

Plate Heat Exchangers as Refrigeration Condensers

Some Dos and Don'ts



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The design and installation of industrial refrigeration condensers is in theory straight forward. In practice, poorly tuned or malfunctioning components, fouling especially on the water side, inert gas in the system, misplaced pipe lines, etc., can lead to capacity loss, control problems, frequent shut downs and other difficult to find and explain phenomena. This is typical for large custom made plants. Manufacturers of small standard units such as air conditioning OEMs, can usually iron out the problems before a chiller line goes into production. An industrial contractor usually does not have this luxury; the plant has to work immediately.

This article describes how to properly install and operate a refrigeration condenser and a liquid receiver and how to avoid some common pitfalls. The stress is put on water cooled Plate Heat Exchangers (PHE) but most of the information is valid for any type of condenser.

1. Fouling

The majority of condensers

probably operate with cooling tower water. Treatment of cooling tower water depends on the actual water quality, the air quality and sometimes varies with the season and is normally best done by a specialized company, with experience of the particular requirements at the site.

The only special consideration is that a PHE is sensitive to fibre like particles, type grass, seaweeds also leaves and agglomerations of micro organisms, which can be found in cooling tower water. A good screening with a mesh size about half the channel height is usually sufficient.

Do not mistake fouling for corrosion. *Figure 1* shows a plate with hard, rust like deposits. It was initially thought that it was corroded, but the plate was made of titanium, which simply does not corrode in the brackish water used. Moreover, corrosion of titanium does not produce insoluble, rust like deposits.

A closer investigation showed that the deposits originated from the connecting steel pipe work.

2. Non-condensable gases Sources of non-condensable gases (inerts, air) in a refrigeration system can be:

- Insufficient removal before start up due to either a faulty vacuum



Figure 1. Fouling, not corrosion.

About the Author

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pump or a faulty pressure gauge.

- A part of the system is shut off from the rest during the initial evacuation of the air.
- The evaporators operate below ambient pressure, especially in case of many and large unit coolers. The frost can easily break a tube in a unit cooler if the defrosting is not properly done.
- Decomposition products. This is normally a minor source except in ammonia water absorption systems. Under certain conditions ammonia decomposes to hydrogen and nitrogen, especially if nickel is present.
- This decomposition mixture has a lower density than ammonia, which can affect the vent position, see Figure 3B.

The Effects of Non Condensable Gases.

Both the heat transfer coefficient and the temperature difference are decreased, see Figure 2. The denomination “air” will be used in this article as this is the most common inert gas.

When the condensation proceeds:

- The relative concentration of the vapour decreases and thus the saturation temperature and the temperature difference decrease as well.
- There will be an increasingly thick layer of air saturated with vapour close to the condensing surface.

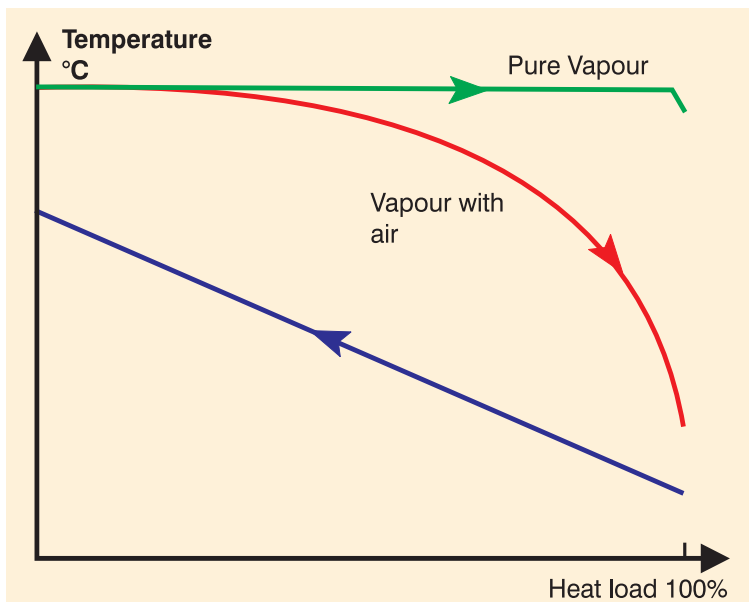


Figure 2: The effect of inert gases on the temperature difference, the heat transfer coefficient and the condensing efficiency.

