

Investigations Of Low Pressure Two-Phase Steam – Water Injector

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- **Introduction**
- **Mathematical model of two-phase injector**
- **Analysis of isobutane two-phase injector**
- **Conclusions**

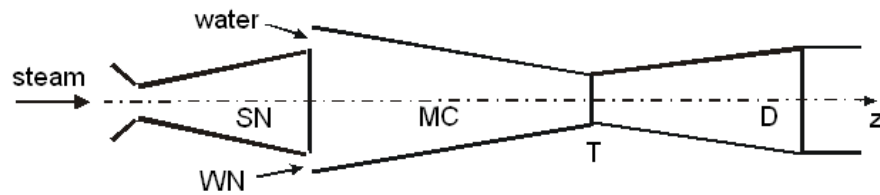
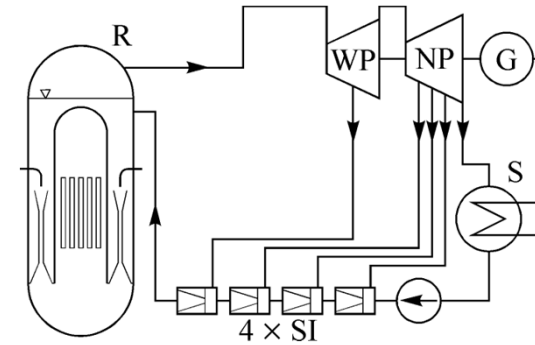
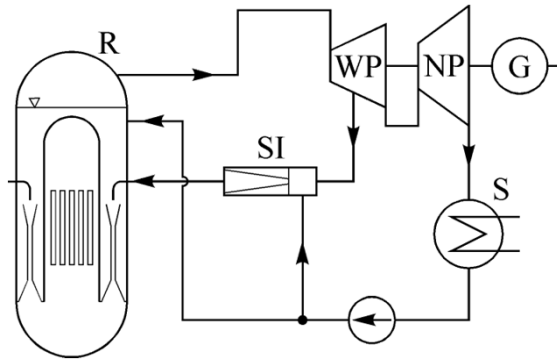


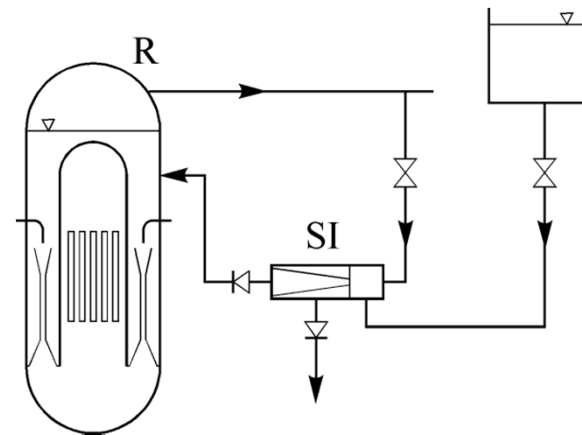
Figure 1. Schematic sketch of steam-water injector:
SN – steam nozzle, MC – mixing chamber, D - diffuser,
T- throat, WN – water nozzle.



Feed water heating device



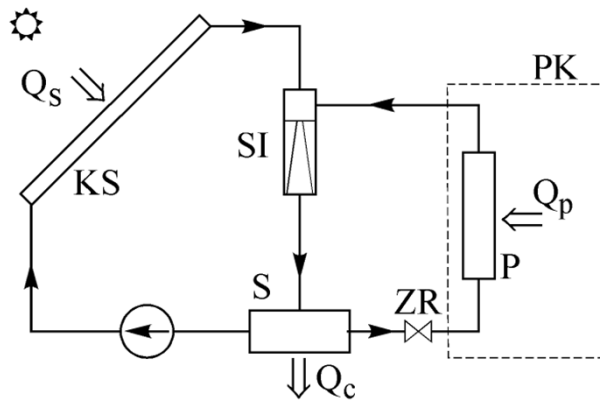
Cooling water feeding device



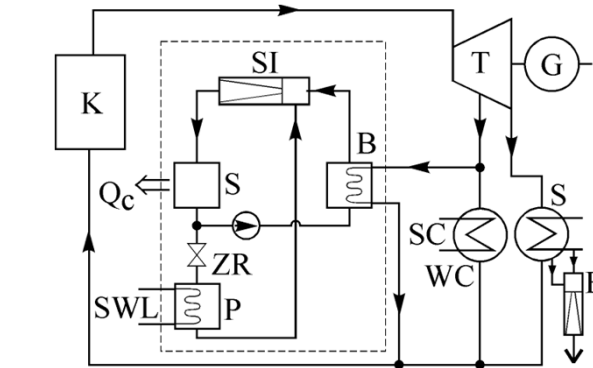
Safety reactor device

Exemplary applications of two-phase injectors in nuclear power systems

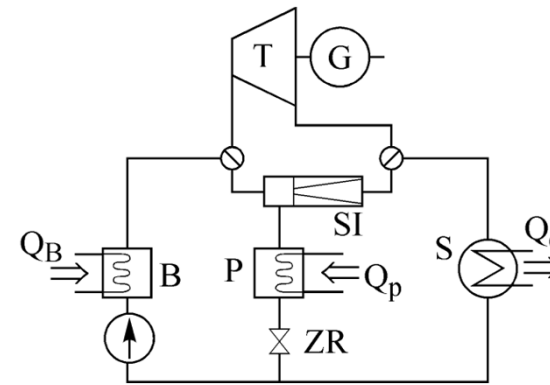
Exemplary applications of two-phase injectors in nuclear power systems



