Disordered flow to the reservoir – measures to improve the situation

Heiko Baum
Gerd Scheffel

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Introduction

The fluid has substantial influence on the development of the water hammer

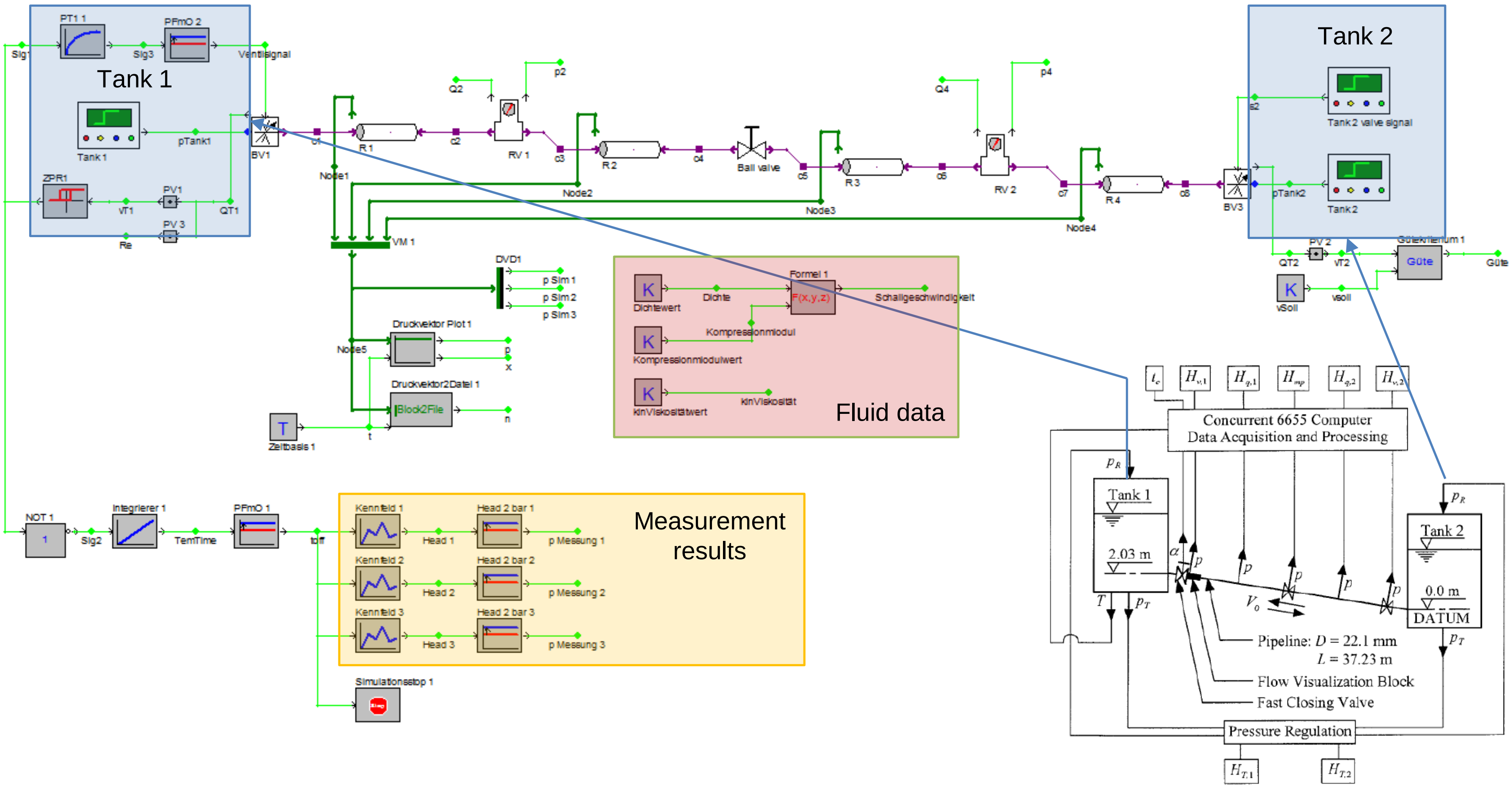
- Ordinary hydraulic machinery is usually filled with mineral oil (e.g. HLP).
- Whereas heavily inflammable fluids are used in pressure die casting machines, whose fluid properties distinguish themselves of those of a mineral oil.
- The different behaviour of the fluid at operation conditions with pressures below atmospheric pressure must be taken into account at the lay-out of the machine’s return line.

Fluid	HLP	HFC	Water
Density at 15 °C [kg/m³]	0.86	1.04 – 1.09	1
Kinematic viscosity at 40°C [mm²/s]	46	46	0.658
Bulk modulus [N/m²]	2.0 x 10^9	3.5 x 10^9	2.14 x 10^9
Recommended temperature range [°C]	-10 – 100	-20 – 60	n. a.
Flash point [°C]	ca. 220	n. a.	n. a.
Ignition temperature [°C]	310 – 360	none	none
Bunsen coefficient for air at 20 °C	0.08 – 0.09	0.01 – 0.02	< 0.02
Speed of sound at 20 °C [m/s]	1,300	ca. 1,400	1,480
Vapor pressure at 50 °C [mbar]	10^{-4} / 10^{-5}	ca. 50 - 80	123
Danger of cavitation	Low	average	high

Datenquellen:
HLP und HFC: Mang, T., Dresel, W., ” Lubricants and Lubrication”
Wiley-VCH Verlag GmbH & Co. KGaA; Auflage: 2 (11. Januar 2007)
Wasser: Internet

Pipe model for water hammer simulation

Simulation model of a water hammer test rig



- The simulation model is aligned to the test rig that was used by *Bergant,* who also published measurements that are reference for the simulation.

