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High efficient, high temperature industrial ammonia heat pump installed in central London

Kenneth Hoffmann*

De Beverspijken 7c, 5221 EE, 's-Hertogenbosch, Netherlands

Abstract

In 2016 GEA will install a 1000 kW ammonia heat pump in a container at street level next to 18 floors residential high rise buildings in central London. A lot of challenges have gone into the design of this project and we would like to present the solutions we have made. The heat source is the extract air from the underground train ventilation shaft. Excessive test have been made to ensure that the dust from the ventilation air do not block up the heat exchanger coil. For the current district heating network up to 80^{0}C hot water is required from the heat pump. By using 2 stage piston compressors it has been possible to achieve heating COP above 3.5. As the project is next to a residential building the installation includes an ammonia adsorber which filtrate the air from the emergency extract fan to ensure no ammonia in the extract air. This was an essential part of the installation as more high rise buildings are planned in the area and ventilation at high level could not ensure that they would not be affected by an ammonia release.

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1. Introduction

Industrial heat pump technology has been a known technology for more than 100 years, but it is only in the last 10 years that it has become an accepted technology with a widespread market area. Earlier heat pump installations were unique to idealist who wanted to stand out from the crowd and install environmental friendly solution even if a return on investment was not guaranteed.

The first major steps towards large industrial heat pumps, that we are seeing today being introduced in district heating systems, started in the 1980's. The oil crises in 1979 started a movement in Sweden and Switzerland to focus development on large heat pumps. Especially in Sweden there were many large heat pump installations in the early 1980's [(1)]. Most of the large heat pumps installed in Sweden in the 1980's were using sewage water as

* Kenneth Hoffmann. Tel.: +44 7876825711
E-mail address: Kenneth.hoffmann@gea.com

heat source. By mid 1980's the oil prices had dropped and it was no longer as attractive to install heat pumps in the district heating system, but the research initiative continued over the years until the focus on low carbon heating returned to the top of the global agenda and larger heat pumps for district heating became attractive again.

2. Environmental consideration

With all major companies having an environmental policy and a clear target of reducing their carbon footprint there is an increased focus on how to reduce the use of gas and oil for heating processes. For most processes in the food and processing industry the products are heated up followed by a cooling process the combination of cooling and heating is the major benefit of industrial compression heat pump. Instead of having a chiller with a Coefficient of performance (COP) of 4 and a gas boiler with a COP of 0.8 (giving a combined COP of 1.25) it is with a combined heating and cooling solution possible to achieve a combined COP of 5 – 10 with an industrial heat pump.

$$COP_{Combined} = \frac{Cooling\ duty + heating\ duty}{Energy\ used\ for\ cooling + energy\ used\ for\ heating}$$

$$Example\ 1: \quad COP_{Combined,chiller+gasboiler} = \frac{800\ kW + 1000\ kW}{200\ kW + 1250\ kW} = 1.25$$

$$Example\ 2: \quad COP_{Combined,chiller+heatpump} = \frac{800\ kW + 1000\ kW}{300\ kW} = 6.00$$

This significant reduces the carbon footprint and help companies achieve their CO_2 reduction targets. In the public sector there is also a commitment to reduce the CO_2 emissions; many different initiatives have been taken and funding made available to try new technology. EU has helped with funding for many new carbon saving projects. This includes the Bunhill II project for Islington council in London.

In addition to reducing the prime energy used for heating there is also an increased decarbonisation of the electricity grid. Over the last years there has been a large reduction in CO_2 emissions from electricity production with an increased amount of the electricity being produced with renewable or cleaner carbons. Many coal fired power plants have been closed down and replace with gas turbines, wind turbines, biomass or nuclear. CO_2 emission from using gas for heating has not changed; this has made it more attractive for building services and large food producers to switch from gas heating to using heat pumps recovering heat from waste heat sources.

