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Relationship of Design Pressure, Test Pressure & PSV Set Point

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(From a paper dated June 28, 2004 in response to numerous questions about the topic)

There have been a number of issues and questions raised over the topic of pipe system leak test pressures, design pressures, and how they relate to the pressure relief device set point pressure. The easiest way to clarify their relationship is to use, as an example, a simplified flow diagram with only the necessary elements included. Using the following simplified flow diagrams this paper will describe the relationship between the pressure relief device, its set point and how and when it affects the design pressure of a piping system, and therefore its leak test pressure.

The leak test pressure (a.k.a., hydro test or pneumatic test) calculation is , per ASME B31.3, based on the design pressure of a piping system. A system, from the standpoint of pressure testing, can be defined in different ways. In context it can refer to:

1. A test circuit, which is an installed segment of a piping system, including all pipe, fittings and components that have been delineated and identified on some document such as a flow diagram.
2. It can also refer to all pipe, fittings, components and equipment in the same service and under the same pressure and temperature conditions.
3. And lastly, it can refer to a complete operating system with parameters defined by the process or utility description.

With regard to this paper, when referring to a system the second definition will apply, as defined above: all pipe, fittings, components and equipment in the same service under the same pressure and temperature conditions.

Piping systems are not required, under B31, to be protected by a pressure relief device. For piping systems that are not protected by a safety relief device, or for systems that can be isolated from a relieving device, the piping shall be designed to withstand the highest pressure that can be developed in that section of pipe (B31.3 para. 301.2.2).

Definitions

In explaining their relationship we have to first of all define design pressure, leak test pressure, and pressure relief device requirements as well as describe their purpose.

Design Pressure: As defined in ASME B31.3 – "*The most severe condition of coincident internal or external pressure and temperature (minimum or maximum) expected during service*". There are caveats associated with that statement, but since they do not affect this discussion we won't involve them. They can be found in B31.3 para. 302.2.4.

What B31.3 means by the previous statement is that the Owner has the responsibility of determining the most severe condition the pipe system will experience. Those severe conditions, both pressure and temperature, are what will be used along with fluid service compatibility, as a basis for specifying the material of construction for the piping material. The design pressure and temperature are used for all material requirements to ensure integrity of the piping system against the most severe service conditions.

Within the ASME BPV Code Section VIII, Division I, the terms Maximum Allowable Working Pressure (MAWP) and Vessel shall be interpreted to mean Design Pressure and Piping System respectively when applied to piping systems. This is in relation to pressure relieving devices.

Leak Test Pressure: There are two basic methods of leak testing piping systems, Hyrdrostatic and Pneumatic. There are other alternative pressure test methods, but they are not within the scope of this paper.

Hydrostatic Leak Test Pressure: Hydrostatic leak test pressure is based on the following equations:

(A) $$P_T = 1.5P$$ or (B) $$P_T = \frac{1.5PS_T}{S}$$

Where:
P_T = Test Pressure, psi
P = Internal design gage pressure, psig
S_T = Stress value at test temperature, psi (see ASME B31.3 Table A-1)
S = Stress value at design temperature, psi (see ASME B31.3 Table A-1

Use equation A for all services in which the design temperature of the fluid service does not exceed the test fluid temperature. ASME B31.3 further states that if the fluid service temperature is in excess of the test fluid, equation (B) shall be used. However, if the stress value of the pipe material at the design temperature is unchanged from its ambient values through its values at the design temperature, then equation (A) can still be used. Refer to Table 3 for examples of stress values for commonly used material.

As an example, ASTM A106 Gr B seamless carbon steel has a stress value of 20,000 psi throughout the temperature range of ambient through 400°F. Above that temperature the stress values decrease as the temperature increases. Through 400°F, for that material, you can see that S_T and S cancel each other leaving the engineer with equation (A).

Pneumatic Leak Test Pressure: Pneumatic Leak Test Pressure is calculated based on 110% of the design pressure.

