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GEOTHERMAL BINARY CYCLE POWER PLANTS – PRINCIPLES, OPERATION AND MAINTENANCE: A CASE STUDY FROM EL SALVADOR

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ABSTRACT

Binary cycle power plants play an important role in generating electricity from low geothermal temperature resources. This paper describes the thermodynamic model of a binary cycle power plant and its components by modelling a basic binary cycle, as well as binary cycles with a recuperator for different turbine inlet pressure. An analysis is made on how the addition of a recuperator in the cycle shifts the maximum point of turbine work output, serves to increase the turbine work output for a given reinjection temperature, and helps when the reinjection temperature is limited by the geothermal water chemistry. The maintenance of binary cycle power plants is highly influenced by different factors, such as the nature of the geothermal fluid used in the primary loop, the nature of the working fluid, the technology and location of the plant, and climate and weather. At the same time, this paper presents the operation and maintenance in the Berlin binary cycle power plants in El Salvador.

1. INTRODUCTION

Geothermal energy has often been associated with the movements of tectonic plate boundaries. El Salvador, a small country in Central America with an area of 21,040 km^2 and a population of 6.2 million, is located in the pacific coast of Central America along the "Pacific Ring of Fire" where the Cocos and the Caribbean plates interact. The volcanic activity and seismicity associated with these plate movements are important for the geothermal potential in the country.

El Salvador was the first Central American country to exploit geothermal resources. Electricity generation using geothermal energy started in 1975. The development has reached a total capacity of 204.2 MW.

In El Salvador, the geothermal resource management, exploitation and production of geothermal energy are developed by LaGeo S.A de C.V and the installed capacity is distributed mainly in two geothermal fields: 95 MW in Ahuachapán geothermal field and 109.2 MW in Berlin geothermal field. Figure 1 shows the location of El Salvador in Central America together with its geothermal fields.

Geothermal systems are classified by temperature, enthalpy and physical state among others. According to the temperature classifications, the geothermal heat varies from below 150°C to above 200°C, and can be a mixture of steam and water, or mainly steam or mainly water. The temperature of the geothermal reservoir defines the type of technology required to exploit the available heat and the utilization of the geothermal resource.

As mentioned earlier, El Salvador has two geothermal fields and both are classified as high-temperature geothermal fields, with Ahuachapán having reservoir temperatures between 230 – 250°C and Berlin with a temperature of 300°C. Generally, the high temperature fields are mainly exploited for generation of electricity as is the case in El Salvador. The technology that has been utilized for exploiting Ahuachapán geothermal fields consists of two single flash condensing turbines and one double flash condensing turbine, while Berlin geothermal field utilizes three flash condensing turbines and one binary cycle power plant.

FIGURE 1: Location of El Salvador in Central America and its geothermal fields

The project for increasing the capacity of the Berlin power plant started in 2005. The power plant now has an increased capacity with the addition of a 44 MW condensing unit and a 9.2 MW binary unit. For the added binary power unit, the temperature used is 180°C and is obtained from the separated water of the production wells. The total installed capacity of El Salvador is forecasted to be about 290 MW by 2015 (Bertani, 2012).

Electricity generation from geothermal energy made a modest start in 1904 at Larderello in the Tuscany region of north-western Italy with an experimental 10 kW-generator (Lund, 2004). Since then, the interest in developing and exploiting geothermal resources began around the world, and today electricity from geothermal energy is considered to be one of the sources of renewable energy worldwide. It has grown to 10,898 MW in 24 countries, producing an estimated 67,246 GWh/yr. The development of the worldwide geothermal power production can be seen in Figure 2.

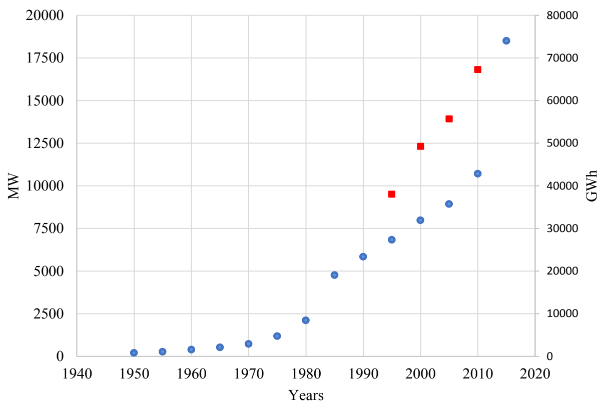

FIGURE 2: Development of worldwide geothermal power production (Bertani, 2012)

The number of geothermal countries is expected to increase from 24 in 2010 to 46 in 2015. Binary power plant technology plays a very important role in the modern geothermal electricity market (Bertani, 2012). The first geothermal binary power plant was put into operation at Paratunka near the city of Petropavlovsk on Russia's Kamchatka peninsula, in 1967, commissioning a 670 kW power plant. It ran successfully for many years, proving the concept of binary plants of today. Nowadays, binary plants are the most widely used type of geothermal power plant with 162 units in operation in May 2007, generating 373 MW of power in 17 countries. They constitute 32% of all geothermal units in operation but generate only 4% of the total installed power. Thus, the average power rating per unit is small, only 2.3 MW/unit, but units with ratings of 7–10 MW are coming into use with advanced cycle design (DiPippo, 2007).

El Salvador has played a major role in the worldwide development of binary power plants, with the first installed binary power plant in the country located in the Berlin geothermal field. In this first unit, the

Organic Rankine Cycle has been used to generate electricity using Isopentane as a working fluid. The binary power plant was designed to utilize remnant heat from the geothermal water (waste brine) to evaporate the Isopentane. This unit is currently producing electricity, however, there has been operational challenges causing tripping of equipment and even resulting to unit shut-downs. Since the unit started running, maintenance and overhaul measures have been developed, and some modification executed on the equipment ensuring continuous operation of the plant at maximum capacity and efficiency. LaGeo has had experience with this technology and is still in the learning process. However, it has been a great first step for the development of electricity production using geothermal water in El Salvador.

