LECTURE 5: Cavitation in pipelines and in pumps, NPSH (net positive suction head)

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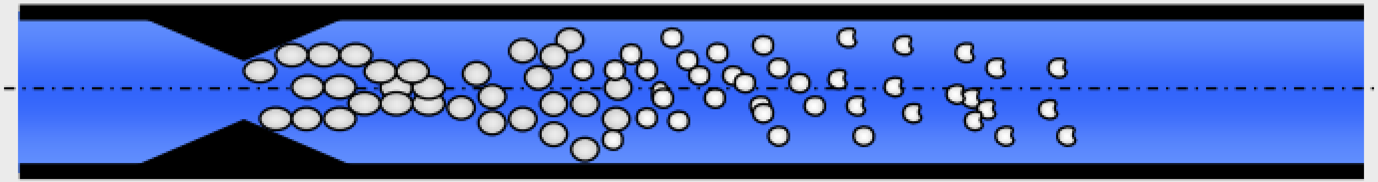
CAVITATION

Cavitation is a physical process, which can arise in liquids. It describes the phase transition between the liquid and the vapour condition.

The process of cavitation has two steps:

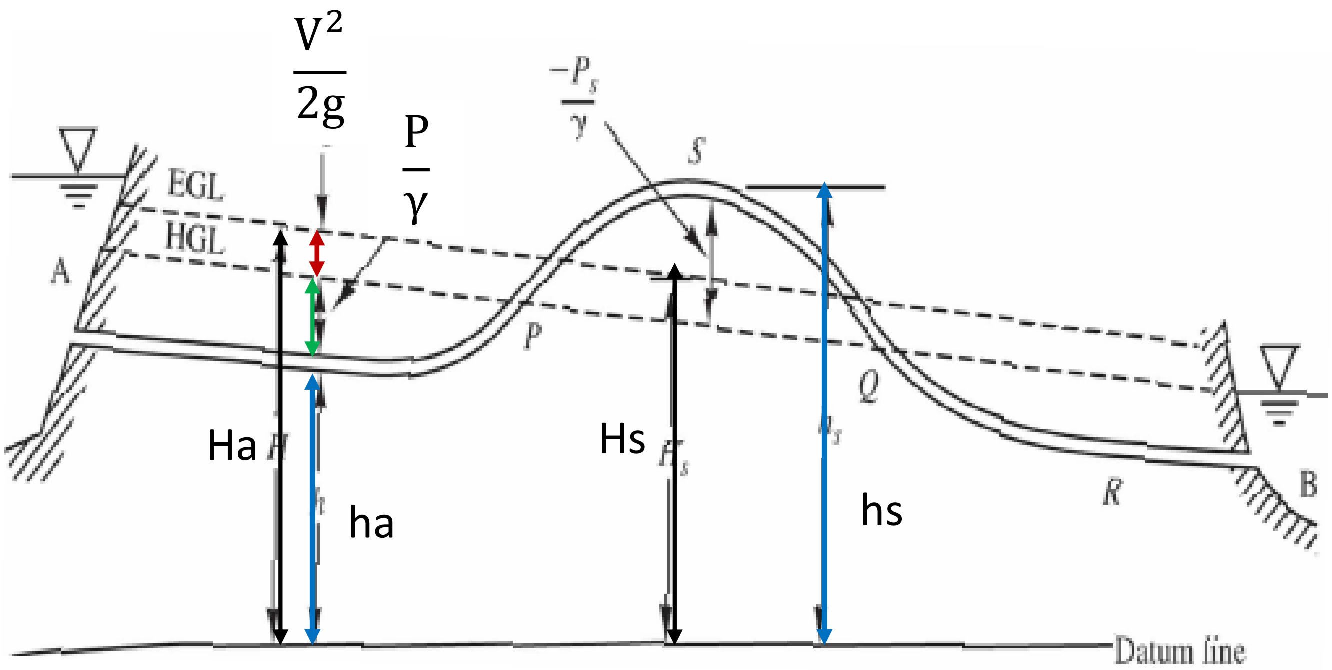
1. step:	Change from **liquid condition** into **vapour condition**.
2. step:	Change from **vapour condition** into **liquid condition**.



