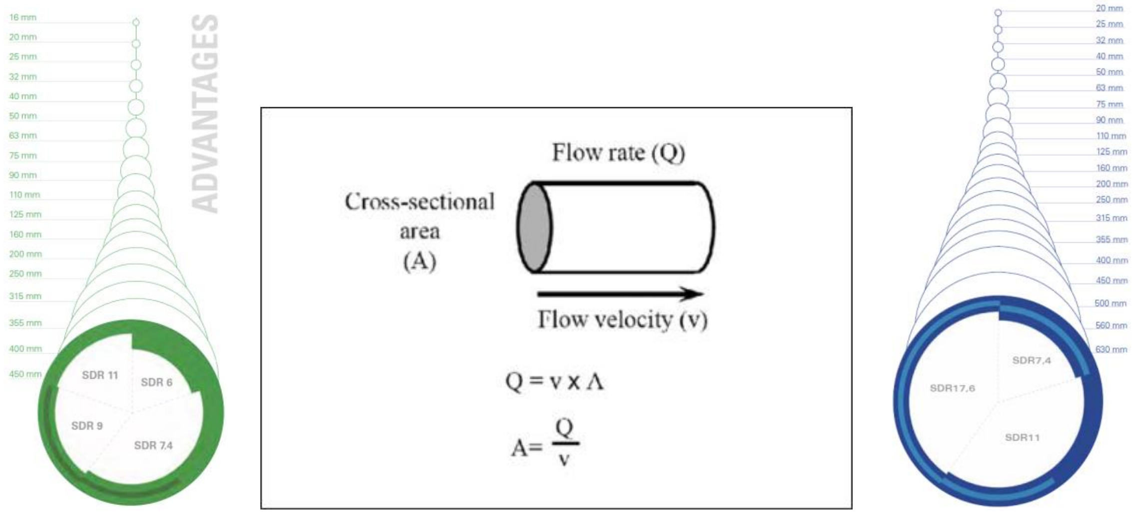
Two Phase Flow Systems.

1) Basic Hydraulic pipe sizing.

What parameters does a designer need to know to make the basic hydraulic pipe size calculations?

- What are the required flow rates [l/s] at the fixtures and appliances and therefore what will be the maximum flow rate running through a pipe?
- What is the water pressure [kPa] available from the main?
- What are the minimum and maximum pressure requirements for outlets to fixtures and appliances?
- What are the permissible (Static and Dynamic) pressure losses [kPa] caused by water running through the pipes and fittings?
- What are the recommended water velocities [m/s] in combination with the specified pipe material and internal diameter (d_i)?

a) Based on a 100% filled (i.e. 100% liquid; incompressible water) pipe, also known as "**One- or Single-Phase Flow**", the relation between flow rate [l/s], velocities [m/s] and internal pipe diameter [mm] can be calculated as below.



Q (Volume) Flow Rate [m^3/s] = Flow velocity (**v**) [m/s] x Cross-sectional area (**A**) [m^2]

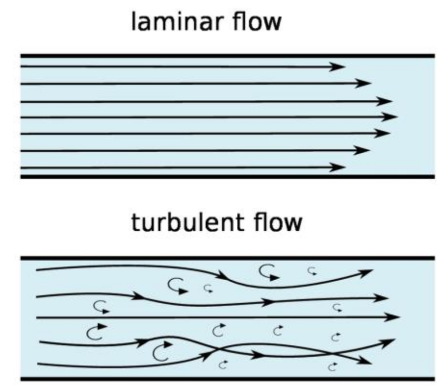
Cross-sectional area (**A**) [m^2] = π/4 x d_i^2 [m]

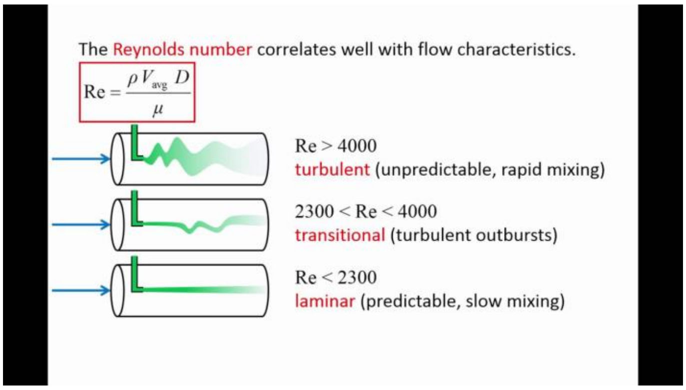
M (Mass) Flow Rate [kg/s] = Density (**ρ**) [kg/m^3] x (Volume) Flow Rate (**Q**) [m^3/s]

