Flooded versus dry evaporation

Introduction

Qplan, specialist for environmentally sound solution in refrigeration, celebrated big step forward to become playing important role as equipment manufacturer in renewing international refrigeration business by supply of novel transcritical CO2 flooded gravitation pack construction to the new Tesco 3k store in Ivancice near to Brno, the Czech Republic.

While some admired the great works and respected the new facility as good track record of Qplan, others might take the opportunity to prevail the discussion perhaps claiming the solution that it can not make sense and point out design as simple "overengineering". The subject of our study for seeking an answer we can share their view or simple that makes it bitter that someone do not hold the key for the technology.

The use of CO2 in commercial refrigeration created a conflict *in* design, *whose issue* is *quite omitted*. This is based *on* behaviour of CO2 *which* is *rather* closer to ammonia, but the technology used complies in most of the cases with the commercial refrigeration and, as a consequence, significant advantages of CO2 disappear.
Technically, *the* conflict means most commercial refrigeration systems use dry evaporation against flooded one. Flooded evaporation in CO2 systems, however, offers significant advantages for the *operators, investors and owners*. Therefore, we *are going to* deal here with the comparison of the two type of system and the description of further benefits.

Preceding the arguments and no matter what solution we are obsessed we can agree that increasing evaporation temperature in running refrigeration system an imperative demand for increasing efficiency.

Main

Our *studies* are based on the comparison of the thermodynamic process of evaporation, on the evaluation of factory data of the compressors and for the last but not least on the practical experiences we have gained from the existing plants.
We considered the
- energy efficiency,
- the reliability,
- the *necessity* for maintenance and *repairs*,

- the cost of investment.

What we have not performed is an analysis of life cycle. It requires *deeper*, time-consuming and costly information.

On the whole, we *are* also very sparse with numeric data because they can lead to *endless* discussion if comparing two systems not already precise*ly* defined.

Energy efficiency

The operation of DX evaporators are limited by the so called MSS curve. [1]The curve defines the relationship between the lowest permissible superheat and the evaporator load as Fig 1 shows. The shape of the MSS curve is dependent on the load conditions and the construction of the evaporator. Experiences show that superheat cannot be less than about 6K at maximal load.

As the air outlet temperature always exceed the superheat temperature, the authoritative difference *DT1* (difference between air outlet and evaporation temperature) cannot be less than about 7K. Ignoring this leads to the most damage of compressors *due to fact that instability occur in injection control below the lowest permissible superheat values.*

Namely, the minimum also means that it is impossible to decrease the DT1 (or increase evaporating temperature) by enhancement of heat transfer coefficient or increasing of evaporator surface.

This *problem* can *only* be avoided by complicated technical systems solutions, but the result of such systems as a whole*, is* used to be very thin *or* even negative.

