What You Should Know about Liquid Thermal Expansion

Saeid Rahimi

01-Dec-2010

Introduction

Pipe rupture due to thermal expansion of blocked liquid between process valves (in process equipment or piping) may not result in significant impact; however, it can produce unacceptable consequences especially with dangerous liquids. Most references provide good guidelines regarding thermal relief valve (TRV) requirements, but there is no straight forward method to specify where a TRV is required. In absence of such a step wise approach, sometimes the TRV is provided based on fluid's volume or nature (hazardous or flammability) while thermal expansion's initial requirements are overlooked.

TRV Requirement

Figure 1 is a simple chart presents some questions which helps user to decide whether TRV is required for specific pipe or equipment. Term equipment refers to any process volume including different types of heat exchanger, air cooler, vessel and pump that satisfies the initial requirements of liquid thermal expansion. The decision flowchart consists of three boxes. The first box checks the initial requirements needed for initiating thermal expansion, while the second box investigates the existing safeguards, design provisions and other alternatives that may be utilized instead of TRV. The consequences of equipment/pipe rupture on human health, plant safety and environment and economical and operational impacts of rupture are reviewed in the third box.

Flowchart questions are described in the following section:

1. System is considered totally liquid filled if liquid volume is more than 95% of system volume. Small vapor or gas pockets can disappear upon heating because of liquid swelling (due to reduction in liquid density), gas condensation, compression and solubilization when system pressure and temperature increases from operating to relieving. In contrast, multi-component mixtures with a wide boiling range can always have sufficient vapor present to preclude becoming completely liquid-fill. Detail study is required to determine if the volume of the vapor pocket is sufficient to prevent system over-pressuring due to liquid expansion.

   For two - phase systems, TRV may not be required as existing gas can absorb the pressure due to liquid thermal expansion. Refer to technical note "A Complete Guideline for Blocked-in Condition" for particular cases where PSV is needed for two phase or gas filled systems.

2. Liquid can get trapped between two valves during plant operation, maintenance, normal and emergency shutdowns. Maintenance and normal shutdown are scheduled activities; they are completed under supervision and according to detailed checklists, procedures and work permits. Equipment and piping are drained as a part of preparation process for maintenance therefore the possibility of liquid thermal expansion is minimum. Liquid can be blocked and go un-noticed in the following condition:

   - Emergency shutdown, when a piece of equipment or part of the plant is isolated automatically by shutdown valves. The position of control valves during shutdown should be taken into consideration. As flow stops, some of the control valves go to the closed position which can create isolated section.
   - Normal operation; there should be no trapped fluid in any process piping and equipment during normal operation but there are particular processes where system can be shut-in during normal operation and draining is not feasible due to time constraint, nature of operation or cost consideration. One typical example is storage area transport piping where pipe sections are regularly shut-in during product shipping and tanker loading without draining.

   Exception: for process systems at very low temperatures (mainly refrigerant cycles, LPG, LNG processes and cryogenic services), due to considerable differential temperature between trapped liquid and ambient temperature, liquid pressure rapidly increases after system is being blocked. So for these systems, operator action (for draining) cannot be relied upon and irrespective of condition at which liquid is likely to be blocked (maintenance, normal or emergency shutdown), the answer to question 2 is yes.

3. The heat source can be internal or external. Internal source of heat is mainly chemical reaction. Hot process and utility streams, heating coil, heating jacket, heat tracing, solar radiation, radiation from flares, fire and ambient temperature are external heating sources. Unlike steam and hot fluid tracing, electrical tracing is not usually considered as a heating source because the temperature is maintained by control system.

