TECHNEWS

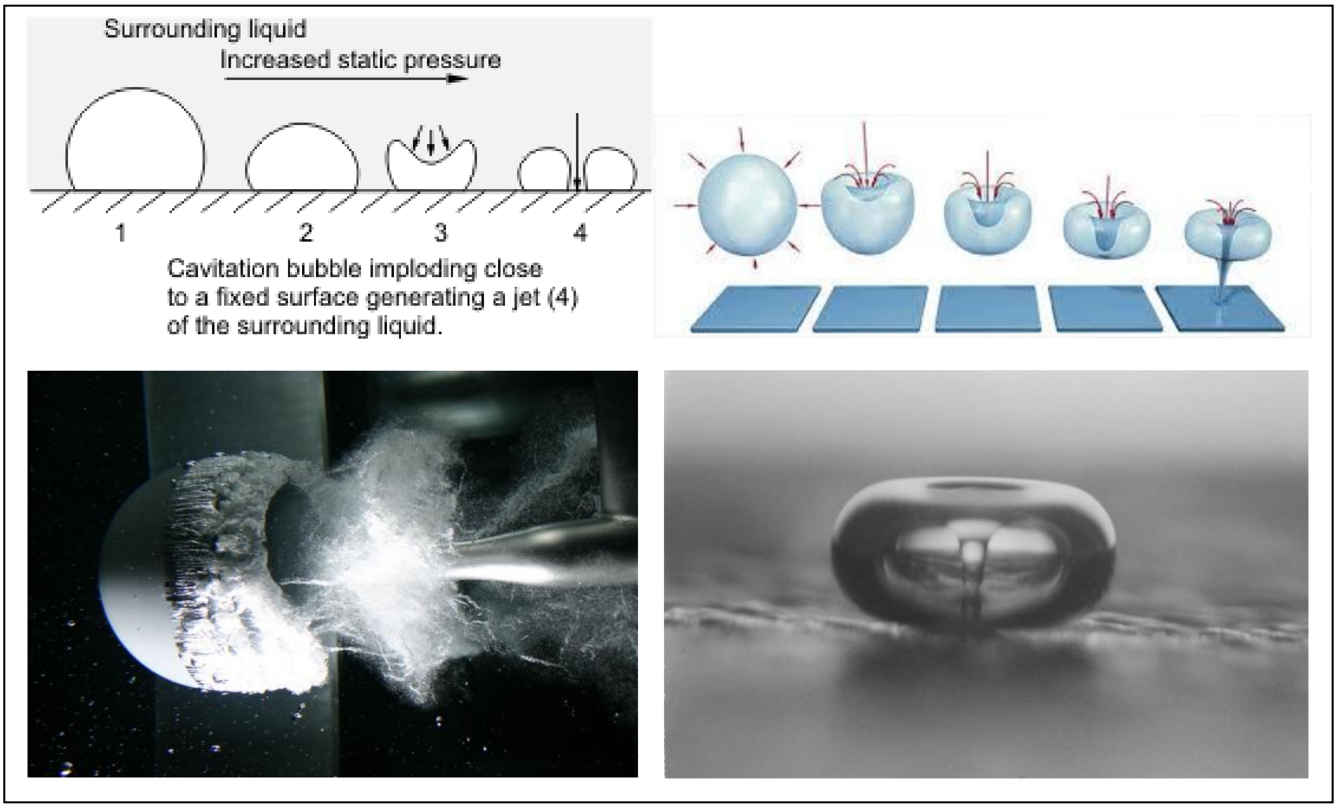
Edition No.2 2017

Vaporous and Gaseous Cavitation.

1) What Is Vaporous Cavitation?

Vaporous Cavitation is a phenomenon where vapour bubbles are generated in a flowing liquid, once the local **static pressure** of the liquid drops below the saturated **vapour pressure** of the liquid, at the actual temperature, followed by the almost immediate collapse/implosion of these vapour bubbles once the local static pressure increases above the saturated vapour pressure of the liquid, at the actual temperature (i.e. phase changes from liquid ➔ vapour ➔ liquid).

The process of implosion of the vapour bubbles takes place in micro-seconds (speed of sound), producing shockwaves, micro jets, noise, light is emitted, the pressure inside the imploding bubbles can reach a very high level of several 100 bars/10 MPa and very high local temperatures (several thousand Kelvin) at the surface of the bubbles for a very short time.
These rapid and frequent implosions of vapour bubbles can cause serious damage by eroding adjacent surfaces. Vaporous cavitation wear is a fluid-to-surface type of wear.



Click on below link to view the video "**Cavitation – Easily explained**" YouTube

https://www.youtube.com/watch?v=U-uUYCFDTrc

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Vaporous Cavitation is a common problem in fluid dynamics with pumps, impellers, propellers, control valves and pipes - causing serious wear, tear and damage. Cavitation wear is also known as cavitation erosion, vaporous cavitation, cavitation pitting, cavitation fatigue, liquid impact erosion and wire-drawing. Under the wrong conditions cavitation reduces components life time dramatically.

