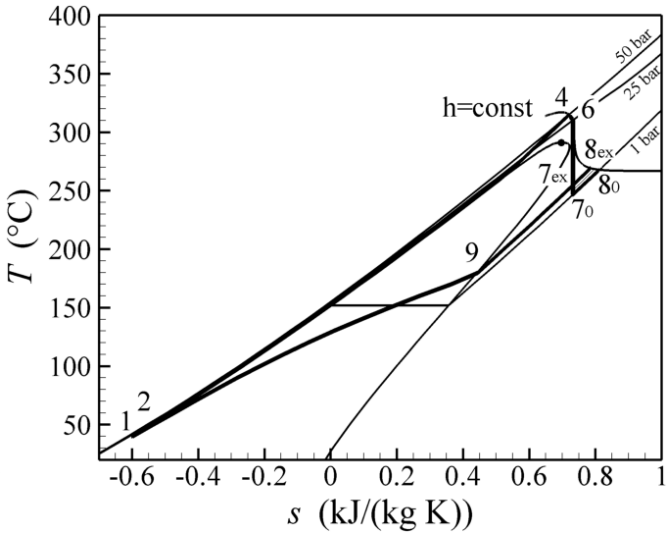
→ Start-up tests

→ Test section

→ Instrumentation

→ Conclusions

TROVA



HEATING

TEST

THROTTLING

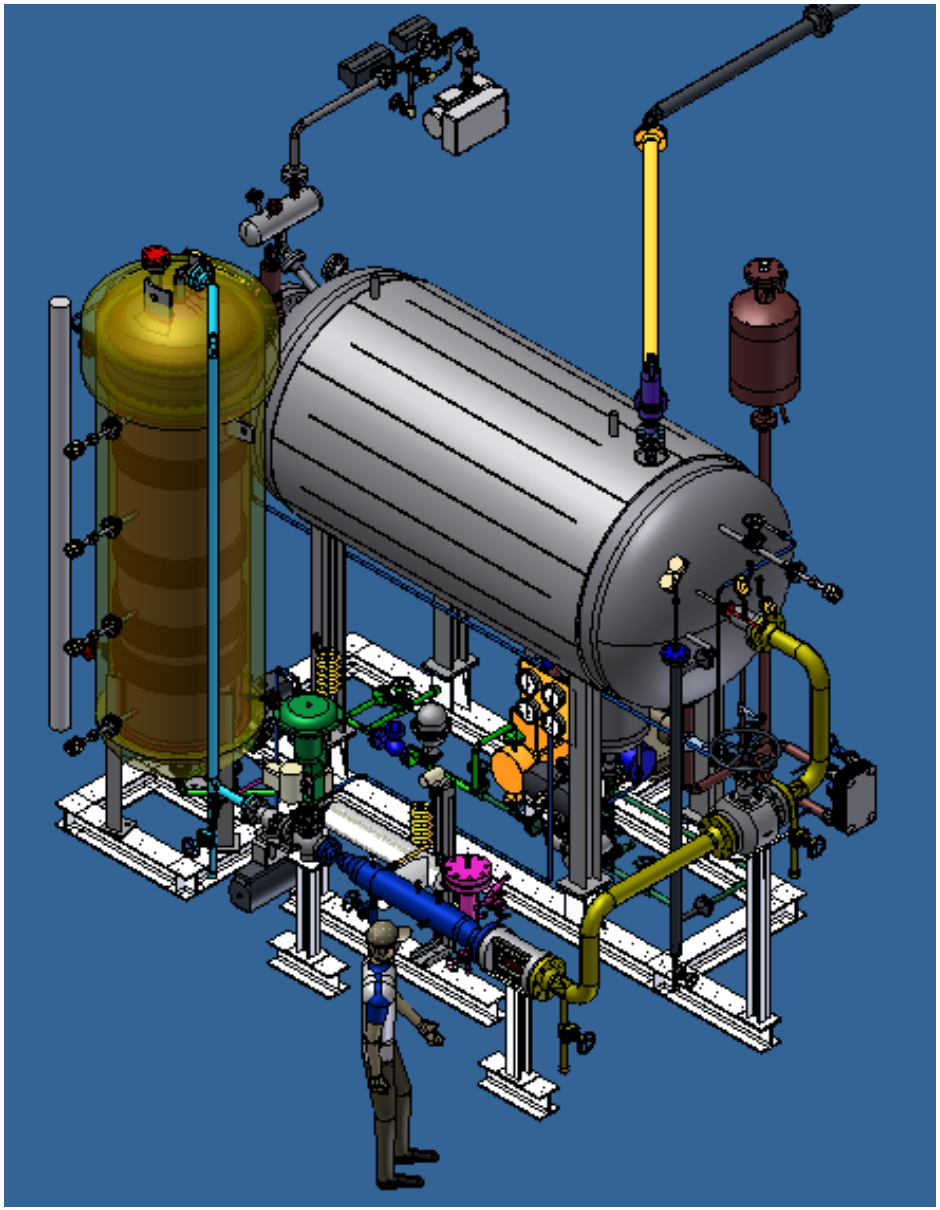
COMPRESSION

COOLING

VACUUM

HPV SAFETY VALVE
BY-PASS CONTROL VALVE
VAPOUR BY-PASS
SEEDING TANK
MAIN CONTROL VALVE
TEST SECTION
LPV SAFETY VALVE + BURSTING DISC
VAPOUR HEAT EXCHANGER
LOW PRESSURE VESSEL
LPV LEVEL
HPV LEVEL
HIGH PRESSURE VESSEL
BAND HEATER 1
LIQUID HEAT EXCHANGER
HOT SINK
EXPANSION TANK
VACUUM PUMP
NON-CONDENSABLE GASES TANK
OIL CIRCUIT
COOLING TOWER
OIL PUMP
WATER PUMP
OIL HEAT EXCHANGER
WATER CIRCUIT
PRESSURE SIDE REVERSE BY-PASS
SUCTION SIDE REVERSE BY-PASS
FLOW DAMPER
CHECK VALVE
METERING PUMP
FILTER