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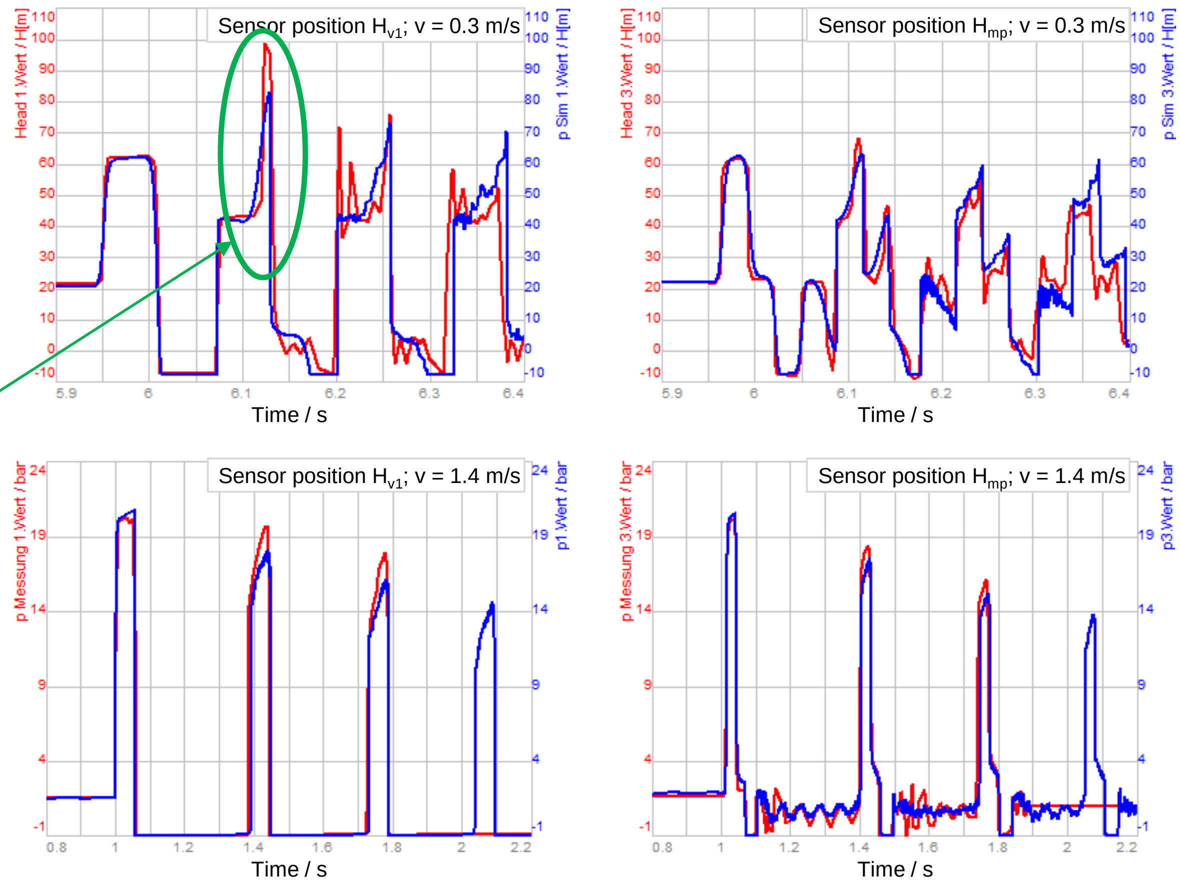
Pipe model for water hammer simulation

Comparison of measurement and simulation

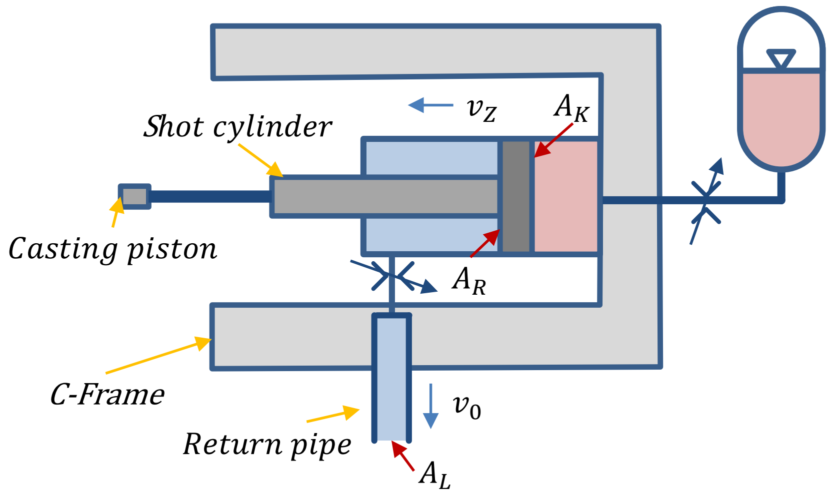
- Red curves represent measurements of *Bergant*. Blue curves are simulation results.
- At 0.3 m/s velocity of flow there is a good agreement between measured and simulated water hammer events. Even short-duration pressure peaks are covered.
- At 1.4 m/s velocity of flow there is also a good agreement between the amplitudes and between the time delays of the water hammer events.



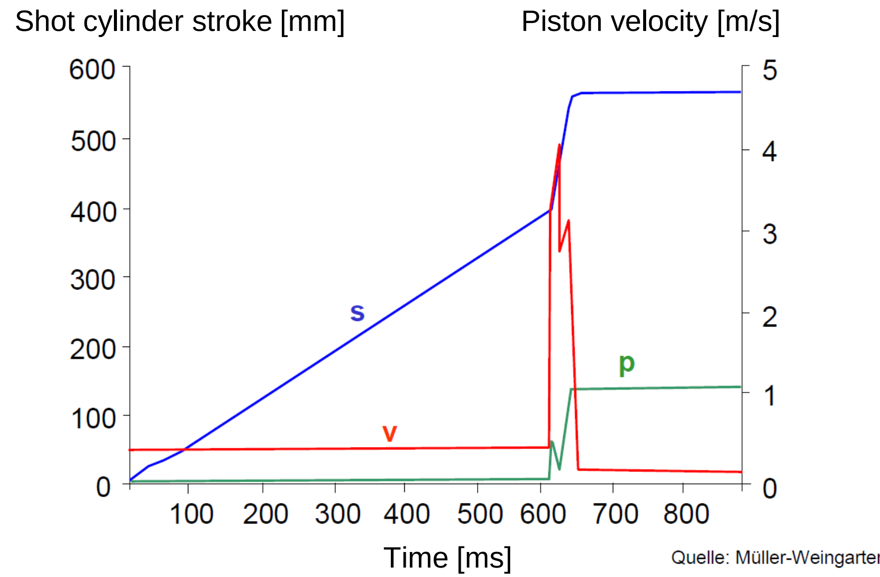
Measurement source: „Pipeline column separation flow regimes" Bergant, A.; Simpson, A. R., Journal of Hydraulic Engineering, 2014, 125:835-848 "