2. BASIC BINARY CYCLE

The concept of the binary cycle power plant, known as an Organic Rankine Cycle (ORC), is a modification of the Rankine cycle where the working fluid, instead of water, is an organic fluid having a low boiling point and high vapour pressure compared with the steam water, along all state points that comprise the thermodynamic cycle.

The geothermal binary cycle power plant is formed by two cycles. The primary cycle that contains the geothermal fluid and the secondary cycle in which the organic working fluid is enclosed. The primary cycle starts from the production wells and ends in the re-injection wells. In the primary cycle, the temperature and the desired flow rates of geothermal fluid are determined by the reservoir´s field properties. The geothermal fluid can either be water or steam. When the geothermal fluid is geothermal water or brine, it is kept at a pressure above its flash point at fluid temperature along the primary cycle, to avoid flashing of geothermal fluid in the heat exchangers. The geothermal fluid temperature at the end of the primary cycle is not allowed to drop to the silica scaling point.

The main components of a basic geothermal binary cycle power plant are the preheater, evaporator, turbine, condenser, and working fluid pump. The schematic diagram in Figure 3 shows the main components of the cycle. The basic thermodynamic process of binary cycles is the Rankine cycle, where the working fluid vapour reaches the superheated condition in the evaporator condenses into the condenser. The simple method to describe a binary power cycle is to follow the T-S diagram shown in Figure 4. The thermodynamic states of the working fluid in the secondary cycle are also shown on the P-H diagram in Figure 5. Such diagrams help in understanding the thermodynamic cycle and different states of the working fluid.

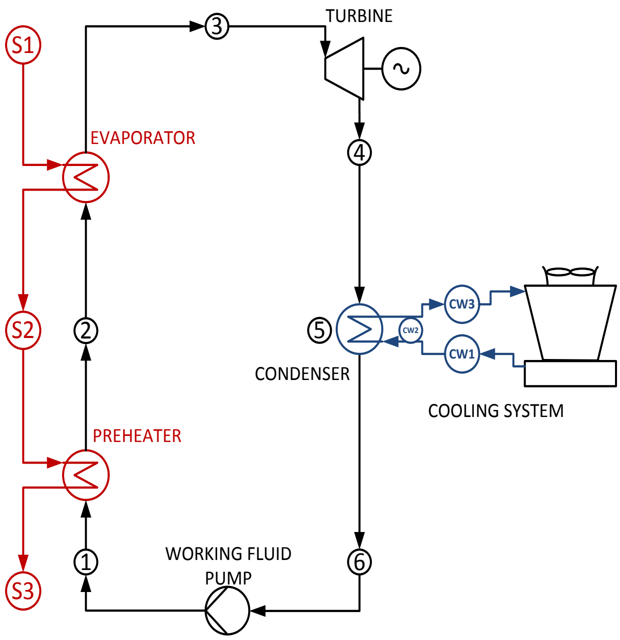

FIGURE 3: Schematic diagram of the basic binary power cycle

The binary cycle (Figure 3) consists of the following four processes:

6 – 1	Isentropic compression in the working fluid pump;
1 – 2 – 3	Constant pressure heat addition in preheater and evaporator;
3 – 4	Isentropic expansion in a turbine; and
4 – 5 – 6	Constant pressure heat rejection in a condenser.

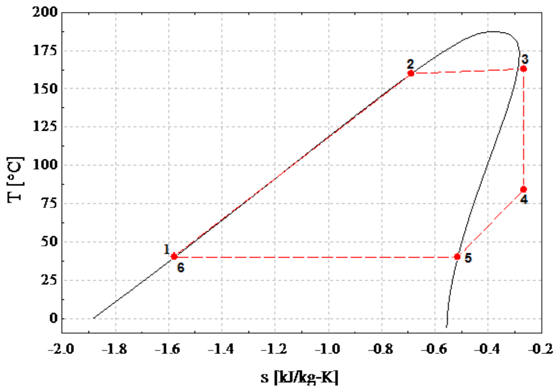

FIGURE 4: T-S diagram for a binary cycle using Isopentane as a working fluid

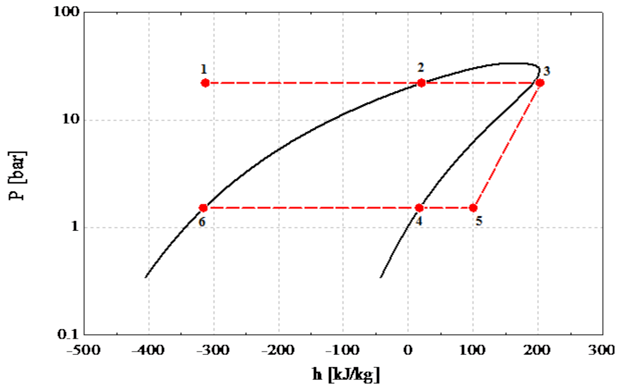

FIGURE 5: P-H diagram for a binary cycle using Isopentane as a working fluid

It is important to note that the area under process 1-2-3 represents the heat transferred to the working fluid in the preheater and evaporator, and the area under process curve 4-5-6 represents the heat rejected in the condenser. The difference between these two areas is the network produced during the cycle (the area enclosed by the cycle curve).

The binary cycle power plants can be cooled by water or air; these methods of cooling are called wet and air cooling systems. In areas where water is valuable, not easily accessible, or conserved, dry cooling systems are used.

