

Effect of Subcooling with Different Refrigerants

In the previous column, we discussed which hydrocarbons can be used as refrigerants. In that context, we showed the effect of using an **internal heat exchanger** between the liquid line and suction line for various refrigerants. The improvement in COP was between **2% and 5%** with **5 K** of liquid subcooling. After publication, I was asked how large the improvement would be with greater subcooling.

In this column, we will examine this question in more detail, and not limit the discussion to hydrocarbons. In general, the improvement (in percentage increase of COP) **per degree of subcooling** is roughly the same regardless of whether the subcooling is small or large—although the **effect per degree decreases slightly** as subcooling increases.

In our refrigeration engineering textbook, which has existed in various updated forms for the last 50 years, so-called **y-factors** are tabulated for several refrigerants. These factors allow one to calculate how subcooling, superheating, and internal heat exchange affect the cooling/heating capacity and the cooling/heating COP.

The principles used here are the same as in the textbook, but space allows only a few examples. We must distinguish between two different cases:

1. **Subcooling using an external heat sink,**
2. **Subcooling created via an internal heat exchanger (IHx).**

1. External Subcooling After the Condenser

Subcooling the refrigerant after the condenser increases the **enthalpy change in the condenser** (q_1 , the heating capacity). At the same time, the **enthalpy change in the evaporator** (q_2 , the cooling capacity) also increases.

If subcooling is created “externally,” e.g., by thermal contact with the surroundings, the **compressor work** (ϵ) does not change (ideally). Thus, both the **heating COP** ($\text{COP}_1 = q_1/\epsilon$) and the **cooling COP** ($\text{COP}_2 = q_2/\epsilon$) increase.

The magnitude of the improvement depends on the amount of subcooling (in kelvin) and the type of refrigerant. Naturally, gaining a higher heating COP requires that the additional subcooling heat can actually be utilized for heating.

2. Subcooling via an Internal Heat Exchanger

Subcooling can also be achieved by heat exchange between the **liquid line** and the **suction line** through an internal heat exchanger. In this case, the suction gas temperature increases at the compressor inlet, which always increases **compressor work**. Thus, internal heat exchange produces **two opposing effects** on COP:

- Both q_1 (condenser capacity) and q_2 (evaporator capacity) increase.
- But **compressor work ϵ also increases.**

Whether the ratios q_1/ϵ and q_2/ϵ increase or decrease depends entirely on the refrigerant. For some refrigerants, an IHX is beneficial; for others, it is not.

A further consequence of using an IHX is that the **discharge gas temperature increases**, which becomes limiting for certain refrigerants.

Example Calculation: 50°C Condensing and 0°C Evaporating

To illustrate the effects of subcooling and internal heat exchange, we calculate an idealized case with:

- **Condensing temperature: 50 °C**
- **Evaporating temperature: 0 °C**
- **Isentropic compressor efficiency: 100%**

For this idealized cycle, the diagrams below show results for **0–20 K** of subcooling, both with external subcooling and internal heat exchange. We compare six commonly used refrigerants: **R32, R134a, R410A, propane (R290), isobutane (R600a), and ammonia (NH₃).**

Results

Figure 1 – COP with External Subcooling

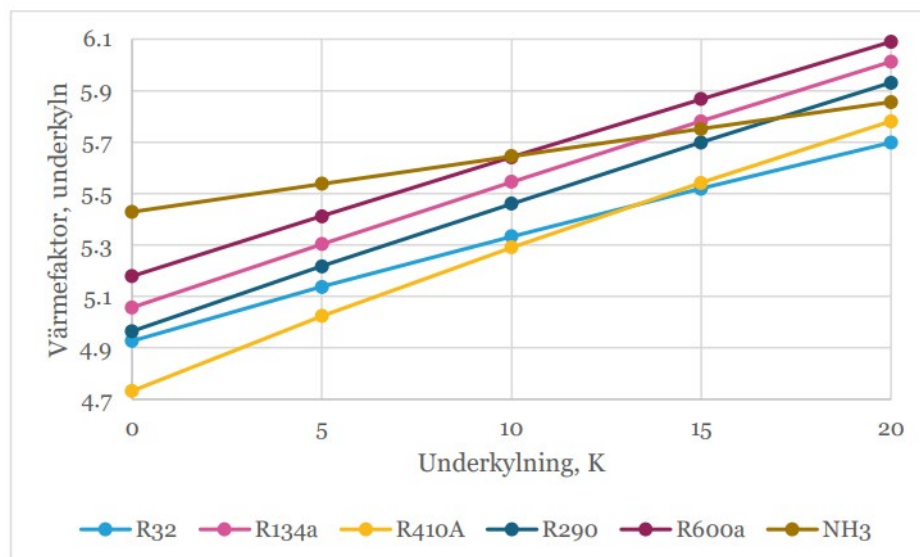


Figure 1. Heating COP as a function of external subcooling at 0 °C evaporation, 50 °C condensation, and isentropic compression.

Figure 1 shows that the heating COP increases clearly for all refrigerants with increasing subcooling. The slope of the curves differs slightly; **NH₃** and **R32** benefit somewhat less from subcooling compared with the others.

