Surge and Fluid Transients in Pipeline Systems

An Online Continuing Education Course for Engineers

Course Number: M-3071

Credit: 3 Hours / 3 PDH / 3 CPD

Surge and Fluid Transients in Pipeline Systems

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Class Outline

This course discusses the physical aspects of surge and other fluid transients in pipeline systems. Surge and fluid transients are a daily occurrence in all liquid pipeline systems. In most cases, the magnitude of fluid transients is low enough to avoid damage to the system. However, surge and fluid transients are almost always present during serious pipeline accidents. It is therefore a requirement of DOT Part 195 that all pipeline systems be protected against the detrimental effects of surges.

This is not a class on the various computer programs used to analyze fluid transients. The engineer must understand the actual physical manifestations of surge before attempting to use a computer program for assessment. Understanding the mechanisms behind surge will allow the engineer to better analyze the computer results.

Subjects covered in this class:

- Liquid transients
- Basis of Calculations
- Surge
- Pipeline Codes
- Components of surge
- Primary surge
- Secondary surge
- Surge facts
- Over-running controls
- Manifold displacement
- Transient analysis
- Surge mitigation
- Other Transient Events

Disclaimers & Clarification

- All examples shown in this class are real-world;

- All examples have been redacted and/or changed to protect the owners;
- Examples shown represent the operation before any changes were made (i.e., before safety measures were put in place).
- Two types of charts will be shown:
- Time plot – one point on the system with the passage of time;
- Distance plot – shows the entire distance of the system with resultant pressures throughout.
- Units are in the English system;
- Units and abbreviations:
- Pressure pounds/square inch (psi); all pressure is gauge unless otherwise noted;
- Force and weight pound (lb);
- Flow barrels per hour (bph);
- Flow gallons per minute (gpm);
- ASME: American Society of Mechanical Engineers;
- DOT: US Department of Transportation;
- MOV: motor-operated valve.

TYPES OF FLOW

There are two types of flow:

- Steady State; and
- Transient.
- Steady-state hydraulics occur when the system has reached equilibrium (pressure and flow are steady);
- *Transient hydraulics occur everywhere else……*

First off, what is the difference between Surge and Water Hammer????

The Answer is…. Nothing.

Both are the same physical phenomenon.

The physics are the same!

For purposes of this class, it is referred to as surge.

LIQUID TRANSIENTS

Transient hydraulics cover situations where steady-state approximation won't work. These situations include:

- Surge pressure
- Valve closures
- Batching
- Pump start-up and shut-down
- Pipeline start-up and shut-down
- Leak and line break analysis
- Changing between operations
- Fluids with changing properties

BASIS OF CALCULATIONS

What are we solving?

Energy equation

$$Q - W = d/dt \int_{cv} (V^2/2 + gz + u)\, \rho\, d\forall + \Sigma_{cs} (V^2/2 + gz + u)\, \rho\, V\, A$$

Continuity equation

$$d(mass)/dt = d/dt \int_{cv} \rho\, d\forall + \int_{cs} \rho\, V\, dA$$

Momentum equation

$$dB/dt = d/dt \int_{cv} \beta\, \rho\, d\forall + \Sigma_{cs} \beta\, \rho\, V\, A$$

For **steady state**, incompressible flow, these equations boil down to:

- $P_1/g + V_1^2/2g + Z_1 + H_p = P_2/g + V_2^2/2g + Z_2 + H_L$ (energy)
- $Q = V\, A$ (Continuity)
- At a steady state, momentum effects cancel out.
- Steady-state hydraulics occur when the system has reached equilibrium.
- **Steady-state does not exist in the real world**; however, steady-state calculations can be used to approximate equilibrium conditions.

For Transients, we are still solving energy; continuity; and momentum equations.

- Transient = Not Steady-State

- Equations that apply for steady state do not apply here.
- However, the original form of these equations (in differential form) does apply.
- Due to complex math, specialized computer programs are needed to analyze transient events in a timely manner.

SURGE

- Surge is the sudden rise in pressure, due to valve closures, sudden pump shutdowns, changes in flow rate, etc.
- **Many major pipeline disasters have been directly linked to surge events.**

Surge pressure rise will find a weak link in the piping system.

Surge Events

- Bellingham, WA (June 10, 1999)
  - valve closure with rapid pressure rises burst the pipeline, spilling gasoline which ignited; three people died as a direct result.
- Lake Charles, LA
  - valve closure with rapid pressure rises caused the valve bonnet to fracture, killing an operator and wounding several others.
- Overland Park, KS (2005)
  - valve closure in a terminal with rapid pressure rise burst a pipeline, spilling gasoline into a playground.
- Los Angeles, CA (May 15, 2014)
  - valve closure in the pump station with rapid pressure rise burst a pipeline in the middle of the street, flooding a business district with sour crude oil.
- ***Many pipeline spills have had an 'unconfirmed' surge element.*** While the official cause of a spill may be corrosion, pinholes, fractures, etc., the rise in pressure due to a surge event is the actual initiator of the spill.

Bellingham Surge Event

The Bellingham spill was the first-time surge was formally acknowledged as the major contributor to the disaster. In this accident, a rise in pressure from a surge event ruptured the pipeline at a point where the pipe had been impacted by excavation activities. A gouge in the pipe from a backhoe bucket was

the initiation point of the rupture, but the rise in pressure that initiated the line break was caused by surge.

The surge event itself was caused by the unanticipated closure of a valve at the delivery terminal. The rise in pressure due to surge caused the rupture. Gasoline flowed out at roughly full line flow rate, spilling into a waterway. The gasoline ignited, killing two persons. A third individual died after being overcome by fumes and falling into the waterway.

Figure 1 shows the actual rupture in the pipeline, after removal by investigators. Figure 2 was taken during the ongoing emergency.

Figure 1: Bellingham Rupture Site

Figure 2: Bellingham Aftermath

PIPELINE CODES

Allowable pressure limits

- DOT Part 195.406 Maximum operating pressure

  "(b) No operator may permit the pressure in a pipeline during surges or other variations from normal operations to exceed 110 percent of the operating pressure limit established under paragraph (a) of this section. Each operator must provide adequate controls and protective equipment to control the pressure within this limit."

- ASME B31.4 404.1.5:

  "Overpressure Crit… …nd other variations fro… …oint in the piping syst…

- In liq… …aximum Allowable Surge…

Bottom line: P… …ring **surges or other variation**… …cted under MOP; there is no allow…

Maximum Oper…

All pipeline opera… …ntifically defensible maximu… …cted just on the establishment …:

- Hydrostatic …
- Pressure rat…
- Anomalous r… …ication of MOP.

The resultant MOP wi… …se inputs. It is possible to have a short section of low-rated pipe, or a single … …d flange, that effectively lowers the MOP for the entire system.

Per ASME B.16.5, steel fittings are typically rated by pressure class; 150 lb., 300 lb., 600 lb., etc. These numbers are maximum pressure ratings at elevated temperatures. At normal operating (ambient) temperatures for a pipeline system, the allowable pressure for each component is higher. The pressure rating for 150 lb. fittings at temperatures between -20 to 100 degrees F is 285 psi. During surges or other variations from normal operations, 150 lb. fittings are allowed up to 313.5 psig.