Pressure drop prediction for a fuel bundle with grid spacers using Rehme pressure drop correlations validation against Pisa University experiments

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Fuel assembly pressure drop correlations (1)

The total pressure drop in a fuel assembly

$$\Delta p_{FA} = \Delta p_{inlet} + \Delta p_{outlet} + \Delta p_{orf} + \Delta p_{support\_grid} + \Delta p_{fric} + \Delta p_{grid\_spacers}$$

Fuel assembly inlet, outlet and orificing pressure losses

$$\Delta p_{inlet} + \Delta p_{outlet} + \Delta p_{orf} + \Delta p_{support\_grid} = (K_{inlet} + K_{outlet} + K_{orf} + K_{support\_grid}) * 0.5 * \rho * v^2$$

v - velocity of the coolant [m/s] which is calculated as:

$$v = \frac{G}{A_{flow} \cdot \rho}$$

G – is the coolant mass flow rate in [kg/s];
$\mathbf{A_{flow}}$ - is the unobstructed coolant flow area [m^2], determined using the design data of the experimental set-up;
$\mathbf{K_{inlet}}$, $\mathbf{K_{outlet}}$, $\mathbf{K_{orf}}$, $\mathbf{K_{support\_grid}}$ – the pressure loss coefficients for the inlet and outlet regions of a fuel assembly, the orificing pressure loss, as well as for the pressure loss due to the support grid, determined using the experimental pressure loss data.

Fuel assembly pressure drop correlations (2)

Pressure loss due to the flow friction along a smooth pipe

$$\Delta p_{fric} = f_{fric} * (L / D_e) * 0.5 * \rho * v^2$$

L - is the test section (tube) length [m];
D_e - the equivalent hydraulic diameter of the flow channel [m];
f_{fric} – flow friction factor which for the turbulent single phase flow can be estimated using the Blasius formula

$$f_{fric} = 0.316 / Re^{0.25}$$

Re - representing the Reynolds number of the flow channel

$$\mathrm{Re} = \frac{\rho \cdot v \cdot D_e}{\eta}$$

parameter η being the coolant dynamic viscosity [kg/(m·s)]

Fuel assembly pressure drop correlations (3)

The pressure loss due to a grid spacer as proposed by Rehme

$$\Delta p_{grid\_spacer} = C_v * \varepsilon^2 * 0.5 * \rho * v^2$$

C_v - is a modified drag coefficient that has been proposed by Dalle Donne

$$C_{v\_norm} = 3.5 + \frac{73.14}{Re^{0.264}} + \frac{2.79 \cdot 10^{10}}{Re^{2.79}}$$

$$C_{v\_max} = \frac{2}{\varepsilon^2}$$

$$C_v = MIN\left[3.5 + \frac{73.14}{Re^{0.264}} + \frac{2.79 \cdot 10^{10}}{Re^{2.79}}, \frac{2}{\varepsilon^2}\right]$$

ε - is the blockage factor of the grid spacer (ratio of areas) which ranges from 0.15 to 0.5 for typical grid spacer designs, where

A_{grid_spacer} is the cross-section area of the grid spacer in the flow path [m^2], and

A_{flow} is the unobstructed coolant flow area [m^2]

$$\varepsilon = \frac{A_{grid\_spacer}}{A_{flow}}$$

$$\Delta p_{grid\_spacers} = N_{spacers} * \Delta p_{grid\_spacer}$$

Design parameters for the PDS-XADS fuel assembly, as well as the Pisa test facility water loop fuel assembly mock-up

	PDS-XADS	Pisa test facility
Geometry	hexagonal	hexagonal
Fuel pins	90	90
Tie rod	1	1
Pin diameter	8.5 mm	8.5 mm
Tie rod diameter	12 mm	12 mm
Pitch	13.41 mm	13.41 mm
Pin length	1272 mm	1272 mm
Active height	870 mm	870 mm
Number of grid spacers	3	3
Grid spacer thickness	0.25	0.25 mm
Grid spacer height	25.0	25.0 mm
Grid spacer dimples	closed/blocked	closed/blocked
Fuel assembly wrapper thickness	2.0 mm	2.0 mm
Mean velocity	~ 0.42 m/s (LBE)	~ 2.5 m/s (water)
Mass flow	~ 41 kg/s (LBE)	~ 25 kg/s (water)
Sub channel area	9330 mm²	10220 mm²
Inlet temperature	~ 300 °C (LBE)	~ 25 °C (water)
Outlet temperature	~ 400 °C (LBE)	~ 25 °C (water)

Parameters used in pressure drop calculations for the Pisa test facility water loop fuel assembly mock-up

Karlsruhe Institute of Technology

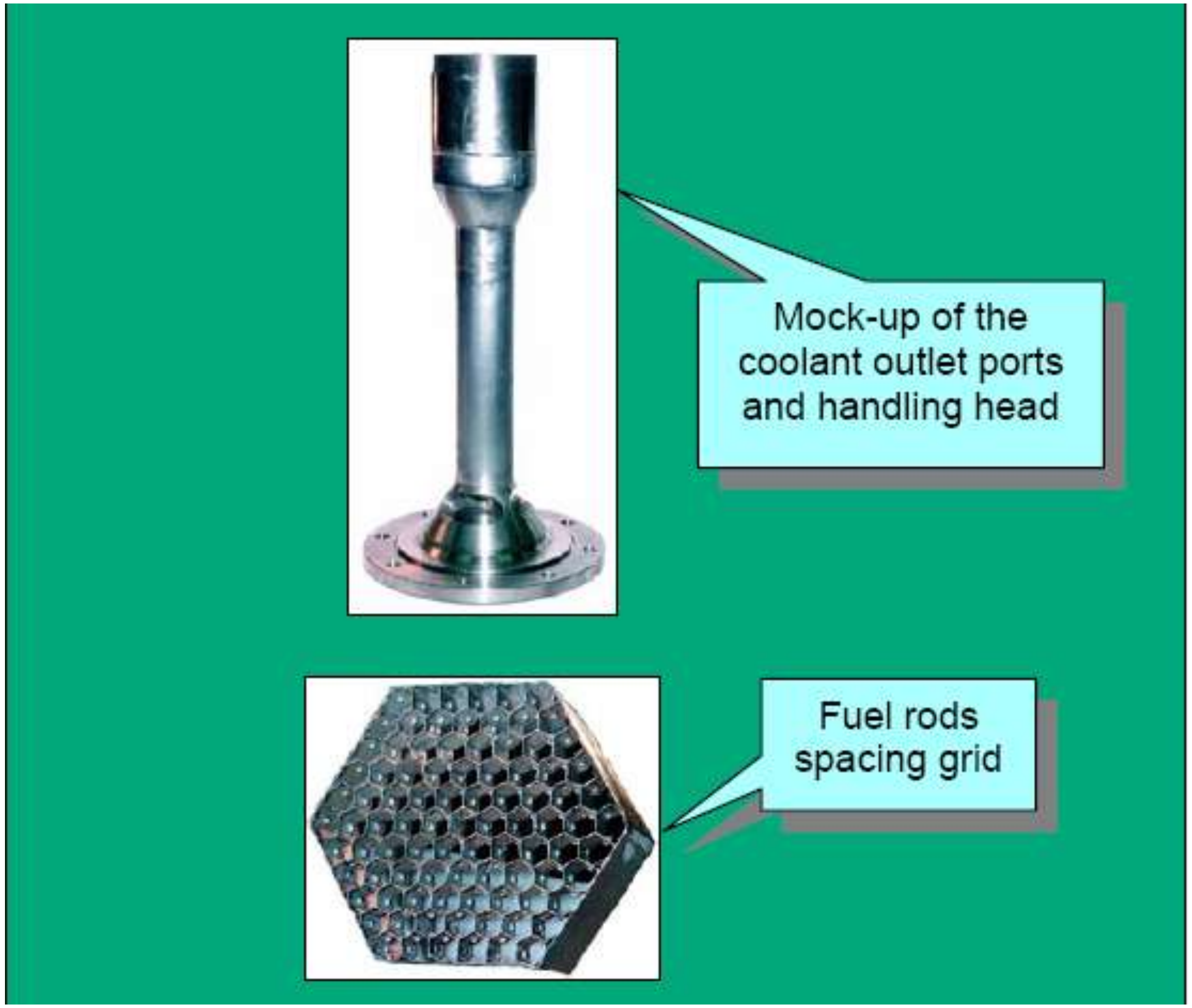
	Pisa test facility
Coolant (water) density (ρ)	988 kg/m^3
Coolant (water) dynamic viscosity (η)	0.001015 kg/(m·s)
Unobstructed coolant flow area (A_{flow})	0.01022 m^2
Inlet pressure loss coefficient (K_{inlet})*	7.15
Outlet pressure loss coefficient (K_{outlet})*	3.65
Orificing pressure loss coefficient (K_{orf})*	0.0
Support grid pressure loss coef. ($K_{support\_grid}$)*	3.3
Test section (tube) length (L)	1.55 m
Equivalent hydraulic diameter (D_e)	0.0142 m
Grid spacer blockage area (A_{grid_spacer})*	0.004862 m^2
Assumed grid spacer blockage factor (ε)*	0.4757
Calculated grid spacer blockage factor (ε)**	0.355
Number of grid spacers ($N_{spacers}$)	3

