Binary Plant Berlin
Operation and Instruction Manual

Design, Procurement and Construction Management for

LaGeo S.A. de C.V.

El Salvador

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1 Introduction and Scope

This manual is intended to provide the necessary information for the operation and maintenance of Binary Plant Berlin. A description of the plant, processes, and equipment is included, in addition to installation, operation, and maintenance instructions. The latter are to a large extent presented in appendices in the form received from manufacturers.

The manual builds up from the general to the specific, where a description of the plant and processes is followed by plant operating instructions and descriptions of equipment.

Major equipment and plant components have been labeled according to the KKS power plant designation system and references are made accordingly throughout the text. The use of the KKS system is intended to facilitate the identification of parts and to clarify operational and maintenance descriptions. A KKS system handbook may be found in Appendix X.

The manual is intended as a guide for Binary Plant Berlin only, i.e. Enex's scope of work as detailed in the contract between Enex hf and LaGeo S.A. de C.V., Contrato N° LaGeo 6/2005, and does not provide guidance on any external works that may have been undertaken in the vicinity.

Figure 1: Binary Plant Berlin general layout.

2 Safety Precautions

It is important to read carefully through the manual before undertaking installation, operation, or maintenance work, in order to ensure that the correct procedures are followed. In particular, the following should be kept in mind:

- Personnel who perform installation, operation, and/or maintenance work must be fully qualified and trained in such work.
- Before attempting to install, operate, or maintain equipment, all related instructions and documentation should be read and understood.
- All special instructions, notes, and warnings must be heeded.
- Caution and good common sense should be exercised at all times during installation, operation, and maintenance procedures.
- Applicable safety standards and work procedures must be followed at all times during installation, operation, and maintenance of equipment.

3 Plant Description

3.1 General Description

Binary Plant Berlin is located near the town of Berlin in Usulután province, at an altitude of 650 meters above sea level and approximately 75 km E-S-E of San Salvador. The Organic Rankine Cycle is utilized in the plant process system to generate electricity, with isopentane as the working fluid, to generate electricity. The gross output is 9,2 MW_e but after ancillary electrical power for circulating pumps, cooling water pumps, cooling tower fans, and other electrical equipment have been deducted, the net production is 7,8 MW_e.

The main equipment and components of the plant are the following:

- **Genset**
  - Turboexpander
  - Gearbox
  - Generator
  - Lube oil console

- **Heat exchangers**
  - Pre-Heaters
  - Reboilers
  - Recuperator
  - Condenser
  - Auxiliary cooling loop heat exchangers

- **Pumps**
  - Isopentane circulation pumps
  - Isopentane fill pumps
  - Isopentane drain (vacuum) pump
  - Cooling water circulation pumps

- Cooling water make-up pumps
- Auxiliary cooling loop pumps
- Brine booster pumps

- **Cooling tower**

- **Transformers**
  - 12,5 MVA 13,8kV/115kV power transformer
  - 2,0 MVA 13,8kV/0,480kV power transformer
  - 30 KVA and 10 KVA 480V/240V transformers

- **Auxiliary systems**
  - Nitrogen system
  - Nitrogen extraction system
  - Pneumatic System
  - Ventilation system
  - Fire protection system
  - Inhibitor system
  - Cooling water chemical treatment system
  - Auxiliary cooling system for genset

