Cavitation

Contents

1. Why is important to know about cavitation?

Cavitation in processes affects the performance of flow equipment and may damage it. Cavitation should always be avoided.

Understanding aspects of cavitation makes it easier to optimise process/system designs and to select and handle flow equipment correctly.

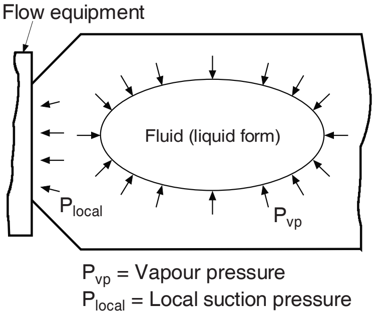


Fig.1.1. Cavitation

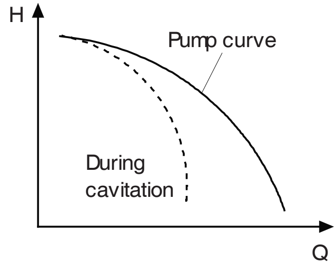


Fig.1.2. Reduced pump performance

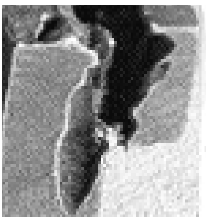

Source: Burgmann

Fig.1.3. Damaged steel part

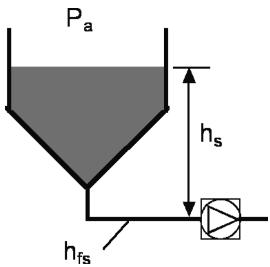


Fig.1.4. Inlet conditions/NPSH$_a$

Examples: Effects of cavitation

1. It is very important to have correct inlet conditions (suction head, pressure drops, fluid temperature etc.) to avoid cavitation.
2. Cavitation may reduce pump performance to nearly zero.
3. Cavitation may cause noise and vibration in the system – and it may damage flow equipment in the long term.
4. Correct process design and correct selection of flow equipment can limit the risk of cavitation.

2. Who should know about cavitation?

All people who work with flow equipment during its life cycle should know about cavitation in flow systems.

Knowing the effects of cavitation, how to identify and how to prevent cavitation helps to ensure that processes are optimised and that errors, damage and personal injuries are avoided. The target groups may include:

1. *Process designers*, who should design inlet conditions so that the available suction pressure is as high as possible to minimise the risk of cavitation.
2. *Pump designers*, who should optimise pump inlet designs to minimise NPSH and the risk of cavitation.
3. *Field operators*, who should be able to identify cavitation and know how to change operating conditions to prevent cavitation.
4. *Beginners in the flow industry*, who should have a basic understanding to work efficiently.

3. What is cavitation?

Cavitation occurs when the pressure in flow systems and flow equipment locally drops below the vapour pressure of the fluid at the current temperature.

Cavitation is caused by difficult suction conditions.

Pressure drop/decrease:

- The pressure at inlet of flow equipment locally drops, e.g. if a valve is throttled in the suction line.
- The local pressure is now below the vapour pressure.
- The fluid boils (evaporates) and generates small vapour bubbles.

Temperature increase:

- The vapour pressure increases above the local suction/inlet pressure.
- The fluid boils (evaporates) and generates small vapour bubbles.

Cavitation occurs:

- The vapour bubbles are carried along with the fluid and collapse (implode) instantly when they enter areas of higher pressure, e.g. a pump casing.
- This collapsing of vapour bubbles is registered as noise. Cavitation has occured.