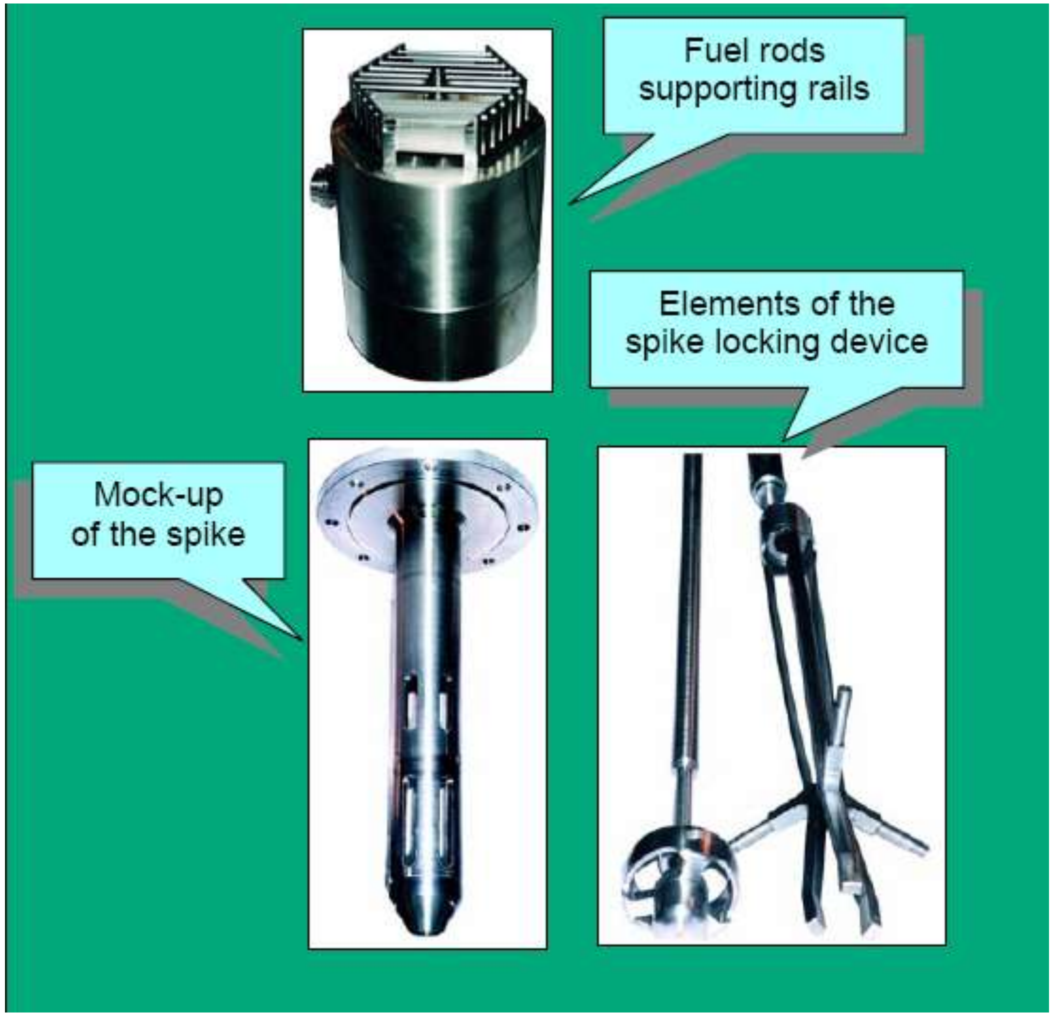
* - determined by the best fit to the experimental data

