What you should know about liquid thermal expansion

Decision flowchart aids in correct thermal relief valve requirements

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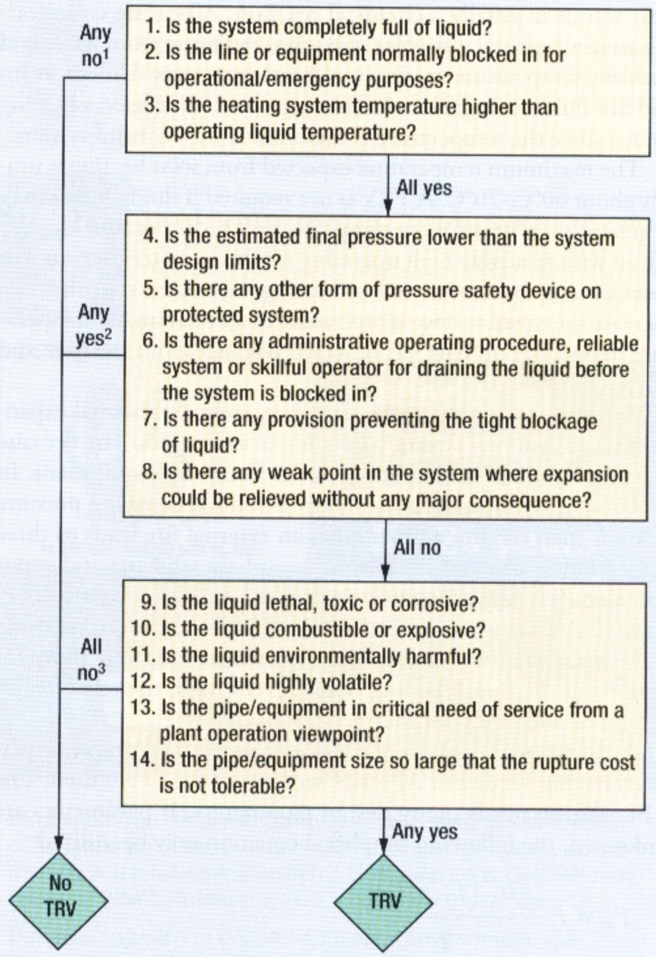
Pipe rupture due to thermal expansion of blocked liquid between process valves may cause limiting effects, but it could produce unacceptable consequences, especially with dangerous liquids. Most references provide proper guidelines regarding thermal expansion relief valve requirements; however, there is no straight forward method to specify when a thermal relief valve (TRV) is required. Furthermore, in the absence of a step-wise approach, sometimes the TRV is provided based on the fluid's volume or nature (hazardous or flammability) while checking thermal expansion's initial requirements has been mistakenly neglected.

TRV requirement. Fig. 1 is a simple flowchart representing questions regarding decisions for a TRV requirement for a specific pipe or equipment. Equipment refers to any process volume including different types of heat exchangers, air coolers, vessels and pumps that satisfy the liquid thermal expansion initial requirements. The decision flowchart consists of three boxes. Box 1 checks the initial requirements needed for initiating thermal expansion, while Box 2 investigates existing safety measures, design provisions and other alternatives that may be utilized instead of TRVs. The consequences of equipment/pipe rupture on human health, safety and environmental aspects, equipment integrity, and economical and operational cost followed by ruptures, are reviewed in Box 3. If any of these consequences are not tolerated, then a TRV should be provided to direct the excess blocked liquid to the confined volume such as another vessel or flare network.

Each question in the decision flowchart is described below in greater detail.

1. The system is considered completely liquid-filled at 95% or greater volume. For a two-phase system with lower liquid fraction and gas system, a TRV is not usually required because existing gas can absorb the increase in liquid volume due to thermal expansion. Small vapor or gas pockets can disappear upon heating due to compression and/or solubilization. In contrast, multi-component mixtures with a wide boiling range can have sufficient vapor present to preclude becoming completely liquid-filled. The liquid volume change due to heating should be estimated to determine if the vapor pocket volume is sufficient for liquid expansion.[1]

2. Process plant piping (on-plot piping) is not normally blocked in, but storage or transport piping sections are regularly shut in during normal operation. This is why few process lines have TRVs.



[1] TRV is not required because thermal expansion will not occur.
[2] TRV is not required since existing safeguard will remove rupture risk but thermal expansion will occur.
[3] TRV is not required since the rupture risk is acceptable but some provisions should be considered for handling rupture consequences.

FIG. 1 Decision flowchart for TRV requirements.

Exception. Process lines or equipment that handle fluids lower than ambient temperature are exceptions. In this case, the answer to question two is *yes*, whether liquid blockage is normally done or not.

