Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

GEOTHERMAL PLANT WITH EFFICIENT ABSORPTION HEAT PUMPS DRIVEN BY INCINERATION CHP PLANT. SUCCESSFUL INJECTION IN SANDSTONE AQUIFER. COUNTRY UPDATE DENMARK.

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Key words: Denmark Thisted Klaipeda Absorption Injection Sandstone Combined CHP Efficiency CO_2.

ABSTRACT

Denmark has widespread geothermal aquifers, which can be used for district heating. However, combined heat and power (CHP) plants cover the heat demand on the Danish district-heating networks. The Danish geothermal development has thus been concentrated on a single geothermal plant in Thisted, development of the geothermal concept - and assistance to projects abroad.

More power from windmills etc. and the increasing efficiency of CHP plants may reduce the heat production from CHP plants and create a need for new geothermal plants. The possibility of establishing a geothermal plant in the Copenhagen area is being investigated. The Danish Government has granted financial support for the initial phases.

The geothermal plant in Thisted with an absorption heat pump driven by an incineration CHP plant operates with low costs and low energy consumption. The plant has operated without injection problems for the 15% saline geothermal water in a sandstone aquifer since 1984. Design concept, investment costs and operating strategy for the plant were reported in papers from the World Geothermal Congress 1995.

The performance of the plant has been improved further and the plant is now expanded to a higher flow (170-200 m^3/h) and with another absorption heat pump, which together with the old can cool the geothermal water to around 10°C.

Widespread geothermal aquifers can be used to produce heat with a high efficiency from geothermal plants with both absorption heat pumps and electric heat pumps integrated with heat and power plants. Such plants can become an important part of an efficient system designed to cover the total need for heat and power. Geothermal plants may also be used for the storage of heat and injection of CO2.

DONG (Dansk Olie & Naturgas A/S) has developed geothermal concepts and computer models for design, financial evaluation and optimisation of operating strategies. It has been involved in geothermal projects in Sweden, Germany, Russia, Poland, Latvia, Check Republic, Slovakia and Lithuania as project manager or partner / subcontractor to other Danish companies.

DONG provides project management for assistance to the design and construction of a geothermal plant in Klaipeda, Lithuanian in co-operation with Houe & Olsen on a project initiated by PGI. Absorption heat pumps shall extract 17-20 MW heat from 600-700 m^3/h 38°C water re-injected at 11 °C through 2 wells in Devonian sandstone. The Danish Environmental Protection Agency has granted 3 million USD for the assistance to the planning, design and construction.

1. INTRODUCTION

Denmark has moderate temperature gradients, but many areas with warm sandstone aquifers, which can be used for district heating. Århus University has investigated the temperature gradients and found typical gradients of around 0.03°C per meter, highest in the deeper layers. GEUS (The Geological Survey of Denmark and Greenland) has identified geothermal resources in sandstone aquifers exceeding the energy needed for district heating in Denmark for hundreds of years.

DONG A/S (Dansk Olie & Naturgas) was granted a sole concession for the exploration and production of geothermal energy in Denmark in 1978 of which one third of the area was given back to the state in 1993. Deep geothermal exploration wells were drilled and seismic investigations were made.

Big variations are found for the Danish salinity and permeability gradients, but a rough rule of thumb for the sandstone aquifers is, that the salinity gradient is 10% per km depth, and that the permeability is halved for each 300 m.

The geothermal plant in Thisted was constructed in 1984 as a pilot plant with an electric heat pump. In 1988 it was expanded to the present plant with an absorption heat pump in co-corporation with the local district heating company assisted by Houe & Olsen. It is now expanded again.

The present plant uses approx. 210 kW electricity to extract up to 4 MW heat from the geothermal water. If the borrowed and fully returned driving heat for the absorption heat pump is left out of the balance then the annual COP can be calculated to 13.8 from the use of 1084 MWh electricity to extract 53.9 TJ heat. If the lost possibility of generating power from the 140-150°C warm driving heat for the absorption heat pump is included, then the COP is lower depending on the actually lost power.

Since 1985 around 30 person-years from professionals with an university degree and 10 million USD has been invested in geothermal activities within Denmark and in Danish paid assistance to projects abroad. Around one third of the investment is private (around 2 third public).

