

Proper Piping for Vacuum Systems

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Optimally designed piping upstream and downstream of vacuum equipment increases equipment efficiency and reduces maintenance. It also minimizes vacuum loss and pressure drop, takes advantage of suction lift to enhance energy efficiency and decreases the risks of flooding equipment or shutting down systems.

Unfortunately, however, contractors or engineering firms doing plant layout frequently either route piping to accommodate existing process equipment, or try to fit pipes into available space. Such slipshod piping configuration contributes greatly to plant downtime and process inefficiency.

In addition, many plant startups and modifications are delayed because a simple piping installation had been performed improperly. And, if a problem is found after startup, it may not be rectifiable without considerable trouble and expense. This article discusses the principles of proper piping design for common plant equipment, such as tailpipes, hotwells and float traps.

Trapped bubbles in tailpipes. A common hazard in barometric or shell-and-tube condenser tailpipes is accumulating gases. Condensate from a shell-and-tube condenser, or cooling water plus condensed steam or hydrocarbons from a direct-contact barometric condenser, always contain air or other non-condensable gases.

A horizontal or slightly downward-sloped line is vulnerable to these gases, which cling to upper pipe surfaces. All types of pipe contain a certain amount of internal roughness and, because of this, gases tend to start clinging and building up in the smallest crevice. In addition, every flanged joint has a slight crack where a gasket is located, thus permitting another place for gases to collect.

As these gases accumulate, they form tiny bubbles, growing into larger ones that eventually become big enough to partially or completely block off piping at that point. The condensate cannot flow downwards and soon its level rises, flooding the condenser.

Testing has proven that if piping changes direction, it must form at least a 45-deg angle from the horizontal (Figure 1). With this amount of sloping, gases will either slide back up the pipe or continue

downward with the thrust of the flowing water. Observe that this is true whether the condenser is a barometric or shell-and-tube unit.

When a change in direction is required, there must always be a vertical straight distance of five pipe diameters or four ft minimum between each change. This allows flowing liquid to develop a minimum velocity head and a straight downward pattern before the first change in direction. There are no valves in the tailpipes shown (Figure 1), for two reasons:

- If a valve is accidentally left closed during startup or on turnaround, or if vibration closes a valve partly or completely, the condition can flood condensers, cause vacuum loss and shut down operation

TAILPIPE HEIGHTS	
Maximum barometric pressure, in. Hg at 32°F	Height in ft (water at 32°F)
31	35.2
30	34.0
29	32.9
28	31.7
27	30.6
26	29.5
25	28.4
24	27.2
23	26.1

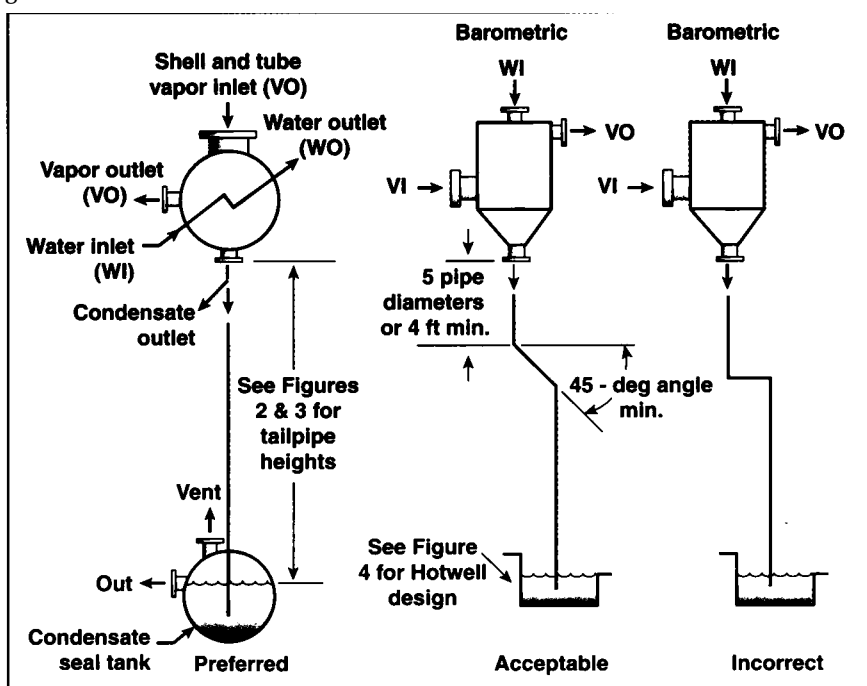


Figure 1 (top). If piping must change direction, it should form at least a 45-deg angle from the horizontal plane; the horizontal piping in the rightmost drawing is vulnerable to gas accumulation.