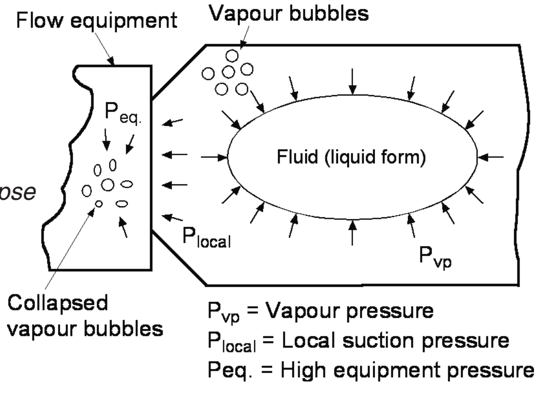


Fig.3.1. Vapour bubbles collapse and cavitation occurs

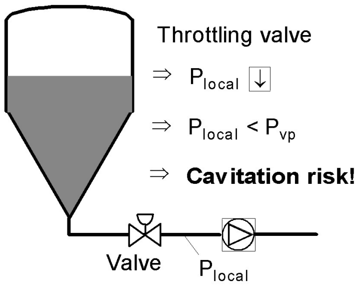


Fig.3.2. Effect of valve throttling

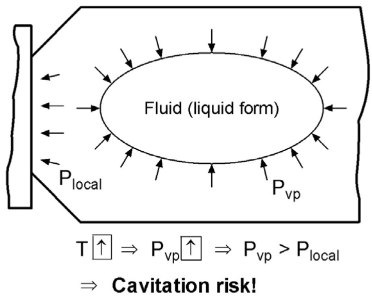


Fig.3.3. Effect of temperature increase

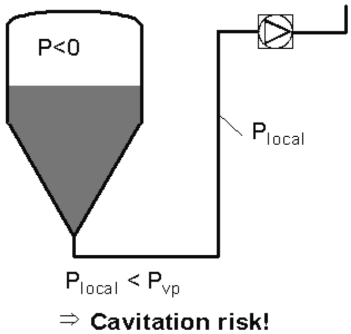


Fig.3.4. Effect of suction lift or vacuum

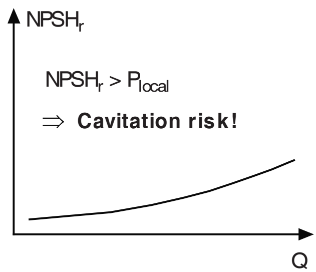


Fig.3.5. $NPSH_r$

Examples of causes of cavitation

1. Pressure drop/decrease in suction/inlet line:
   Local inlet pressure will drop below vapour pressure.
2. Increase of fluid temperature:
   Vapour pressure will increase above local suction/inlet pressure.
3. Suction lift or vacuum:
   This will reduce available suction/inlet pressure, maybe to below the vapour pressure.
4. Too high capacity in system:
   The flow equipment requires higher suction/inlet pressure ($NPSH_r$) than is currently present in the suction/inlet line (P_{local}).

4. What is NPSH?

NPSH (Net Positive Suction Head) specifies the suction pressure required ($NPSH_r$) or available ($NPSH_a$) in the suction line of a process. Normal unit: m or ft

$NPSH_r$:

- Required minimum pressure that must be present in the suction line to prevent cavitation.
- Result of equipment design (e.g. pumps).
- Should be as low as possible.
- Normally specified in pump flow charts.
- Increases with increasing capacity.

$NPSH_a$:

- Available suction pressure at current process conditions.
- Should be as high as possible.
- Result of suction conditions - can be calculated.

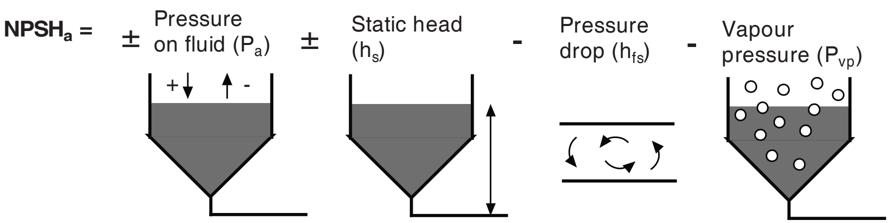


Fig.4.1. Calculation of $NPSH_a$

Formula:

$$NPSH_a = P_a \pm h_s - h_{fs} - P_{vp}$$

Where:
P_a = Pressure absolute above fluid level (bar a or psia)
h_s = Static suction head (m or ft)
h_{fs} = Pressure drop in suction line (m or ft)
P_{vp} = Vapour pressure (bar a or psia)

