TURBODEN ORC – LATEST TECHNOLOGY FOR LARGE-SCALE BINARY POWER PLANTS, WITH RELEVANCE TO NEW ZEALAND APPLICATIONS

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ABSTRACT

The document introduces Turboden's recent experience with three state-of-the-art geothermal power plants in Germany (ca. 5 MWe in size each) and a 25 MWe power station under development in Turkey.

The paper describes some technological aspects of these binary plants, with a specific focus on type of thermodynamic cycle, configuration adopted and the optimisation drivers.

The influence of working fluid selection on the efficiency is explained, as well as the design criteria for key components like heat exchangers and air-cooled condensers, with the deriving economic benefits in terms of enhanced energy production.

In addition, economic aspects such as remuneration of the energy - so different between Germany and other countries like New Zealand and Turkey - and other surrounding conditions like grid requirements and island mode operation are discussed.

Lastly, the paper highlights the relevance to New Zealand of Turboden's technological advancements and its experience with high temperature heat sources, heat decoupling (CHP) and hybrid plants.

1. BENEFITS OF THE USE OF ORC TECHNOLOGY IN GEOTHERMAL APPLICATIONS

Rankine cycles with organic working fluid (ORC) have been used for several decades for power production and represent the most efficient way to generate electricity from low to medium enthalpy geothermal sources.

ORC plants are environmentally more acceptable than any other kind of geothermal power plant because the geothermal fluid can be segregated throughout the whole process. In this way the release of gases or other substances to the environment can be prevented, thus virtually eliminating pollution problems. Past the power plant, the geothermal fluid can be totally re-injected, thus maintaining the reservoir's recharge and pressure and ensuring the sustainable use of the resource for future generations. Air cooled condensers can be employed to virtually eliminate any consumption of water and reduce the visual impact, compared to wet cooling towers and their vapour plume.

In ORC systems the turbine has no contact with the potentially aggressive geothermal fluid, which is confined inside the tubes of the heat exchangers, thus avoiding erosion and corrosion.

For a wide range of resources and boundary conditions binary power plants are the best technical and economic choice: they have a definite thermodynamic advantage in terms of power production compared to the conventional flash steam cycles for resources at moderate temperatures (up to 150-180°C) and can be used for electricity generation with low-temperature resources (close to 90-100°C), which would not be feasible with steam turbines. By selecting the most appropriate working fluid among a range of suitable organic media, the thermodynamics of the ORC can be optimised and therefore its power output and energy generation.

2. TURBODEN HISTORY AND EXPERIENCE

2.1. ORC technology made in Italy

Turboden is an Italian company and a global leader in the design, manufacture and service of ORC turbogenerators that harness heat to generate electricity and thermal power from renewable sources including biomass, solar, geothermal energy and waste heat from industrial processes, engines or gas turbines, or from the incineration or the gasification of waste.

The company was founded in 1980 by Mario Gaia, Professor of Energy at the Politecnico di Milano. In the 1980's and 1990's the company developed research projects in solar, geothermal and heat recovery applications and designed its first commercial units for the Swiss and Austrian markets. At the end of the 1990's Turboden installed the first biomass ORC in Switzerland and after that the great diffusion of its ORC units began, first in the German market and then all around Europe.

In 2009 Turboden became part of UTC Corp. and in 2013 was acquired by Mitsubishi Heavy Industries, a world leader in geothermal power generation machinery.

Prof. Mario Gaia has successfully implemented his vision for the ORC technology, is now Honorary Chairman of Turboden and has retired from teaching, but his daily presence in Turboden's head office in Brescia ensures that the spirit of the company is maintained, as well as its mission to constantly strive to implement reliable and efficient ORC technical solutions.

2.2. All-round experience

With its 35 years experience Turboden is among the pioneers of ORC technology. Currently there are more than 250 ORC plants manufactured by the company in operation and further 50 plants are under construction. These units, all featuring in-house designed turbines, have demonstrated an average availability exceeding 98% and more than 6,000,000 operating hours have been accrued.