- **Tanks**
  - Fire protection tanks
  - Isopentane tank

- **Cranes**
  - 25 ton building crane
  - Cooling tower cranes

- **Pipes and fittings**

- **Valves**

- **Instrumentation**

- **Control system**

- **Communication system**

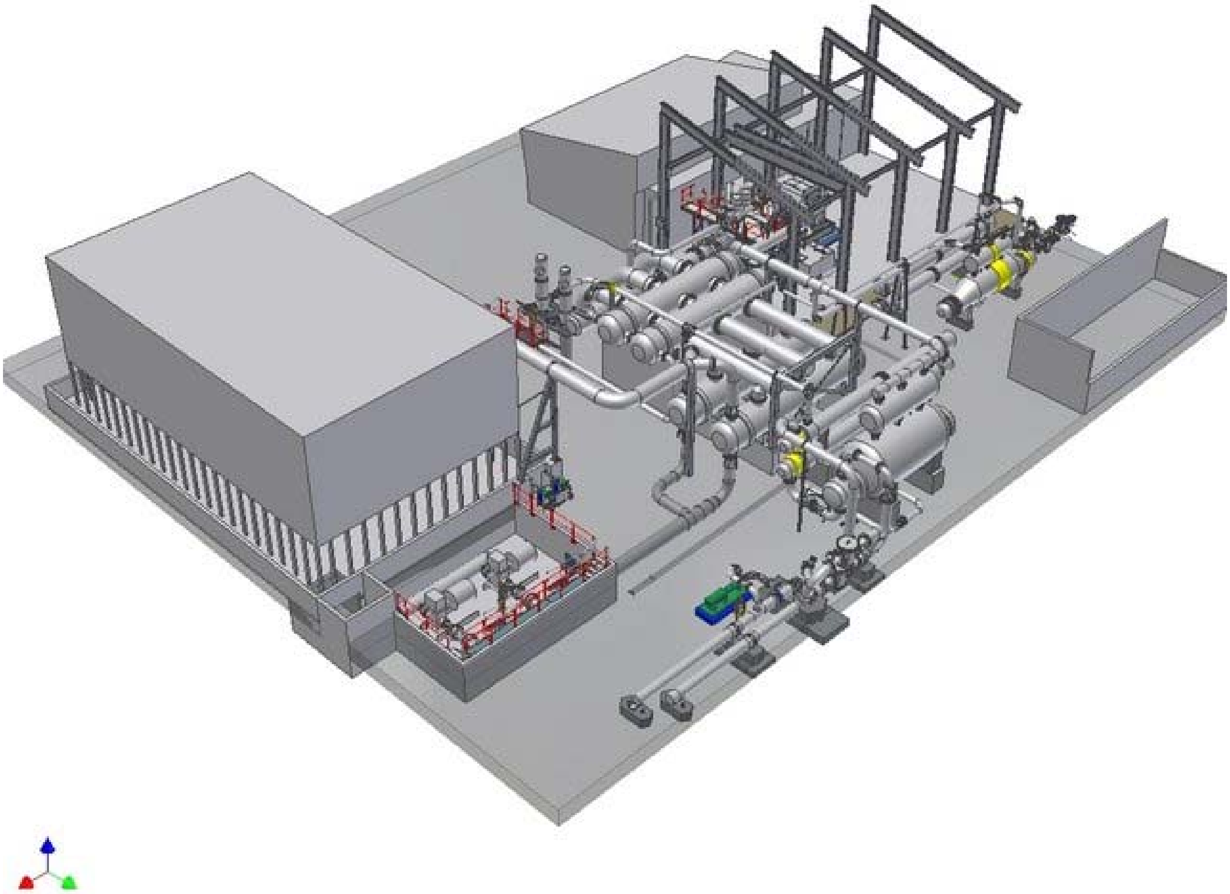

Figure 2: Binary Plant Berlin.

3.2 Process Description

The process is divided into three main loops as shown schematically in figure 3:

1. Primary loop: refers to the brine circulation; heat source.
2. Secondary loop: refers to the isopentane process cycle.
3. Cold end: refers to the cooling water circulation; heat sink.

These are described further below.

