DISTRICT HEATING AND COOLING WITH LARGE CENTRIFUGAL CHILLER-HEAT PUMPS

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Abstract: With prices for primary energy resources soaring, the recovery of "waste energy" is getting into the focus of attention. The global climate change reminds us to limit the use of primary energy resources to a minimum, thus exploiting "waste energy" potentials wherever feasible. The process of upgrading low grade waste heat is especially interesting where large amounts of such energy are available at one point. This is for example the case in sewage treatment plants, alongside main sewers or at the smoke stacks of waste incineration plants using wet type flue gas cleaning. In all this cases, large amounts of valuable high grade heating energy can be produced with a minimum input of primary energy. Even if the "waste energy" potential is abundant and easily exploitable, the aspect of overall thermal efficiency is considered crucial for the final decision to invest in large heat recovery installations.

Key words: S*koyen Vest Plant, Nimrod Plant, Katri Vala Plant, Waste Incineration Plant Malmö, large centrifugal, heat pumps, centrifugal, combined heating and cooling, waste water*

1 INTRODUCTION

Described are four applications of large centrifugal heat pumps - chillers for the use in large district heating and district cooling systems. Operation of the units is either in heat recovery mode or in combined heating and cooling mode.

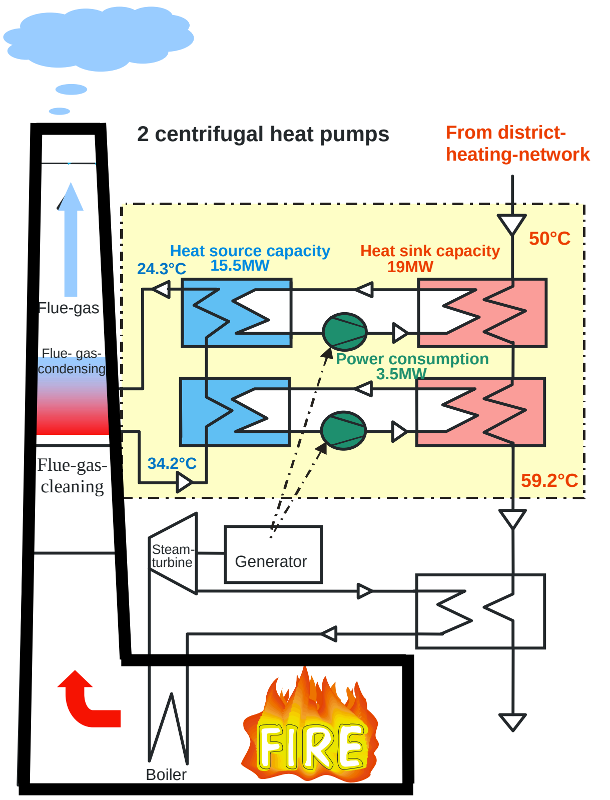
Application 1: Heat recovery from wet flue gas cleaning process. Heating capacity 19MW
Application 2: Combined heating and cooling. Cooling capacity 48MW
Application 3: Heat recovery from raw sewage water and hot water production of 20MW at +90°C
Application 4: Combined heating 90MW and cooling 60MW, a combination of heat recovery from cleaned sewage water and heat rejection to sea water.

2 WASTE INCINERATION PLANT MALMÖ - HEAT RECOVERY FROM WET FLUE GAS CLEANING PROCESS

In the year 2001 a new waste-to-energy plant was built in Malmö/Sweden. An important part in this plant was the installation of a 19MW heat pump using the flue gas condensation as heat source. The heat pump is supplying hot water with a temperature of up to 70°C to the district heating system of the community of Malmö.
The two heat pumps are connected in series on the heat source side and on the heat sink side; this improves considerably the overall coefficient of performance COP. There are operating points with lower district heating temperatures where a COP of up to 6.5 can be achieved.

Technical data:

Number of units	2
Type	Heat pump
Refrigerant	R134a
Cooling capacity	15'500 kW
Cold water temp. in/out	34.2 / 24.3°C
Cold water flow	1’350 m3/h
Heating temp. in/out	50 / 59.2-70°C
Heating water flow	1’800 m3/h
Power at terminal	3'500 kW
Heating capacity	19'000 kW
Coefficient of performance	5.43



Waste-to-Energy plant Malmö Sweden

Figure 1: Waste incineration plant Malmö - Heat recovery from flue-gas condensing

The first two heat pumps for Malmö waste incineration plant were taken into operation 2002 successfully. After 5 years of successful operation 3 additional heat pumps (for a new waste to energy plant) were installed in 2007.

3 NIMROD PLANT IN STOCKHOLM - COMBINED HEATING AND COOLING

3.1 History in district heating:

The city of Stockholm is operating a district heating system since several decades; the heating system includes the whole city including the near suburb.