TROVA



→ The TROVA

→ Start-up tests

→ Test section

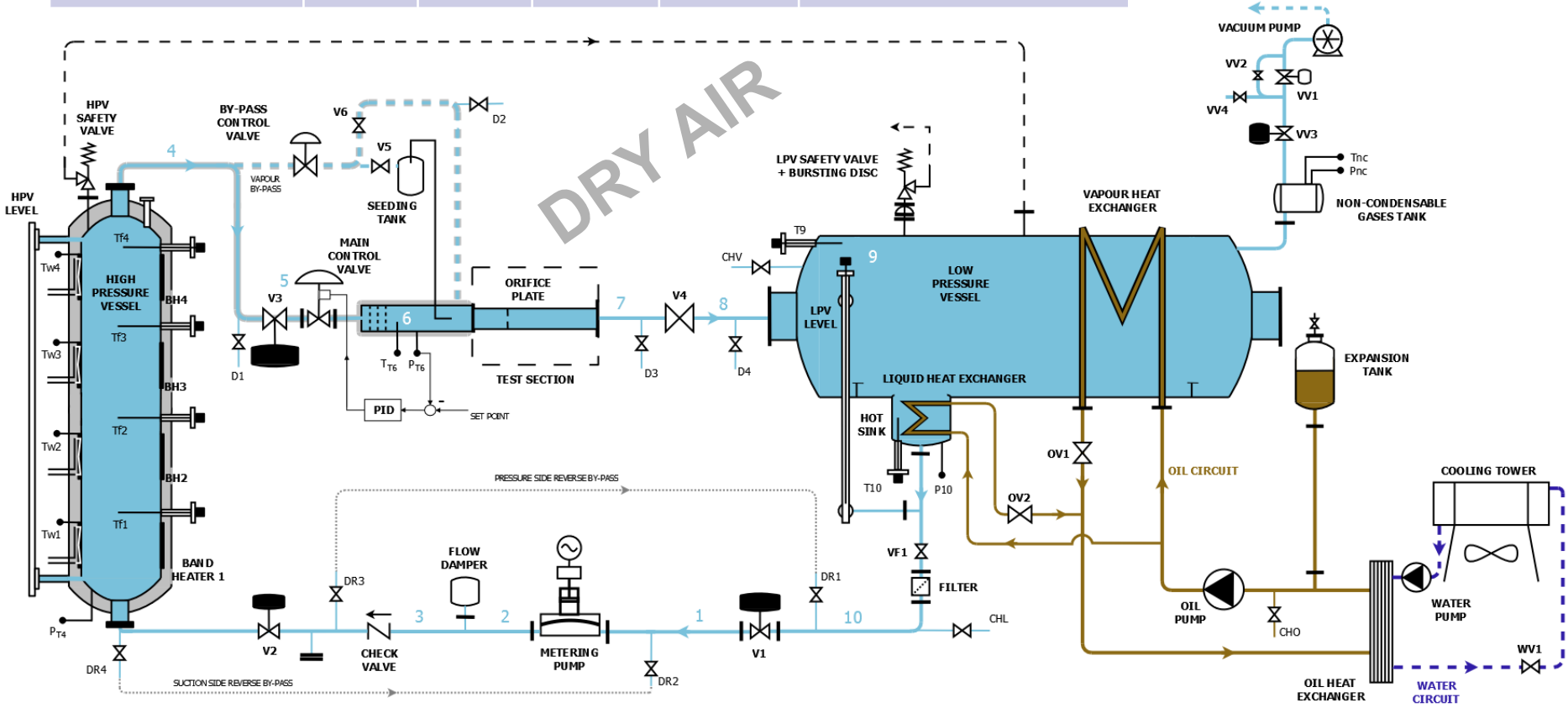
→ Instrumentation

→ Conclusions

Sealing tests

Test	*t* h	*P* bar_A	*T* °C	T_{ref} °C	$\partial P/\partial t\|_{Tref}$ mbar/h (mbar/day)
$OUTWARD_{FULL}$	19	6.30	54	25	-3.0
$INWARD_{FULL}$	36	0.01	32	25	+0.2 (+4.8)
$OUTWARD_{HPV}$	4	7.75	195	200	-6.0

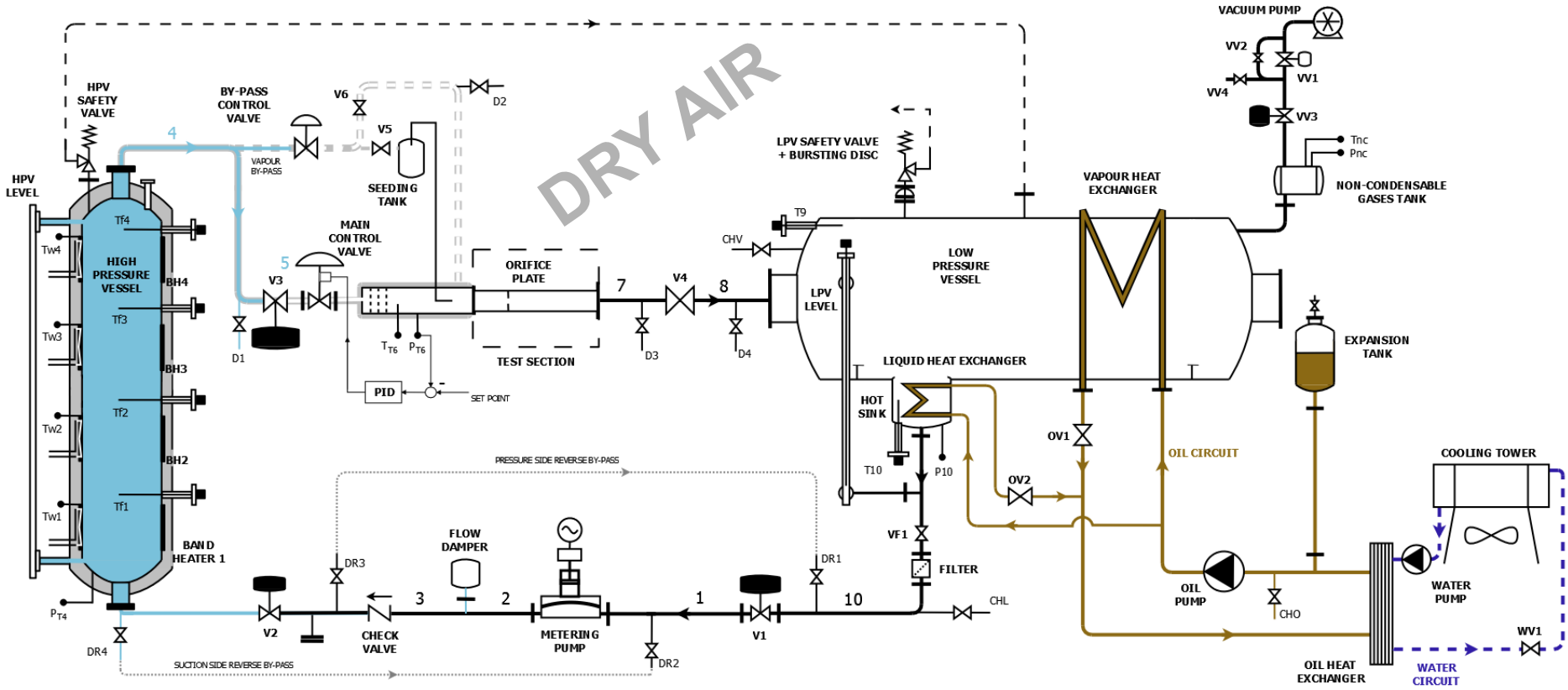
ACCURACY P mbar	*ACCURACY T* °C
± 1.0	± 1.5



