A Guideline for Design Pressure – Part 1

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Introduction

All process equipment in general should be designed for the maximum pressure which can be attained in service during normal operating, upset, startup and shutdown conditions. For example, centrifugal pumps are often provided without relief valve as they are designed for highest possible pressures corresponding to blocked outlet condition. However, this pressure in most cases is extremely high, unpredictable or not economically feasible to design for. That is why equipment are usually designed for a pressure which is calculated by adding margin to maximum operating pressure and full protection is achieved by a relief valve set at or below specified design pressure.

As shown in Figure 1, this margin should be sufficient to accommodate high pressure alarm and high pressure trip and to avoid unintentional relief valve opening.

The design pressure and temperature form the basis for mechanical design of equipment and piping. Therefore, it is vital to specify all design pressures in conjunction with the corresponding design temperatures (coincident design conditions) for calculating minimum wall thickness and related aspects of vessel and piping design.

This note presents some guidelines on design pressures of pressure vessels and pumps. Part-2 will cover the rest of the equipment.

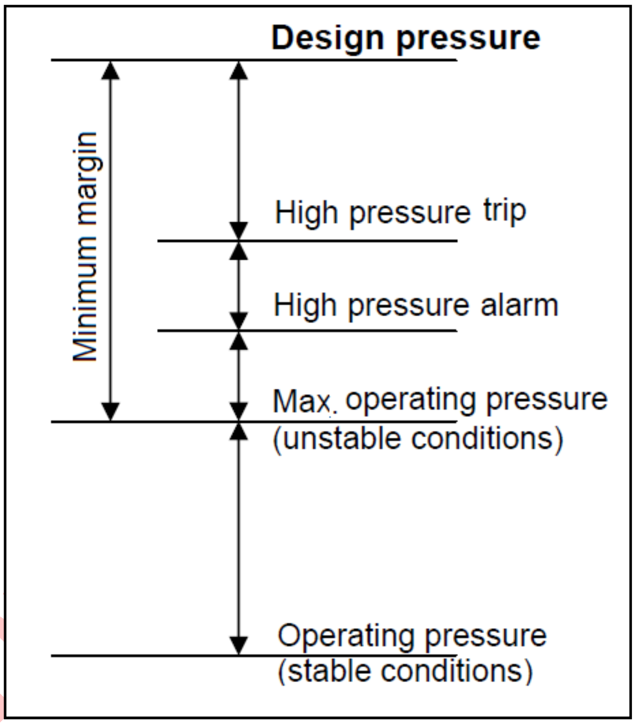

Figure 1 – Margins between operating and design pressure

Pressure Vessel

Table 1 specifies a typical guideline for the design pressure of a pressure vessel in line with ASME Sec. VIII recommendations. This table specifies the minimum margin between Maximum Operating Pressure (MOP) and design pressure, so any value higher than this can be acceptable.

Maximum Operating Pressure (barg)	Design Pressure (barg)
Under (full or partial) Vacuum	Full Vacuum & 3.5barg (if external pressure is Atmosphere)
0 to 1.7	3.5barg
1.7 to 18	MOP + 1.8bar
18 to 69	1.10 x MOP (with conventional relief valve)
>69	1.07 x MOP (with conventional relief valve)

Notes:

1. For liquid filled pressure vessel on pump discharge, pump section guidelines to be followed.
2. If pressure vessel in protected by rupture disc sufficient margin should be maintained between operating pressure and disk set (burst) pressure in order to prevent unintentional risk rupture. For example, conventional tension-loaded rupture disk is subject to premature failures if operating pressure exceeds 70% of burst pressure.
3. MOP is a temporary pressure that can be reached occasionally. For example:
   - during operating cycles such as start/end of run operation (Note 5)
   - foreseeable event that may decease pressure drop such as bypassing the upstream exchanger

- by closing the valve downstream of the vessel
- due to temporary increase in temperature

In other words, MOP is the maximum expected pressure due to operating fluctuations not upset or emergency conditions. MOP for pressure vessels in hydrocarbon service which are protected by high pressure alarms and shutdown devices should be 105% higher than Operating Pressure (OP) in barg (min. OP + 1.0bar) otherwise MOP is equal to OP.