Water hammer simulation in return pipes

Problem description



Piston ring area:	A_R
Pipe cross section:	A_L
Cylinder velocity:	v_Z
Fluid velocity of flow:	$v_0 = \frac{A_R}{A_L} \cdot v_Z$

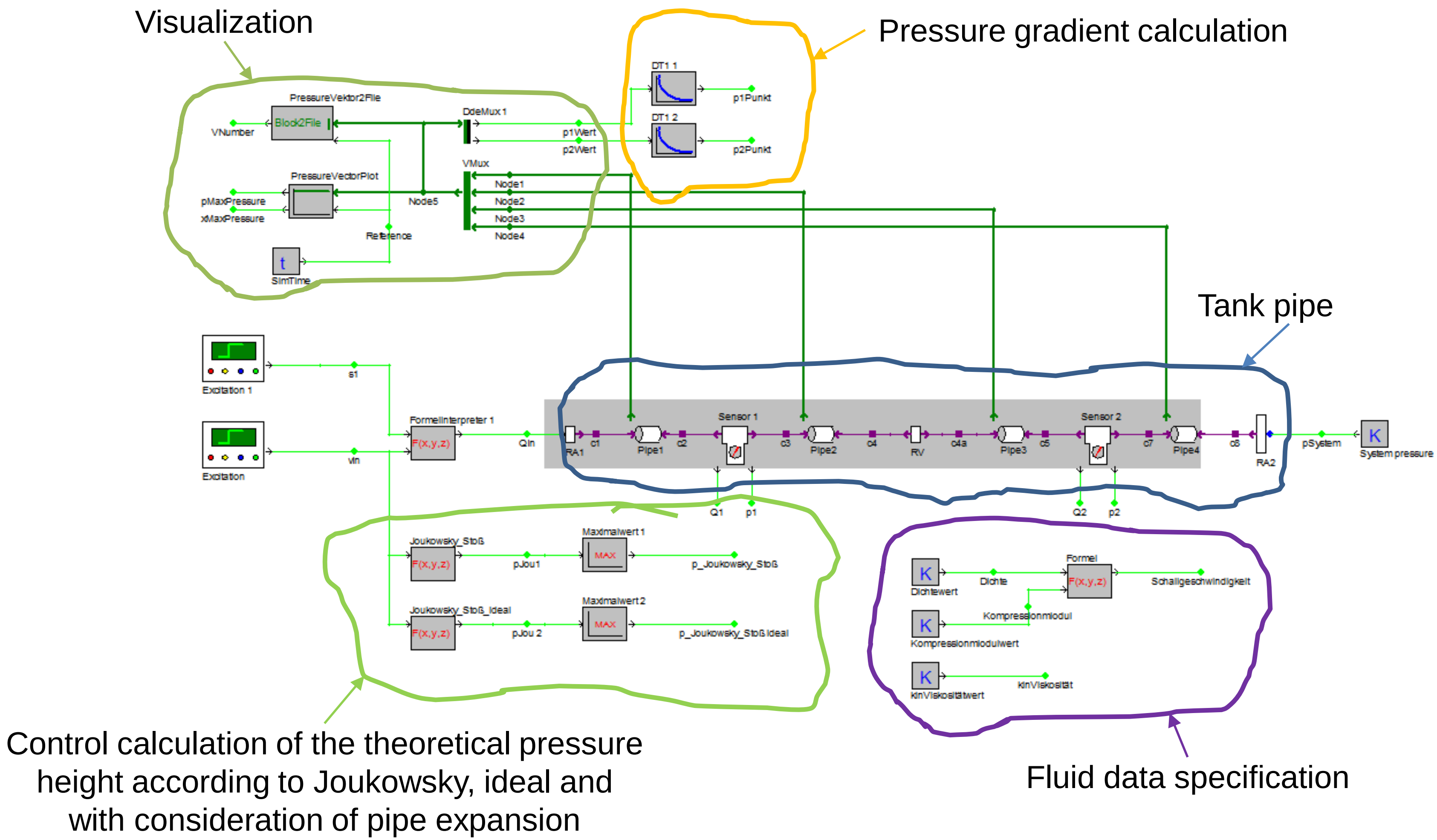


Quelle: Grundlagen der Gießereitechnik
PowerPoint-Präsentation des Vereins Deutscher Giessereifachleute e.V. VDG
www.vdg.de, 2005

- Modern die-casting machines do have shot cylinder velocities of more than 12 m/s. Through this the fluid's velocity of flow in the tank pipe reaches up to 30 m/s.
- Because the deceleration time of the shot cylinder is shorter than the deceleration time of the fluid column in the tank pipe, cavitation or pseudo cavitation occurs followed by water hammer events.