The effort has been invested in the expansion of the Thisted plant, development on the geothermal concept, preparation for future project in Denmark and in Danish assistance to studies, plant construction and operation of plants abroad.

Plants with heat pumps extracting heat from ground water and solar heated earth, air and water are not included in the above. Approx. 250 ground water based units were installed in the early eighties and approx. 37.500 other heat pumps are in operation today extracting heat from primary earth and air. The extracted heat is approx. 3400 TJ/year, average system COP approx. 2.8.

Please read also the abstract as part of the introduction.

2. GEOTHERMAL PLANT IN THISTED

Details for the plant were reported in papers from the World Geothermal Congress 1995. The performance of the plant has been improved further and the plant is being expanded now.

An explorative production well to 3.3 km was drilled in Thisted 1982 and a 63°C aquifer was tested, but not chosen due to a high fines content possibly creating fines migration problems. The geothermal plant in Thisted extracts heat from the 45°C warm 100 Dm Gassum sandstone aquifer at 1250 m depth.

Comprehensive testing of corrosion and precipitation was made on a test plant with a cooling tower using metal plate coupons in the warm and cooled geothermal water before designing the plant. The 45°C geothermal water is 15% saline by weight, pH is 6.1 and the gas content 6 vol.% (by degassing to 1 barg, primary methane and nitrogen, CO_2 =0,3 vol.% of the gas)

The primary conclusion was, that if degassing and air ingress is avoided then: Precipitation is not a problem, corrosion rates will be below 0.1 mm per year in carbon steel, AISI-316 is suitable for moving parts protected by a steel housing and the thin plates in plate heat exchangers must be of titanium.

2.1 Thisted Plant design

The present plant extracts up to 4 MW heat with an absorption heat pump from 150 m^3/h of 45°C, 15% saline geothermal water. The geothermal water is re-injected into the Gassum sandstone aquifer 1.5 km from the production well. A picture is enclosed as Figure 1.

The plant was initially constructed as a small pilot plant with an electric heat pump (1984) and expanded to the present plant with an absorption heat pump in 1988. The electric heat pump was later removed from the plant because it did not pay to use it considering the much lower operating costs for the absorption heat pump.

The LiBr-water absorption heat pump is driven by 140-160°C hot water from boilers and a combined heat and power incineration plant (CHP).

All of the heat used to drive the absorption heat pump is recovered on the district-heating network together with the extracted geothermal heat. The driving heat for the absorption heat pump is thus free if it normally goes direct to the district-heating network. A schematic of the plant is shown in Figure 2.

The plant is designed to avoid air ingress in the geothermal loop and keep the injected water clean with:

- Carbon steel tubes (diffusion proof and even corrosion)
- AISI 316 at selected places (e.g. balls in ball valves)
- Filtering of water to one micron in bag and cartridge filters
- Operating system and design avoiding low operating pressures
- Nitrogen bottles securing overpressure during stops
- Gravel packs in production and injection well
- Computer controlled fail safe valves

2.2 Organisation for Thisted Plant

DONG owns the geothermal loop and has the responsibility for operating manuals and the operation, while Thisted Varmeforsyning (the district heating company) owns the rest of the plant and maintains the daily operation of the plant.

The initial geothermal Pilot Plant was erected and operated by DONG. The expansion to the present demonstration plant with the absorption heat pump was performed in joint venture with Thisted Varmeforsyning assisted by Houe & Olsen, who also designed the combined heat and power incineration plant.

2.3 Operation of Thisted Plant

The plant is stopped each spring when the incineration CHP can cover the heat demand alone and restarted each autumn. The stop and start sequence is fully automatic except for check of clean water before start of injection. The operating strategy in Thisted include:

- Clean up pumping to a sewer system at restarts of the plant
- Not allowing injection before the geothermal water is without oxygen and checked clean by filter coupons
- Always keeping the geothermal loop pressurised (e.g. switch from flow control to pressure control while stopping the plant. Nitrogen supply when the plant is stopped)

The design and operating strategy has, together with a low CO_2 content and no H_2S, avoided corrosion and injection problems and the plant has demonstrated, that a geothermal plant using 45 °C, 15% saline water with injection in a sandstone aquifer can:

- Have low operating costs
- Have corrosion rates of approx. 0.06 mm/year in iron pipes
- Use 10-15 kW electricity on heat pump to extract 4 MW
- Inject millions cubic meters 15% saline geothermal water through 15 years in sandstone at low stabile pressures
- Run a submersible pump for 7-8 years without inspection.
- Have around one unplanned stop per year
- Use less than one set of one micron filters per year

The injection well in Thisted is prepared for clean up by nitrogen lift, but this has not yet been needed.

