



UNITED NATIONS  
UNIVERSITY

GEOTHERMAL TRAINING PROGRAMME



LaGeo S.A. de C.V.

## NEW DEVELOPEMENT IN THE ORC TECHNOLOGY

**Dr. Páll Valdimarsson**

Reykjavik University / Atlas Copco GAP Geothermal competence Center

Reykjavik / Cologne

ICELAND / GERMANY

*pallv@ru.is / pall.valdimarsson@de.atlascopco.com*

### ABSTRACT

This paper treats a few aspects of the Organic Rankine Cycle technology. The benefits of variable geometry inlet guide vanes (IGV's) in radial turbines for the ORC cycle are presented and discussed. One of the areas where variable IGV's are beneficial is cogeneration of power and district heat. Cogeneration and how the district heating should be connected to the power plant is presented, as well as the benefits from the variable IGV's. The third theme treated is the so-called transcritical ORC cycle, which is already established in waste heat recovery, but is now making its entry into geothermal power production. Finally a hybrid power plant is discussed, in this case a back pressure steam turbine is used together with an ORC plant, making release of non-condensable gases easier, as well as enabling the use of wells with lower wellhead pressure than what a flash plant could use.

### 1. THE ORC TECHNOLOGY FOR GEOTHERMAL POWER PRODUCTION

The most common technology for geothermal power production is a flash cycle, where the geothermal fluid is allowed to boil and the generated steam is expanded through a steam turbine in one or two pressure stages (single/double flash), usually in a condensing plant. Back pressure turbines have low efficiency and are seldom used. Some geothermal fields have very high enthalpy, so that the fluid from the wells is only steam, and no separation of brine and steam is needed. Then all the well fluid can be directly expanded through a turbine (dry steam cycle).

If the enthalpy of the geothermal fluid is low, then the steam generated in a flash cycle will not have sufficient quality for power production. The ORC technology is used to produce power from such sources.

Power generated from geothermal heat is divided on the various power plant types as shown in Figure 1.

The ORC plants are usually smaller than the flash plants. The average size of a geothermal ORC plant is around 5 MW. The number of geothermal power plants of each type is shown on Figure 2.

The ORC technology traces its origins back to early last century. The first application of ORC in a geothermal application was a research plant in Paratunka, Kamchatka in 1967. The first geothermal ORC turbine built by Atlas Copco started operations in 1982 in East Mesa, California. A photo of this turbine is shown on Figure 3.

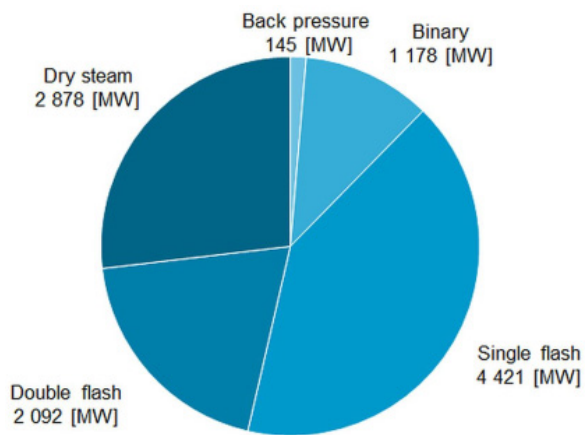


FIGURE 1: Installed power in geothermal power plants 2010 (Bertani, 2010)

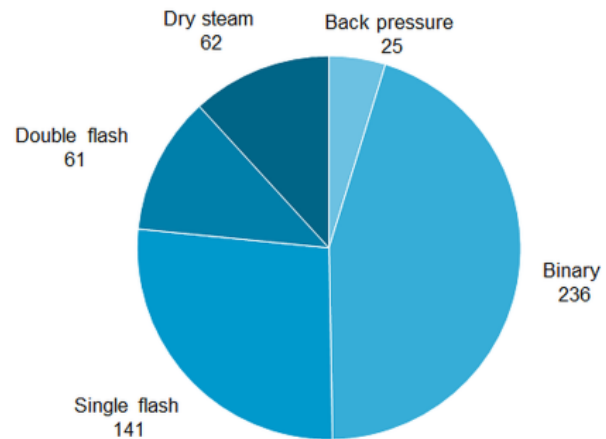


FIGURE 2: Number of geothermal power plants by type 2010



FIGURE 3: The Atlas Copco geothermal ORC turbine in East Mesa 1982

The basic ORC cycle does not offer much innovation. The boundary conditions for a geothermal power plant are far from being similar from field to field, from location to location.

