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Steam Accumulators and Steam Boiler Response to Load Changes

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Introduction

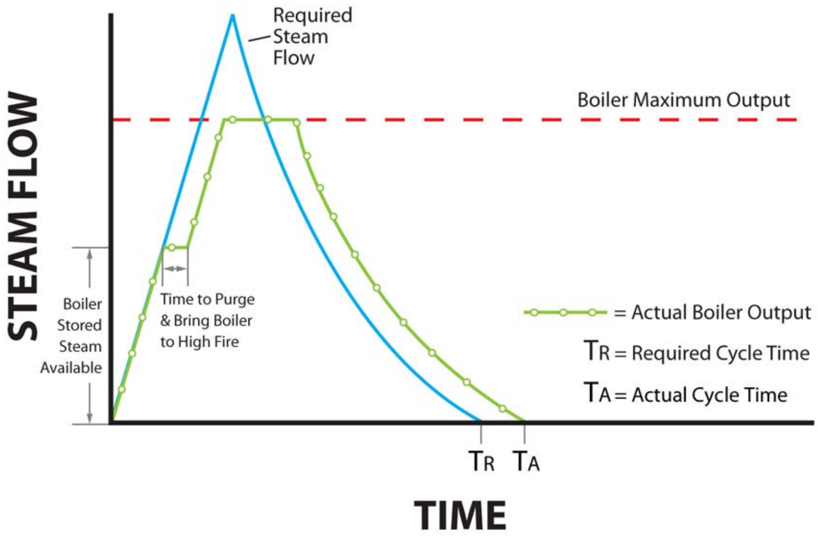
Certain steam-using equipment, when initially placed in service, will use steam at a rate far in excess of the boiler's maximum output. The cold metal in the steam-using equipment can transfer energy from the steam source nearly as fast as steam can be supplied to the equipment. Consequently, a boiler will rapidly depressurize.

A rapidly depressurized boiler can suffer poor steam quality and nuisance low-water shutdowns. To mitigate these consequences of high steam demand, specifying engineers must oversize the boiler, design in back pressure regulators to control depressurization or use a steam accumulator.

Generally, end users will not bear the additional cost of an oversized boiler, and back pressure regulation will starve the steam-using equipment, causing high cycle times. One solution to this challenge is to incorporate steam accumulation equipment into the steam system design.

The steam flow graph (Figure 1) demonstrates the load profile from a typical autoclave and the steam boiler system servicing the autoclave without an accumulator. According to the graph, if steam accumulation is not used, cycle times for the autoclave will be longer than desired. This paper will explain how a steam boiler responds during high load demand periods and the principles of steam accumulation. Recommendations that mitigate the consequences of high instantaneous steam demand are also discussed.

Figure 1:



Typical autoclave steam requirement with no accummulator and standard prepurge flame establishment

Boiler Response to Sudden Steam Demand

Steam boilers seem to operate efficiently with good steam quality when subjected to a steady steam demand at a rate matching the output of a boiler. Consequently, when a steam system valve opens quickly, a rapid steam load demand occurs, and the boiler will depressurize. When insufficient steam is available, depressurization occurs in seconds.

