10th International Symposium on District Heating and Cooling

September 3-5, 2006

Tuesday, 5 September 2006

Sektion 5 b

Heat/cold generation

A periodic process for enhanced district cooling generation

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1 Introduction

In urban areas utilisation of district cooling (DC) has increased rapidly in recent years. Both residential houses and commercial and institutional buildings have removed their old cooling equipment and connected to DC. Central cooling generation plants are utilised to chill a circulating water flow that is distributed through underground pipelines, similar to the district heating (DH) pipelines, and utilised at the client's premises indirectly over the heat exchangers for space cooling. The supply temperature for the DC water is usually approx. 6 °C. After the heat exchange the DC water is returned to the central cooling generation at a temperature of approx. 16 °C.

One way to cool the circulating DC water is to utilise a compressor-driven cooling machine, i.e. a heat pump with the main components in the refrigerant circulation: compressor, condenser, pressure release valve and evaporator. The evaporation temperature of the refrigerant is some degrees centigrade below the DC feed water temperature. The condensation temperature is dependent of the media, to which the condensation heat is transferred. District heating is often needed, parallel to district cooling. It is therefore an interesting option to recovery the condensation heat into DH water at a suitable temperature level.

2 Objectives

A proposed improvement for the compressor-driven DC generation process is discussed in this paper, [1], [4]. The enhanced process is called here Periodic District Cooling (PDC) process. In the PDC process the key feature is to lower the pressure difference over the compressor for a certain cooling task and thus to reduce the compressor power demand. By this way the cold factor (COP), defined as the ratio between the created cooling effect and the compressor effect, can be improved. The savings in the electricity cost of the cooling task is the result of the improvement.

3 Continuous District Cooling generation process with heat recovery to District heating water

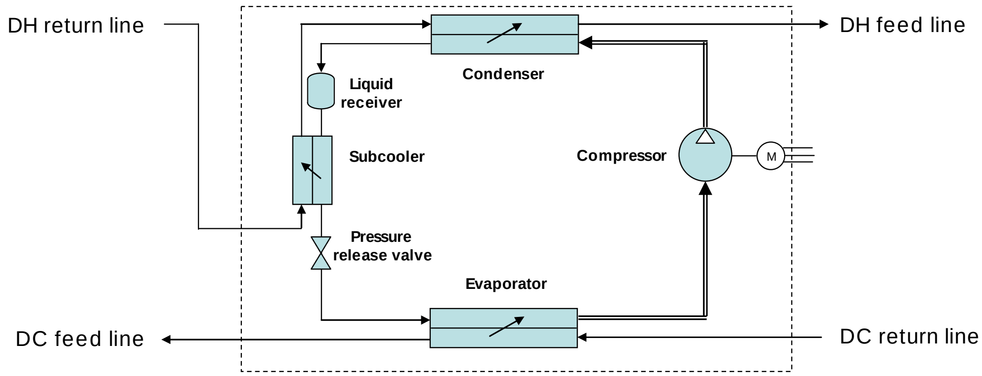

Figure 1. Continuous Compressor-driven DC Generation Process with condensation heat recovery into DH water.

A compressor-driven DC cooling process with the heat of the condensation recovered into the DH return water is discussed in this paper. The process is shown schematically in Fig. 1. The refrigerant that is considered is R 134a, but other media can also be used in the process.

The DC water is cooled in the evaporator and the heat from the cooling is transferred to the circulating refrigerant. The inlet and outlet temperatures of the DC water are chosen here as 16 °C and 6 °C, respectively. The evaporation temperature of the refrigerant depends on the heat transfer area and the heat transfer coefficient of the evaporator.

The DH water is heated in the condenser with the condensation heat. The refrigerant condensate from the condenser is collected in the liquid receiver and cooled by the inlet DH water in a subcooler.

The performance of the described one-stage process can be improved by different known ways, for example by a two-stage cascade process or by using a number of one-stage processes in series. These processes are more complex to build and their use has been small. In Fig. 2 a cooling process with four one-stage cycles is presented.