CAVITATION IN PIPELINES

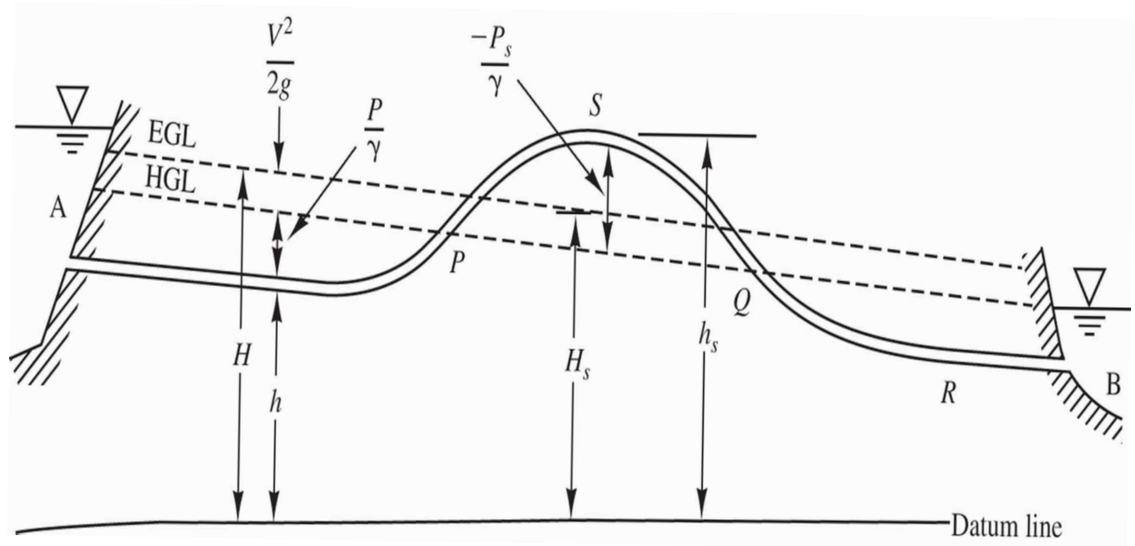
HA= Hs+ hL ← Energy equation

8.1 Cavitation in Pipelines



h= Pipe axis level at point A

H= Total head at point A



$$H = \frac{V^2}{2g} + \left(h + \frac{P}{\gamma}\right)$$

Total Head for point A➔ $Ha = \frac{Va^2}{2g} + \left(ha + \frac{Pa}{\gamma}\right)$

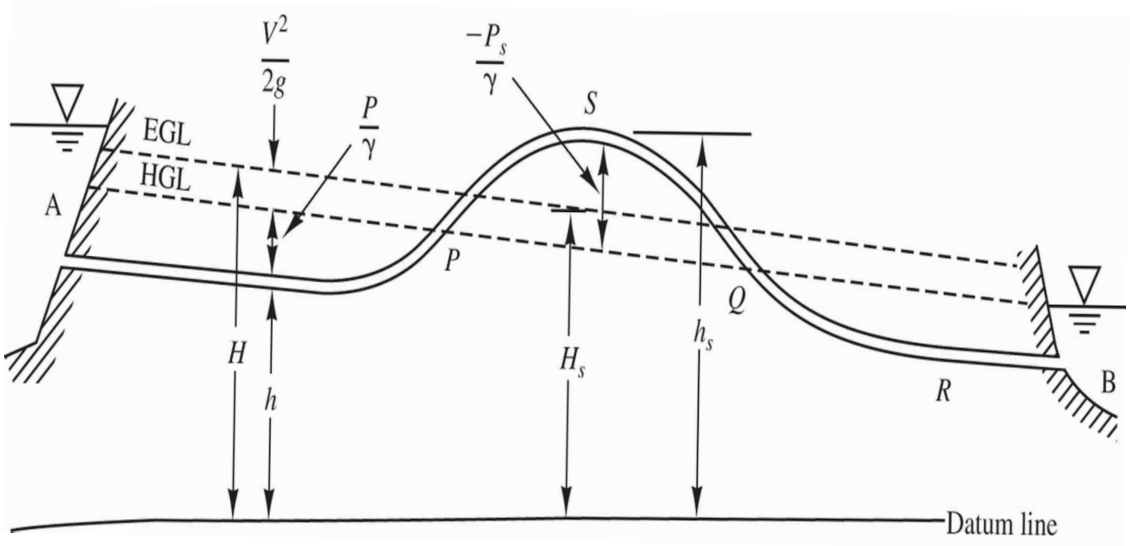
Total Head for point S➔ $Hs = \frac{Vs^2}{2g} + \left(hs + \frac{Ps}{\gamma}\right)$

