Water hammer

Water hammer (or, more generally, fluid hammer) is a pressure surge or wave resulting when a fluid in motion is forced to stop or change direction suddenly (momentum change). Water hammer commonly occurs when a valve is closed suddenly at an end of a pipeline system, and a pressure wave propagates in the pipe.

The magnitude of the pulse

Water hammer can be analyzed by two different approaches, rigid column theory which ignores compressibility of the fluid and elasticity of the walls of the pipe, or by a full analysis including elasticity. When the time it takes a valve to close is long compared to the propagation time for a pressure wave to travel the length of the pipe, then rigid column theory is appropriate; otherwise considering elasticity may be necessary[1]. Below are two approximations for the peak pressure, one that considers elasticity, but assumes the valve closes instantaneously, and a second that neglects elasticity but includes a finite time for the valve to close.

The maximum magnitude of the water hammer pulse, assuming a valve that closes instaneously, can be estimated from the Joukowsky equation $\Delta P = \rho a \Delta C$, where ΔP is the magnitude of the pressure wave (Pa), ρ is the density of the fluid (kgm−3), a is the speed of sound in the fluid (ms−1), and ΔC is the change in the fluid's velocity (ms−1). The pulse comes about due to Newton's laws of motion and the continuity equation applied to the deceleration of a fluid element.

As the speed of sound in a fluid is the , the peak pressure will depend on the fluid compressibility if the valve is closed abruptly. When the valve is closed slowly compared to the transit time for a pressure wave to travel the length of the pipe, the elasticity can be neglected, and the phenomenon can be described in terms of intertance or rigid column theory. For this case, one approximation to the maximum pressure (using Imperial units), P, produced in a water filled line is : $P = 0.07VL / t + P1$ where P1 is the inlet pressure, V is the flow velocity in ft/sec, t is the valve closing time in seconds and L is the upstream pipe length in feet. To keep water hammer low, pipe-sizing charts for some applications recommend flow velocity at or below 5 ft/s (1.5 m/s).

Effects and mitigation

If the pipe is suddenly closed at the outlet (downstream), the mass of water before the closure is still moving forward with some velocity, building up a high pressure and shock waves. In plumbing this is experienced as a loud bang resembling a hammering noise. Water hammer can cause pipelines or equipment such as filter housing to break if the pressure is high enough. Air traps or stand pipes (open at the top) are sometimes added as dampers to water systems to provide a cushion to absorb the force of moving water in order to prevent damage to the system. (At some hydroelectric generating stations what appears to be a water tower is actually one of these devices.)

On the other hand, when a valve in a pipe is closed, the water downstream of the valve will attempt to continue flowing, creating a vacuum that may cause the pipe to collapse or implode. This problem can be particularly acute if the pipe is on a downhill slope. To prevent this, air and vacuum relief valves, or air vents, are installed just downstream of the valve to allow air to enter the line and prevent this vacuum from occurring[citation needed].

Dynamic Equations

The water hammer effect can be simulated by solving the following partial differential equations where V is the fluid velocity inside pipe, ρ is the fluid density and Bm is the equivalent bulk modulus, f is the friction factor.

Possible causes

Sudden valve closure, Pump failure , Check valve slam (due to sudden deceleration, a check valve may slam shut rapidly, depending on the dynamic characteristic of the check valve and the mass of the water between a check valve and tank).

Software

Most water hammer software packages use the method of characteristics to solve the differential equations involved. This method works well if the wave speed does not vary in time due to either air or gas entrainment in a pipeline. Many commercial and non commercial packages exist today.

Software packages vary in complexity, dependent on the processes modeled. The more sophisticated packages may have any of the following features:

- Multiphase flow capabilities
- An algorithm for cavitation growth and collapse
- Unsteady friction - the pressure waves will dampen as turbulence is generated and due to variations in the flow velocity distribution
- Varying bulk modulus for higher pressures (water will become less compressible)
- Fluid structure interaction - the pipeline will react on the varying pressures and will cause pressure waves itself

Mitigating measures

Water hammer has caused accidents and fatalities, but is usually less threatening. In many cases damage is limited to breakage of pipes or appendages. An engineer should always assess (at least qualitatively) risk of a pipeline burst. Pipelines with hazardous goods should always receive special attention and should be thoroughly investigated.

The following characteristics may reduce or eliminate water hammer:

- Low fluid velocities.
- Slowly closing valves. Toilet flush valves are available in a quiet flush type that closes quietly.
- High pipeline pressure rating (expensive).
- Good pipeline control (start-up and shut-down procedures).
- Water towers (used in many drinking water systems) help maintain steady flow rates and trap large pressure fluctuations.
- Air vessels work in much the same way as water towers, but are pressurized. They typically have an air cushion above the fluid level in the vessel, which may be regulated or separated by a bladder. Sizes of air vessels may be up to hundreds of cubic meters on large pipelines. They come in many shapes, sizes and configurations. Such vessels often are called accumulators.
- Air valves are often used to remediate low pressures at high points in the pipeline. Though effective, sometimes large numbers of air valves need be installed. These valves also allow air into the system, which is often unwanted.
- Shorter branch pipe lengths.
- Shorter lengths of straight pipe, i.e. add elbows, expansion loops. Water hammer is related to the speed of sound in the fluid, and elbows reduce the influences of pressure waves.
- Arranging the larger piping in loops that supply shorter smaller run-out pipe branches. With looped piping, lower velocity flows from both sides of a loop can serve a branch.
- UPS (uninterruptible power supply) is sometimes installed to dampen the initial pressure wave by keeping the system running for some time after a power trip.[citation needed]
- Flywheel on pump.
- Pumping station bypass.