The geothermal resources are vastly different from field to field. Some fields have non-condensable gas mixed with the fluid, some have mineralized brine requiring special design to avoid scaling, some have high enthalpy and consequently some have low enthalpy.

The cold end conditions for the power plant are also different from location to location. In some cases cooling and condensation can be done by natural cooling water from the ocean or a river. Sometimes no water at all is available, leaving an air cooled plant at the mercy of sun and high air temperatures. The third dimension is the question if there is a market for the residual heat from the plant in the form of district heating of buildings, industrial drying or aqua/agriculture.

Therefore this paper will focus on the adaption of the ORC cycle to different boundary conditions – an area where most improvements are likely to happen in the future.

## 2. RADIAL TURBINES WITH VARIABLE GEOMETRY INLET GUIDE VANES

The inlet guide vanes to a turbine stage accelerate the fluid by converting enthalpy into kinetic energy. The velocity of the fluid exiting the guide vanes is thus dependent on the pressure difference over the vanes as well as the inlet pressure, enthalpy and mass flow.

The turbine has to run at a fixed rotational speed in order to keep the frequency of the electricity generated constant.

This means that if the guide vane exit velocity vector is not exactly at the design value (both size and direction), the angle of attack as the flow meets the leading edge of the rotor blade will not be correct. Variations in this angle of attack lead to losses, and thus a drop in the isentropic efficiency of the turbine.

Variations in the flow of the working fluid through the turbine in an ORC power plant are most frequently caused by variations in the amount of geothermal fluid available to the power plant, this can be caused by variations in the flow produced by the wells or because of demand for the geothermal fluid by other processes, such as district heating on a cold day.

Variations of the pressure difference over the guide vane stage are most frequently caused by variations of the temperature of the cooling air or water, which in turn will influence the condenser pressure.

A radial inflow turbine can be built with inlet guide vanes which can be moved. Such turbine is capable of handling large pressure ratios, so they have only one stage – or only one set of inlet guide vanes. The construction of the Atlas Copco radial inflow turbine is shown on Figure 4.

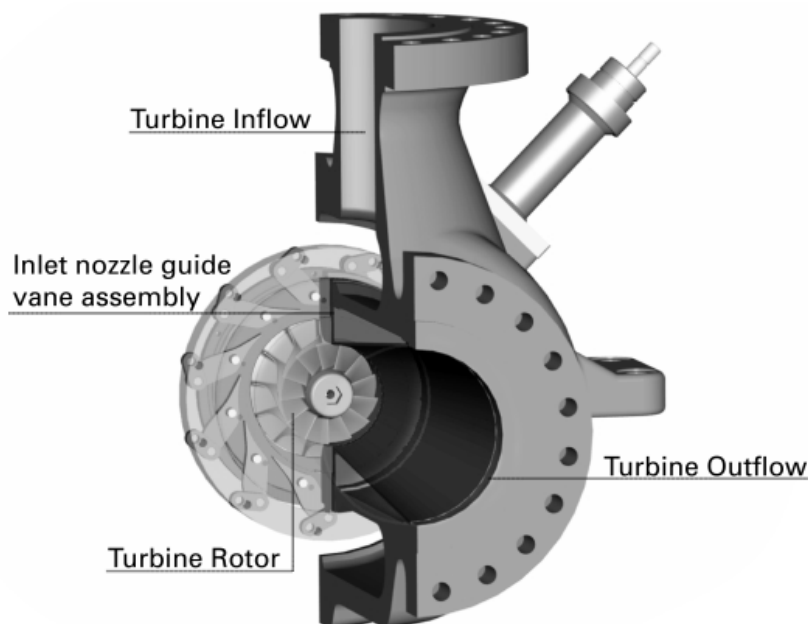


FIGURE 4: Schematic of the Atlas Copco radial ORC turbine

The guide vanes are moved in such a way that the flow area between the vanes changes, and work thus similarly to a turbine control valve in an axial turbine. But the difference is that the flow change in the

radial turbine is not made by throttling the flow, but by changing the flow area for acceleration of the fluid. The direction of the flow vector is changed at the same time by ingenious design of the guide vane form.

A simplified picture of the inlet guide vane system in the Atlas Copco turbine is shown on Figure 5.