2.4 Economics

Operating costs vary through the years, but the following has been estimated as average costs for 20-25 years at the present operating conditions (150 m3/h geothermal water, 7 month operation annually and one USD = 7 DKK:

	Thousand USD per year
Production pump & wells	30
Absorption heat pump	10
Pipes, valves, control system, building	15
Filters & nitrogen etc.	5
Operating personnel	30
Administration etc.	20
Electricity	70
Total	180

Payment for borrow of absorption heat pump driving heat is not included (receives driving heat from incineration CHP plant at 140-150°C and returns it at a temperature sufficient for district heating, but not for power production).

The Investment costs in 1982-1988 money were DKK 71.5 million including exploration/production well to 3.3 km and electric heat pump plant from the pilot plant. The plant is financed by DKK 39,8 million from DONG, DK14.2 million from Thisted Varmeforsyning and DKK 17,5 million from EU.

The present annual heat extraction from the geothermal water production is 50-55 TJ. It is limited by the heat production from the incineration CHP plant, which covers the heat demand alone in the summer time. It is thus not possible to repay all the investment costs at the present operating conditions.

The annual operating costs are, however, very low, the heat demand is increasing slowly and the absorption heat pump is often operating on 140% load making it possible to obtained a much better cooling of the geothermal water by having more heat pumps, e.g. in serial. The geothermal flow can also be increased. This will increase the income, but more operating hours are still needed to make the whole project including explorative cost profitable.

3.0 Ongoing expansion of Thisted Plant

It was decided to expand the geothermal plant in the autumn 1999. The basis for the decision was a 50% expansion of the production capacity for 1.5-2 million USD. DONG provides project management for the expansion with Houe & Olsen as subcontractor.

The expansion includes a frequency control of the submersible pump in order to increase the capacity and reduce power costs when the full capacity is not needed. The heat demand is only increasing slowly. It was therefore decided to increase the production by increasing the flow from the old submersible pump gradually - accepting a break down. A new bigger submersible pump is then put on stock to be installed when needed.

This concept has lead to the installation of both a frequency controlled booster pump and injection pump. The booster pump makes it possible to obtain a higher flow rate from the existing submersible pump without having pressures below the bubble point (approx. 5 barg).

The booster pump may also reduce the required size for the new submersible pump and reduce the problem of adjusting both the pressure and the flow without running it unbalanced - and thus increase the expected life time.

Altogether the plan is to install a new absorption heat pump, additional injection filters (1 micron cartridge filters), a frequency control for the submersible pump and frequency controlled booster - and injection pumps. Further, the larger submersible pump is bought and put on stock for later use.

This is panned to bring the geothermal flow capacity up to 175 m^3/h with the existing submersible pump and 180-200 m^3/h when the new submersible pump is installed. The additional absorption heat pump is expected to bring the injection temperature down to 10-13 ^oC.

A preliminary lay out for the plant is shown in Figure 3. It is taken from an excel/VB programme used to optimise the design and operating strategy.

Bids for the new heat pump and experience from bids for the Klaipeda plant etc. has confirmed that the calculated performance is realistic for present LiBr-water based commercial heat pumps.

A full coupling of the heat pumps in series (where absorbers in series preheat the district heating water and the condensers in series or parallel transfer the remaining heat) would increase the cooling of the geothermal water with approx. 1°C. However, the old heat pump is not designed for a separate heat supply from the absorber and the condenser - and it is also not designed for the full future flow rate on the district-heating network.

An intermediate solution with a coupling of the absorbers in series, but with bypass of part of district heating water at the old heat pump absorber, may also be considered. According to our calculations two new large "standard" LiBr-water absorption heat pumps could cool the geothermal water to 5°C heating 40°C water.