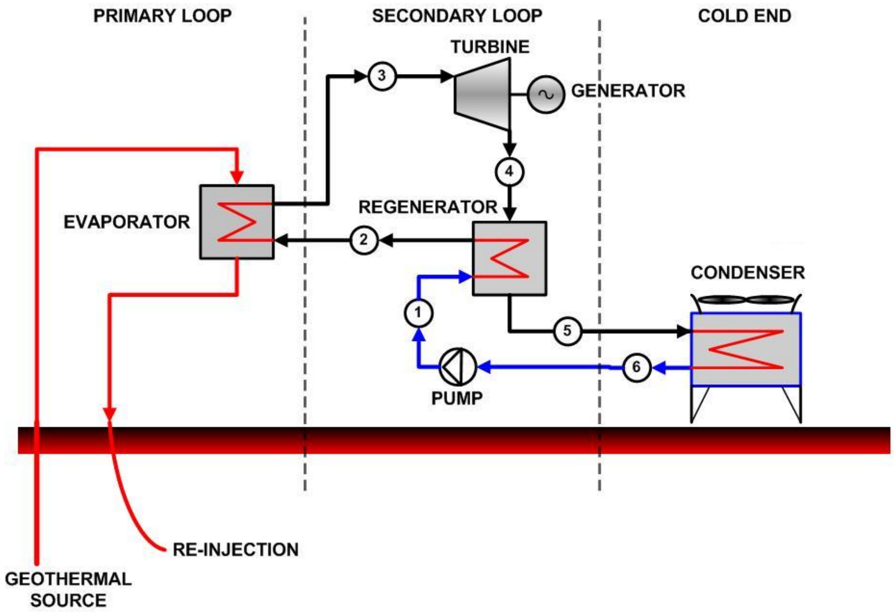

Figure 3: Process Diagram

3.2.1 Primary Loop

The primary loop is a collective term for two separate brine loops, one from the TR-4/5 boreholes and the other from the TR-2/9 boreholes. The former carries 221 kg/s of brine at 22 bar$_a$ and has an interface with the secondary loop in pre-heaters and reboiler 1. The latter carries 79 kg/s at 11 bar$_a$ and has an interface with the secondary loop in pre-heaters and reboiler 2. The brine is cooled down to 140°C before being reinjected into the reservoir.

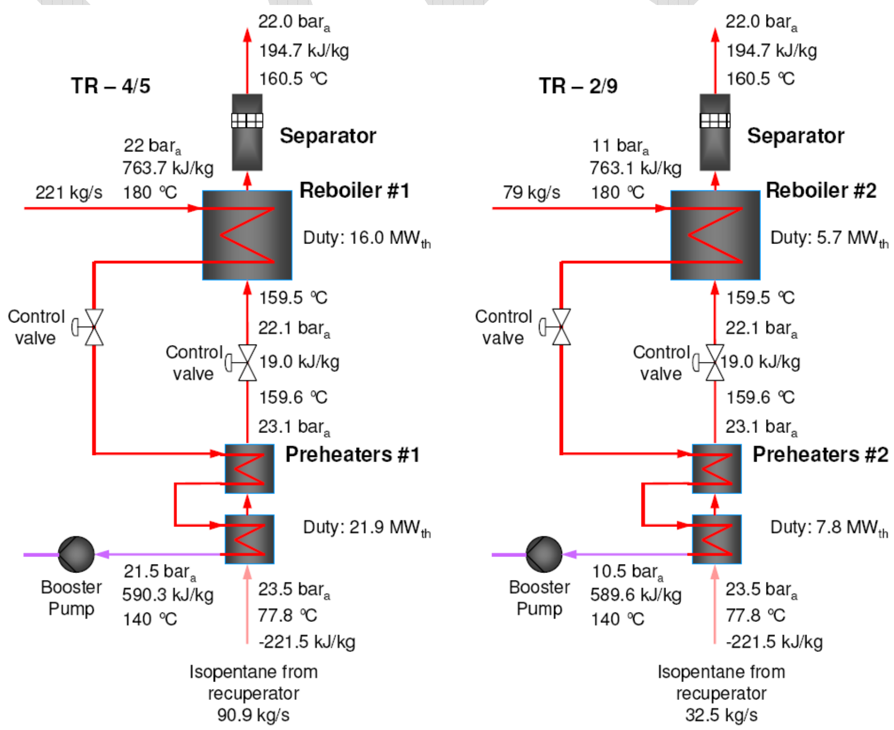

Figure 4: Reboilers and primary loop process diagram.