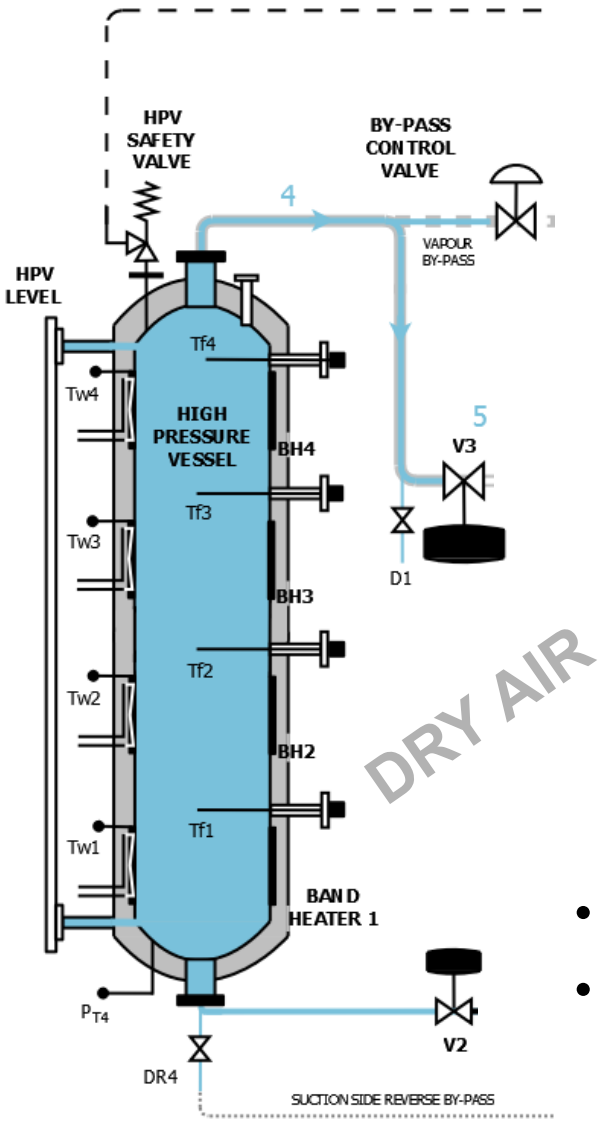
Sealing tests

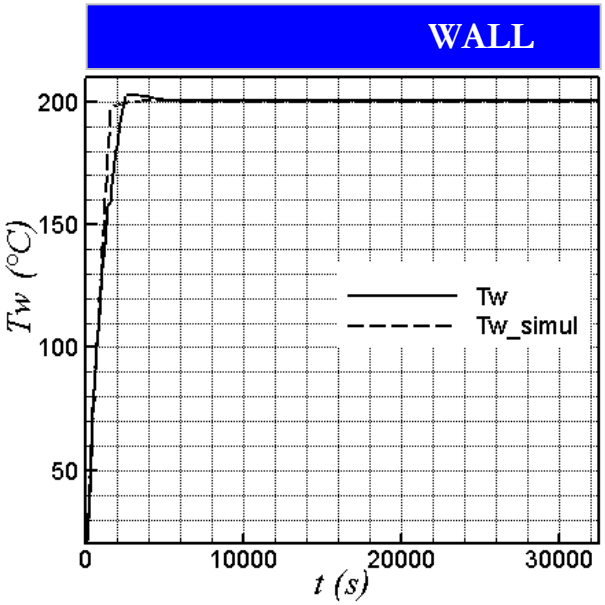
Test	*t* h	*P* bar_A	*T* °C	T_{ref} °C	$\partial P/\partial t\|_{Tref}$ mbar/h (mbar/day)
$OUTWARD_{FULL}$	19	6.30	54	25	-3.0
$INWARD_{FULL}$	36	0.01	32	25	+0.2 (+4.8)
$OUTWARD_{HPV}$	**4**	**7.75**	**195**	**200**	**-6.0**

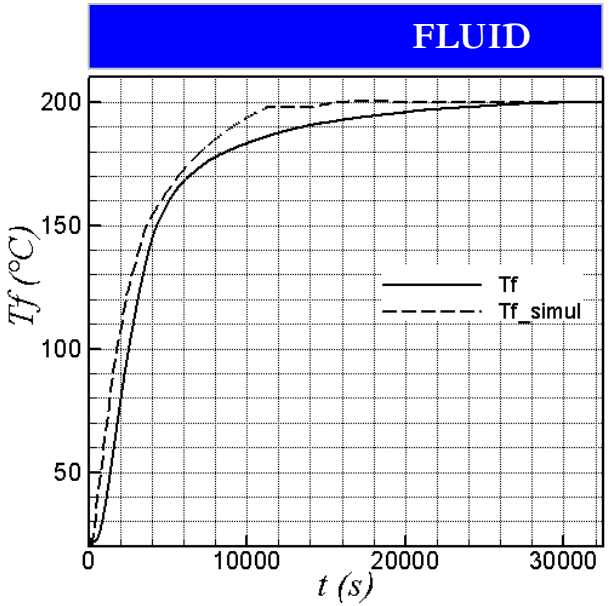
ACCURACY P mbar	*ACCURACY T* °C
± 1.0	± 1.5