The vapour has to diffuse through this layer. The result is a decreasing heat transfer coefficient.

- Some refrigerant remains in the vapour, regardless of the exit temperature.

Example: 1000 kg R22, containing 1 % air, condenses

A. PHE, all types.

For all vapours, vent from:

- ◆ A bottom port (the one opposite the condensate exit)
- ◆ A liquid receiver
- ◆ The pipe work

B. S&THE: Venting shall be done at the end of the heating surface, close to the exit.

a) Top vent
(Inerts lighter than the vapour).

- ◆ There is usually a vent at the top of the shell.
- I. All vapours except ammonia & water.
- II. Ammonia, if hydrogen is present.

b) Bottom vent
(Inerts heavier than vapour)

- ◆ A vent close to the condensate exit (but usually none present).
- ◆ The pipe work.
- ◆ A liquid receiver
- I. Water.
- II. Ammonia, if no hydrogen.

Venting of ammonia (PHE or S&THE):

1. Let a hose from the vent discharge below the surface in a bucket with water.
2. Bubbles emerges => air
3. No bubbles => no air.

Figure 3 : Venting positions for refrigerant condenser systems.

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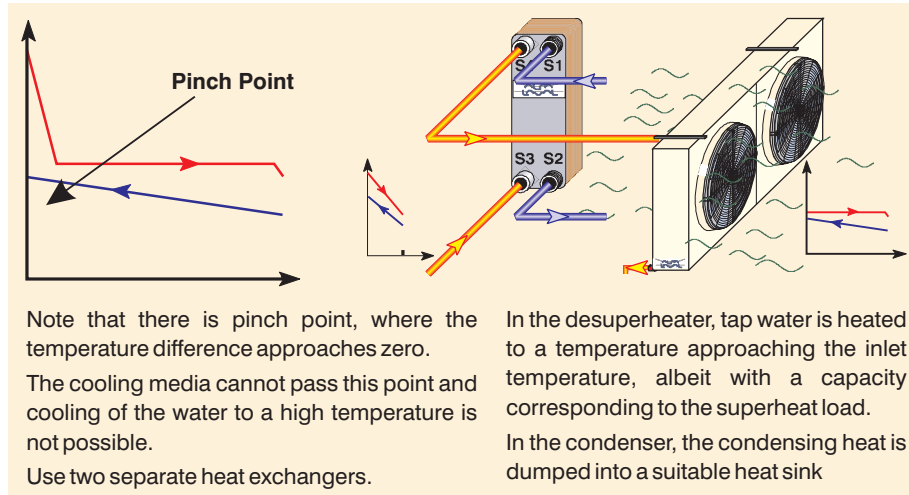


Figure 4 : Cooling of a superheated vapour

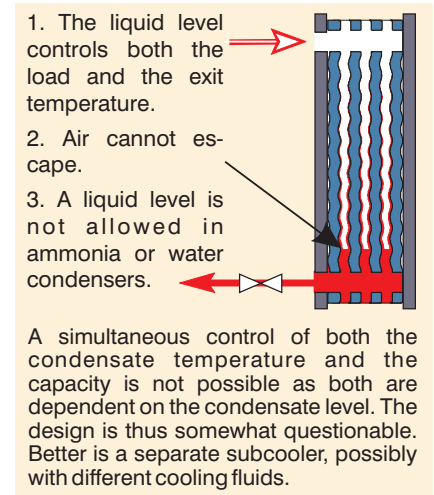


Figure 5 : Condenser & Subcooler

- ◆ The condensate flows into the liquid receiver (LR) via a large condensate pipe, which ends at the top of the LR.
- ◆ Vapour can flow from the LR back to the condensers as the pipe is not filled with condensate.
- ◆ If the LR is placed in a warm machine room, vapour produced in the LR can recondense in the condenser.
- ◆ The vapour flow has to be very small or there is a risk of condensate blocking of the channels.
- ◆ Vents can be placed at a port, at the exit pipe or at the LR.
- ◆ An equalization line is not allowed as this equalizes the pressure before and after the condenser. To compensate for the pressure drop a condensate level must be created. This can only be done in the channels, which then are blocked.