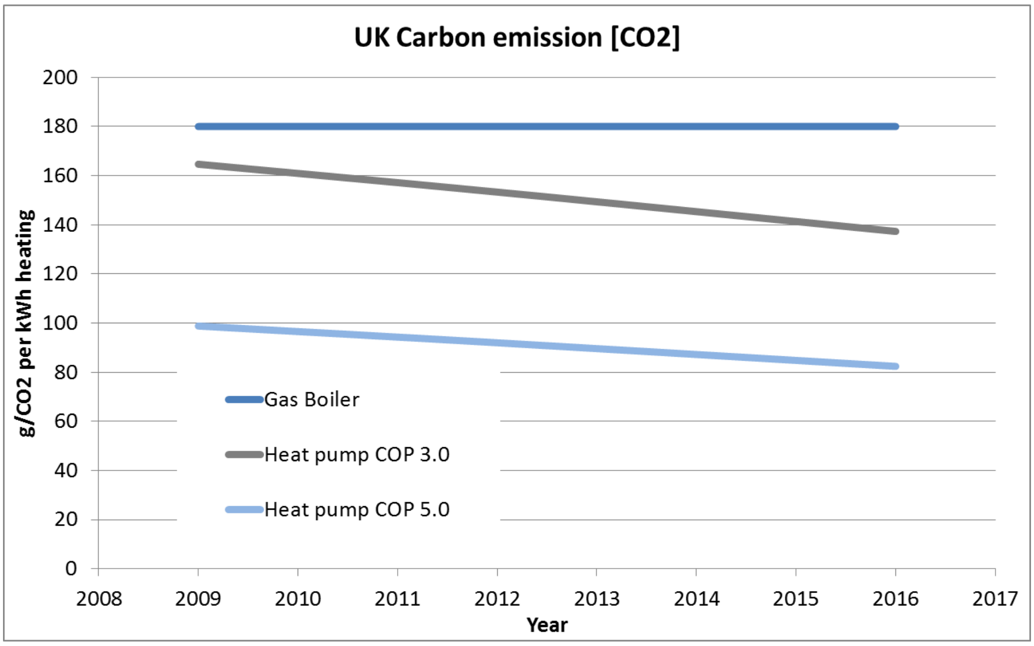

Figure 1: CO2 (g/kWh)emission from heat production either by using a gas boiler, heat pump with a COP of 3 or a heat pump with a COP of 5. The graph shows how the decarbonisation of the electricity grid is lowering the CO_2 emissions from heat pumps.

In the UK CO_2 emission from electricity production have dropped from 494 g/kWh in 2009 to approximately 412 g/kWh in 2016(2). The emission from burning gas have stayed at 183g/kWh(2) during the same period. The same scale of reduction has been seen across Europe in recent years. This trend will continue with an expected complete decarbonisation of the electricity grid by 2050.

With the increased interest in CO_2 reductions from the public service and large companies follows a continued development of new heat pump product based on natural refrigerant to satisfy the customer needs. Natural refrigerant has a very low global warming potential (GWP) value and a release of refrigerant to atmosphere will not undo the carbon savings made when running the plant, which otherwise, often is the case with heat pump using synthetic refrigerant with high GWP value. Since Thomas Midgley Jr invented the synthetic refrigerants (CFC's) in the 1920's many synthetic refrigerants have followed, but when it was realized in 1987 that the quantity of synthetic refrigerant on the market had a detrimental effect on the global environment a phase out process started. First focus was to reduce the refrigerants with high ozone depletion effect (CFC's), later followed the phaseout of refrigerant with low ozone depletion effect (HCFC's) and at the moment there is a phaseout process in effect of refrigerant with high Global warming effect (HFC's). The chemical industry continues to develop new synthetically refrigerants but the issue with them all is that they are synthetically and the long term effect of using them are not known. Natural refrigerant has a well-known global environmental effect and do not risk being banned or phased out.