** - calculated based on geometric design data

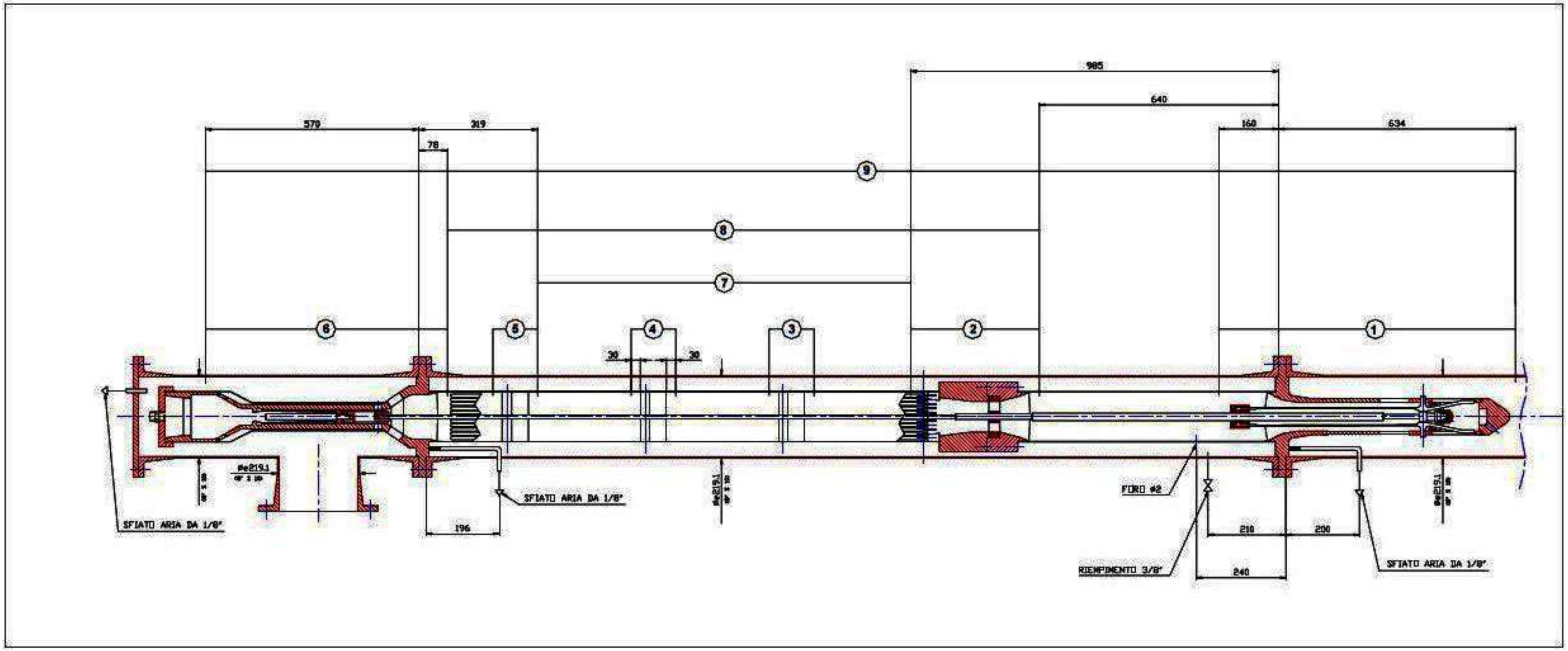
Views of PDS-XADS Sub-assembly Test Section at Scalbatraio Laboratory of the Pisa University