Turboden has brought the ORC technology into 32 countries worldwide and most importantly has contributed to its use in at least 25 different applications and industries, using not less than 8 different working fluids.

The company has always looked at geothermal energy with great interest, starting from the plants in Zambia in 1988, in Tuscany in 1992, in Altheim (Austria), in operation since 2001; and more recently in Soultz-sous-Forets (France), the first EGS plant in Europe, where the water is injected into deep hot rocks, artificially fractured to increase their permeability, and is heated to a temperature of about 170°C.

In 2012 Turboden designed, built and commissioned with Enel Green Power and the Politecnico di Milano the first supercritical ORC plant in Europe, a 500 kWe prototype with hybrid direct cooling (so called 'dry & spray') and tested its flexibility with variable heat input and its behaviour at supercritical and subcritical conditions.

Having made plant performance optimisation a top priority, between 2012 and 2013 the company successfully implemented an extremely efficient 5 MWe plant in Sauerlach (Bavaria) for the Munich Public Utilities Company SW//M and two other 5.6 MWe plants in the same region (in Dürrnhaar and Kirchstockach) for the leading company Hochtief Energy Management, now SPIE Group. More details on these plants are available in Chapter 3.1 and in Turboden's 2015 WGC paper [3]. A fourth geothermal plant in the area (in Traunreut) is under construction: the 4 MWe ORC unit will also deliver up to 12 MW thermal power to the local district heating system. These Bavarian plants are air-cooled and carefully integrated into the rural context and prepared to supply heat to the existing district heating network.

A further 5 MWe geothermal plant has been commissioned recently in the Oita prefecture in Japan, Kyushu Island. This plant uses a geothermal source at 140°C with about 15% steam.

At the time this paper is being written there are 5 Turboden ORC plants in Turkey (2 in operation and 3 under construction), of which only one is geothermal, a 3 MWe unit under construction for the community of Afyonkarahisar (Turkey). It will exploit a 110°C liquid source and is water cooled. This ORC unit can be regarded as a demonstration that small-scale/low-temperature binary plants are feasible, even in less subsidised markets.

The latest achievement in the geothermal space for Turboden is the signature of a Memorandum of Understanding for the design and construction of a 25 MWe ORC unit, again in Turkey.

Figure 1: Dürrnhaar geothermal plant

2.3. Distinguishing features

The design of the turbine (casing, blading) is carried out by Turboden, representing the core know-how since its foundation in 1980. In the last 15 years the maximum power output of its axial turbine has grown almost 20 fold, with a current maximum capacity exceeding 15 MW. Turboden's turbines can now feature up to 6 stages and boast an average isentropic efficiency between 85 and 88%, maintaining robust design and low RPM (from 1500 to 3600). Multi stage axial turbines are also less sensitive to discharge pressure variations than radial turbines, showing nearly constant efficiency over a wide range of operating conditions. The use of axial geometry is a traditional configuration for Turboden's turbines and the most widely adopted in turbomachinery design and ORC turbogenerators, proven by many millions of working hours; yet they undergo strict quality tests in the factory. The overhung cantilever (Turboden standard) construction and a patented seals & bearing replacing system allow the turbine to remain sealed with the fluid inside, thus ensuring easy and quick maintenance procedures.

Also the experience with many different working fluids - from siloxanes, to hydrocarbons, to refrigerants - and heat sources and temperatures - from 80°C water, to low pressure steam, to 300°C thermal oil, to 900°C off-gas – as well as with hybrid sources (e.g. solar + heat recovery), have gained the company and its more than 100 engineers a unique wealth of knowledge and IP.

Heat rejection and cooling systems of the ORC have been studied and implemented in all the possible forms and devices, from water cooling (from district heating water to river water), to traditional evaporative cooling, to dry cooling (ACC and air-coolers), to different types of hybrid (dry & spray, evaporative condenser). This accrued experience is beneficial to optimise each set of site conditions.