Water hammer simulation in return pipes

Simulation model

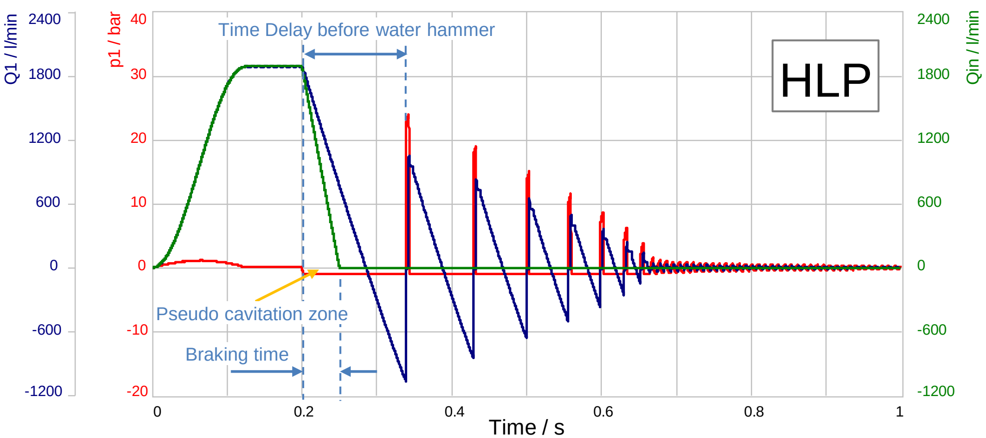


Water hammer simulation in return pipes

Comparison of water hammer calculation for HLP 46 and HFC

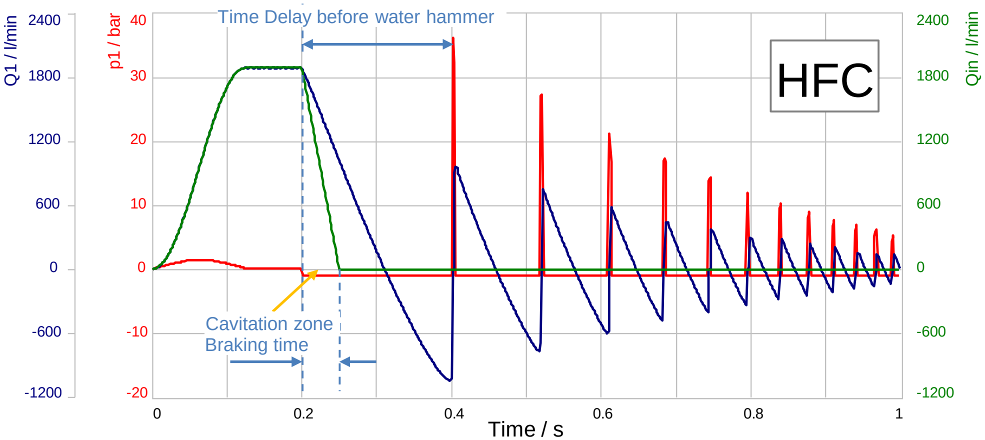
Boundary conditions:

- Fluid: HLP 46, 40 °C
- Amount of undissolved air: < 0.03 %
- Pipe length: 2.5 m
- Pipe diameter: 100 mm
- Velocity of flow: 4 m/s
- Braking pressure difference: 1 bar
- Valve closing time: 50 ms



Boundary conditions :

- Fluid: HFC, 40 °C
- Amount of undissolved air: = 0.001 %
- Pipe length: 2.5 m
- Pipe diameter: 100 mm
- Velocity of flow: 4 m/s
- Braking pressure difference: 1 bar
- Valve closing time: 50 ms



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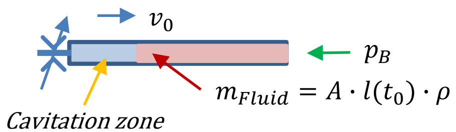
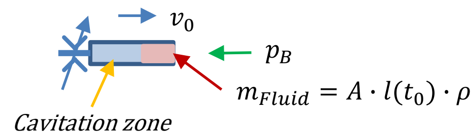
Dr.-Ing. Heiko Baum
Dr.-Ing. Gerd Scheffel

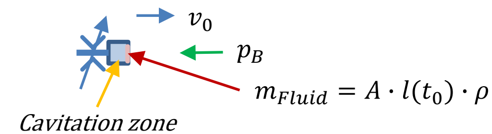
Water hammer simulation in return pipes

Cavitation zone expansion during water hammer events

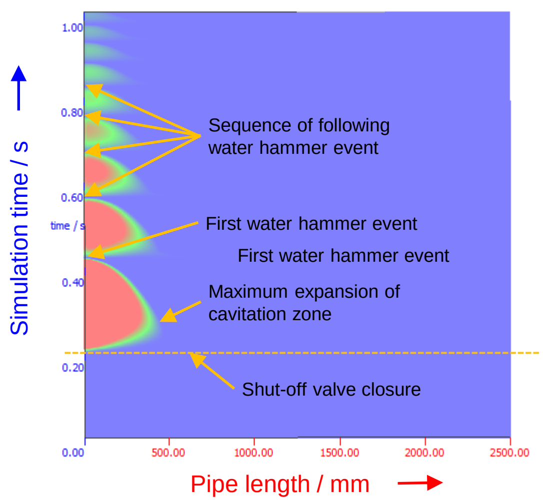
- The simulation considers stationary and frequency dependent friction.
- Depending on the pressure the fluid properties are permanently adapted.
- The cavitation zones are visualised for different tank pipe lengths and velocities of flow.



