Aalto University
School of Engineering

MEC-E5003

FLUID POWER BASICS

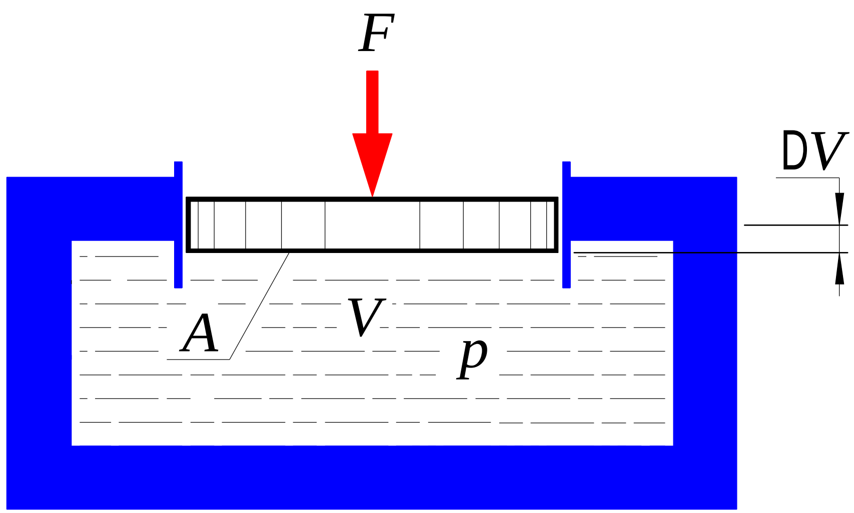
Study Year 2018 - 2019

Hydraulic fluids, part 1

Aalto University
School of Engineering
Mechanical Engineering / Engineering Design / Mechatronics / Fluid Power

Compressibility of fluid and elasticity of system

$$\Delta V = \frac{1}{K_f} \cdot V_0 \cdot \Delta p$$



K_f = Bulk modulus of fluid, [N/m^2]

$\sim 1500 \rightarrow 2000$ MN/m^2

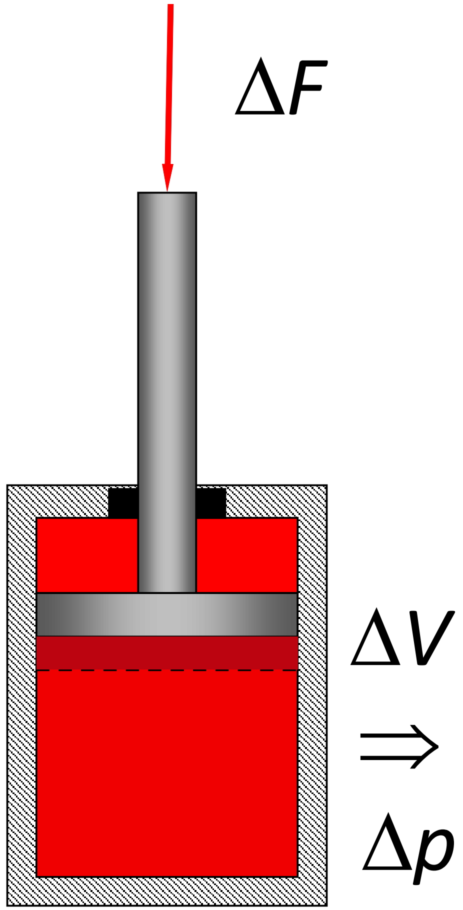
Mineral oil	K_f = 1.5 GPa - 1.6 GPa
Water	K_f = 2.1 GPa - 2.2 GPa

The pressure in a fluid volume can be changed (also) by altering the size of the fluid volume

Attention: the sign (–)

$$\Delta p = -\frac{K_f}{V}\Delta V$$

- K_f bulk modulus of fluid [Pa]
- V (changing) volume full of fluid [m^3]
- ΔV change in volume [m^3]