PDS-XADS Sub-Assembly Details

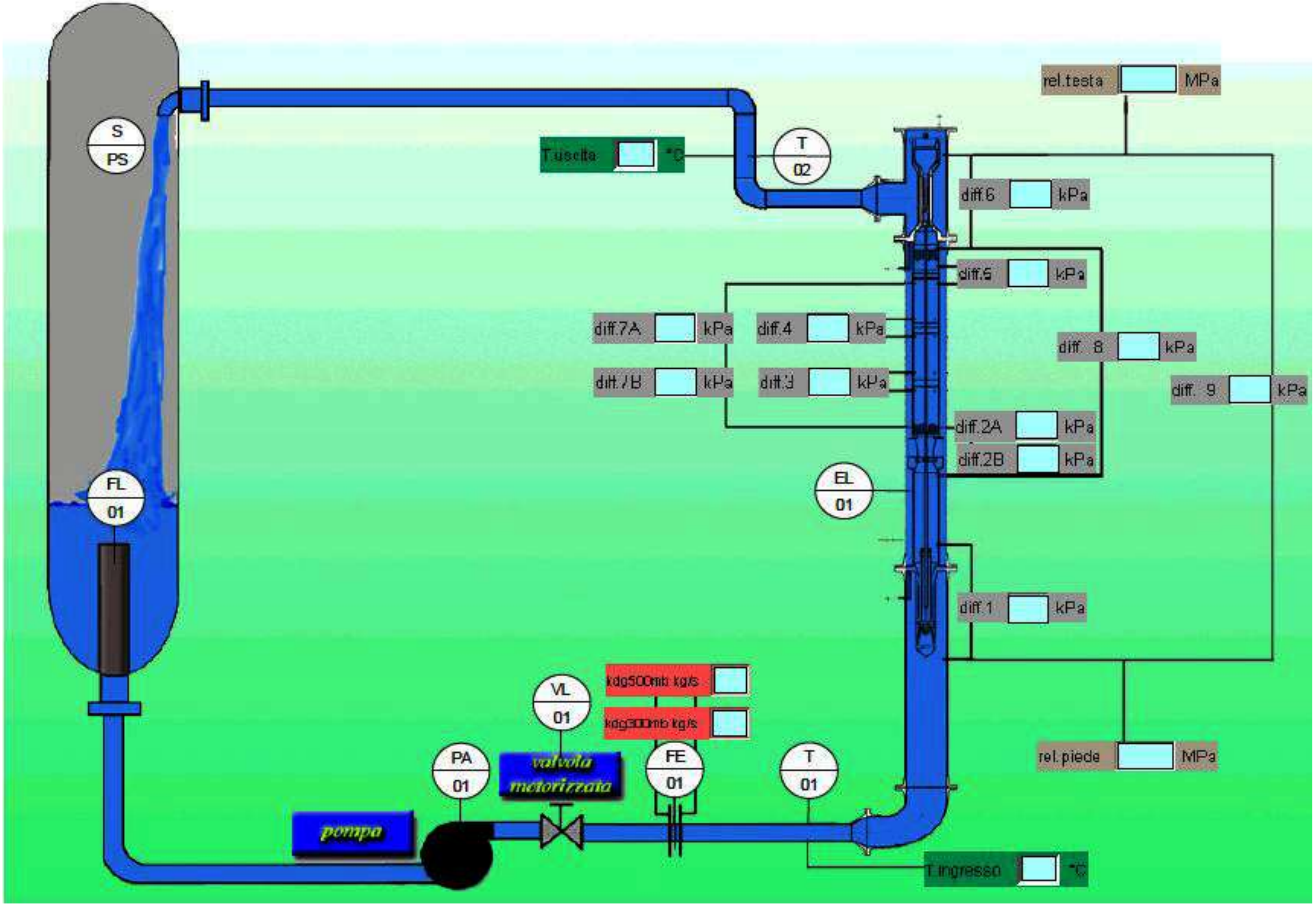




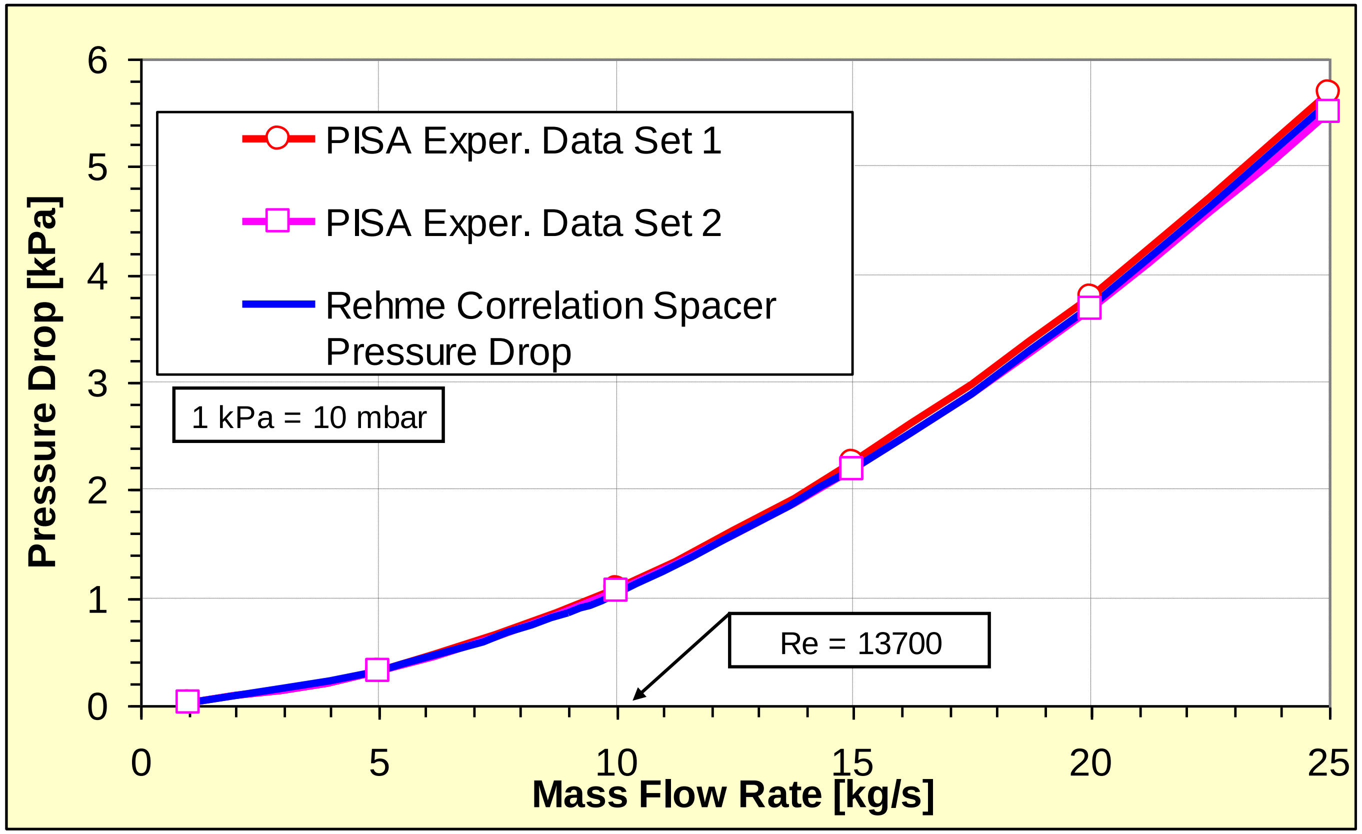
Test section for fuel assembly pressure drop measurements



Experimental water loop at Scalbatraio Laboratory of Pisa University (2003)



Single grid spacer pressure drop (1)

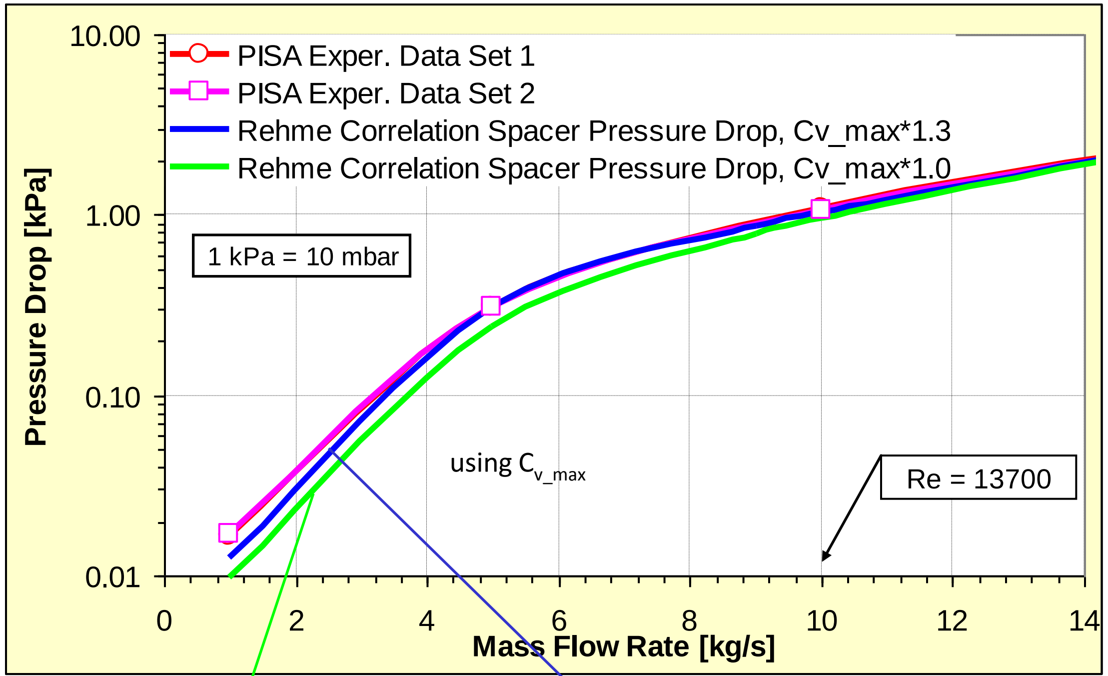


Comparison of SIM-ADS calculational results and measured data for a single grid spacer pressure drop, where ε = 0.4757 and C_v as calculated using

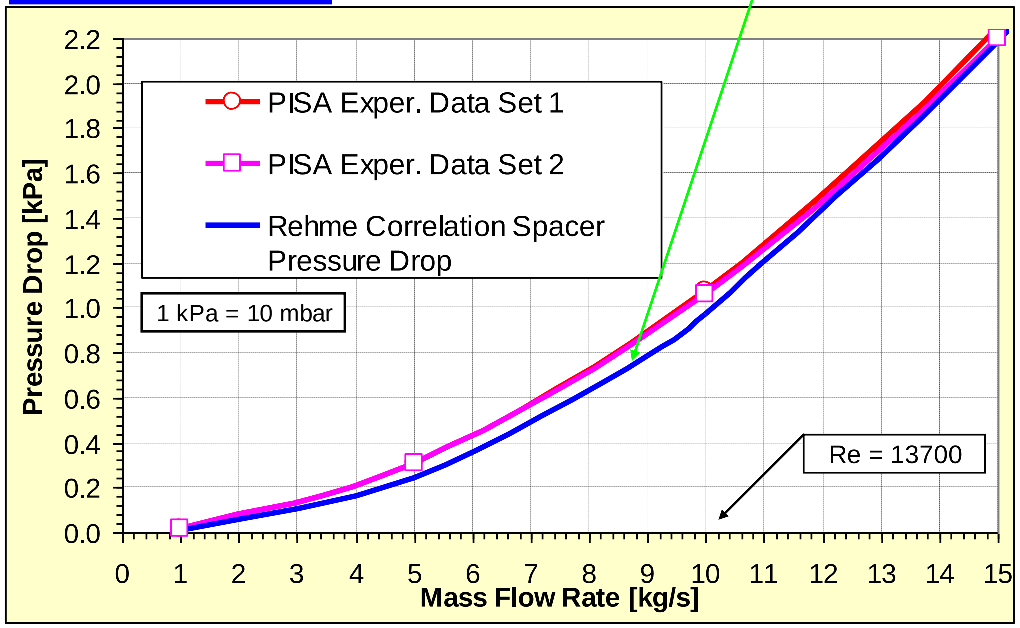
$$C_v = MIN\left[3.5 + \frac{73.14}{\mathrm{Re}^{0.264}} + \frac{2.79\cdot 10^{10}}{\mathrm{Re}^{2.79}}, \frac{2}{\varepsilon^2}*1.3\right]$$