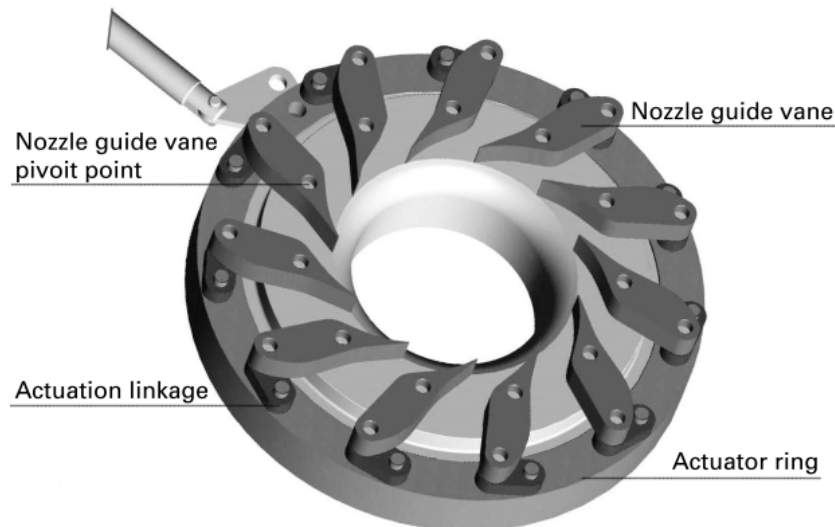


FIGURE 5: Schematic of the Atlas Copco variable IGV system

The result of this is that the turbine is able to maintain high isentropic efficiency over a wide range of operating conditions. This is especially important for power plants with air cooled condensers, where the pressure ratio changes due to air temperature variations. The same applies for cogeneration power plants where the district heating has to get preference during cold days.

### 3. COGENERATION OF POWER AND DISTRICT HEAT IN AN ORC POWER PLANT

An ORC power plant may have residual heat which can be used as a heat source for district heating. Heating of buildings is in fact just to keep the indoor temperature at 20°C, so theoretically it should be sufficient to supply heat at 21°C to the building heated. In reality there are many geothermal district heating systems having supply temperature as low as 50-70°C all year. Most of the buildings in Iceland have district heating supply temperature at or below 80°C all year (Samorka, 2014). The geothermal district heating in China may have supply temperature as low as 50°C.

An ORC power plant which has no limitation on the temperature of the geothermal fluid due to scaling or secondary process requirements has frequently highest power production at a return temperature around 70°C. This is of course dependent on the cycle design, but can be taken as a “not unusual” value. It is obvious that if the geothermal fluid can be cooled more, that heat will be free of charge for a district heating network.

Therefore the main issue in operating an ORC power plant in cogeneration with a district heating system is how the coupling between the systems can be arranged so that as much as possible of the heat supply to the district heating system is free of charge.

It is obvious that the lower the district heating return temperature from the district heating system to the power plant is, the more of the heat needed for reheat will be free of charge. The only way to lower the district heating return temperature is to stimulate the consumers to install large surface radiators, allowing a minimal temperature difference between the indoor air and the return temperature. Usually this has to be done through the tariff system.

The connection which is recommended by Atlas Copco is shown on Figure 6.