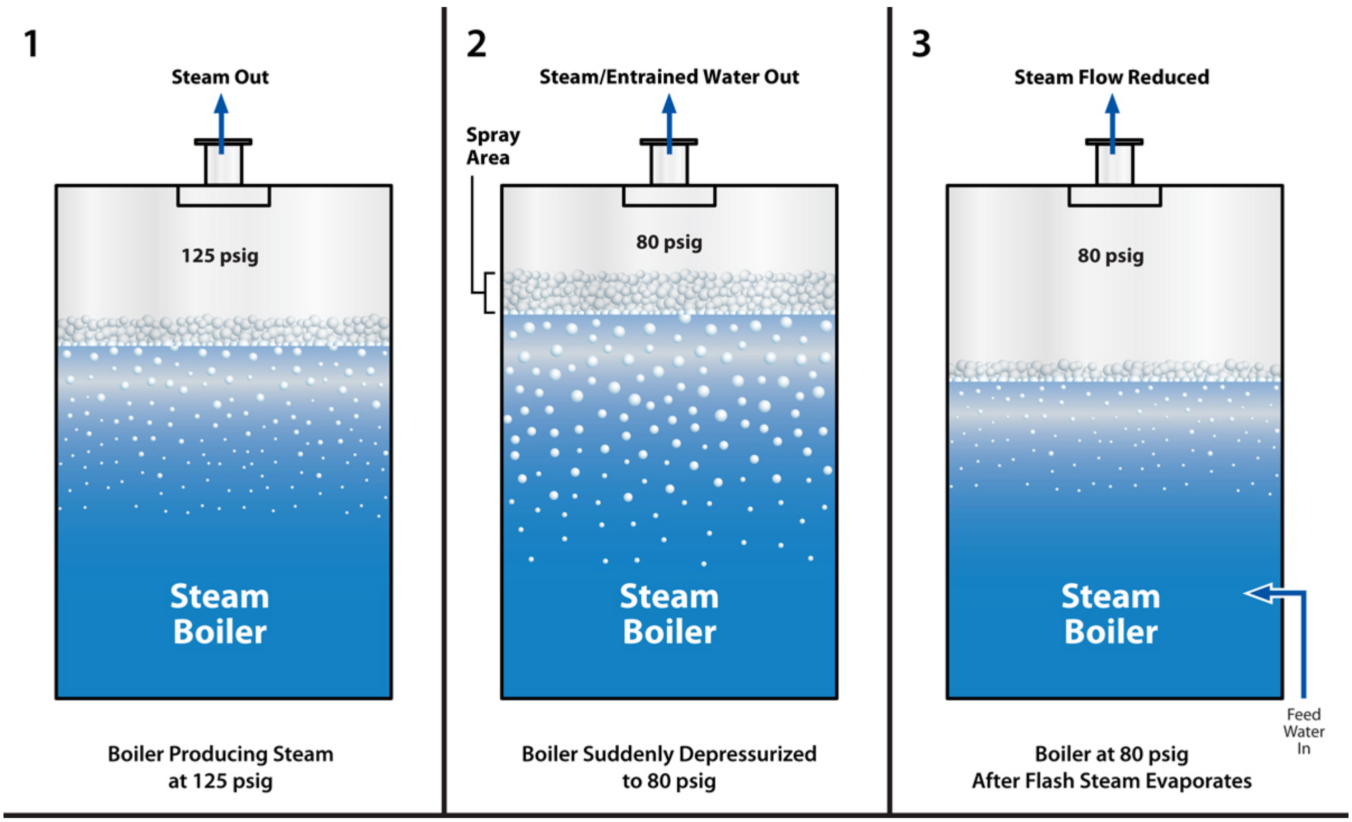
To fully understand the consequences of this depressurization event, one must consider what is happening inside and outside the boiler pressure vessel. Figure 2 shows a sequence of boiler internal events when a rapid depressurization event occurs. Under steady state low demand conditions (picture 1), the boiler will produce steam via even nucleate boiling. Water level fluctuations are minimal, and steam quality is generally very good.

When depressurization occurs (picture 2), the entrained steam bubbles enlarge, water volume expands and the spray area also enlarges. The spray area is a layer of foam or water spray above the boiler water and is a consequence of thousands of bubbles collapsing at the surface of the boiling water. Good steam quality is usually associated with a small spray area. The size of the bubbles and surface tension will dictate the depth of the spray area. It is during this phase of the depressurization event that steam quality can suffer.

In addition to the increased spray area, the steam velocity through the steam nozzle will also increase as the boiler pressure decreases (given an equal mass flow rate). The increased velocity through the steam nozzle will tend to pull more entrained water with the steam and cause carryover.

In the final phase (picture 3), the flash steam is boiled off, the boiler level controls call for water and the feed water system provides make up water. The injection of cooler feed water causes the steam bubbles to further collapse and the water level to quickly fall. It is during this phase of a rapid depressurization event that the boiler may experience low water shutdowns and significantly lower steam flow rates. Preheating the feed water will help minimize this quenching effect, but not eliminate it altogether.