At the very beginning the heating took place by burning of oil and coal in combination with the production of electricity, CHP (combined heat and power, steam turbine condensing to the district heating network).
Beginning of 1980 due to the steadily increasing oil prices, heat pumps were installed in the Stockholm area with a capacity of more than 600MW. These heat pumps produce today nearly half of the required heat demand of the city. Due to available nuclear power plants the costs of electrical energy is relatively low and has made the operation of heat pumps competitive.
During the Summer period, for the heating of tap (sanitary) water, a further optimisation takes place as the heat pumps are in operation during night time only, filling up the hot water storage tanks with very low electrical energy costs.
Sea water and waste water is mostly used as heat source for the heat pumps.

3.2 District cooling as new application

During the last few years an increasing demand of cooling was required, due to increased use of computer technology.
In the first instance it was obvious to use the freely available chilled water production of the existing heat pumps, however due to the fact that they are usually working directly with waste water or sea water as heat source, an intermediate cycle, with plate heat exchangers was required, with limited capabilities due to the required temperature approach.
This so called free cooling as a by-product of heat pump operation is today not sufficient any more to satisfy the need of cooling demand in the city of Stockholm and its vicinity.

3.3 Combined heating and cooling in Nimrod plant

Due to the fact that with every cooling process there is also waste heat generated, it was useful to work out a concept which allows various operating modes in order to operate the chiller / heat pumps more efficient over a longer period and, making therefore the investment more attractive:

There are 4 chiller / heat pumps installed in the Nimrod plant. The centrifugal compressors are switched in parallel for Summer cooling production of 48MW. However during this period heat recovery is not required as there is sufficient capacity available from the existing heat pumps.
The same units are producing during Spring, Autumn and Winter a cooling capacity 24MW with a full heat recovery of 35.6MW at a temperature level of 78°C. For heat recovery operation mode the centrifugal compressors are switched in series.

Each chiller / heat pump consists of two centrifugal compressors and is able to operate at the following modes, described below:

3.3.1 Cooling only:

During Summer with high cooling demand, the waste heat from the condenser is removed with sea water of max. 22°C, therefore the condenser and sub cooler are equipped with Titanium tubes.
The two centrifugal compressors are then working in parallel, in a single stage mode, with a single stage expansion, producing a cooling capacity of up to 7MW plus 5MW = 12MW i.e. with 4 units a total of 48MW..
Depending on the cooling demand, one or the other, or both compressors can be put in operation.
If needed, the part load of each chiller / heat pump can be controlled down to 10% of its nominal capacity, with a reasonable high efficiency, with the use of inlet guide vanes. The chilled water temperature outlet is kept constant to 5°C

3.3.2 Combination of cooling and heating:

During Spring, Autumn and Winter, with moderate cooling demand of up to 24MW, but simultaneous need of heating, the waste heat from the condenser is supplied to the district heating network at a temperature outlet of 78°C and a maximum heat capacity of 35.6MW. The two compressors are then working in series in two stage compression mode, with two stage expansion using an economiser after the first stage expansion.
The compressor with the larger volume flow is working as 1st stage and the smaller one as 2nd stage compressor.
The control system is controlling the required cooling capacity; the surplus heat is supplied fully to the district heating network at a temperature level of up to 78°C. I.e. this operation mode delivers heat which can be sold in addition to the cooling, with a total COP of above 5.

3.4 Conclusion:

The possibility to use the units at various modes allows to operate the chiller / heat pumps 8000 hours per year and makes therefore the investment more profitable compared to units operating only in one mode like cooling only, or heating only.

All operating modes can be changed electronically via the PLC control system; it will close and open the corresponding shut off valves and would change the control parameters.

