Water Hammer

Water Hammer is an effect of a pressure rise that accompanies a sudden change in the velocity of the flowing water. Pressure surge may be initiated by quick closing or opening of a valve as well as starting or stopping of a pump in an uncontrolled procedure. For example, when the pump shuts down, the fluid column continues to move forward and low pressure is created. In fact, if the pressure differential is below the vapor pressure of the water, a vapor pocket will be formed creating even higher transient pressure. The continuing motion, however, will quickly stop and reverse itself to impact against a closed check valve. A large powerful wave associated with very high pressure can develop, transferring the line from one end to the other until it is dissipated by the fluid friction. In severe cases, the consequences of such a pressure surge wave are ruptured pipes, fittings, or hose lines. The high pressure is developed where flow's kinetic energy is converted to strain energy.

The magnitude of the water hammer can be estimated using the momentum - impulse equation for fluids:

$$F = Q \cdot P \cdot \Delta V$$

Where:
- F = Static forces.
- Q = Flow rate.
- P = Density of water.
- ΔV = Change in water velocity.

The relationship in terms of head rise and change in velocity is:

(imperial) $$\Delta p = \frac{0.433\,a\,\Delta v}{g}$$ or: *(SI Units)* $$\Delta p = \frac{a\Delta v}{g}$$

where:
- Δp = pressure rise (psi ; m H_2o).
- a = pressure wave velocity (ft/s ; m/s).
- Δv = velocity change (ft/s ; m/s).
- g = acceleration of gravity (fps/sec^2; m/s / sec^2).

The maximum pressure rise (Δp) is when the flow is stopped and all the kinetic energy is converted to strain energy, but the pressure will drop to a very low level when the flow is in the opposite direction. The time required for the pressure wave to travel from one end to the other and back is:

$$T = \frac{2L}{a}$$

- L = length of pipe
- a = wave velocity

The speed of the pressure wave is at most the speed of sound in water (Sonic velocity for water 4911 ft/sec; 1497 m/sec).

The pressure wave velocity in the water depends on the modulus of elasticity for water (k) and density of water (p) and is given by :

$$a = \sqrt{\frac{k}{p}}$$

The true speed of the pressure wave will be slower than the speed of sound due to the slight expansion of the pipe. The speed of the pressure wave can be estimated by a:

$$a = \sqrt{\frac{K}{p \cdot (1 + K \cdot D / E \cdot e)}}$$

Where:
- D = Internal pipe diameter.
- E = Modulus of elasticity.
- e = Pipe wall thickness.

At the design stage, careful consideration should be given to the location of control and shutoff valves and to their operating times. Where practical, valves are best located close to the pump but this may not always be possible. A pump, starting on a system with a closed valve, remote from the pump, may result in excessive head rise. The magnitude of this head rise is greatly influenced by the ratio of time for the pressure wave to travel to the valve and back to the pump and the time the pump takes to increase speed to normal working conditions. If the pump start-up is long compared to the wave's travel time, head rise will be low; but if it is less than the wave's travel time, the excess head rise may be very high. Normally in fire protection systems, the pipes are pressurized with the jockey pump, which could be a significant factor in reducing pressure surges when the pump starts. Actually, when a deluge system starts, or hydrant or monitor valves open, the high pressure low capacity jockey pump is not able to maintain the system pressurized, and the fire pump is activated by the low pressure signal. By the time the fire pump starts, the system is only partially filled with water at a very low pressure, and even vacuum conditions might be developed in high elevation pipe sections. Therefore, if the fire pump accelerates rapidly to full speed, high velocities could be induced in the system before pressure increases in the deluge system or hydrant valves, often resulting in bursting of a hose or pipe. Moreover, the rapid changes in the water flow velocity between filling up low pressure pipe sections at high speed and an abrupt stoppage, particularly when there is no demand, could be an additional cause for severe pressure surge impacts. The fire pump's start-up time should be adjusted depending on the length of the system and the opening characteristics of the deluge valves.

Free air in the pipe system introduces elasticity, thereby reducing the pressure wave velocity. Since pressure rises are directly proportional to the pressure wave velocity, the presence of air is beneficial, provided it is distributed or trapped in a manner that reduces the effective pressure wave velocity.