The cooling to 5°C is, however, not optimal at the present price level for heat considering the required size of the heat pumps. A cooling to 7-11 °C is, however, quite realistic and much lower than the evaporator outlet temperatures read from typical performance curves for single absorption heat pumps.

4.0 Plans for demonstration plant in the Copenhagen area

A large part of the Danish heat demand is covered by heat from district heating networks. The district heating networks operate the whole year. In the summer time the heat is normally only used for preparing hot tap water by domestic heat exchangers, but it is occasionally also used for room heating on a chilly day.

The annual heat production to Danish district heating networks is approx. 125 PJ from primary combined heat and power plants. The largest Danish district heating network is situated in the Copenhagen area, where two large transmission systems distributes heat to several local district heating networks from several CHP plants based on coal, gas and garbage - and some gas and oil based peak load boiler stations.

More power from windmills etc., increasing efficiencies for heat and power plants and the construction of smaller CHP units is expected to reduce the future production from CHP plants. Geothermal plants are suitable for a non-polluting supplementary heat production.

It has thus been decided to start preparations for a future need for a more substantial heat production from geothermal plants by investigating the possibility of establishing a geothermal plant in the Copenhagen area. The Danish Government has granted financial support for the initial phases.

The seismic coverage in the area is poor, but there are several possible sandstone aquifers including the Gassum aquifer known from the gas storage in Stenlille and deeper aquifers known from Sweden (from wells around Malmö and seismic lines on land and in the sound).

DONG has formed a group with the heat and power producers and transmission companies in the Copenhagen area region to prepare the establishment of a demonstration plant. A co-operation with Sydkraft Värme Malmö AB has also been established to gain from the sharing of information and possibly also drilling etc. if it is decided to establish a geothermal plant in the same period.

It is the plan to shoot marine and land based seismic lines and to drill an exploration well to 2.2 km in year 2000-2002. The exploration well is planned reused as production well. An injection well is planned drilled and a surface plant constructed in the years 2002-2004.

A preliminary concept for a demonstration plant in the Copenhagen area is shown in Figure 4. (print out from geothermal prospecting and evaluation programme).

5 COMBINED CONCEPTS

5.1 Integrated geothermal and heat & Power plants

Integrated heat & power plants (CHP) and geothermal plants using the widespread aquifers with moderate temperature levels can produce heat and power with a very high efficiency. Concepts covering a varying demand for heat and power with combined cycle CHP plants driving geothermal plants with both absorption and electric heat pumps have been developed.

An integrated plant with active absorption heat pumps and passive electric heat pumps e.g. selling 88MW heat and 45MW while power burning 100MW fuel is shown on Figure 5.

The same integrated plant with active absorption and electric heat pumps selling e.g. 284 MW heat and no power while burning 100 MW fuel is shown on Figure 6.

When there is a changing need for heat and power the integrated plant can adapt to the need. The total efficiency will drop with increasing power sale from the 284% efficiency (Figure 6.) when selling heat only to 48% when selling power only.

The CHP plant is assumed to comprise a gas turbine with exhaust boilers supplying hot water for district heating and steam to drive a high-pressure turbine condensing in the absorption heat pumps generators. If the CHP plant include a low-pressure turbine (hardly advisable considering the few annual operating hours), then the efficiency may be increased to 52 % when selling power only.

Figure 7 shows the efficiency for integrated plants in a situation with a need for both heat and power based on the ratio between sold heat and power (min. shown heat sale = CHP heat). The plot includes curves, for:

- Geothermal plants with absorption heat pumps and electric driven heat pumps based on 45°C geothermal water
- Geothermal plants with absorption heat pumps and electric driven heat pumps based on 65°C geothermal water
- Geothermal plants with absorption heat pumps and geothermal plants with heat exchangers only based on 45°C geothermal water

The integrated plant may also buy power and use electric heat pumps only in a period where windmills or other non-polluting power producers can cover the power demand alone.

The geothermal plants producing heat from a 65 or 45°C aquifer are assumed to use 6-7% power compared to the heat extracted from the geothermal water using absorption heat pumps only and 23-28% power compared to the condenser heat using electric heat pumps only.

The annual power production to Danish consumers is approx. 125 PJ - nearly exactly the same as the heat production to Danish district heating networks. This and the curves on Figure 7 makes it evident, that substantial savings on fuel can be obtained by combining CHP plants with geothermal plants.