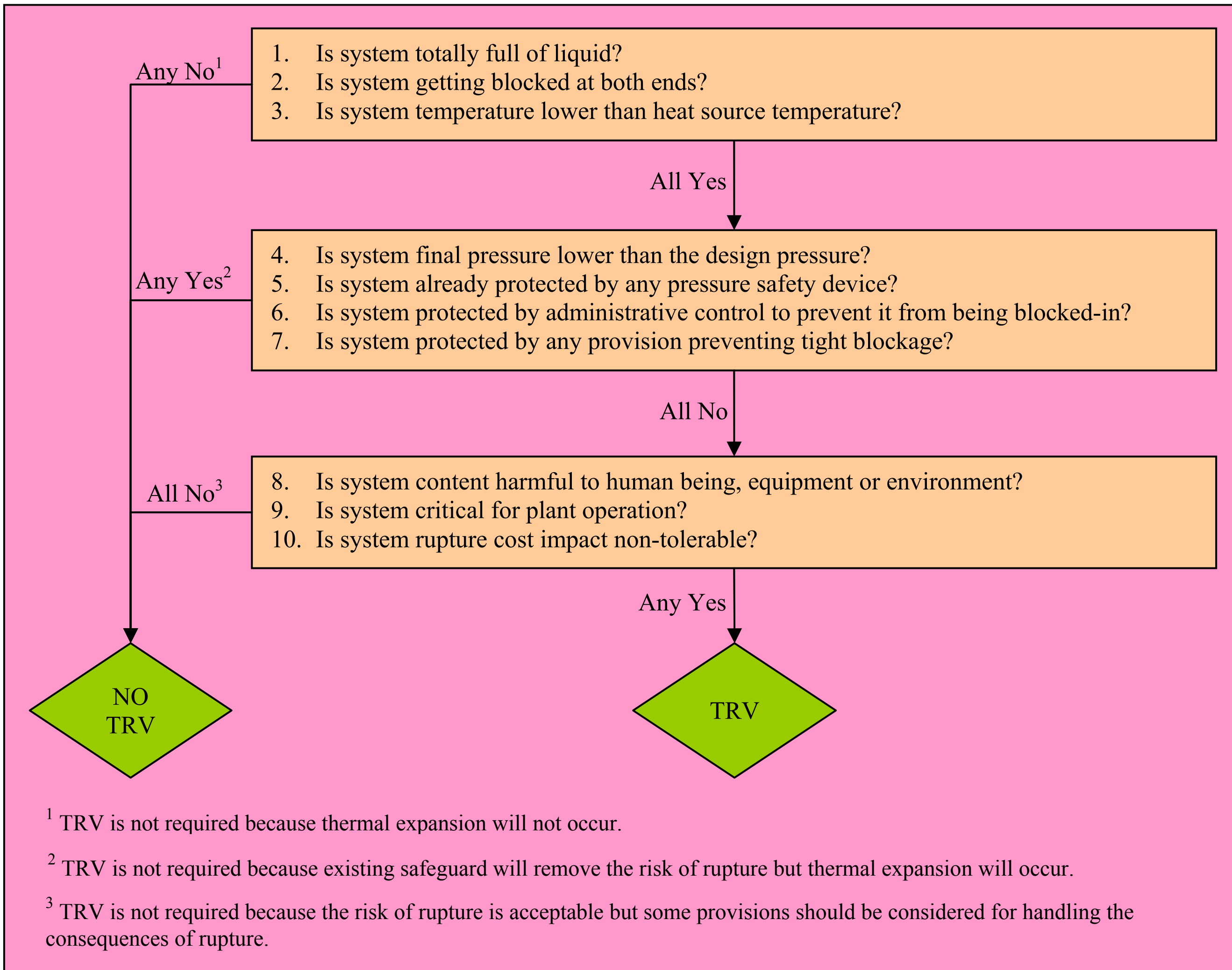

Figure 1 - Decision flowchart for thermal relief valve requirement

Hot process streams and utilities (hot water, hot oil or steam) are usually used for heating process streams in shell and tube heat exchangers. Blocking liquid in cold side of heat exchanger while hot stream is flowing will result in cold side over-pressurization.

The maximum temperature expected from solar heating is usually about 60°C to 85°C, TRV is not required if fluid temperature is higher than this temperature. The reason is that blocked liquid with relatively high operating temperature tends to cool down or keep its temperature instead of heating up. Flare heat radiation can increase the surface temperature of metal to much higher temperature depending on flare gas flow rate, distance from flare and burning duration.

External fire is not usually considered a heat source if the thermal expansion is studied for a system consisting only pipes. Fire case is source of heat if the system includes liquid-full equipment.

4. For estimating pressure rise due to liquid thermal expansion, the equations recommended in API-521 section 5.14.4.1 are used. API relations need lots of design parameters, so if these parameters are unknown, the following simplified equation may be utilized:

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

Where,

$$\chi = \frac{1}{\nu_1} \frac{\left(\nu_1 - \nu_2\right)}{\left(P_2 - P_1\right)} \qquad (2)$$

For calculating final pressure, final temperature should be specified. The heating source temperature can be considered as final temperature. But generally TRV will pop up long before liquid temperature reaches the source temperature. In other words, 5 to 10°C increase in liquid temperature is sufficient to increase the pressure from operating to design pressure. For example, according to equation (1) for blocked-in water at 20°C, the pressure will raise about 4 bars for each 1°C increase in temperature:

$$\frac{\Delta P}{\Delta T}=\frac{\alpha_V}{\chi}=\frac{2.1\,x\,10^{-4}\left(\frac{1}{^{\circ}C}\right)}{4.56\,x\,10^{-5}\left(\frac{1}{bar}\right)}=4.6\left(\frac{bar}{^{\circ}C}\right)$$

NOMENCLATURE	
P	Pressure, kPa (psia)
T	Temperature, °C (°F)
v	specific volume of liquid, m3/kg (ft3/lb)
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

5. The relief rate due to liquid thermal expansion is very low, so if another pressure safety device is already provided to protect system against another emergency case, it will be able to protect the system against liquid thermal expansion as well.