When a deluge system opens, first the atmospheric air present in the system is released through the nozzles or sprinklers. Because of the large density difference between air and water, the flow rate volume of air that can pass through an orifice for a given line pressure is much greater than that of water. If the velocity of water is V_1 while air is being expelled, the sudden reduction in water velocity is V_2 as the air is finally expelled and water reaches the nozzles or sprinkler. The pressure rise is:

$$\Delta p = \frac{V_1 - V_2}{2g}$$

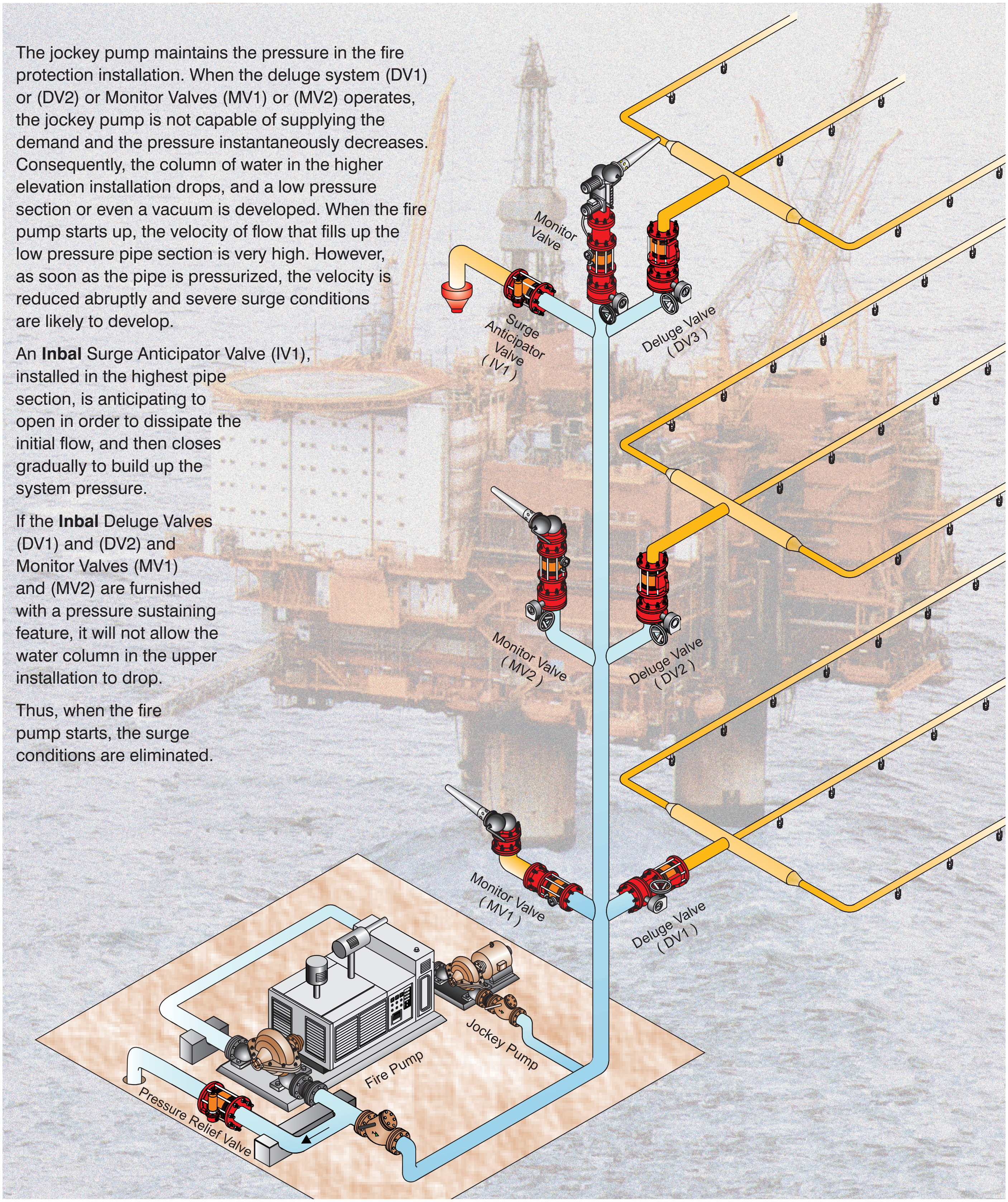
The control valve's inherent flow characteristics (% traveled vs. relative flow through the valve) have an effect on pressure surge development. Programmed closing or opening of a control valve will reduce the maximum pressure, provided the valve's operating time is longer than the wave's travel time, to and back from the fire pump or pressure source.

The jockey pump maintains the pressure in the fire protection installation. When the deluge system (DV1) or (DV2) or Monitor Valves (MV1) or (MV2) operates, the jockey pump is not capable of supplying the demand and the pressure instantaneously decreases. Consequently, the column of water in the higher elevation installation drops, and a low pressure section or even a vacuum is developed. When the fire pump starts up, the velocity of flow that fills up the low pressure pipe section is very high. However, as soon as the pipe is pressurized, the velocity is reduced abruptly and severe surge conditions are likely to develop.

An **Inbal** Surge Anticipator Valve (IV1), installed in the highest pipe section, is anticipating to open in order to dissipate the initial flow, and then closes gradually to build up the system pressure.

If the **Inbal** Deluge Valves (DV1) and (DV2) and Monitor Valves (MV1) and (MV2) are furnished with a pressure sustaining feature, it will not allow the water column in the upper installation to drop.

Thus, when the fire pump starts, the surge conditions are eliminated.



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