Industrial heat pump for a high temperature district heating application

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ABSTRACT

Domestic heat pumps for shallow geothermal heating of family houses are popular and the range and supply of standard solutions is large. However, in applications for large capacities and temperatures, like district heating in the mega Watt range, standard solutions for high temperatures are scarce and usually not suitable off-the-shelf, which demands customized industrial heat pumps to be designed to fit the specific application.

At the Brædstrup CHP plant in Denmark, a pilot project deployed in 2012, is being tested involving a seasonal thermal energy storage system in underground boreholes, charged by excess thermal energy from thermal solar panels. An industrial heat pump system using the natural refrigerant ammonia, is extracting the thermal energy from the storage when needed, and produce hot water at 85°C, for the district heating grid. The heat pump also acts as contributor to electricity grid peak shaving during high wind power and photo voltaic production periods.

1. INTRODUCTION

The Brædstrup combined heat and power (CHP) plant supplies district heating to approx. 1500 homes in the town of Brædstrup. The heat was traditionally produced in 3 gas motors, as a by-product of the electricity production and supplemented by a natural gas boiler, for peak loads. The price development and concerns about future availability of natural gas, has however spawn a wish for the plant to be less dependent on the natural gas as a single source of energy.

The Brædstrup CHP plant is owned by the 1500 consumers and is a non-profit organisation, so the consumers have an interest in influencing and securing their heating costs for the future. It was decided in 2007, to erect 8.000m^2 of thermal solar panels to supplement the district heating system that was still based on natural gas. It however quickly became obvious, that the peak production of hot water during summer far exceeded the consumption in this period, so a second stage project involving a pilot project BTES seasonal storage quickly took form.

2. THE HEAT PUMP SYSTEM

The expected temperature in the BTES after charging the system, is about 40 – 50°C, which is inadequate for direct use as district heating. A heat pump is consequently needed to extract the thermal energy from the BTES, and lift the temperature to the required useful level of 85°C, which is the peak load outgoing temperature of the district heating system, during colder periods. The specified heat pump capacity output for this pilot project was approx. 1.5[MW]

2.1 Challenges for a suitable heat pump system

The top three challenges for the heat pump solution:

- The high temperature output of 85°C
- Natural refrigerants are preferred
- High degree of flexibility regarding the energy source temperature.

2.2 High temperature output of 85°C

The specified outgoing temperature of 85°C, proved to be a challenge, since most high temperature heat pumps have their limits at around 75°C outgoing water temperature. It was discussed and considered to settle for a lower temperature heat pump, and then raise the water temperature the remaining 10-15 degrees, with traditional heating source like a gas boiler. It was however decided to go for a heat pump solution capable of the full temperature increase.

3. THE CHOICE OF REFRIGERANT

The previously described challenge of reaching the high outgoing temperature of 85°C is also highly linked to the fact that the choice of refrigerants is rather limited, for larger systems in Denmark.

3.2 HFC refrigerants considered

The local legislation allows a refrigerant charge of synthetic HFC refrigerant of 50 kg per refrigerant circuit, in heat pump applications. For refrigeration and air conditioning equipment, the limit is only 10kg. Most other heat pumps considered, that are capable of higher temperatures, are relying on the use of R134a or R245fa, and the heat pumps typically contain several hundred kilos of refrigerant charge.

Even if it is possible to comply with the limit of 50kg per circuit, there are still problems with using HFC refrigerants. In Denmark, Norway and other countries, HFC refrigerants are heavily taxed and with leakage rates on factory built heat pumps starting at typically 2-3% annually, this can evolve in to a considerable expense over time.

Legislation and constraints on HFC refrigerants are getting tighter year by year and with an expected lifetime of an industrial heat pump of typically 20-25 years, it can be discussed if HFC refrigerants, is a future safe choice of refrigerant.

Newly developed HFO refrigerants, with low GWP factors was not considered since these, basically still HFC refrigerants, are unproven, expensive and not released for all compressor types and applications. HFO's are not seen as long term solution refrigerants by for instance GreenPeace.[1)]

3.2 Natural refrigerants considered

One of the natural refrigerant considered, was CO_2. Newly developed heat pump systems with outgoing temperatures of up to 90°C was already deployed in district heating applications using waste water or sea water as heat source. They however seem to be best suitable and most efficient for high temperature lifts, and usually have semi hermetic compressors which sets a limit for the suction gas temperature, because of the suction gas cooled motor. This means that with a BTES temperature of 40°C, the evaporation temperature has to be below 20°C, which can give a efficiency drop. The high operational pressure of up to 130[bar], can make custom built and application adapted CO_2 heat pump solutions quite costly, because of specially built vessels and the necessary approvals.

