12th IEA Heat Pump Conference 2017

Rethink Energy in Industrial Heat Pumps NOW!!

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Abstract

Industrial heat pumps can often have a totally different business case than you see for domestic type heat pumps. Industrial heat pumps are often used in production of food and beverage, which utilises both the cooling and the heating capacity of the heat pump. This increases the efficiency because the absorbed power in the compressor does not increase but the energy generated on both sides of the heat pump is used in the process either at the same time or it can be buffered for later use. Now that the technology and the possibilities have been understood and the business case looks good, the demand from the market for higher temperatures and bigger heat pumps turn back on the manufacturers. Here the challenge has been taken up. The race for producing compressors for higher pressures, first for CO_2, but now also for NH_3 and other refrigerants are surfacing in the market.

Also new refrigerants with properties that offer possibilities not seen before keeps pushing up the boundaries. Some of the low GWP refrigerants enables manufacturers to go as high as 160°C. However, with water with a critical temperature of 373°C allows even higher condensing temperatures. Future will show where it all ends, but we already know now that the temperatures in industrial heat pumps will be much higher than in the smaller domestic heat pumps we know today, mainly because the heat source is different and the business case allows it. Why will we do it? Because we can and because we have to de-carbonise the industry.

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Selection and/or peer-review under responsibility of the organizers of the 12th IEA Heat Pump Conference 2017.

Keywords: Industrial heat pumps, Heat reovery, Process energy

In this paper we will look at the currently used technologies and how they are being used. Can they be pushed further up and enable use in other applications or do we change technology? The heat pumps are also used in the district heating and cooling systems and in smaller local heating and cooling network. Different approaches are used to optimise the efficiency and user friendliness to get the highest efficiency in the everyday usability.

1. Introduction

The business case for domestic heat pump is very different from a heat pump used in industrial processes where it can have big financial consequences if the heat pump does not work when needed. On the other hand there is also a lot of money to gained by using heat pumps in industrial systems compared to domestic heat pumps.

Most domestic heat pumps are using either the ambient air or the ground water as heat source. In some cases you can connect your heat pump to some river water or sea water, but all domestic heat pumps have one thing in common: The cooling capacity is rarely used for something, basically is just a heat source. In the industrial systems you can use both the cold side and the heating capacity but in some cases not at the same time. This will require a buffer capacity. In dairies this is not a problem because they already have many and large tanks for handling the milk.

The sympatic thing about the domestic customer is that the financial patience is longer. Industrial customers require a simple payback in the matter of 2 to 3 years. Some companies are more patient and allow for pay back times of 5 years under specific circumstances. Marketing also plays a role here.

Many domestic heat pumps warm up the water to about 55°C to 60°C. Industrial heat pumps are currently delivering warm water at 80°C to 90°C. Quite some research projects are looking temperatures over 100°C up to 200°C. From litterature and conference abstracts we can find suggestions for different solutions as shown in Table 1. So where is it all going?

Table 1 Summary of abstracts for the 12th Annual IEA Heat Pump Conference in Rotterdam, 2017

Refrigerant	HP temperature range °C	HP source temperature range °C	Comment
R717	60°C to 92°C	-10°C to 40°C	COP=3.5@10/80°C
R718	60°C to 200°C	7°C to 120°C	Steam production
R600	50°C to 140°C	20°C to 80°C	Steam production
R245fa	70°C to 120°C	20°C to 70°C	COP=5.18@70/120°C
R365mfc	160°C	80°C	COP=1,5+
R1234yf			
R1336mzz(Z)	130°C to 150°C	90°C	COP=5=>2.85
R1233zd(E)	200°C		COP=3.5
R1234ze(E)	120°C	60°C	
R1234ze(Z)			
CO_2-NH_3-H_2O			

Looking at the submitted abstracts for the 12th Annual IEA Heat Pump Conference in Rotterdam in 2017 we can create the above table. You will notice that only one blend is included in the research projects presented at this conference. There is also a quite spread range in temperatures. One cannot avoid noticing the COP values presented and this will be discussed in the following.

Mechanical Vapor Recompression (MVR) is very much of a topic when it comes to heat recovery. This technology is very promissing and at first sight quite simple, but with development and optimisation it can become as advanced as any other cycle. The trick is the efficiency and the operational life time of the equipment used for the process. Even small droplets will erode the surcase of the impellers, if you use a turbo compressor to do the compression. The key to success will be efficiency over the current boiler technology.