See: www.aquatherm.com.au under "Technical/Aquatherm Service Programs"

"Flow Rate and Velocity **aquatherm green** and **blue** pipes"

b) When we are dealing with a 100% filled pipe (**single-phase flow**), we can also calculate whether we have a laminar flow or a turbulent flow, based on the Reynolds number.





Newtonian Fluid Reynolds Number (Re) Formula

$$Re = \frac{\rho V D}{\mu}$$

μ – fluid dynamic viscosity in $kg/(m.s)$

ρ – fluid density in kg/m^3

V – fluid velocity in m/s

D – pipe diameter in m

c) We can also calculate the pressure losses by using **The Hazen-Williams Formula**.

$$P = 6.05 \times \frac{Q^{1.85}}{C^{1.85} \times D^{4.87}} \times 10^5$$

- P = Pressure loss [bar/mtr.] or [100 kPa/mtr.]
- Q = Flow rate [l/min]
- C = Hazen-Williams coefficient (specific for the type of pipe material)
- D = inside hydraulic diameter (d_h) [mm]

- The Hazen Williams method is only valid for water flowing at ordinary temperatures between 40 °F (4.44 °C) to 75 °F (23.89 °C).
- The Hazen-Williams formula gives accurate friction head loss for fluids with kinematic viscosity of approximately 1.1 cSt (water at approx. 20^o C). (1 cSt (centiStokes) = 10-6 m2/s)

<u>Note that the Hazen-Williams formula is empirical and lacks a theoretical basis.</u>

See: www.aquatherm.com.au under "Technical/Aquatherm Service Programs"

"Friction Head Loss"

d) In a single-phase flow pipe system calculations for heat loss through pipe walls can be made fairly easy because of stable boundary layers. Therefore temperature variations in the fluid, flowing through the pipe system, are easy to calculate.

See: www.aquatherm.com.au under "Technical/Aquatherm Service Programs"

"Heat Exchange and Energy Costs"

2) What happens if we have entrapped air in a water filled system?

When you not only have water in your pipe system but also entrapped air (i.e. liquid + gas), we are speaking of a **Two- Phase Flow** pipe system.

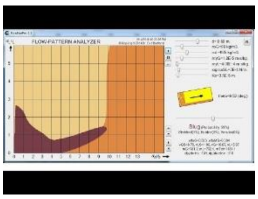
Other combinations of Two-Phase Flows are:

- Liquid + Solids (flowing mudslides or quicksand)
- Gas + Solids (sand transport)

Since gas (air) is compressible, the density (ρ) of gas is very different from liquid (water) and gas properties vary considerable with temperature, all above practical calculations are much more complex in a Two-Phase flow, compared to a Single Phase Flow.

- Flow rate and velocity calculations are difficult, since the pipe is not 100% filled with liquid (water). Actual water velocities can be much higher than originally calculated, based on a single-phase flow.
- Pressure drop calculations are complex due to constant friction changes and phase mixing.
- Heat loss through pipe walls are complex, because of unstable boundary layers and phase mixing.
- Temperature variations in the fluid are difficult to predict, because of turbulence and phase mixing.
- Flow stability can vary with two phase flow and violent flow changes can occur.