3. TAILORED SOLUTIONS FOR DIFFERENT FRAME CONDITIONS

3.1. German frame conditions

The basic principle of the German Renewable Energy Sources Act (EEG) is that the operators of electricity grids are obliged to accept and give priority to electricity provided by renewable energy sources and to pay minimum prices stipulated by law for a 20 year period [1].

Figure 2: Sauerlach geothermal plant

The high drilling and water circulation risks and related costs, due to the very deep reservoirs (between 3 and 5 kilometres), still represent in Germany a barrier to investment, which has not yet been balanced out by the feed-in tariffs. For this reason the tariffs have been progressively increased. At the time of the bid and design of the three above-mentioned plants the feed-in tariff was 20 €-cents per kilowatt-hour, applied to the gross electrical output. In addition, a heat-use bonus of 3 €-cents per kilowatt-hour was guaranteed when electricity generation was combined with delivery of thermal energy for heating.

For obvious reasons, thermodynamic solutions that enhanced the Gross power with correspondingly higher auxiliary consumptions seemed to be suitable (e.g. supercritical cycles). However, the expected inflation trend of the cost of electricity for the plant auxiliaries has been a concern for the developers and as a result their preference moved towards net-power optimised-cycles, like the two-level-pressure implemented by Turboden.

3.1.1 The two (double) level pressure cycle principle

In general, when a variable temperature source is available (geothermal water) and the economic frame conditions push towards the adoption of high heat exchanger surface, the adoption of a technical solution that allows to match the form of the heat release curve of the geothermal water with the heat absorption curve of the energy conversion cycle proves convenient.

When a classic subcritical ORC cycle is selected the heat transfer curve has the typical shape represented in Fig. 3 below.

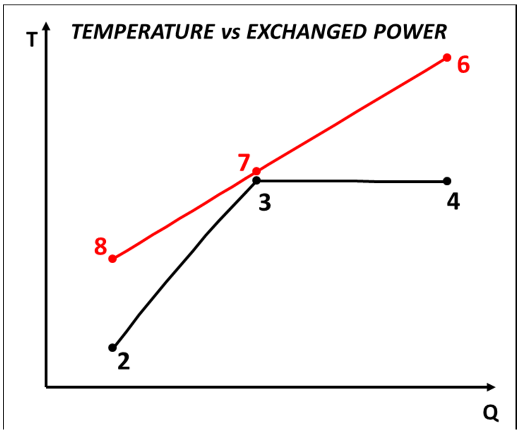

Figure 3: Temperature/Heat diagram of saturated single level cycle showing the pinch point

The presence of a minimum temperature difference point ("pinch point") at the beginning of the working fluid evaporation does not allow an effective matching of the two curves. As a result, when the pinch point temperature difference (temperature difference between points 7 and 3 in Fig. 3) becomes small, the increase of heat exchange area becomes increasingly ineffective in terms of additional power that can be obtained.

For example, for a single level cycle with 245fa as working fluid with 2°C pinch point, operating on a geothermal water heat source at 150°C, the increase of the heat exchange area up to 250% of the original value would gain a power increase of less than 1% [1].

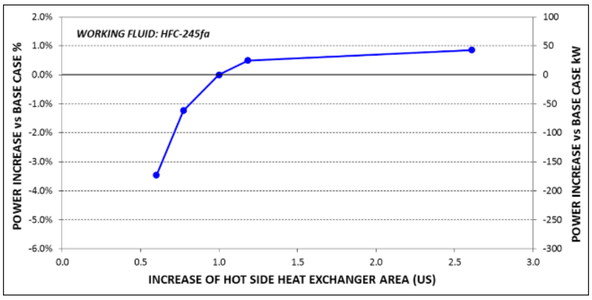

Figure 4: Influence of the heat exchange area on performance starting form a pinch point of 2°C according to Gaia and Pietra (2013) [2]

In order to increase the power production with enhanced heat exchange area, the aforementioned plants implemented by Turboden use two-evaporation pressure level cycles. With the input available at the plant locations (about 140°C) this solution allows a significant performance increase compared to a single level cycle assuming same heat exchange area.