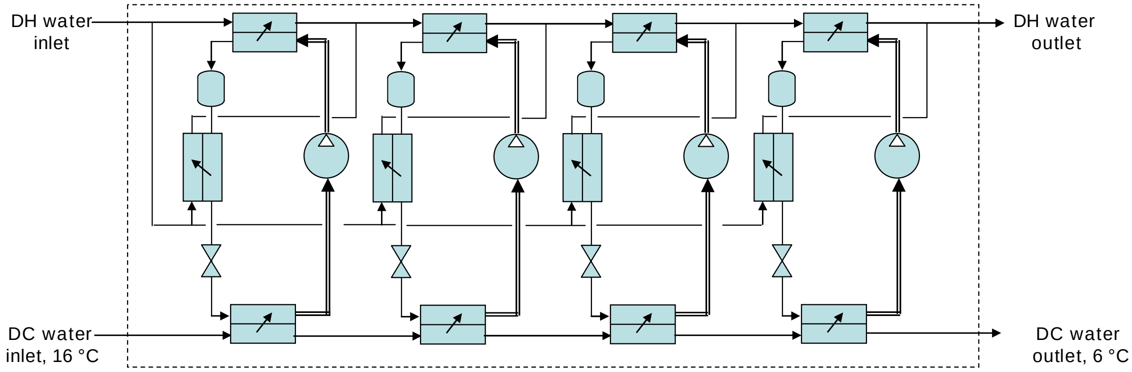

Figure 2. Four one-stage compressor cycles for DC Generation Process with condensation heat recovery into DH water.

In this enhanced process the COP is increased, because the temperature decrease of the DC water and the temperature increase of the DH water is taking place stepwise.

It is to be noted that the inlet DH water is let partly in the condensers and partly in the subcoolers. Subcooling takes place in each cycle with the inlet DH water. After each subcooler the DH water is mixed with DH water, which comes from the condenser in the cycle. The two flows coming to the mixing point can have nearly the same temperature with suitable flows of the DH water to the subcoolers.

4 The Periodic Cooling Process (PDC)

4.1 Process description

In the PDC process the compressor-driven cooling process is similar as in Fig. 1. The improvement of the COP is obtained by arranging the process to run in periods. The obtained performance is similar as if there would be several compressors, as in Fig. 2. The pressure difference and the power demand of the water cooling compressor are lowered by utilising periods with gradually decreasing evaporation temperatures. By this way the overall cold factor is increased, compared to the conventional cooling generation process. The principle idea of the PDC process is shown in Fig. 3.

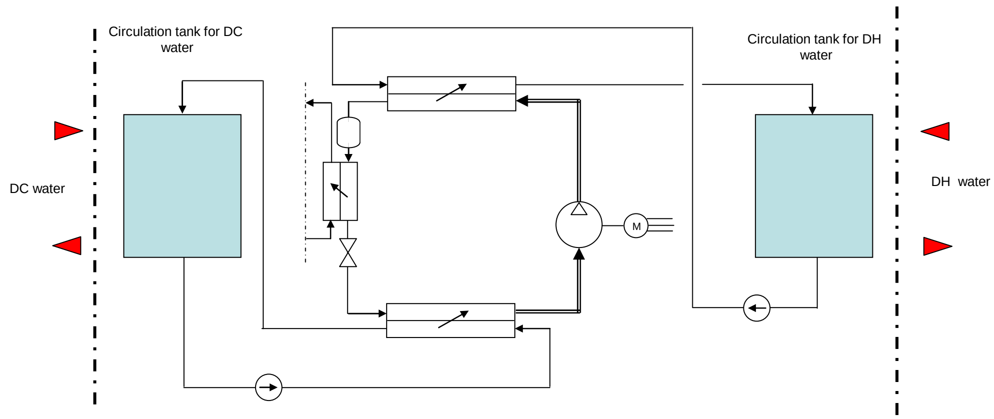

Figure 3. Periodic District Cooling Generation Process.