2. Energy Efficiency

After the discussions about the global warming and the global warming potential (GWP) of the refrigerants have come to a state where it has globally been agreed to reduce the concumption and thereby also the emmissions of CO_2 eqvivaltents of the emitted refrigerants, we start to get some clarity of the future refrigerants. When we look at the full list of blends with more than 80 blends, it is very difficult to see a way through. At the latest edition of

Chillventa, I collected information from the various refrigerant manufacturers and tried to make a list of what options there are in the field. It is quite a long list with very many blends and pure gases.

Traditional	**Low GWP alt.**	**GWP 150-299**	**GWP 300- 400**	**GWP 400 - 999**
R-22	R-457A		R-444B	Solstice N20
	R-454C			
R-404A	R-457A	R-454A		
	R-454C			
	R-455A			
R134a	R-1234yf			R-456A
	R-1234ze(E)			R-450A
	ARM-42			R-513A
	R1233zd(E)			R-513B
R410				R-32
				R-452B
				R-459A
				R-454B

Table 2 Alternatives organised by their GWP. R1233zd is more for high temperaratures e.g. for high temperature heat pumps. To this list can be added the list of natural refrigerant.

Refrigerants are just one part of the whole system and the energy efficiency does not comre from the refrigerant alone. Also the definition of efficiency has many facets. By this is ment efficiency compared to what and under which economic conditions.

We often compare heat pumps with other solutions and we are comparing technologies. It is all a technical subject and it can seem obvious when we propose a heat pump. What we sometimes forget is the relationship price wise between electricity and the alternative fuels. We also forget that a boiler costs much less than the large industrial heat pumps. In some countries a COP of 1.5 may be attractive but in many others it will not be of much interest. So what is the compelling argument that can sell our solutions? In Denmark electricity is about 3 times more expensive than gas or oil. It is a political fixed relationship. If you go to asia and do the same comparison you will see 10 times more expensive electricity. Also stability of the electric grid can be an issue in some part of the world. For some productions one minute of cut off electricity can equal €150.000 or more in product losses.

At a meeting in Copenhagen I was asked if we could produce heat pumps at 500 to 600°C because 180°C was something and nothing. The working conditions were not discussed, but 500 to 600°C seems a little over the limits with the current technologies. However, the market sizes we are now looking at are more than big enough for all participants as it is and concentration on these markets is financially more attractive and efficient than the very high temperatures in a distant future. The nessesity of R&D in future solutions are well understood but in order to get more attention, it is very important to have the arguments in place for each application with a well prepared business case showing the advantages over the alternative including financial arguments, environmental arguments and technical arguments. What added value does the proposed heat pump offer the customer. At Chillventa 2016 we saw a two stage heat pump compressor exhibited. Not very many noticed the compressor and the comparisons, perhaps they also did not understand the purpose of the two stage compressor. This type of compound compressors are normally for low temperature applications. Communication efficiency is in demand.

Very few manufacturers are ready with compressors for water as refrigerant. It has therefore also been quite a challenge to get through the development process which has been going on for more than 15 years since the first launch of a water vapor compression systems presented in the midt 1990's. The first system was running very well for aproximately 10 years but was damaged during a thunderstorm that damaged some inverters and resulted in compressor damages which were to expensive to repair.

The owner was prepared for a second trial when we asked and has invested in a new machine room for the new unit.

The compressor is an axial compressor and a cooling capacity about 850 kW@9°C water out and 16°C water in on the cold side and about 30°C condensing temperature. The same compressor for a district heating system, with some strenghtning modifications will be able to deliver about 20MW under the right working conditions. This is a big change in capacity but also in motor power which puts higher loads on the bearings. The compressor is lubricated with water which is a challenge, also when we consider the softened water.

The number of revolutions per minute is 14500. The speed on the tip is over the sound of speed and causes no problems. What can cause problems is if droplets hit the surface of the impleller and therefore big efforts have been made to design a system that does not create unwanted pressure drops while avoiding water droplets not beeing separated.

As water is evaporated, you accumulated impurities and calcium in the evaporator but in some cases it can also reach the compressor causing serious damages to the impeller. These impurieties must be flushed out from time to time without breaking the vacuum. If we go to a heat pump at temperatures over 100°C the negative temperatures will no longer be a problem. Avoiding flashing in the bearings and for the heat pumps boiling is a task to be taken seriously to avoid break down.