In order to show the advantages of the two level cycle, a comparison has been made with two different single level cycles under typical German frame conditions. The cycles have been compared with same assumptions for component efficiencies and heat exchange coefficients comparing the required heat exchange surface and the achievable net power. The comparison shows that about 10% additional net power can be produced with the same hot heat exchange area compared to a saturated single level cycle [3].

Similar results can be obtained with a supercritical cycle where the matching of heat release curve is obtained thanks to the shape of the typical supercritical heat absorption curve with transition from liquid to vapour at variable temperature.

3.2. Maximisation of plant reliability and performance

The German conditions for geothermal development, in particular the high initial investment and risk, the high value of the energy and the resulting strong penalties imposed by the clients for lower performance and lower availability than guaranteed, pushed Turboden towards the implementation of precautions and measures in the design and construction of its German units, resulting in the following additional technical advantages:

3.2.1. Redundancy

The two working fluid loops are completely independent and therefore one loop can be operated also when the other cycle requires to be shut down for maintenance activities.

In case one of the turbines (say the high-temperature "HT" turbine) requires to be shut down, the whole plant is shut down and the LT unit is re-started in a very short time. In fact the electric generator is the only item connecting the two parts of the plant and it can be disconnected quickly (operation sequence required: remove coupling cover, remove coupling bolts, re-install coupling cover, actuate valves, select turbine low-temperature "LT only' operation, re-start ORC). This operation would require about 1.5 hours, including re-start.

In addition to this, the overall energy production is higher if the different loops are stopped for maintenance at different times because in "LT only" operation the low temperature cycle benefits from the geothermal water not being cooled by the high temperature loop. Thanks to a suitable design of turbine and working fluid loop and overdesign of the working fluid pumps, in "LT only" operation mode the plant can achieve a relevant overload compared to the nominal production of the LT cycle.

3.2.2. Efficient heat decoupling

Another advantage compared to a single level cycle is the possibility to decouple and deliver heat for a heat user (e.g. district heating network) with comparatively lower impact on the electric power generation.

This is a key point under German conditions for the following reasons:

• From an environmental point of view, the saved carbon emissions are higher if the heat is used for heating purposes, due to the fact that the thermal efficiency for a geothermal heat source is up to10 times higher when it is used for heating (100% thermal efficiency compared to 10 – 12% electrical efficiency), while the same ratio is about 2 for fossil heat sources (roughly 80% thermal efficiency compared to roughly 40% electrical efficiency). Thus geothermal heat displaces much more fossil fuels if used for heating purposes.

• The economic value of the heat for electricity production is roughly €25/MWh if a feed in tariff of €250/MWh and a net electrical efficiency of 10% are considered. The economic value of heat is often 2 to 3 times higher, especially if used for district heating.

• While heat use is preferred from both environmental and economic points of view, suitable heat users are mostly available only for a limited number of hours per year (winter heating). Therefore combined plants with efficient and flexible heat decoupling are regarded as very important. This is also the reason why the German legislation has introduced a "bonus for cogeneration".

Turboden has demonstrated the advantages of the subcritical two-pressure level solution instead of a supercritical single level cycle, which could have been an alternative way of reaching similar performance at nominal operating conditions [3].

3.2.3. Island mode

For the geothermal power plant in Sauerlach the tender required Island Mode Operation capability. In case of failure of the grid the ORC plant is able to supply the power required by all auxiliaries (including the geothermal water pump), thus maintaining the plant in operation. The Island Mode Operation capability has been successfully implemented and tested thanks to fast turbine admission valves that can finely regulate the power output and mitigate the over-speed peak of the turbine (at grid failure). Island mode presents a number of advantages, the main being:

a) the plant is maintained in operation and ready for a new re-connection with the grid;

b) less time is spent by the operators to check and re-start the plant;

c) limitation of the number of start and stop cycles for the geothermal pump (possible cause of damage/blockage);

d) avoided interruption of the flow in geothermal water pipeline and filters, when chances are higher for scaling and precipitations inside the tubes and filters to occur, with impact on availability and maintenance cost for cleaning;

e) increased availability of the delivery of the heat to the district heating.