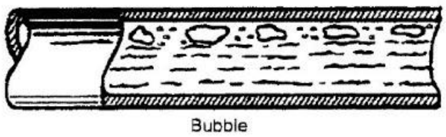
In most cases it is necessary to use experiments and measurements to develop empirical relations. Below video shows flow regimes in a pipe transporting gas and liquid. It uses realistic data and explains how the flow changes under various conditions in different sections of the pipe.
Click on below picture to start this YouTube video. YouTube



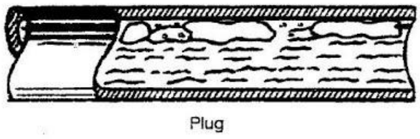
https://www.youtube.com/watch?v=7Tsomarcq30&t=750s&index=7&list=WL

Several flow patterns can occur in a **horizontal pipe** with **Two Phase Gas Liquid Flow**:

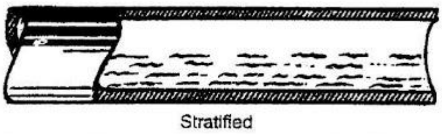
Bubble flow (with minimum vapour bubble)



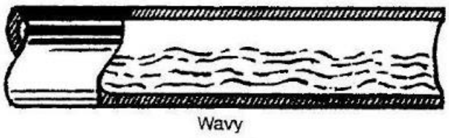
Plug flow



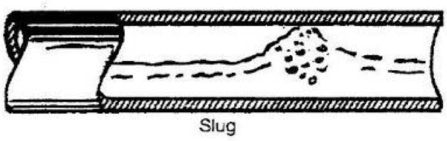
Stratified flow



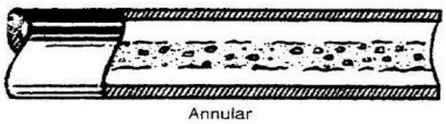
Wavy flow



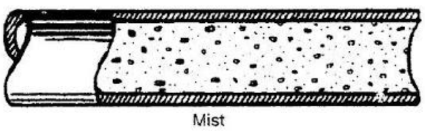
Slug flow

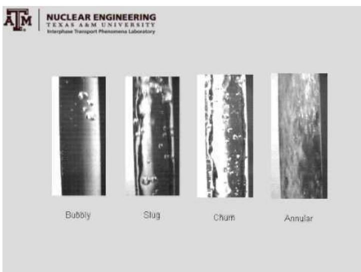


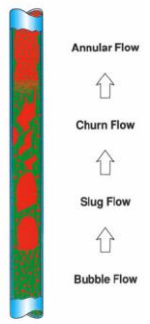
Annular flow



Mist/Dispersed flow (with minimum liquid droplet)

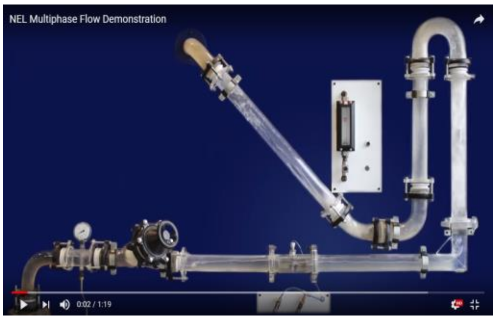






Flow patterns for a vertical pipe.

Below and above YouTube videos give a good demonstration of the different flow patterns in a Two-Phase Flow (liquid-gas) system. Click on pictures to start the YouTube videos.



https://www.youtube.com/watch?v=GMp9Oc0Dy_U https://www.youtube.com/watch?v=vGmTLAfTHBc

3) Two Phase Gas Liquid Flow can cause several destructive problems:

- Impingement erosion
- Splashing erosion
- Cavitation erosion
- Flashing erosion
- Flow induced vibration
- Surge / Hammer
- Noise
- Decrease process performance
- Phase separation / Column Separation

Impingement, Splashing, Cavitation & Flashing Erosion

Two phase gas liquid flow can lead to impingement, cavitation & flashing erosion.
It can induce high shear stress on the surface and increase material removal rate.

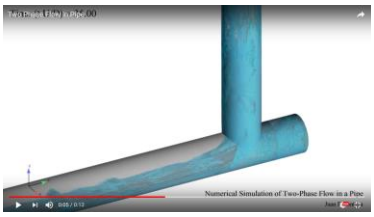
Flow Induced Vibration

High velocity compressible fluid in pipe is moving in turbulence pattern. Turbulence flow will induce vibration on pipe. Once the flow induced vibration frequency meeting the natural frequency of pipe support, resonance occur can lead to severe movement of pipe support. Present of two phase gas liquid flow can generate different level of frequency and increase possibility of resonances.