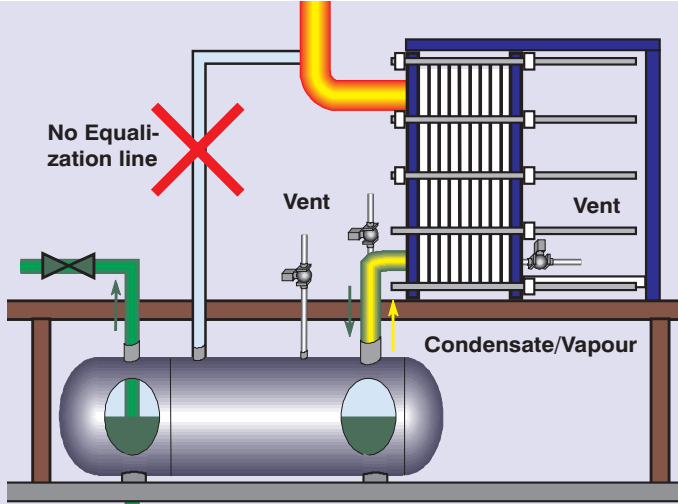


Figure 6A : Through liquid receiver. No equalization line.

- ◆ These two designs are very similar.
- ◆ In the **surge LR (B)** the condensate flow by-passes the LR entirely. There is no counter current vapour flow in the condensate pipe, which can have a reasonably small diameter.
- ◆ In the **through LR (C)** the condensate pipe discharges below the liquid level in the LR, at the very bottom of it. Here as well, the condensate pipe can have a small diameter.
- ◆ The difference is that the condensate body in B only act to even out variations in the system filling, it remains fairly constant and is thus prone to be heated from the outside.
- ◆ In C, the condensate body is constantly replaced by cold condensate and is thus less sensitive to outside heating.
- ◆ As the vapour cannot pass the condensate pipe, a vent cannot be placed at the LR, only at the exit pipe or the port

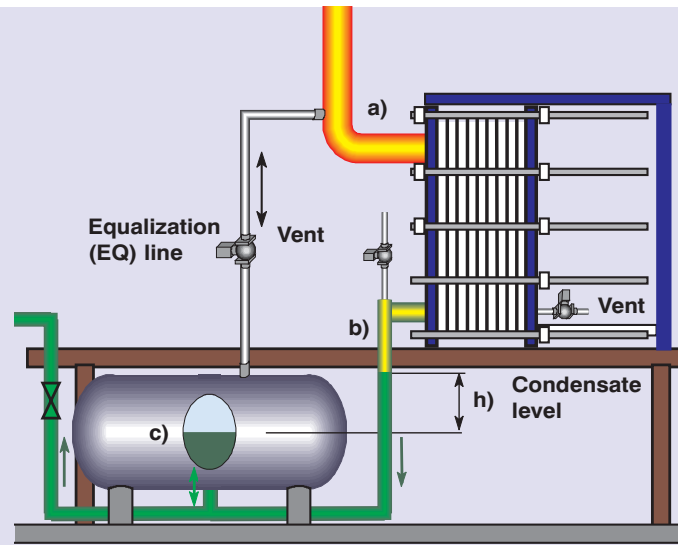


Figure 6B : Surge liquid receiver (with equalisation line)

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- ◆ There has to be an equalization line (EQ) to take care of the inevitable vapour flow. This can now be larger than from the LR in the previous design (6A). The vapour need not to flow in counter current to the condensate, and thus no flooding.
- ◆ A. If there a pressure drop between a) and c), a liquid column – h, corresponding to $\Delta P(a-c)$ –, is created in the condensate pipe to compensate for this.
- ◆ B. This liquid level also pushes vapour from the LR back into the condenser where it joins the vapour from the compressor at the condenser inlet.
- ◆ To obtain the necessary liquid level for A & B above, there must be a sufficient height difference between the condenser and the LR, otherwise the condenser floods.
- ◆ As the vapour flow can be larger than for 6A, it can be used to connect to a refrigerant cooled oil cooler.