The PDC cooling process in Fig. 3 is run so that the DC water is gradually cooled from the inlet temperature to the outlet temperature. A circulation tank is used along the evaporator. Similarly, the DH water can be heated gradually by using a circulation tank on the condenser side.

Circulation tanks, shown in Fig.3, are filled in the beginning of the circulation phase and emptied in the end. The filling/emptying phase can be arranged to proceed so that both the DC and DH supply and return water flows are continuous. Two buffer tanks are needed in connection to the circulation tank.

One example of how the PDC process can be realised is shown in Fig.4. Only the DC side tank arrangement is shown.

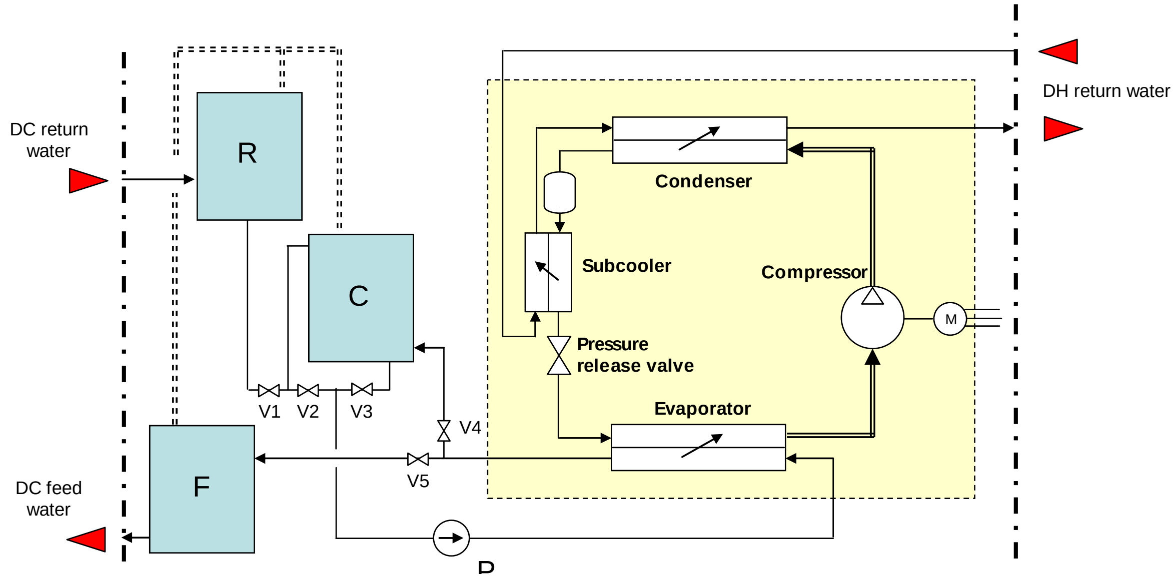

Figure 4. DC water side tank arrangement in the PDC process.

DC water comes continuously from the DC network at the temperature of 16 °C to a return water tank, denoted by R. The water leaves the cooling process from a feed water tank, denoted by F, at the temperature of 6 °C. The circulation tank is denoted by C.

The PDC process has two phases in each period:

Phase 1: Valves V1, V3 and V5 are open, valves V2 and V4 closed. Water is fed from tank R to the top of tank C in a faster speed than the DC return water is filling tank R. Tank R gets empty. At the same time water from the bottom of tank C is fed via the evaporator to tank F. Water inlet takes place in a faster speed than the water outflow to the DC feed water line. Tank F gets filled.

Phase 2: Valves V1, V3 and V5 are closed, valves V2 and V4 open. Water of tank C is taken from the top and circulated to the evaporator. The colder water returns to the bottom of tank C and thus unnecessary mixing of the waters at two different temperatures is minimised. At the same time tank R is gradually filled and tank F gets empty.

The circulation pump P is running during both phases and circulates water from tank C to the evaporator and back.

With the described arrangement the temperature of the water which comes to the evaporator remains nearly constant as long as there is uncooled inlet water left in tank C. The temperature decreases, when the water that has passed once through the evaporator starts to pass again through the evaporator

The arrangement creates a number of cooling steps. The number of steps can be chosen. Below, for the sake of comparison with the multi-cycle process in Fig. 2, the step number is chosen as four.