3.2.2 Secondary Loop

The secondary loop refers to the isopentane process cycle, which carries a flow of 123.3 kg/s under design conditions and consists of a series of semi-stepwise changes in the physical states of the organic working fluid. These changes are embodied in the following:

- **Evaporation** in the reboilers through heat exchange with brine.
  - The isopentane undergoes a phase change at approximately 159.5°C.
- **Expansion** in the turbine.
  - The pressure drops from 22.0 bar_a to 1.85 bar_a.
  - The temperature drops from 160.5°C to 92.9°C.
- **Cooling** in the recuperator.
  - The temperature drops from 92.9°C to 52.6°C.
- **Condensation** in the condensers through heat exchange with cooling water.
  - The isopentane undergoes a phase change at approximately 1.8 bar_a.
  - The temperature drops from 52.6°C to 44.8°C.
- **Compression** by the isopentane circulation pumps.
  - The pressure is raised from 1.78 bar_a to 23.78 bar_a.
  - The temperature increases from 44.8°C to 46.1°C.
- **Heating** in the recuperator.
  - The temperature increases from 46.1°C to 77.7°C.
- **Heating** in the pre-heaters.
  - The temperature increases from 77.7°C to approximately 159.5°C.

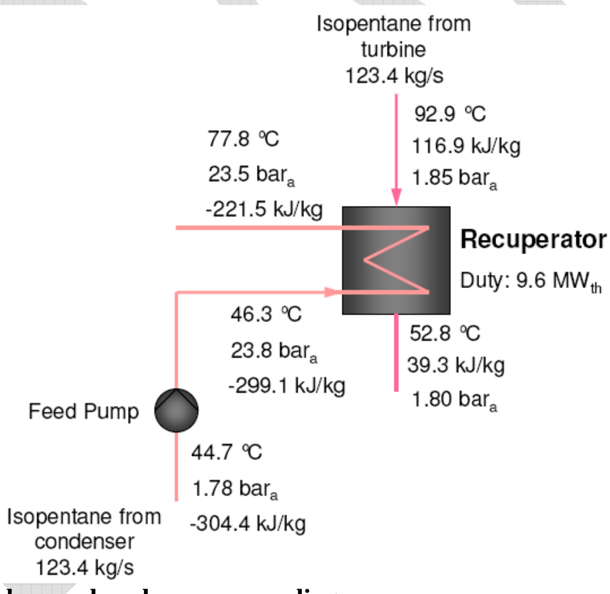

Figure 5: Recuperator and secondary loop process diagram.

3.2.3 Cold End

The cold end refers to the cooling water cycle, which carries a flow of 1,013 kg/s under design conditions and consists of a few semi-stepwise changes in the physical states of the cooling water. These changes are embodied in the following:

- **Cooling** in the cooling tower through heat exchange with the atmosphere.
  - The temperature drops from 38.3°C to 28.3°C.

- The elevation drops by approximately 5.8 m.
- **Elevation** by the cooling water pumps.
    - The elevation increases by 5.8 m.
- **Heating** in the condenser through heat exchange with isopentane.
    - The temperature increases from 28.3°C to 38.3°C.

In the cooling tower, the water is cooled down partly through sensible heat transfer and partly through latent heat transfer, when a portion of the water evaporates. Due to this evaporation, blow-down, and drift, a constant supply of make-up water is needed to replenish the system.