3. BINARY CYCLE WITH RECUPERATOR

The binary cycle can be modified with the incorporation of the recuperator. The recuperator is another heat exchanger and represents additional equipment in the binary cycle power plant. The incorporation of a recuperator is shown in Figure 6. The figure shows the position of the components in the cycle. The recuperator increases the temperature of the working fluid at the preheater entry (point 2) and thus leads to the re-injection of the geothermal fluid from the preheater at higher temperature (point S3).

Point S3 is the outlet of the geothermal fluid from the preheater. This point has design temperature limits imposed by the risk of scaling or the requirements of a secondary process.

Figures 7 and 8 show the simulation results for a basic binary cycle and a binary cycle with a recuperator for different reinjection temperatures. This simulation for both cycles was done using Isopentane and n-Pentane as a working fluid with an inlet temperature of the geothermal fluid of 180°C. For the calculations, 221 kg/s of geothermal fluid and a condensing temperature of 40°C as are assumed. The calculation is based on an ideal binary cycle.

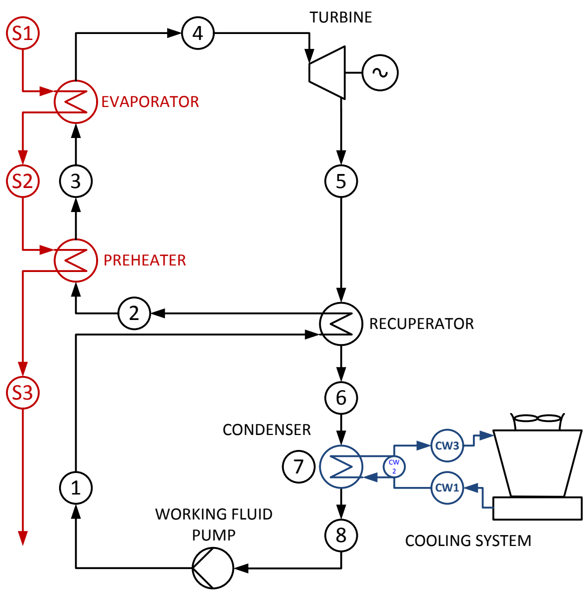

FIGURE 6: Schematic diagram of the binary power cycle with a recuperator

The addition of a recuperator causes no change in the maximum turbine work output of the binary cycle as shown in Figure 7 and 8. The recuperation process does not increase the turbine work output, but the efficiency increases as a result of less input of heat from the geothermal fluid (Valdimarsson, 2011). The addition of a recuperator however, causes shift in the maximum point of turbine work output of the cycle with respect to reinjection temperature.

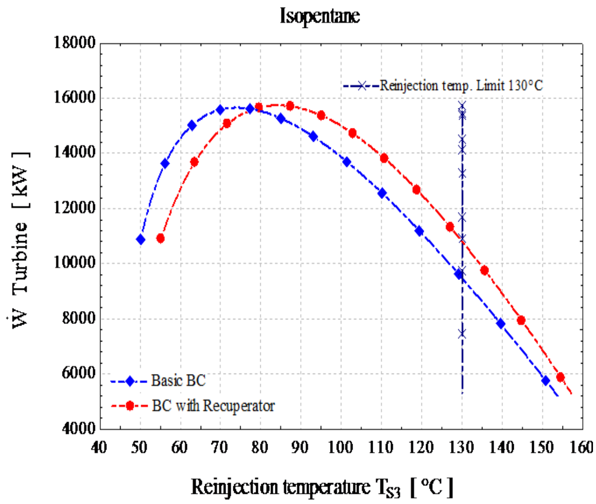

FIGURE 7: Variation of turbine work output with reinjection temperature for Isopentane

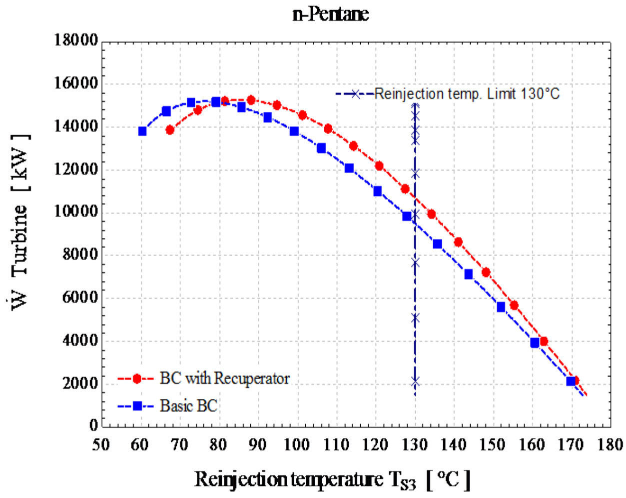

FIGURE 8: Variation of turbine work output with reinjection temperature for n-Pentane

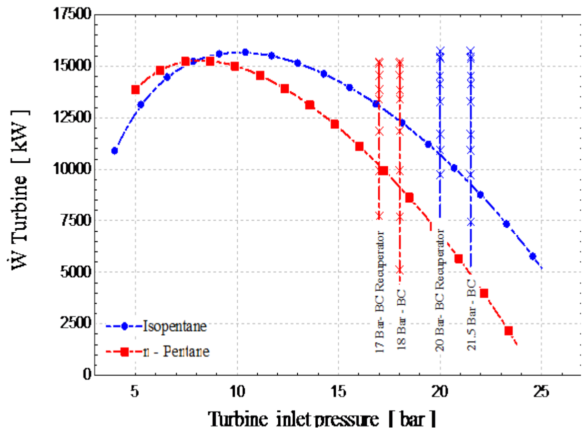

FIGURE 9: Turbine work output against turbine inlet pressure for Isopentane and n-Pentane at same reinjection temperature (T_{53}=130°C)

When the reinjection temperature is limited by the chemistry of the geothermal water, adding a recuperator serves to increase the turbine work output for a given reinjection temperature. Figures 7 and 8 show that the turbine work output is increased by 15% at 130°C reinjection temperature. Figure 9 shows the value of pressure that fits for 130°C when Isopentane and n-Pentane are used in a basic binary cycle and binary cycle with a recuperator.