Solar air conditioning



Trigeneration
(injector refrigeration system)



Cogeneration

The general motivations of application of the two-phase injector instead of a mechanical pump in these systems are:

- two-phase injector is driven by part of steam that is generated already in the system; in this case the refrigeration system is fully thermal driven, without any consumption of electric power to drive the system;
- two-phase injector operates as a pre-heater of water supplied to the steam generator improving the system efficiency;
- this type of injector is more simple and reliable than mechanical liquid pump because it has no moving parts and is not influenced to possible cavitation that may occur in mechanical pumps.

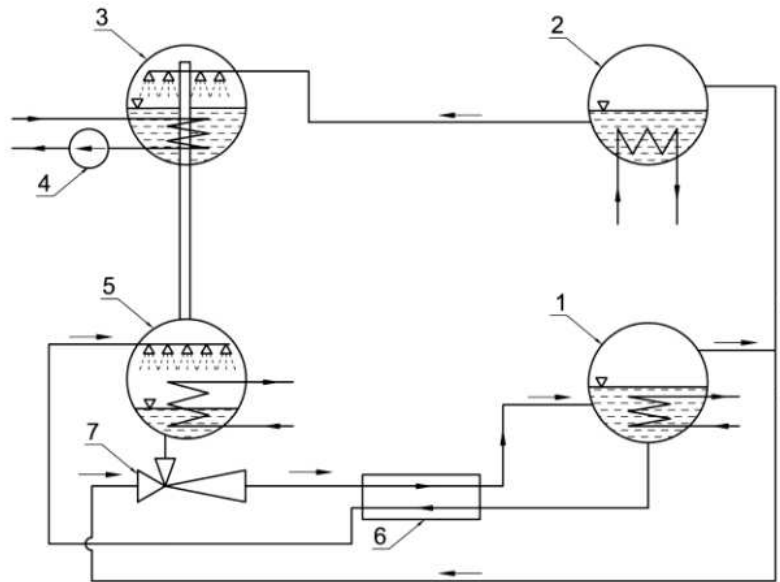


Figure 1: Modified absorption LiBr refrigeration system with two-phase injector as a liquid pump: 1– steam generator; 2 – condenser; 3 – evaporator; 4 – cold water pump; 5 – absorber; 6 – internal heat exchanger; 7 – steam-water injector.