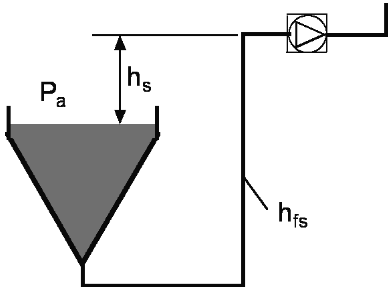


Fig.4.2. $NPSH_a$

General:

- P_a = 1 for open tank
- P_a > 1 for pressure
- P_a < 1 for vacuum
- h_s > 0 for flooded inlet
- h_s < 0 for suction lift

$NPSH_a > NPSH_r \Rightarrow$ No cavitation!

Examples: NPSH – calculations/cavitation check

Process:
Water at 45 °C (113 °F)
P_a = 1 bar a = 10m = 33ft (open tank)
h_s = - 3m = - 10ft (lift)
h_{fs} = 1.5m = 5ft
P_{vp} = 0.096 bar a = 1m = 3.3ft

Pump selected: $NPSH_r$ = 3.5m = 11.5ft

$NPSH_a$ (m) = 10-3-1.5-1 = 4.5m > 3.5m $\Rightarrow$ No cavitation!
$NPSH_a$ (ft) = 33-10-5-3.3 = 14.7ft > 11.5ft $\Rightarrow$ No cavitation!

5. Cavitation in theory

Cavitation check:
$NPSH_a > NPSH_r \Rightarrow$ No cavitation!

In other words:

Cavitation can be identified in theory by calculations. Cavitation will occur if the available suction/inlet pressure is lower than the pressure required from flow equipment in the flow system.

General:

The available suction/inlet pressure ($NPSH_a$) should always be identified if there is indication of difficult suction/inlet conditions or other critical process conditions.

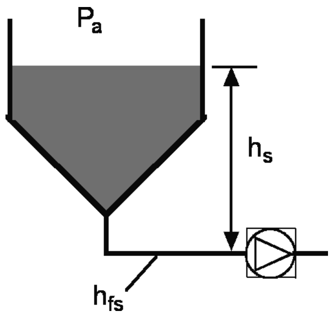


Fig.5. Cavitation check

Examples of identification of cavitation – calculations

Process:
Sugar solution at 50 °C (122 °F)
P_a = 1 bar a = 10m = 33ft (open tank)
h_s = 1.5m = 5ft
h_{fs} = 9m = 30ft
P_{vp} = 0 (assumed)

Pump selected: $NPSH_r$ = 3.5m = 11.5ft

$NPSH_a$ (m) = 10+1.5-9-0 = 2.5m < 3.5m ⇒ Cavitation will occur!
$NPSH_a$ (ft) = 33+5-30-0 = 8ft < 11.5ft ⇒ Cavitation will occur!

6. Cavitation in practise

Cavitation will affect performance of the process and the flow equipment. Cavitation may damage the fluid and the flow equipment.

Cavitation can be identified in practise as:

- Noisy operation.
- Vibration in system and flow equipment.
- Damage of processed fluid.
- Reduced or no performance of flow equipment.
- Visual leakages in flow equipment.
- Visual mechanical damage in flow equipment, including corrosion and erosion.

Note!
The first and most common signs of cavitation are noise, vibration and reduced performance of flow equipment.