Figure 2:



Equally important to steam production and pressure are the events that occur outside the boiler pressure vessel. Anytime the steam header pressure falls below the operating set point, the burner lights, and fuel energy is converted to steam.

However, the burner ignition sequence is a little more complicated than just turning a valve on and off. Boiler codes require that each time the burner gets a signal to ignite, the boiler combustion chamber must be purged long enough to exchange the air in the furnace several times to prevent pre-ignition from any tramp fuel left over from the previous ignition cycle.

This purge sequence is followed by pilot light ignition and a period of flame proving. Once the pilot is established, only then can the main burner ignite. This entire sequence of actions will take a minute or longer to start converting fuel to steam. Most boilers set up with standard flame safeguard controls cannot react fast enough and commence steam production in response to a sudden steam demand.

Likewise, normal steam headers and control valves are designed to keep steam flow at or below some velocity (6000-8000 feet per minute) and maintain a minimum steam pressure to the steam-using equipment. Consequently, a normal steam delivery system will not provide any means to protect the boiler from rapid depressurization.

Instantaneous Steam Production

Boiler depressurization rate is a function of the boiler and steam system's ability to create instantaneous steam. The amount of instantaneous steam a boiler system will produce is simply the amount of stored steam the boiler will release when the steam header starts to depressurize. Furthermore, the amount of stored steam in the boiler can be expressed as the sum of the steam stored in the steam chest (accumulated dry steam) and the steam stored in the pressurized boiler water (accumulated flash steam).

Boiler Instantaneous Steam Flow = Accumulated Dry Steam + Accumulated Flash Steam

Accumulated dry steam. Another important factor in instantaneous boiler response is steam chest volume. All steam piping and boiler steam space will maintain a reservoir of steam. If you determine the volume of this area, you can use steam specific volume data to determine the mass of steam stored. For example, if a boiler has a steam space of 3 cubic feet and there are 100 feet of 1.5-inch schedule 40 steam piping (0.014 square feet cross sectional area), the total steam chest will be 3 cubic feet + (100 feet x 0.014 square feet) = 4.41 cubic feet.

At 125 psig, steam has a specific volume of 3.23 cubic feet per pound. Therefore, the total mass of steam stored is 4.41/ 3.23 = 1.4 pounds of steam. This amount of stored dry steam in the steam chest is relatively small compared to the stored flash steam of the boiler water. However, the steam chest volume plays an important role in the rate of boiler depressurization and subsequent steam quality. If a boiler is too rapidly depressurized, the violent resultant boiling can cause boiler water to become entrained in the steam spray and carried over into the steam piping.

Accumulated flash steam. A more significant amount of stored steam is contained in the pressurized water in the boiler. When a boiler is operating at a set pressure, the boiler water is also at that pressure and will release steam rapidly when it is depressurized.

To determine the amount of flash steam, one needs to know the upper boiler operating pressure limit and the minimum load pressure limit. The upper boiler operating pressure limit is the pressure which shuts off the boiler burner (i.e. call for heat satisfied). The minimum load pressure is the lowest pressure required to operate the equipment requiring the steam. The difference between the two pressure levels will provide the useful instantaneous pressure drop the boiler will experience when a load steam valve opens. This sudden decrease in pressure will cause the boiler water to rapidly boil and produce steam similar to when hot pressurized condensate is flashed in a flash tank.

Figure 3:
Flash Steam Chart

PERCENT (%) FLASH STEAM

Condensate Pressure (PSIG)	Flash Tank Pressure (PSIG)								
	0	5	10	20	30	40	60	80	100
5	1.6	0.0							
10	2.9	1.3	0.0						
15	3.9	2.4	1.1						
20	4.9	3.3	2.1	0.0					
30	6.5	5.0	3.7	1.7	0.0				
40	7.8	6.3	5.1	3.0	1.4	0.0			
60	10.0	8.5	7.3	5.3	3.7	2.3	0.0		
80	11.8	10.3	9.1	7.1	5.5	4.2	1.9	0.0	
100	13.3	11.8	10.6	8.7	7.1	5.8	3.5	1.6	0.0
125	14.9	13.5	12.3	10.4	8.8	7.5	5.3	3.4	1.8
150	16.3	14.9	13.7	11.8	10.3	9.0	6.8	4.9	3.3
200	18.7	17.3	16.2	14.3	12.8	11.5	9.4	7.6	6.0
250	20.8	19.4	18.2	16.4	14.9	13.7	11.5	9.8	8.2
300	22.5	21.2	20.0	18.2	16.8	15.5	13.4	11.7	10.2
350	24.1	22.8	21.7	19.9	18.4	17.2	15.1	13.4	11.9
400	25.6	24.2	23.1	21.4	19.9	18.7	16.7	15.0	13.5