3.2.4. Power plant components

- Heat Exchangers and pipelines: To avoid corrosion issues and increase durability of the heat exchangers, the material adopted for the parts in contact with geothermal water is the super duplex stainless steel SAF2507 (e.g. tube-sheet, distributor channel, partition plate and heat exchanger tubes).The material of the interconnecting pipeline between heat exchangers and Balance of Plant, where the geothermal water flows, is 904L (1.4539) an austenitic stainless steel. On the ORC's working fluid side traditional carbon steel is used for the heat exchangers shells and for most of the piping. Both HT and LT cycles are equipped with shut-off valves able to isolate any heat exchanger from the rest of the circuit (e.g. for maintenance operation). In this way only a small volume of the plant needs to be drained during maintenance operations and the time spent to restore the plant in the normal configuration is shorter.

- Air Condenser: Where the noise emissions level allowed was low and the free area available for the ACC small, GFRP fans were installed. Up to 35% of the fans can be stopped, with the plant still running. The air condenser is composed by a large number of bundles interconnected to each other in parallel. To limit the influences of different condensing pressure of the bundles (e.g. fans of one bay out of order), the pipeline, where the liquid phase is collected, foresees a routing with the presence of a syphon/vapour trap.

- ORC feed pumps: Different configurations are adopted in the plants. The configuration able to guarantee the highest availability is the one present in geothermal power plant of Sauerlach. HT cycle and LT cycle are equipped with 2 pumps, completely redundant (2x100%) and in case of failure of the one pump or other device and auxiliary connected to it, the control system is programmed to switch on the stand-by redundant pump without shutdown of the ORC plant.

- Drainage system: About 70 tons of working fluid are used in each plant. Cost and type of the working fluid influenced the design concept of the drainage system. As for the air condenser, the target was to limit the loss of working fluid during maintenance, without compromising the maintenance operation. The drainage circuit is able to guarantee to drain each volume of the ORC circuit independently of the others. For example, if the filter of the ORC feed pump is clogged, it is possible to maintain the plant in operation using the redundant pump, meanwhile it is possible to isolate the dirty filter from the rest of the circuit, drain the liquid phase and recover the vapour phase into the main tank, execute the cleaning operation and restore the filter without influencing the operation of the plant or decreasing the availability. The drainage system installed consists of:

  i. A tank/receiver with a volume sufficient to contain all the inventory of working fluid of the plant;

  ii. Two transfer items; a pump to move the liquid phase from the tank to the plant or vice-versa and a compressor, able to extract the vapour phase and to push it in a condenser where it is condensed and conveyed into the main tank;

  iii. Chiller circuit using R-134a as medium to condense the vapour phase of HFC-245fa.

- Auxiliary equipment: an ORC plant is also composed of auxiliary components and circuits. If an auxiliary device is closely related to the normal operation of the plant, it shall be designed in order to guarantee the highest availability. Auxiliary components closely related with normal operating condition are:

  i. Lubrication circuits: Six different lubrication circuits are installed. High availability is guaranteed by redundant pumps and instrumentation installed on each circuit. Furthermore the configuration adopted guarantees a complete division between lubricant circuits required by the HT cycle and lubricant circuits required by LT cycle. Therefore in case one of the two cycles is stopped it is possible to re-start the plant with the required lubricant circuits only;

  ii. Auxiliary cooling system: In this close circuit a mixture of water and glycol is used and the system has the function to cool the electric generator and the lubricant oils of turbine and gearbox (if present). The circuit is composed of plate heat exchangers where the lubricant oils are cooled, two air-coolers and two pumps. Like the lubricant circuits, where redundant pumps and instrumentation are installed to guarantee the highest availability, in this circuit also the air-coolers are redundant. In fact in case of failure of one air-cooler the second is able to dissipate the full thermal power by increasing the speed of the fans. The result is low own-consumption during the normal operation and availability of the plant guaranteed in case of failure;