Scenarios exist, where integrated plants can produce heat with close to 1000 % efficiency. This can happen for integrated plants with absorption heat pumps only working together with boilers producing heat to district-heating networks.

Power and heat from the CHP plant is then used to drive geothermal plants with absorption heat pumps only supplemented by borrowed boiler heat. The boiler heat is fully returned at a sufficient temperature and there is no fuel consumption associated with the borrow and return of this driving heat. The integrated plant has then produced the heat using only the fuel consumed by the CHP plant. The produced head may exceed 1000% of the used fuel at very good conditions.

The heat balance for a more typical plant e.g. selling 855 MW heat while burning 100 MW fuel is shown on Figure 8.

5.2 Combination with heat storage and CO_2 removal

A geothermal plant can be part of a “zero emission plant”, where power and driving heat for absorption heat pumps at the geothermal plant comes from a combined heat and power plant and harmful emissions, primary CO_2 , are injected. It can also be combined with heat storage - e.g. in order to store excess summer heat production. Such combined concept was reported in my papers from the World Geothermal Congress 1995.

The pressure in a geothermal aquifer will normally exceed the critical CO_2 pressure of 72.8 bar and the critical temperature of 304.2 K. Injected CO_2 will thus remain in dense phase or be dissolved in the geothermal water.

The cost of extracting and injecting the CO_2 may e.g. ad up to 40 USD per ton CO_2 and a combined geothermal and CHP plant with CO_2 injection can contribute both to the heat and power supply producing heat and power at more than 100% efficiency.

Atmospheric air contains approx. 0.033 vol.% CO_2 and 20.95 vol.% oxygen. The total amount of oxygen on the earth is approx. 1.2×10^{15} ton. The annual CO_2 emission is 10-20 ton CO_2 per capita in industrial countries.

If 6 billion people on the earth each shall inject 14 ton CO_2 in the ground annually, then 60 billion ton oxygen shall be removed from the atmosphere annually. This would remove 1% of the oxygen in 200 years. Less CO_2 will be injected in reality and the injection can contribute to the reduction of the CO_2 emission until the production can be reduced.

Figure 1. Geothermal plant in Thisted with basin used to remove methane when clean up to sewer, wellhead shelter, geothermal plant, heat accumulation tank and incineration based CHP plant supplying driving heat to the absorption heat pump.

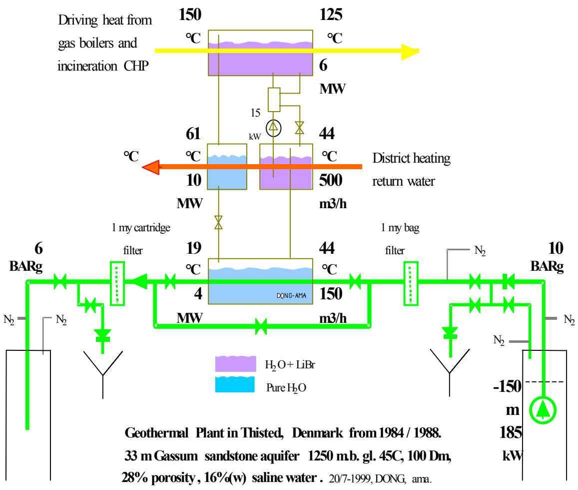


Figure 2. Present demonstration Plant in Thisted with absorption heat pump on nearly 140 % load. New absorption heat pump, a larger frequency controlled submersible pump and frequency controlled booster - and injection pumps are installed.
Figure 3. is enclosed on next page.

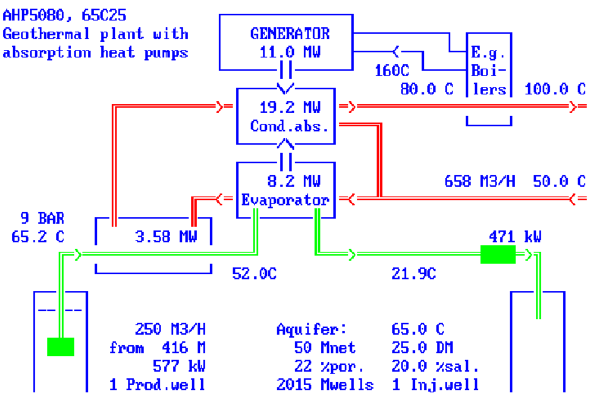


Figure 4. Preliminary concept for demonstration plant in the Copenhagen area from geothermal prospecting and evaluation programme (one of several alternatives).

