

HIGH TEMPERATURE HEAT PUMPS TECHNOLOGY FOR GEOTHERMAL DISTRICT HEATING APPLICATIONS

ABSTRACT

Already since more than three decades high capacity centrifugal heat pumps are reducing CO₂ emissions and are supplying hot water up to 90°C to district heating systems. In most cases the heat is recovered from low temperature heat sources like waste, river and sea water.

However, with the centrifugal heat pump technology energy can also be exploited from high temperature heat sources like geothermal water. With an intelligent heat pump system the district heating return temperature can be boosted and at the same time the exploitation of the geothermal heat source can be increased.

In this paper four examples of large centrifugal heat pumps in district heating applications using ground, water from the Neocomian and Dogger aquifers will be presented. The heating capacity of presented examples ranges from 5'000 to 8'650 kW.

KEY WORDS

High temperature heat pumps, district heating, centrifugal compressor, ground water, geothermal water, Neocomian aquifer, Dogger aquifer

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1. GROUND WATER

Ground water with the mean temperature of 14°C is the most cost-effective heat source from the investment point of view. In contrary to river or lake water the temperature of ground water is almost constant even in the winter period. In summer, ground water can be used for cooling of heat pumps in chiller-mode and rejected heat may be stored underground for reuse during the heating season. With a 2-stage unit heat may be lifted up to 90°C.

Direct use of ground water as a heat source requires a special design of evaporator. However, installations with an intermediate heat exchanger between ground water and clean chilled water are also widely used. Even if there is an additional water loop and pump this

solution offers a very good flexibility. Figures 1a and 1b show simplified schemas of two-stage heat pump with the heating capacity of 5'000 kW designed for a project in the region Île-de-France. In winter and intermediate season the heat pump produces hot water at 80°C and chilled water at 5°C simultaneously. As the cooling demand especially in winter is reduced, the required heat source capacity may be completed from the ground water by means of an intermediate heat exchanger. As shown in Figure 1a, the compressors are connected in series producing very high isentropic lift. The coefficient of performance (COP) for heating is 3.0 and if the complete cooling capacity of 3'350 kW may be used, the total COP for heating and cooling rises up to 5.0.

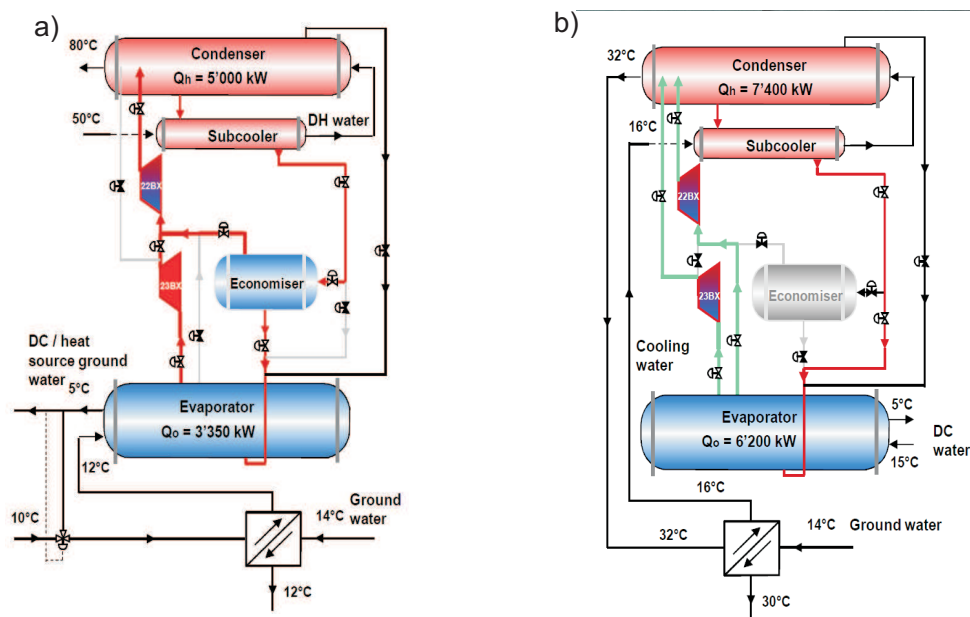


Fig. 1. Simplified schema of heat pump UNITOP 23/22 (project Île-de-France): a) in 2-stage operation for hot water production at 80°C, b) in 1-stage operation. Compressors in parallel