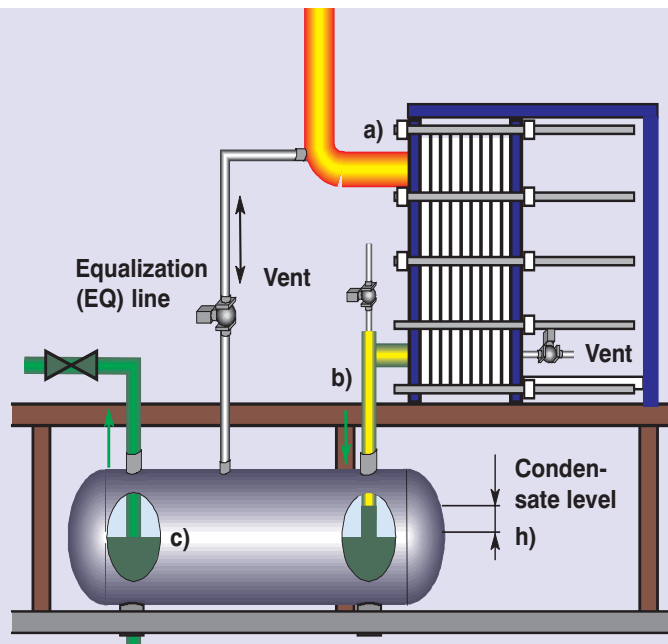


Figure 6C :Through liquid receiver (with equalization line)

at 45°C. After the condenser (DP=0.1 bar), the temperature has decreased to 40 °C and 193 kg R22 remains at the exit.

Detection of air

See the troubleshooting matrix in Figure 10 and Figure 3.

It is easily seen that it can be very difficult to distinguish if it is air or condensate, which is blocking the surface. A thermal camera is a good help but the pictures might be inconclusive.

An undampened, i.e. not filled with liquid, pressure gauge, type Bourdon, shows the small, rapid pressure variations, which arise when a vapour containing air is compressed. The needle vibrates, to the point that it can hardly be seen. Compressing a pure vapour is a stable process, thus there are no needle vibrations. It obviously means that the compressor shows variations but piston, screw and scroll compressors show this pressure variation. It is thus a good indicator of the presence of air.

Venting can be used – see Figure 3 how to install a vent – but it is a negative test: If the venting is done for a long enough time and there is no improvement of the performance, there was obviously no air present. Unfortunately, a lot of refrigerant has by then escaped.

Ammonia is a special case. Ammonia is extremely soluble in water. If the vent is connected to a hose and the exit from the hose is then dipped into a bucket filled with reasonably cold water, only air will emerge at the surface, in bubbles. Ammonia whether liquid or vapour, with or without air, dissolves in the water. There are no

bubbles, only some noise and movements on the surface. See the case study in Figure 9. Venting positions are shown in Figure 3.

3. Desuperheaters and subcoolers

See Figures 4 and 5

4. Condensate exit and liquid receivers

See Figures 6A to 6C

5. Condensate blocking of the surface.

- Contrary to what is generally thought, the reason for a condensate back-up in the condenser is normally not some obstruction in the condensate line. After all, there is a very large and efficient obstruction in the condensate line – the expansion valve – which does not impede the proper flow of the condensate.

- One reason for a condensate back-up is a misplaced equalization line (Figure 7) or too high a pressure drop anywhere in the system – and not only in the condensate pipe - between the equalization line connection points and a LR not designed for this, see Figure 6 A – C.

- Another reason is that condensers of different pressure drops are installed in parallel and there is not sufficient height in the adjoining condensate pipes to create the necessary equalizing liquid column, see Figure 8.