where C_{v_max} is increased by 30%

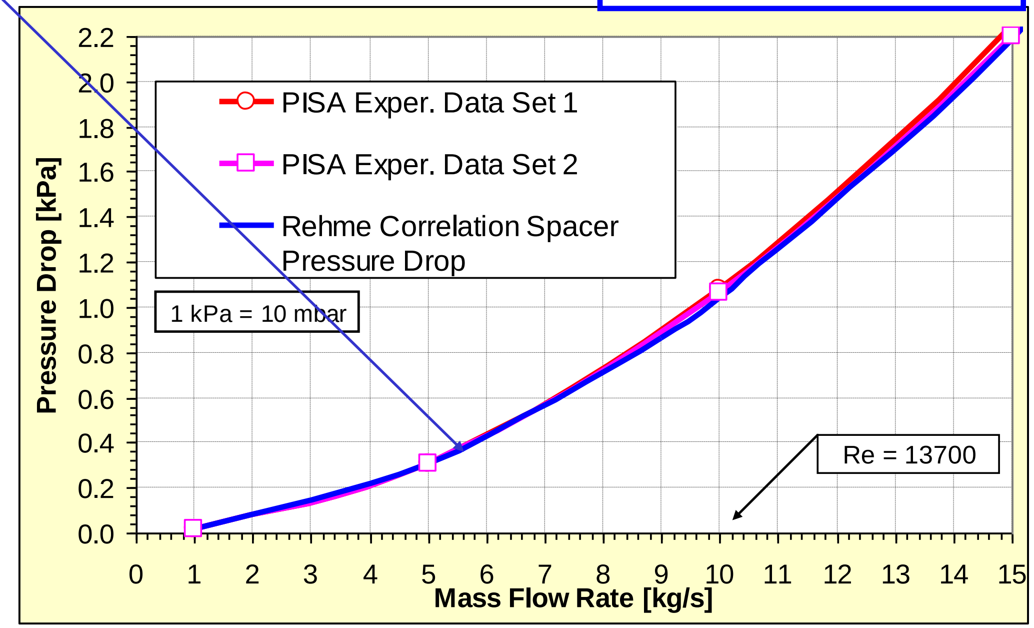
Single grid spacer pressure drop (2)