The disadvantage with natural refrigerants is that they are toxic, flammable or explosive (or all of the above). It is important to ensure the quality of the design and that the necessary risk assessment has been done when manufacturing equipment with natural refrigerant. For ammonia heat pumps there are 3 steps to ensure the safety of the equipment. 1. Keep the ammonia charge low, 2. Ensure leakage to the air is not harmful to the public. 3. Detect any leakage to the water system.

3. The heat pump design

For the 1000 kW 2-stage heat pump manufactured for Bunhill 2 project the ammonia charge is approximately 350 kg. A similar HFC installation would have at least double the charge. The heat pump consists of a combined evaporator/separator in a fully welded shell. There are 4 heat exchangers in series in the heating circuit to optimise the performance of the heat pump. First the district heating water is used to cool the de-superheated gas from the low-stage compressor, afterward the water is heated in series through the subcooler, condenser and de-superheater from the 2 high stage compressors.

The design criteria for the heat pump are based on heating water returning at 55°C and being supplied at 75°C. The air will be cooled from 24°C to 14°C in the cooling coil with water at 13°C / 8°C. At these conditions the total cooling duty is 780kW, the absorbed power of the 3 compressors are 275 kW and the heating duty is 1,034kW giving a heating COP of 3.7

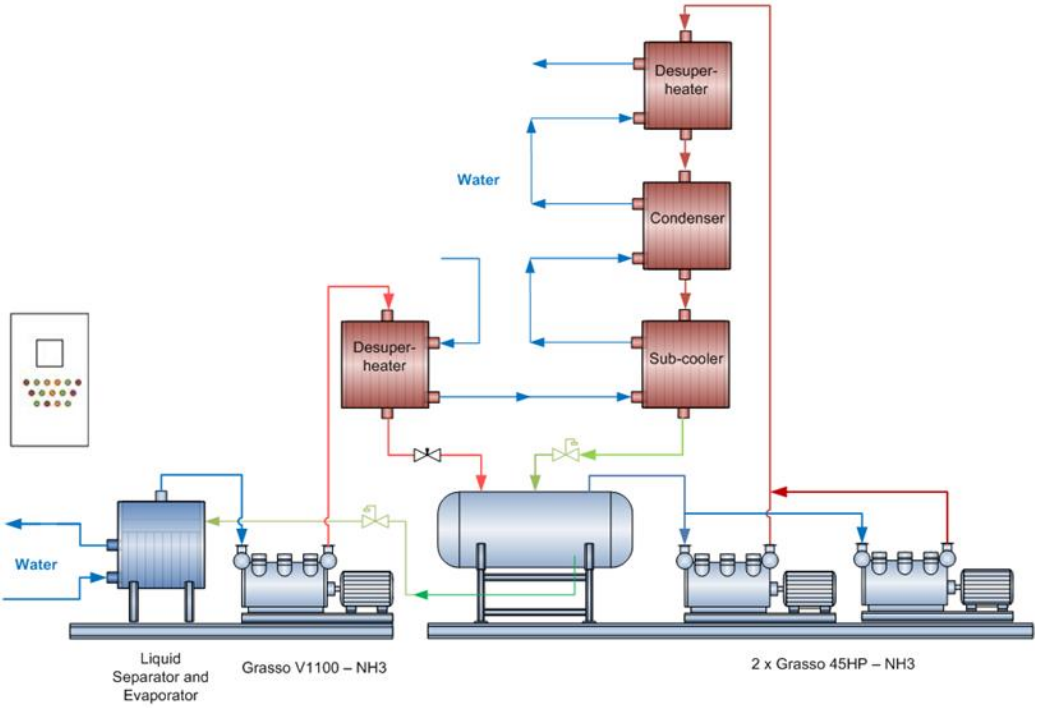

Figure 2: Schematic of heat pump installation for Bunhill II for Islington council. The cooling water is cooled in a fully welded shell and plate evaporator. The heating water is heated in 4 shell and plate heat exchangers in series to optimise the performance.