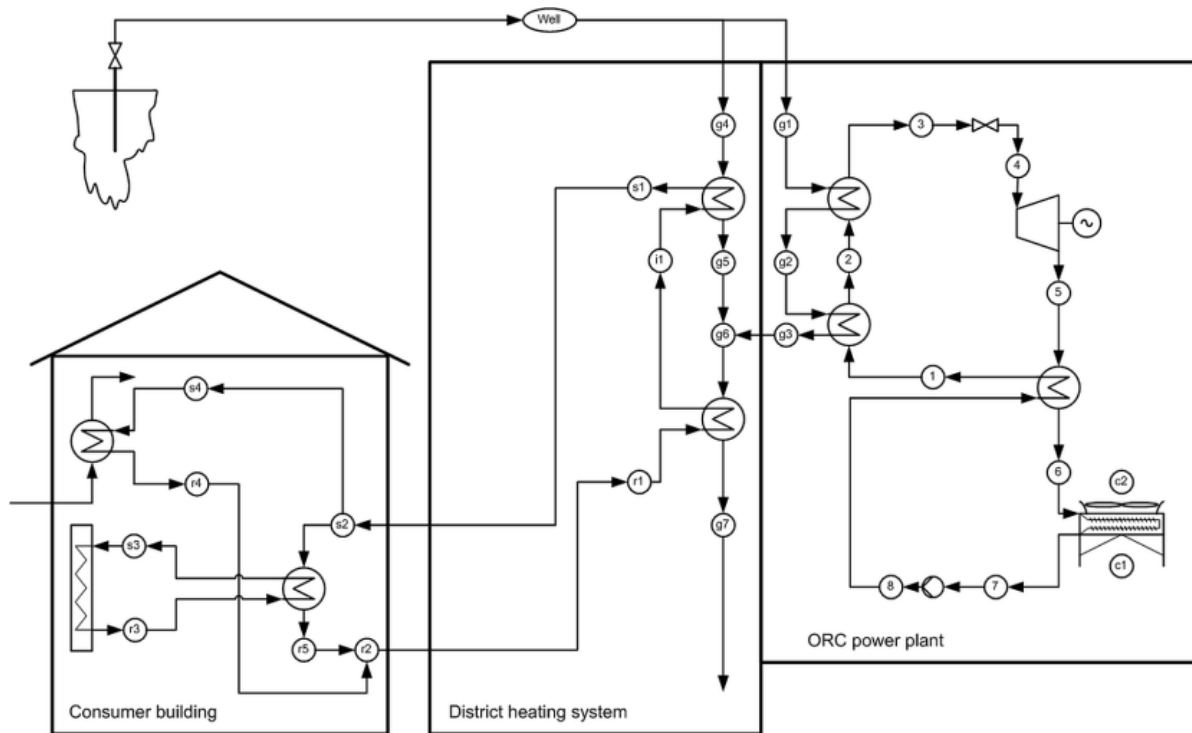


FIGURE 6: Schematic of the Atlas Copco district heating cogeneration connection

The geothermal fluid which is used at point g4 is taken away from the power plant and will reduce what is available for the plant in point g1. This flow is therefore very costly, and the cost is represented by lost revenue because of reduction in electrical power output. But the fluid in point g3 has given all the useable heat to the power plant. All heat from this source can be seen as free of charge.

The lost revenue is shown on Figure 7 as an area in a duration diagram for a design made by Atlas Copco.

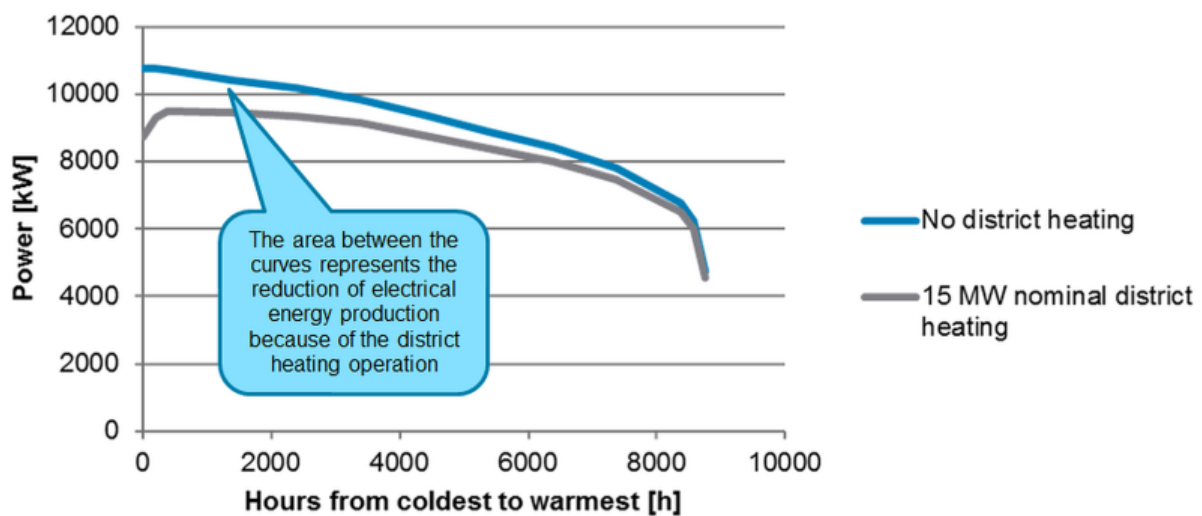


FIGURE 7: Power duration curves for a sample case of cogeneration

The quality of the cogeneration connection is best seen by looking at the reduction of flow available to the power plant because of the district heating. Figure 8 is a similar diagram as in Figure 7, but now with the flows of geothermal fluid to the plant and to the district heating system:

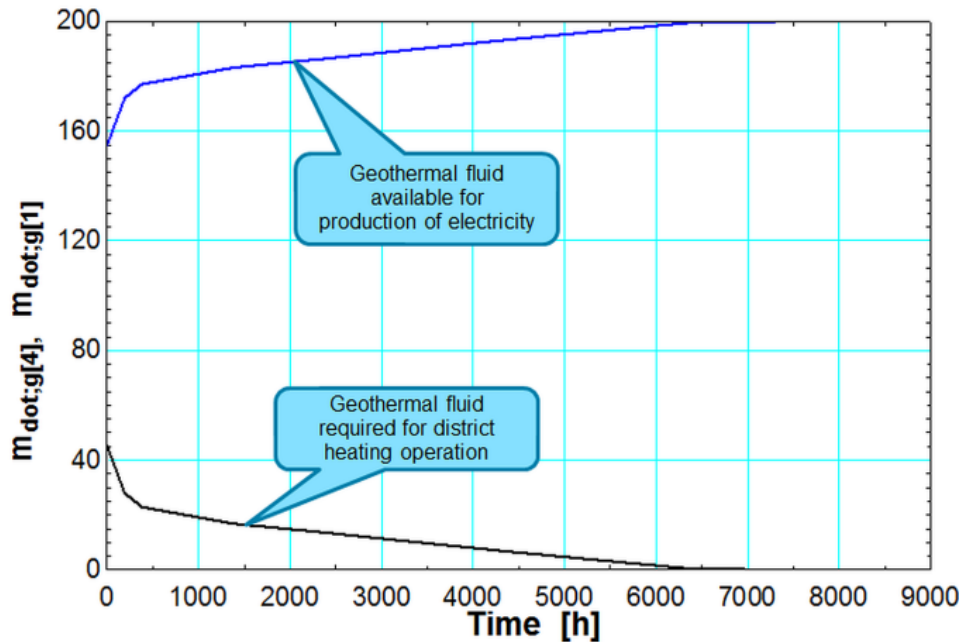


FIGURE 8: Flow duration curves for a sample case of cogeneration

These flow changes will lead to change in working fluid mass flow through the turbine. As these flow changes are related to the outside air temperature (building heating load changes) the condenser pressure will change at the same time. Thus the velocity vector from the turbine inlet guide vanes will change, unless the change is compensated for by movement of the vanes. The duration curve of the Atlas Copco variable inlet guide vane radial turbine is shown on Figure 9.

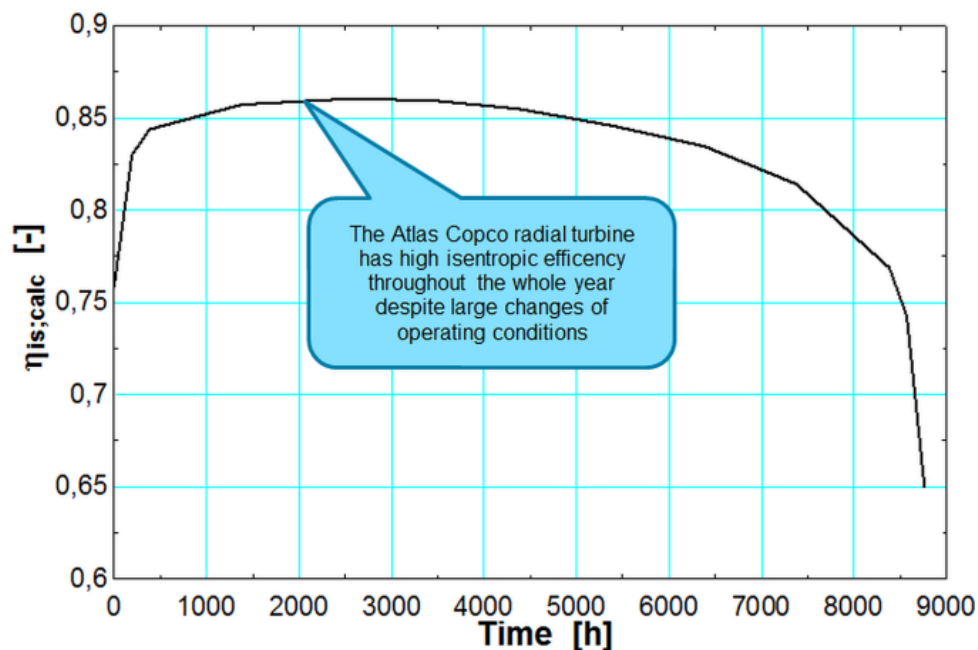


FIGURE 9: Turbine isentropic efficiency duration curves for cogeneration

#### 4. TRANCRITICAL ORC POWER PLANTS

A transcritical ORC power plant has pressure higher than the working fluid critical pressure on the high pressure side of the plant. The condenser is operating in the same way as in a conventional ORC plant, having pressure well below the working fluid critical pressure. The working fluid is thus supercritical on the high pressure side and subcritical on the low pressure side, leading to the logical designation “transcritical” for the cycle.