Click on below link to view the video "**Cavitation Causes and Effects**" YouTube

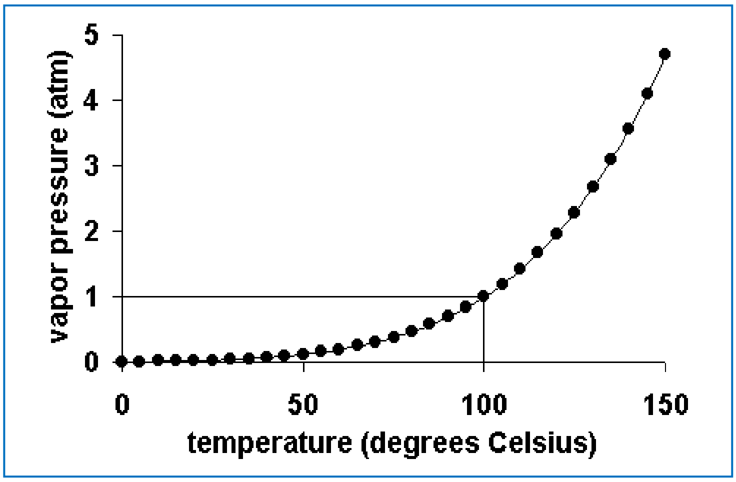
https://m.youtube.com/watch?v=oRYYP4F8LTU

Examples of Vaporous Cavitation damage

What is vapour pressure?

Vapour pressure is defined as *"the pressure exerted by a vapour in thermodynamic equilibrium with its condensed phases (solid or liquid) at a given temperature in a closed system".*
The equilibrium vapour pressure is an indication of a liquid's evaporation rate. It relates to the tendency of particles to escape from the liquid (i.e. boiling).
A substance with a high vapour pressure at normal temperatures is often referred to as *volatile*.
The pressure exhibited by vapour present above a liquid surface is known as **vapour pressure**.
As the temperature of a liquid increases, the kinetic energy of its molecules also increases.
As the kinetic energy of the molecules increases, the number of molecules transitioning into a vapour (i.e. boiling) also increases.

Therefore the vapour pressure of a liquid varies with its temperature, as the following graph shows for water. **The higher the water temperature, the higher the vapour pressure!**
The line on the graph shows the boiling temperature for water.



http://www.msduncanchem.com/Reference_Tables/water_vapor_pressure_chart.htm

When water starts to boil on the stove, the rising water temperature causes the vapour pressure of the water to rise above the "normal ambient (air) pressure" (1 atm). Vapour bubbles will be formed. In the case of cavitation, it works the other way around. The water temperature remains the same but the static (water) pressure drops below the vapour pressure of the water, causing vapour bubbles to form.

⇨ **The higher the water temperature the lesser the static water pressure has to drop to form vapour bubbles!**

Click on below link to view the video "**Vapour pressure and boiling**" YouTube

https://www.youtube.com/watch?v=ffBusZO-TO0

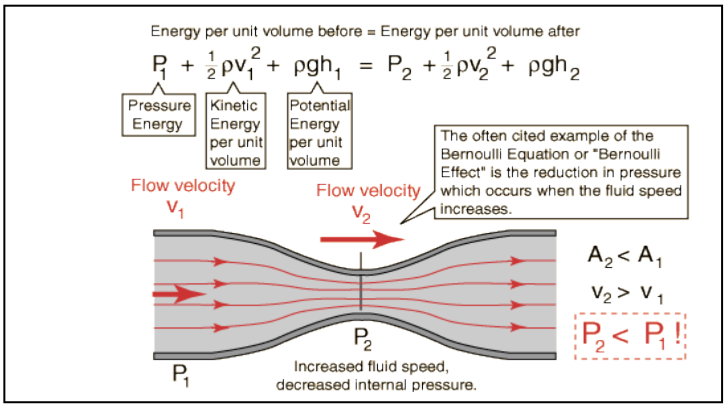
What can cause the static pressure of the water to drop?

For that we have to explain the **"Bernoulli Equation"** (first published in **1738**).
The Bernoulli Equation is based on Newtown's 2nd law of Motion, the principle of the conservation of energy, and is valid for incompressible media (constant density; i.e. water in reticulation systems), ignoring friction by viscous forces and thermal effects.

Bernoulli states that, in a steady flow, the sum of all forms of energy in a fluid along a streamline is the same at all points on that streamline.