Heating tests





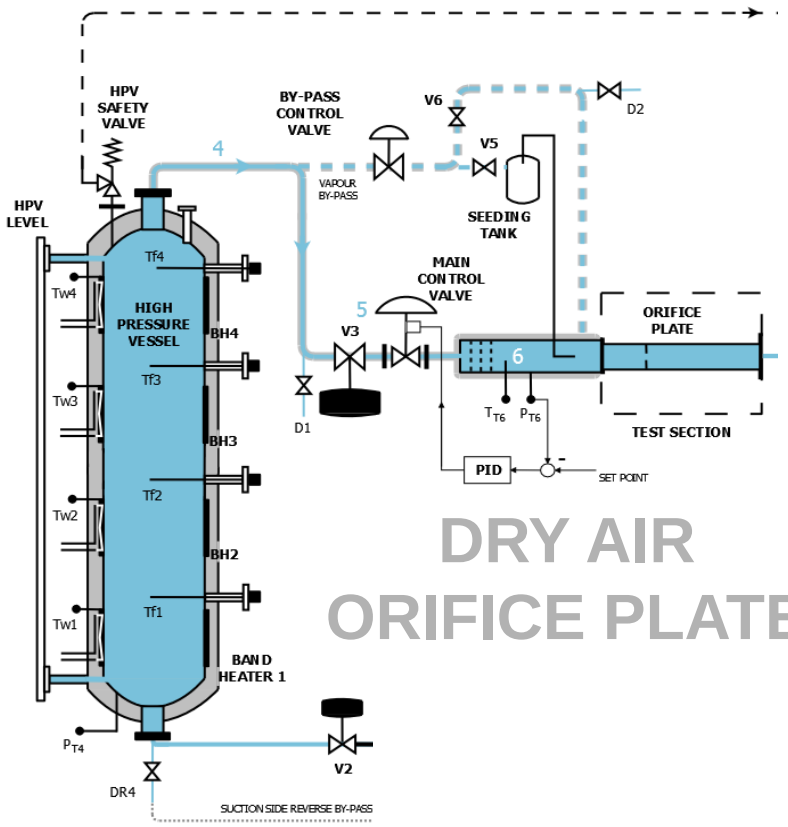


TEST CONDITIONS	
P bar	***T*** °C
7.0	**200**

- **Heating system** good
- **Prediction at wall** good
  at bulk worse

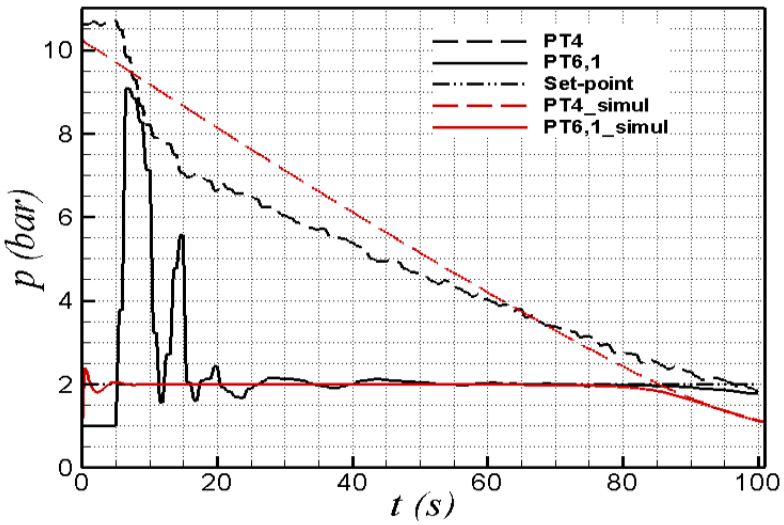
→ **CHURCHILL-CHU CORRELATION**

MCV test – 1st



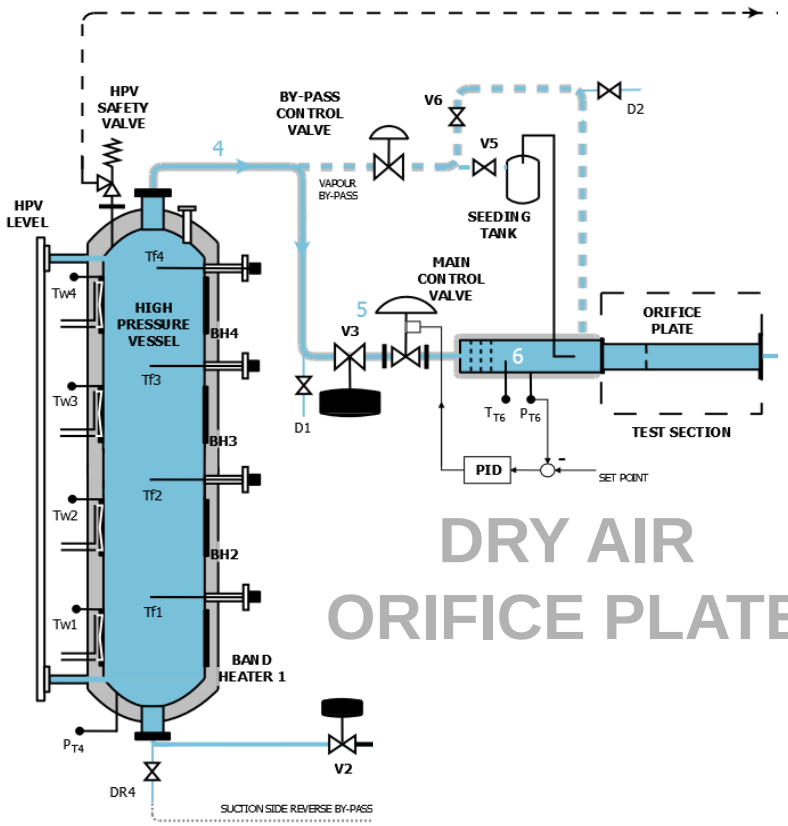
MCV

- **INDUSTRIAL PID**
- **BASIC POSITIONER**

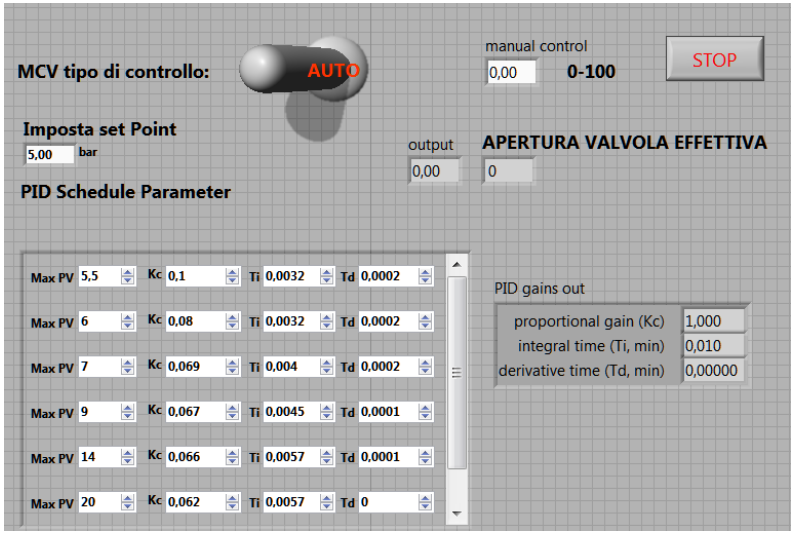


1st EQUIVALENT TEST					
P_{T4} bar_A	T_{T4} °C	P_{T6} bar_A	$D_{orifice}$ mm	t_{test} s	t_{lim} s
10.25	50	2.0	20	40	85