Rys. 1. Uproszczonego schemat pompy ciepła UNITOP 23/22 dla projektu Île-de-France: a) dwustopniowy tryb pracy do wytwarzania wody o temperaturze 80°C. Sprężarki połączone szeregowo, b) jednostopniowy tryb pracy. Sprężarki połączone równolegle

The cooling demand rises in summer and at the same time the need of heat production for sanitary water heating is limited. As shown in Figure 1b, the compressors may be connected during the summer period in parallel to increase the cooling capacity of the heat pump up to 6'200 kW. Both compressors may be operated simultaneously or individually, what offers very effective partial load regulation. The condenser is cooled indirectly by the geothermal water pumped back to the geothermal well at 30°C. The switching from 2-stage (compressors in series) to 1-stage operation (compressors in parallel) is performed fully automatically by the combination of valves.

The performance data of the heat pump for both operating modes are shown in Table 1. It may be seen that in summer mode, the value of COP for cooling in 1-stage operation rises up to 5.1.

Table 1

Performance data of UNITOP 23/22

Tabela 1

Dane techniczne pompy ciepła UNITOP 23/22

	Winter mode	Summer mode
Cooling capacity	3'350kW	6'200kW
Evaporator regime	12/5°C	15/5°C
Heating capacity	5'000kW	7'400kW
Condenser regime	50/80°C	16/32°C
COP cooling	2.0	5.1
COP heating	3.0	–
COP total	5.0	–

Figure 2 shows a general arrangement of UNITOP 23/22. The unit with the dimensions 3'800 × 9'000 × 3'200 may be delivered as a complete package ready for the installation on site. Thanks to the possibility of operation in different modes, very effective partial load conditions and the heat source balancing with geothermal water in winter, the heat pump adapts to very various operating conditions and can be operated all-the-year with the highest efficiency.

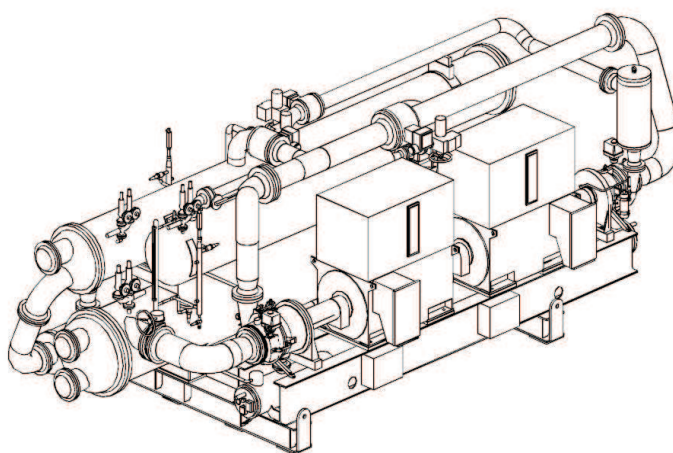


Fig. 2. General arrangement of 2-stage heat pump UNITOP 23/22 for hot water production at 80°C

Rys. 2. Rysunek złożeniowy 2-stopniowej pompy ciepła UNITOP 23/22 do wytwarzania wody ciepłowniczej o temperaturze do 80°C

2. WATER FROM THE NEOCOMIAN AQUIFER

In February 2013 DALKIA FRANCE commissioned the first geothermal installation using water from the Neocomian aquifer, which provides heat to 3'500 accommodations and two large public buildings in the commune Le Plessis-Robinson in the southwestern suburbs of Paris. The heat source is water at 39°C with the volumetric flow of 200m³/h exploited from a 900 m deep geothermal well. Between geothermal and evaporator water an intermediate heat exchanger with a temperature gap of 1°C has been installed. The geothermal water is cooled down to 15°C and injected into a geothermal well.

The extracted heat is then upgraded to 70°C by means of heat pumps. After the long study the solution with two FRIOTHERM's 1-stage heat pumps type UNITOP 22 has been chosen. As shown in Figure 3, the evaporators and condensers are connected counter-currently in series. This arrangement allows equalising of compressors isentropic lifts and increases significantly the COP value. The return temperature from district heating network varies between 40 and 50°C. The technical data of heat pumps are shown in Table 2.