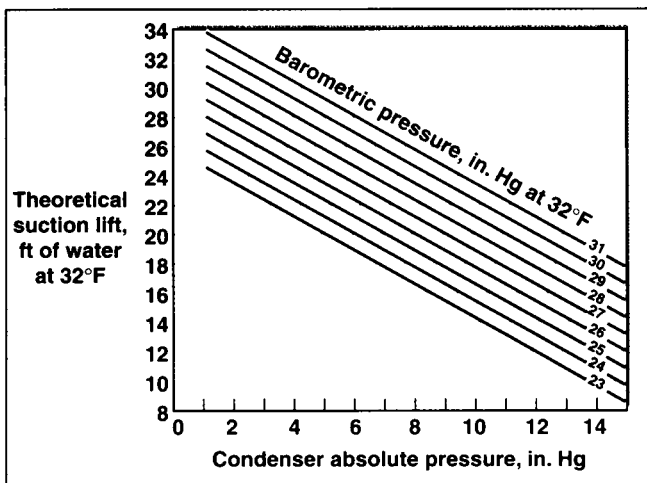


Figure 2. Use the absolute pressure of a condenser, plus barometric pressure, to estimate suction-lift values.

- Any valve, by definition, causes pressure drop. Unlike a smooth piece of pipe, a valve creates a node, in which products such as hydrocarbons, salts or rust can accumulate. This leads to excessive pressure drop, or can result in closing off piping completely and possibly shutting down operations

CONFIGURING FOR SUCTION LIFT

Suction lift is a function of vacuum systems that can be used to advantage in piping (Figure 2). For example, it can enhance a pumping system by reducing the load on an existing motor.

Imagine, for instance, pumping a liquid from one level up 80 ft to a vessel operating under vacuum. The vacuum or suction lift can be used to reduce the total dynamic head (TDH) requirements for the system's pump and motor.

This reduces the horsepower used and possibly the motor size, thus saving energy and money. Another application is to merely move liquid from one tank to another without a pump.

To find a specific value for a given piece of equipment with Figure 2, use the lowest expected condenser pressure at the minimum cooling-water temperature at the inlet (for barometric systems), or the minimum condensing pressure due to loading. The barometric pressure, in addition to the absolute pressure in the condenser, greatly affects the suction lift. I recommend using the highest recorded barometric pressure for calculation, and taking 80% of the theoretical suction lift to cover any overlooked condition.

For an actual check of suction lift, obtain the barometric pressure directly at the installation point, and measure the condenser or vessel absolute pressure. Using Figure 2, move vertically upward from the actual condenser pressure reading, to the barometric pressure. At the intersection, move horizontally to the left to read suction lift in ft H₂O.

TAILPIPE HEIGHTS

Recommended minimum effective tailpipe heights are shown, based on water at 32°F (Table, opposite page). This height should be based on the absolute maximum recorded barometric pressure for given equipment, regardless of the anticipated condenser operating pressure. This pressure information must be used in piping design when vacuum equipment is placed in a building or an elevated structure.

For example, consider an installation site with a highest recorded barometric pressure of 30 in. Hg. The plant has been laid out, and the most-economical placement of the vacuum vessel (assume a process precondenser) is at an elevation of 32 ft, next to the evaporator. Based on the 30-in.-Hg maximum pressure, the minimum effective tailpipe for water should be 34 ft.

The result, however, is that water will flood the pre-condenser by 2 ft. As something must be changed, the logical solution is to move the evaporator and condenser to the next floor level, or to elevate them enough to overcome the difference.

Note that the values in this chart are based on water; heights should be corrected if any hydrocarbons or other substances are present. For hydrocarbons, good installation practice is to use at least 45 ft, regardless of barometric pressure.

It is difficult to predict actual heights needed for hydrocarbons under vacuum. Some have a tendency to foam, which suggests the rule-of-thumb minimum of 45 feet. If the specific gravity of the liquid in the tailpipe is known, the height should be adjusted accordingly.