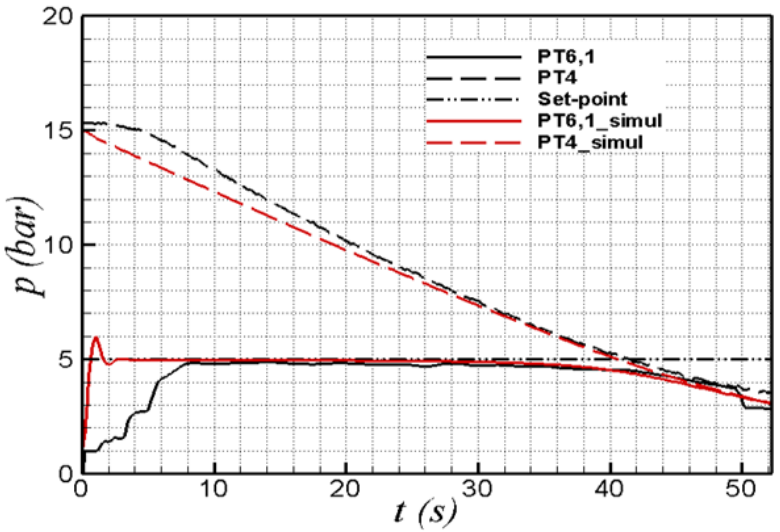
MCV tests



LabView PID CONTROLLER + INTELLIGENT POSITIONER



EQUIVALENT TEST & RESULTS					
P_{T4} bar_A	T_{T4} °C	P_{T6} bar_A	$D_{orifice}$ mm	t_{test} s	t_{lim} s
15.25	50	5.0	20	26	35



→ The TROVA

→ Start-up tests

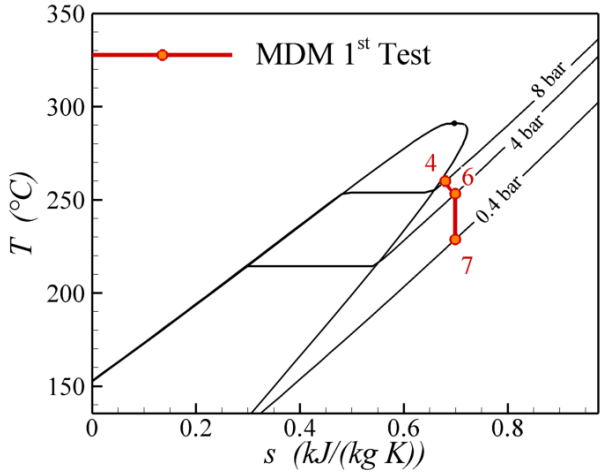
→ Test section

→ Instrumentation

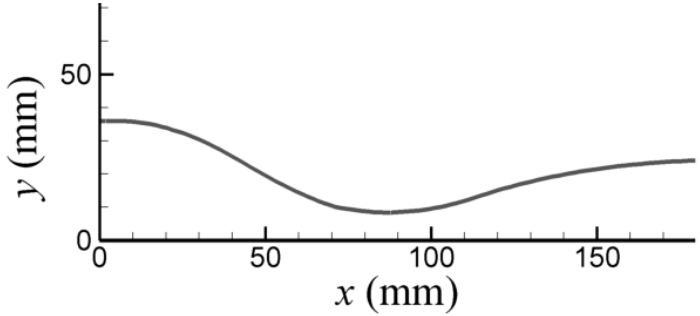
→ Conclusions

Test section – design & arrangement

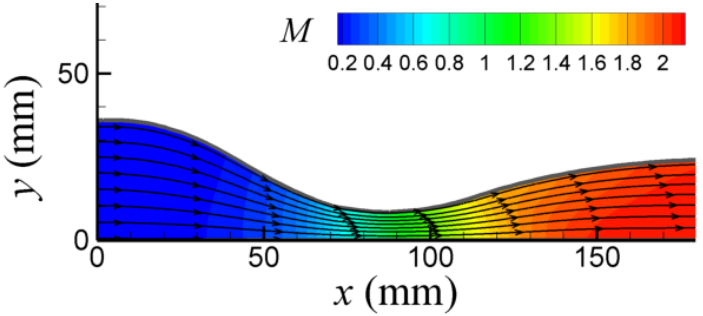
DESIGN OF THE 1st ORGANIC VAPOR TEST						
FLUID	P_{T6} bar_A	T_{T6} °C	Z_{T6}	β	M_7	t_{test} s
MDM	**4**	**253.2**	**0.85**	**10**	**2.05**	**50**