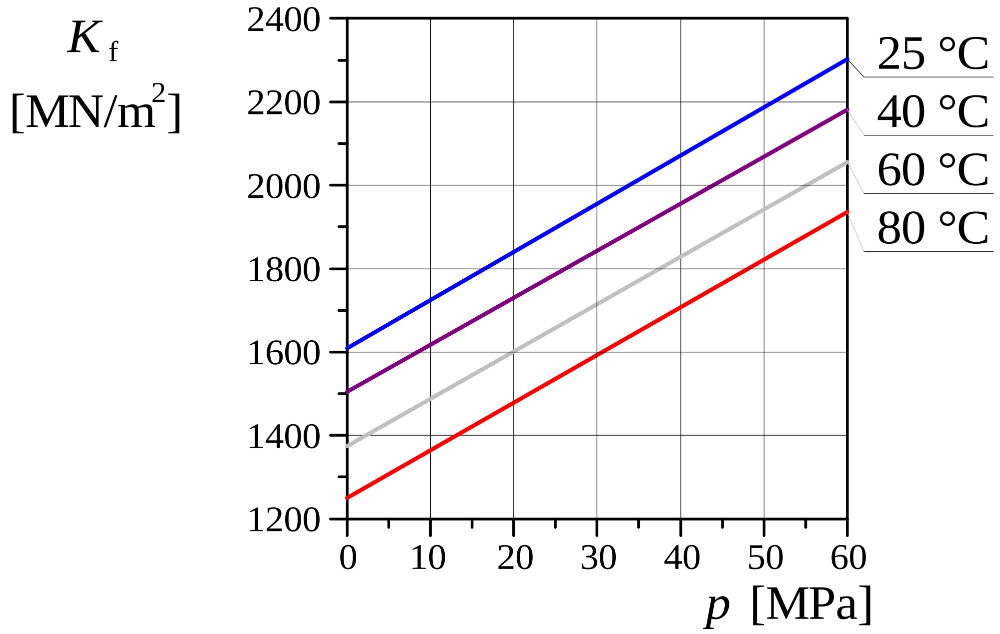
How much does pressure increase if the volume of a (stiff) chamber filled with hydraulic oil is reduced by 1 %?

Bulk modulus of fluid [Pa], ~ $1.6 \cdot 10^9$ Pa (mineral oil)

$\Delta V/V = 0.01 \Rightarrow \Delta p = 16 \cdot 10^6$ Pa = 160 bar

Bulk modulus of fluid

Effect of pressure and temperature



Volume of cylinders
divided by
Total volume
etc.

Effective bulk modulus of system K_e

Fluid — Cylinders (structure) — Pipes (structure) — Hoses (structure) — Air

$$\frac{1}{K_e} = \frac{1}{K_f} + \sum_{i=1}^{N1}\left(\frac{V_{c,i}}{V_t}\cdot\frac{1}{K_{c,i}}\right) + \sum_{j=1}^{N2}\left(\frac{V_{p,j}}{V_t}\cdot\frac{1}{K_{p,j}}\right) + \sum_{k=1}^{N3}\left(\frac{V_{h,k}}{V_t}\cdot\frac{1}{K_{h,k}}\right) + \frac{V_a}{V_t}\cdot\frac{1}{K_a}$$

Effect of system components

$$K = \frac{E_m \cdot s}{d}$$

Pipes, cylinders, etc.