Figures 10 and 11 show the simulation results of a basic binary cycle and a binary cycle with a recuperator for different turbine inlet temperatures. The simulation uses the same parameters and assumptions as for the previous simulation and at a constant reinjection temperature of 130°C. When the reinjection temperature is constant in both simulations, this condition leads to simulate the same amount of available heat that can be exchanged in the preheater and the evaporator.

The result for these simulations shows that for Isopentane and n-Pentane as working fluids in a binary cycle with a recuperator, the turbine work output increases according to the design inlet pressure for the turbine.

The recuperator will be large and expensive and will cause pressure drops in the system, as well as associated losses. The basic binary cycle will be economical if the geothermal fluid does not have reinjection temperature limits (Valdimarsson, 2011).

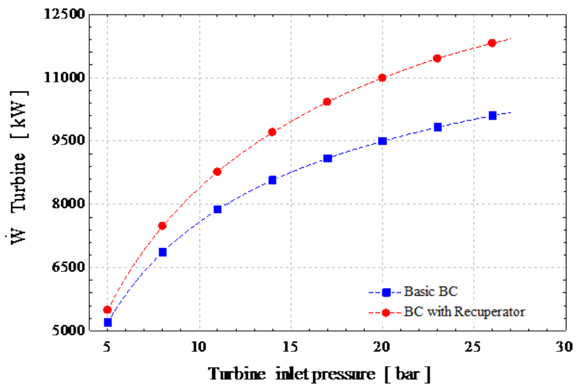

FIGURE 10: Variation of turbine work output with turbine inlet pressure for Isopentane

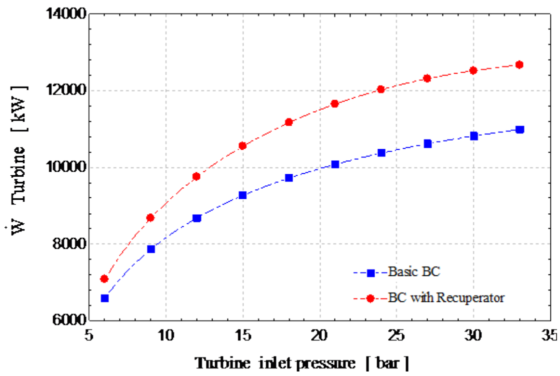

FIGURE 11: Variation of turbine work output with turbine inlet pressure n-Pentane

4. CASE STUDY: BERLÍN BINARY POWER PLANT

The Berlín binary cycle power plant is located at Berlin, Usulután in El Salvador, at wellpad TR-9, and is known as Unit 4. The Berlín geothermal field has four power plant units; the development history is summarized in Table 1. The Berlín binary cycle started its construction in 2005 and was commissioned in 2007. The goals of this binary power plant are to generate electricity based on geothermal energy to supply the demand of the country, increase the efficiency of the Berlín geothermal field and contribute to the local sustainable development. The binary cycle power plant technology is used for first time in El Salvador.

In Berlin, the amount of additional power that could be generated from the separated water in a binary unit depends on how much heat can be removed from the separated water before scaling becomes a problem. The geothermal water from Berlin liquid dominant reservoir has about 1% of total dissolved solid (TDS) with appreciable amounts of calcium and boron (100 to 200 ppm). When the water is separated in cyclone separators at 10 bars and 185°C, the water contains 800 ppm of silica and for this condition, the separated water has a silica saturation index (SSI) of 0.95 %. Additionally, when the separated water is cooled the SSI increases, for example SSI: 1 at 180 °C and SSI: 2.2 at 100°C (at 2.2 silica is oversaturated). A research was conducted to minimize scaling potential in the re-injection system, and the result recommends 130°C as a lowest temperature value, implementing acid dosing to maintain the pH between 5.5 to 6.0 (SKM, 2004).

TABLE 1: Berlin geothermal field development in El Salvador (Guidos and Burgos, 2012)

Phase	Building years	Technology	Units	MWe/Unit
Well head units	1992	Back pressure steam turbine	2	5 * Out of operation
Unit 1 & 2	1999	Condensing steam turbine	2	28
Unit 3	2005	Condensing steam turbine	1	44
Unit 4	2007	Isopentane binary cycle unit	1	9.2

Geothermal wells in the Berlin geothermal field produce two phase fluids, geothermal water and steam. The steam is used to feed the turbines in the power plant and the geothermal water is re-injected in the wells downstream of the production wells and power plant. The binary cycle power plant in Berlín is designed to remove an internal energy from the geothermal water that has a temperature of 180°C to generate electricity. The geothermal water used in this unit comes from wells TR4/5 and TR2/9, where steam is used to generate electricity in Units 1 and 2. The Berlin binary cycle power plant is a good example of a bottoming power plant.

The organic Rankine cycle is utilized to generate electricity and this binary power plant uses Isopentane as its working fluid. The gross power output is 9.2 MWe and its own energy consumption for the circulation pumps, cooling water pumps, cooling tower fans, and other electrical and auxiliary equipment is taken from the same generation. Therefore, the net power production delivered to the grid is 7.8 MWe.