The working fluid enters the high pressure side as compressed liquid. Heat is added to the fluid, but as the pressure is higher than the critical pressure, the fluid cannot boil. There are no bubbles created, there is no interface anywhere between a vapour phase and a liquid phase. The fluid just gets less dense and more vapour-like as the temperature increases. When the fluid has been heated to sufficiently high temperature, it can be expanded through a turbine.

The benefit of the transcritical cycle is that the temperature difference over which the heat is transferred in the “vaporizer” can be made less than what it is in a conventional ORC cycle, provided that the source fluid has only sensible heat. If heat is transferred over a finite temperature difference, entropy will be generated and exergy will be lost. This is minimised in the transcritical ORC cycle. Therefore the transcritical cycle is at its best when the source fluid is liquid water or gas, and no condensation (latent heat) is in the source fluid.

A temperature-heat duty diagram of a transcritical cycle is shown on Figure 10.

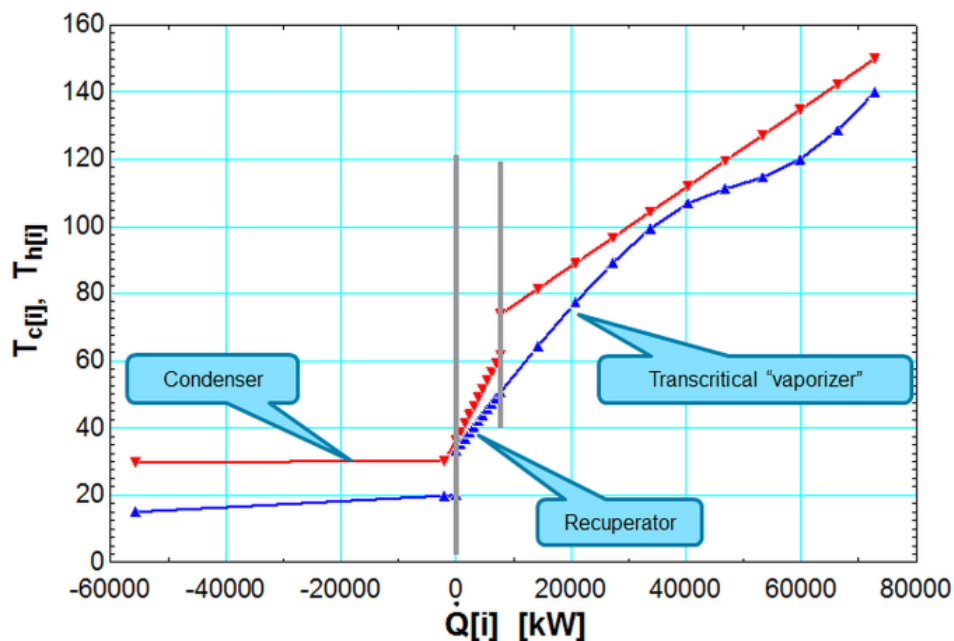


FIGURE 10: A temperature-heat duty diagram for a transcritical ORC cycle

Atlas Copco has already built and commissioned a transcritical 2 MW ORC plant for waste heat recovery in Judy Creek, Canada in December 2012. The design and construction of this plant has given valuable insight into the transcritical ORC cycle, and is now as well offered for geothermal applications. Figures 11 and 12 show the main plant components.

#### 5. NON-CONDENSABLE GAS (NCG) AND HYBRID ORC POWER PLANTS

High enthalpy geothermal wells usually deliver a mixture of brine, steam and non-condensable gas. The mixture is separated in a flash cycle, and the steam-gas mixture is then expanded through a

turbine. The brine is disposed of at a temperature corresponding to the separator pressure, which is in turn a result of an optimisation, taking well productivity and cycle performance into consideration. In many cases the brine can be cooled to a still lower temperature before scaling occurs.