- E_m modulus of elasticity
- s thickness of wall
- d inner diameter

$K_h = 70\text{–}700\ \mathrm{MN/m^2}$ Hoses

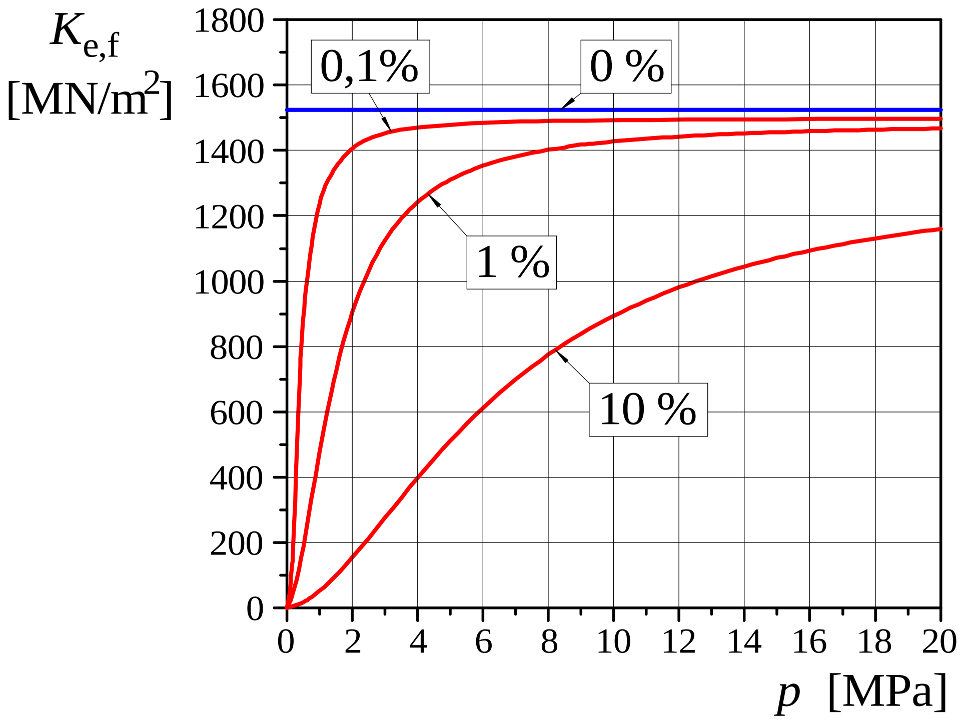
$K_a = 1{,}4 \cdot p$ Free air (air bubbles)

$$\Delta V = \frac{1}{K_e} \cdot V_t \cdot \Delta p$$

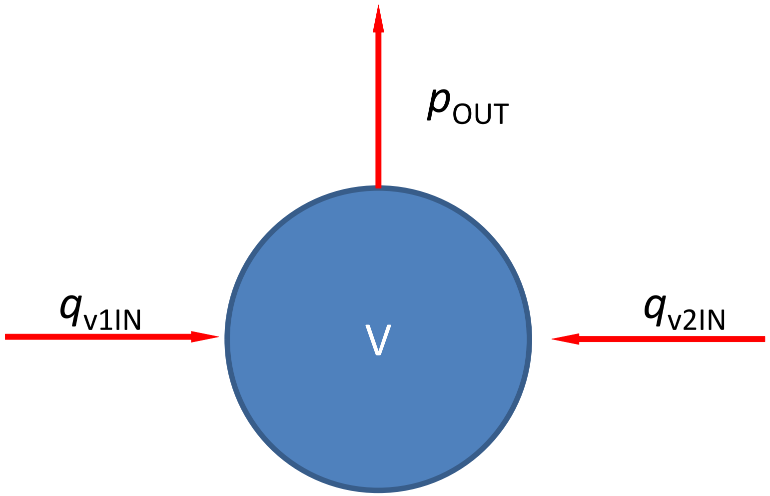
Significance and effect of elasticity

- depends on application
- no significance in force production
- has an impact on the accuracy in position, speed and acceleration control systems
- defines the actuator's mechanical stiffness

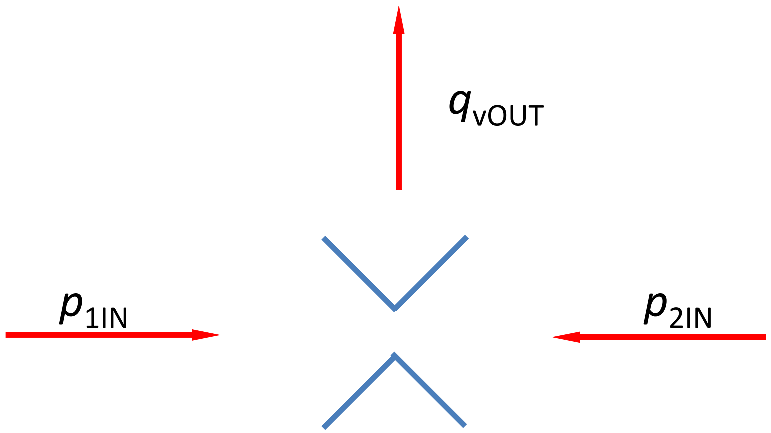
Effect of free air and pressure on the bulk modulus