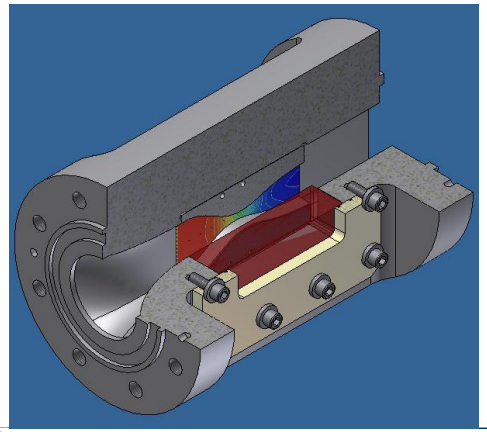


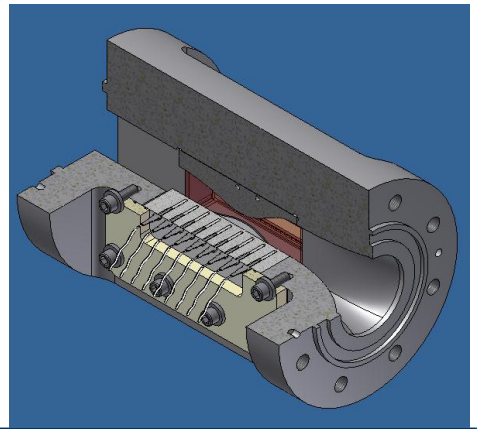
Nozzle design: MOC + SW, polynomial

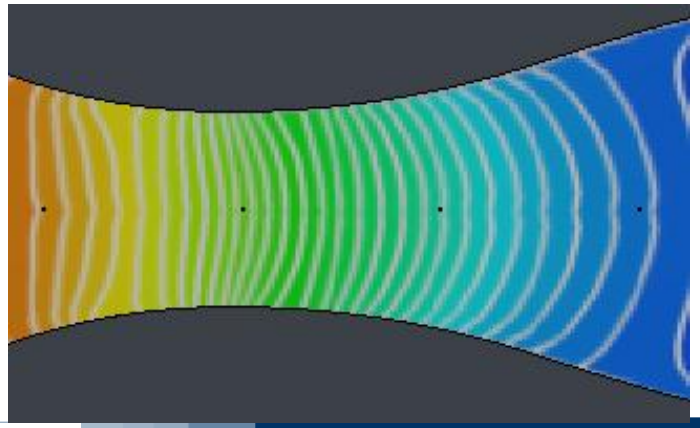


CFD calculations: zFlow + LUT









→ The TROVA

→ Start-up tests

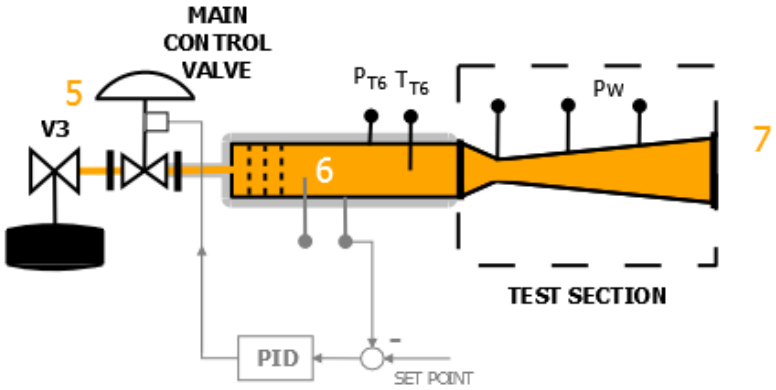
→ Test section

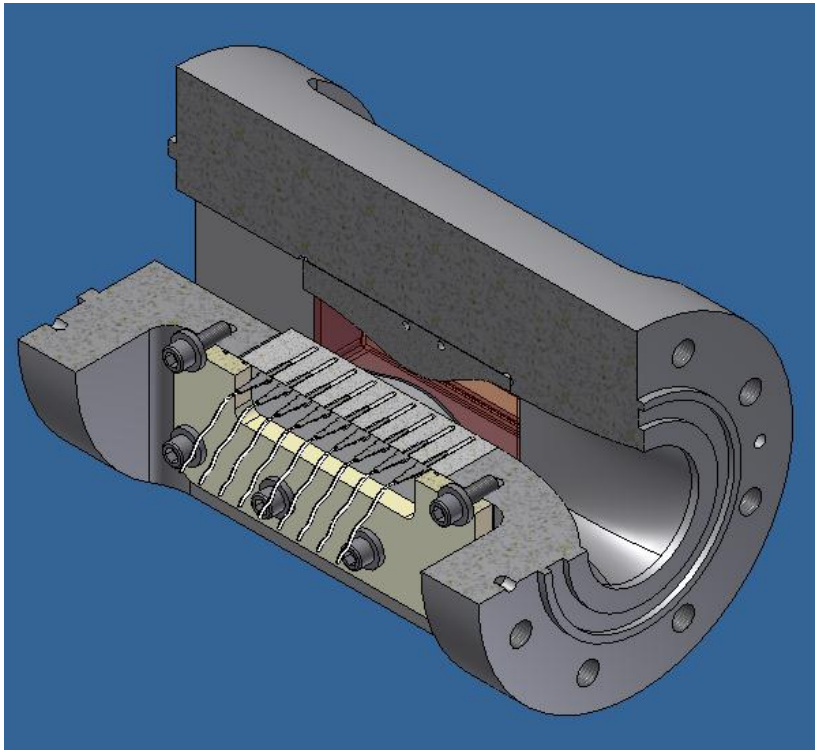
→ Instrumentation

→ Conclusions

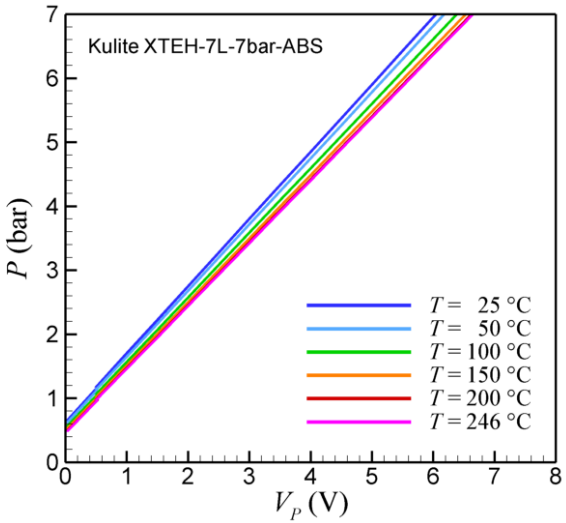
Instrumentation set up

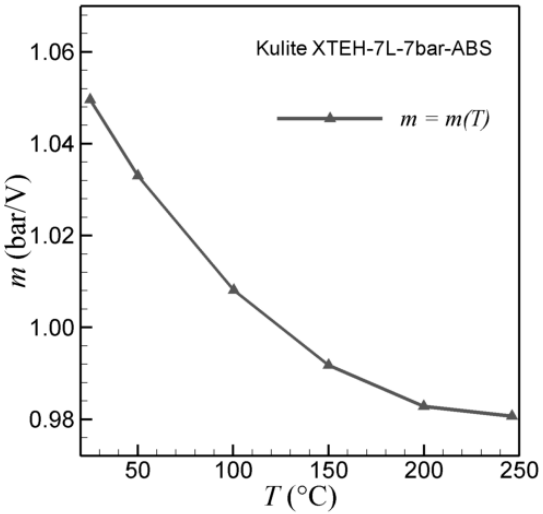
INSTRUMENTATION						
PROPERTY	*SENSOR*	*TYPE*	*CALIBRATION*		*UNCERTAINTY*	
			P (bar_A)	*T* (°C)	*P* (%FS)	*T* (°C)
T_{T6}	Thermocouple	J (Fe – Cu Ni)	–	25 – 250	–	± 0.4
P_{T6} , P_W	Piezo-resistive	Kulite XTEH	1 – FS (3.5÷ 40)	25 – 250	± 0.07	–