In Berlin binary cycle power plant, the process is divided into three loops. The first loop is the geothermal water circulation, heat resource. The second loop is the working fluid process, and the third loop is the cooling water circulation.

In the first loop of this binary power plant, the heat source is coming from two reinjection systems, one pipeline collects the geothermal water from wells TR-2 and TR-9, and the system is called TR2/9. Another pipeline collects the geothermal water from the wells TR4 and TR5 and the system is called TR4/5. Figure 12 shows the process diagram for the first loop. The system TR4/5 carries 221 kg/s of hot water at 22 bars, while the system TR2/9 carries 79 kg/s at 11 bars. The geothermal water exchanges heat with the working fluid in the preheater and the evaporator. This exchange takes place in both systems and the vapour of the working fluid leaves the evaporators at 22 bars. The geothermal water is then cooled down from 180 to 140°C before being re-injected.

The second loop is the Isopentane process cycle. The amount of working fluid used in Berlin power plant is 123.3 kg/s. Table 2 shows the changes along the loop and the parameters of the working fluid under design conditions.

The third loop corresponds to the cooling water cycle; the flow of water in this cycle is 1,013 kg/s. In this loop, the water removes the heat from the working fluid through the condenser, which is a shell and tube heat exchanger type. The water interchanges the removed heat with the atmosphere in the cooling tower. A set of pumps is used to circulate the water from the condenser to the cooling tower. Due to evaporation during heat exchange, blow down and drift, constant make-up water is needed. The make-up pumps deliver 20.3 kg/s of condensate water from the pond of condensation units.

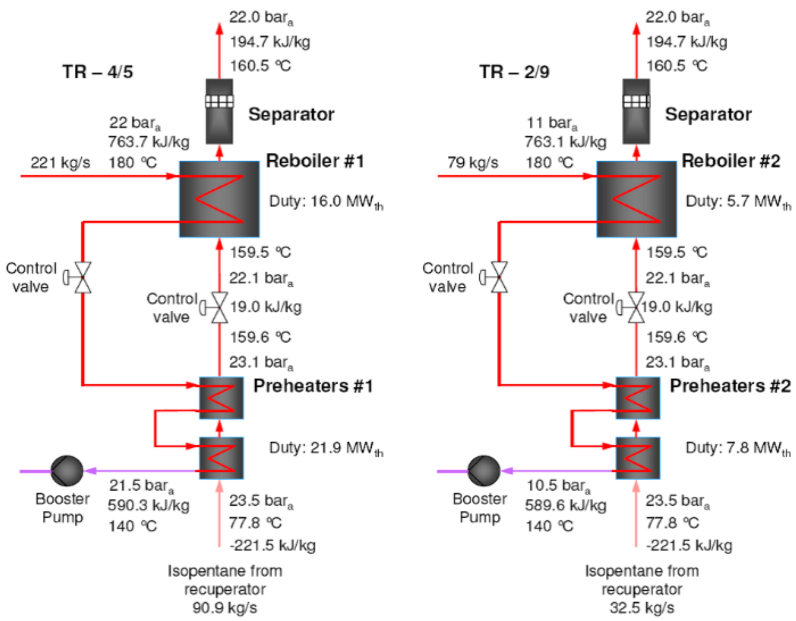

FIGURE 12: Preheaters, evaporators and the first loop process diagram (ENEX, 2007)

In the Berlin binary cycle, the turbine-gearbox-generator is mounted on a structural steel skid. In the turbine, the working fluid expands from the inlet to the outlet pressure in two steps: The first step takes place in the inlet guide vanes (IGV) (variable nozzles) and the final step takes place in the radial wheel or rotor (Figure 13). The turbine converts the kinetic energy into mechanical work, transmitted by the shaft to the generator via a gear box (GE-Energy, 2013). The turbine case is sealed at the shaft by a dry face mechanical seal. Nitrogen and air are injected as a sealing and cooler fluid. The mechanical seal has an internal division in the labyrinth seal, i.e. front labyrinth (working fluid) and back labyrinth (lubrication oil) sides. The nitrogen goes through the front labyrinth side and is mixed with the vapour, to ensure that the working fluid is retained in the turbine. The mix of air and purge nitrogen goes through the back labyrinth side of the mechanical seal and flows toward the vent cavity, so this mix removes any heat generated in the mechanical seal and ensures that the lubrication oil mist does not migrate to the expander process. The gearbox is connected to the turbine through a power shaft and connected to the generator through a low speed coupling. This gearbox reduces the turbine shaft speed from 6490 to 1800 rpm. The generator is a brushless excitation type ABB unit with a horizontally mounted rotor and air to water closed circuit cooling. It produces a current of 13.8 kV and 60 Hz.

TABLE 2: Design condition for the working fluid at each step along the process in the cycle

Working fluid phase change	**Parameters**		
Evaporation	Temperature	159.5	°C
Expansion	Turbine inlet pressure	22	bar
	Turbine outlet pressure	1.85	bar
	Turbine inlet temp.	160.5	°C
	Turbine outlet temp.	92.9	°C
Cooling	Recuperator outlet temp.	52.6	°C
Condensation	Condenser pressure	1.8	bar
	Condenser outlet temp.	44.8	°C
Compression	Pump discharge press.	23.78	bar
	Pump discharge temp.	46.1	°C
Heating in recuperator	Temperature	77.7	°C
Heating in preheater	Temperature	159.5	°C

The heat exchanger in the Berlin binary cycle is used to transfer heat between different fluids. Figure 14 shows the arrangement of all shell and tube heat exchanger in this plant. Basically, the heat exchanger transfers heat from the geothermal water to the working fluid in the preheater and evaporator; between the exhaust vapour and liquid working fluid in the recuperator; and from the working fluid to the cooling water in the condenser. The working fluid in the process flows in the shell side in this equipment.