Using standard flash steam charts and the water volume (manufacturer's data) in the boiler, one can easily determine the amount of steam the boiler will surrender when rapidly depressurized. The chart in Figure 3 can be used if the condensate pressure is considered the boiler pressure and the flash tank pressure is considered the minimum steam load pressure.

For example, if a boiler that has a water volume of only 77 gallons and maintains the header pressure of 125psig is depressurized to 80 psig (minimum load limit), 3.4 percent of the boiler water will flash to steam. The instantaneous steam flow, therefore, is 3.4 percent x 77gallons x 8.34 pounds per gallon = 21.8 pounds of steam.

If the boiler was depressurized to less than 80 psig, even more instantaneous steam would be produced. However, since any steam below 80 psig is not useful to the load equipment, this steam cannot be considered available.

Obviously, the water volume of a boiler is critical to responding to sudden load changes. Generally, boilers with high water volumes are more able to handle steam load swings. Similarly, the larger water volume in an oversized boiler will produce more flash steam under these conditions.

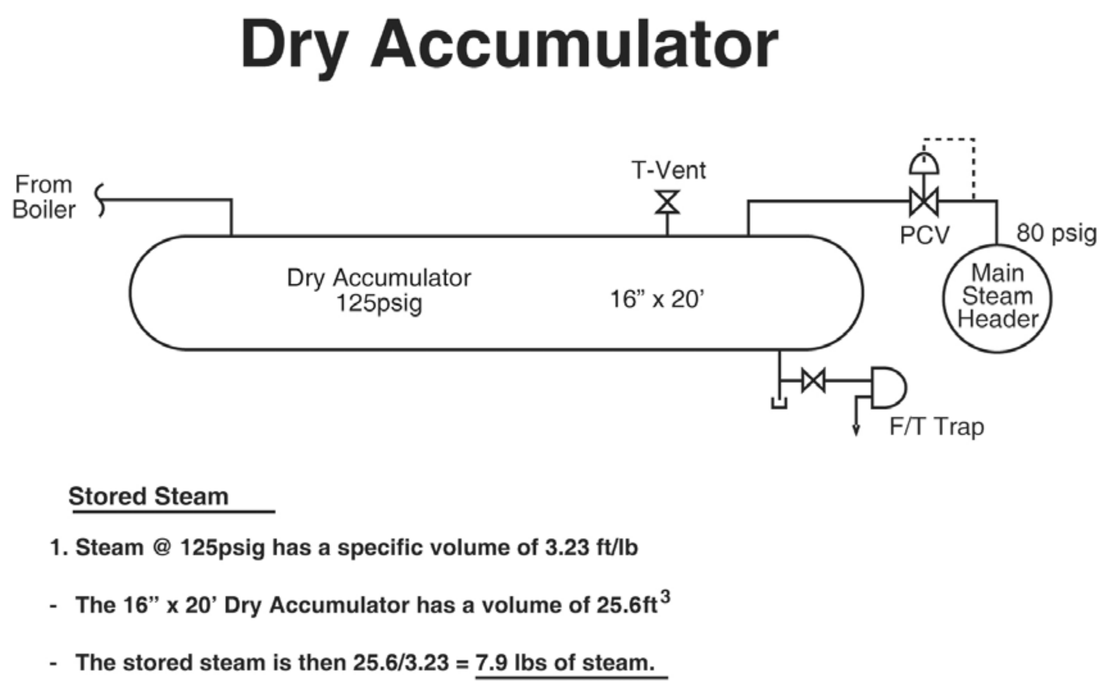
Design Enhancements Can Help Reduce Depressurization

Several design enhancements can be utilized to help reduce rapid boiler depressurization and its consequences. One simple enhancement is incorporating a standing pilot. This option reduces the burner response time from a low steam pressure signal, allowing the pilot to stay lit when the boiler meets the pressure set point. With the pilot still lit, and a call for heat signal received from the pressure controls, the pre-purge sequence can be eliminated. Consequently, the burner can go directly to main flame.