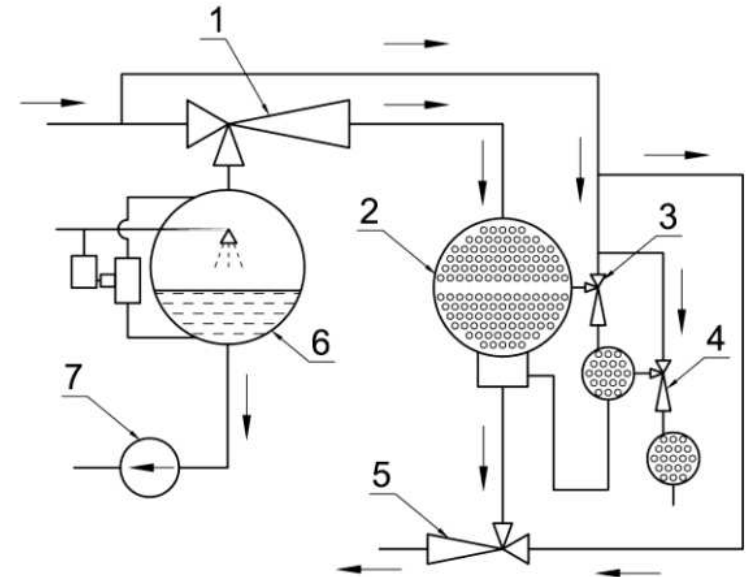
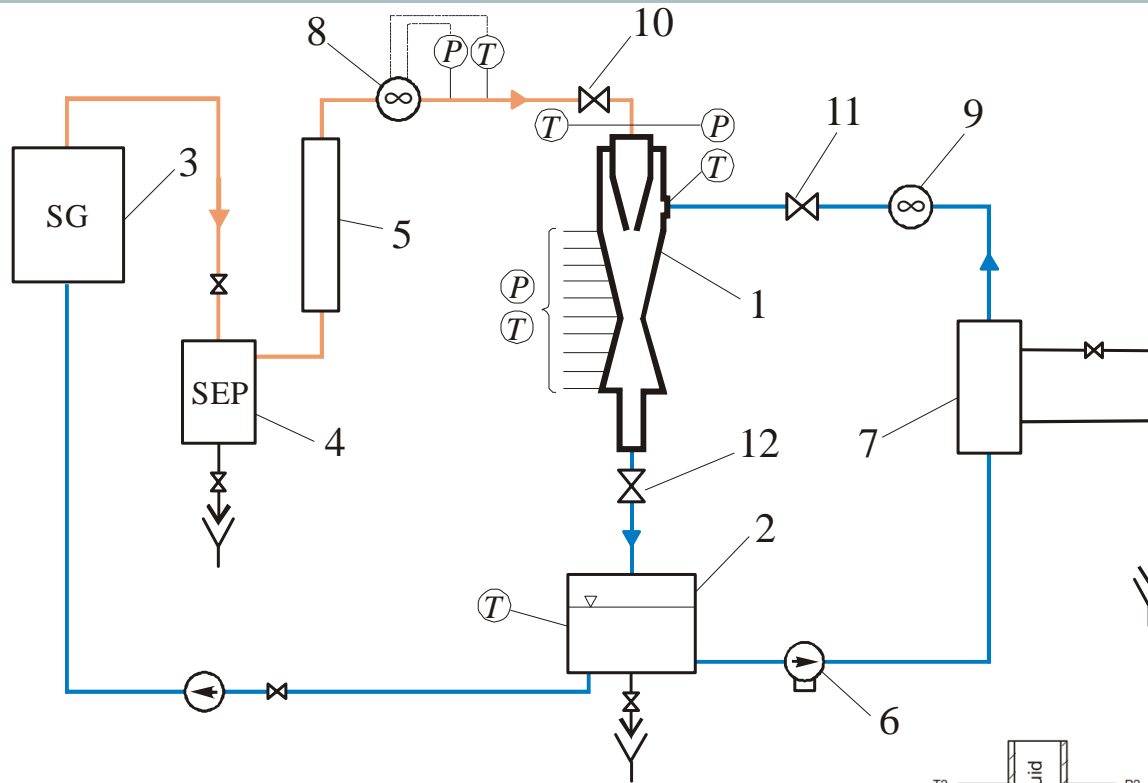


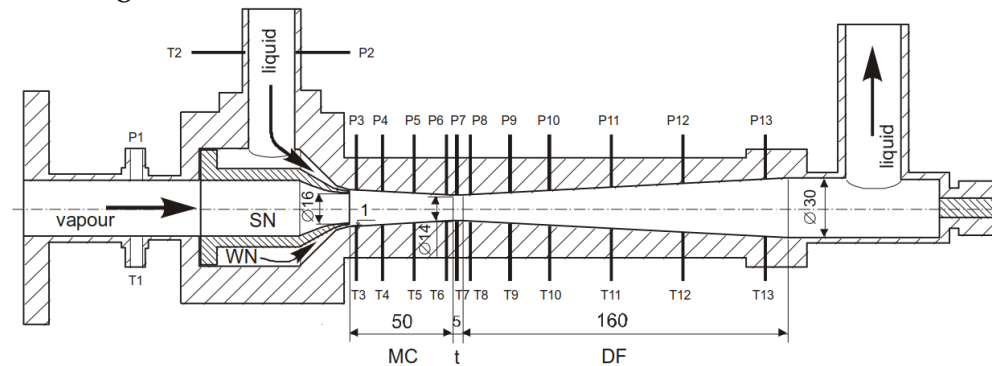
Figure 2: Modified steam ejection refrigeration system with two-phase injector as a liquid pump: 1– motive ejector; 2 – condenser; 3 – ejector vacuum pump of 1st step; 4 – ejector vacuum pump of 2nd step; 5 – steam-water injector; 6 – evaporator; 7 – cold water pump.