The cooling tower has the main function to remove the heat from the water used in the condenser. The cooling tower acts as a final heat sink in the process by delivering this heat into the environment. This cooling tower is a counter flow type and has two fans that draw air upward against the flow of water dropping from the top. Operating under design conditions, the tower can handle a flow of up to 4,122 m^3/hr. The water from the condenser to the cooling tower is pumped by centrifugal pumps that are designed as a single stage, double suction and a horizontal split volute type.

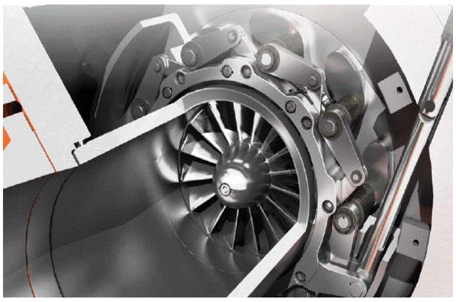

FIGURE 13: Inlet guide vanes (IGV) and radial wheel of turbine (GE-Energy, 2013)

The working fluid pumps are vertical, centrifugal and multistage types. The pumps are equipped with a mechanical seal, with a cartridge design that allows the seal to be changed without having to take the pumps parts. The mechanical seal is flushed by an American Petroleum Institute (API) plan. The API helps to select the type and control for mechanical seal applications. For working fluid pumps in the Berlin binary unit, the temperature at the seal should be maximally 10°C above the pumped working fluid temperature. The working fluid pumps are driven by a three phase electrical motor.

As mentioned above, the mechanical seal used in the turbine casing works with nitrogen in the working fluid side and both fluids exist as a mix in the outlet of the turbine. To remove the non-condensable nitrogen from the working fluid, a nitrogen extraction system is installed in the condenser, where the working fluid liquefies and the nitrogen remains in the gas phase which is ejected to the atmosphere from a gas separator.

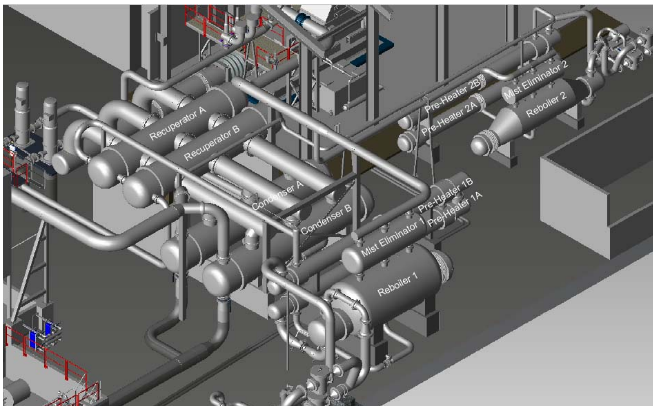

FIGURE 14: Shell and tube heat exchanger in the Berlin binary plant (ENEX, 2007)

The units have auxiliary systems, which allow automatic control and monitoring the Berlin binary cycle. These are the nitrogen generator system, pneumatic, ventilation, fire protection, inhibitor, auxiliary cooling water for generator-gearbox-turbine set, lubrication, instrument and control systems.

The operation is totally automatic, locally and remotely monitored. Figure 15 shows the actual screen for the process that is used by the operator to monitor the cycle. According to the operation manual for the binary unit (ENEX), these units have the following operation procedures: preconditions for start-up, turbine start-up, turbine warm start, normal operation, normal shutdown, turbine trip, and trip of the working fluid cycle. For operation of the Berlin binary plant, there is only one operator in shifts. The operator in shift is responsible for monitoring all the parameters of the unit, fixing troubleshooting and executing start-ups and shutdowns procedures. The operator works in 8 hour shifts.