To ensure that there is not too much superheat before the high stage compressor, the low stage compressors discharge gas is released in an intermediate receiver below liquid level. There is a level sensor in the intermediate vessel, which ensures the ammonia level is at least 1 diameter (of the inlet gas pipe) above the inlet gas pipe. As the low stage compressor we installed a GEA V1100 piston compressor (25bar design pressure) and as the 2 high stage compressors are installed GEA 45HP piston compressors (50 bar design pressure). The low stage compressor ensures that the 1000 kW heating capacity can be achieved at varied ventilation air temperatures between 10^{0}C to 30^{0}C. The minimum part load of the system is 25% of the design capacity. The low stage compressor can run at reduced capacity by reduction in rpm due to VSD drive and reduction of the number of cylinders in operation. The high stage compressors will always be running with all cylinders engaged and will only be capacity controlled by VSD. When running the high stage compressors close to its limit of 80^{0}C condensing temperature sudden change in capacity, when adding cylinders while running, can lead to the compressor shortly operating outside its operating limits, which can lead to either a stop of the compressor or failures, which should be avoided.

4. Heat source

The heat source for the heat pump is an existing ventilation shaft from London Underground. Currently the air is being extracted from the underground to ambient at ground level. A 780 kW water cooled cooling coil will be mounted in the airstream with a reversible fan extracting 70m^3/s. Most of the time of the year the air from London Underground will be cooled before vented to atmosphere. On warm days the airstream will be reversed and chilled across the cooling coil before vented into the Underground tunnel. London Underground has experience with this type of installation from other parts of London where the air is being chilled before vented to the Underground tunnels.

There is a big difference in the air quality from street level compared to air extracted from the Underground. The Underground air has a very high metal content[(3),] whereas the air quality on busy London streets, mainly (around 80%) is NO_x, PM_{10} and $PM_{2.5}$ from exhaust and brakes from cars, busses and trucks[(4)]. To avoid the coil being blocked up by the pollutant a wide finspacing has been chosen (4 fins per inch). Based on London Undergrounds experience from other sites and tests made with the cooling coil it is estimated that the coil will need to be cleaned every 6 – 12 months.

Year of report	Stations dust level range mg/m^3	Trains dust level range mg/m^3
2004/5	0.01 to 1.14	0.06 to 0.61
2006/7	0.04 to 1.38	0.12 to 0.56
2007/8	0.06 to 0.98	0.13 to 1.44
2009/10	0.04 to 1.38	0.12 to 0.56
2011	<0.02 to 1.23	0.03 to 0.30
2013	0.01 to 0.96	0.08 to 0.56

Figure 3: Analysis of the particles in air in the underground: Around 90% of the dust is iron, 1-2% quartz, 0.1-0.2% chromium, 0.6-1.0% manganese and 0.1-1.5% copper.

When the system was designed it was decided to keep the ammonia charge as small as possible and instead of having ammonia directly in the cooling coil, there is an intermediate water loop. This reduces the ammonia content of the heat pump and in case of a leaking coil in the air stream there is no risk of releasing ammonia into the airstream, whether it is to atmosphere or to the Underground train tunnel.

5. Heating circuit safety

All heat exchangers in the heat pump are fully welded shell and plate type. These have a compact and robust design with low ammonia charge compared to shell and tube heat exchangers. The hot water circuit is topped up with London water, which can have high chloride content. Normally stainless steel AISI316 is used as the plate material in heat exchangers but with chloride content above 60 ppm stress pitting corrosion can occur in stainless steel when water temperature are above 50^{0}C. For this project is chosen SMO254 steel for the plates in the heat exchangers. This has a considerably higher resistance to chloride in the water. SMO254 is duplex steel which is 20 – 30% more expensive than AISI316. Titanium was also considered as an alternative, but titanium is much more expensive and they are supplied in a thinner material, so although it will be resistant to corrosion it may not offer the same robustness as SMO254 at the high pressure. With the hotgas from the compressors entering the de-superheater at around 140^{0}C it is possible that the water will locally in the heat exchanger exceed 100^{0}C, to avoid boiling the water pressure should always be kept above 5 bar in the hot water system.