Simulation model



"Fluid volume": pressure is solved, flow rates as inputs

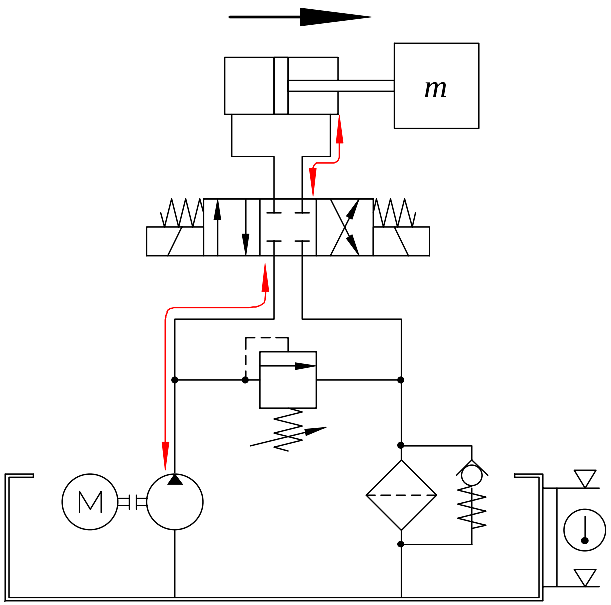


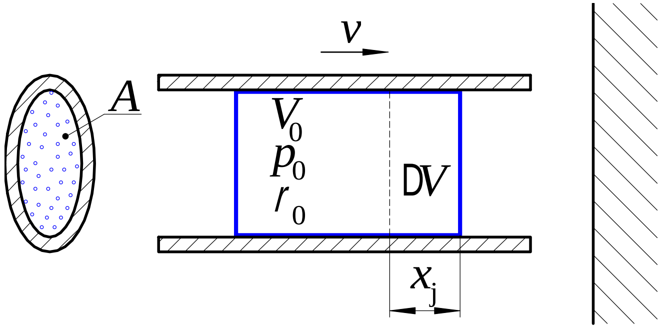
"Valve": flow rate is solved, pressures as inputs

- Common way to realize a model of a system is to divide it into
  - Fluid volumes (pressure is essential to these volumes)
  - Components between fluid volumes ("valves" ja "pumps", flow rate is essential to these volumes)

Pressure surge (aka shock)