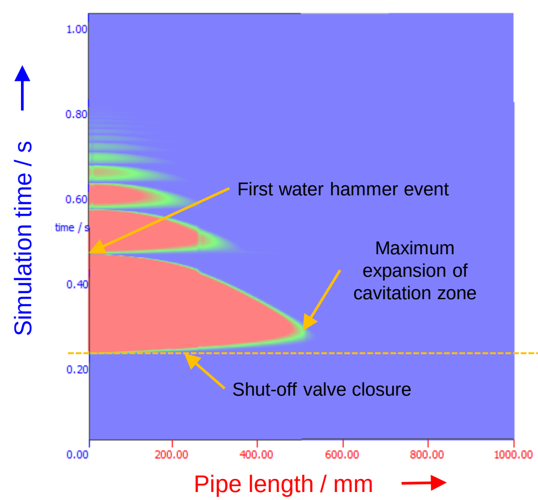




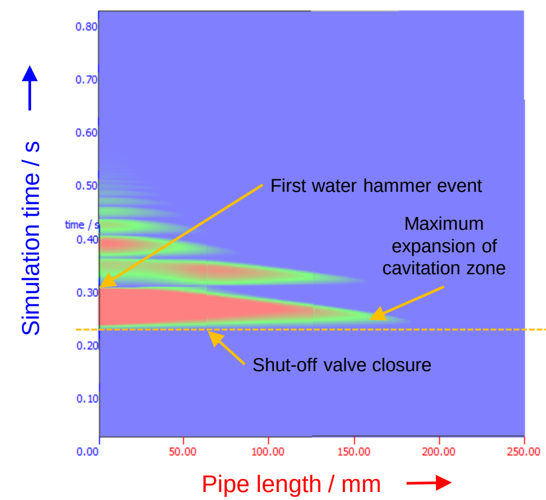
2.5 m pipe – 4 m/s



1 m pipe – 14 m/s



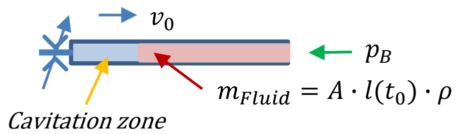
0.25 m pipe – 30 m/s

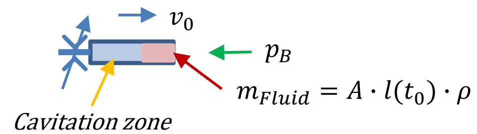


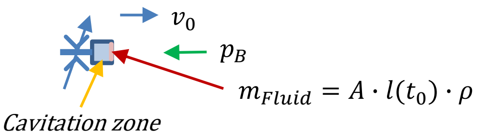
Water hammer simulation in return pipes

Speed of sound during water hammer event

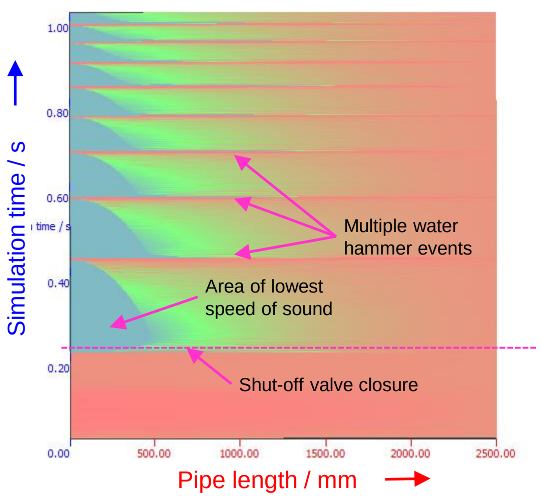
- Due to the pressure dependent change of the fluid properties, the speed of sound is not constant during a water hammer event.
- The variation of the speed of sound is visualised for different tank pipe lengths and velocities of flow.



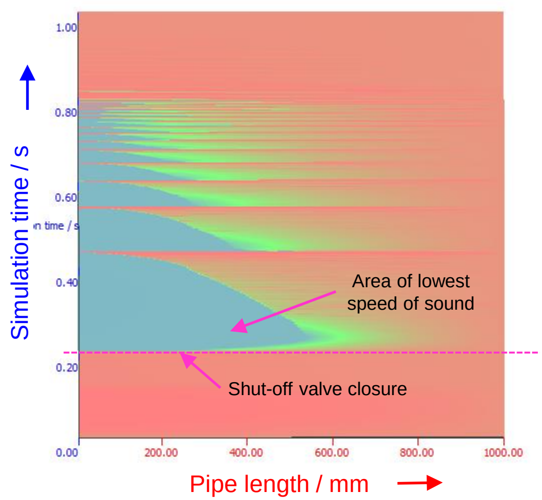




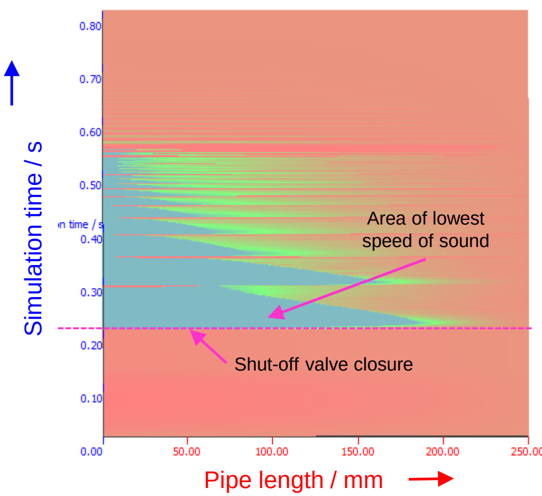
2.5 m pipe – 4 m/s



1 m pipe – 14 m/s



0.25 m pipe – 30 m/s



Automatic water hammer analysis

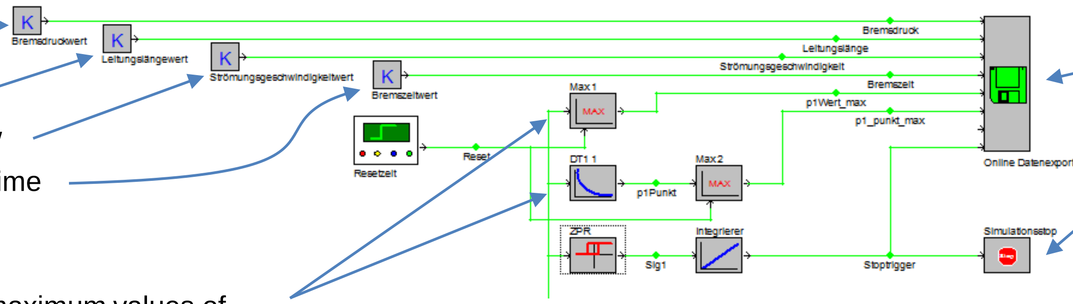
Parameter field of an automated water hammer analysis

Braking pressure

Pipe length

Velocity of flow

Valve closing time



Data export component

Simulation stop:

After exceeding the adjusted pressure level (water hammer event) the simulation terminates after a given time delay

Calculation of maximum values of pressure and pressure gradient during simulation

Parameter	Pipe length	Velocity of flow	Valve closing time	Braking pressure difference
Subdevision	0.25 m to 2.5 m in 0.25 m steps	0.0 m/s to 30 m/s in 1.0 m/s steps	10 ms to 150 ms in 20 ms steps	1.0; 2.0; 3.5; 6.0; 8.5; 16.0 and 31.0 bar
Amount	10	31	8	7
Data field 1 (Braking time and breaking pressure is constant)	10 x 31 = 310 simulations		constant	constant
Data field 2 (Braking pressure is constant)	8 x Data field 1 = 2,480 simulations			constant
Data field 3	7 x Data field 2 = 17,360 simulations			