HOTWELL DESIGN

The designer must carefully consider open hotwell design in a process (Figure 3). Good practice recommends that the hotwell

area be equal to 1.5 times the tailpipe volume measured from the bottom of the tailpipe to the

point of overflow (not less than 12 in.). The large volume is needed to ensure there is enough liquid present to seal the tailpipe.

As vacuum is produced, the water rises in the tailpipe to the height induced by the vacuum, minus the barometric pressure. If there is insufficient hotwell area present, the seal will be broken and air drawn into the tailpipe, affecting the performance of vacuum-producing equipment and the process. The pressure could rise dramatically, affecting the process pressure, and possibly shutting down plant operations.

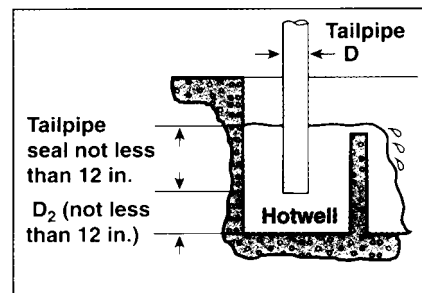


Figure 3. Sufficient hotwell area is necessary to contain vacuum in a tailpipe.

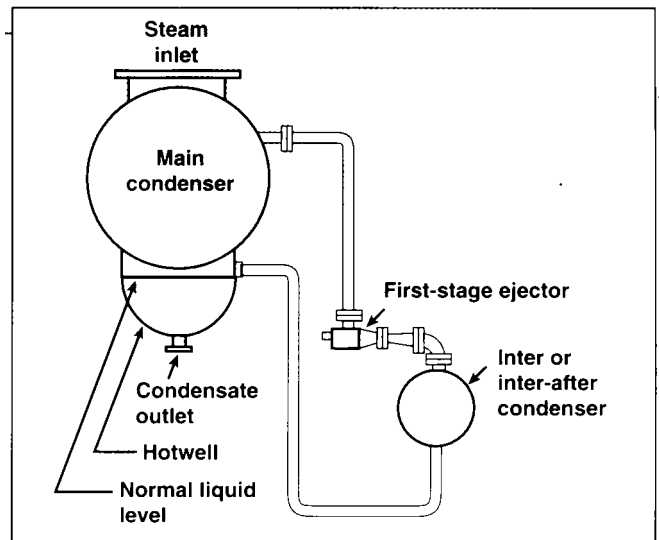
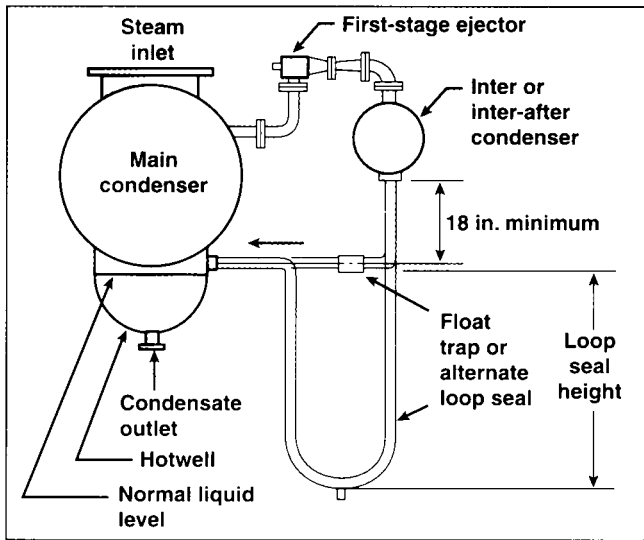
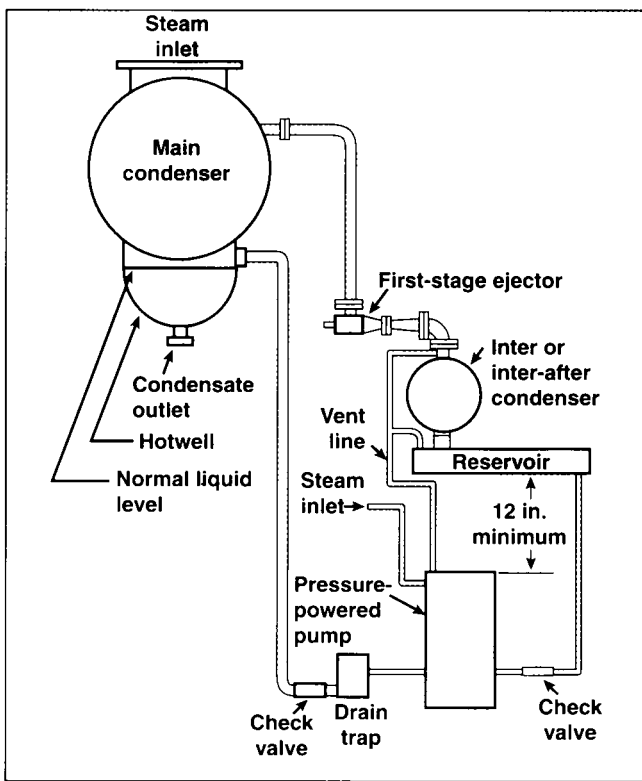