  iii. Non-condensable purging system: It monitors the presence of non-condensable gases (e.g. air) in the ORC circuit and in automatic mode it is able to purge them (inlet of air is possible during maintenance operation or in winter when the condensing pressure is lower than atmospheric pressure); the result is that production of electricity is always according to the relative design condensation pressure. In case of maintenance on the purging system the shutdown of the ORC plant is not required;

  iv. Instrumentation: To guarantee a high availability the instruments involved in main regulation loops (e.g. level, pressure) or main alarms are redundant and connected in different I/O boards of the PLC;

  v. Distributed control system (DCS): The control system used is PCS7 and it manages and controls the whole plant. Redundant CPU and redundant servers are installed. The plant can be started-up and stopped in automatic and remote mode;

  vi. Transformers: Redundant step-up and step-down transformers are installed.

3.3. Frame conditions in Turkey and New Zealand

Compared to Germany, under Turkish frame conditions feed-in tariffs are substantially lower (between USD 105 and 118 per MWh depending on the share of local content). In New Zealand there is no FiT at all.

On the other hand the geothermal resources are well known, shallower and with higher enthalpy, resulting in substantially lower drilling cost and lower power plant specific cost ($/kWe) and thus developers and investors enjoy relatively low risks and good feasibility. In addition, production wells are typically self-flowing wells that can be operated without downhole pumps, hence eliminating the associated technical risk and electrical own-consumption (this consumption can reach up to 20% of gross power in a typical German project).

A first result of the lower value of electricity generation is that the higher cost of the refrigerants (optimum solution for thermodynamic cycles employed in Germany by Turboden) is normally not justified in terms of additional cash flow resulting from higher electricity generation. In addition, flammability of working fluids is rarely a concern in countries like New Zealand and Turkey, as the plants are typically constructed in uninhabited areas. However, potential requirement of compliance to Seveso II/COMAH directives may favour the use of non-flammable fluid in the future.

Typical geothermal fields in New Zealand and Turkey provide for self-flowing wells with wellhead pressures that are normally below gas breakout pressure. Therefore at wellhead a two phase geothermal fluid is available for electricity production. Normally the two phases are separated at wellhead and sent separately to the ORC unit. A typical solution consists in using the two flows in parallel for working fluid evaporation; in particular the solution in Fig. 7 shows a single evaporator shell, with two dedicated and separate tube bundles; one for the geothermal steam and one for the geothermal brine. The condensate from the steam evaporator bundle is mixed with brine exiting the liquid evaporator bundle and used for working fluid preheating.

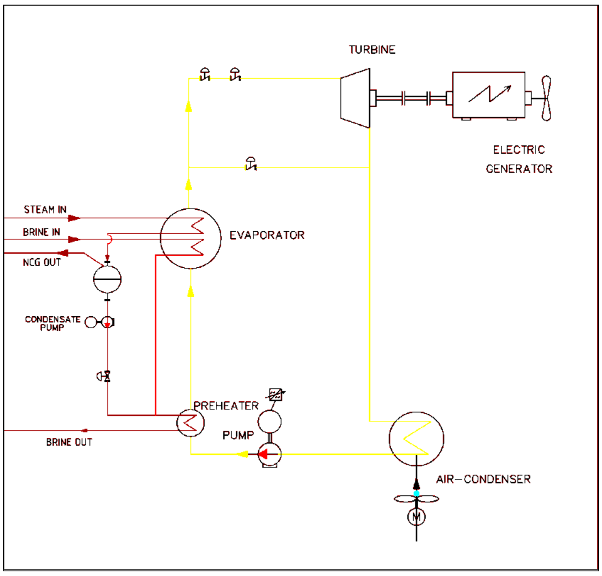

Figure 7: Conceptual P&ID for pressure single level cycle using vapor and brine for working fluid evaporation

Due to the presence of non-condensable gases, the vapour flow has a characteristic heat release curve with heat capacity that decreases together with temperature reduction. The exact shape of the heat release curve depends on the actual characteristics of the stream (steam fraction, NCG fraction and pressure).