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Dr.-Ing. Heiko Baum

Dr.-Ing. Gerd Scheffel

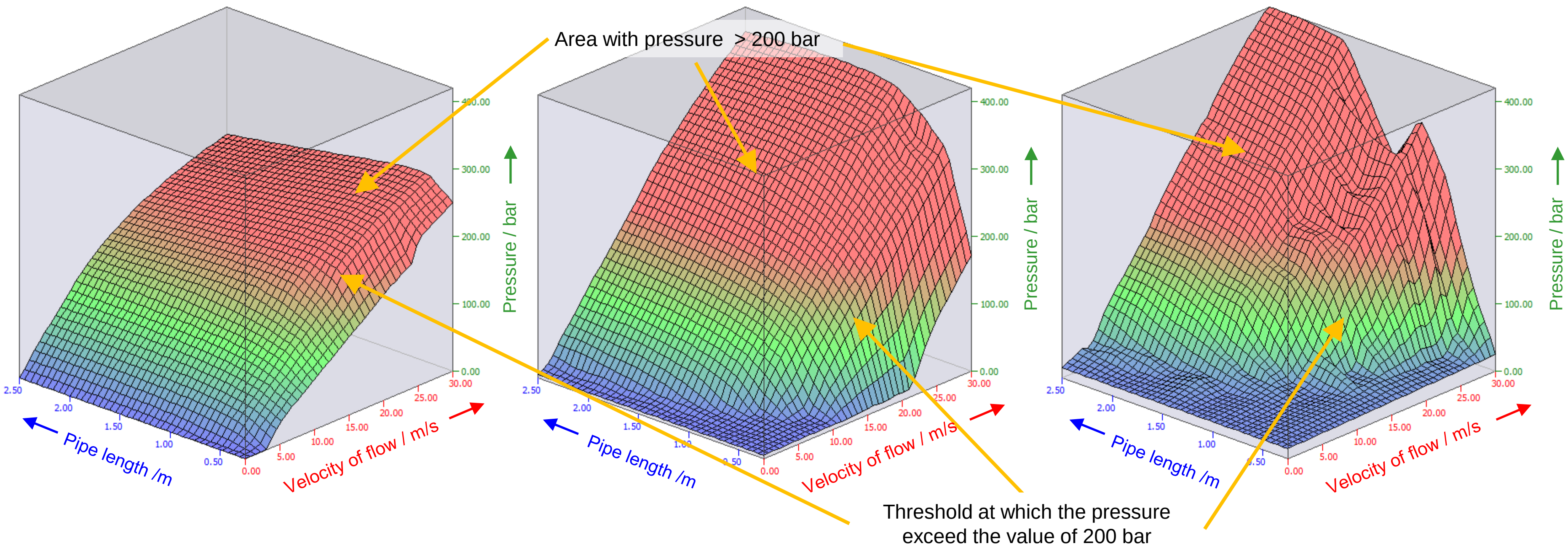
Automatic water hammer analysis

Variant computation at 10 ms valve closing time

Braking pressure difference: 1 bar

Braking pressure difference: 6 bar

Braking pressure difference: 16 bar



Boundary conditions :

- Fluid: HFC, 40 °C
- Pipe diameter: 100 mm
- Amount of unsolved air : 0.001 %

Constants:

- Braking pressure difference: 1, 6 and 16 bar
- Valve closing time: 10 ms

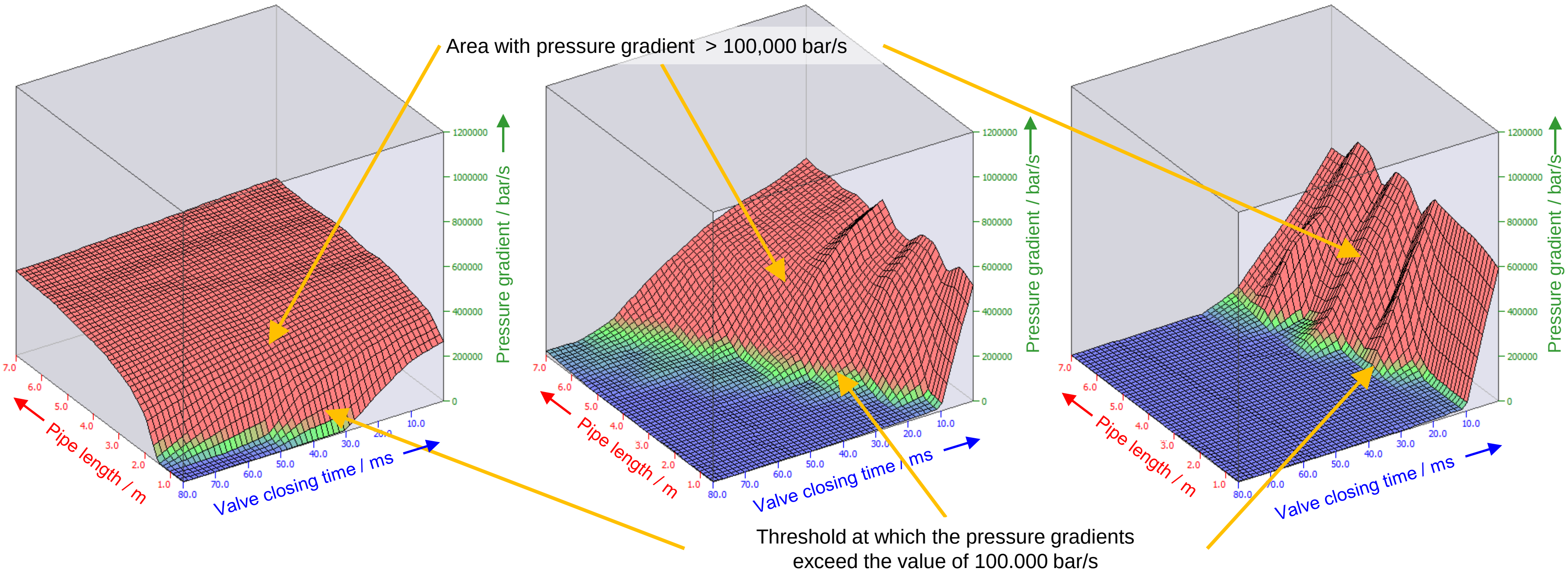
Variables:

- Pipe length: 0.25 m bis 2.5 m
- Velocity of flow: 0 m/s bis 30 m/s

Automatic water hammer analysis

Variant computation at 4 m/s velocity of flow

Braking pressure difference: 1 bar	Braking pressure difference: 6 bar	Braking pressure difference: 16 bar



Boundary conditions:

- Fluid: HFC, 40 °C
- Pipe diameter: 100 mm
- Amount of unsolved air: 0.001 %

Constants:

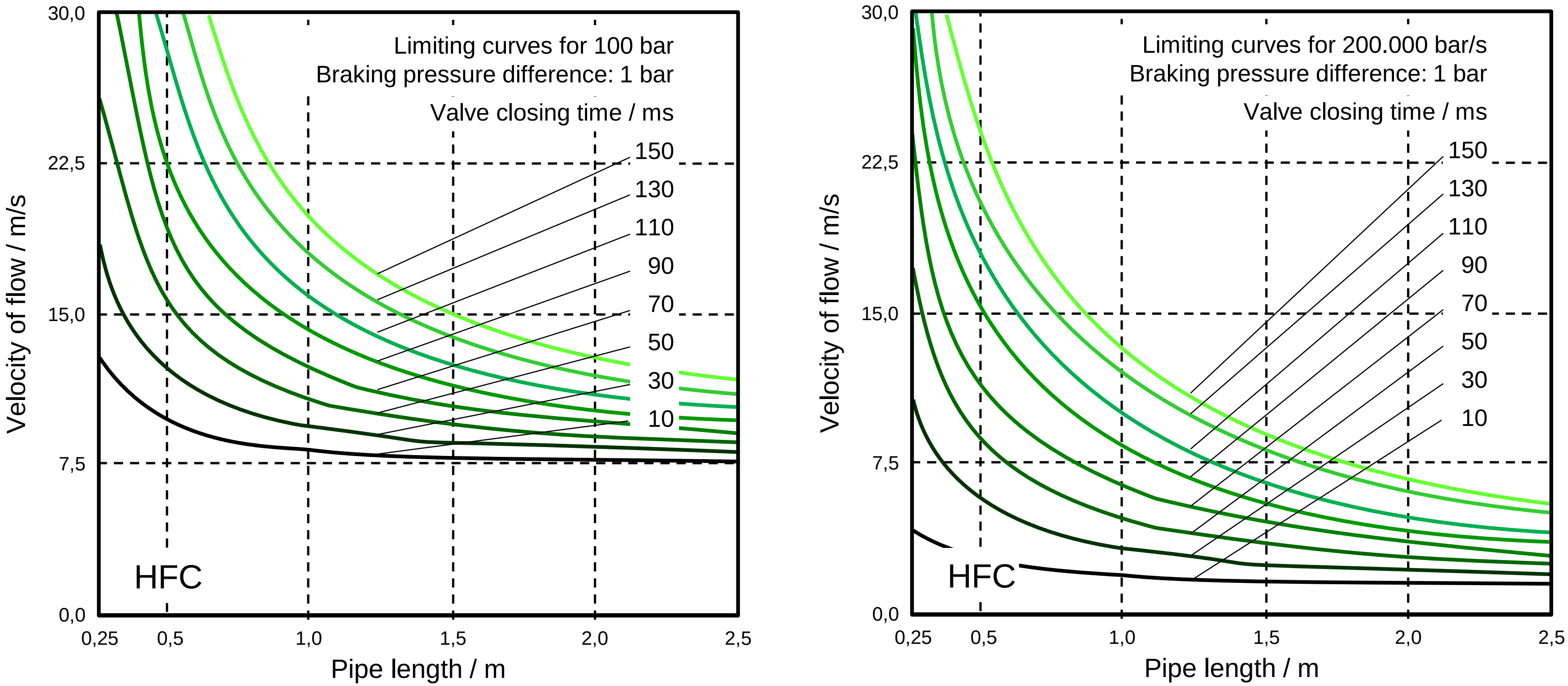
- Braking pressure difference: 1, 6 and 16 bar
- Velocity of flow: 4 m/s

Variables:

- Pipe length: 0.5 m to 7 m
- Valve closing time: 10 ms to 80 ms

Nomograms and remedial measures

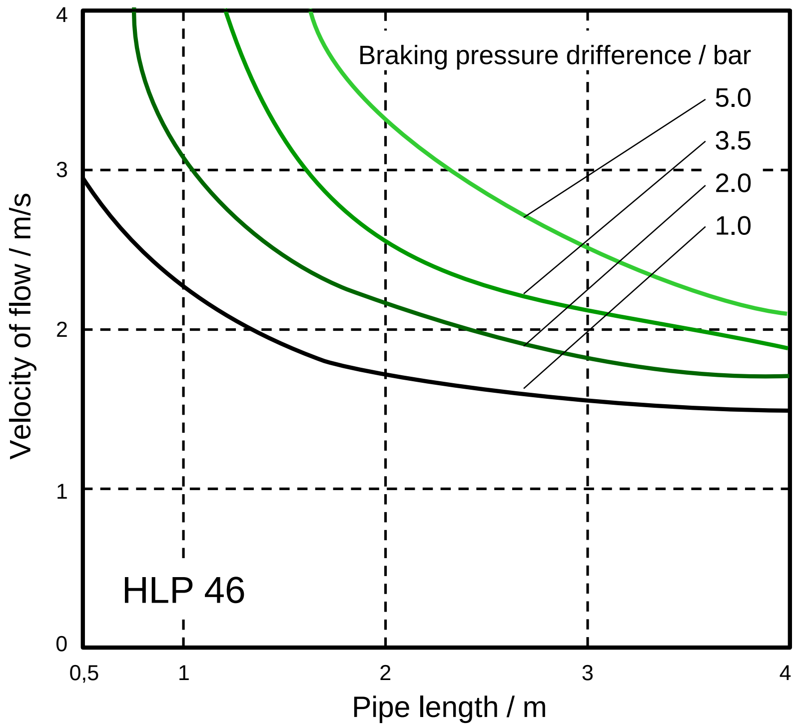
Limiting curves of maximum pressure and maximum rise in pressure