Figure 1 A two stage semihermetic heat pump compressor

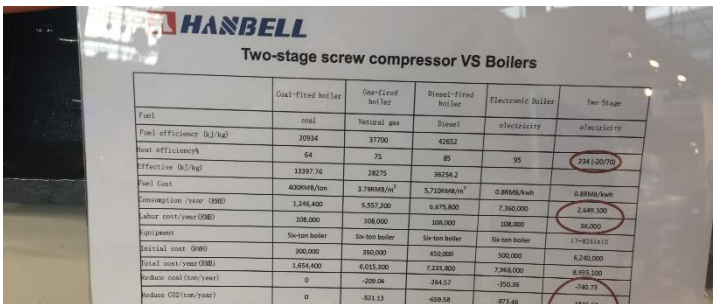


Figure 3 Comparing a two stage screw compressor with a boilner





The trend in district heating is going towards lower temperatures in order to reduce the transmission losses, which lower the requirement for high pressure compressors for this market segment. For years the Danish district heating suppliers have been garanteeing a supply temperature of 70°C but now they are considering to lower it to 60°C. This is high enough to kill legionella.

So where is it we see the market for high temperature heat pumps? It is for process heating where the main competition comes from boilers. The possibility using waste heat from the process, compressed air and exhaust air from process and air conditioning can give very high COP's and reduce the simple payback time to less than 2 years. 2 year simple payback time is often a barrier for getting the order. Some companies allow 3 years simple pay back time for immidiate investment and then have 5 years simple pay back time for special projects where also other considerations come in to play especially when they benefit the final product and production.

3. Charge

From a safety side the charge is very much in the picture. Especially flammable and toxic refrigerants can be regulated locally. The charge can be a barrier for the wider use of e.g. ammonia heat pumps if the charge is high in the city center. However, with a limited charge and an effictive scrubber system in place it is often possible to install system with quite high capacities. Figure 2 shows the development from a 1995 low charge chiller to the 2004 chiller with the similar capacity. At the same time the footprint and the heat exchanger technology has changed allowing the lower refrigerant charge.

Other refrigerants such as propane have the flammability issue and the lower the charge is the better. Here heat exchangers with small channels can help reducing the charge. In the chillers you can reduce the charge by about 30% by changing from tube&fin to microchannel technology. As a side benefit of the small channels used with CO2 systems, this can also be used with flammable refrigerants.

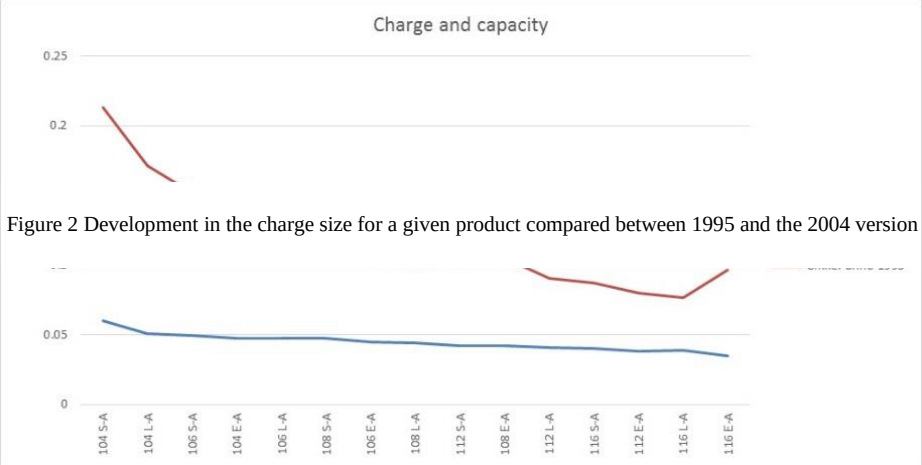


Figure 2 Development in the charge size for a given product compared between 1995 and the 2004 version

For indoor installation the system can be incapsulated with a separated ventilation system including a explosion proof fan motor sitting outside. By sucking out the air you get a negative pressure in the cabinet and the venting channel. In this way you avoid gas can leak in to the building. All controls are be placed outside the cabinet. A sensor in the cabinet cuts off the power supply if you reach LFL. In this way no gas can enter the building. This technique can be used with any refrigerant as well for other reasons.

