DYNAMIC BEHAVIOR - WATERHAMMER AND SURGE IN CO2 PIPELINES AND PIPING

Waterhammer can occur in any system containing a fluid subjected to sudden velocity changes. The higher and the faster the change in flow rate, the larger the pressure shock wave will become.

The sudden change in velocity could be initiated by either the fast opening or closing of a valve or fast starting-up or shutting down of a pump. If a valve is suddenly closed, the water upstream the valve will still continue to flow towards the valve for a few milliseconds and the pressure builds. This increased pressure results in a shock wave traveling back upstream. The shock wave will continue to travel back and forward until friction and reflection losses have diminished the pressure surge. On the other hand, downstream the closing valve the flow wants to continue flowing and thereby creating a very low pressure or even vacuum. If the pressure becomes sufficiently low, evaporation of the liquid and consequently cavitation can take place. Cavitation is the formation of gas bubbles due to a (local) pressure(s) below the vapor pressure of a liquid followed by implosion of these bubbles when subjected to higher pressures.

The size of the pressure shock wave and vacuum caused by waterhammer depends on several fluid parameters. For instance the density, elasticity and compressibility of the fluid. Furthermore, the vapor pressure of the liquid determines the probability of cavitation. Also, due to higher design pressures, the pipelines will be stiffer due to a thicker wall. In a more rigid pipeline it will take longer for a pressure shock wave to fade out.

In the LLSC transportation chain waterhammer will most likely occur in the supercritical offshore pipeline, the ship loading and barge unloading facility at the hub, the topsides of the ship and in the flowline from ship to the offshore reservoir (Figure 12). For the first, the flow should be (almost) continuously, while for the others frequent start-up and shutdowns are taking place. The latter would result in higher probability of damage to the system. An advantage of the flexible hose used for the flowline from ship to (un)loading tower (Figure 12) is that it will reduce the effect of waterhammer in this part of the flowline as the elasticity of the hose will dissipate some of the energy of the shock wave.

Figure 12: Example of mooring ship to SPM (courtesy of SBM Offshore)

Possible effects of waterhammer are pump failure, destruction of metering equipment and possibly pipe collapse. Different measurements can be taken to either prevent waterhammer or minimize its effects. Below some of the possibilities are summarized.

- Prevention by proper design and selecting the right operating parameters. For instance, the use of low flow rates and appropriate valve closing/opening times. The pipeline diameter should be selected so that the flow velocity in combination with the valve closure times will not cause a pressure surge in the system;
- Reduction of the drop in liquid flow velocity and therewith reducing/eliminating the waterhammer. The start-up and shutdown of pumps should be done slowly, this could be achieved by installing Variable Speed Drive (VSD) on the pumps. Alternatively a flywheel or buffer tanks could be added to absorb the energy from the pressure surge;

- Controlling the pressure in the pipeline system. Installing pressure relief valves to open if the pressure becomes too high and vacuum breakers to prevent vacuum and cavitation in the system.

However, waterhammer could then still occur if the pump fails or during an emergency shutdown. Therefore, waterhammer analysis and calculations have to be done and the system should be designed according to the maximum pressure that could be reached.

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