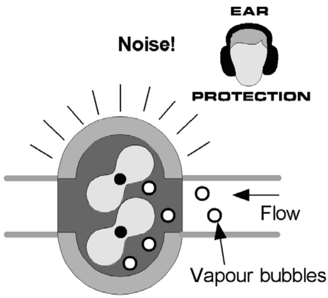


Fig.6.1. Noise

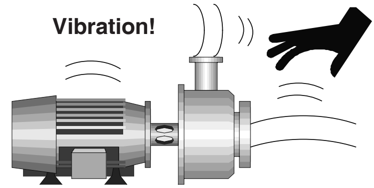


Fig.6.2. Vibration

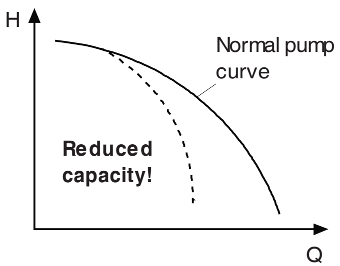


Fig.6.3. Reduced pump capacity

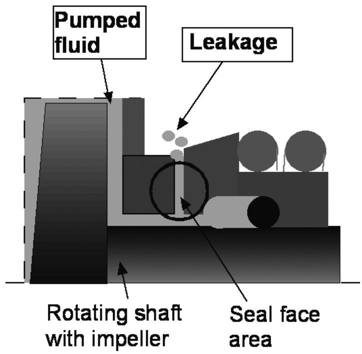
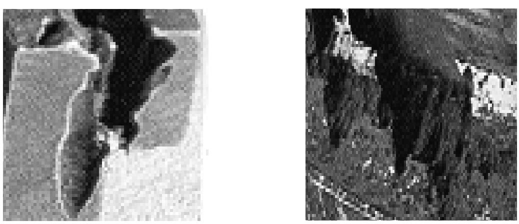


Fig.6.4. Leaking seal (principle)



Source: Burgmann

Fig.6.5. Damaged steel parts

7. Short-term effects of cavitation

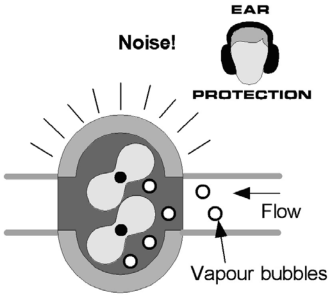
The short-term effects of cavitation are noise, vibration and reduced performance in the system and in flow equipment.

Noise and vibration in system:

- Normally easy to hear, feel and see.
- Normally a good indication of cavitation if the noise and vibration can be removed, e.g. by reducing capacity in the system.

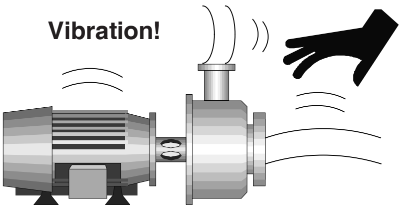
Reduced performance of centrifugal pump:

- Cavitation is defined as a pressure reduction of 3% of normal head.
- Cavitation may be identified by the pump flow chart.
- Current system pressure and capacity should be measured and compared with the pump flow chart.
- Cavitation has occured if the head has been reduced by more than 3%.



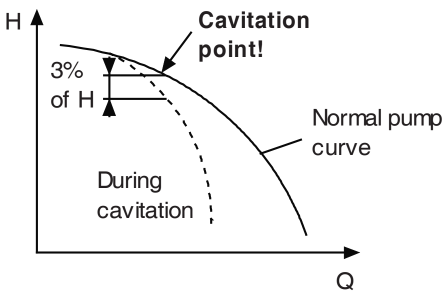
Pay attention to excessive noise!

Fig.7.1. Noise



Pay attention to excessive vibration!

Fig.7.2. Vibration



Pay attention to pump performance!

Fig.7.3. Reduced pump performance

8. Long-term effects of cavitation

The long-term effects of cavitation are leaking flow equipment, damage to system and flow equipment and damage to processed fluid.

Leaking seals:
May be caused by vibration or beginning material/seal surface damage.

Damaged flow equipment:
- Cavitation will cause mechanical damage as well as increased local corrosion and erosion.
- Cavitation will actually “eat away” the material. The first sign will be an uneven surface finish.
- The material will disappear into the processed fluid.

Damaged processed fluids:
Shear sensitive fluids or similar may be damaged by the vapour bubbles and the collapsing of the bubbles (very high local pressure).