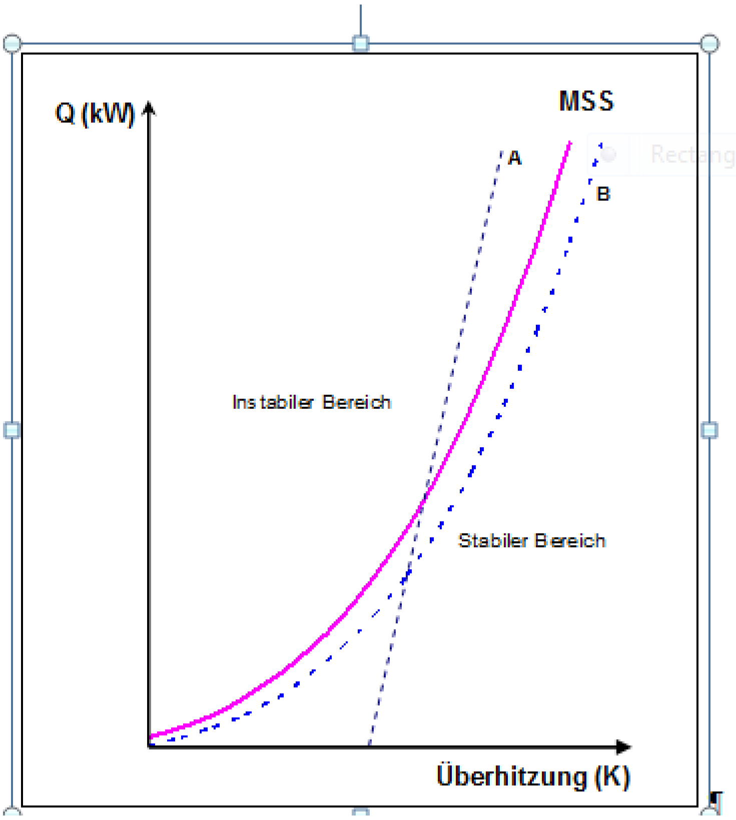

Fig 1

At flooded evaporation, the liquid enters into the evaporator on evaporating pressure and returns into the liquid separator as a two-phase mixture *("wet evaporation")* and so *the DT1 is* not subject *to* the limitations of dry evaporation. The achievable *DT1* depends only on the heat transfer and the

surface and it is only a matter of cost/benefit analyse.
Flooded evaporation also shows a higher heat transfer as seen from Fig 2.
Fig 2 presents the heat transfer of an evaporator from Co. Güntner for different refrigerants and both for dry and flooded operation as a function of pressure drop, which represents the load *in implicit mode*.

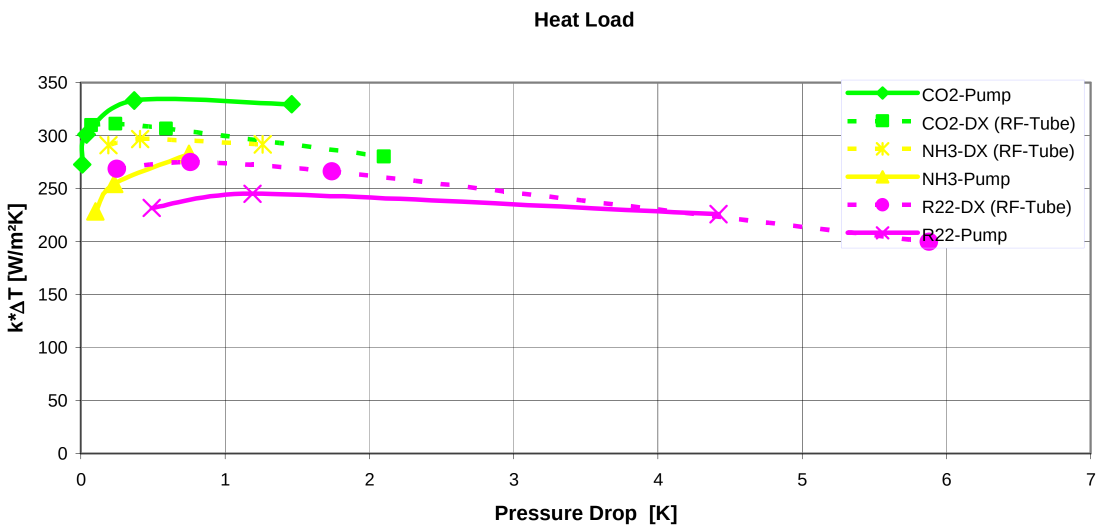

Fig. 2

As shown, the improvement of flooded evaporation at CO2 moves about 10-12% which can be equivalent of 0,6 – 0,8K in decreasing in D*T1* or increasing in evaporation temperature. This improvement can also be higher if the evaporator is constructed directly to flooded system or/and by applying forced (pump) recirculation.
The refrigeration plants for supermarkets, planned and installed by Qplan Ltd. were designed as flooded system but for display cabinets which was originally dimensioned with dry evaporation for an evaporation temperature of -7°C. During the operation we gentle increased stepwise the evaporation temperature and found that the sustainable evaporating temperature laid about -4°C, even higher at significant partial load.
The reasons *are*, *they* made *it* possible were:
- better heat transfer of flooded evaporation,
- utilizing the part of heat transfer surfaces, which originally was intended as *superheating zone*,
- the decreasing of D*T1* at partial loads.