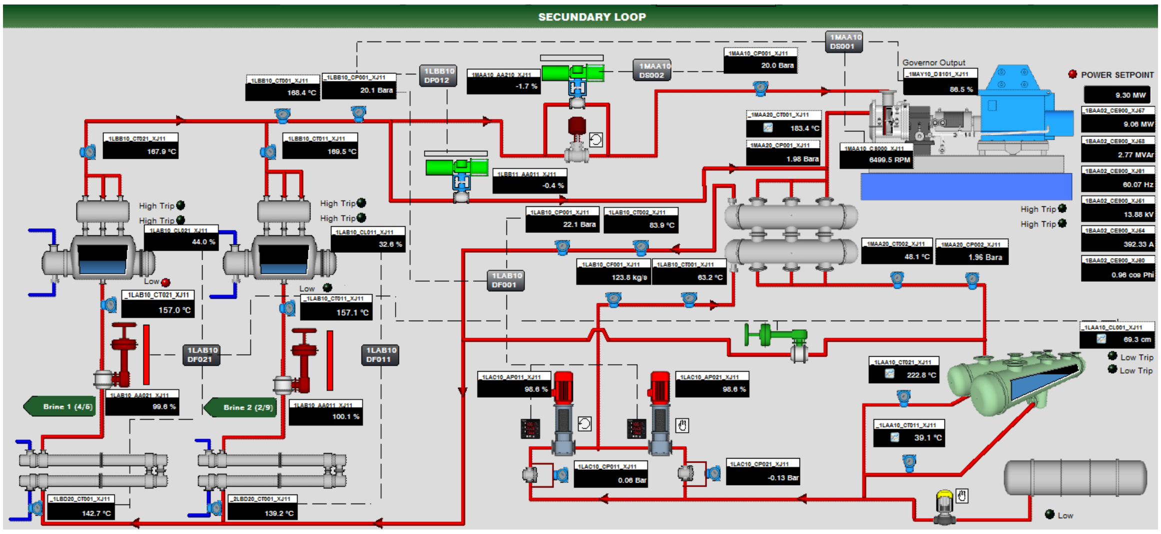

FIGURE 15: Screen of the second loop in the Berlin binary power plant

5. BINARY CYCLE MAINTENANCE WORK AND EXPERIENCES

The maintenance of a binary cycle power plant includes a series of activities carried out on each component of the binary plant in order to ensure its continuous performance. The maintenance of the binary cycle power plants is highly influenced by different factors, such as the nature of the geothermal fluid used in the primary loop, the nature of the working fluid, the technology and location of the plant, climate and weather. In order to operate a binary cycle power plant as a base load unit, a perfect maintenance programme is a challenge to ensure high availability and reliability. Corrosion and scaling are the most common problems in binary power plants.

To develop the maintenance activities, it is required to have a maintenance management programme to help in coordination, control, planning, implementing and monitoring the necessary activities required in each component of the binary plant. There are variety of maintenance programme and methods dealing with the following basic maintenance strategies: corrective, preventive, predictive and proactive maintenance. The best maintenance programme analyses and applies the correct combination strategies for each component of the whole power plant. Also, nowadays software are available that can help manage these activities, like Dynamic Maintenance Management (DMM) used in the Svartsengi power plant and Maximo software used in the Berlin power plant. These software have been designed to manage assets and help to automate all aspects of maintenance. These software have the following common functions: machinery history, preventive maintenance schedules, work orders, condition monitoring, condition based flagging, time accounting, fault reports, safety improvements, expense tracking, procurements, trending and performance reports (DMM, 2013; Projetech, 2013).

In this report, the basic maintenance strategies are summarized, the major mechanical maintenance activities carried on turbine, heat exchangers, pumps and cooling towers of the binary cycle power plants are described. The report also describes certain experiences from Berlin binary cycle power plants during their operation and maintenance.

As mentioned above, the basic maintenance strategies are corrective, preventive, predictive and proactive maintenance. Corrective maintenance strategy proposes to run the machinery until it fails. This strategy seems to be economic because the manpower requirements and their costs are minimal. However, when the machinery fails unexpectedly, it is necessary to schedule manpower at the site in emergency shifts, have a complete stock of spare parts available in a warehouse, and make a contract with a specialist in case of emergency. The shut down time depends on the magnitude of the failure. In addition, an unexpected failure can be an unsafe condition or environment, to personnel and facilities. All these factors need to be considered for a corrective maintenance strategy since failure cannot be predicted and for which the cost will be high.

Preventive maintenance consists of scheduling maintenance activities aimed to prevent failures and breakdowns in the machinery. The main goal of this strategy is to prevent the failure before it occurs. The preventive maintenance activities consists in equipment check, lubrication, oil changes, leaks, tightening of bolts, mechanical adjustments, partial or complete overhauls, etc. At the same time, the operating hours according to the manufacturer's recommendations are scheduled to change worn parts before they really fail. This strategy has the advantage that during maintenance, the workers can identify if the machinery needs further maintenance, and also they can record the deteriorations in the machinery and suggest a time for the next maintenance. The associated costs for this technique are related to the long availability and service life of the machinery. The strategy helps in controlling the shut down time period of the machinery. The disadvantage of this strategy includes unnecessary maintenance, incidental damage to components and the risk of unexpected failure still prevails. Preventive maintenance includes the predictive strategy maintenance.

Predictive maintenance strategy mainly focuses on measuring the operating conditions of the machinery and evaluates if the machinery is working under certain standard conditions. Logging of measurements is done over time, and strategies are recommended to take corrective measures when the measurements go beyond standard operating limits. This strategy requires new tools, software and specialized technicians to obtain and analyse the data, as well, to predict when the machinery must be repaired. Vibration monitoring condition is the most common technique to monitor operation conditions (for example, the continuous monitoring systems installed on the bearing pedestals on the set turbine-gearbox-generator). However, the vibration technique is limited to monitor mechanical conditions, therefore, other monitoring and diagnostic techniques that can be useful to maintain reliability and efficiency of the machinery include: acoustic analysis, motor analysis technique, thermography, tribology, process parameter monitoring, visual inspections, and other non-destructive testing techniques.

Proactive maintenance focuses its work on reducing the failure recurrence or unexpected failure, determining the root cause of previously occurred failures (Asaye, 2009).

In binary cycle power plants, besides the different maintenance practices that are summarized above, major overhauls are carried out according to the manufacturer's recommendations. The common major overhaul period for a binary cycle power plant is between 40,000 to 48,000 hours. The development of the principal mechanical maintenance activities during the major overhauls of the main equipment, the experiences of maintenance, development in Svartsengi and Berlin binary cycles power plant, are mentioned below:

5.1 Turbine

The turbine is the main component in the binary cycles. For this component, the maintenance activities are as follows:

- Disassembling the turbine wheel and nozzles ring;
- Checking the condition of the turbine wheel and nozzles ring;
- Checking the condition of the turbine mechanical seal, o-rings and bearings;
- Checking and cleaning the oil tank filter and change the oil;
- Checking the gearbox; and
- Performing non-destructive testing, such as liquid penetrant, magnetic particles and ultrasonic.

The objectives during the major overhaul are to look for wear, cracks and damage in the movement parts, furthermore some critical parts should be replaced according to the manufacturer's recommendations.