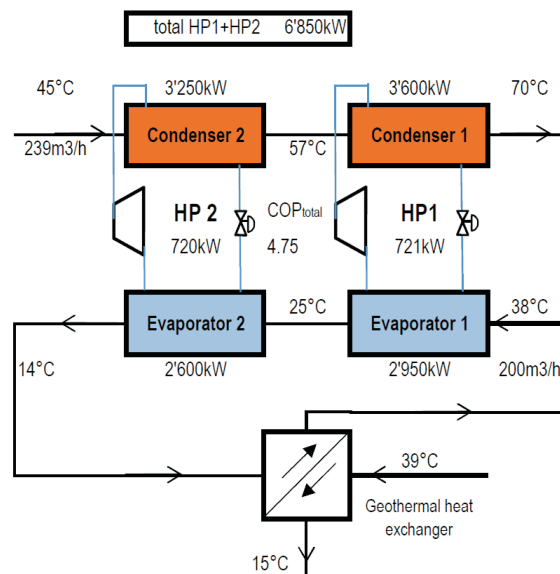


Fig. 3. Heat pumps arrangement (project Le Plessis-Robinson)

Rys. 3. Układ pomp ciepła w projekcie Le Plessis-Robinson

Figure 4 shows the annual heat duration curve for the district heating network of commune Le Plessis-Robinson. The maximum heating capacity of installed heat pumps of 6'850 kW with the partial load operation covers more than 78% of the annual heating demand. During the coldest days the complementary heat is produced by means of gas boilers.

It is very important to design the heat pumps for the basic load of the district heating, what maintain the maximal number of operating hours with the highest heat pump/-s performance.

Table 2

Performance data of UNITOPs 22

Tabela 2

Dane techniczne pompy ciepła UNITOP 22

	HP2	HP1
Cooling capacity	2'600 kW	2'950 kW
Evaporator regime	25/14°C	38/25°C
Heating capacity	3'250 kW	3'600 kW
Condenser regime	45/57°C	57/70°C
COP heating	4.50	5.00
COP total	4.75	

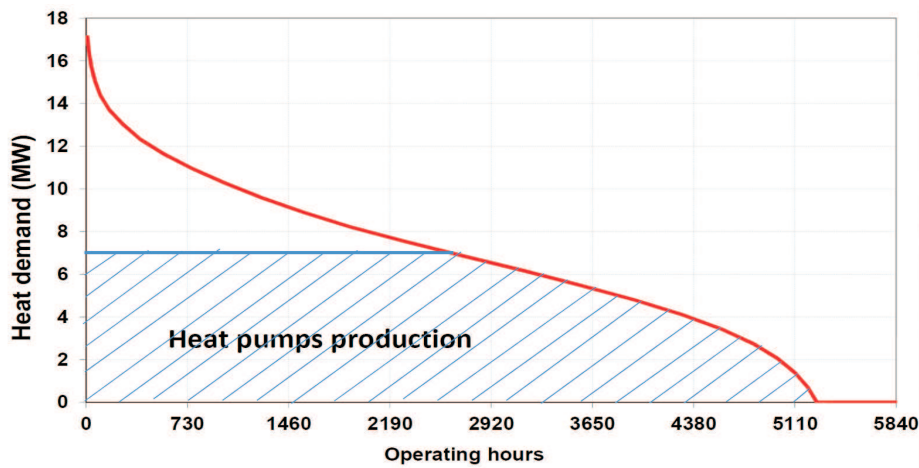


Fig. 4. Annual heat load duration curve for Le Plessis-Robinson (DALKIA France)

Rys. 4. Wykres uporządkowany rocznego zapotrzebowania na moc cieplną dla projektu Le Plessis-Robinson (DALKIA France)

Figure 5 shows a general arrangement of 1-stage heat pump UNITOP 22 designed for Le Plessis-Robinson project. The dimensions of heat pump are 5'400 x 2'000 x 3'000. The units have been designed to fit in the existing room of heating plant.

3. WATER FROM THE DOGGER AQUIFER

As found by Michard G. et al. (1988), waters from the Dogger formation of the Paris basin utilized for heating, have a chlorinity in the range 0.07–0.6 mole/litre and a temperature in the range 48–80°C. However, most of the Dogger geothermal wells provide water at