The selected separator pressure sets a limit to which wells can be used. If a well has not sufficient wellhead pressure to bring a decent amount of fluid to the separator, then the well is unusable and the investment in the well has to be written off.

The gas which went through the turbine will not condense, and has to be removed from the condenser. This may require considerable effort, as the condenser pressure in a flash plant is 90% or so of absolute vacuum. Figure 13 shows a simple schematic of such a flash plant.

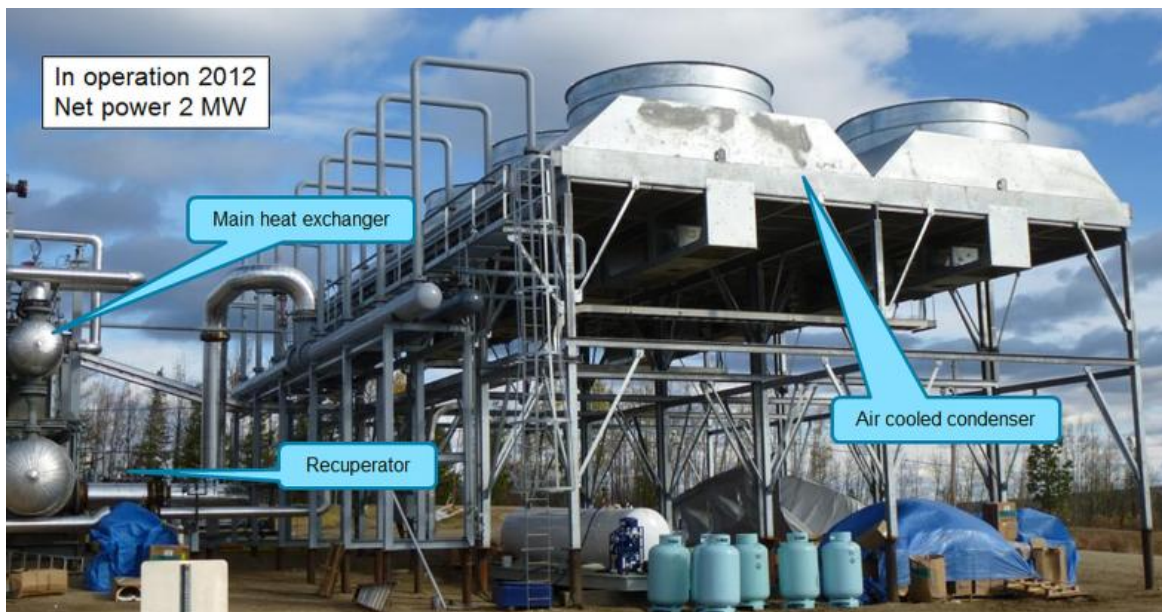


FIGURE 11: The cold end of the transcritical ORC plant in Judy Creek, Canada



FIGURE 12: The hot end of the transcritical ORC plant in Judy Creek, Canada



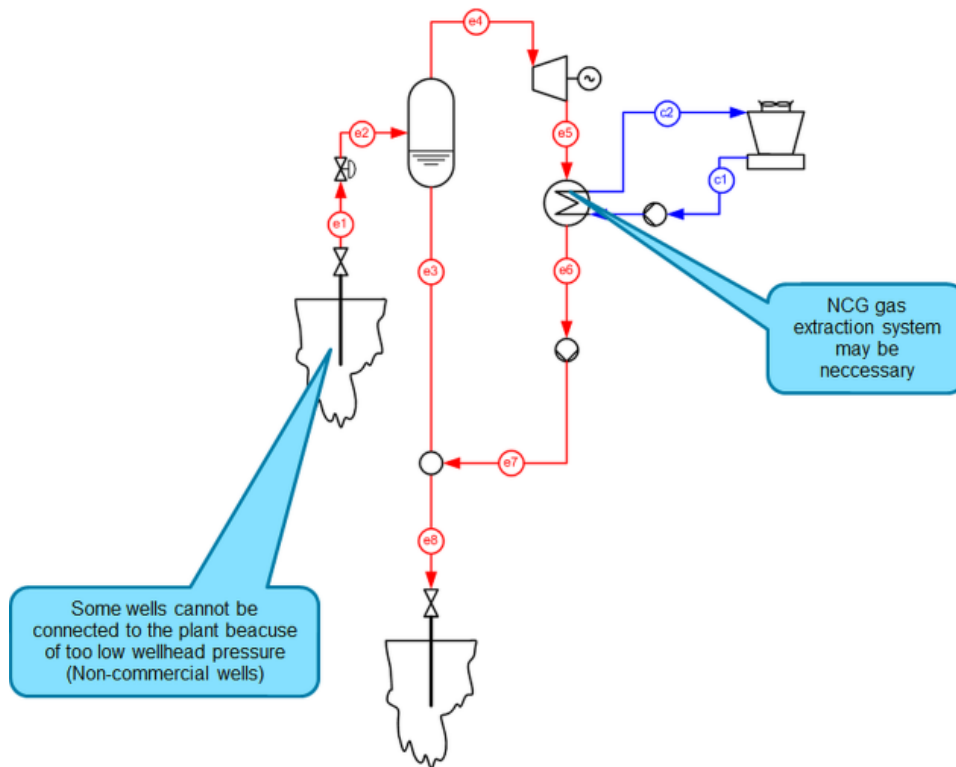


FIGURE 13: Simple flash plant schematic

A hybrid plant has both a steam turbine and an ORC cycle attached. The steam turbine is then a back pressure turbine, and serves the purpose of lowering the pressure against which