Ha=HS

$\frac{V^2}{2g}$ and h_s is a fixed positive value and the summation of $h_s + \frac{V^2}{2g} > Hs$

Hence, pressure head can only be negative value.

$$\left(\frac{-P}{\gamma}\right) + h_s + \frac{V^2}{2g} = H_s = \text{Total Head at summit point}$$



NEGATIVE PRESSURE EXIST IN THE PIPELINE WHENEVER THE PIPELINE RAISED ABOVE THE HYDRAULIC GRADIENT LINE"

- Negative pressure reaches a maximum value at the summit , "

$$\left(\frac{-\mathrm{Ps}}{\gamma}\right)$$

- Water flow from S to R must flow against pressure gradient.

Higher pressure at R ➔ Lower pressure at S

Water always flows toward lower-energy locations.

CAVITATION IN PIPELINES

- If elevation head decrease > pressure head increase between S and R ➔ water flows from S to R

$$\mathrm{Dh}_{1-2} = \left(\frac{\mathrm{P}_2}{\gamma} - \frac{\mathrm{P}_1}{\gamma}\right) + \mathrm{h}_{f12}$$

Elevation head decrease

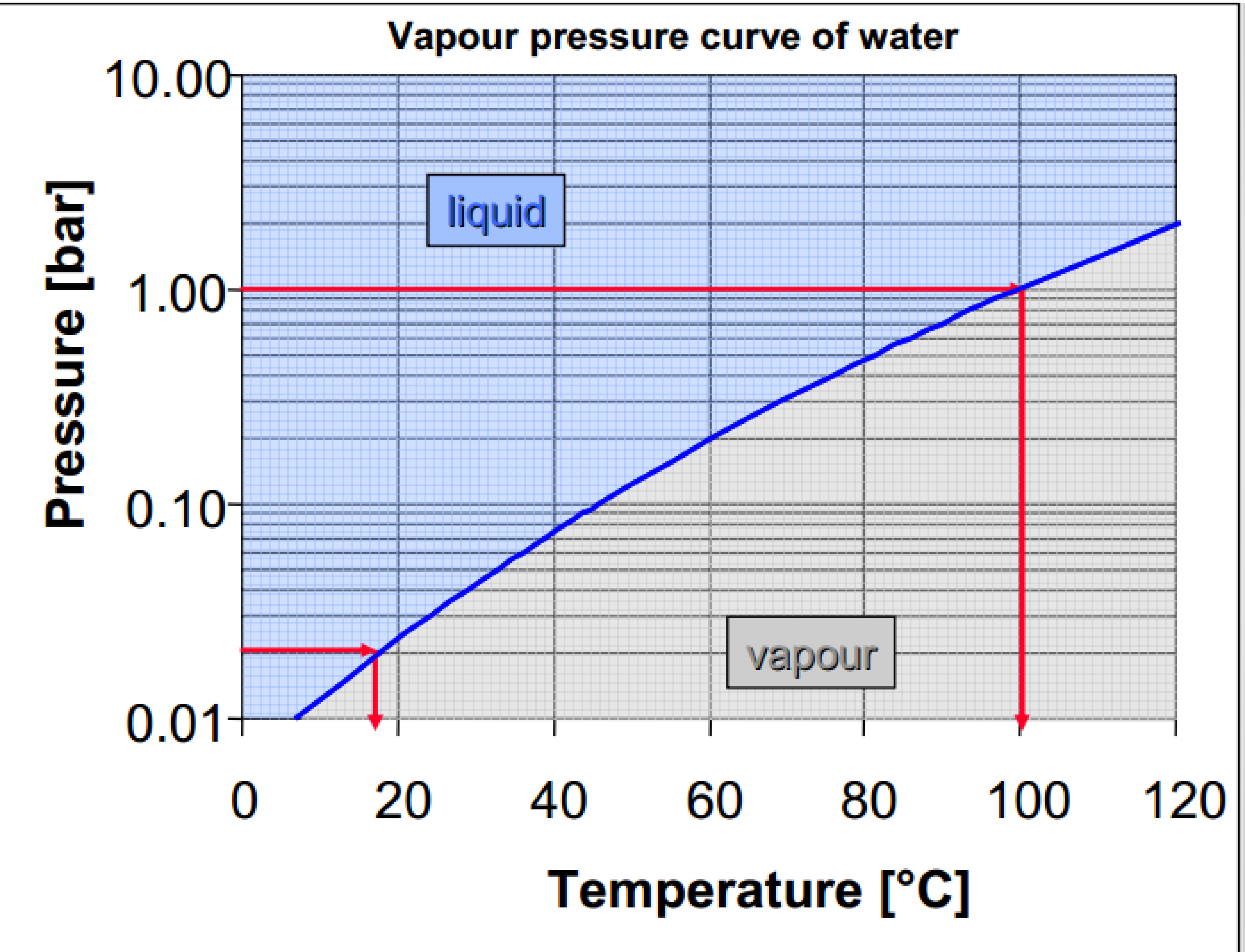
Pressure head increase

Head loss between 1 to 2

It is important to maintain pressure at all points in a pipeline above the vapor pressure of water.

- Vapor pressure of water $\cong$ a negative water column of 10 m at 20^0C.
- When the pressure in a pipe drops below vapor pressure of water
    - water will be vaporized
    - vapor pockets (cavitation) forms
    - separates water in the pipes
- These water pockets collapse in regions of higher pressure downstream.
- The action of vapor collapse is very violent, causing vibrations and sound that can greatly damage the pipeline.

Water Evaporation



At atmospheric pressure (1 bar) water evaporates at 100°C.

When the pressure decreases, the evaporation process already starts at low temperatures.

Example:

At a pressure of 0.02 bar water evaporates already at a temperature of 18°C.

The total energy of a flow medium is basically composed of the following individual types of energy:

Potential energy

Pressure energy

Velocity energy

\+ Loss energy

Σ constant

The sum of this individual energy types is constant!