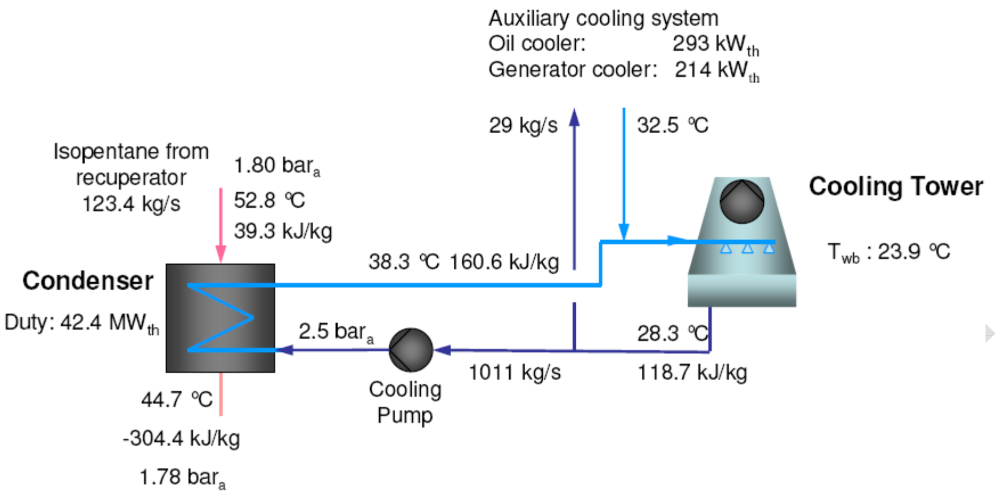

Figure 6: Condenser and cold end process diagram.

4 Installation

All equipment should be installed according to instructions from manufacturers. Please see Appendices for further information.

5 Plant Operating Instructions

5.1 General

Following is a description of the control system of the binary plant process in Berlin. The description is in four parts i.e. prior to start up, start up, normal operation and shut down. Instruments and equipments are referred to by the KKS codes.

5.2 Prior to start up

Prior to start up the cycle is filled with isopentane. The procedure is as follows:

- The pneumatic system is in operation as well as the N_2 - generation system.
- Air is drawn from the cycle using a portable vacuum pump. All valves in the isopentane cycle are open. When the pressure in the cycle is below 0,005 bar_a the cycle is considered to be sufficiently free of air.
- Isopentane control valves 1LAB10-AA021 and 1LAB10-AA011 and turbine bypass valve 1LBB11-AA011 are closed. Bypass valve 1LAB12-AA010 is open.
- Isopentane is pumped from the isopentane storage tank using pump 1LAJ10-AP011. The isopentane is piped to various parts of the cycle using the drainage piping.
- The isopentane filling of the cycle is complete when the following liquid levels are correct.

1LAA10-CL001	Liquid level in condensers
1LAB10-CL101	Liquid level in recuperators, tube side
1LAB10-CL011	Liquid in reboiler 1, shell side
1LAB10-CL021	Liquid in reboiler 2, shell side

The cooling tower basin is filled with water prior to start up. Water is pumped to the cooling tower basin using the cooling water make up pumps 1GHE10-AP011 and 1GHE10-AP021.

Brine is piped to the power plant by closing brine valves 1LBD10-AA201 and 2LBD10-AA201 and opening brine valves 1LBD10-AA010, 1LBD20-AA012, 2LBD10-AA010 and 21LBD20-AA012. These valves are all manually operated.

The brine flows past the heat exchangers through the open bypass control valves 1LBD10-AA202 and 2LBD10-AA202 while the brine control valves 1LBD20-AA010 and 2LBD20-AA010 are closed.

The expander shall be made ready for start up. This includes the following:

- Confirmation of the oil level, adjust oil level if required.
- Confirm that the expander shut down valve and the expander control vanes are closed.
- Flow of seal gas is established. The temperature of the seal gas shall be greater than 20 °C and the correct pressure difference of the seal gas shall be confirmed.
- Main and auxiliary oil pumps are started. The correct oil pressure and normal oil difference pressure across oil filter is confirmed. The oil temperature from the oil cooler shall be checked.

5.3 Start up

1. *Cooling tower, cold end*

   The cooling water circulation pumps 1PAB10-AP011 and 1PAB10-AP021 are started. The cooling water circulation pumps cannot be started unless the signal from level switch 1PAB10-CL101 in the cooling water basin is correct i.e. water level in the cooling tower basin is high enough.

   Cooling tower fans 1PAB10-AN011 and 1PAB10-AN021 are started when cooling water temperature 1PAB10-CT010, reaches 27 °C. The pressure in the condensers and recuperators will be below 1 bar_a during the start up.

2. *Isopentane pressure*

   Isopentane control valves 1LAB10-AA021 and 1LAB10-AA011 are closed. One of the isopentane circulation pumps 1LAC1-AP011 and 1LAC10-AP021 is started and the pressure measured by 1LAB10-CP001 reaches a set value. Bypass valve 1LAB12-AA010 is open and ensures minimum flow through the isopentane circulation pump. The second isopentane circulation pump is started when the first one has reached 90% speed.