Unfortunately, the standing pilot option is only allowed for boilers < 2 million BTU input (CSD-1 code). A second design feature used to prevent rapid boiler depressurization is the use of a back pressure regulator or an orifice plate in the steam line between the boiler and the steam-using equipment. Both designs restrict the steam line to retard the steam flow during high demand periods. Consequently, the steam-using equipment is starved of steam, and cycle times may become longer than desired.

Two other design enhancements can be incorporated to minimize the consequences of high instantaneous steam load demands. The first enhancement is the use of a dry accumulator and the second is the use of a wet accumulator.

Figure 4:



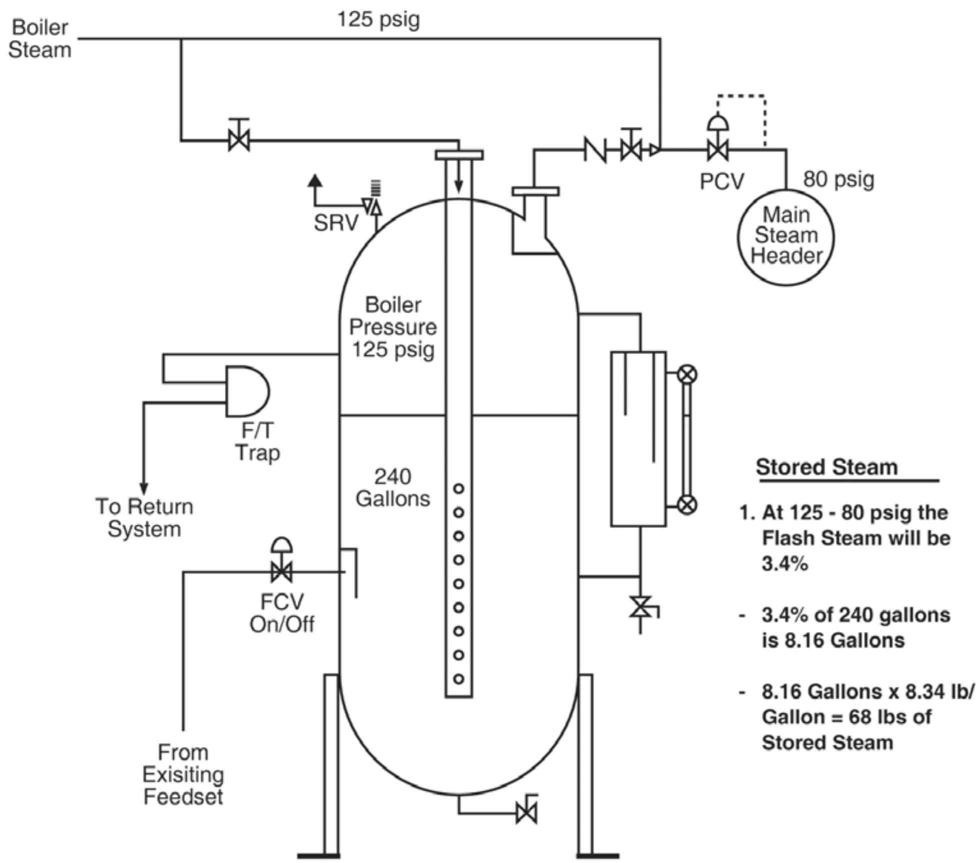
Both design enhancements increase the mass of stored steam. Either type of steam accumulation will not create steam, but rather, create a means to store steam. Only adding fuel energy to a boiler will create more steam.