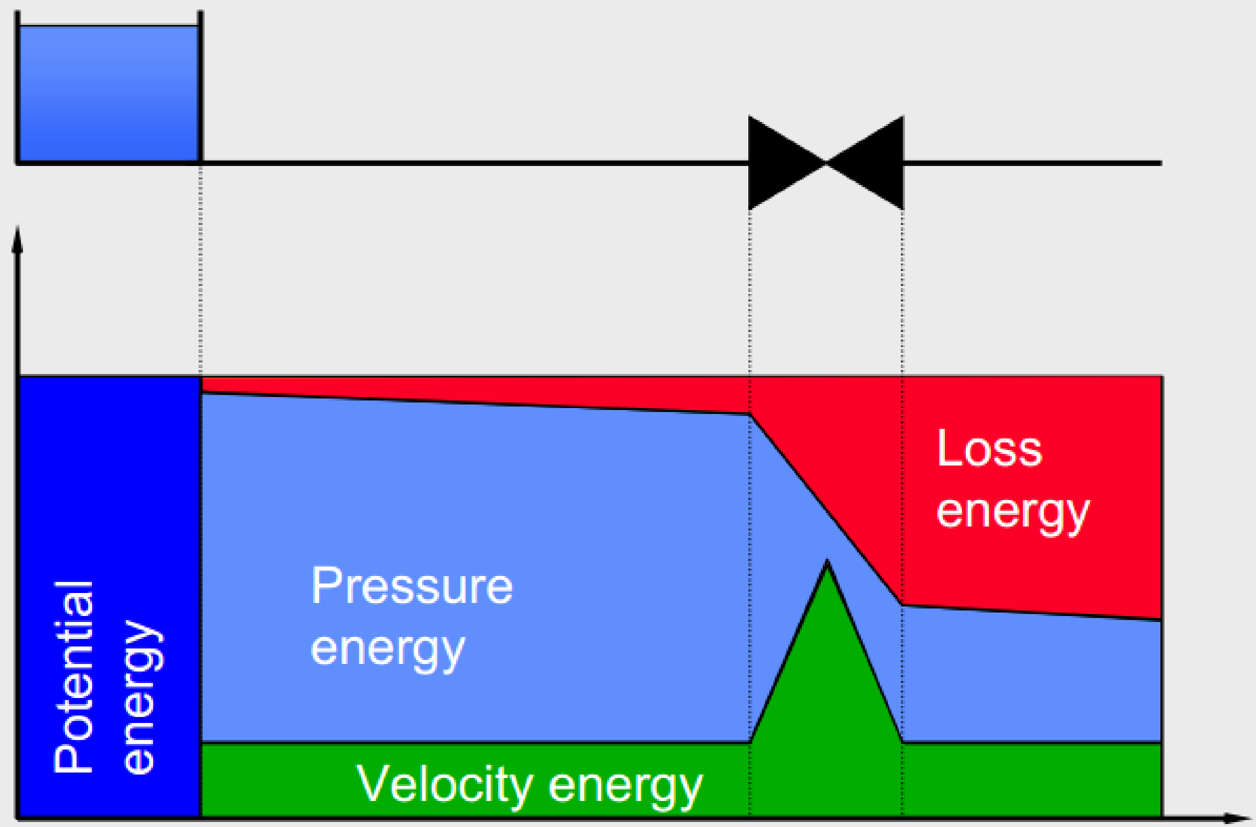
Energy Equation

Energy forms in pipelines

In the store reservoir the existing total energy of the static flow is stored as potential energy.

In case of flow through a horizontal pipeline this available potential energy is converted into:

- **velocity energy**
- **pressure energy**
- **loss energy**

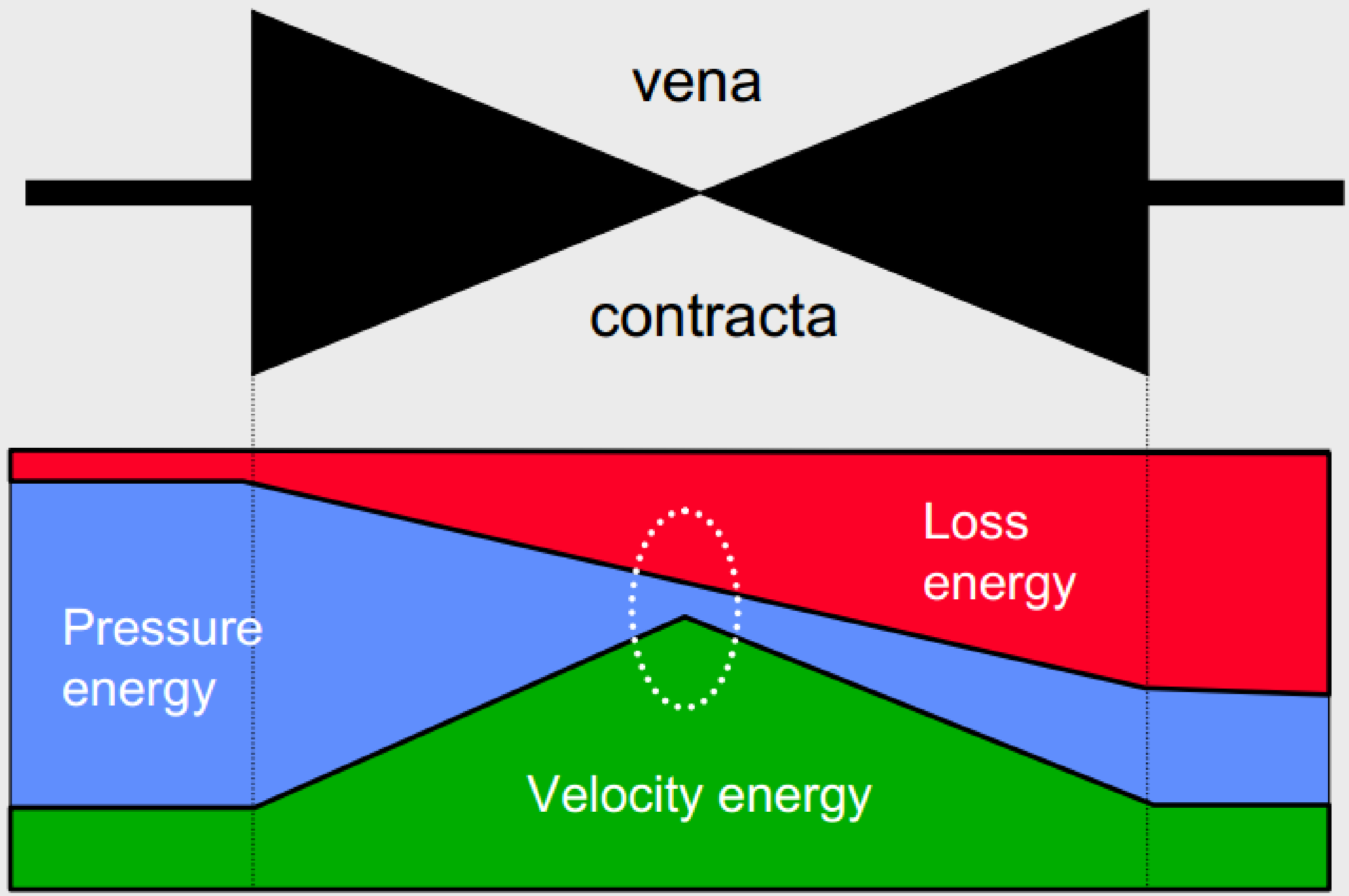


Change of energy forms at the throttling

Due to the contraction of the flow cross section at the throttling point, the flow velocity and thus the corresponding portion of energy rises considerably.