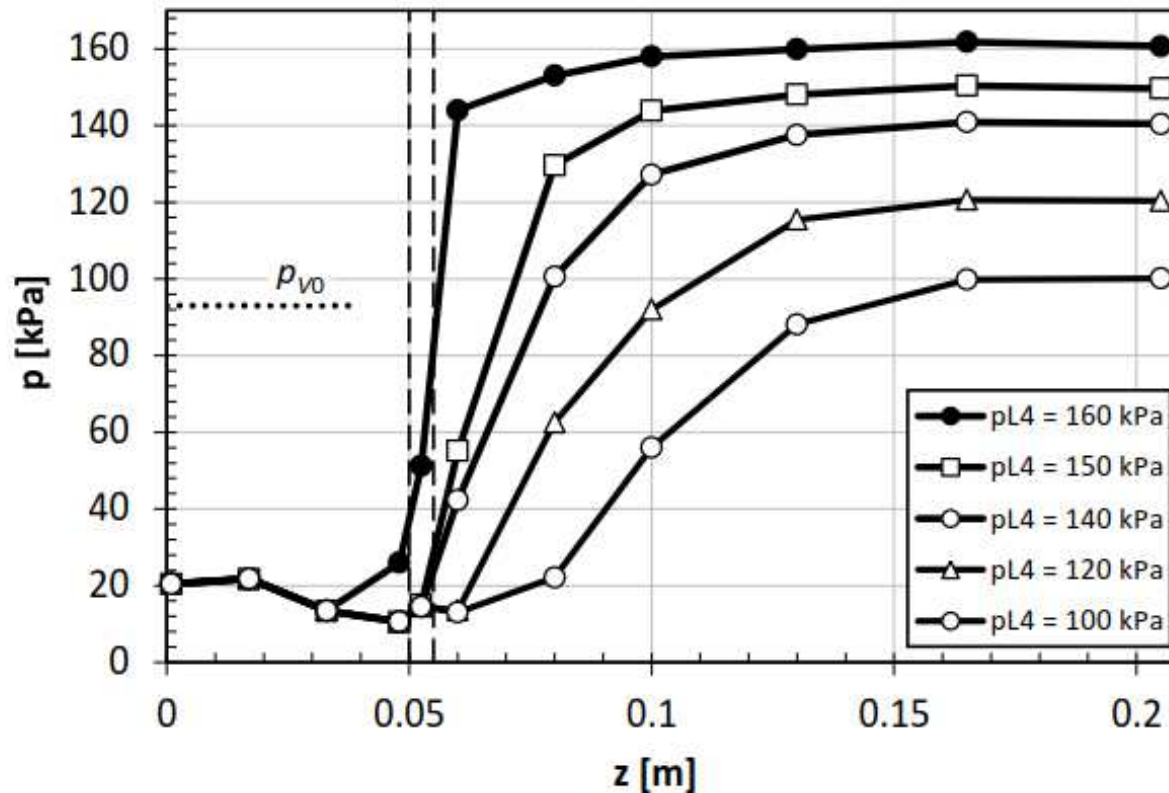
Experimental investigation



- 1 – low pressure steam-water injector,
- 2 – water tank, 3 – steam generator,
- 4 – steam separator, 5 – steam superheater,
- 6 – water pump, 7 – water cooler,
- 8 – steam flow meter, 9 – water flow meter,
- 10 – steam pressure control valve,
- 11 – water flow control valve,
- 12 – back-pressure control valve

SN – steam nozzle, WN – water nozzle,
MC – mixing chamber, DF – diffuser,
t – throat, T1 - T13 – temperature measurement,
P1 - P13 – pressure measurement.





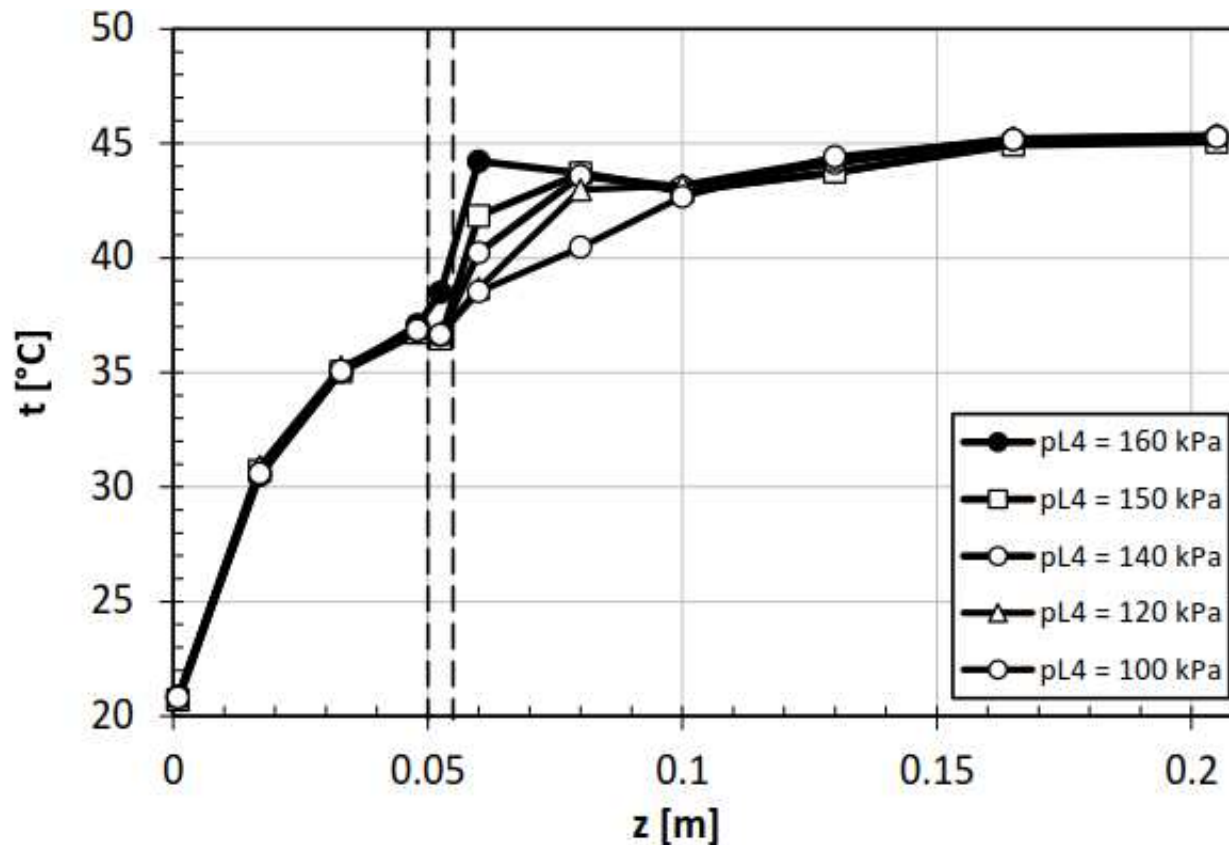
Distributions of pressure p along the LPSI mixing chamber and diffuser wall measured for constant inlet flow parameters and selected values of back-pressure p_{L4} .