Water and air in this context are relatively safe but when the pressures are increased they can become a subject of safety discussions. A saturation temperature at 200°C equals 15bar(a), but 250°C equals 40bar(a). If we look in the History of Refrigeration[1]

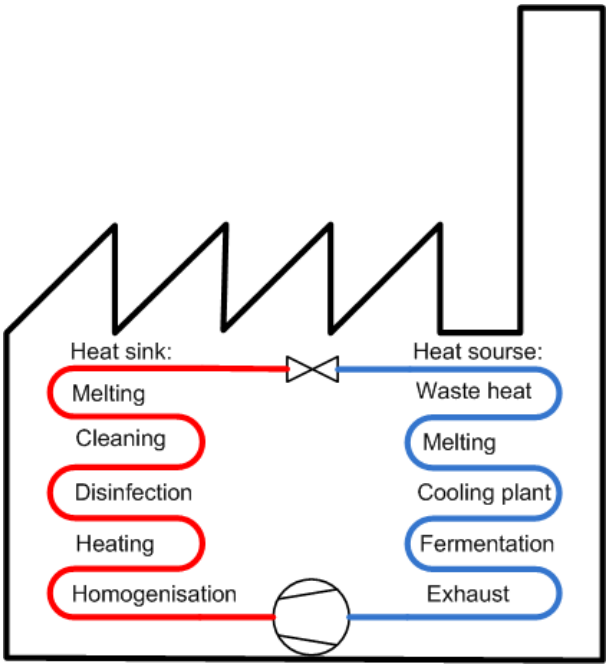
we know that in the early days of refrigeration you worked at pressures up to 2000bar, which also led to accidents from time to time.

4. Temperature and heat recovery

The main problem with high pressures in some cases is the shaft seal which can only handle a limited pressure. This puts the limit on open type compressors for NH_3 and H_2O, but when we have a motor that has a high tolerance to ammonia and water, this problem will be solved. The trick will be to have the high efficiency currently provided by copper winding based motors. This is a real challenge that has been worked with for years with variable success.
Many heat pumps are used for some kind of drying process. Wood and wood products are dried using heat pumps. By using both the cold and warm side you get a very efficient drying efficiency.

In a smaller scales the technology is used for drying clothes in laundryies.

A lot of heat is produced for producing cold for storrage and freezing food. This heat can be used for cleaning the production area. When the cooling need and heating need does not coinside the heat can be stored in large vessels.



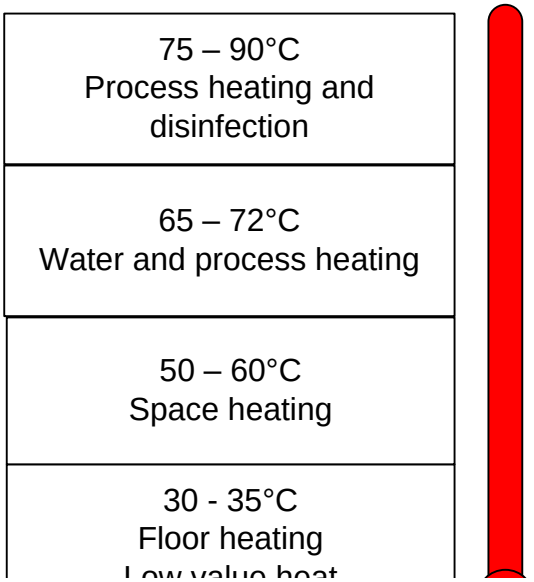


Figure 3 Heat pumps are used for different temperature levels

In Holland it is not allowed dump waste hot water warmer than 20°C in the nature. So you can cool this waste water in a chiller as first stage. Then you can use another chiller to cool the condenser on the first refrigeration chiller and boost the temperature to 60 or 90°C for use of hot tap water or for disinfection of contaminated water.

We have seen in Holland a project where 20°C water is circulated as heat source and the local heat pumps produce hot tap water from this. This way the distribution losses are minimised greatly compared to the district heating used in e.g. in Denmark

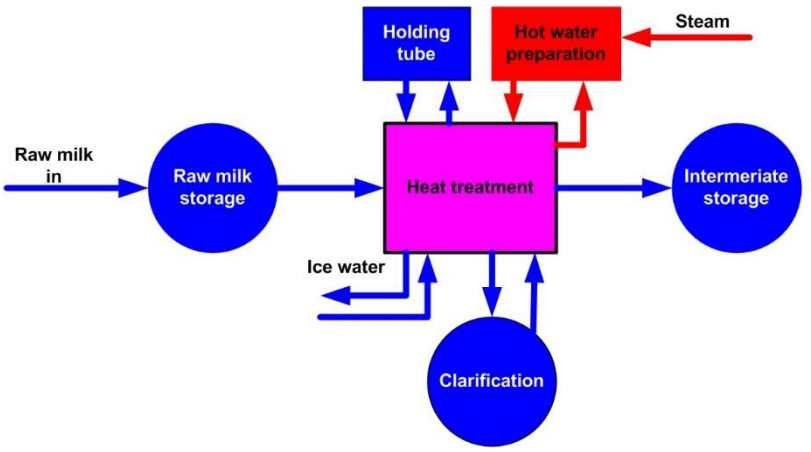
In the Denmark the district heating is often waste heat from the electricity production. This increases the efficiency of the used total used fuel. But the distribution losses especially in the summer period are high just be able to produce hot water in the middle of the day.