Due to throttling also the number of losses rises considerably.

At the vena contracta the remaining pressure energy and thus the local pressure decrease considerably because of the constancy of the total energy.



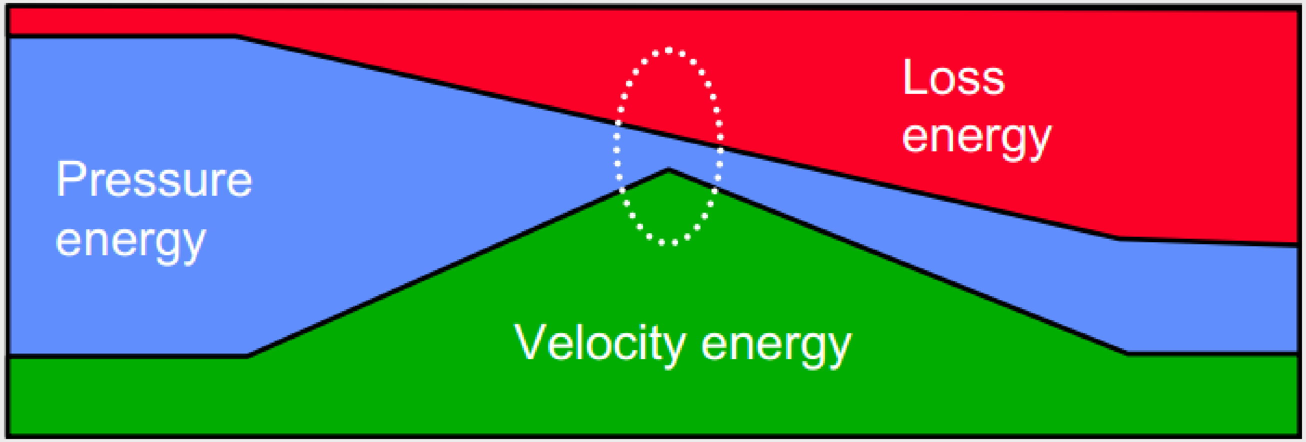
Change of energy forms at the throttling