Figure 2 – COP with Internal Heat Exchange (IHX)

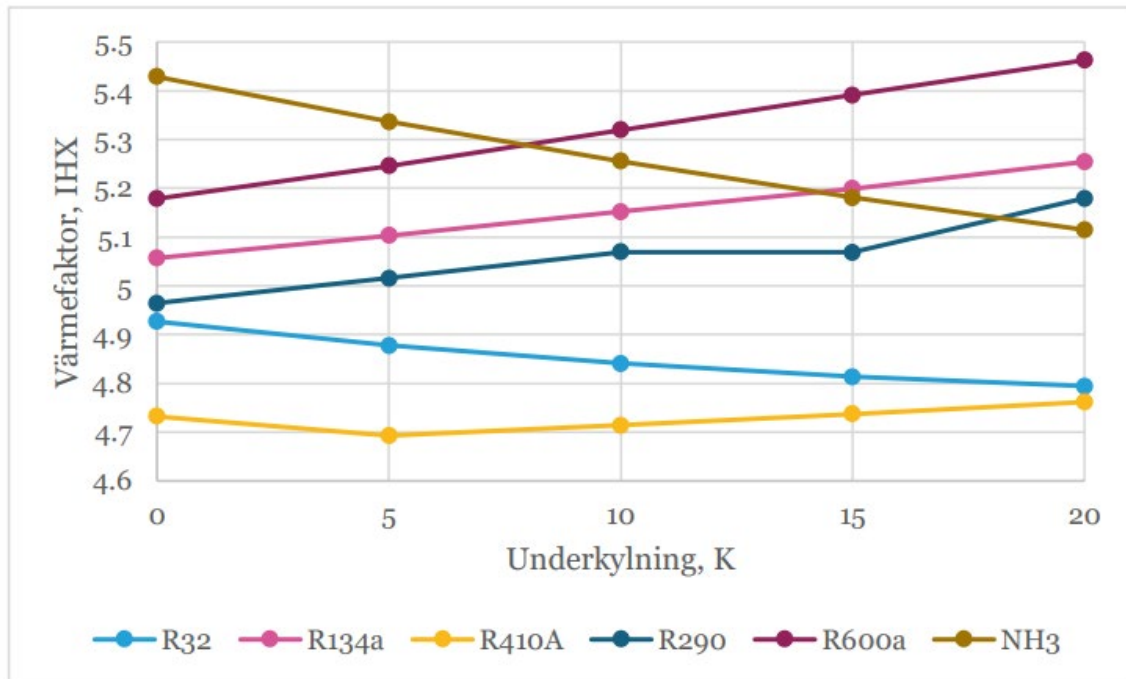


Figure 2. Heating COP as a function of subcooling with an internal heat exchanger between liquid and suction lines, at 0 °C evaporation and 50 °C condensation.

Figure 2 shows the COP when subcooling is achieved via an internal heat exchanger. It is clear that **NH₃** and **R32** deviate significantly from the other refrigerants, showing a **decreasing COP** with increasing subcooling under IHX conditions.

As usual, the cooling COP is exactly **one unit lower** than the heating COP; thus, the cooling-COP curves would have the same shape, but shifted downward.

Figure 3 – Discharge Gas Temperature

Figure 3 shows the discharge gas temperature (assuming isentropic compression). There are already large differences between refrigerants **even without subcooling**, but the differences increase further with greater subcooling. Again, **NH₃** and **R32** stand out, resulting in **higher discharge temperatures** than the other refrigerants.

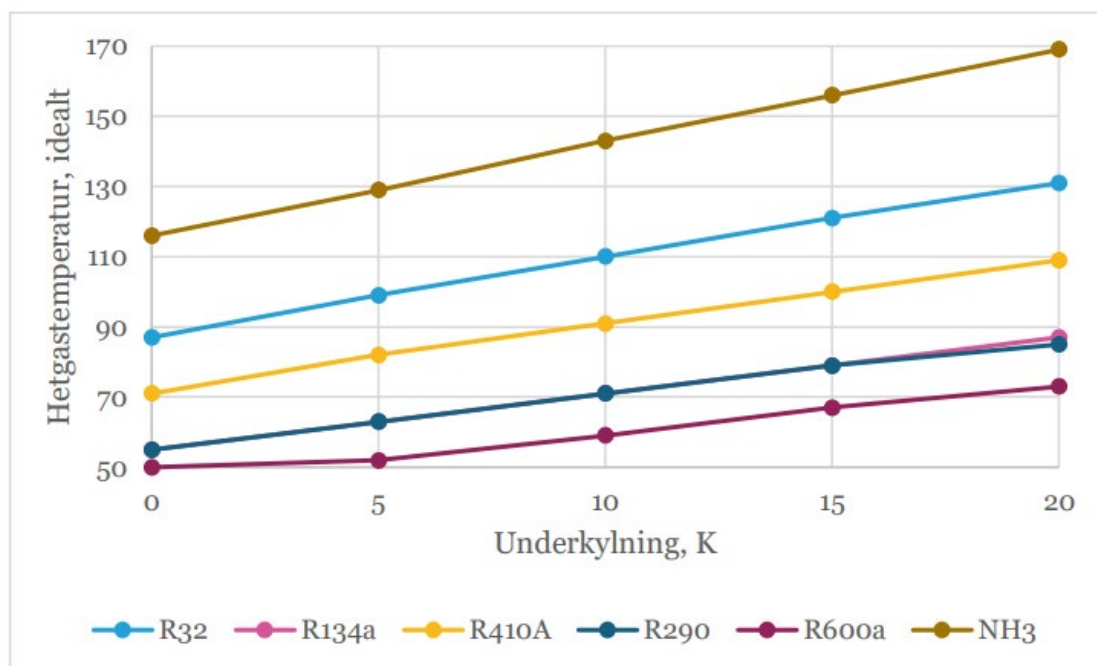


Figure 3. Discharge gas temperature as a function of subcooling, with internal heat exchange, at 0 °C evaporation and 50 °C condensation under isentropic compression.

Summary

Three of the six refrigerants—**R290, R600a, and R134a**—show clear benefits from subcooling and/or internal heat exchange. These three also maintain **moderate discharge temperatures**, which is advantageous.