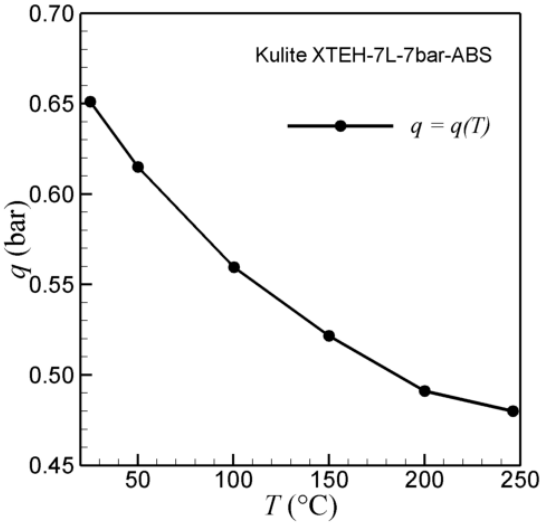




Transducer calibration

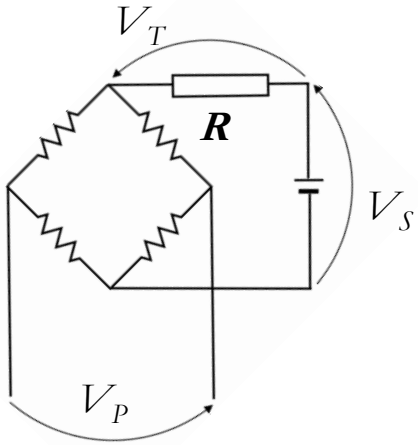


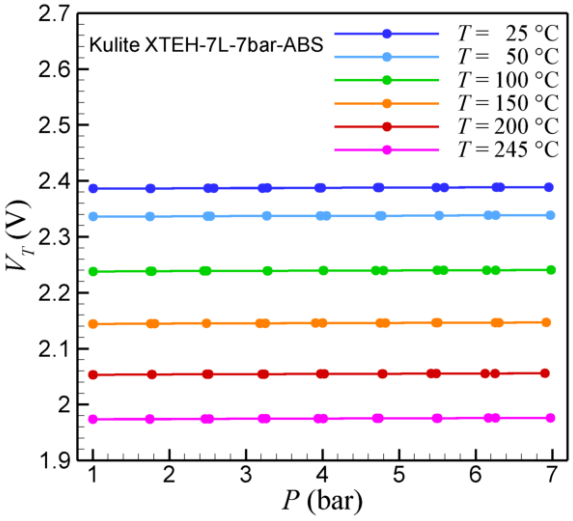


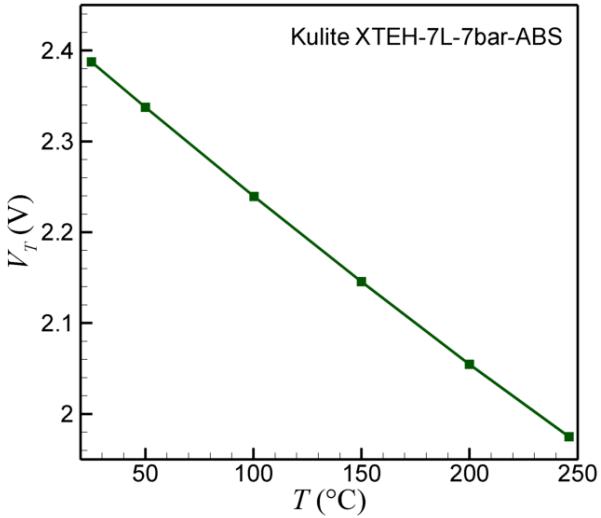


Thermal drift → *(P, T)* calibration $\quad T_{sensor} \rightarrow \{m(T_{sensor}), q(T_{sensor})\}$

T_{sensor} ? → additional *R* & calibration $\quad V_T \rightarrow T_{sensor}$







→ The TROVA

→ Start-up tests

→ Test section

→ Instrumentation

→ Conclusions

Conclusions

START-UP

- ✓ Sealing test → ~ OK
- ✓ Heating & MCV behaviour → OK (model improvement)
- ✓ Instrumentation setup *(P, T)* → OK