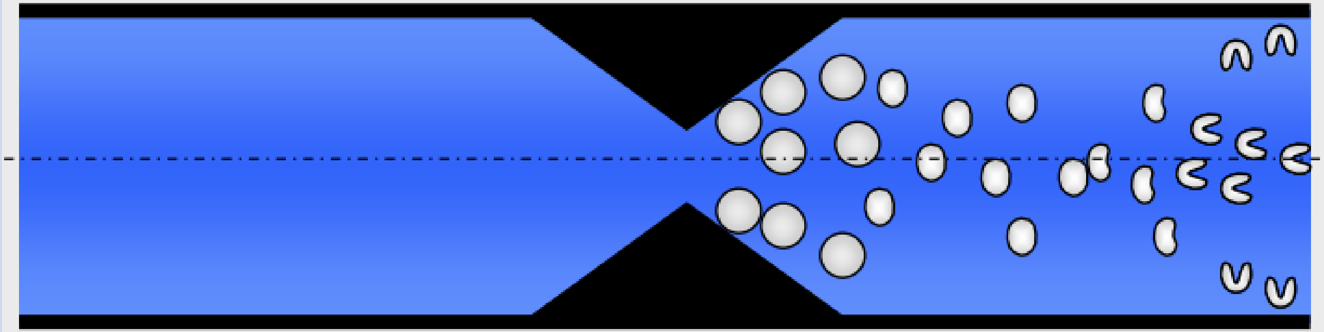
If at this point the water pressure gets lower than the vapour pressure of the medium, it will evaporate.

There will be vapour bubbles, ...

... which are deformed under increasing pressure...

... and will finally implode.