In the beginning of phase 2, as water is taken from tank R into tank C, the water is at its maximum temperature, 16 °C. The circulating water is cooled 2.5 °C, in the average, in the evaporator during one pass. The fourth cooling step takes place during phase 1, as the water from tank C passes through the evaporator and is cooled to 6 °C, before it is let to tank F.

4.2 Circulation water flow

The chosen number of steps defines the water flow through the pump. The number is denoted here by *N,* the return water flow to tank R by $\dot{m}_r$ and the feed water flow from tank F by $\dot{m}_f$.

Clearly, for the overall water flow balance the return water flow and the feed water flow must be equal

$$\dot{m}_r = \dot{m}_f \qquad (1)$$

The water flow from tank R to tank C is denoted by $\dot{m}_{R\_C}$ and from tank C to tank F by $\dot{m}_{C\_F}$, respectively.

The water flow through the circulation pump, denoted by $\dot{m}_P$ is

$$\dot{m}_P = N \cdot \dot{m}_r \qquad (2)$$

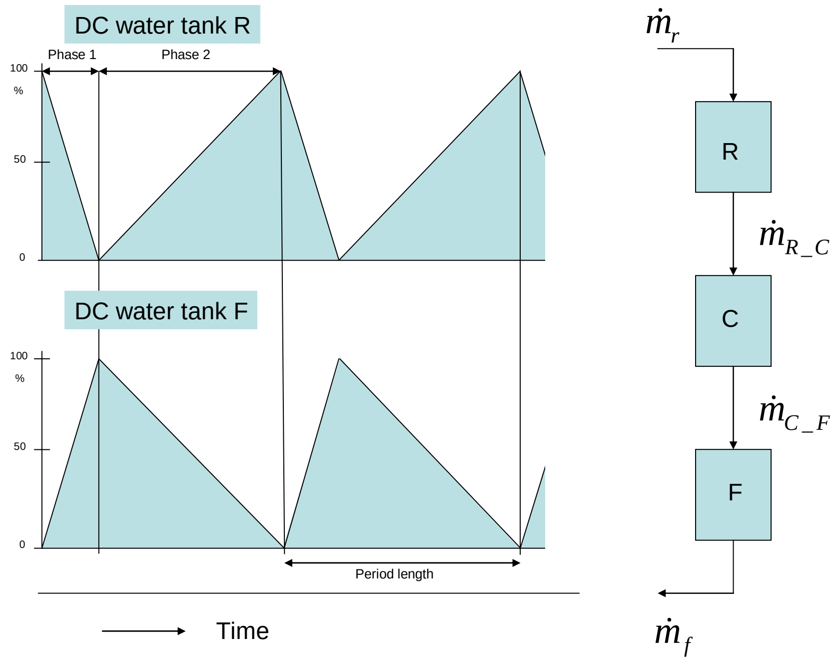

Figure 5. DC water levels in tank R and F during phase 1 and 2.

If, for example, the total temperature decrease is 10 °C (from 16 to 6 °C) then with a step number N = 4, the duration time of the phase 1 is 25 % of the total period time.

4.3 Evaporation temperatures

Along the stepwise cooling of the circulation water the evaporation temperature is lowered. The evaporation temperatures are approx. 9, 7, 5 and 3 °C in the steps with the logarithmic mean temperature difference over the heat transfer surface from approx. 5 K to 4 K.

4.4 Gas transportation between R and F

The DC water tanks are all operated at atmospheric pressure. During phase 1, when tank R gets empty and tank F gets filled, the gas in tank F is flowing to tank R via the gas pipelines, shown by dashed double lines in Fig. 4. During phase 2, when tank R gets filled and tank F gets empty, the gas from tank R is flowing to tank F. The tank C is also connected to the gas pipeline to maintain the atmospheric pressure. Gas could be nitrogen in order to avoid air in the DC water and minimise the inside corrosion of the DC water pipelines.