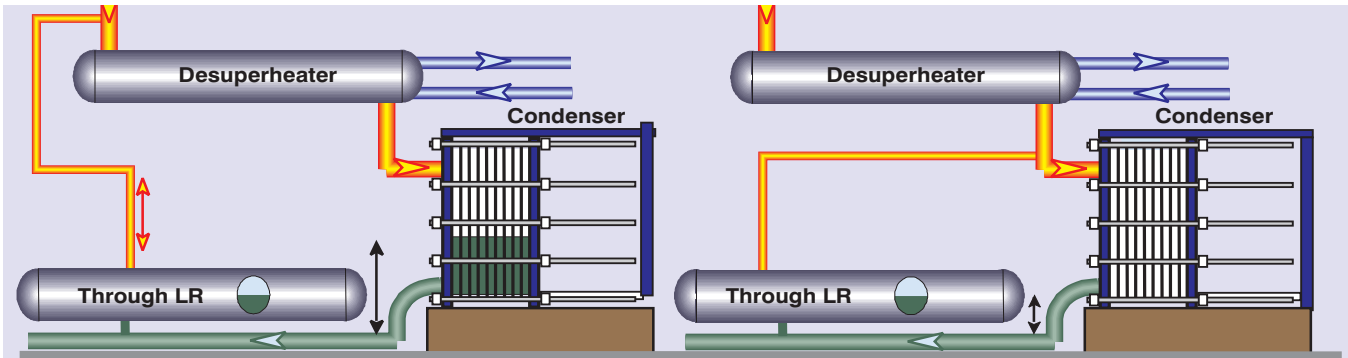
- There can be a temporary blocking if the expansion valve is placed far above the condenser. When the valve closes, condensate might flow back to the condenser and flood this. Avoid placing the valve far above the condenser.

6. Case Studies

See Figures 7, 8 and 9.

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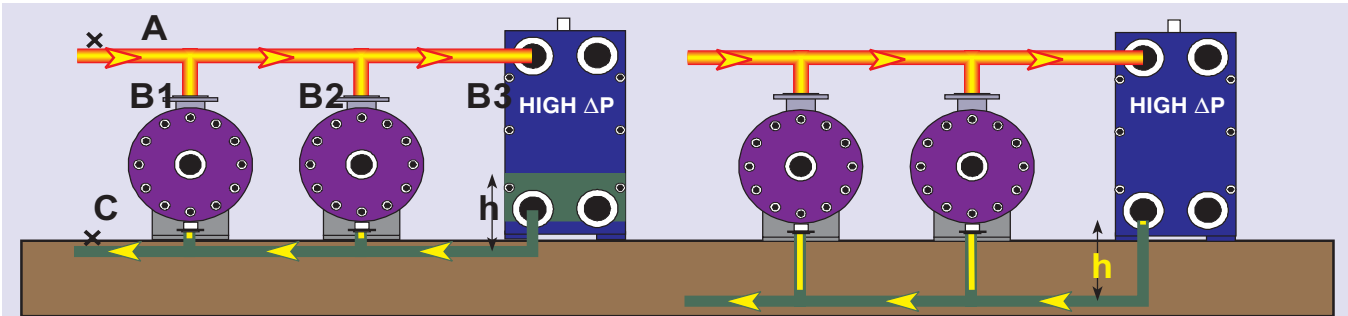
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Problem: The plate condenser didn't give the rated capacity. A substantially subcooled condensate indicated a flooded condenser.
Discussion: The system was equipped with a "surge" LR. See figure 6B. In this case, the equalization line was connected to before a

desuperheater with a fairly large ΔP and the resulting liquid column became high and flooded the condenser.
Solution: Reconnection of the equalization line to immediately before the PHE drained the condenser.
Comments: Misplaced equalization lines and poorly conceived LRs are a common source of condenser troubles.

Figure 7: A misplaced equalization line



Problem: The PHE didn't give the capacity. A substantially subcooled condensate indicated a flooded condenser.
Discussion: The ΔP is higher in the PHE than in the S&THEs. Obviously, the ΔP from point A to C have to be the same regardless if the path is A-B1(2)-C or A-B3-C. At the exit of the condensers, the pressure is lower in B3 than in B1 & B2. The condensate lines form a communicating system

with a lower pressure in one leg, B3. That causes a higher liquid column h - to form in this leg. Unfortunately in this case, the condensate pipes connect just below the exits, the higher liquid column in B3 builds up in the plate channels, floods these and the effective area is decreased.
Solution: The collector pipe was lowered and the liquid column is now created in the vertical pipe outside the PHE.

Figure 8: Parallel connected condensers

4. Vibration of an undamped discharge pressure gauge => Air in the vapour.

Oil: Stable

- The condenser seemed to be well drained to the LR. It had recently been opened, inspected and found clean. No physical obstruction was found in the adjacent pipes.
- However, a reading of the inlet water and the exit condensate temperature showed practically the same temperature.
- The cause could be either of two possibilities, a flooded condenser or air in the vapour, but it is difficult to determine which.