Dashed lines indicate the extent of cylindrical throat.

Inlet steam parameters:

pressure 93 kPa, mass flow rate 111 kg/h, superheating 27 °C.

Inlet water parameters: temperature 20 °C, mass flow rate 2670 kg/h.



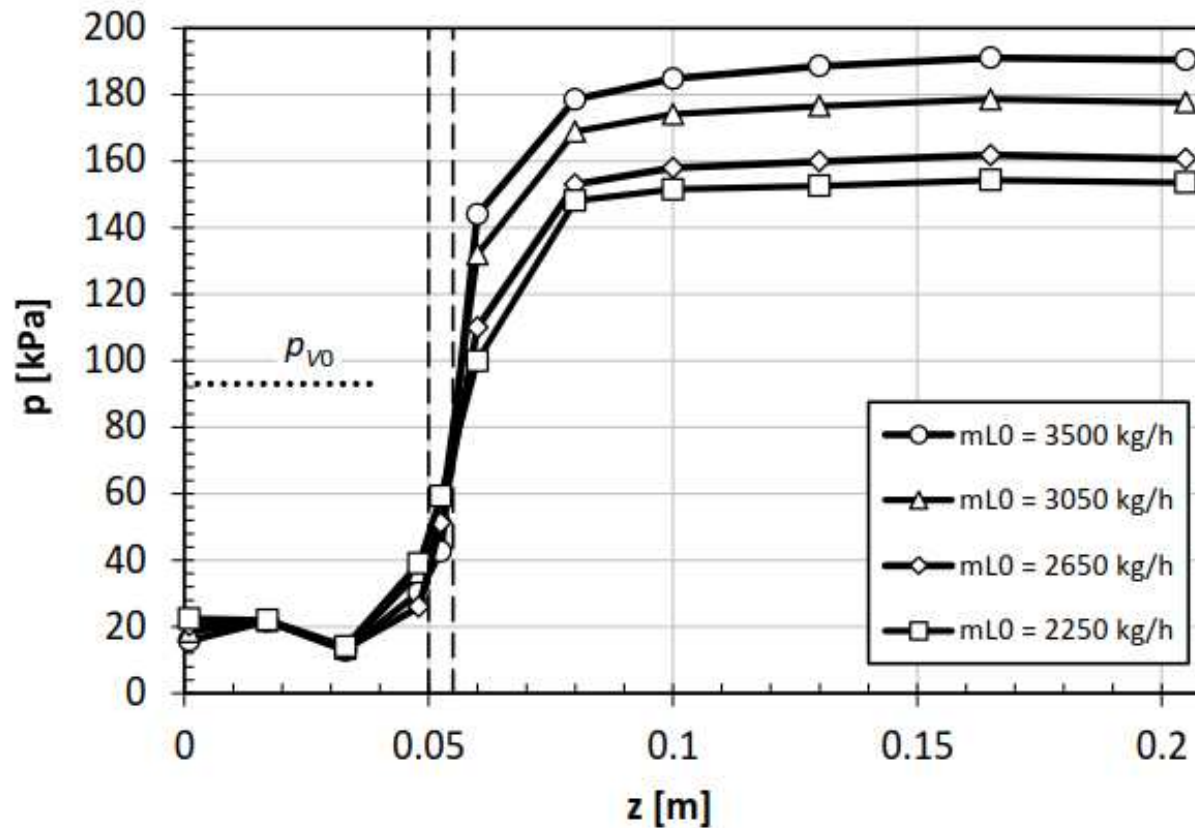
Distributions of temperature t along the LPSI mixing chamber and diffuser wall measured for constant inlet flow parameters and selected values of back-pressure p_{L4} .