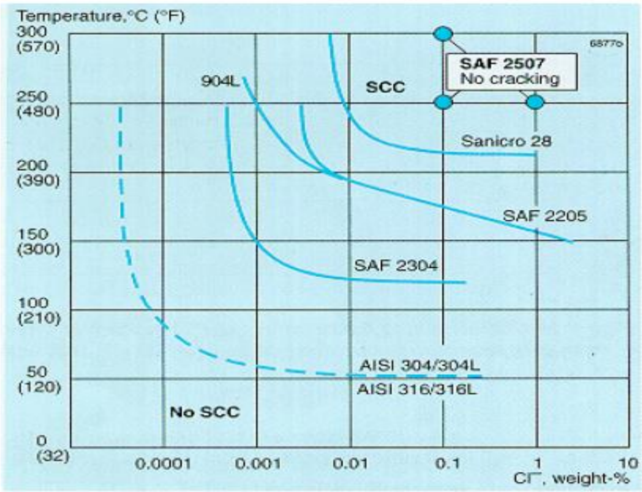

Figure 4: The table above shows the limits for when stress cracking corrosion can occur in different types of steel. The properties of SMO254 are similar to 904L

If one of the plates in the heat exchangers should leak it will leak into the water circuit and to avoid corrosion of copper valves or heat exchangers in the water circuit there is fitted Ph sensors. The ammonia content is very small in the heat pump and large water content in the water circuit, so there is only a very small risk that the ammonia content will exceed 100 ppm in the water circuit and corrosion of copper items will start occurring.

6. Ammonia safety in urban areas

It will not be headline news if we have a leak of ammonia into the water system, but if any ammonia smell is rejected into the surrounding environment it is sure to create publicity and not in a good way, so to get around this issue there will be installed a new ammonia adsorber technology on site which will 100% eliminate any smell of ammonia that could be rejected from the installation.

During normal operation the extract air from the plant room will be rejected above the roof of the nearby 18 story block of flats. When the plant is being serviced (some ammonia smell can be expected) or an ammonia alarm is set off all the ventilation air will be filtrated through a carbon filter, which will absorb all the ammonia leaving 0 ppm of ammonia in the air after filtration. We have investigated other options but no other solution can offer 100% removal of the ammonia in the air. Water scrubbers and acid based scrubbers reduces the ammonia content in the air below dangerous levels, but they do not completely remove the ammonia in the air, and with many people in the area with no knowledge of ammonia safety levels, any prevailing ammonia smell can cause panic. Although the ventilation air is being rejected at the highest level, there are taller buildings being built nearby, amongst them a 42 story tower. Depending on the wind direction all the ammonia from the ventilation air could be directed straight to these building if the air is not completely free of ammonia.

