CONTROLLING SURGES IN LIQUID PIPELINES

Class # 6020.1

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Controlling surges in liquid hydrocarbon applications is a complex task that requires experienced engineers to dissect every section of the system. They must take into account every "what if" scenario and design a system that will protect piping, equipment and personnel. This paper provides a basic understanding of transient pressures, how they can occur and how they can be controlled.

What are Pressure Surges

Pressure surges can also be referred to as water hammer or transient pressures. It is the rapid fluctuation in pressure due to a change in the flow stream.

Terminology

- ESD System – An Emergency Shut-Down System which, initiated either manually or by automatic control sensors, enables rapid and effective shutdown of relevant operations and equipment in a safe and controlled manner.

- Pipeline Period - The time required for a pressure signal to travel the length of the pipeline system in use from one end to the other and back again. The time is twice the length of the pipeline divided by the wavespeed.

- Wavespeed – The velocity of sound in the fluid when flowing in a pipe, and is the speed at which surge pressures are transmitted along a pipeline.

Why do Pressure Surges Occur

When assigned the task of designing protection for a liquid pipeline one must have a complete understanding of pipeline hydraulics. Pressure surges are subject to occur in all fluid pipeline systems and are caused by the rapid velocity fluctuations that occur in a pipeline that can be generated by any of the following:

1. Rapid closing or opening of a manual or power operated valve
2. Starting or stopping a pump
3. Closure of an automatic (ESD) emergency shutdown device
4. Rapid closure of a check valve

Fluid travels naturally at a given pressure and rate until a change in the flow occurs. One of the most serious pipeline problems that occur is line blockage. If a valve is rapidly closed and the line is blocked while an upstream pump is running, the sudden closure of the valve along with the momentum of the fluid column can overstress the pipe resulting in material failure.

The same will result when a pump fails or is shut down in the event of a power failure, however, not as severe as line blockage. With a power failure the column of fluid downstream of the pump will drop rapidly but continue to flow without any way to pack the line leaving behind a low-pressure region. The column of fluid will be overcome by the opposing force of a static head, resulting in an accelerated velocity in the reverse direction towards the pump.

Pressure surges are also caused by the closure of an unlinked ESD valve while loading ships. If while loading a ship the line begins to experience a high pressure surge the ESD valve on the ship will close while the pump inland continues to run having the same effect as previously explained.

Long pipelines can pose dangerous pressures when static fluid is shut-in between valves and thermal expansion occurs. In this situation, pressure relief will be required.

Joukowsky Formula

In simple pipe systems where rapid collapse of vapor cavities do not occur the Joukowsky formula can be used to determine estimated maximum overpressure.

P= .8Wv (Pipeline Rules Of Thumb, Page 335)

Where P = surge pressure, PSI
w = weight of liquid per cubic foot, lb.
V = velocity change, FPS

The above equation does not take into account complex systems where the pressure transient may bounce off boundaries and can combine to produce even greater surges. With a properly designed surge relief system, users can mitigate failure such as fatigue of piping and equipment and possible avoid catastrophic failure of the pipeline equipment or line itself. Failure would result in unsafe work environments including financial losses in millions of dollars.

How to Control the Surge

In general, all systems where pressure is contained must have some form of pressure relief, **which is often mandated and regulated by local authorities.** The design of systems is dependent on a complex range of factors including but not limited to, the potential for pressure increases, the volumes which must be passed by the pressure relief equipment in operation and the capacity of the system to contain pressures.

Hydraulic Modeling
A hydraulic analysis should be completed on the system design to determine if and where potential surges could occur in the pipeline. This includes existing installations where new pipelines may be connecting to existing lines. With software modeling programs available, pipeline engineers are able to model many different scenarios for each application to determine the precautions that are needed to protect the system.

Sequenced Pump Shutdown
Some pump station designs employ multiple pumps so that when one of the pumps is started or stopped, the stopped pump has a minor impact on the overall pipeline velocity. These systems control supply and can prevent surges during normal pump operation. However, after a power failure the pump will trip instantly and cause a sudden stoppage of flow. Almost all pumping systems need additional surge equipment to prevent surges after a power failure.

Surge Relief Equipment

With every attempt to control surge pressures in pipelines a surge relief system should be installed to protect the system. The three most common devices available are accumulators, rupture discs & pins and also relief valves.

Surge Accumulators
Surge accumulators operate with a tank that has an internal gas filled bladder. As the pressure increases in the pipeline it will expel into the tank compressing the gas filled bladder absorbing the shock and then emptying back into the pipeline. This system is ready for immediate use after an overpressure event. For large pipelines multiple accumulators may be used to displace larger volumes of fluid however, cost and available space for the tanks need to be considered.

Rupture Discs & Pins
Rupture discs are a one-time-use membrane that fails at a predetermined set point. Rupture discs provide a nearly instantaneous response to an increase in pressure but once the disc has ruptured it will not reseal. A valve either upstream or downstream from the rupture disc must be closed in order to stop flow passing through the pipeline. While the replacement cost of the disc is economical, the cost associated with draining the pipeline and installing the replacement disc needs to be considered.

Rupture pins valves are also a one-time use device where the ends of the pins are supported between two bushings exterior to the valve body. The pin holds the valve seat in the closed position and once the valve inlet surge pressure has exceeded the tensile strength of the pin, it will buckle allowing the valve to open and release the flow. This valve will not reseat and another valve will have to be closed to stop flow. The rupture pin must then be replaced in order to close the valve.

Relief Valves
A relief valve is a normally closed valve that opens when a pre-set pressure has been reached. The pre-set pressure can be set at an adjustable spring (direct acting of pilot controlled), or it can be direct acting gas loaded or electrically activated by a pressure sensing or controlling device. Spring loaded direct acting relief valves are sometimes used, but the set point will change as the valve opens due to the compression of the spring. This may require an overpressure adjustment up to 25% above set point. This type of valve can also slam open and closed during relief operations resulting in secondary surge waves to occur.

Pilot operated pressure relief valves are self-contained and are relatively slow to respond, especially when compared to direct acting valves. They are best used on clean, refined product applications such as gasoline and diesel fuel oil and caution should be used if considering this type of valve on higher viscosity fluids since this can result in slower response time. Pilot operated valves should not be used in applications where debris such as paraffin or high metal contents can clog up sensing lines resulting in an unresponsive valve.

Gas loaded relief valves are direct acting valves and are designed to regulate and control maximum pipeline pressures. Gas loaded relief valves are normally closed then open as inlet pressure increases.
These valves offer exceptionally fast response speed and are far less sensitive to viscosity and can be considered for applications such as crude oil since there are no sense lines to clog or affect valve operation.

Summary
Understanding, predicting, and protecting against transient behavior in liquid lines is one of the most important stages in pipeline design. . Proper safety measures must be taken to abate surges and protect employees, equipment and the environment.

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