Pressure Relief Device: The relief valve is actuated by inlet static pressure and designed to open during emergency or abnormal conditions to prevent a rise of internal fluid pressure in excess of a specified design value. Pressure relief devices come in various types and styles. The relief valve type can be specified in the following styles: relief valve, safety valve, safety relief valve, conventional pressure relief valve, balanced pressure relief valve, and pilot operated pressure relief valve. There is also the non-reclosing pressure relief valve. The rupture disc type can be specified as a fragmenting style or non-fragmenting style. There is also the pin-actuated device.

For this paper the type or style of pressure relief device is not relevant, what is relevant is that when one is present in the system how does it relate to the design pressure and therefore the test pressure.

The Basics

The ASME BPV Code requires that equipment under its Code stamp be protected from over pressurization; there is no such requirement for piping systems. When a pressure relief device is specified for an equipment item the MAWP of the equipment is the set point for the relief device. The set point pressure is the pressure at which the valve is forced from its seat. From that initial release to its full discharge there is a 10% increase above set point.

While a piping system can use the set point of a pressure relieving device on an equipment item it is connected to as its design pressure, it can only do so if there is no means to isolate that piping from the relief device. However, simply isolating a piping system from the pressure relief device does not automatically put that piping in jeopardy. Isolation from a relief device is acceptable if there is no means for energy, in the form of heat transfer or chemical reaction, to be added to the fluid in the isolated piping sufficient to cause extreme over pressurization.

Extreme over pressurization, as it applies here, is a temporary pressure/temperature condition that would exceed the pressure rating of the piping system. If there is a potential for a temporary extreme over pressurization it becomes the Owner's responsibility to determine if the ASME pipe Classification should be upgraded to contain the pressure or a relief device installed.

The engineer must be aware that ASME B31.3 allows for transient excursions (variations) of pressure in excess of the pressure rating or the allowable stress within specified limits. Refer to ASME B31.3 par. 302.2.4 for specific information.

Another point that needs to be made has to do with an the earlier statement whereas, "…Maximum Allowable Working Pressure (MAWP) and Vessel shall be interpreted to mean Design Pressure and Piping System respectively when applied to piping systems." The MAWP for equipment and Design Pressure for piping systems are determined based on two different methodologies.