4. The MOP for the following systems have become an industry design practice:
   - For systems containing very light components such as pressurized LPG and propane (refrigeration loop), MOP is equal to the vapor pressure at maximum expected operating temperature. For cold systems, maximum ambient temperature is usually the maximum possible temperature that system can attain during shutdown.
   - For compressor suction KOD and cooler, maximum settle-out pressure is considered as MOP. This is the equilibrium pressure reached between the suction and discharge isolating valves (SDV) of the compressor when the compressor is stopped or shut down.
5. The design pressure must also account for all alternative modes of operation such as regeneration, start/end of run, summer/winter cases and upset or transient conditions such as start-up, shutdown, ramp up/down, pressure surge, settle-out condition, etc.
6. For equipment operating in equilibrium with flare system pressure, the design pressure of the equipment shall be equal to the flare design pressure.
7. Hydraulic pressure due to elevation differences (especially for relief valve in liquid service) between equipment and relief valve inlet nozzle must be taken into account by reducing relief valve set pressure or increasing equipment design pressure.
8. Pressure vessels shall not normally have a design pressure of less than 3.5barg, especially when fitted with relief valve relieving to the flare system. Lower design pressures may result in larger flare system to meet acceptable backpressures. The minimum design pressure of 2.0barg can be used for a pressure vessel with relief valve discharging to atmosphere.
9. For vessels that are subject to the steam out, a separate set of design conditions (typically 3.5barg and 150ºC) should be specified. Specifying steam out condition is extremely important for vessels designed for 3.5barg and low temperatures as it may govern the vessel mechanical design.
10. In order to prevent higher pipe ratings and costly materials, the margin between MOP and design pressure can be reduced by changing relief valve type. For a conventional (spring loaded or balanced bellows) relief valve, MOP has to be less than 90% of set pressure whereas some vendors offer relief valve with soft seating with MOP up to 93% of set pressure without leakage (design pressure = 1.07 x MOP). Consult vendor on suitability of soft seating for your application. Another solution is to replace conventional with pilot operated relief valve. With pilot operated valve, the margin between MOP and design pressure can be reduced to 5% (design pressure = 1.05 x MOP).
11. In order to eliminate all or some of overpressure causes or significantly reduce relief load, the margins between the maximum operating pressure and the design pressure may be increased, so that the equipment can tolerate pressure caused by an emergency condition. For example overpressure due to fuel gas/nitrogen blanketing control valve failure is eliminated if design pressure of a pressure vessel is increase to design pressure of blanketing fluid.
12. Unless otherwise stated, the design pressure specified by the process engineer applies to the vapor phase at the top of a vessel.
13. For columns, the same design pressure is selected for the top of the column and associated condenser, reflux drum and inter connecting piping.
14. The design pressure at the bottom of a column (vapor phase) is determined by adding the column pressure drop to the column overhead design pressure. Liquid density and maximum liquid height in the bottom specified on the process data sheet allows the vessel designer to calculate the bottom thickness. The minimum density for this calculation should be 1000kg/m3.
15. Utility systems are generally be assigned a common design pressure, adequate for all parts of the system taking both pressure drop and elevations into consideration. Specifying different design condition and protection with relief devices for equipment in the same system may only be considered if this results in significant cost saving.
16. When the design pressure for items which are remote from the source of pressure is being determined, it is necessary to consider the pressure drop through the circuit.
17. To minimize the need for full flow relief valve, a group of equipment in series (with almost identical operating pressures) may be logically grouped to have the same design pressure irrespective of operating pressure profile. Consequently, a relief valve on front end of the train is sized for full flow relief (blocked outlet) and downstream equipment is protected by individual valves sized for smaller relief load (typically external fire).

- **Vacuum Condition**

18. Equipment operating at pressures below atmospheric pressure (0 barg) shall be designed for full vacuum. Some companies design the vessel for full vacuum when maximum operating pressure is below 0.5barg.
19. Equipment that can face vacuum condition under abnormal conditions shall be designed for full vacuum or protected by vacuum relief valve. This includes:

- Equipment exposed to steam purging during start-up, shut down or regeneration
- Equipment normally operating full of liquid that can be blocked in and cooled down
- Equipment containing condensable vapor that can be blocked in and cooled down, such as steam drum and pressure storage containing sub-atmospheric vapor pressure materials (e.g., some alcohols and aromatics).
- Loss of heat input (coil, jacketing, tracing or reboiler failure) where cooling continues by a condenser or through heat loss such as fractionation of alcohols and aromatic solvents
- Loss of heat input where considerable quantities of steam are generated such as sour water stripper or amine regenerator
- Rapid withdrawal of nonvolatile liquid from a vessel (especially liquid filled ones) shall be treated on a case-by-case basis. They shall be designed for full vacuum unless fully reliable protective devices are provided (vacuum breaker, atmospheric vent, pressurization gas, low pressure trip, etc.). For example, vacuum can occur in cooling water side of an exchanger located 10 meter aboveground depending on cooling water return pressure and cooling tower elevation.