Reduction the cost of investments

Needs smaller compressors

Dry systems are usually designed with a total superheat at compressor inlets about 15K. This experiential value is necessary for protecting compressors against wet operation and to provide a reliable oil return. Although it can slightly improve the COP,-only *in transcritical operation*, its most negative effect is the increasing of the specific volume which requires higher capacity of compressors.
Flooded system runs practically with 0K superheat *therefore* needs smaller compressors.
Table 1 shows the efficiency and the necessary volume of two systems of equal refrigeration

capacity, one with dry and one with flooded evaporation.
Evaporating temperature is -5°C.
The useful superheat is 6K and the total superheat is 15K

	Dry	Flooded	Change
COP	1,87	1,86	-0,1%
Less volume of compressor(s)	0,0123m³/s	0,0120m³/s	2,5%

Table 1

Table 2 shows values of efficiencies and volumes when DX system runs with the usual -7°C , while the flooded system with -4°C evaporating temperature, according to Qplan's own measurements.

	Dry	Flooded	Change
Evaporating Temperature	-7°C	-4°C	
COP	1,77	1,91	+7,9%
Less volume of compressor	0,0131m³/s	0,0116m³/s	12,9%

Table 2

For both tables was the calculated gas cooler outlet temperature 41°C.

At flooded system exists the possibility of continuously optimizing the evaporating temperature. Although at Qplan`s systems we did it manually; as we increased the suction pressure while observing if there was enough refrigeration capacity, we *didn't* see any obstacle of applying automatic control.
An additional note to whom they are not assured yet calculations *can be easily controlled* by the public software "SimpelOneStage CO2 Cycle".

Expansion valves cancelled

There are no expansion valves and their controls *required* but cheaper solenoid valves and controllers *are applicable*.

Cost increasing facts

- The size of liquid receiver is usually larger than of the intermediate receiver at dry systems
- Applying of electronic level control *on liquid separator (for emergency level). This belongs to Qplan's safety management, while designers of Lorentzen systems used to take the risk and omit it on the intermediate receiver.*
- At forced recirculation systems the cost of pumps and energy consumption. *However,* this surplus compensated by the better efficiency *whenever it is required. What so more, Qplan owns state-of-the-art solution where pump and the electrical consumption incurred can be replaced by gravity-fed-circulation.*
- Need for devices for oil return from liquid.

Reliability

No expansion valves

It is well known that a significant part of mechanical troubles can lead back to the malfunction of expansion valves. A slightly dirt under the seat of a valve can cause liquid leak against the suction side threating compressors.

Not proper setting the parameter of valves causes hunting of the systems with loss of efficiency as a consequence.

Beside the advantage of favourable so called "adaptive cooling" (continuous modulated control of EEV) in modern DX system, a drawback to this practice is the excess superheating on small loads (small valve opening) due to the ineffective surface of evaporator which leads to decline on COP because the compressor suction inlet temperature increased.

Higher resilience

The higher volume of the liquid separator and the ongoing interoperability to evaporators slows down the pressure increase in case of standby or break down.

The question may arise; if flooded system is better the dry why not expands it to a greater extent?

- **As told before** most of systems for supermarkets are built by companies who do not hold the knowledge to the system design and are not committed to acquire new technologies.
- **Fear of new.** Self CO2 technology is new and nobody wish to combine it with extra news.
- **Myths:**
  - Flooded systems are more complicated! – Wrong, it is more simply (no expansion valve) but *design* needs *more complex* knowledge.
  - Oil return from liquid is problematic! - Wrong, the mixture *is* drained continuously and after separation by inner heat exchange *is* fed to the suction manifold of compressors. The technology is well known and well-proven at ammonia systems.
  - needs more charge. Considered, Lorentzen system has an intermediate receiver with charge, the difference is not significant. Nevertheless, the magnitude of charge is not a big issue at CO2 systems. *The* charge is much less expensive than it used to be at HFC systems.

Qplan Ltd. has in the last 6 years provided 87.000m² supermarkets – not only in Hungary- with flooded CO2 plants with a built-in refrigeration capacity of 4,2 MW. Although the plants were originally designed as pump recirculation systems, we switched some of them to gravity fed and since they work very well. All plant runs according to the design assumptions or better, without any major troubles.

Literature:

[1] Huelle, Z.R.: Heat load influences upon evaporator parameters. Report No. 3.32 at the XII International Refrigeration Congress in Madrid.

Software: SimpelOneStage; Morten Juel Skovrup, IPU Denmark Refrigeration and Energy Engineering
www.ipu.dk