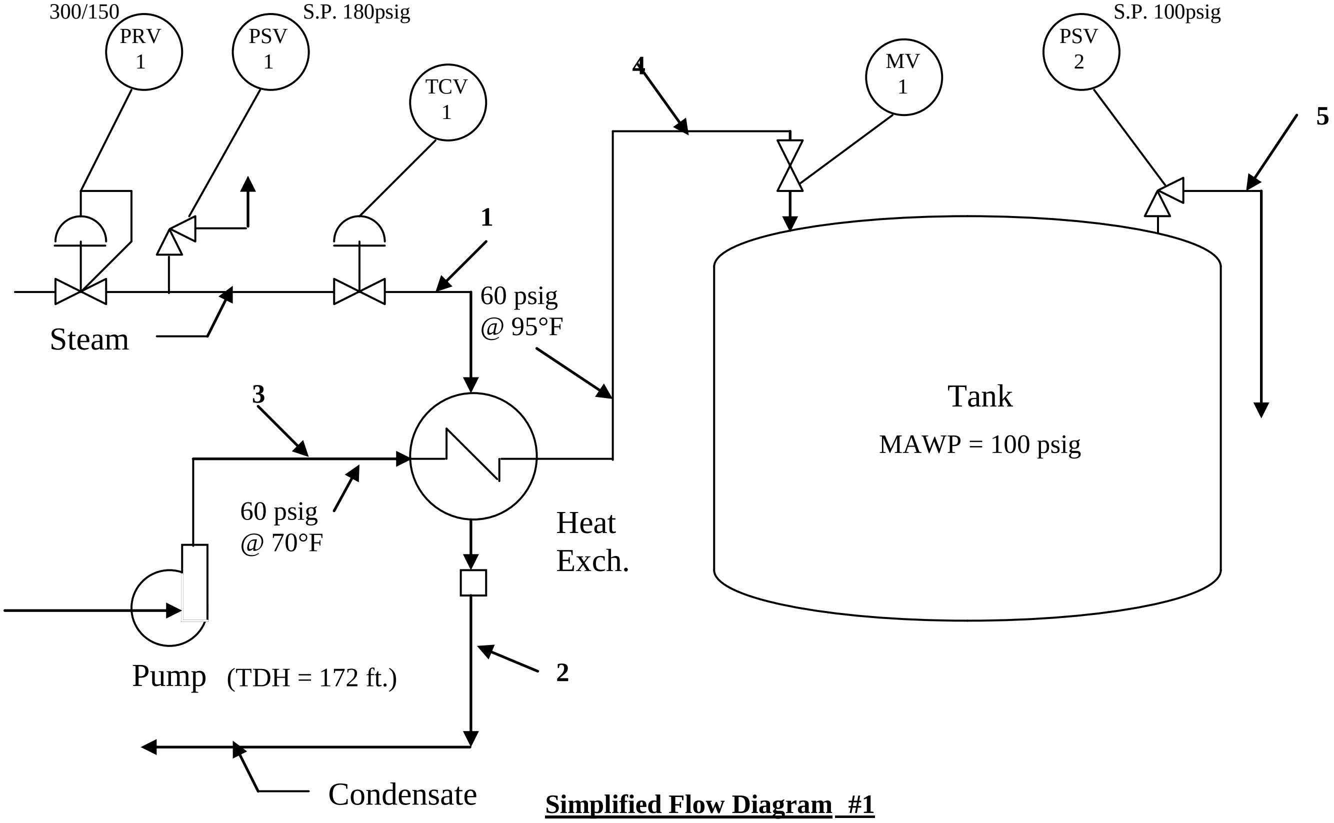
When equipment, and we'll assume a plain generic holding tank, is developed a design pressure and temperature are assigned. These design conditions, along with the other requirements of the tank, are used to determine nominal metal thickness, weldment design, nozzle ratings, etc. After the tank is fabricated the actual material thickness, weldments and other as-built physical characteristics of the tank are compiled and used in a series of complex calculations to determine the actual MAWP of the tank. Once determined, the MAWP will replace the initial design pressure for the tank. It is also used to determine the relief device set point pressure.

With regard to a Piping System, the design pressure, with respect to the equipment MAWP, is determined based on service conditions, not the limits of the system components. Once the design conditions are determined based on service conditions, the piping system pressure Classification can be specified. While the pressure Classification of the piping system will exceed that of the design pressure it does not constitute a reassignment of the design conditions as in equipment design. The design conditions are specific to the service not to the piping material.

Sample Exercises

Sample Exercise #1

Having laid some of the groundwork we can now define the relationship between the relief device pressure set point, the design pressure of the piping system, and the leak test pressure. Using the following flow diagram you can see that PSV-2 on the Tank has a set point equal to that of the Tank's MAWP. PSV-2 is designed to protect the Tank and its interconnecting piping. As a dedicated component of the Tank it is required to meet the design criteria of the Tank's MAWP.



Simplified Flow Diagram #1

Table 1 – Flow Diagram #1 Line Profile

Line No.	Service	O. Press	O. Temp.	D. Press.	D. Temp.	Test	Comments
1	Steam	150	365	180	380	270	
2	Condensate	30	365	60	380	90	
3	Process	60	70	*180	*380	270	*Based on steam heat transfer
4	Process	60	95	*180	*380	270	*Based on steam heat transfer
5	Proc. Discharge	30	95	100	120	150	

If manual block valve MV-1 did not exist lines #3 & #4 would also be protected by PSV-2. However, with MV-1 in place the possibility of isolating those lines from PSV-2 exists. The engineer now has to determine: 1. If the piping and components that make up lines #3 & #4 are capable of withstanding the design limits of the fluid service under a dead-headed condition, 2. If the piping system pressure Classification will have to be upgraded to withstand the design conditions without pressure relief, and 3. Being isolated from any relieving device, the most sever condition of pressure and temperature the piping could potentially see.