The return temperature from the district heating network is often about 40°C. This is a good heat source for a heat pump and if the temperature can be lowered with heat pumps the overall efficiency will increase. The boilers become more efficient with lower feed water temperature. So it is a win-win. So heat pumps, especially in the perifery of the net-work, will be able to greatly improve the efficiency of the network and at the same time improve the comfort in the houses in the winter period.

Industrial heat pumps will be a good option for serving villages and smaller communities. In cities like London or other big cities one industrial heat pump will be able to supply both the cooling and heating for high rise buildings, perhaps in some cases with two stage systems depending on the temperature lift.

Figure 4 In the modern industrial food and beverage factory there are many possibilities for recovering waste heat and use it for cleaning and processes such as homogenisation in daieries, fermentation in brewerie etc.

5. A business case



In the case of a dairy you can see that there are possibilities for optimizing the production by using heat pumps. Steam has traditionally been used for preparing hot water for pasteurizing the milk and for cleaning milk bottles (mostly in the past). At the same time we have high cooling requirements for cooling incoming milk and final products.

By using the condenser capacity as heat source you can produce hot water for pasteurizing the milk. In this way you can avoid producing the steam for heating the water and at the same time avoiding rejecting low

value heat which by the heat pump becomes a high value heat. You also avoid using electric power on the cooling tower, water in the cooling tower and chemicals in the cooling tower. You can also produce hot water for cleaning, and if the water is over 90°C, you can theoretically avoid using chemicals as well. Theoretically – because the trend goes towards more chemicals and lower temperatures.

The same exercise can be done at a variety of industrial production sites such as breweries, slaughter house, professional kitchens etc.

6. Summary and conclusions

A lot of research is put in to development of industrial heat pumps so they in the future can take over where we today use fossil fuels. When we today are selling heat pumps we are up against traditions, regulations and cheap alternative solutions based on fossil fuels. This will change when the cost of developing the alternatives become too high. We need to prepare the systems now so the industry can meet the demand as it rises. It can be difficult to produce a good business case at the current conditions, but this will change gradually as we run dry on fossil fuels.

There is also a desire to decarbonise the industry in general for other reasons than just cost of fossil fuels. The marketing value of being able to declare that your production is green must not be under estimated.

In industrial processes there is also an on-going optimisation going on in order to reduce the energy consumption. Also energy recovery is coming more and more in to the picture. By analysing the processes in the production you can get good ideas on how and where you can recover the heat and use it elsewhere.

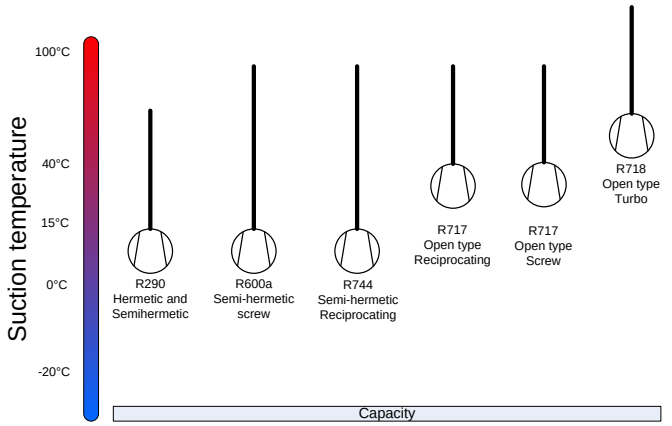


Figure 5 The open type compressors can operate at a higher suction gas temperature because the motor can be cooled either by water, which is preheated, and still is over the ambient temperature so you avoid condensation in the motor but still sufficient cooling the motor not to over heat. The small semi-hermetic compressors are greatly dependent on the cooling of the suction gas.

In Figure 5 we see approximate operating and delivery temperatures that are obtained for different types of compressors. This will probably change with the types of refrigerant that can be used in the future, it just reflects what is currently used.

So final remark is: rethink the energy use in connection with industrial heat pumps now. It is a technology that has many qualities and a bright future.

[1] Thévenot, R.: A History of Refrigeration throughout the world, Translated from French by J.C. Fidler, International Institute of Refrigeration, 1979.