ENGINEERING
TOMORROW

White Paper

Highly Efficient Heat Reclaim with CO_2

Introduction

Refrigeration systems with transcritical CO_2 have been taking market shares during recent years. Since 2007 the market in Denmark has turned from conventional refrigeration systems with HFC or cascade systems with CO_2 and HFC towards transcritical CO_2 systems. Today, transcritical systems are everyday business and the technology is mature.

The field studies carried out looking at refrigeration only shows that the annual energy consumption is on the same level, or better, as HFC DX systems. The article contains a short back ground on the theory behind heat reclaim in transcritical systems, and the efficiency will be compared with the efficiency of HFC systems.

Transcritical systems back ground

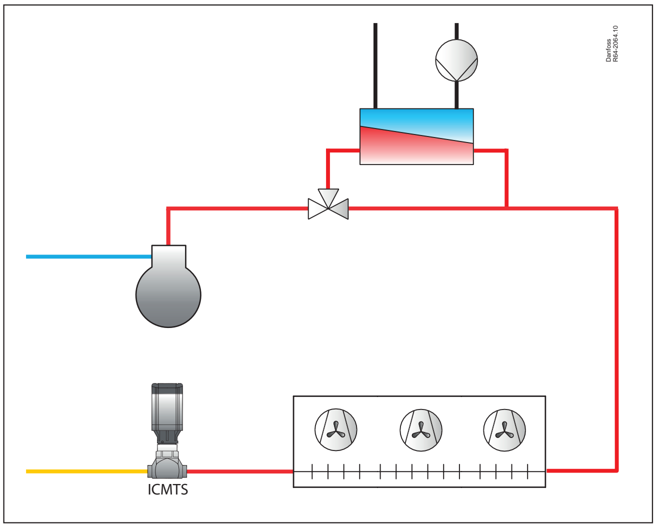
In normal systems with HFC refrigerants the pressure and temperature are tied together, but on transcritical systems pressure and temperature can be controlled individually. This gives some possibilities regarding heat reclaim.

During normal operation without heat reclaim the high pressure is kept at a level where the optimum COP is obtained. This is done automatically by the electronic controller. During cold periods the pressure is normally kept at minimum 40 bar ~ 5 °C or higher. At this pressure there is almost no heat to reclaim. If the pressure is raised the amount of heat that can be reclaimed is increasing.

Example

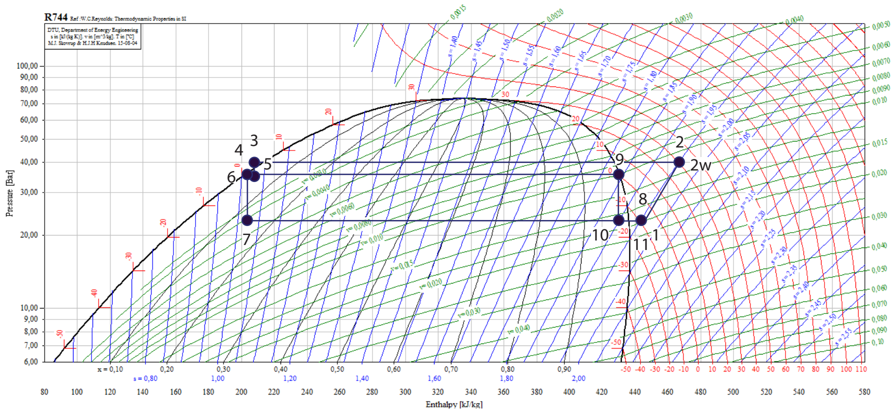
Water is heated from 15 °C to 55 °C. The ambient temperature is -5 °C and the heat load on the system needs to be reclaimed with the lowest possible energy consumption. The temperature difference of the heat reclaim HX is set to 5 K. The temperature out of the gas cooler is kept at 4 °C in all cases where the gas cooler is active.

The system used consists of one or more compressors, heat reclaim heat exchanger with pump, 2 3-way valves, air cooled gas cooler and a high pressure control valve with electronic controller.



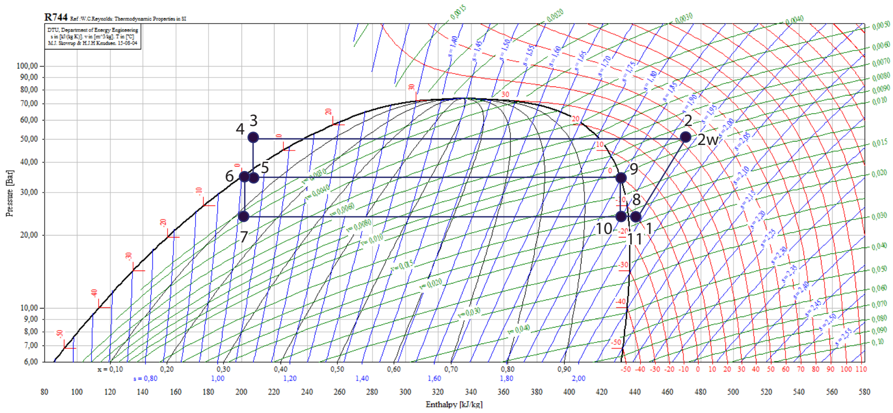
Under these conditions the discharge temperature from the compressors is approx 35 °C and therefore it is not possible to make 55 °C hot water.