Source: Change in flow velocity

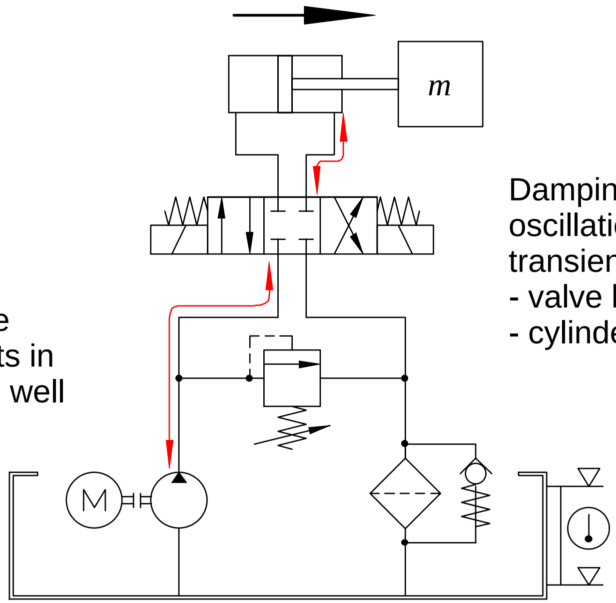




$$E_{kin} = \frac{1}{2} \cdot m \cdot v^2$$

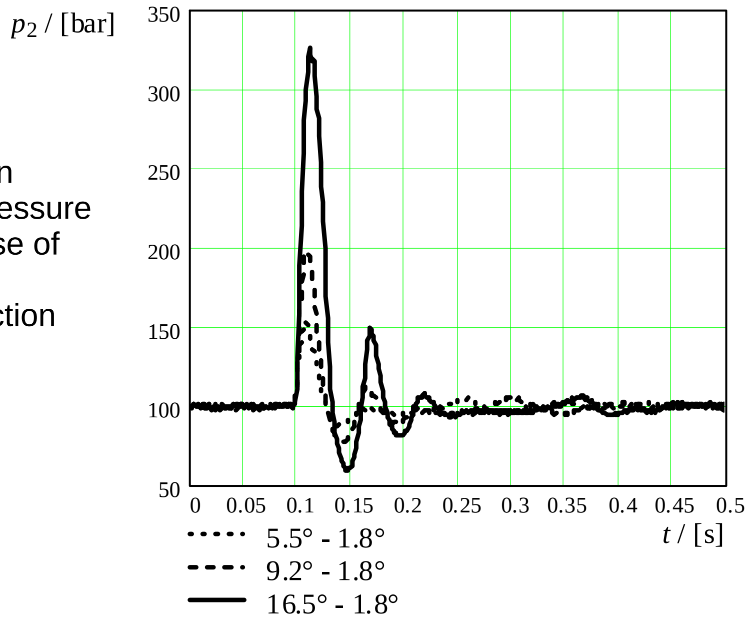
$$E_{spr} = \frac{1}{2} \cdot k_R \cdot x_j^2$$

Outcome: Rise of pressure level and shock wave



Pressure transients in pipes as well

Damping of piston oscillation and pressure transients because of
- valve leakage
- cylinder seal friction