Problem: This ammonia condenser could operate with only one of the two compressors. Once the second started, the pressure increased and cut out the compressors.

The steps of the problem analysis are shown above.

Solution: Ammonia is easy to vent. A vent was placed on the LR and the vapour was fed into a bucket filled with ice water. If there is

air in the ammonia, it bubbles, pure ammonia doesn't bubble.

After about an hour bubbling, the pressure gauge calmed down and became steady after four more hours venting. It was then possible to operate the plant with both the compressors.

Comments: An undamped manometer is a valuable tool for inerts checks, especially with difficult to vent halocarbons.

Figure 9 : Compressor cut out

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Causes Observations	A. Air	B. Condensate blocking of condenser surface	C. Restriction in refrigeration line.*	D. Fouling or blocking of water channels	E. Too small condenser.**
1. Too high condenser pressure.	Yes, if the expansion valve lets air pass or if a finite amount accumulates	Yes	Yes **	<=	<=
2. The pressure continues to increase until the compressor HP cut-out.	For small amounts, normally not. For larger amounts yes, but it takes time (minutes) until enough condensate (air) has collected.		Yes **	Yes, but a slow process, (months, years)	Yes, rapid (< minute)
3. Discharge pressure > condenser pressure	No	<=	Yes, if before condenser	No	<=
4. The condensate exit temperature is much colder than the pure vapour saturation temperature.	Yes	<=	No	<=	<=
5. A sight glass at the exit shows both a vapour and a liquid phase.	The presence of vapour/liquid surface at the exit is no sure sign of air, it could simply be that the condenser is well drained and thus there is no large liquid level at the bottom.	No, condensates moves up into the surface but it could also be a small vapour bulk, which cannot escape.	Yes **	No, presumed a well drained condenser	<=
6. An unequal temperature distribution along the plate pack. (Possibly more marked on the water side) (Use of a thermal camera)	No, not typical	<=	Yes, if abnormal DP in the port	Yes. If many blocked channels, the water temperature will not increase here.	No.
7. Even temperature along the plate pack (refrigerant side) but a clear difference between top and bottom.	Yes, a fair temperature drop from the top to the bottom	Yes, possibly a marked change where the condensate level is.	**	If a vapour with a large superheat, the top part could be different from the bottom. This is valid for a correct PHE as well.	
8. The discharge manometer needle vibrates, §3.3 Especially useful for halocarbons	Yes	No	<=	<=	<=
9. Venting from the top of the condensate exit pipe.	Gas or vapour emerges	Liquid emerges, see also 5B.	<= **	Gas or vapour should emerge if well drained.	<=
10. Venting into a bucket with water. (For ammonia)	Bubbles emerges.	No bubbles, no air	<=	<=	<=
11A. There is a temp. diff. on the water exit pipe just after the exit. Between left and right. This indicates a maldistribution over the channel width.	Yes, especially if low pressure drops on both the sides.	No	<=	Yes, if uneven fouling over the channel width	No
11B. As 11A. Between top and bottom. This indicates a maldistribution along the plate pack.	No, not typical.	<=	Yes. If abnormal DP in the port	Yes. If water channels close to either frame plate are blocked. See 6D	No
12. Water pressure drop is too high.	No	<=	<=	Yes, If several blocked channels.	Yes
13. Vapour pressure drop is too high.	Yes, especially if the condenser is a brazed PHE with a distributor (normally used as an evaporator).	Yes, but a condensate level is the result, not the cause.	Yes	No	Yes.
14. Water exit temp. too low Note: Check flow rate.	Yes	<=	<=	<=	<=
15. Condensate blocking part of the surface (This can be both a cause and a result)	No, normally not	See Fig. 6 A-C	Yes, together with a faulty EQ line, Fig. 6A-C	Blocked channels create an internal EQ line on the vapour side, Fig. 6.	No
17. Vapour emerges undensated	Yes	No	No	Yes, but initially should be OK	Yes, from start

* Anywhere between the compressor and the expansion valve.

** A restriction can cause a condensate back-up, which then can have various effects, see column B.

*** Either because of incorrect physical properties, design errors, an incorrect duty specification, too high water temperature, etc.

Figure 10 : A troubleshooting matrix for refrigeration condensers, mainly valid for PHEs