Figure 4 (top, left). Don't skimp on loop-seal height in order to cut costs.

Figure 5 (top, right). In this incorrect example, the inter- or inter-after condenser will be flooded on the shell side.

Figure 6 (left). The addition of a steam-powered pump corrects the deficiencies of Figure 5.



If a float trap is used (Figure 4), the intercondenser should be at least 18 in. above the normal liquid level of the condenser into which condensate is dumped. If a loop seal is used, the loop-seal height should be equal to the difference between the highest operating pressure in the intercondenser minus the main condenser's lowest operating pressure.

In looking at the highest intercondenser pressure, the designer should also consider off-design or startup conditions. In addition, the designer should take into account extremely small loads to the main condenser when using the coldest condensing-water temperature. This will yield the lowest main-condenser pressure.

Since piping is relatively inexpensive, loop-seal height should not be shortened to save a few dollars. Generally, an 8- to 10-ft loop seal should be adequate; but this height should be determined by the manufacturer of the ejector or condenser. The valve at the bottom of the tailpipe is for draining the unit when it is idle, to prevent freezing or rusting, and to service the tailpipe equipment.

Frequently, the designer runs into a space problem, requiring that the ejector condenser be located below the normal liquid level in the hotwell of the condenser. This could be a problem if piping is configured as in Figure 5 — condensate will not flow out of the intercondenser because there is insufficient piping distance between the two condensers to allow this. The inter- or inter-after condenser will be flooded on the shell side losing vacuum and shutting down the system.

LOOP SEALS AND FLOAT TRAPS

Using an intercondenser to remove condensate from an ejector to another condenser operating at a lower pressure is a typical piping configuration that can frequently be problematic. However, following a few simple guidelines will eliminate problems. The configuration discussed in the following paragraphs should be used primarily for turbine-exhaust condensers and their associated inter- and inter-after condensers.

Whenever hydrocarbons are present that will condense in the inter- or inter-after condensers, or when the vacuum system is on a platform elevated about 40 ft in the air, a condensate receiver or seal tank should be used (leftmost diagram of Figure 1).

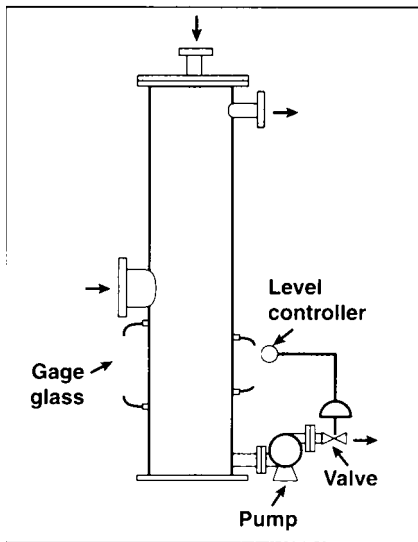


Figure 7. A "low-level barometric" configuration has an extended shell body to form a storage tank.

low-pressure steam of 50 psig or less. The designer should always try to pipe equipment relatively simply, as shown in Figure 4, because additional hardware (such as a pressure-powered pump) may be needed, adding to the complexity of existing piping.

Two other equipment configurations are useful when space is at a premium. First, a barometric configuration has its shell body extended to form a storage tank, with a level controller modulating an overboard valve, plus a condensate pump removing liquid in the storage area (Figure 7). This setup is often called a "low-level barometric."