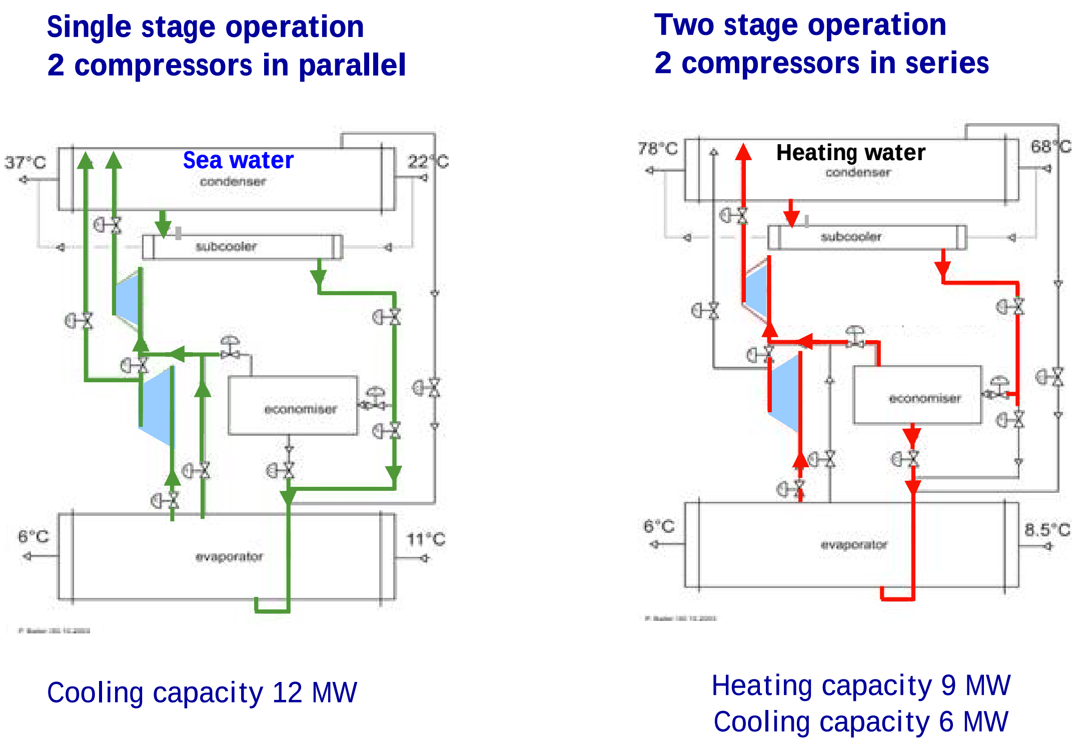


Figure 2: Nimrod Plant: P&I-diagrams showing parallel and two-stage operation

The first 3 units were taken successful into operation 2002, a fourth unit one year later.

4 SKOYEN VEST PLANT IN OSLO - HOT WATER PRODUCTION AT +90°C

Oslo is upgrading low temperature energy from waste water "big style" -to +90°C with a two-stage centrifugal heat pump.
Commissioning of Norway's largest heat pump took place in December 2005 with a heating capacity of 18'400 kW from one single unit.
With this heat pump the energy supply company was enlarging its heating supply by 9% to 1'000 million kWh per year.
This is the world's largest heat pump using raw waste water as heat source. With a heating capacity of 18'400 kW, the plant generates an annual heating capacity of 90 million kWh by recovering waste heat from one of Oslo's largest waste water channel.
The further development of the district heating system is one of the city of Oslo's most important goals in order to reduce the local impact on the environment. The heating energy produced is preferably recovered from waste burning or produced in by environment friendly techniques like wood burning plants and heat pumps exploiting coastal water as heat source.
The Skoyen plant is housed in a subterranean cavern which is connected to one of the main waste water channels of Oslo.

Technical data:

Number of units	1
Type	Heat pump
Refrigerant	R134a
Cooling medium	Raw waste water
Cooling capacity	12’134 kW
Cooling water temp. in/out	10.0 / 5.8 °C
Cooling water flow	2400 m3/h
Heating water temp. in/out	67.2 / 90 °C
Heating water flow	541 m3/h
Power at terminal	6’620 kW
Heat capacity	18’754 kW
Coefficient of performance	2.83

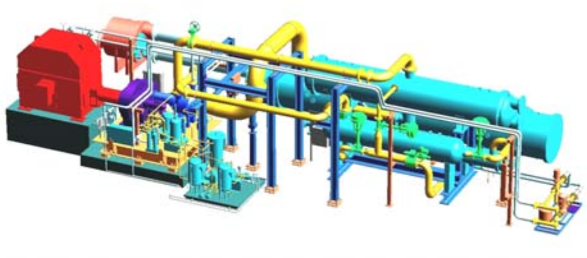


Figure 3: Skoyen Plant: design phase

Figure 4: Skoyen Plant: machinery room

After the end of the first heating period in 2006 the energy supply company ordered a second heat pump, slightly smaller than the first one, which was installed and successful commissioned end of 2007. Both heat pumps can now operate in series or in parallel depending on actual needs.

5 THE KATRI VALA PLANT IN HELSINKI - COMBINED HEATING AND COOLING

This is the largest combined chiller heat pump installation in the world producing simultaneously 60MW cooling capacity and 90MW heating capacity = 150MW of cooling + heating capacity.
The required electrical input is 30MW i.e. a superb COP of 5 can be achieved (150MW / 30MW).
During Winter season the required cooling is done by sea water, while heat is produced by using cleaned waste water as heat source.

This installation is intended to operate more than 8000hours per year.