20. Vessel not designed for full vacuum shall be suitable for partial vacuum. At minimum vessel shall be designed for 0.5 bara.

Pump

- **Centrifugal pump**

Generally the pump, discharge piping and all liquid filled equipment on discharge side of a centrifugal pump are designed for the shut-off condition where there is no relief valve for protection of the circuit. The design pressure is the higher of the following:

- Normal Suction Pressure (NSP) + Shut-Off Pressure (SOP) or
- Maximum Suction Pressure (MSP) + 9.81 x maximum fluid density x pump differential pressure

If there is a possibility that pressure of suction vessel rises when pump operates in shut-off condition then design pressure is equal to:

- Maximum Suction Pressure (MSP) + Shut-Off Pressure (SOP)

This is applicable to reflux pump, pump around pumps or any pumping system where closing pump discharge valve causes pump suction vessel's liquid level and pressure to rise.

Where:

- NSP = upstream equipment operating pressure + NLL of upstream equipment
- MSP = upstream equipment relief valve set pressure (design pressure) + HHLL of upstream equipment

Some companies are using MSP = upstream equipment relief valve relieving pressure + static head from relief valve to the pump suction which results in the most conservative design pressure.

SOP should be obtained from pump characteristic curve (pump actual head at zero flow) but in absence of vendor data following relation can be approximately used:

- SOP = C x 9.81 x maximum fluid density x pump differential pressure

Where C coefficient is:

- 1.25 for constant speed pump
- 1.3 for variable speed pump
- 1.3 for high-head multistage pump
- 1.3 for vertical pump
- 1.4 for turbine-driven pump

Some companies multiply above SOP by 1.1 and use it in pump design pressure calculation. This is because API-610 allows 10% tolerance on SOP of pump during actual testing. In other words, if during acceptance test the pump delivers a pressure 10% higher than what vendor has indicated on performance curve, it should be acceptable to purchaser.

- **Reciprocating Pump**

The design pressure of a steam-driven reciprocating pump and downstream equipment may be set by the maximum process pressure which the steam cylinder is able to produce at maximum steam pressure. In this case, no pressure relief device is required. However, in most cases it is not economical to set the design pressure of downstream equipment as high as this maximum stalling pressure. In these cases, a relief valve (with the set pressure lower than stalling pressure) would be required to protect the downstream equipment against overpressure.

For a reciprocating pump driven by electric motor, relief valve serves the dual purposes of protecting the pump and downstream piping from overpressure, and protecting the driver from overload.

Relief valve located at the discharge of reciprocating pumps should be set according to the following guideline (see Note 1 as well). This also sets the design pressure of the pump and piping and liquid filled equipment on discharge side of it.

- Discharge pressure + 3 bar — for discharge pressure ≤ 10 barg
- 1.2 x Discharge pressure — for discharge pressure > 10 barg – with pulsation dampener
- 1.3 x Discharge pressure — for discharge pressure > 10 barg – without pulsation dampener

- **Positive Displacement Pump**

Positive displacement pumps, such as rotary, gear, and diaphragm pumps, discharge design pressure also is considered well-below the maximum permissible pressure developed by pump driver and normally requires relief valve for protection of the pump and downstream equipment. Relief valve located at the discharge of pump should be set according to the following guideline (see Note 1 as well). This also sets the design pressure of the pump and piping and liquid filled equipment on discharge side of it.

- Discharge pressure + 2 bar — for discharge pressure ≤ 20 barg
- 1.1 x Discharge pressure — for discharge pressure > 20 barg

Note:

1. In order to prevent relief valve opening due to discharge vessel's design pressure, the minimum set pressure of relief valve should be:

- Discharge vessel's design pressure + pressure drop of discharge side + destination static head

If this pressure is considerably higher than pump design pressure calculated based on discharge pressure, increasing the system rating and the cost of piping and pump, a highly reliable instrumentation system (high-high pressure trip) may be used on case to case basis to isolate the pump from discharge vessel.

Contact

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