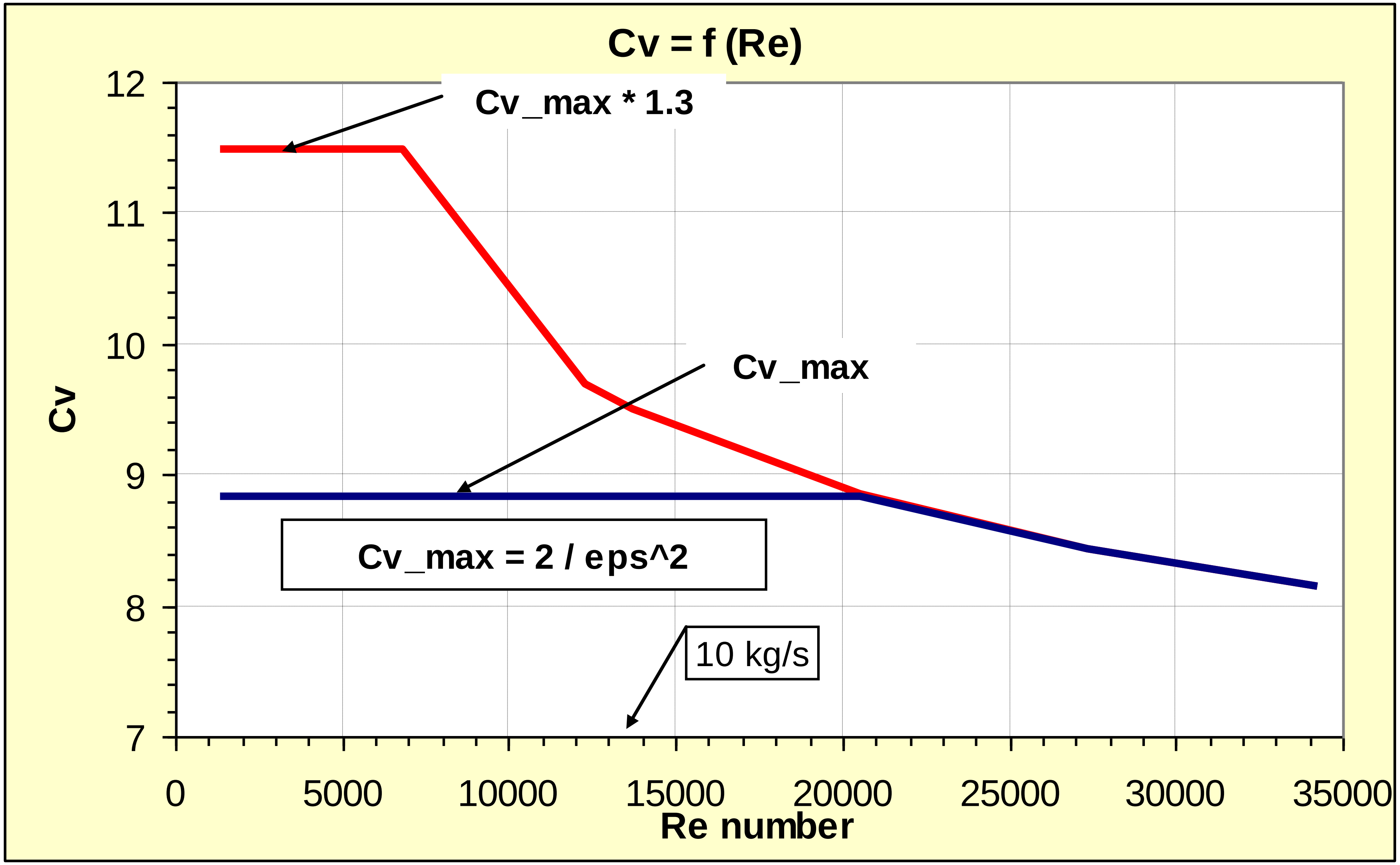
using C_{v_max}



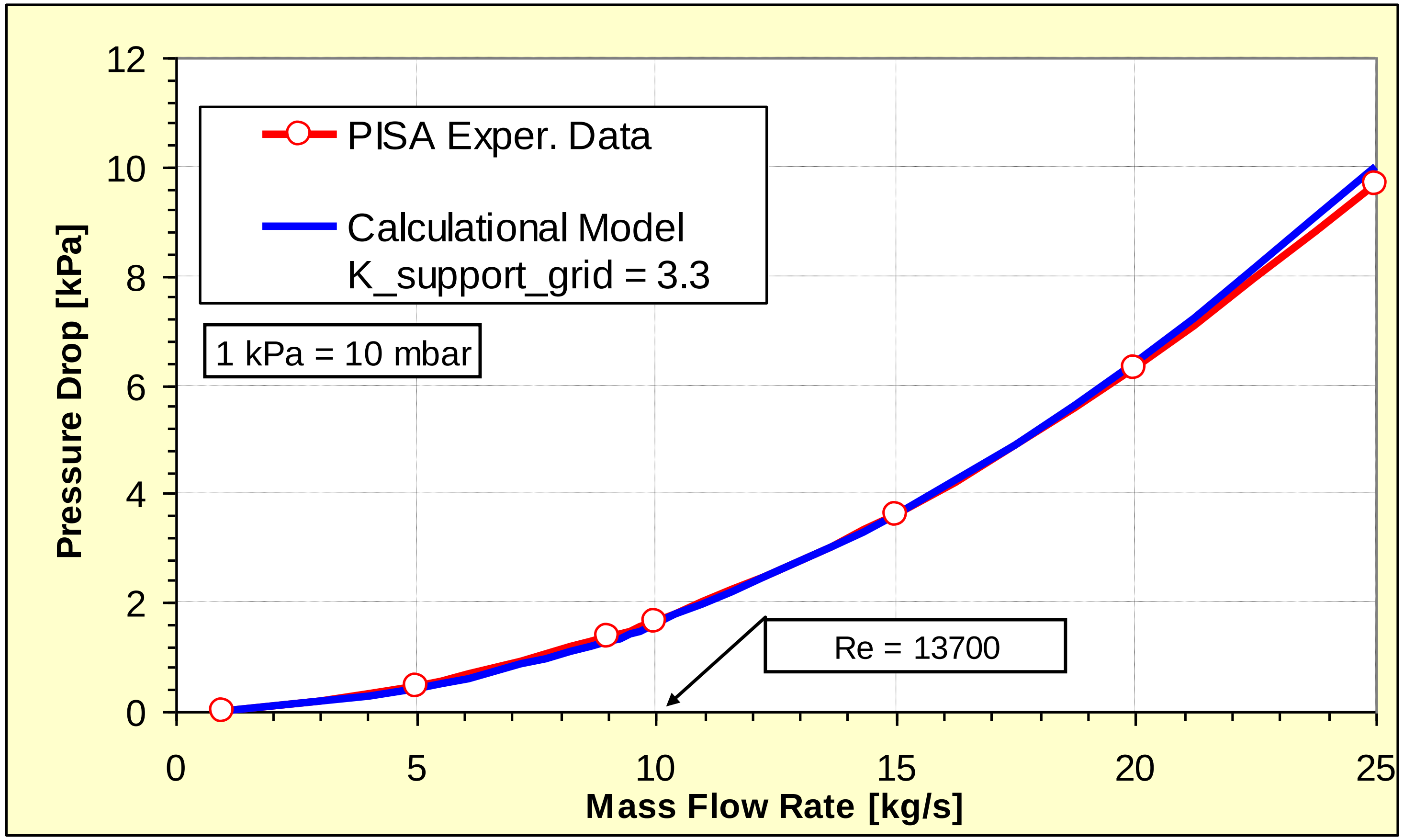
using C_{v_max} * 1.3



Influence of C_{v_max} on C_v vs Reynolds

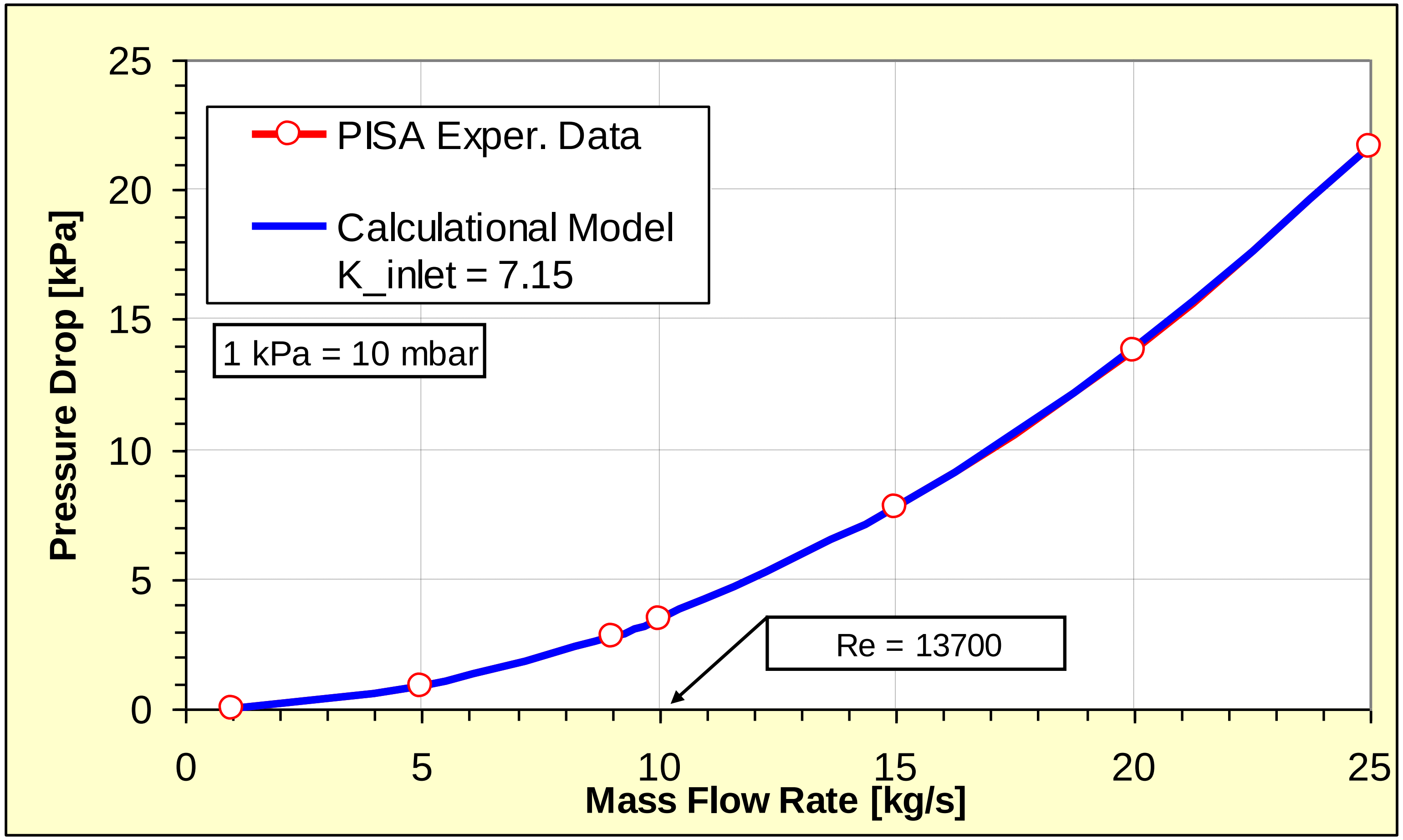


Support grid pressure drop



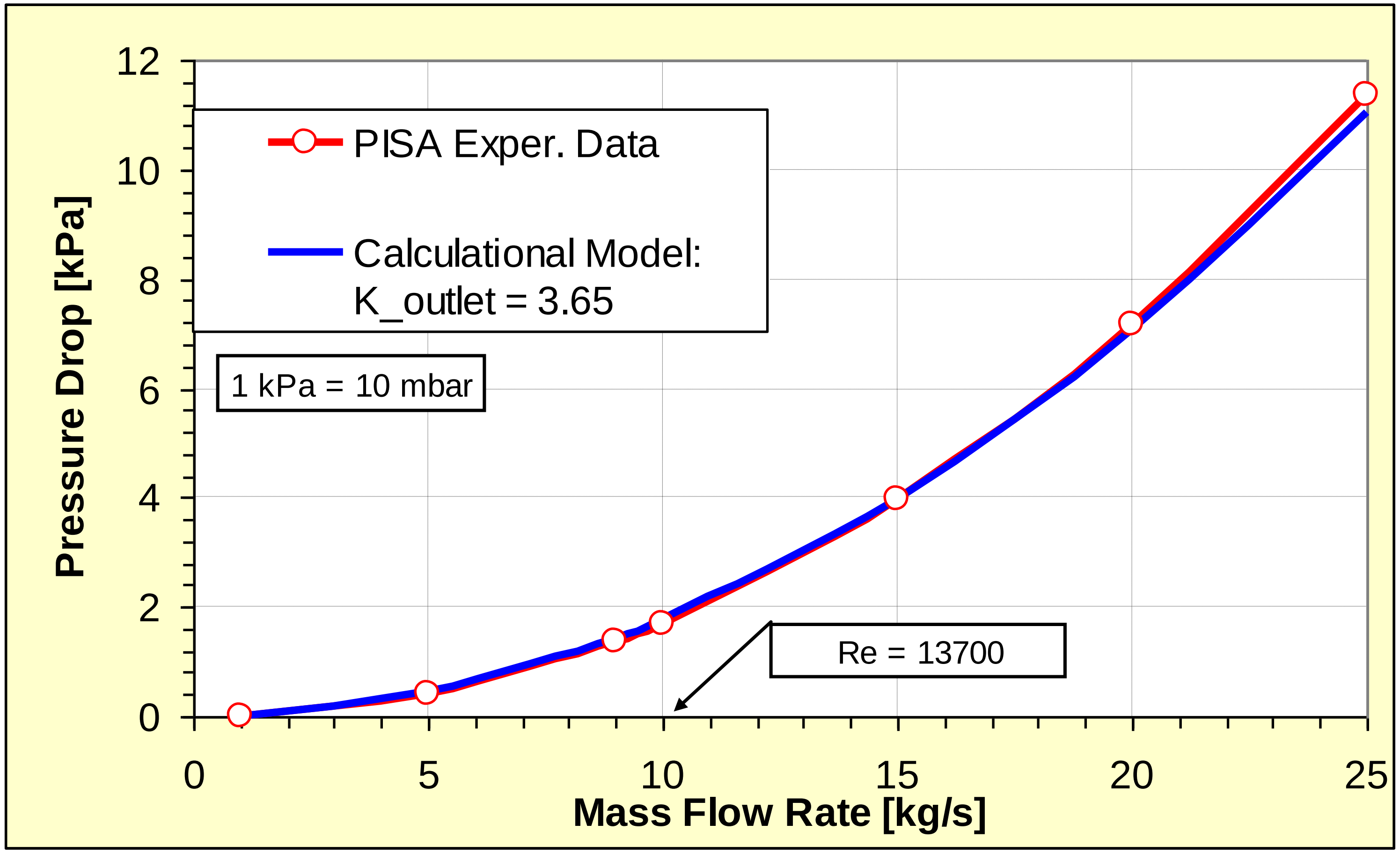
Comparison of SIM-ADS calculational results and measured data for