To make the system able to reach 55 °C the discharge needs to be at least 55 °C and therefore the pressure needs to be pushed upwards.



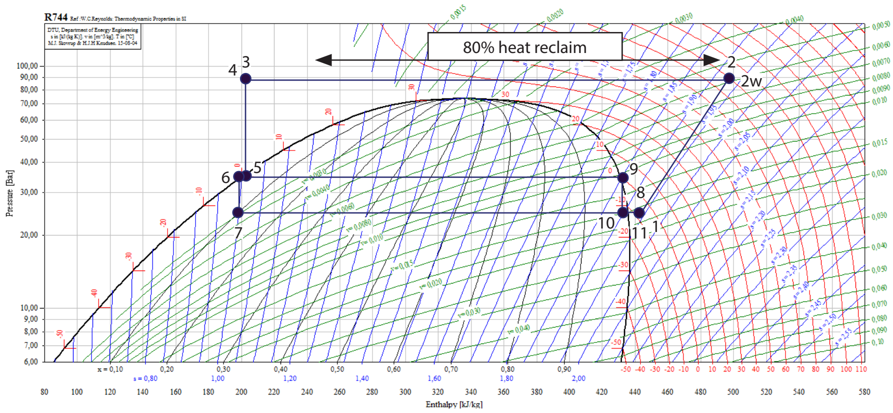
At 50 bar high pressure the discharge temperature is 55 °C and therefore it is possible to start reclaiming heat from the system but there is no temperature difference of the heat exchanger.

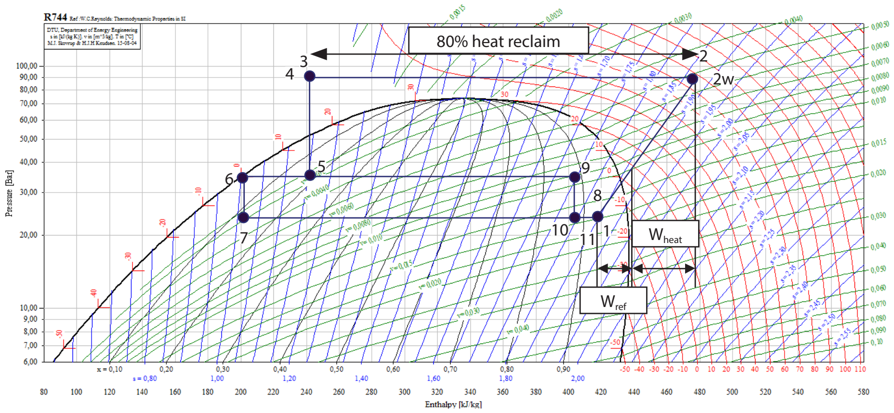
By increasing the pressure further the amount of heat taken out of the system is increasing.



At 80 bar approx 80 % of the heat is reclaimed at a cooling COP of 3.13. To increase the ratio to more than 80 % the pressure can be pushed up and the gas cooler can be by-passed.

By doing this the ratio will go to 100 % because there is no heat lost to the ambient, but all heat is reclaimed. This will put in more compressors to compensate for the lower compressor performence at high discharge pressure.





Under these conditions all heat is reclaimed and the COP of the system is approx 2.6.

Since the heat output from the system varies with the pressure it is interesting to look at what the heating COP of the system is. The system consumes energy in the conditions that it is running with optimised pressure (in this example 40 bar). This means that no mater how much heat we pull out of the system it will consume energy. Therefore the heating COP of the system is calculated as the heating capacity divided by the extra energy consumed by the compressors. This is done because then it is possible to compare the heating COP with alternative heating sources.

P_gc [bar]	COP ref [-]	Ratio	COP Heat [-]
40	8.8	0 %	–
50	5.7	0 %	–
60	4.3	25 %	2.6
70	3.6	40 %	3.1
80	3.1	80 %	5.1
80	3.1	100 %*	5.1

**By-pass of air cooled gas cooler*

The ratio is the ratio between the maximum heat available and the heat used. The heating COP is varying with the ambient temperature. At high ambient temperatures the compressor load used for refrigeration is higher and therefore the compressor load for heating is less. At lower ambient temperatures the pressure can not be decreased, and therefore this will not effect the heating COP. If the ambient temperature was chosen to be 3 °C instead of -5 °C then the result will be as shown in the table.