Technical data:

	Summer	Winter
Number of units	5	5
Type	Chiller / Heat pump	Heat pump
Refrigerant	R134a	R134a
Cooling medium	District cooling water	Sea water, indirect
Cooling capacity	60’000 kW	60’000 kW
Cold water temp. in/out	20.0 / 4.0 °C	10.0 / 4.0 °C
Cold water flow	3’225 m3/h	8’600 m3/h
Heating water temp. in/out	45.0 / 88.0 °C	50.0 / 62.0 °C
Heating water flow	1’850 m3/h	6’105 m3/h
Power at terminal	30’565 kW	23’850 kW
Heating capacity	90’565 kW	83’850 kW
Coeff. of performance	2.96	3.51
produced thermal energy, total	150'565 kW	-
Coeff. of performance, overall	4.93	-

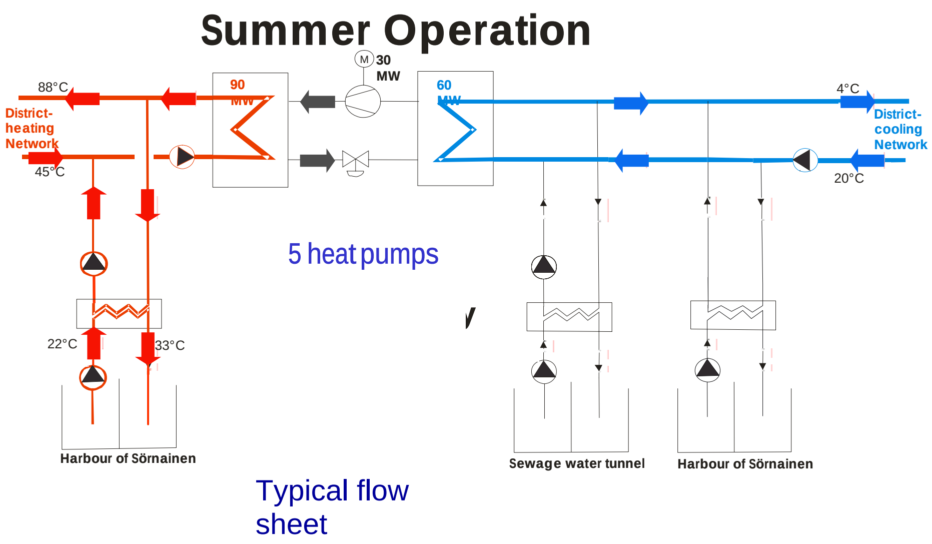


Figure 5: **District heating / cooling production “Katri Vala”, Helsinki, Finland**

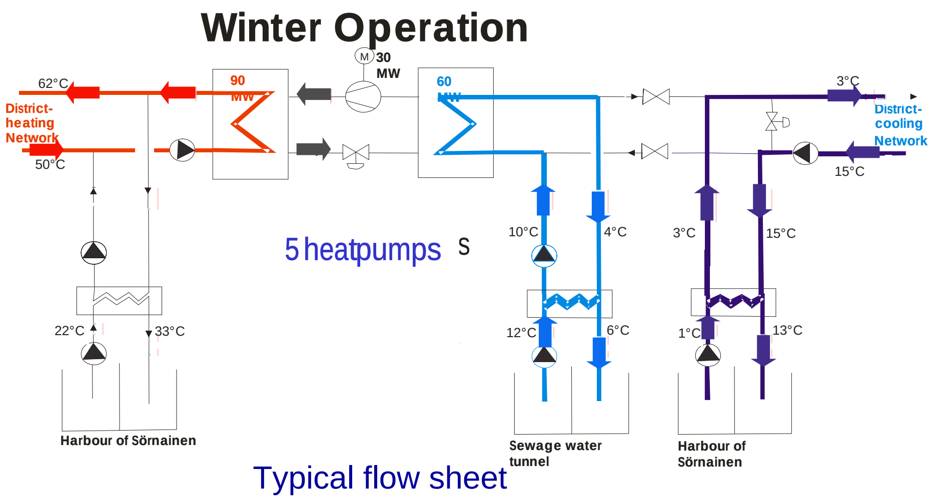


Figure 6: **District heating / cooling production "Katri Vala", Helsinki, Finland**

The commissioning of the complete Katri Vala plant and the first production of thermal energy took place in 2006.

5 CONCLUSION - RELIABILTY OF TECHNOLOGY, FUTURE DEVELOPMENTS AND CHALLENGES

About more than 140 heat pumps, producing hot water with temperatures above 70°C, are installed world wide since 1980. The heat pump plants described in this article are only showing a small part of the nowadays available applications.
Almost all of the heat pumps plants installed starting from the early 1980's are today still in operation, which is showing the high reliability of this technology.
The raw waste water heat pumps in the Oslo Sandvika plant are operating since 1989 in continuous operation producing cooling and heating with an accumulated compressor operation time of over 150'000 hours for each compressor.
Future developments could be an extension of the heat pump operation range in temperature and capacity to exploit new heat sources and to extent the field of applications.
As one of the important future challenges we could see the fact that compressors need to be adapted to new refrigerants.

6 REFERENCES

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