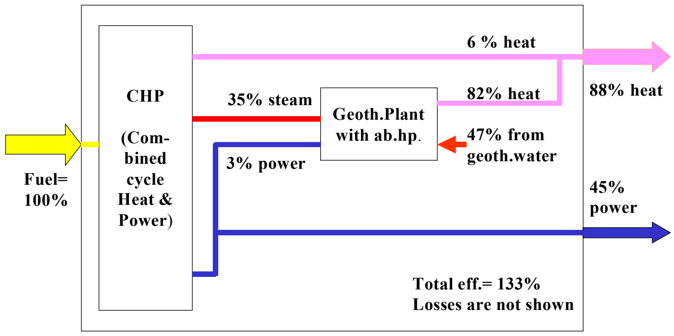


Figure 5. Combined cycle CHP and 65°C geothermal water. E.g. 88MW heat and 45 MW electricity from 100MW fuel.

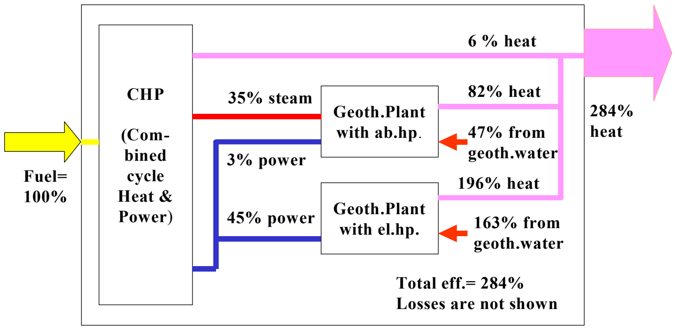


Figure 6. Combined cycle CHP and 65 °C geothermal water. E.g 284% MW heat from 100MW fuel.

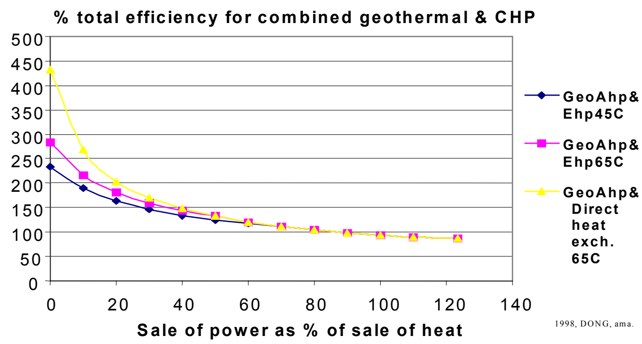


Figure 7. Efficiency for integrated plants at different ratios between heat and power production.