In responding to the three points above, the first thing that needs to be addressed is establishing the piping system design pressure. With regard to lines 3 & 4 in the flow diagram, since the potential exists for those lines to be isolated from any relieving device, the set point of PSV-2 cannot be considered a limiting pressure. Looking then at lines 3 & 4 the engineer needs to consider if there are any internal or external influences that could cause a temperature, and consequent pressure increase internal to the pipe.

Assuming this is not a reactive process fluid the only other apparent source of heat energy would come from the steam feed to the heat exchanger. As you can see by the diagram the piping downstream of the pressure reducing valve is protected by PSV-1. This valve protects the piping in the event PRV-1 fails to regulate, allowing 300 psig steam to blow through.

PSV-1 has a set point of 180 psig. This was determined by adding a safety factor of 30 to the 150 psig desired steam operating pressure downstream of the PRV. The design temperature for the 150 psig steam line will be the correlated saturated steam temperature at 180 psig, or 380°F. If the steam side of the heat exchanger can potentially see this temperature then it can be transferred to the process side of the heat exchanger. In stating this, and predicting a worse possible situation by having MV-1 closed, the heat from the steam side of the heat exchanger would transfer to the process side heating the hold up fluid beyond its expected service temperature. Assuming the fluid to have a heat capacity close to that of water the relative pressure for a closed system at 380°F would also be 180 psig. These conditions, 180 psig at 380°F, can then be considered the most severe pressure & temperature conditions for lines 3 & 4.

The other external pressure influence on lines 3 & 4 is the pump TDH. Since the TDH indicated on the flow diagram (172 ft) is well within the pressure range (should the pump be deadheaded) for a lower joint Classification it does not present a problem.

Returning to the now established design criteria of 180 psig at 380°F for lines 3 & 4, the system joint Classification and the leak test pressure has to be determined. At 380°F a ASME B16.5 Class 150 flange joint has an extrapolated pressure limit of 206 psig using Table 2-1.1, which is above the design pressure. This indicates that a Class 150 piping system will work.

Should the design requirements have been in excess of the Class 150 rating the engineer could have referred to B31.3 para. 302.4, as mentioned earlier, in which "…ASME B31.3 allows for transient excursions (variations) of pressure in excess of the pressure rating or the allowable stress within specified limits." When considering the need to upgrade the pressure Classification for a piping system, refer to this section to determine if a possible over pressure situation can be considered "occasional variations above design conditions." If the assumption can be made that possible pressure & temperature excursions in excess of the design conditions are within the acceptable requirements of B31.3 para. 302.2.4, then the engineer may elect to apply these caveats to accommodate the requirements for a Class 150 piping system.

The hydro test pressure for line #1 would be based on the 180 psig design pressure, which is also the set point for PSV-1. Even though the system design temperature is 380°F the allowable stress for ASTM A106 pipe is unchanged from the test fluid temperature so equation (A) above can be used. The hydro test pressure would therefore be 180 x 1.5 = 270 psig.

Lines 3 & 4 also have a design pressure of 180 psig and would undergo the same test pressure as line #1.

Clarification

One issue needs to be clarified here. The ASME B16.5 Class 150 pressure rating of the A105 carbon steel flange joint is 285 psig at ambient conditions. This would be the MOC for line #1, the steam line. Assuming lines 3 & 4 are