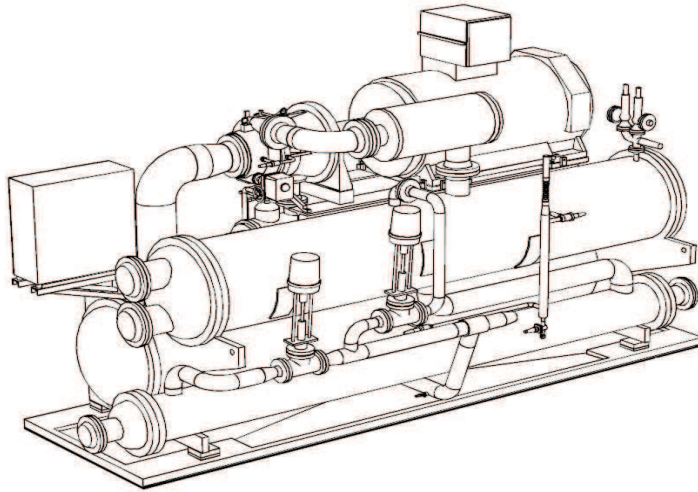


Fig. 5. General arrangement of 1-stage heat pump UNITOP 22 for hot water production at 70°C (project Le Plessis-Robinson)

Rys. 5. Rysunek złożeniowy 1-stopniowej pompy ciepła UNITOP 22 do wytwarzania wody ciepłowniczej o temperaturze do 70°C (projekt Le Plessis-Robinson)

temperatures around 70°C, what allows a direct use of geothermal heat transferred into a district heating network in the intermediate heat exchangers. The flows of geothermal water from the Dogger nappe of the Paris basin are in the range of 250 m³/h.

Figure 6 shows titanium heat exchangers of a geothermal installation with Dogger water in the region Île-de-France. The volumetric flow of Dogger water is 280 m³/h and the



Fig. 6. Titanium heat exchangers of a geothermal installation with Dogger water

Rys. 6. Tytanowy wymiennik ciepła instalacji geotermalnej z wodą ze zbiornika utworu jurajskiego doggeru

temperature oscillates around 76°C. Depending on the network return temperatures, the thermal power transferred into a district heating varies between 6'300 and 11'000 kW.

The utilisation of geothermal heat in the most of district heating systems is limited by the high return temperature from the network. This effect is magnified especially during the winter time, when the return temperatures in some installations may increase even up to 60°C. As a consequence, geothermal water with a relatively high temperature has to be injected into a geothermal well.

An excellent solution to boost the geothermal wells' exploitation even at high return temperatures is offered by centrifugal heat pumps. The most efficient way of implementation, is the installation of heat pump for the cooling of district heating water before entering into a geothermal heat exchanger. Reduced district heating water temperature allows to recuperate more heat from geothermal water.

Figure 7 depicts such type of arrangement for the mentioned before installation in the region Île-de-France. The district heating water is cooled in the heat pump's evaporator from 55 to 37.5°C, then is reheated in two stages firstly by the geothermal water up to 67.2°C and finally in the condenser up to 89°C. In this case, the use of heat pump increases the exploitation of heat from geothermal water by 5'550 kW.

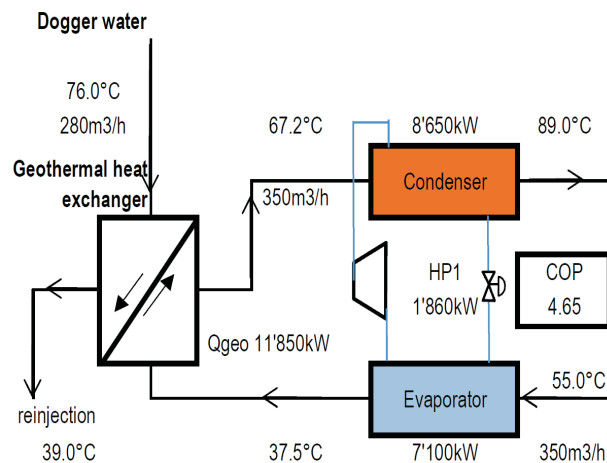


Fig. 7. Heat pump arrangement for boosting of geothermal well exploitation

Rys. 7. Układ pompy ciepła zwiększający eksploatację energii z odwiertu geotermalnego

Depending on the customer's needs, different heat pumps arrangement may be proposed.

Figure 8 presents a very effective use of the heat pump for a boosting of geothermal well exploitation in the district heating network with higher volumetric flow. The return flow is split into two streams. The evaporator gets the same volumetric flow as the flow of geothermal water and the rest flows through the condenser. The evaporator water is cooled down by 10.3°C and then is reheated by the Dogger water up to 71°C. The extracted heat in the evaporator is rejected by the heat pump into the condenser water, lifting its temperature

up to 61.6°C. After that, both hot water streams flow together producing hot water at 67.5°C. The use of heat pump in this application increases the thermal power extracted from geothermal water by 3'000 kW. As the required temperature lift is not high, the COP of the heat pump gives very high value of 6.3.