An off-shoot of this is shown (Figure 8) with the same storage and controls, but with a shell-and-tube intercondenser mounted on top. The condensate pump, in both cases, must be carefully sized for the net positive suction head (NPSH) available.

Both of these examples are extensively used throughout industry. The designer, as stated, must carefully look at the pump NPSH, but generally a suction head of 4-5 ft is adequate. The only other design criterion is sizing the control valve to satisfy downstream conditions.

HYBRID SYSTEMS

Some designs feature ejectors with a shell-and-tube intercondenser plus a liquid ring vacuum pump (LRVP). In such configurations, the LRVP must be located directly below the condenser (Figure 9).

This system, commonly called a "hybrid system," is very cost effective. As the LRVP is located directly below the condenser, this application elim-

Such a problem can be resolved (Figure 6). Basically, this configuration requires a pressure-powered pump, which runs on steam. The pump size and steam pressure and quantity required are functions of total lift and actual lb/h of condensate to be pumped.

Depending on the steam pressure available, lift can be as high as 300 ft—though the needed height is typically only 8 to 15 ft, requiring relatively

inates a second shell-and-tube intercondenser, possibly a shell and tube aftercondenser, and two additional steam-jet ejectors, realizing considerable space savings.

Note, however, that an LRVP is limited, because it is pumping condensate as well as any noncondensable gases. An LRVP can only pump a percentage of condensate, compared to the seal liquid required. Each individual system should be analyzed for its particular limitations.

Note, also, that a single-stage ejector, or as many as four stages upstream of the intercondenser, could be required in some cases. Figure 9 uses a two-stage configuration simply to depict the principle of the system.

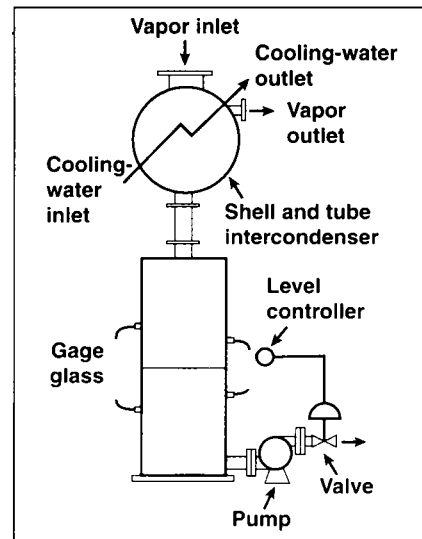


Figure 8. A variation on the low-level barometric, the low-level shell-and-tube configuration adds an intercondenser on top

PROTECTING AGAINST CONDENSATE

Vapor piping entering and leaving condensers in a vacuum system with condensibles present can result in serious operating problems if designed incorrectly (Figure 10). With barometric condensers (Figure 10a), it is important to note that condensate is splashing down the barometric walls and could run down the vapor inlet, unless the inlet is protected by a dam or series of elbows.

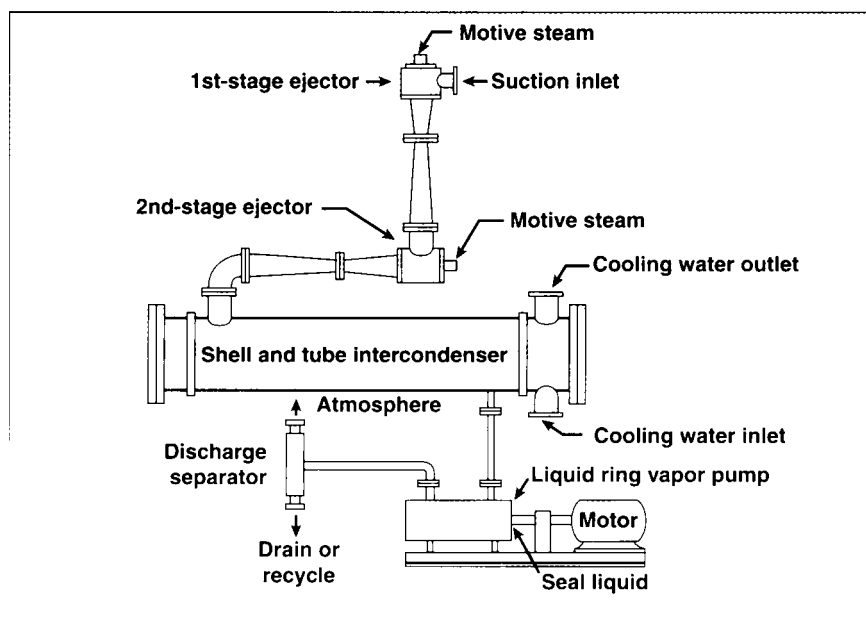


Figure 9. A liquid-ring vacuum pump eliminates a second shell-and-tube intercondenser, as well as steam-jet ejectors.