Surge & Hammer

When Two phase gas liquid is slugging, severe vibration can occur when liquid slug is knocking/splashing on the pipe wall, especially at bend and elbow. Sudden movement can cause water hammer. Under designed pipe support may fail due to severe vibration.

Click on below picture to start the YouTube video. YouTube



https://www.youtube.com/watch?v=xf_BN5K0pd8

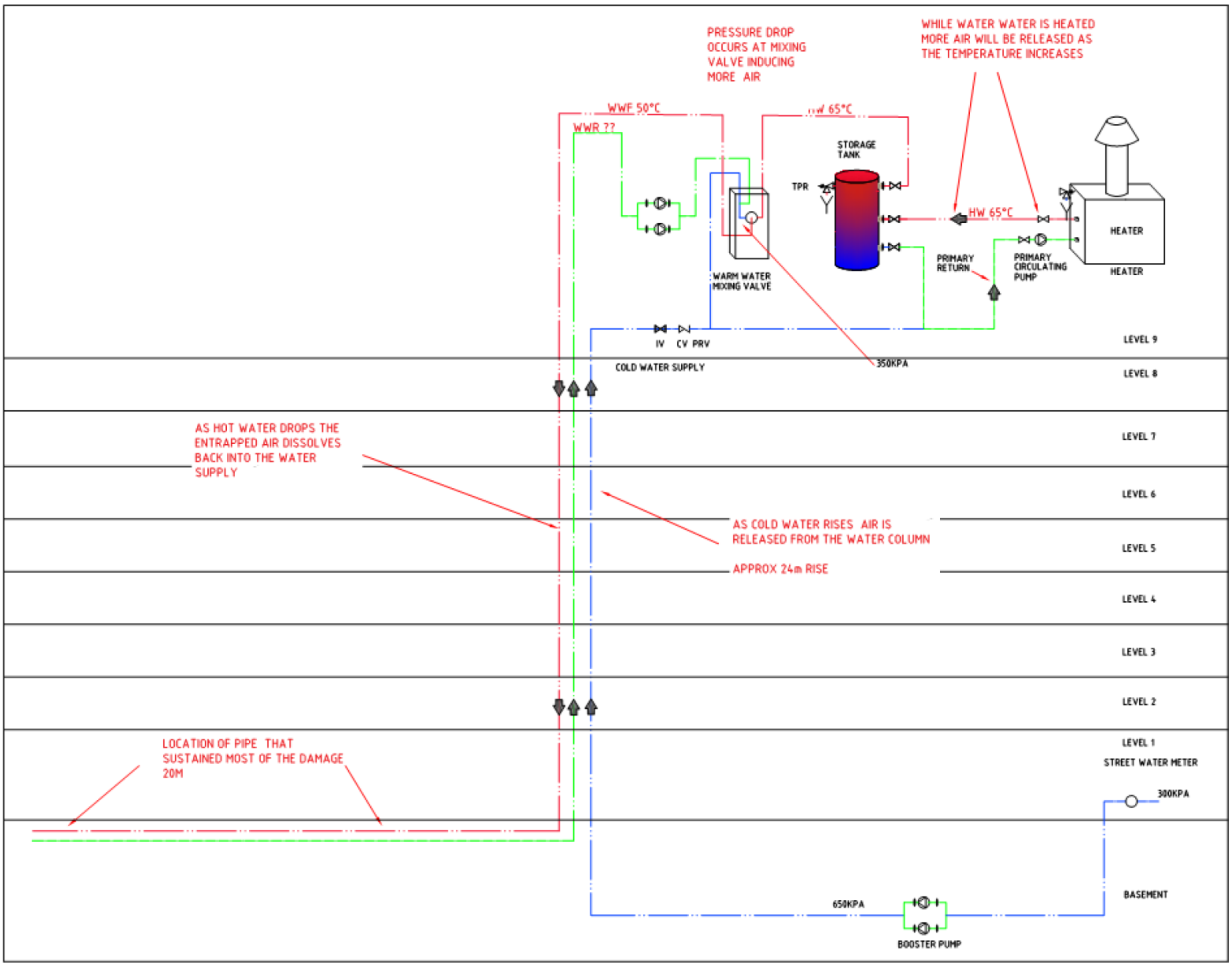
Noise

Above phenomenon such as Impingement, Splashing, Cavitation & Flashing Erosion, Flow Induced Vibration and Surge & Hammer may also generate noise which potentially exceeded the allowable noise limit.