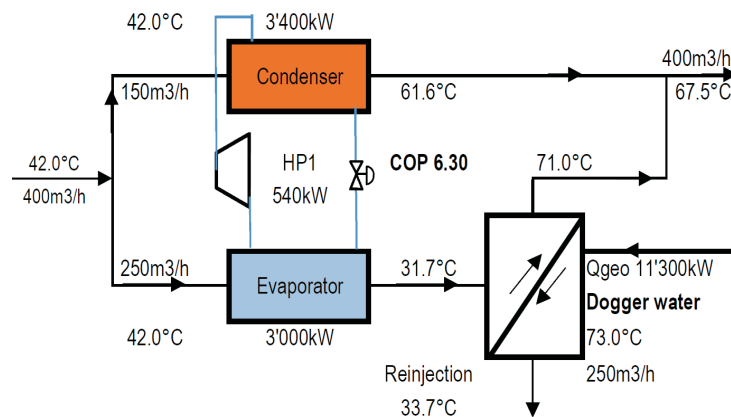


Fig. 8. Heat pump arrangement for boosting of geothermal well exploitation for district heating network with higher volumetric flow

Rys. 8. Układ pompy ciepła zwiększający eksploatację energii z odwiertu geotermalnego dla sieci ciepłowniczych o większych przepływach wolumetrycznych

It is obvious that volumetric flow and return temperature in district heating networks vary continuously. Thus, it is of crucial importance in the heat pump design to take into account all possible operating conditions.

Figure 9 shows the picture of the FRIOTHERM's heat pump type UNITOP 33C widely used in the high temperature geothermal applications.



Fig. 9. Heat pump UNITOP 33C designed for boosting of geothermal well exploitation with Dogger water

Rys. 9. Pompa ciepła UNITOP 33C zaprojektowana do zwiększenia eksploatacji ciepła z odwiertu geotermalnego z wodą ze zbiornika

CONCLUSIONS

The presented high temperature centrifugal heat pump technology has been developed over the last 35 years and offers mature solutions for geothermal installations. It enables the exploitation of heat from ground and waters from the Neocomian aquifer by upgrading it to the temperature levels required by the district heating networks. Furthermore, the heat pumps may significantly increase the exploitation of heat from water hosted by the Dogger aquifer with very high COP values.

As presented above, very different heat pumps arrangements are possible. Their design depends on heat source temperatures, heat source volumetric flow, condenser outlet temperature, volumetric flow and return temperature of district heating water, partial load conditions and so on. Each geothermal project requires an individual study to optimise heat pump design and its hydraulic implementation for the operation in all possible district heating conditions with the highest performance.

REFERENCES

MICHARD G., BASTIDE J.-P., 1988 — Etude geochimique de la nappe du dogger du Basin Parisien. *Journal of Vulcanology and Geothermal Research*, Volume 35, issues 1–2, September, (1988), 151–163.

TECHNOLOGIA WYSOKOTEMPERATUROWYCH POMP CIEPŁA DLA CIEPŁOWNICTWA SIECIOWEGO W ZASTOSOWANIACH GEOTERMALNYCH

STRESZCZENIE

Już od ponad trzech dziesięcioleci odśrodkowe pompy ciepła zasilają sieci ciepłownicze wodą o temperaturach do 90°C, przyczyniając się do znacznej redukcji emisji CO₂. W większości przypadków do odzysku ciepła używane są niskotemperaturowe źródła ciepła, takie jak ścieki, woda rzeczna bądź morska.

Jednakże przy użyciu technologii odśrodkowych pomp ciepła mogą być również eksploatowane inne dolne źródła ciepła, takie jak woda geotermalna. Zastosowanie inteligentnego systemu pompy ciepła umożliwia podwyższenie temperatury powrotu sieci ciepłowniczej do wymaganego poziomu przy jednoczesnym zwiększeniu eksploatacji źródła geotermalnego.

Artykuł prezentuje cztery przykłady zastosowań odśrodkowych pomp ciepła dużej mocy w aplikacjach ciepłowniczych używających wody gruntowej ze zbiorników w utworach jurajskich (neokomu i doggeru). Moc cieplna użytych urządzeń waha się w zakresie od 5 000 do 8 650 kW.

SŁOWA KLUCZOWE

Wysokotemperaturowe pompy ciepła, ciepłownictwo sieciowe, odśrodkowe sprężarkowe pompy ciepła, woda gruntowa, woda geotermalna, zbiornik wodonośny neokomu, zbiornik wodonośny doggeru