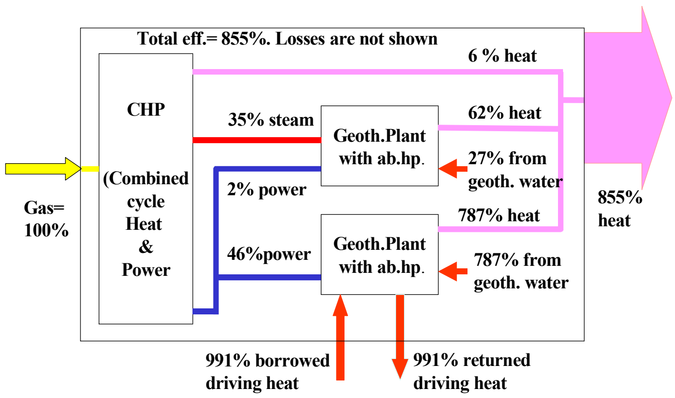
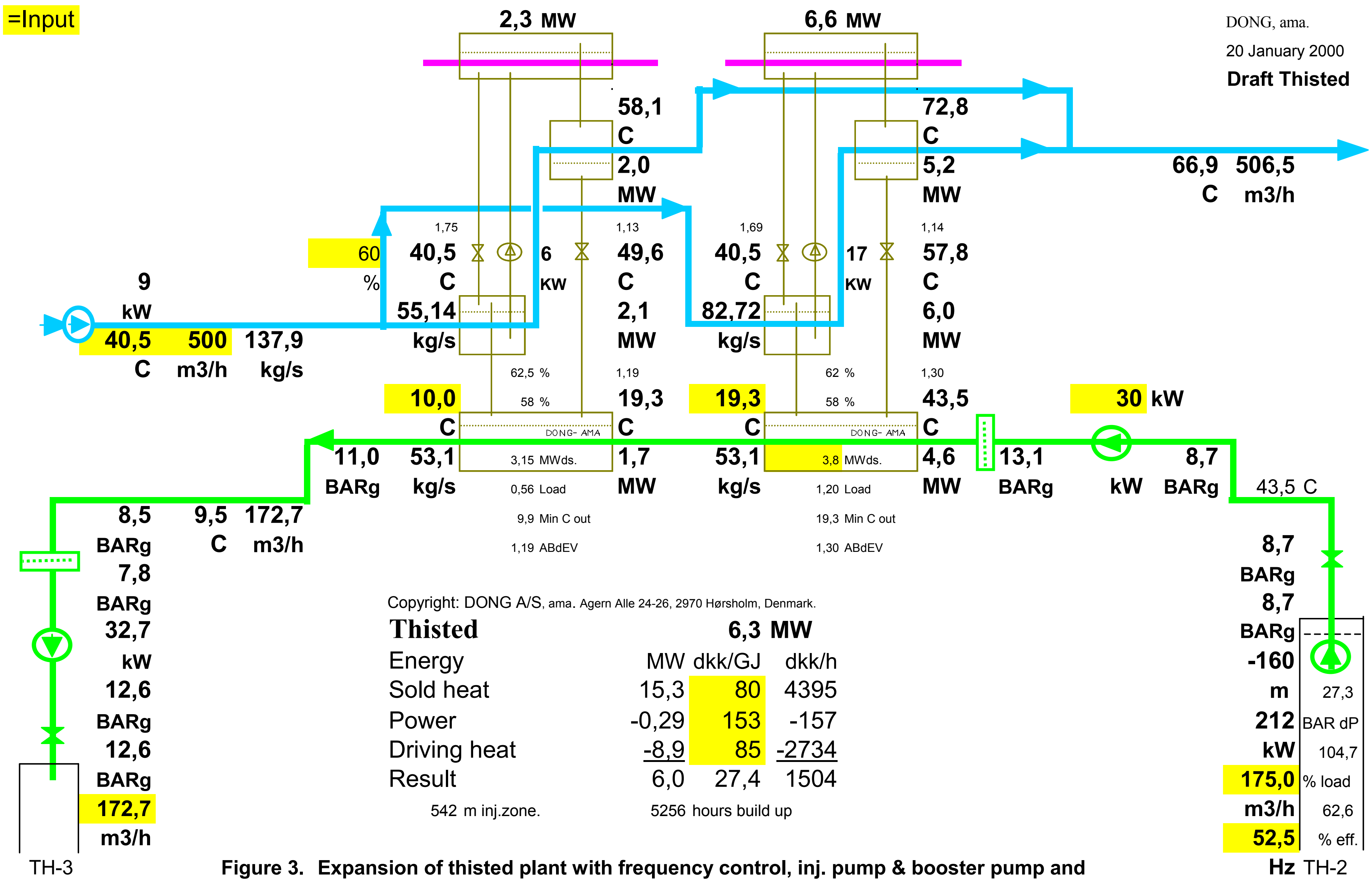


Figure 8. Combined cycle CHP and 45 °C geothermal water. Borrow of driving heat from existing boilers. E.g. 855 MW heat from 100 MW fuel.



Thisted	6,3 MW		
Energy	MW	dkk/GJ	dkk/h
Sold heat	15,3	80	4395
Power	-0,29	153	-157
Driving heat	-8,9	85	-2734
Result	6,0	27,4	1504

542 m inj.zone. 5256 hours build up

Figure 3. Expansion of thisted plant with frequency control, inj. pump & booster pump and new AHP. From pc-programme used to optimise design and operation strategy.