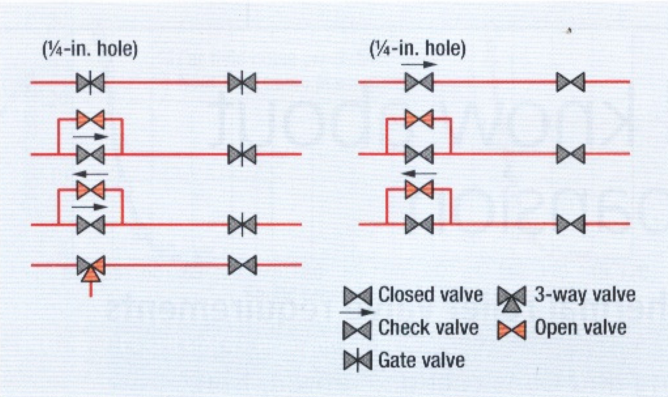


FIG. 2 Design provisions for releasing the pressure due to thermal expansion.

3. The heat source can be internal or external. An internal heat source is usually a chemical reaction. A heating coil, heating jacket, heat tracing, solar radiation, radiation from flares and ambient temperature are external heating sources. Unlike steam and hot fluid tracing, electrical tracing is not considered a heating source since the temperature is maintained by a control system.

The maximum temperature expected from solar heating is usually about 60°C–70°C. A TRV is not required if fluid temperature is greater than heat source temperature. This is because blocked liquid with relatively high operating temperature tends to cool or keep its temperature instead of heating. Flare heat radiation can increase the metal surface temperature to a much higher temperature depending on flare gas flowrate, distance from the flare and burning duration.

External fire is not considered a heat source if thermal expansion is studied for a system consisting of only pipes. The fire case is a heat source if the system includes liquid-full equipment. In this case, if the liquid's initial boiling point at relieving pressure is lower than the fire temperature, an external fire leads to three stages: liquid thermal expansion, two-phase relieving and vapor relieving (fire case—liquid vaporization). From a pressure safety valve (PSV) sizing viewpoint, a PSV sized for the vapor relieving stage is adequate because the first two stages are short transient periods. If the fluid's boiling point is very high, the relief device should be sized only for thermal expansion.

4. In estimating pressure rise due to thermal expansion, equations recommended in API-521 section 5.14.4.1[1] are used. The API relation needs many design parameters. If parameters are unknown, the following simplified equation may be utilized:

$$P_f = P_i + \frac{\alpha_V \left(T_f - T_i\right)}{\chi} \tag{1}$$

where:

$$\chi = \frac{1}{v_1} \frac{\left(v_1 - v_2\right)}{\left(P_2 - P_1\right)} \tag{2}$$

When calculating final pressure, the final temperature needs to be known. The heating source temperature can be considered the final temperature. Generally, a TRV will pop up long before liquid temperature reaches the source temperature. In other words, a 5°C–10°C increase in liquid temperature is sufficient to increase the pressure from operating to design pressure. For example, the pressure will raise about 4 bars for each 1°C increase in water blocked in temperature at 20°C as per Eq. 3 calculation:

$$\frac{\Delta P}{\Delta T} = \frac{\alpha_V}{\chi} = \frac{2.1\times10^{-4}\left(1/_{^\circ C}\right)}{4.56\times10^{-5}\left(1/_{bar}\right)} = 4.6\left(^{bar}/_{^\circ C}\right) \tag{3}$$

5. The required relief rate due to liquid thermal expansion is very small, so if another pressure safety device is provided to protect the system from any other emergency case, it will relieve the pressure by pop-up action.

6. Draining the liquid trapped between block valves is a normal practice done by the operator within the process plant; hence, a TRV is not normally provided for on-plot piping. If there is any specific requirement for liquid draining, it should be clearly mentioned in shutdown or maintenance procedures. Draining 10% liquid volume is enough to prevent thermal expansion. Conversely, storage area piping or liquid transport lines (off-plot piping) due to the operation type and accessibility limitation are regularly blocked in without liquid draining. Utilizing lock-open (LO) valves can be considered a reliable preventive device since this valve type is locked in the open position during operation and closed only under permit.

7. The process designer can consider some provisions such as drilling a small hole in the check or block valve (if it is gate) or adding an open bypass around the check valve or block valve if leakage through additional facilities is acceptable. Placing a check valve around one block valve is another alternative. The check valve is closed during normal operation and it will be opened when thermal expansion takes place. A three-way valve can also be installed instead of a block valve[2] (where applicable) to ensure that the piping system never becomes completely blocked in. Fig. 2 illustrates these alternatives.

8. One of the piping items that is considered as a weak point, is a check valve. API-521 section 5.14.4.2 takes no credit for reverse flow-back (leakage) through a check valve; however, other references consider the check valve's leakage sufficient to relieve excess liquid.