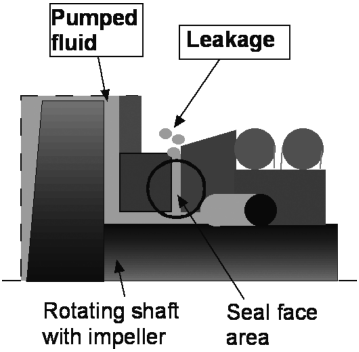


Fig.8.1. Leaking seal (principle)

Pay attention to leaking equipment!

Source: Burgmann

Fig.8.2. Damaged steel part

Pay attention to damaged parts!

9. How to stop cavitation once it has occurred

Cavitation can be "removed" by optimising the parameters that adversely affect the suction conditions and the requirements of the flow equipment.

Parameters involved:

$NPSH_a$: $NPSH_a = P_a \pm h_s - h_{fs} - P_{vp}$
Static head, pressure drops, temperature
$NPSH_r$: System capacity

$NPSH_a > NPSH_r \Rightarrow$ No cavitation!

Static head:

If possible, maximise the static head, either by moving a pump to a lower point or by increasing the fluid level in the tank.

Pressure drops:

If possible, open any valves in the suction line to minimise pressure drops.

Temperature:

If possible, reduce the fluid temperature so that the vapour pressure will be below the available suction pressure.

System capacity:

If possible, reduce the system capacity so that the required suction pressure ($NPSH_r$) is lower than the available suction pressure ($NPSH_a$).
This should stop cavitation and minimise risk of future cavitation.

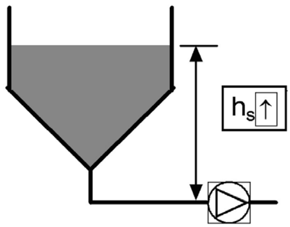


Fig.9.1. Maximise static head

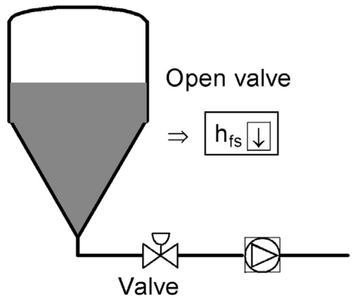


Fig.9.2. Open valves in suction line

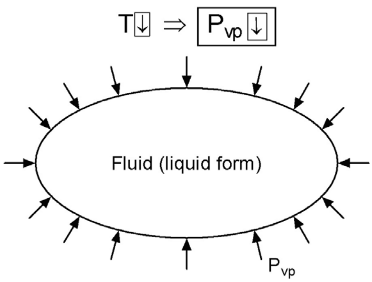


Fig.9.3. Reduce fluid temperature

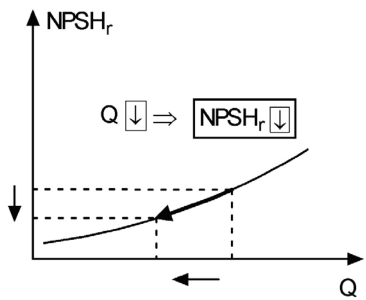


Fig.9.4. Reduce capacity in system

10. How to avoid cavitation when designing processes

Cavitation can be avoided by designing the process and selecting flow equipment so that the available suction pressure in the system is always higher than the pressure required from flow equipment.

In other words:

$$\mathbf{NPSH_a = P_a \pm h_s - h_{fs} - P_{vp} > NPSH_r \Rightarrow}\ \textbf{No cavitation!}$$

Static head:
Maximise the static head, considering available space in the plant.

Pressure drops:
Minimise pressure drops:
- Use few flow components, bends, tees, reducers etc.
- Use large tube diameters.
- Use bends with large radii.
- Optimise routing of piping, use tees correctly.

Vacuum and temperature:
Pay special attention to vacuum and high temperatures in the process. This indicates difficult suction conditions.

System capacity/$NPSH_r$:
Select pumps with suction capability ($NPSH_r$) that is suitable for the required system capacity.