the support grid pressure drop, using K_support_grid = 3.3 (determined by the best fit to the experimental data)

SA inlet pressure drop



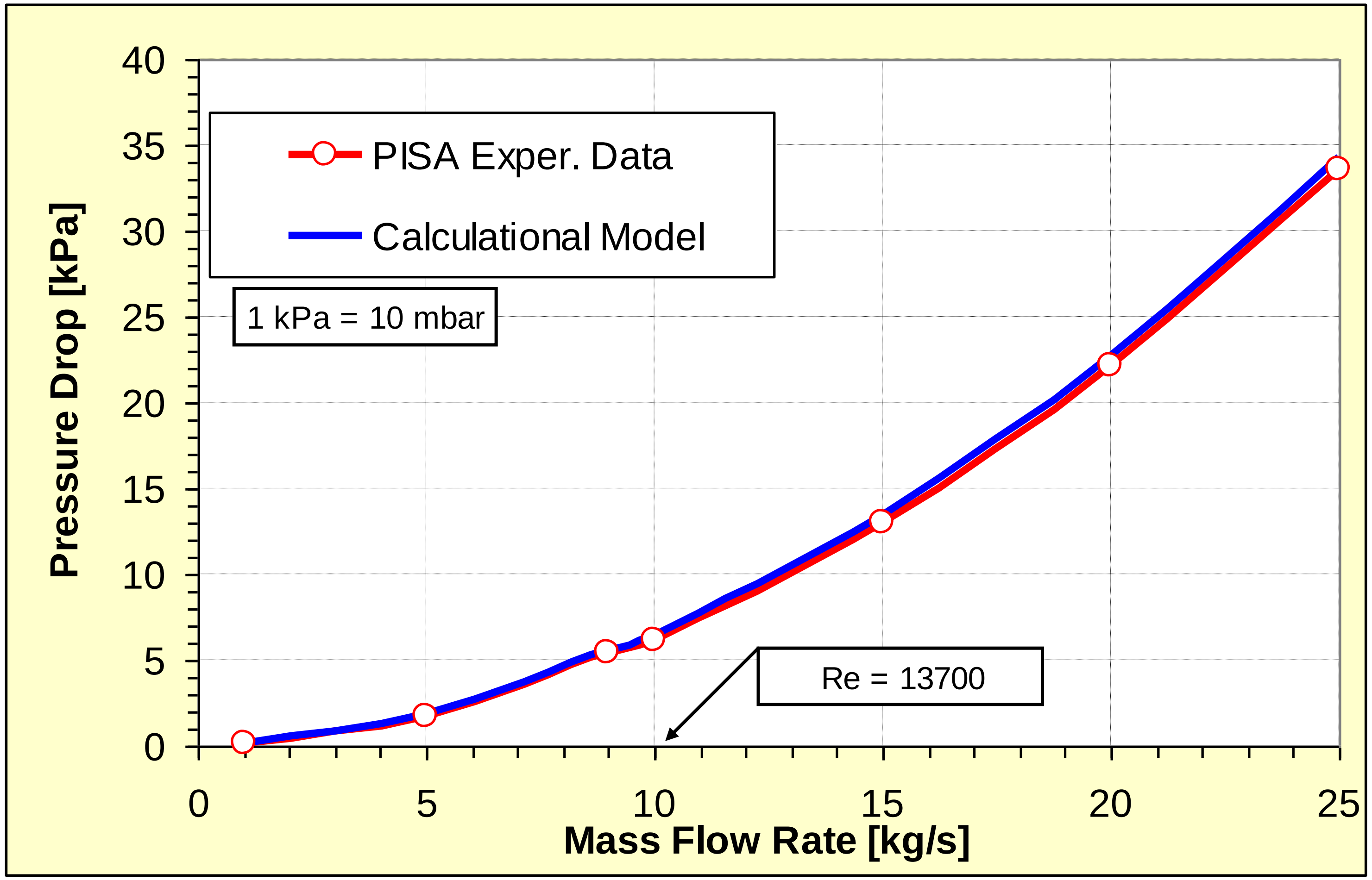
Comparison of SIM-ADS calculational results and measured data for SA inlet pressure drop, using K_inlet = 7.15 (determined by the best fit to the experimental data)