The fact that a part of the evaporation heat comes from the vapour condensation can help in matching the heat release curve with the heat absorption curve of the working fluid. In general the additional performance achievable by using a two pressure level decreases with increasing steam content in wellhead flow. This is shown clearly in the temperature/heat diagrams below that represent a single pressure level cycle with isobutane as working fluid with a 140°C geothermal source. In Figure 8, case A (top) assumes negligible steam content, while in case B (bottom) a vapor flow of 6% of total mass flow is assumed (5% steam and 1% NCG at 4 bar abs pressure).

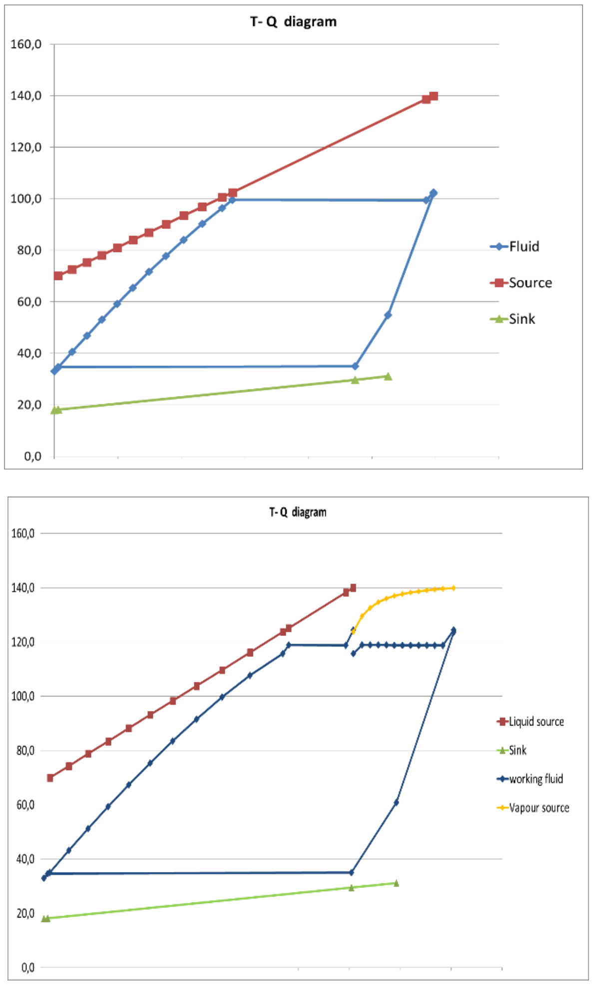

Figure 8: Temperature/Heat diagram of single pressure level iso-butane cycles on a 140°C fluid without vapor content (case A: top) and with 5% steam plus 1% NCG content (case B: bottom)

The diagram for case B (bottom) shows that the additional heat coming from the condensation of the steam covers a relevant part of the evaporation heat of the working fluid and leads to a similar slope of brine cooling and working fluid preheating lines in the temperature/heat diagram. It is evident that the matching of working fluid preheating and brine cooling curves is not as good in case A as it is in case B.

The additional net power that can be achieved with a two pressure level cycle with the same heat exchange surface and working fluid has been calculated for both scenarios. The calculations have been run with the following assumptions:

- *Geothermal Fluid temperature: 140°C*

- *Vapour content: case A 0%; case B 6% (5% steam and 1% NCG at 4 bara pressure)*

- *Condensing temperature: 35°C*

- *Minimum brine outlet temperature from ORC: 70°C*

- *Turbine isentropic efficiency: 85%*

- *Pump isentropic efficiency: 75%*

The additional power of the 2 pressure level cycle is 6.5% for case A, while it is negligible for case B.

The above considerations show that the two pressure level solution successfully adopted in the Bavarian plants may be advantageous only in some cases under Turkish or NZ conditions (with low steam content) while in other cases (with high steam fraction) a one pressure level cycle may prove the best choice.

4. COMPONENTS AND CONFIGURATION IMPLEMENTED IN THE 25 MW PROJECT

After the consolidated presence in Turkey with 5 plants awarded, Turboden has recently signed a MoU for a 25 MWe power plant in this country.