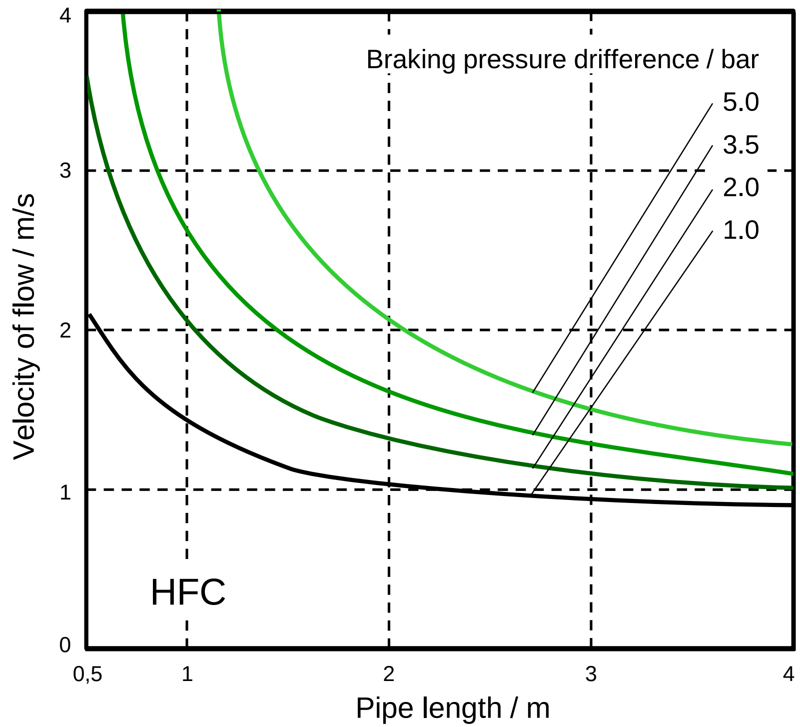


- The limiting curves represent thresholds, above which pressure or pressure gradient exceed a certain value during the automated calculation.
- With slower valve closing times the limiting curves are shifting towards higher velocities of flow.

Nomograms and remedial measures

Comparison of critical pressure gradients for HLP and HFC fluid

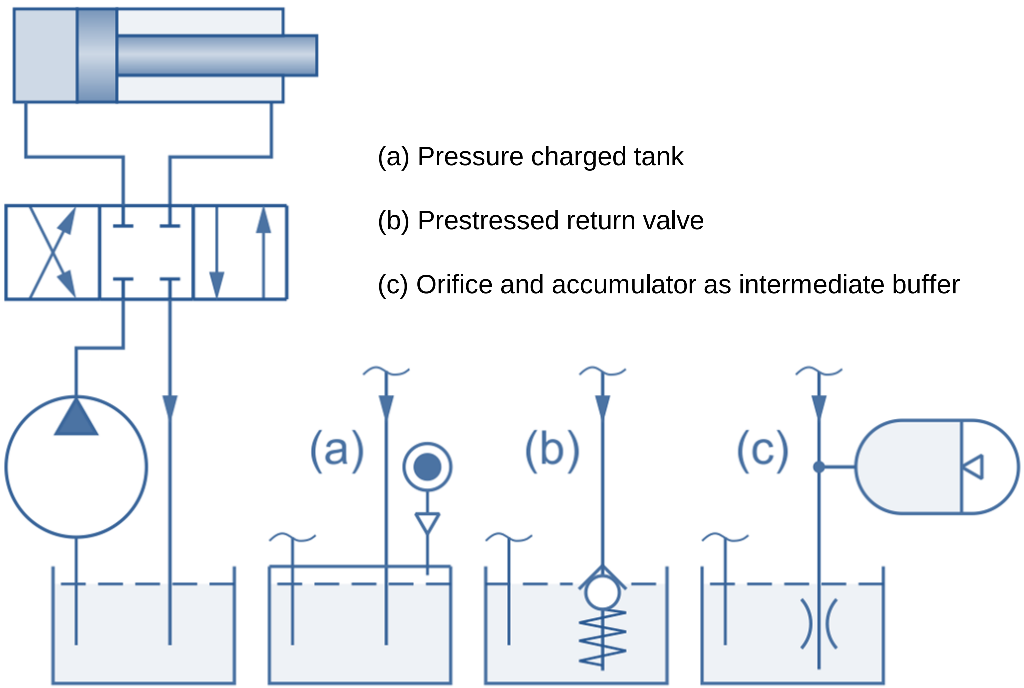




- The direct comparison of HLP and HFC nomograms illustrates how distinct water hammer depends on the machine's fluid.
- The fluid's viscosity is a major influence factor. Through this the risk of water hammer changes with the operation temperature of the machine.

Nomograms and remedial measures

Measures to rise the braking pressure



(a) Pressure charged tank

(b) Prestressed return valve

(c) Orifice and accumulator as intermediate buffer

- The atmospheric pressure available in open tanks usually does not suffice for a water hammer free deceleration of the moving fluid column returning to the tank.
- All additional measures to increase the braking pressure difference require energy but disturbances and damages are avoided and the life time of the plant is extended.

Summary

- Water hammer events in tank pipes that can lead to damages to the plant by cavitation and diesel effects are not tolerable for modern dynamic hydraulic drives.
- To avoid such problems the design of the tank pipe must be incorporated with higher priority into the design of the hydraulic system.
- The simulations presented show that nowadays numerical pipe models are available to calculate water hammer events even under consideration of cavitation effects.
- Modern simulation tools are also able to automatically compute design parameter fields. Thus, the engineer can analyse the water hammer vulnerability of the tank pipe prior to its realisation.
- Subsequently the simulation is also the tool of choice if remedial measures must be developed. The simulation is especially suitable to unveil unwanted side effects that may arise if the remedial measure interacts with the rest of the tank pipe system.

Thank you for your attention!

Contact:

- Dr.-Ing. Heiko Baum
  heiko.baum@fluidon.com
  FLUIDON GmbH, Aachen
- Dr.-Ing. Gerd Scheffel
  gerd.scheffel@parker.com
  Parker Hannifin GmbH, Kaarst