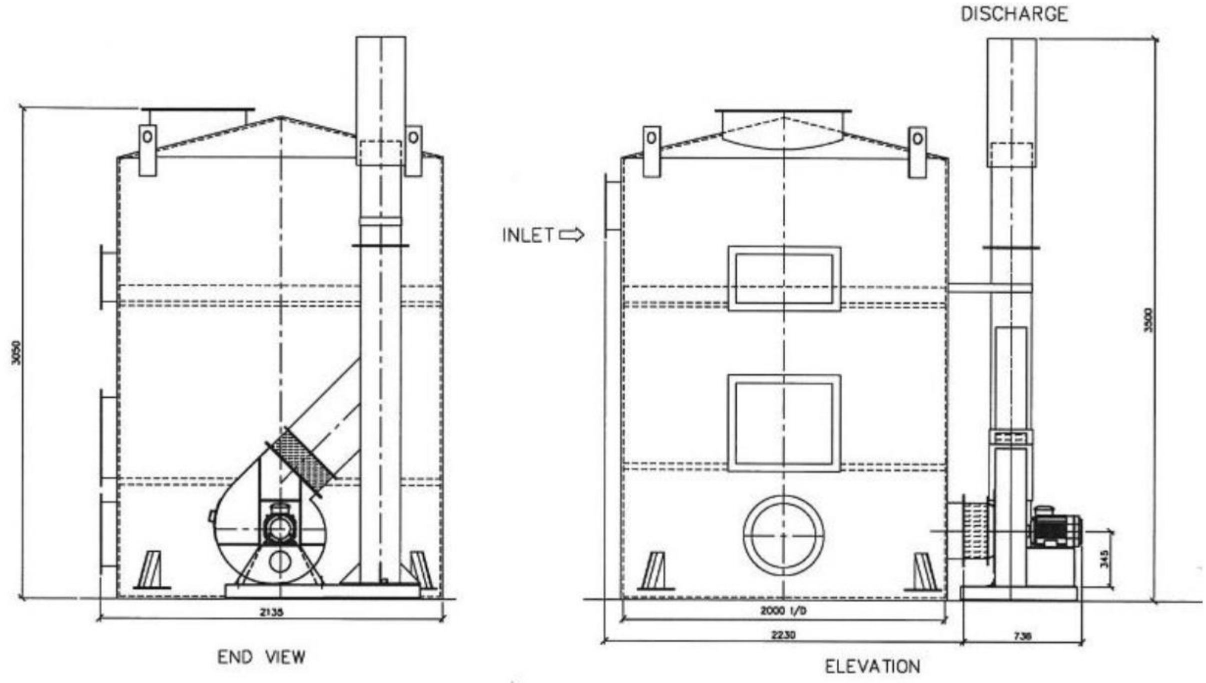

Figure 5: Schematic of the ammonia adsorber, where carbon pellets absorbs any ammonia in the air stream leaving it ammonia free at the exhaust to ambient

We have done several tests to find the best absorbent material. The material used is a carbon base pellet, with an additive to improve the ammonia absorbent properties. In our test we found that that material can absorb up to 5.6% ammonia. For the project in London the adsorber is selected based on 4.6% ammonia adsorption. To absorb the 350 kg in the ammonia heat pump, there is installed 8000 kg of absorbent material. To avoid having to replace the whole content, a maintenance layer (10%) is at the top where small ammonia leaks (from maintenance) will be absorbed so the main content will stay active throughout the life of the installation.

With the global agreement made on the 14th October 2016 to phase out all HFC's this could be a key showcase installation on how to keep natural refrigerant safe in an urban area.

7. Conclusion

With an optimised design using high efficient piston compressors, it is possible to take heat from a cooling circuit at 13ºC to 8ºC and heating water from 55ºC to 75ºC with a coefficient of performance above 3.5 only using 1 kwh of electricity for each 3.5 kwh of heat generated. By using heat exchangers with duplex steel (SMO254) material it is possible to avoid corrosion of the heat exchangers although the heating circuit is using untreated London water for top up giving chloride content up to 100 ppm. It is possible to have safe ammonia installation at ground level in busy urban area by applying ammonia scrubbers in the exhaust ventilation stream from the plant room and thereby eliminating all the ammonia content in the air in case of service, leakage or failure.

References

[1] Introduction and development of the Swedish district heating systems
Karin Ericsson, Lund University, Sweden, March 2009

[2] UK Government GHG (greenhouse gas) Conversion Factors for Company Reporting 2009 – 2016, 5/10-2016
Department of Energy & Climate Change

[3] Air Quality on the Underground 2004 – 2013 http://content.tfl.gov.uk/air-quality-on-underground.pdf
Transport for London

[4] Source appointment for the city of London corporation, Chetan Lad, 15/7/16