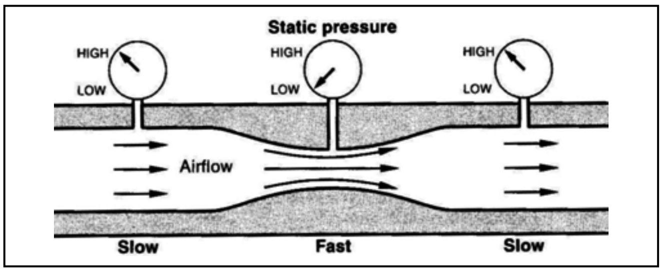
This means that the sum of internal (or pressure) energy (static pressure), kinetic energy (dynamic pressure) and potential energy remains constant.
(Total pressure = Static pressure + Dynamic pressure).

Based on the above, the simplest form of the **Bernoulli Equation** can be written as:



P = static pressure at a point on a streamline (**shown on a pressure gauge**) [Pa].
ρ = constant density of the fluid [kg/m^3] (approx. 1000 kg/m^3 for water).
v = velocity of the fluid at a point on a streamline [m/s].
g = acceleration due to gravity [m/s^2] (approx. 9.81 m/s^2).
h = hydraulic head at a point on a streamline [m].

The Bernoulli Equation tells you that an increase in the velocity of the fluid – implying an increase in its kinetic energy (½ρv^2 = dynamic pressure) – occurs with a simultaneous decrease in (the sum of) its internal energy (P = static pressure) and potential energy (ρgh).



Therefore in pipe systems vaporous cavitation typically occurs either as the result of an **increase of velocity** (kinetic energy) or an **increase in the pipe elevation** (potential energy).

➔ The static (water) pressure (P) drops below the vapour pressure of the water at its temperature.

An increase of (water) velocity [m/s] in a pipe can be caused by a flow constriction:

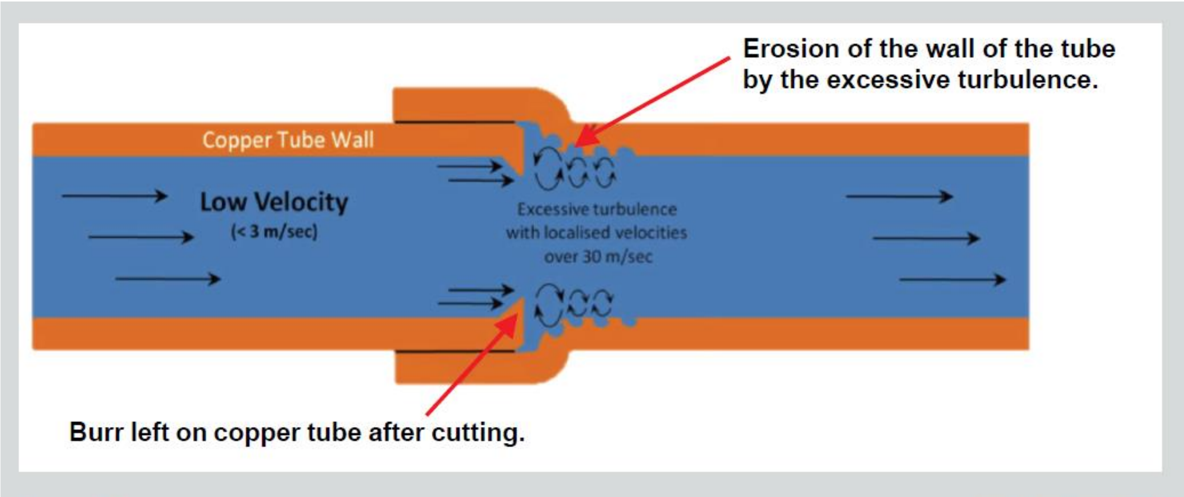
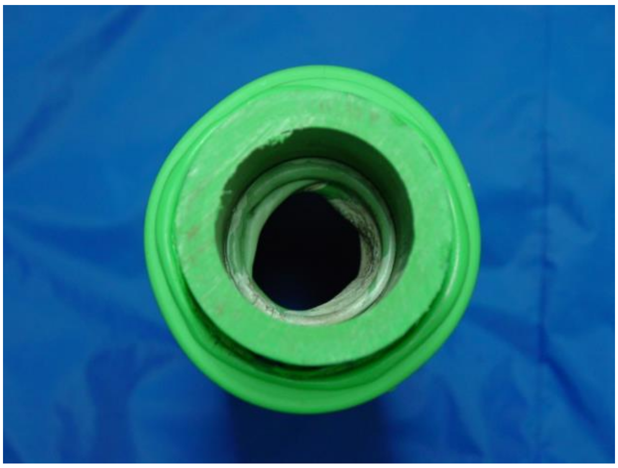


Figure 6.9
Explanation of how turbulence causes Erosion Corrosion

Burr left on a Copper tube after cutting causes Erosion Corrosion / Cavitation.