the wells will have to produce. The back pressure of the steam turbine has to be higher than atmospheric pressure to facilitate easy disposal of the non-condensable gas, but still low enough to allow wells with lower wellhead pressure to be connected. Figure 14 is a simple schematic of a hybrid geothermal power plant.

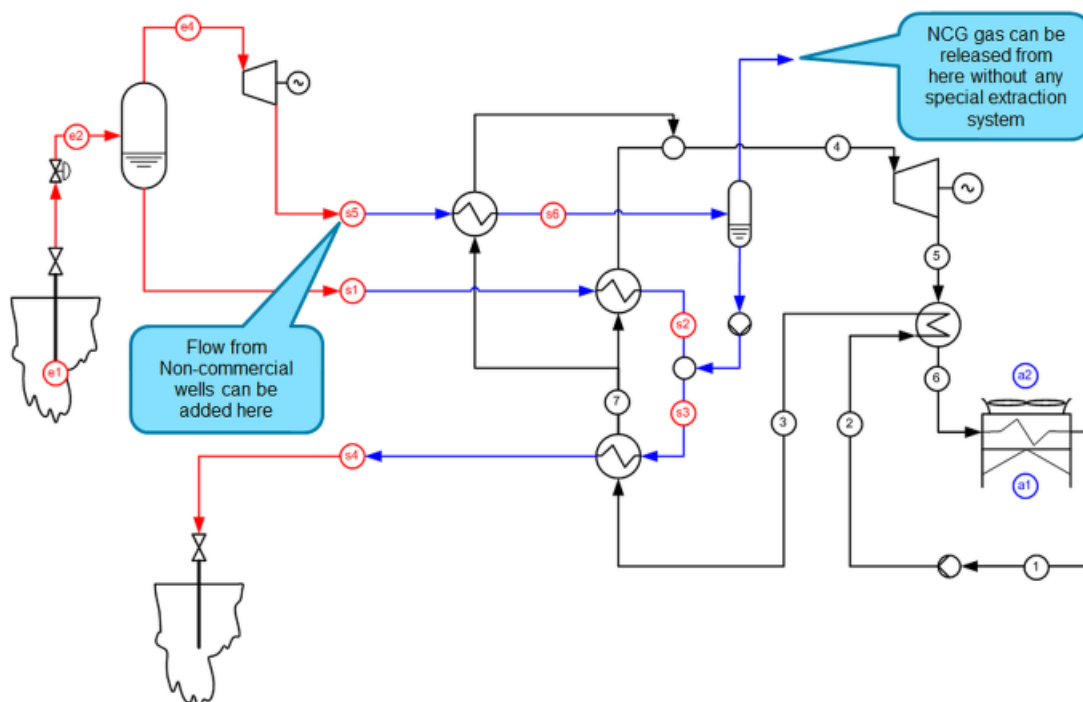


FIGURE 14: A simple schematic of a hybrid geothermal plant

An added benefit of the hybrid plant is that the steam condensate can be mixed with the brine before it gets really cold. Having diluted the brine will result in that the brine scaling limit is lowered and more heat can be extracted from the geothermal source fluid.

#### REFERENCES

Bertani, R., 2010: Geothermal power generation in the world 2005–2010 update report. *Proceedings World Geothermal Congress 2010, Bali, Indonesia*, 41 pp. Web: <http://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/0008.pdf>

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