As shown in the previous chapters, Turboden compares different configurations and working fluids before selecting the most effective, both in terms of economic and technical perspective. The following are results that can be regarded as representative also for a good starting point for the design of a binary unit suited to NZ conditions:

- Working fluid: The best working fluid in terms of reduction of irreversible losses, considering the heat release curve of the geothermal water and steam, in this case is iso-butane. This is also evident as the critical temperature is very close to the inlet temperature of the geothermal steam and brine.

- Configuration: the optimum solution in terms of producible energy, capex, and simplicity of operation and maintenance is a single pressure level saturated cycle with two turbines coupled to the same electrical generator. Each turbine receives the same quantity of iso-butane, evaporated by means of two evaporators in parallel with the geothermal steam and brine. The system is so conceived that it is possible to feed at design point each heat exchanger with 50% of the total geothermal flow, so that in case of maintenance (e.g. cleaning) of one evaporator (or pre-heater), it is possible to feed the other side with its design flow, with no risk of solids deposition due to lower velocity inside the tubes than the design point. Furthermore, it makes it possible to do maintenance to one of the two turbines, by simply de-coupling the turbine and keeping the other running and producing electricity (the time required is about 1.5 hours).

- Turbine: At the heart of the plant two 12.5 MWe Turboden axial turbines are the key for the maximization of the power output over the wide range of operating conditions. In fact, thanks to the multistage axial configuration, not only reliability and ease of maintenance have been optimized, but also the amount of net energy generated throughout a year is expected to be the highest among all the other solutions available on the market. This is possible thanks to an isentropic efficiency always > 85% over the whole range of operation.

- Heat Exchangers and pipelines: The system is equipped with shut-off valves able to isolate any heat exchanger from the rest of the circuit (e.g. for maintenance operations), installed both on the geothermal water side and on the working fluid side. In this way only a small volume of the plant shall be drained during maintenance and the time spent to restore the plant in the normal configuration is shorter.
- Air Cooled Condenser: The main drivers that influence the design are: working fluid (always above ambient pressure) and own consumption. In order to avoid leakage of working fluid all the main components of the air condenser are welded and no flanges are present. A traditional configuration with plug bonnets was discarded to adopt a solution with cylindrical welded bonnets. Also the interconnection nozzles between condenser and pipeline are welded. The tube to tube-sheet connection is strength- welded, too. Free area available to install the air condenser, noise levels allowed and internal power consumption are other interconnected parameters that influence the choice of material of the fans and type of transmission and motors. The air condenser is composed of a large number of bundles interconnected to each other in parallel. Two passes on the fluid side has been adopted, in order to avoid the typical sub-cooling undesired effect traditionally present in the standard one-pass solution so far implemented in similar plants by others.

- ORC feed pumps: A configuration able to guarantee the highest availability with redundant pumps (3x50%) for each turbine. In case of failure of one pump or other devices and auxiliaries connected to it, the control system is programmed to automatically switch on the stand-by redundant pump with no shutdown of the ORC plant.

- Hybrid cooling system: This solution envisages the use of an Air Cooled Condenser, with the optional addition of a water cooled condenser and a cooling tower to be used in the summer season to increase the Power Output. These components can be easily added in a second stage, with maximum 1 day stop of operation of the plant, thanks to blind flanges already present on the exhaust ducts of the turbines. This feature increases the net power output all over the range of operation, obviously showing the highest benefit during the hot dry season.

5. CONCLUSION

Turboden has ample and varied experience in the design, manufacture and service of ORC turbogenerators installed in more than 30 countries in the world. This has earned the company a substantial manufacturing record and the capability to analyse site conditions and optimise plant design for the benefit of the owner – being mindful of the market in which the owner operates.

Turboden is now a part of the Mitsubishi 'family' which includes flash turbines in New Zealand since 1989 and looks forward to working with owners and engineers in New Zealand to deliver a new generation of ORC plants in this country.

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