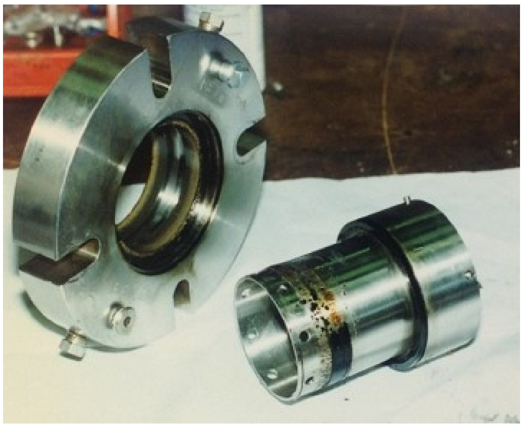

FIGURE 16: Shell and tube heat exchanger in the Berlin binary plant (ENEX, 2007)

Since the start of its operation, the major corrective maintenance activity in the Svartsengi binary power plant, was associated with the mechanical seal. The mechanical seal showed failures in the seal faces caused by the wrong type of lubrication oil. Nowadays, the mechanical seal is working well and the failure is eliminated by lubricating the mechanical seal with high thermal resistance oil. Figure 16 shows the mechanical seal damages.

In the Berlin binary cycle power plant, the mechanical seal is of the dry face seal type and this type of seal has a disadvantage. The disadvantage is the requirement for injection of seal gas during operation and even during shutdown time. This is required to dissipate heat generated by the dry face seal and to avoid contact of the seal faces with the lubricating oil and oil mist on one side and working fluid on the other side. Figure 17 shows the mechanical seal damage. When the mechanical seal is damaged, the amount of seal gas flowing to the working fluid side increases the discharge pressure and decreases the turbine work output, because of the presence of incondensable seal gas flowing in the process.

In the Berlin binary cycle power plant, the nozzle ring of the turbine was changed because of erosion and jamming problem. The change included a new design for the nozzle ring.

5.2 Heat exchangers

The heat exchangers are the components where the geothermal fluid, the working fluid and the cooling fluid interact. The major maintenance work in the heat exchanger is cleaning the heat exchanger area, depending on the process conditions. As it is known, the geothermal fluid flows through the tubes, the major problem found in the heat exchanger is associated with the chemistry of the fluid, i.e. scaling problems. The working fluid side theoretically doesn't require a cleaning process. The cleaning process can be carried out with pressurized water and chemical cleaning. A recommended practice is to run a pressure test to verify the seal of the heat exchanger, to avoid contamination of the working fluid.

FIGURE 17: Mechanical seal contaminated and damaged (The Berlin binary power plant)

In Svartsengi, the geothermal fluid used in the binary power plant is steam, and there have been no major problems. While, in Berlin binary cycle power plant, geothermal water is used in the primary loop, and scaling problems associated with the chemistry of the fluid are present. In Berlin, chemical and pressurized water cleaning process is used during the maintenance work. The pressure test is done in the Berlin binary cycle, to ensure tightness of the heat exchanger. During this test, when leakage is identified in the tubes, they are blocked in order to avoid contamination of the working fluid with the geothermal fluid.

5.3 Working fluid pumps

The working fluid pumps are the component that feed the working fluid in the binary cycles. For this component the maintenances activities are as follows:

- Checking the intermediate bearing sleeves and bushing against wear;
- Checking the shaft and impellers;
- Checking the causing wear ring and the impeller wear ring against any wear;
- Checking the parts against corrosion and erosion;
- Carefully checking the coupling against any wear;
- Checking the bearing cage against any wear;
- Checking the run out of the shaft;
- Checking condition of pump mechanical seal and o-rings;
- Changing oil; and
- Checking the coupling alignment.

In the Svartsengi binary power plant, the major overhaul is carried out for the working fluid pumps after every 40,000 hours and during this work the shaft, sleeves, bushing, wear ring, bearing, mechanical seal, and shaft are replaced. The pump is equipped with a single mechanical seal and the cartridge design allows the mechanical seal to be changed without taking it apart.

In Berlin binary cycle power plant, the working fluid pumps have the same overhaul schedule as in Svartsengi. The mechanical seal in Berlin binary cycle power plants has been changed from single to double seal type. The advantage of the double mechanical seal is that it eliminates leakage of working fluid into the atmosphere and the working fluid losses are eliminated during a failure of the seal. The cartridge design allows changing the mechanical seal without taking it apart.

5.4 Cooling systems

The main function of cooling systems is to condense the working fluid and dissipate the removed heat to the environment. The condensers in Svartsengi are water and air coolers and the maintenance activity is to clean the heat exchanger areas and check the seal in the system. In the Svartsengi power plant, the air cooled condensers have a leakage, which is stopped by installing a short sleeve inside each tube at the end of the header box. These sleeves are installed using hydraulic tube expansion technology. The sleeves are expanded for tight contact with the parent tube in the header box. Figure 18 shows the air condenser, the leakage zone and the sleeves that are used to seal the condenser.

FIGURE 18: Air condensers and the leakage zone

The Berlin binary cycle has a wet cooling system, and the mechanical maintenance work is carried out on the circulating water pumps, gear box and fans. For these components, the maintenance activities are as follows:

- Checking the intermediate bearing and bushing against wear;
- Checking the shaft and impellers;
- Checking the parts against corrosion and erosion;
- Carefully checking the coupling against any wear;
- Checking condition of pump mechanical seal and o-rings;
- Checking the coupling alignment;
- Checking the gears against any wear;
- Checking the fan blades; and
- Changing the gearbox oil.

In the Berlin binary cycle power plant, the circulation water pumps were changed, after corrosion problems were found. The construction material of these pumps was changed from cast iron to stainless steel, and also the material of the stuffing box was changed to a mechanical seal. The corrosion was caused by the chemistry of the condenser water which was used as the cooling fluid.

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