In the example depicted in Figure 4, using a steam system with 100 feet of piping, we can increase the stored steam mass significantly if we replace 20 feet of 1.5-inch pipe with a 16-inch diameter section of pipe. This oversized section of pipe is called a "dry accumulator."

A 16-inch x 20-foot pipe has a volume of 25.6 cubic feet. At 125 psig and a steam specific volume of 3.23 cubic feet per pound, this equates to almost 8l pounds of steam storage. By adding this dry accumulator, we can increase the dry steam storage more than five fold. The 6.6 pounds of extra steam will slow down the depressurization rate of the boiler and help mitigate water carryover from the boiler.

When an accumulator is used with a pressure control valve, as shown in this example, it becomes very effective in mitigating the effects of high instantaneous steam demand. The advantages of a dry accumulator tend to be more associated with boiler protection from low water shutdowns and carryover prevention, than with a substantial reservoir of stored steam for the load equipment.

Figure 5:



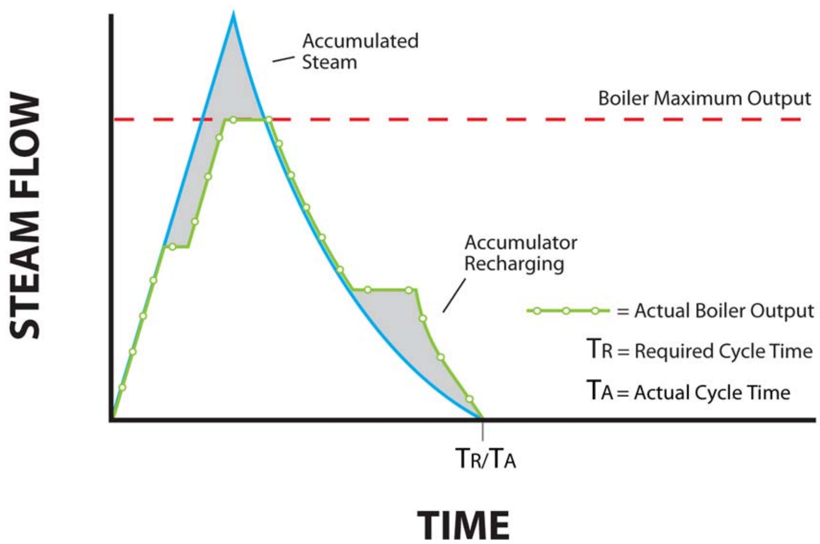
Wet Accumulator

If more instantaneous steam is required than a dry accumulator can supply, then a wet accumulator can be used. A wet accumulator is a pressurized vessel in line with the boiler steam line. This vessel is pressurized to the boiler operating pressure and will discharge stored steam when the header is depressurized. Once depressurized, the boiler will recharge the accumulator when the load equipment no longer requires steam. Therefore, during idle periods of the steam use cycle, the accumulator can be fully recharged and be readied for the next cycle. The amount of stored steam is proportional to the water volume and change in pressure.

Using flash steam charts, similar to the one in Figure 5, you can calculate how much water must be stored to provide ample steam when depressurized. This example shows how much stored steam will be made instantaneously available with a wet accumulator holding 240 gallons at 125psig that is depressurized to 80psig. It is quite easy to see that a vessel designed as a wet accumulator will store significantly more steam than the same size dry accumulator.

The boiler pressure vessel with normal water level is actually a wet accumulator. Applying the design of steam accumulators to the original autoclave steam flow diagram (Figure 1) will result in shortened cycle times. This is shown in Figure 6.

Figure 6:



Typical autoclave steam requirement with accummulator

Summary

Steam load management is often neglected during the design phase of a steam delivery system. As a result, in the case of a boiler that serves steam-using equipment that cycles like an autoclave or sterilizer, steam quality and quantity at start up may suffer significantly. Understanding the significance of the events inside and outside the boiler pressure vessel during a rapid steam load demand period and choosing the correct design enhancements will reduce the consequences of rapid depressurization. Two enhancements – dry steam and wet steam accumulators – offer good solutions that combat the consequences associated with high steam demand applications. Sized right, steam accumulators will greatly shorten cycle times of autoclaves and similar equipment while maintaining good steam quality.