9. If the blocked liquid is dangerous to personnel health or is highly corrosive, rupture is not tolerable and a TRV should be provided.

10. If the blocked liquid is combustible or explosive, rupture is not tolerable from a plant safety viewpoint, then a TRV should be provided.

11. If releasing liquid through a rupture has a major environmental impact, rupture is not tolerated and a TRV should be provided to direct the liquid to a closed system.

12. If highly volatile materials continue to release through a rupture until liquid is totally vaporized, maintenance performance may not be possible for a long time depending on the system's total liquid inventory. Aside from downtime due to maintenance, valuable material loss and volatile organic compound emissions are other concerns.

13. If the line or equipment is not critical, it can be bypassed in a rupture case without any major interruption in a process operation; then, a TRV is not required.

14. Generally, pipes with a diameter more than 1 ½ in. or longer than 30 m are considered large pipes.[3] If pipe diameter or length is less than 1 ½ in. and shorter than 30 m, the pipe rupture cost is expected to be lower than the TRV cost, so no TRV is required in this case. This advice should be considered carefully

and approved by the project owner. Equipment operating full of liquid should be provided with a TRV if the quantity of blocked-in liquid is higher than 0.5 m^3.

TRV relief rate. For a liquid-full system, Eq. 4 (in SI), can be used to calculate the approximate relief rate value:

$$q = \frac{\alpha_V \phi}{1{,}000\ dC} \qquad (4)$$

Reference 3 presents different correlations for calculating the cubical expansion coefficient.

For calculating thermal relief rate, some assumptions shall be applied:

- For heat exchangers, the maximum exchanger duty during operation is taken as the heat transfer rate. The trapped liquid heat transfer coefficient is substantially lower than the flowing liquid heat transfer coefficient, and the heat transfer rate is generally controlled by free convection of trapped liquid inside the pipe. Therefore, using maximum exchanger duty is the most conservative assumption.
- If the fluid properties vary significantly with temperature, the most severe operating conditions should be used.
- Fuel to fired heaters or heating medium to other equipment is continuously flowing at maximum conditions. Control valves on heater fuel or heating fluids will be assumed to be fully open.
- Eliminating TRVs due to the presence of temperature control system that will close the heat source in case of liquid blockage, is not allowed.

TRV sizing. Since it is not easy to determine the relief rate through a TRV, in most systems NPS ¾ x NPS 1 (DN20 x DN25) relief valve can be used, even though it is commonly oversized. Two general applications where TRVs are larger than DN20 x DN25 valves are long pipelines of large diameter in uninsulated, aboveground installations and large vessels or exchangers operating liquid-full. For these cases, relief rate calculation and TRV size checking are recommended.

TRV location. Usually, any location on a pipe or equipment is suitable for installing a TRV. The availability of a suitable discharge route and maintenance requirements may limit the options. A relief valve may be located on a pipe rather than on the equipment if both belong to the same blocked-in system. For ease of service, a TRV should be located at the lowest elevation and at platforms.

TRV discharge location. If the liquid temperature is above its flash point, greater than 300°C or if any answer to questions 9–12 in the flowchart is *yes*, the liquid must be discharged into a closed system, such as a flare header, process or drain vessel. A relief valve can be connected to a vessel where the particular liquid is stored. If the vessel is far away, the TRV discharge line can be connected to the pipe section that is out of the blocked-in system so that the TRV acts like a bypass around the block valve. If relief is to the process, the TRV shall discharge to a location that is always capable of absorbing the relieved material. Other valve's location and possible positions at the time of discharge shall be taken into account. If a liquid is not dangerous, the TRV discharge line can be routed to grade (atmosphere). **HP**

NOMENCLATURE

d	Liquid relative density referred to water at 15.6°C, dimensionless
C	Specific heat capacity of trapped liquid, J/kg K
P	Pressure, kPa (psia)
q	Volumetric relief rate, m^3/sec
T	Temperature, °C (°F)
v	Specific volume of liquid, m^3/kg (ft^3/lb)
ϕ	Heat transfer rate, Watt
α_V	Cubical expansion coefficient of the liquid, 1/°C (1/°F)
χ	Isothermal compressibility coefficient of the liquid, 1/kPa (1/psi)

SUBSCRIPTS

1	First condition
2	Second condition
i	Initial condition
f	Final condition

LITERATURE CITED

1 American Petroleum Institute, API RP 521, "*Pressure relieving and depressuring systems*" 5th Ed., January 2007.
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3 Bravo, F. and B. D. Beatty, "Decide whether to use thermal relief valves," *CEP*, December 1993, pp. 35–38.

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