4.5 Heat recovery

One option for the condensation heat recovery is to transfer the heat into DH water. In the illustrative example below the heat is assumed to be recovered at the temperature of 64 °C, which is 20 °C above the chosen return water temperature of 44 °C. The tank arrangement at the condenser side is similar as the arrangement at the evaporator side (Fig.4).

The heat is assumed to be recovered also from the subcooler. In the PDC process the DH return water is used all the time for subcooling. After having passed the subcooler the DH water is mixed with the outlet water from the condenser. The water temperatures of the two flows are approximately at the same level. The water flow from the subcooler is less than 5 % of the total water flow.

5. Performance estimation

The performance of the PDC process is estimated in a simulated 4-step case in Table 1. The PDC process performance is compared to a conventional compressor-driven one-stage cooling process with 1MW cooling effect. The gas volume flow at the compressor suction side is kept constant and a constant isentropic efficiency of 0.7 is assumed. The water flow into the subcooler is controlled so, that the refrigerant temperature after the subcooler is approx. 3 K above the inlet DH water temperature.

Table 1. Heat flows and COP for a 4-step PDC process in comparison with the one-stage continuous process.

step	$\dot{Q}_C$	$\dot{Q}_E$	P_{Compr}	COP
	kW	kW	kW	-
1	1548	1218	330	3.691
2	1461	1104	357	3.092
3	1382	1009	373	2.705
4	1311	929	382	2.432
mean	1425	1065	360	2.958
continuous process	1386	1000	386	2.591
Cooling effect increase		65		

In Table 1 the heat flow to the condenser and the subcooler is denoted by $\dot{Q}_C$, the heat flow from the evaporator by $\dot{Q}_E$ and the compressor effect into the refrigerant cycle by P_{Compr}.

The increase of 65 kW, i.e. 6.5 % in the cooling effect is obtained with approx. 26 kW or 6.7 % lower electricity consumption.

If, on the other hand, the cooling effect were the same in the two compared processes, a saving in the electricity consumption would be approx. 48 kW or 12.4 %.

6 Discussion

If the PDC water tank system is added in an existing cooling generation process the cooling capacity of the plant is increased, as indicated in Table 1. In the comparison of the PDC process with a conventional process without the tank system, a trade-off between the additional investments in PDC against the increased cooling effect/savings in electricity shall be considered.

The price level of the equipment and the electricity prices are the key factors in the economic calculations. The plant may need buffer tanks for DC water in any case due to often quite strong fluctuations in the cooling effect demand. Such buffer tanks could be utilised directly in the PDC process. Water tanks in the PDC process can be atmospheric, so the tank costs can be kept low. The annual operation hours of the cooling equipment is to be considered as they have a strong influence in the economy.

The tank system should, of course, be designed as small as practical. Circulation tank volume is designed with the chosen number of circulations and the total period time. The minimum needed tank volume should be evaluated on the basis of tests with real cooling equipment. That has not been within the scope of this study.

7 Conclusion

The PDC process gives a possibility to increase the cooling effect in DC generation. The condensation heat could be recovered into DH water instead of discharging the heat for instance into atmosphere or into low temperature cooling water.

Acknowledgements

This study has been made in connection with a research project "Integration of district heating and cooling in regions and buildings". The Finnish Funding Agency for Technology and Innovation, Tekes, and the industrial companies participating in the research project are gratefully acknowledged for the financial support of the study.

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Abstract

The use of District cooling (DC) has increased rapidly in recent years. A common way to produce cold is to cool a circulating water flow with a compressor-driven cooling machine. Water is then supplied to the clients in underground pipelines, for instance at approx. 6 °C. The return water is for instance at a temperature of approx. 16 °C.

It has been suggested that the heat of condensation could be recovered into the district heating (DH) water. An enhanced process for that task is discussed in this paper. In the periodic cooling generation (PDC) process the pressure difference and thus the power demand of the water cooler compressor is lowered by transporting the circulating DC water through a tank system. The cooling factor can be increased by the PDC process, compared to a conventional cooling generation process.

Keywords: District cooling, periodic cooling generation process