If the process vessel is a turbine, liquid can run down the pipe from the barometric condenser, tearing apart turbine blades, causing serious damage and major expense plus a shutdown. Even with a less-critical type of process vessel, such as an evaporator, water can contaminate product, increase process load or ruin product completely.

Condensible vapors flowing in a pipeline will naturally condense since the pipe is usually cooler than the saturation temperature of the vapor it contains. Vapor piping entering and leaving a barometric condenser (or a shell-and-tube condenser) must not contain any pockets where this liquid can accumulate. This liquid will add another flashed load to the ejector, or could seal off the line completely, resulting in a downgraded system.

The absolute pressure upstream of a pocket will rise dramatically, indicating that ejectors are not working satisfactorily. This will cause a false alarm, while equipment may actually be performing properly.

Edited by Irene Kim

AUTHOR

Loren E. Wetzel is assistant manager of contract engineering for Graham Manufacturing Company, Batavia, NY. He received his B.S. degree in mechanical engineering from Rochester Institute of Technology in 1956. He has been employed full time at Graham Manufacturing Inc. since graduation. During initial employment, he was trained in every department in the fabrication shop, as well as both the heat exchanger and vacuum engineering departments. He specialized in ejector design, including being in charge of the ejector testing and service departments. During this time, he was also a senior contract engineer. He has been involved at length in the research and development of ejectors.

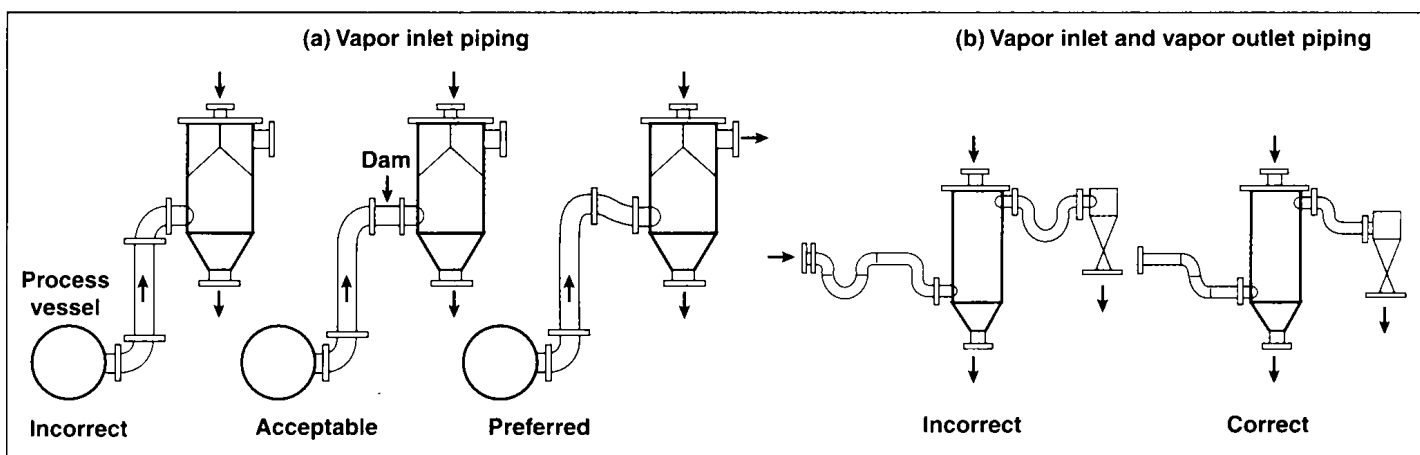


Figure 10. Vapor inlet piping should prevent condensate from splashing down barometric walls (a); inlet and outlet piping should not have any pockets in which condensed liquid can accumulate (b)