Source: ***"Chemical & Process Technology" Problems caused by two phase gas liquid (February 27th 2010).***

4) Hot water feeding from the roof/top floor and entrapped air.

The majority of the Hot Potable Water Reticulation Systems (**HWRS**) in Australia are fed from hot water units and storage cylinders, located on the roof or top floor of a (high rise) building.
As a consequence of locating the plant room on the top floor of the building, hot potable water and the entrapped air (and *Chlorine gas*??) are forced down the building, via the risers.
Below schematic drawing, made by Phil Woolhouse Hydraulics (PWH), explains what happens with the entrapped air in the HWRS pipe system.



Schematic drawing representing a typical hot potable water plant location and air entrapment by Phil Woolhouse Hydraulics (PWH).

http://pwhydraulics.com.au

Without installing proper air release/bleed valves or automatic de-aerators, we are creating a **Two Phase Flow** system, which can cause the destructive problems as mentioned in the above chapter 3).

Specifically in the risers, a Two Phase Flow ((Hot) Water + Entrained Air) can cause a so called "Waterfall Flow".
Below YouTube video explains the phenomenon of a "Waterfall Flow".

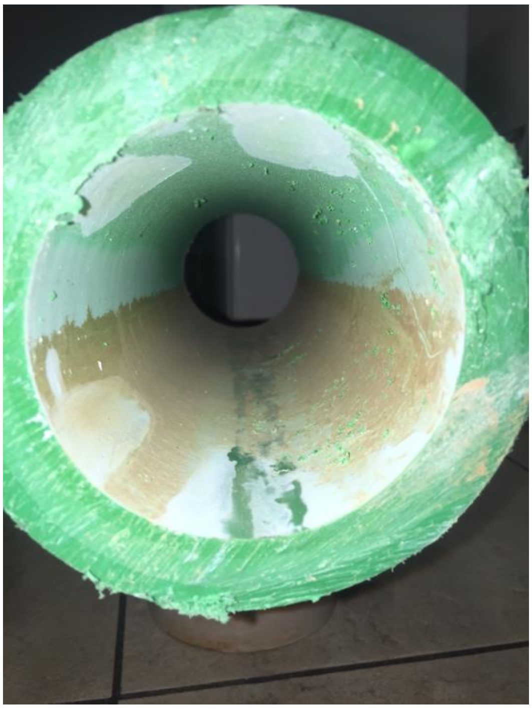
Click on below picture to start the YouTube video. YouTube

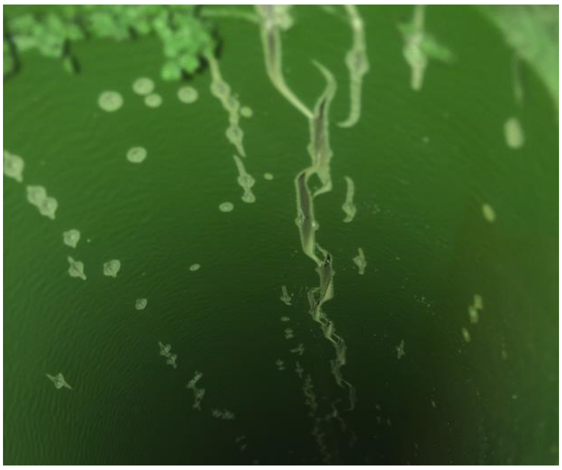
https://youtu.be/r_lrR_Y4_UM?list=WL

A Waterfall Flow creates extra pressure / head loss, loss of energy and reduces the flow.
Since a Waterfall Flow reduces the flow and a Two Phase Flow creates a lower rate [l/s] than originally calculated, based on a single-phase flow, residents can start to complain about low hot water supply and too low hot water temperatures.

5) Examples of pipe material failures in HWRS caused by Two Phase Flow.

All pipe materials can suffer from the destructive damage, caused by Two Phase Flow.





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