Dashed lines indicate the extent of cylindrical throat.

Inlet steam parameters:

pressure 93 kPa, mass flow rate 111 kg/h, superheating 27 °C.

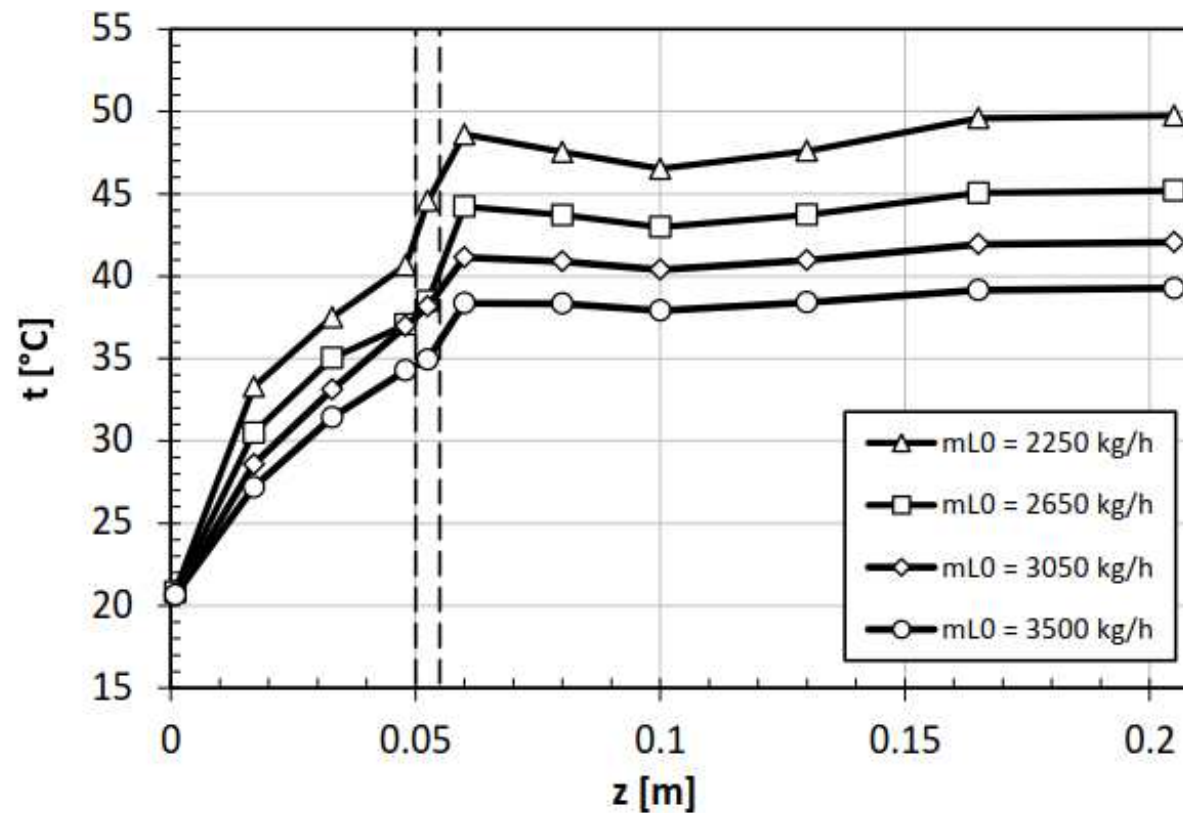
Inlet water parameters: temperature 20 °C, mass flow rate 2670 kg/h.



Distributions of average pressure p along the LPSI mixing chamber and diffuser wall .

Dashed line indicates the extent of cylindrical throat.