P_gc [bar]	COP ref [-]	Ratio	COP Heat [-]
50	5.7	0 %	–
60	4.3	25 %	5.6
70	3.6	40 %	5.0
80	3.1	80 %	7.3
80	3.1	100 %*	7.3

**By-pass of air cooled gas cooler*

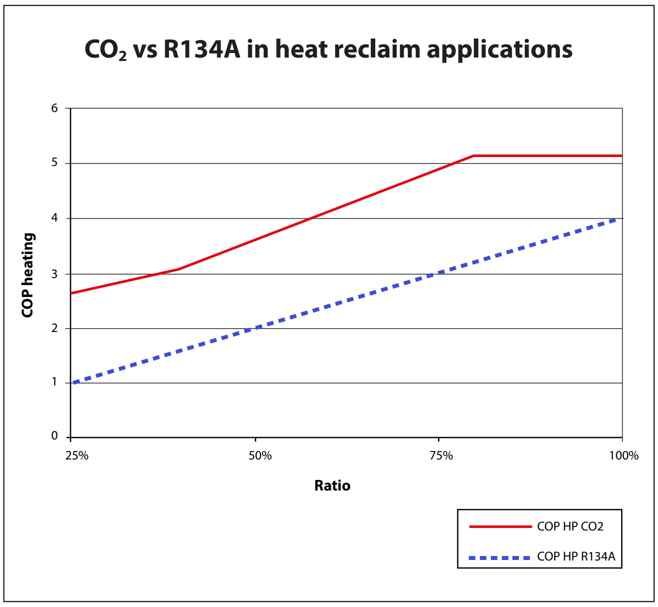
The results show that the ambient temperature has a significant impact on the heating COP and the heating COP is highest at full load. If the high COP is desired at part load the system can be build as a CO_2 heat pump on top of the refrigeration system.

Comparing CO_2 transcritical with other heat sources

In the section above the heating COP is calculated, but the interesting part is if it is cheaper or more expensive compared to other heat reclaim systems and other energy sources.

Other heat reclaim systems

To be able to compare the COP from CO_2 to the COP of other refrigerants it has to be done in a fair way. For the other refrigerants it is chosen to run at -10 °C evaporation and to condense at 55 °C to be able to supply 55 °C hot water. Sub cooling is set to 2K. The minimum condensing temperature is set to 15 °C.



From the chart above it can be seen that the heating COP for CO_2 is from approx 25 % to 150 % better that R134A and best at part load which is the main part of the year.

Heat pump systems

To get around the problem with part load a heat pump can be put on top of the system. This makes the COP of the system as good as possible regardless of the load on the system.

The COP in heating mode has been calculated at 5 °C evaporating (equivalent to the lowest possible condensing for the transcritical CO_2 system), 55 °C condensing and 2 K sub cooling. The calculation has been done for most of the commonly used refrigerants on the market.

Refrigerant	COP heating
R134A	3.7
R290	3.7
R404A	3.3
R410A	3.4
CO_2 transcritical heat pump	5.1

The table shows the COP for different refrigerants. From the data it shows that CO_2 has a COP that is from 38 % to 55 % higher that the conventional refrigerants.

Other energy sources

An alternative to a CO_2 heat reclaim system could be an oil or gas burner. The question is what is the most economical choice? The COP calculated in this example for a CO_2 heat reclaim system is between 2.6 and 7.3. The exact COP is a question of what type of systems it is (Heat pump or heat reclaim), the load profile for the heat reclaim and the ambient temperature. This can be matched with other energy sources with the following equation.

$$\text{Ratio} = \frac{\textbf{Price Electricity}\left[{}^{€}/_{kWhr}\right]}{\dfrac{\textbf{Price Alternative Energy}\left[{}^{€}/_{kWhr}\right]}{\textbf{COP}_{Heat}}}$$

If this ratio is smaller than 1 then the CO_2 solution is not the most economical solution. In most cases a heat reclaim or heat pump solution is economically attractive. In many cases a heat reclaim solution is attractive if the COP is higher that 2 or 3, but this of course depends of the energy prices and local taxes.

Conclusion

The example above shows :

- Heating COP in a transcritical heat reclaim system from 2.6 to 7.3 depending on load and ambient temperature.
- CO_2 is from 25 % to 150 % better than R134A in a heat reclaim system depending on the load.
- In a heat pump system CO_2 is from 38 % to 55 % better than the HFC refrigerants compared with.
- The COP in a heat pump system is higher than a heat reclaim system at part load, but at full load the difference is very little. If it is feasible to install a heat pump system depends on the load profile and the investment costs.
- Very often CO_2 heat pumps or heat reclaim systems are a very attractive alternative to a oil or gas burner

The conclusion is made on the data in the example. If the data are different the conclusion will be different, but there are some guide lines.

- CO_2 is feasible at high temperature lifts. The lower temperature the inlet water or media the better efficiency CO_2 will have. The exit temperature is not that important. Up to 80 °C is realistic with good efficiency
- CO_2 is not the refrigerant to chose if the outlet media temperature is low and the temperature difference between inlet and outlet is low.

There are thousands of CO_2 instalations globally. However, today the uptake of transcritical CO_2 has by far had the largest share on the European continent in distributed refrigeration systems. It is now common that installations are done with heat reclaim as it has proven beneficial to reclaim the heat, even in the hotter climates.