SA outlet pressure drop



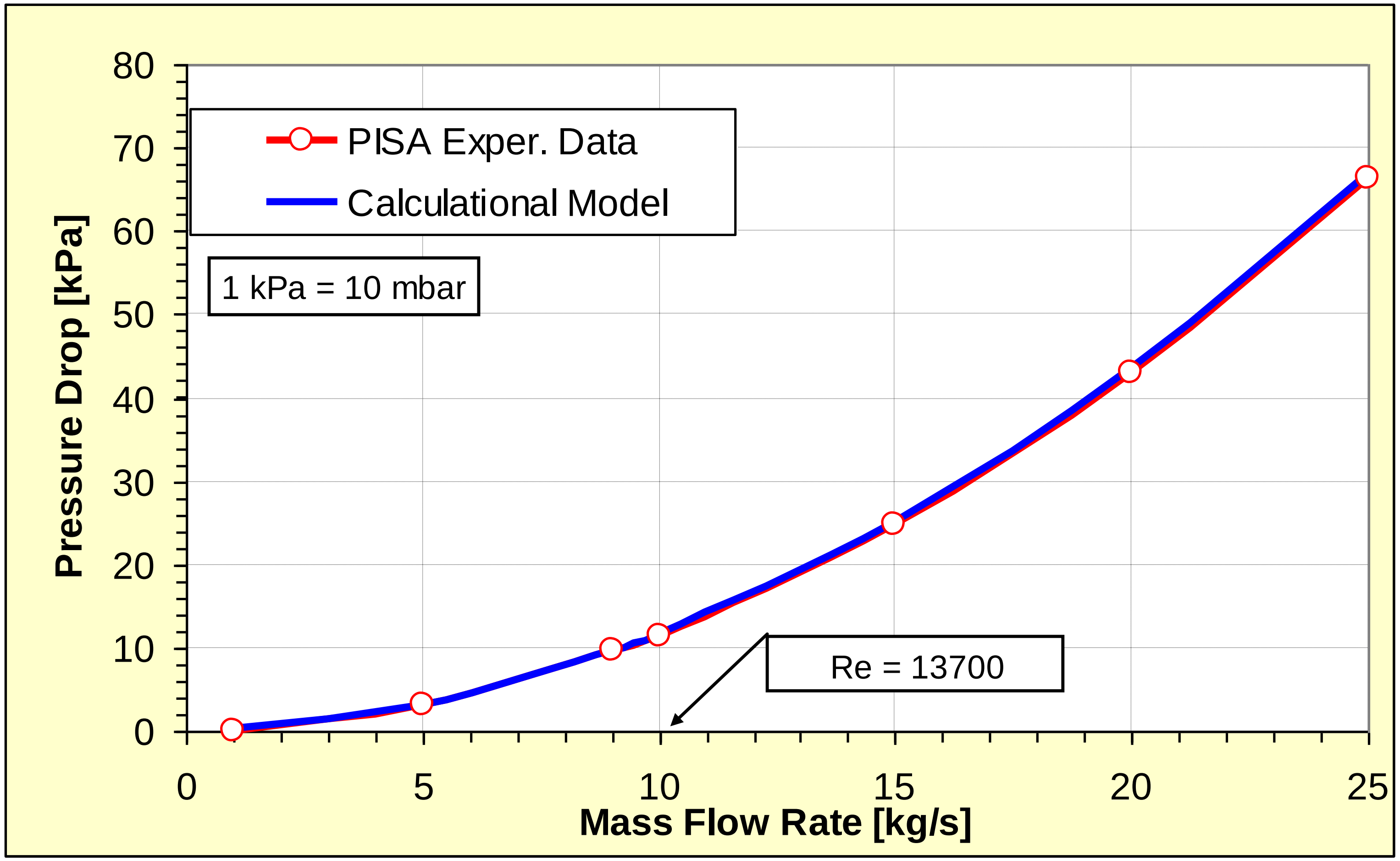
Comparison of SIM-ADS calculational results and measured data for SA outlet pressure drop, using K_outlet = 3.65 (determined by the best fit to the experimental data)

Fuel pin pressure drop



Comparison of SIM-ADS calculational results and measured data for the fuel pin pressure drop (flow friction plus 3 grid spacers plus support grid pressure drop)

Total SA pressure drop



Comparison of SIM-ADS calculational results and measured data for the total SA pressure drop

Conclusions (1)

The good agreement found between the experimental data and the calculated pressure drops across an entire sub-assembly indicates, that

(1) the procedure proposed by Rehme to calculate the pressure drop across a grid spacer allows predictable retracement of experimental data, and

(2) the SIM-ADS code can be used for calculating reasonable estimates of pressure drop across entire sub-assembly designs.

Based on the presented study and comparison of the simulation results with the experimental data, one can state that, **using slightly modified Rehme/Dalle Donne pressure drop correlations for pressure drop prediction in a fuel bundle with grid spacers, it is possible to obtain very good agreement with the experimental measurements of the fuel assembly pressure drops in various segments of a fuel assembly**, provided that the grid spacer blockage factor can be estimated to a reasonable degree of confidence.

Conclusions (2)

In relation to that, parameter C_{v_norm} should be calculated as follows:

$$C_{v\_norm} = 3.5 + \frac{73.14}{\mathrm{Re}^{0.264}} + \frac{2.79 \cdot 10^{10}}{\mathrm{Re}^{2.79}}$$

but parameter C_{v_max} calculation is proposed to be modified to $C_{v\_max} = 2.6/\varepsilon^2$ instead of the old Dalle Donne formulation - $C_{v\_max} = 2/\varepsilon^2$.

Finally, authors of this paper propose that Rehme grid spacer pressure drop correlations, together with the proposed C_{v_max} modification, should be used consistently by all analysts performing thermal-hydraulic calculations for fast spectrum reactor systems having fuel assemblies with grid spacers in the reactor core.

Acknowledgement

The authors of this paper would like to acknowledge the support of the staff of Scalbatraio Laboratory of Pisa University, who provided us with the experimental data that gave us the basis for the above presented analysis and comparisons.

Further reference

An additional study of similar experimental results obtained in a water loop of the KArlsruhe Liquid metal LAboratory (KALLA) test facility (2008) along with the investigation results presented here, will be published in the near future in the Nuclear Engineering and Design journal.