6. Putting popper operating procedures in place and using trained operators can be considered enough safety measure (subject to Client approval). Draining the liquid trapped in system is a normal practice done by operator; however this requirement can be clearly spelled out in normal shutdown or maintenance procedures. Utilizing valve interlocking system ensures correct valve sequencing (closing process heat source before liquid is being blocked in both sides). Valve locking devices also can be considered as reliable preventive device as it is locked in open position and cannot be closed without permit and supervision.

7. The process designer can consider some provisions such as drilling a small hole in the check valve or block valve (if it is gate) or adding an open bypass around check valve or block valve if leakage through bypass is acceptable. Placing a check valve around one of the block valves 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 one of the block valves (where applicable) to ensure that the piping system never becomes completely blocked-in. Above mentioned alternatives are depicted in Figure 2.

   If liquid is blocked because of control valve closure, minimum limit stop can be used to prevent valve from full closure. If liquid is blocked by check valve in one side, the check valve leakage can be considered sufficient to relieve the excess liquid especially for liquid blocked in short pipes when the heat transfer rate is limited. API-521 takes no credit for leakage through check valve whereas some other references do.

8. If the blocked liquid is dangerous for personnel health (toxic, carcinogenic, corrosive, etc), combustible or explosive, no rupture is tolerable. If releasing the liquid through the rupture has major environmental impact, therefore no rupture is tolerated and TRV should be provided to direct the liquid to closed system. Highly volatile materials continue to release the material through rupture until liquid is totally vaporized, therefore doing any sort of maintenance will not be possible for a long time depending on the total liquid inventory of the system. Aside from downtime due to maintenance, loss of valuable materials and volatile organic compound (VOC) emissions are other concerns.

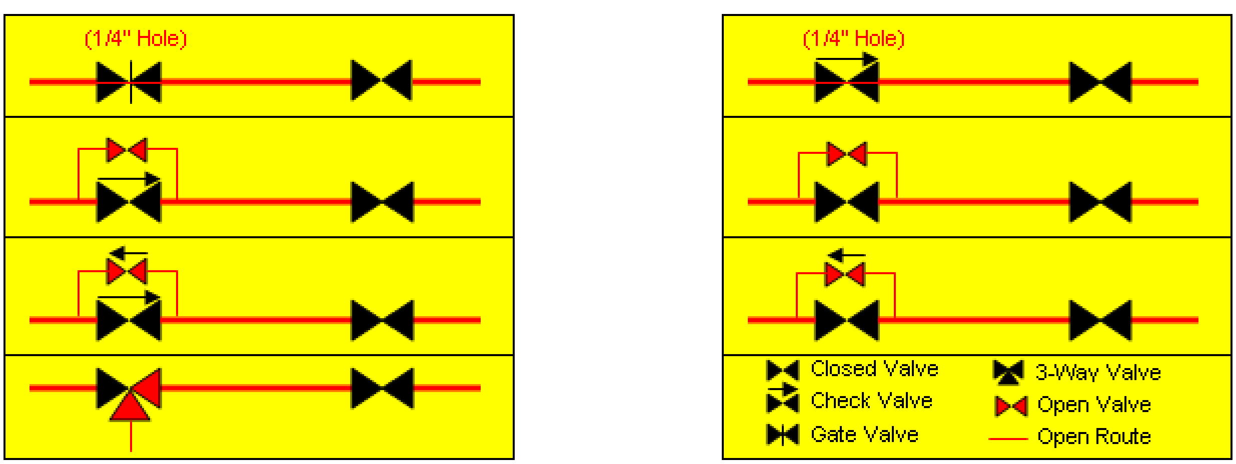

Figure 2 – design provisions for releasing the pressure due to thermal expansion

9. If the line or equipment is not critical for plant operation, it can be bypassed in the case of rupture without any major interruption in process operation.

10. Pipes with diameter more than 1 ½" and longer than 30 m are generally considered large pipes. The rupture cost of smaller pipe 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 project owner. Equipment operating full of liquid should be provided with a thermal relief valve if the quantity of blocked in liquid is higher than 0.5 m3.

Contact

Please feel free to contact S.Rahimi@gmail.com or ContactUs@chemwork.org should you have any comment, question or feedback.