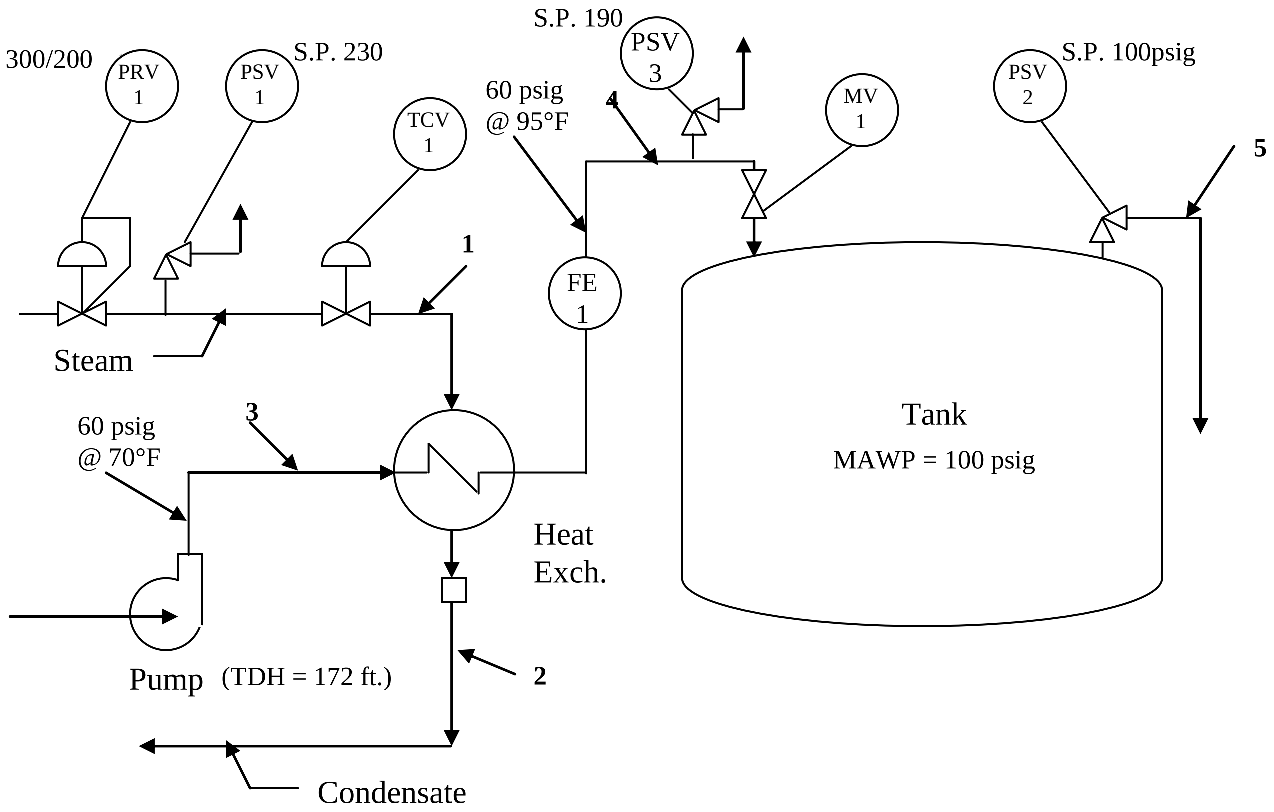
316L stainless steel process lines the flange joint would be A182 Gr F316L stainless steel with a Class 150 joint rating of 230 psig at ambient conditions.

There is sometimes confusion as to how this is interpreted when there is a situation in which the test pressure, in this case 270 psig, exceeds the flange rating of 230 psig. The 270 psig test pressure is acceptable under the following explanation. The flange joint, irrespective of design pressure, can be tested at 1.5 x rated pressure rounded off to the next higher 25 psi. A 316L SS Class 150 joint, per ASME B16.5 Table 2-2.3, can then be tested at 230 psig x 1.5 = 322 rounded up to 325 psig. The leak test pressure, in this case, does not exceed the test limit of the flange joint.

Sample Exercise #2

In this exercise we will change the pressure of line #1, downstream of PRV-1, to 200 psig with a design pressure of 230 psig. We have also added FE-1 and PSV-3 to line #4. FE-1 has a design limit of 200 psig at 385°F. Based on the same analogy we used in Sample Exercise #1, the 230 psig design pressure of line #1 at a steam temperature of 399°F could transfer to the hold-up fluid in lines 3 & 4. While the piping itself is suitable for the extraneous pressure FE-1 is not. In order to prevent damage to FE-1 we specify and install PSV-3 for line #4 with a set point of 190 psig. The steam table translates 190 psig into 384°F. FE-1 is now protected from over pressurization and extreme temperatures with the installation of PSV-3.