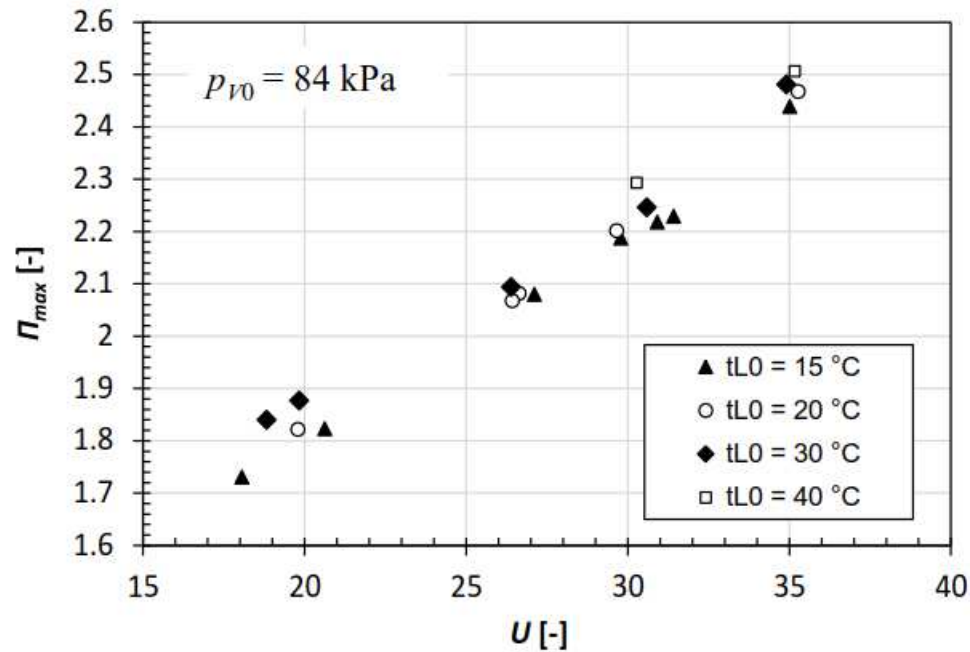
Inlet steam parameters:
pressure 93 kPa,
mass flow rate 111 kg/h,
superheating 26 °C.
Inlet water temperature 20 °C



Distributions of temperature along the LPSI mixing chamber and diffuser wall .

Dashed line indicates the extent of cylindrical throat.

Inlet steam parameters:
 pressure 93 kPa,
 mass flow rate 111 kg/h,
 superheating 26 °C.
 Inlet water temperature 20 °C