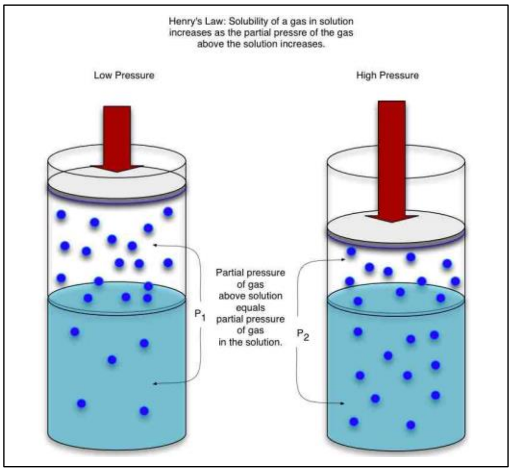
Poor socket fusion weld left an excessive internal bead.

2) What Is Gaseous Cavitation?

Gaseous Cavitation is a diffusion process that occurs whenever the (static) pressure falls below the saturation pressure of the non-condensable gas dissolved in the liquid.

The diffusion process is best explained by ***Henry's Law* (1803)**.
"Gas will dissolve in a fluid until there is an equilibrium between the partial pressure of the gas and the pressure in the fluid."

This means that smaller amounts of dissolved gases can be present in a fluid as the temperature rises or the pressure drops. In other words, a fluid will absorb more or less gas or release dissolved gases in certain locations in an installation under the influence of pressure and temperature.



Click on below link to view the video "**Henry's Law**" YouTube

https://www.youtube.com/watch?v=18Y_2IAM5qY

In the case of (frequent) pressure fluctuations in a system, gases will (frequently) diffuse in and out of the liquid (i.e. water).

"While vaporous cavitation is extremely rapid, occurring in (a) microsecond(s), gaseous cavitation is much slower; the time it takes depends upon the degree of convection (fluid circulation) present.

Cavitation wear occurs only under vaporous cavitation conditions - where the shockwaves and micro jets can erode the surfaces. Gaseous cavitation does not cause surface material to erode.

Gaseous cavitation creates a lot of noise, generates high (even molecular level cracking) temperatures and degrades the chemical composition of the fluid through oxidation.
Entrained air and dust particles in the fluid serve as nucleation sites for the formation of vapor cavities".

*Source: "**Proactive Maintenance for Mechanical Systems**", **chapter 8.7** "**Cavitation Wear**" by **Dr.E.C. Fitch** (Published **1992**). President Tribolics Inc., Emeritus Professor & Director Fluid Power Research Center Oklahoma State University Stillwater (USA).*

Cavitation hot spot areas

Many areas in hydraulic systems are prone to cavitation wear, such as:

- Downstream of control valves that have high pressure differentials.
- In the suction chambers of pumps.
- In rapidly moving actuators (both linear and rotary types).
- In leakage paths (across seals, valve seats) where high velocities cause pressure levels to drop below the vapour pressure of the fluid.
- In all devices where fluid flow is subjected to sharp turns (elbows), restrictions of flow with subsequent expansions (in cocks, flaps, valves, diaphragms).
- Rapidly operating (back flow) valves, and quick starting pumps can cause water hammer (pressure pulse), which can cause cavitation (separation and collapsing of a water column).

Click on below link to view the videos on **water hammer** YouTube

https://www.youtube.com/watch?v=VBa7DSSmWrE

https://www.youtube.com/watch?v=X9UbzcanuDk

Cavitation disturbs the normal operating conditions of fluid-type systems and destroys the surfaces of components. The process consists of cavities forming when pressures are low, the growth of subsequent bubbles as pressure stabilizes and finally the collapse of the bubbles when the cavities (gaseous or vaporous bubbles) are exposed to high-pressure.

Reducing Cavitation Wear

In cavitation wear, micro cracks propagate to the point where the material can no longer withstand the impulse load that the imploding vapour bubbles impose. Therefore, particles finally break off and enter the system. As with any fatigue failure, micro cracks first form at stress risers (notches, tears, undercuts, welding defects, etc.) or at heterogeneous areas of the material.
A rough surface is prone to cavitation wear and the damage increases as the surface becomes rougher.

In many cases, design engineers can minimize cavitation damage by properly selecting materials, pipe sizing (velocities) and/or the installation of a micro-bubble deaerator (preventing gaseous cavitation). For example, stainless steel may be selected instead of aluminium or copper and use hard facing with a cavitation-resistant alloy on the exposed surface.
Rubber and other elastomeric/plastic coatings can also help minimize cavitation wear.
Despite their low resistance to cavitation, these surfaces reflect the shock wave without causing intense damage.

(Excerpt from the book entitled Hydraulic System Design for Service Assurance by E.C. Fitch and I.T. Hong.)

Cavitation damage control starts at the drawing board by a properly engineered design.