Hydrocarbons was considered, but was rejected because of the lack of references and proven application examples. Here the pressure is low at high output temperatures compared to most other refrigerant systems, which means that close to standard vessels and components can be used from a pressure directive point of view. However, the flammability of hydrocarbons could give application problems and extra installation costs with ATEX certifications, if the refrigerant charge exceeds certain levels.

The choice of refrigerant fell on R717, ammonia because of its efficiency and the fact that ammonia has zero ODP and GWP. Natural refrigerants will not be phased out, so it is a safe choice without the threat of possible future refrigerant conversion, with the drops in capacity and efficiency consequence. It is a known component technology and a proven refrigerant, also for industrial heat pumps. The discharge pressure is however higher for the 85°C output, than the traditional limit for R717 heat pump systems, which has been approx. 75°C, until the recent years.

The drawback in using ammonia is the toxicity issue. Ammonia is highly toxic, and even lethal, to inhale in high concentrations, if the refrigerant should escape from the heat pump system. Ammonia has however a distinctive smell, which will alert people of a leak, a long time before even remotely dangerous concentrations occur in a machine or utility room. Ammonia can also be flammable, but only in a narrow window of mixture, with atmospheric air.

3. FLEXIBLE DESIGN

The recent years product development in vessels and heat exchanger technology for high pressure ammonia systems, has given the market some highly advanced components to choose from. The vessels are optimized for lowest possible refrigerant charges and the sturdy design with steel components and x-ray'd welding's, give very low leakage rates, and is more robust than most soldered copper systems for synthetic refrigerants.

The heat pump for the Brædstrup district heating plant use fully welded steel shell and plate heat exchangers. The flooded evaporator heat exchanger design with built-in liquid separator function, keep the refrigerant charge down to approx. 50kg, which is quite impressive considering the 1.4[MW] heat output.

The vessels, specifically the evaporator side, need a high degree of operational flexibility, because of varying temperature of the heat source (the BTES). During the design phase, calculations resulted in expected BTES heat source temperatures between 50°C and 15°C, depending on the time and season. During fall and heating season start-up, the temperature may start at 50°C, and in spring, it may be as low as 15°C.

The evaporator heat exchanger adopted form industrial refrigeration, is designed for constant flow and delta T. The necessary flexibility for this BTES heat pump application is in a pump shunt system in front of the exchanger, which will keep the flow constant to the exchanger, but will allow alterations in delta T and flow from the BTES system. The flexibility is further improved with two thermal energy storage tanks of 2000m^3 and 5500m^3.

The compressor type chosen for the heat pump is a twin screw design, with 60 bar design pressure. Part load operation is without the usual compressor slide

valve, but with frequency converter and compressor variable speed drive. This improves part load efficiency, but is also an important factor in reaching the precise kW consumption, when using the heat pump for balancing the electricity grid, which is an important parameter in the overall project business case.

The fact that the discharge gas has a high temperature when leaving the compressor, is utilized in a discharge desuperheater heat exchanger. The hot gas temperature of up to 120°C, is used to boost the temperature of the out-put water. Also the compressor cooling and lubrication oil is cooled with the out-put water in two stages, to keep as much energy in the system as possible. This means that the dimensioning outgoing water temperature of 85°C, can typically be reached with a lower condensing temperature of 82°C, and the remaining 3 degrees is then taken from the cooling oil and the hot gas, in three separate heat exchangers.

4. CONCLUSIONS

An industrial heat pump systems with the natural refrigerant ammonia, enables the Brædstrup district heating plant to extract thermal energy from a seasonal borehole thermal energy storage system, charged by thermal solar panels. The heat pump is able to produce hot district heating water up to 85°C, and this is possible using a natural refrigerant with no Ozone Depletion Potential and zero Global Warming Potential. The heat pump is used for peak shaving and electricity grid balancing, during high wind power and photo voltaic production periods, where the price of electricity is low or occasionally even negative.

The system supplies sustainable and cost competitive district heating based on renewable solar and wind energy, and is thereby reducing the plants carbon emission and dependability on natural gas.

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