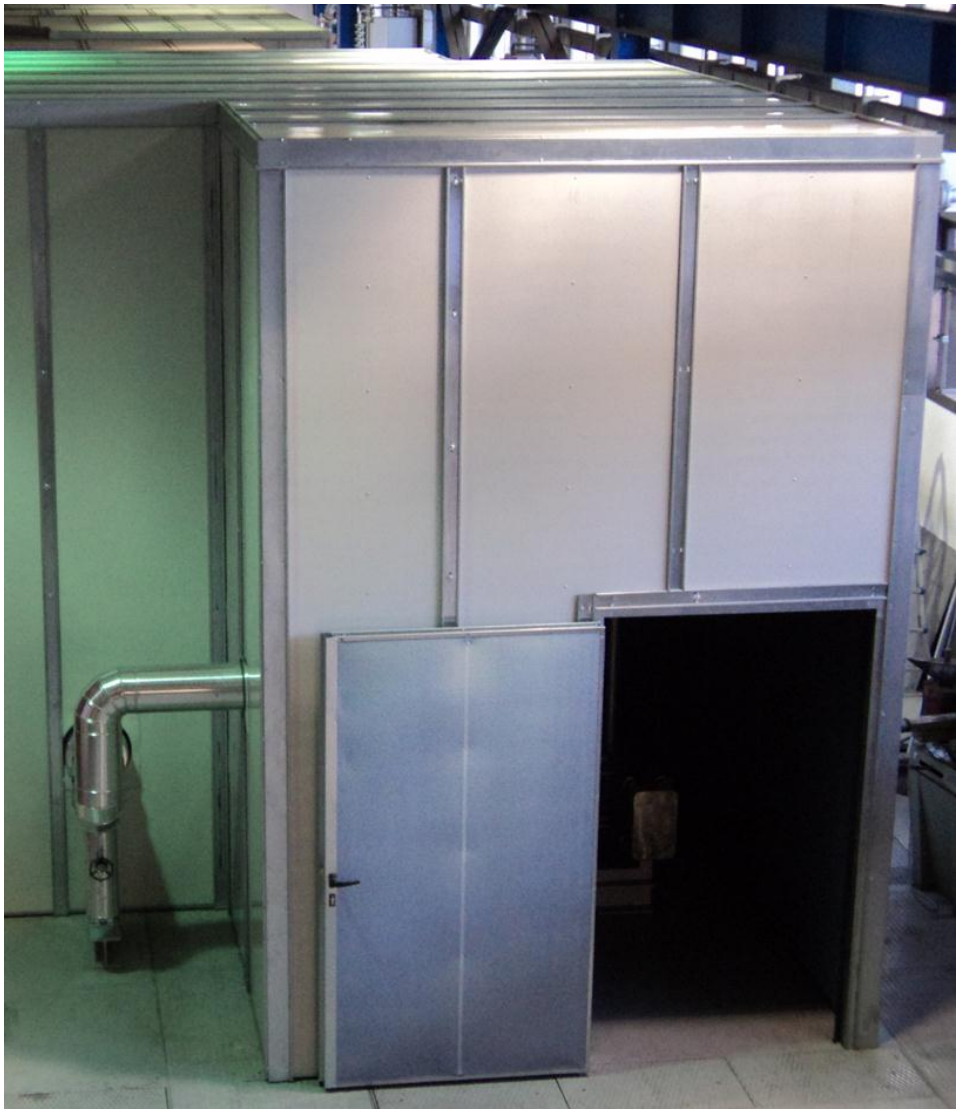
TEST

→ 1st Test scheduled December 2013

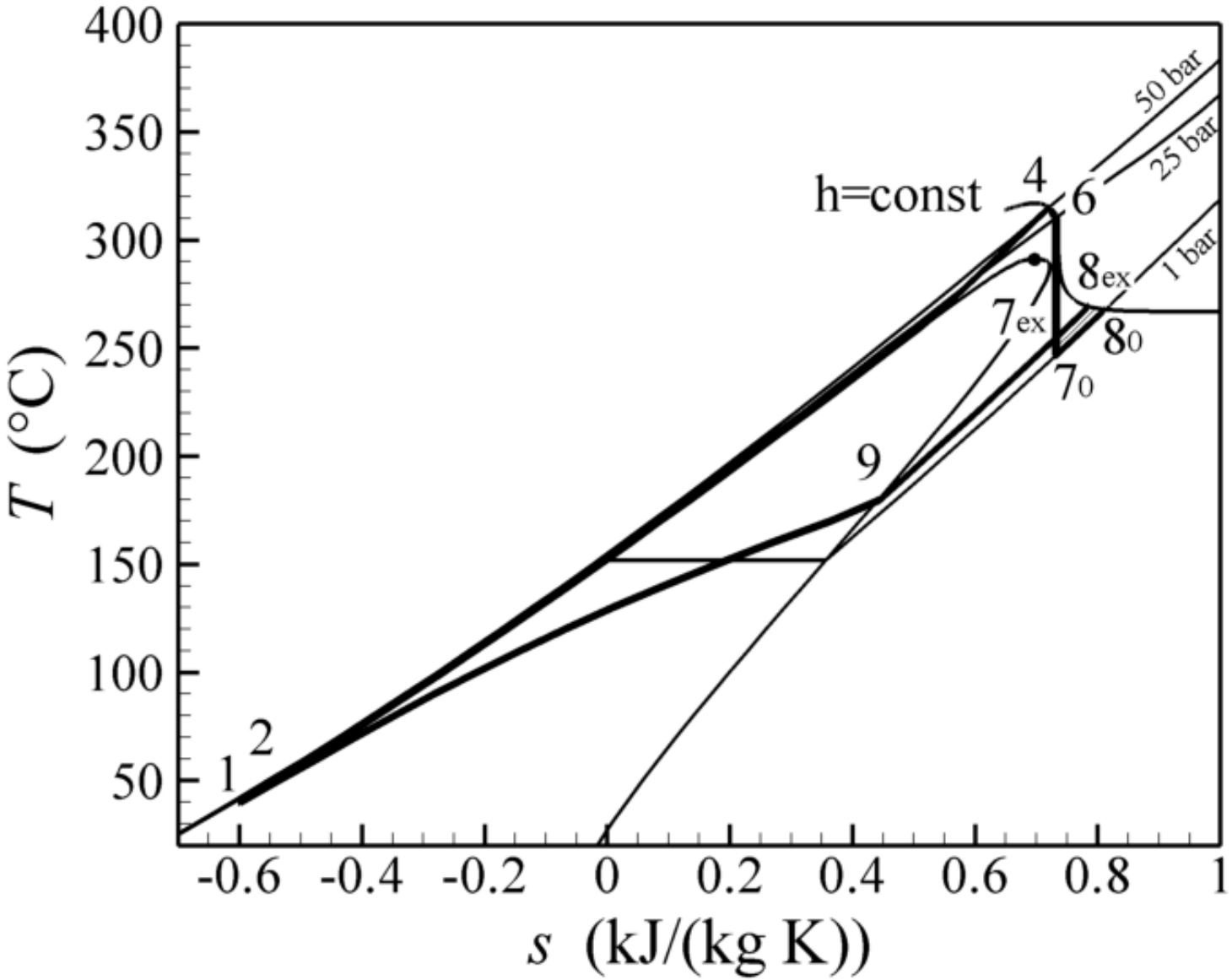
→ LDV system set up

→ Full test campaign

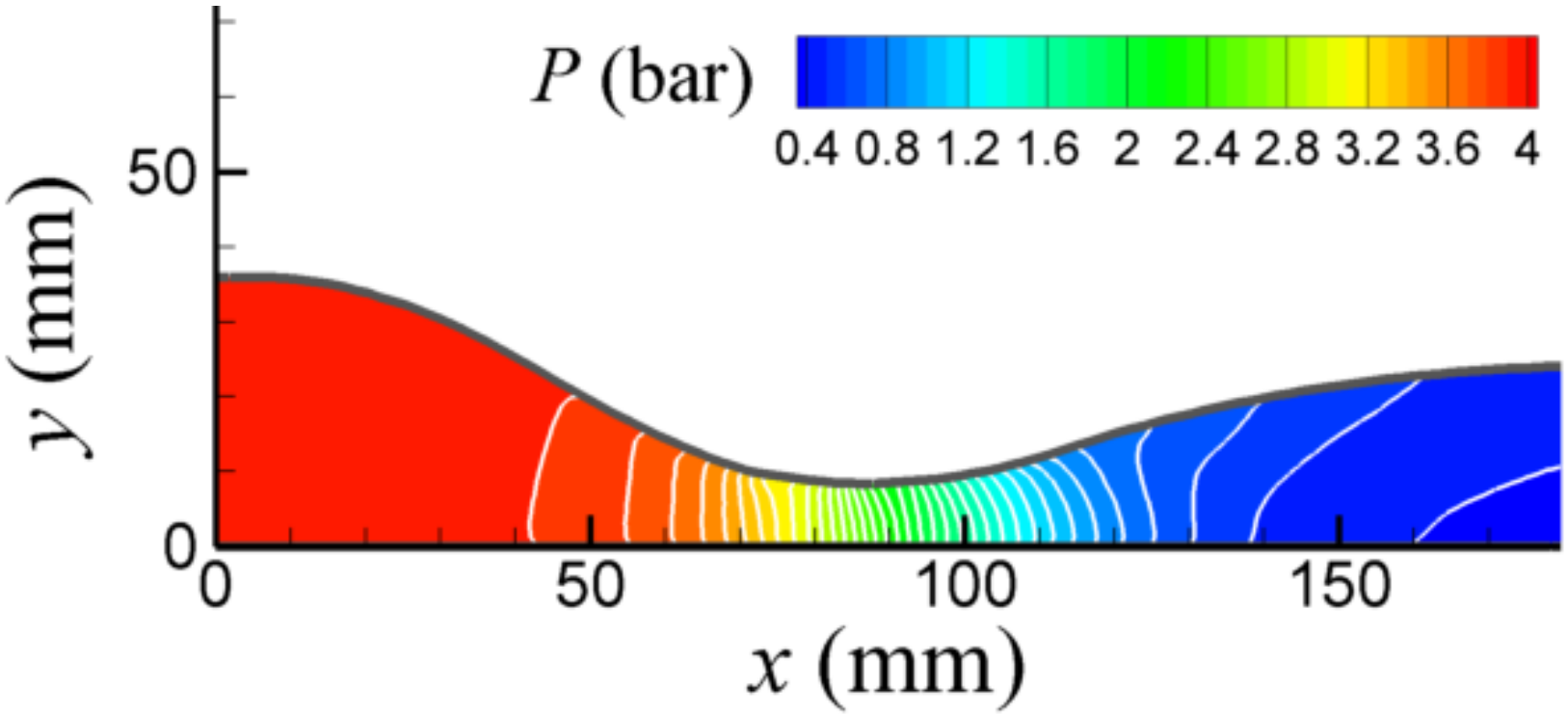
THANK YOU FOR YOUR ATTENTION



TROVA thermodynamic cycle



Nozzle CFD calculation



Orifice plate