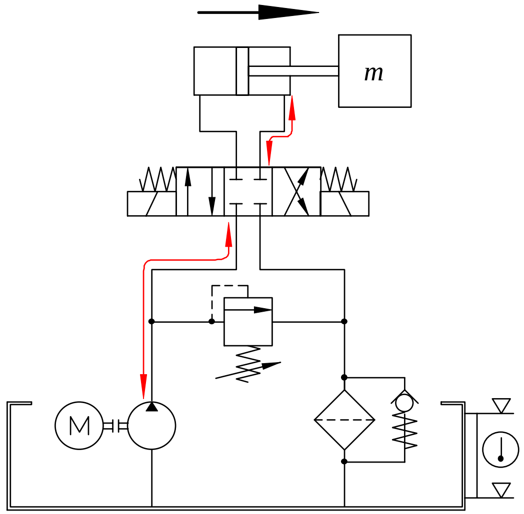


Velocity of pressure wave

$$c = \sqrt{\frac{K_e}{\rho}}$$

Critical time

$$t_{cr} = \frac{2 \cdot l}{c}$$

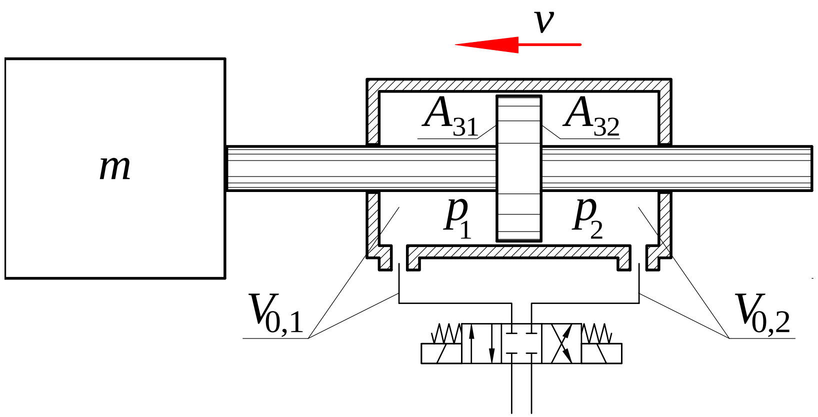


$$t_c > t_{cr}$$

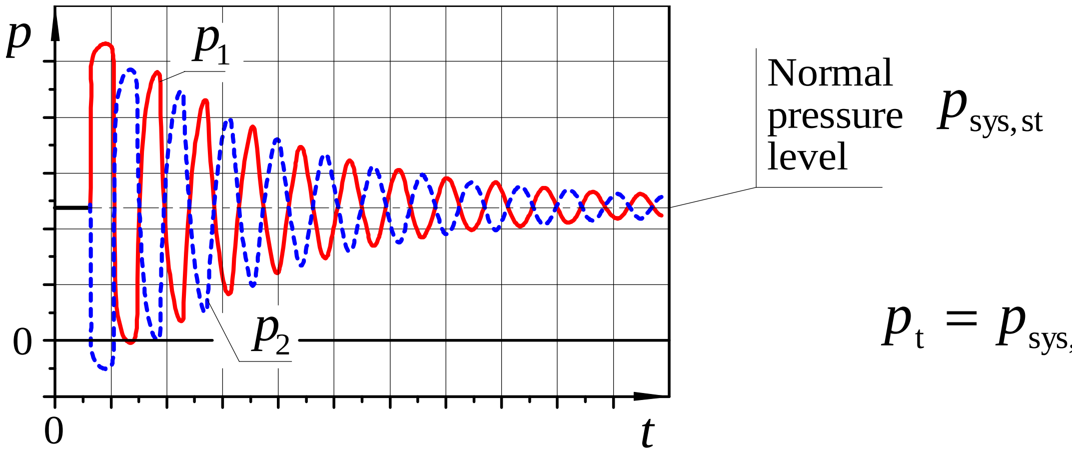
$$t_c < t_{cr}$$

$$\Delta p_{max} = \frac{2 \cdot l \cdot \rho_0 \cdot v}{t_c}$$

$$\Delta p_{max} = \rho_0 \cdot c \cdot v$$



Risk of cavitation



$$p_t = p_{sys,st} + \Delta p_{max}$$

Consequences of pressure shock:

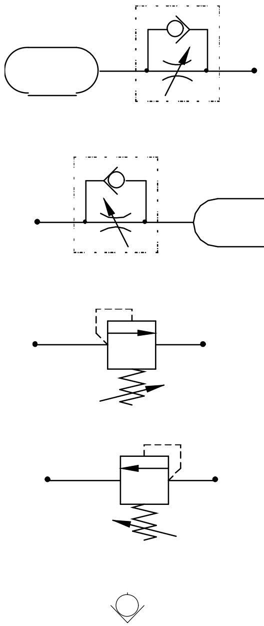
- damages the hydraulic system
- damages systems connected to hydraulic system

Diminishing the pressure shock:

- lower flow velocity
- slower valves
- lower actuator velocities
- smaller inertial loads
- larger fluid volumes
- with assisting components

Effects of these actions?

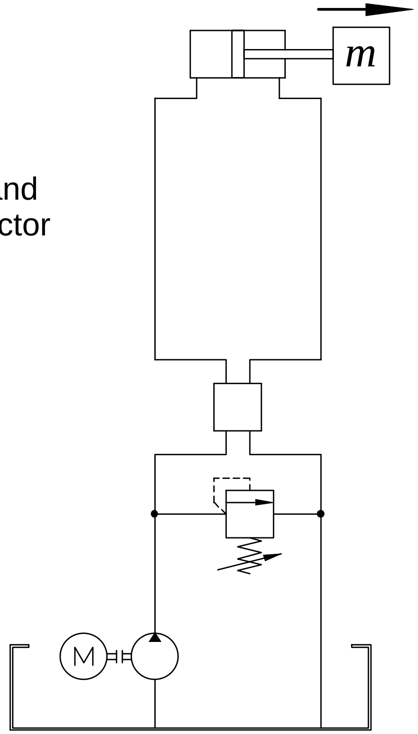
Diminishing pressure shock with hydraulic components