With the design pressure set for lines 3 & 4 at 190 psig by the set point of PSV-3 the hydro test pressure would then be calculated at 190 x 1.5 = 285 psig.



Simplified Flow Diagram #2

Table 2 – Flow Diagram #2 Line Profile

Line No.	Service	O. Press	O. Temp.	D. Press.	D. Temp.	Test	Comments
1	Steam	200	387	230	399	270	
2	Condensate	30	387	60	399	90	
3	Process	60	70	*190	380	285	*Based on PSV-3 set point
4	Process	60	95	*190	380	285	*Based on PSV-3 set point
5	Proc. Discharge	30	95	100	120	150	

Summary

The design pressure and temperature of a piping system, unlike the MAWP for equipment, is not predicated on the piping material of construction, but instead on calculated fluid service design conditions. Piping systems are generally specified to contain those design conditions. However, there are circumstances, as in Sample Exercise #2, in which it is more economical and/or safe to specify and install a pressure relief device for a potential, but not too possible upset, rather than upgrade the piping system material to contain a significant pressure and/or temperature increase above operating conditions.

It is the Owner's responsibility to set the guidelines for determining design conditions. Following are examples of such guidelines:

> *System Design Pressure*: Unless extenuating process conditions dictate otherwise, the design pressure is the pressure at the most severe coincident of internal or external pressure and temperature (minimum or maximum) expected during service, plus the greater of 30 psi or 10%.
>
>> *As an example we will use 100 psig saturated steam service. The operating pressure would be 100 psig. The greater of 30 psi or 10% of that would be 30 psi. Add that to the 100 psig operating pressure and the design pressure is 130 psig. If it was 400 psig saturated steam the greater safety factor would be the 10%, or 40 psi, making the design pressure 440 psig.*
>
> *System Design Temperature*: Unless extenuating process conditions dictate otherwise, the design temperature, for operating temperatures between 32°F and 750°F, shall be equal to the maximum anticipated operating temperature, plus 25°F rounded off to the next higher 5°.
>
>> *Using the above example of 100 psig saturated steam service the operating temperature would be 338°F. A 25°F safety factor added to the operating temperature would be 338 + 25 = 363°F rounded off to 365°F.*

In both sample exercises, given earlier, line #4 had a manual valve MV-1 that could potentially isolate that line from PSV-2 on the tank. If MV-1 did not exist the piping would still have to be evaluated on its own and as an integral part of a system. Without MV-1, if there were no extenuating circumstances, line #4 could use the set point on PSV-2 as its design pressure.

With regard to pressure leak test equations A & B on page 1, you can see by Table 3 how stress values for stainless and carbon steels remain constant through 300°F, 400°F, and 500°F respectively. As long as the service design temperature, in relation to those materials, is at or below those respective temperatures it is acceptable to use equation (A) to calculate the test pressure using ambient fluids.

Table 3 – Allowable Stress of Some Commonly Used Pipe Material

ASTM	Basic Allowable Stress (ksi) at Metal Temperature (°F)						
	Min to 100	200	300	400	500	600	700
A53 Tp E Gr A	16.0	16.0	16.0	16.0	16.0	14.8	14.4
A106 Gr B	20.0	20.0	20.0	20.0	18.9	17.3	16.5
A269 Tp 316L	16.7	16.7	16.7	15.5	14.4	13.5	12.9
A270 Tp 316L	16.7	16.7	16.7	15.5	14.4	13.5	12.9
B88 Soft Annealed	6.0	4.8	4.7	3.0	0.8	—	—
B88 Hard Drawn	12.0	12.0	11.6	10.5	—	—	—

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