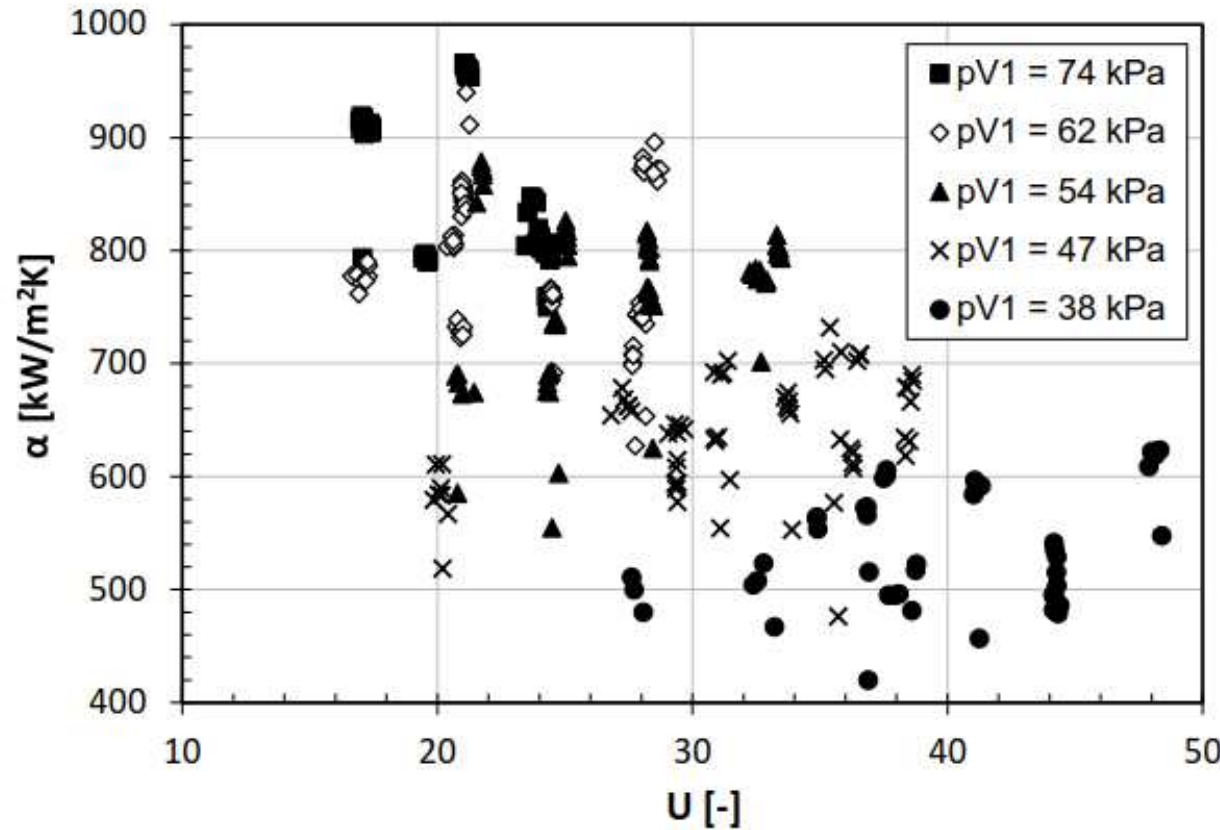


$$\Pi = \frac{P_{L4} - P_{L0}}{P_{V0} - P_{L0}}$$

$$U = \frac{\dot{m}_{L0}}{\dot{m}_{V0}}$$

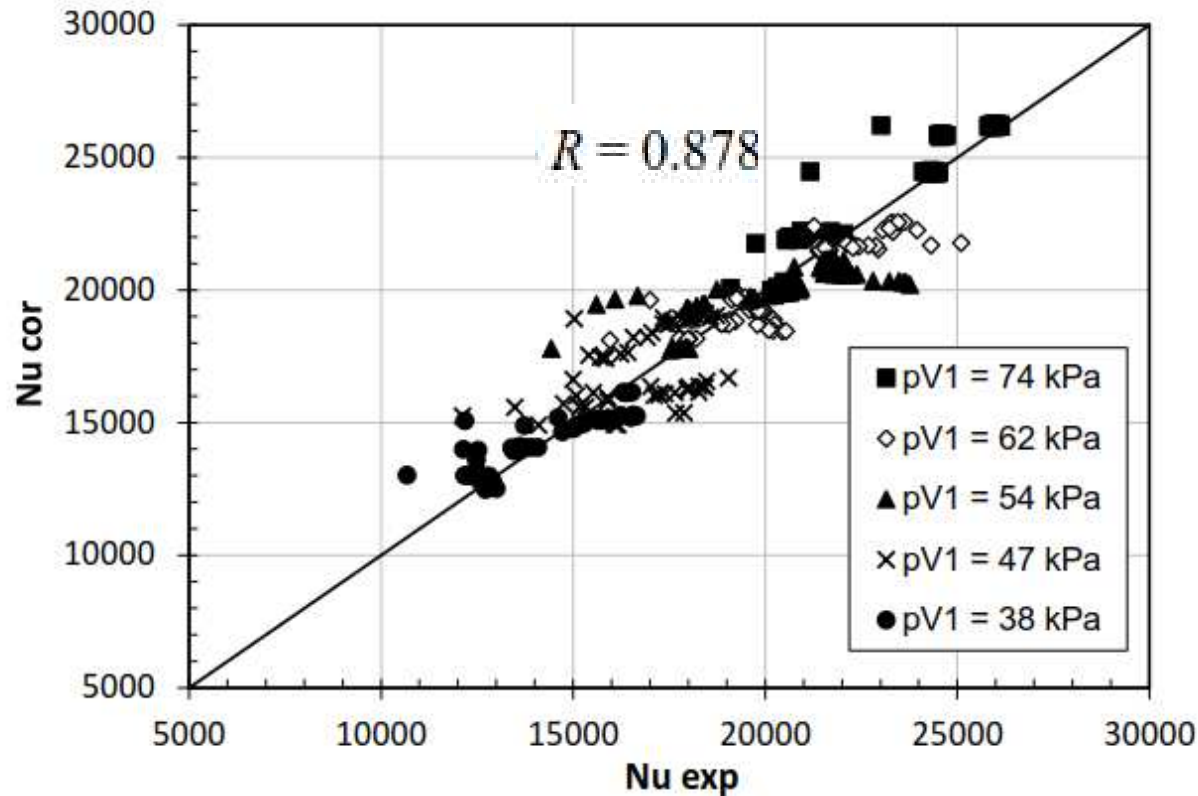
Compression ratio $\Pi = f(U)$ calculated for the LPSI driven by a steam at pressure $p_{V0} = 84 \text{ kPa}$, flow rate 100 kg/h and superheating $26 \text{ }^\circ\text{C}$.

Inlet water temperature t_{L0} was in the range $15 - 40 \text{ }^\circ\text{C}$.



Average heat transfer coefficient α calculated from pressure and temperature distributions in the LPSI mixing chamber.

The points are grouped by mixing chamber inlet pressure p_{V1}



Correlated vs experimental average heat transfer coefficient α for LPSI mixing chamber.

The points are grouped by mixing chamber inlet pressure pV1

$$Nu = 0.18 Re_{V1}^{1.04} U^{0.25} S_1^{0.17} Oh_{L1}^{0.43}$$

$$137000 < Re_{V1} < 263000, 16 < U < 49, 24 < S_1 < 44, 0.0024 < Oh_{L1} < 0.0045,$$

Conclusions

- Flow characteristics of a low pressure steam-water injector (LPSI) has been presented.
- The profiles of pressure and temperature in the LPSI are typical for a vapor–liquid injector of the central motive nozzle arrangement.
- The principal pressure gain of the liquid stream takes place in a region of condensation wave which forms in diffuser close to the mixing chamber throat.
- During the reported experiments with LPSI, the highest observed compression ratio Π reached about 2.5
- The discharge to motive pressure ratio, p_{L4}/p_{V0} , was approximately 2.2.
- Attention was paid to the evaluation of heat transfer coefficient α during condensation in the LPSI mixing chamber.
- For the LPSI they reach 1 MW/m²K. In comparison to the previously investigated
- supercritical steam injectors, they are higher by about 50 %.