Accumulator and
one way restrictor
valve

Pressure
relief valve

Check valve



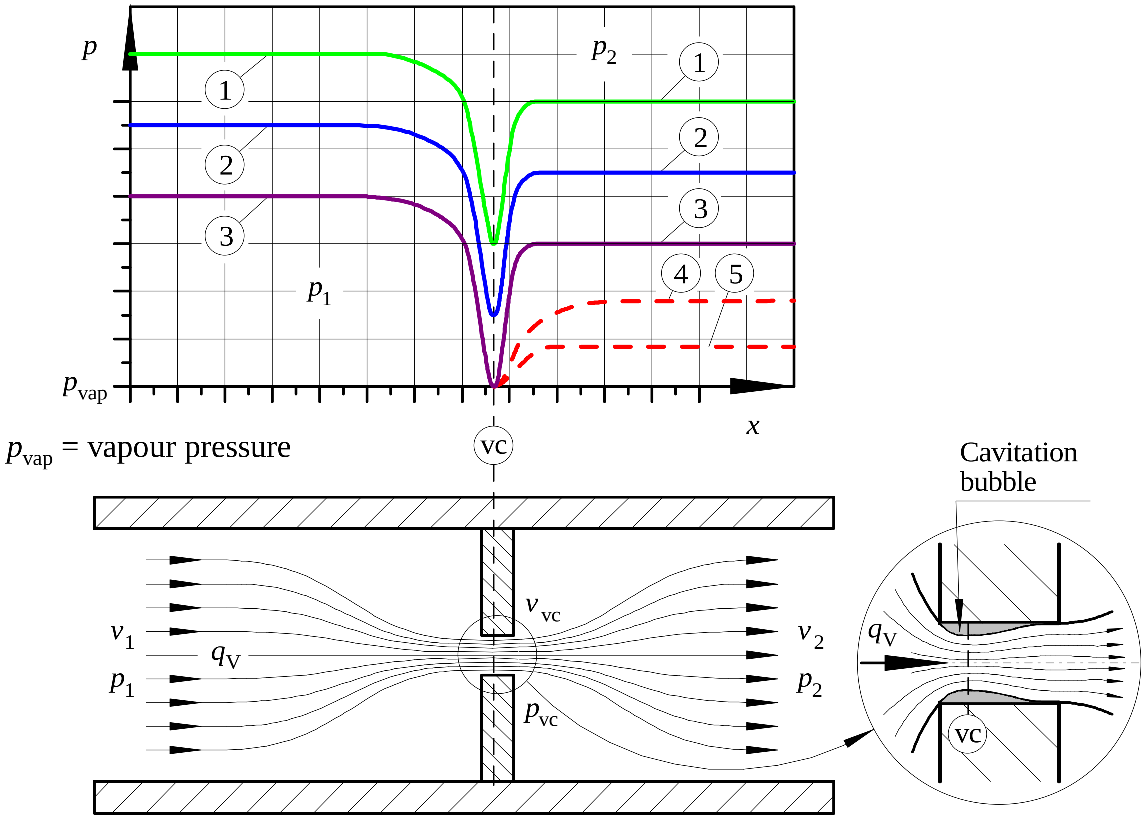
Cavitation

Pressure in fluid lowers below atmospheric pressure:
- in fluid dissolved air separates into air bubbles
® air bubble cavitation

Pressure in fluid lowers to vapour pressure of the fluid:
- vapour bubbles start to appear
® cavitation

Lowering of the pressure is due to pressure losses in the flow channel

Cavitation appears typically in:
- pumps and their suction lines
- orifices (throttles)



$$q_V = C_q \cdot A \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$

Cavitation
in orifice

$$q_V \neq C_q \cdot A \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$

Consequences of cavitation

When pressure rises:

- bubbles collapse rapidly (“implosion”)

® pressure shocks

® material damages, rapid wear, noise

In addition in pumps

® the vapour bubbles reduce output flow

Lecture themes – Intermediate Recap

Does the elasticity of fluid have any significance?

Pressure shocks, harmless heaving?

Cavitation, is it something to worry about?