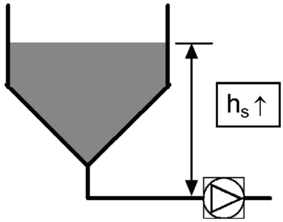


Fig.10.1. Max. static head

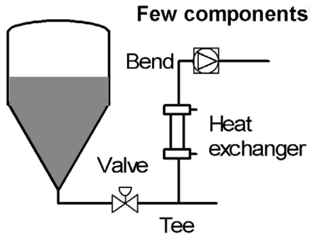


Fig.10.2. Few components

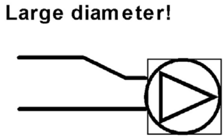


Fig.10.3. Large diameter

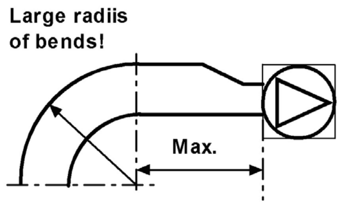


Fig.10.4. Large bend radii

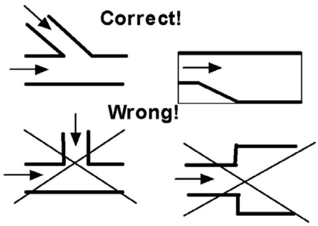


Fig.10.5. Correct routing

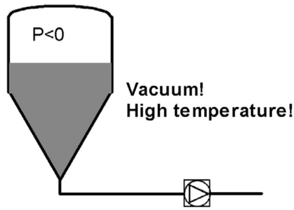


Fig.10.6. Vacuum and temperature

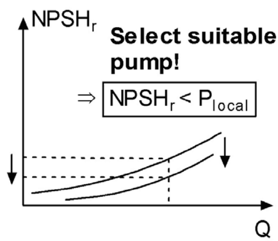


Fig.10.7. Minimise $NPSH_r$

Glossary

Absolute pressure	Total pressure, e.g. of a fluid.
Capacity	The maximum volume of fluid that can pass a certain area per unit of time.
Cavitation	The formation and collapse of regions of low pressure in a flowing liquid. Occurs when fluid pressure in flow equipment locally drops below the vapour pressure of the fluid at the current temperature.
Flooded inlet	Positive inlet pressure/head.
Flow equipment	Equipment used in flow systems. Examples are heat exchangers, pumps, valves, tubing, fittings and tank parts.
Fluid	Liquids/media (non-solid and non-gas) processed in flow systems.
Head	Total vertical height which a fluid is lifted. Also specified as elevation.
Inlet/suction	Pressure at which a fluid enters flow equipment.
NPSH	**N**et **P**ositive **S**uction **H**ead.
$NPSH_r$	Required minimum pressure in suction line to avoid cavitation.
$NPSH_a$	Available suction pressure at current process conditions.
Pressure	Force per unit area.
Pressure drop	Result of frictional losses in piping and flow equipment.

Pressure Force per unit area.

Pressure drop Result of frictional losses in piping and flow equipment.

Shearing Motion between fluid layers in laminar flow.

Static suction Difference in height between fluid/tank level (suction side) and center, e.g. of a pump.

Suction lift Negative inlet head/pressure.

Vacuum Pressure below atmospheric pressure.

Vapour pressure Minimum required external pressure to prevent vaporisation of a fluid.

Other handbooks in this series

1. Pressures in flow systems
2. Cavitation
3. Fluid properties
4. Pumps for sanitary processes
5. Centrifugal pumps
6. Sizing centrifugal pumps
7. Rotary-lobe pumps
8. Sizing rotary-lobe pumps
9. Pump motors
10. Pump-shaft seals
11. Troubleshooting pumps
12. Flow control
13. Materials for flow equipment
14. Valves for sanitary processes
15. Single-seat valves
16. Mix-proof valves
17. Regulating valves
18. Troubleshooting valves
19. Valve automation
20. Standards and regulations