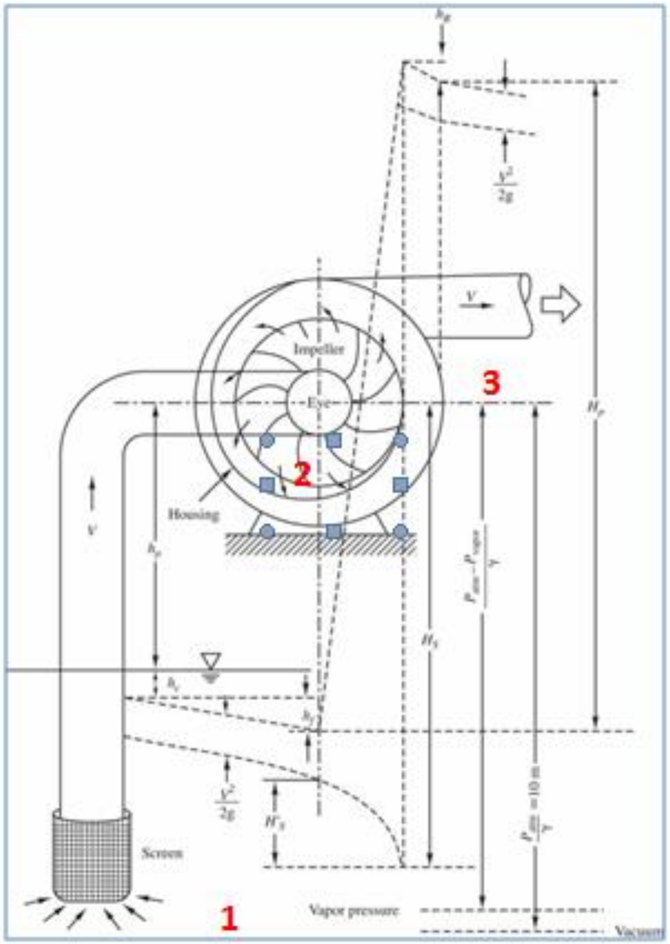
Typical cavitation damages

Cavitation damages at a butterfly valve.

Operating conditions:

- upstream pressure: 1.2 -1.4 bar
- downstream pressure: 0.1 bar
- flow velocity: 2.2 m/s (referred to DN)
- duration of operation: 2 years
- opening degree of disc: approx.: 30°

CAVITATION IN PUMPS



$$z_1 + \frac{V_1^{\,2}}{2g} + \frac{P_1}{\gamma} = z_2 + \frac{V_2^{\,2}}{2g} + \frac{P_2}{\gamma} + h_L$$

$V_1 = 0$, $P_1 = P_{atm}$ $V_2 \rightarrow V_s$, $P_2 \rightarrow P_S$

$$h_p = z_2 - z_1$$

$$0 + \frac{P_{atm}}{\gamma} = \frac{V_S^{\,2}}{2g} + \frac{P_S}{\gamma} + h_{L(1-2)} + h_P$$

$$\frac{P_S}{\gamma} = \frac{P_{atm}}{\gamma} - \left(\frac{V_S^{\,2}}{2g} + h_{L(1-2)} + h_P\right)$$

NPSH (NET POSITIVE SUCTION HEAD)

Net Positive Suction Head avaliable ($NPSH_A$) = $\frac{P_S}{\gamma} - \frac{P_V}{\gamma}$

$$= \frac{P_{atm}}{\gamma} - \frac{P_V}{\gamma} - \left(\frac{{V_S}^2}{2g} + h_{L(1-2)} + h_P\right)$$

|

Net Positive Suction Head Required ($NPSH_R$) = $\frac{P_S}{\gamma} - \frac{P_3}{\gamma} = = {H_S}'$

To avoid cavitation $P_3 > P_V$ ➔ $NPSH_a > NPSH_R$

$$\frac{P_S}{\gamma} - \frac{P_V}{\gamma} > \frac{P_S}{\gamma} - \frac{P_3}{\gamma}$$

Safety factors other dissolved gases in water, $NPSH_a - 0.6\ m > NPSH_R$

$NPSH_{avaliable}$ vs $NPSH_{required}$

- $NPSH_{avaliable}$ is calculated for each system
- $NPSH_{required}$ is given by pump manufacturer

The formula for calculating $NPSH_A$:

$$NPSH_A = H_A \pm H_Z - H_F + H_V - H_{VP}$$

Term	Definition	Notes
H_A	The absolute pressure on the surface of the liquid in the supply tank	• Typically atmospheric pressure (vented supply tank), but can be different for closed tanks. • Don't forget that altitude affects atmospheric pressure (H_A in Denver, CO will be lower than in Miami, FL). • Always positive (may be low, but even vacuum vessels are at a positive absolute pressure)
H_Z	The vertical distance between the surface of the liquid in the supply tank and the centerline of the pump	• Can be positive when liquid level is above the centerline of the pump (called static head) • Can be negative when liquid level is below the centerline of the pump (called suction lift) • Always be sure to use the lowest liquid level allowed in the tank.
H_F	Friction losses in the suction piping	• Piping and fittings act as a restriction, working against liquid as it flows towards the pump inlet.
H_V	Velocity head at the pump suction port	• Often not included as it's normally quite small.
H_{VP}	Absolute vapor pressure of the liquid at the pumping temperature	• Must be subtracted in the end to make sure that the inlet pressure stays above the vapor pressure. • Remember, as temperature goes up, so does the vapor pressure.