3. *Heating, preheater-reboiler set 1*

   Brine from TR 4/5, i.e. brine flowing to preheater-reboiler set 1 (1LAB10-AC021, 1LAB10-AC022 and 1LAB10-AC023), is used when starting the isopentane cycle and the turbine. Brine from TR 2/9 starts to flow through preheater-reboiler set 2 (1LAB10-AC11, 1LAB10-AC12 and 1LAB10-AC13) only when the isopentane cycle as well as the turbine is running.

   Brine starts to flows into preheaters and reboiler 1LAB10-AC021, 1LAB10-AC022 and 1LAB10-AC023 when control valve 1LBD20-AA010 is opened. In the beginning bypass control valve 1LBD10-AA202 is also fully opened. The brine flowing from preheater 1LAB10-AC021 will be colder than 140 °C in the beginning. The flow of brine through the reboiler and the preheaters is gradually increased by closing bypass control valve 1LBD10-AA202.

4. *Flow of isopentane*

   The stop valve of the turbine 1MAA10-AA010, the stop valve bypass 1MAA10-AA210 and the bypass control valve 1LBB11-AA011 are closed. The isopentane in the reboiler and preheaters is heated by the brine and starts to boil. Pressure in the hot side of the cycle, measured by 1LBB10-CP001, will increase. When the pressure reaches a set value turbine bypass 1LBB11-AA011 opens and isopentane flows into the low pressure side. There the isopentane is cooled and condensed in the recuperators 1LAB10-AC010, 1LAB10-AC020 and the condensers 1MAG10-AC011 and 1MAG10-AC021.

   When the isopentane starts to boil in reboiler 1LAB10-AC023 the level in the reboiler, measured by 1LAB10-CL021, drops below the set point and control valve 1LAB10-AA021 opens. When the control valve 1LAB10-AA021 is 10% open the cycle bypass valve 1LAB12-AA010 is closed.

5. *Turbine start*

The start up of the turbine depends on whether it is cold or warm. The turbine is considered to be warm when the difference of the temperature of the turbine casing and the gas in the turbine measured by the turbine exhaust is less than 10 °C or if the turbine has be shut down for less than 30 minutes. Otherwise the turbine is cold.

5.1. Turbine cold start

The turbine can be started once the pressure, measured by 1LBB10-CP001, is high enough, i.e. when the pressure is 22 bar_a. Turbine bypass control valve 1LBB11-AA011 is designed for 35 kg/s at 22 bar_a pressure and at higher flow the pressure will be higher. A restriction is on the flow of brine through the preheater and reboiler with respect to this pressure i.e. if the pressure, measured by 1LBB10-CP001, is higher than 23 bar_a the bypass control valve 1LBD10-AA202 opens. Consequently only part of the brine can flow through the heat exchangers unless the turbine is running.

The turbine is started according to the following sequence:

- *Warm up*. The shut down valve 1MAA10-AA010 is closed. Inlet guide vanes are approximately 5% open. The shut down valve bypass 1MAA10-AA210 is opened 15%. Hot isopentane will bleed through the 5% open inlet guide vanes heating the turbine. The turbine is warm enough when the temperature difference between the turbine casing and the gas in the turbine measured by the turbine exhaust is less than 10 °C. The warm up time is set in the control system to 45 minutes. After 40 minutes of warm up the turbine drain valve 1MAA10-AA001 shall be opened for 2 minutes.
- *Ramp up*. As the turbine start button is pushed the shut down valve bypass 1MAA10-AA210 is fully opened and simultaneously the inlet guide vanes opens and the turbine starts to rotate according to a start-up ramp preset in the governor. The generator fans starts when the turbine is started. When the turbine reaches 85% speed a signal from the governor is sent to the AVR to initiate excitation. The auxiliary oil pump stops.
- *Synchronisation*. When the generator reaches 98% speed a synchronisation signal is sent to the synchronisation panel. If the generator breaker has not closed 5 minutes after reaching 98% of the speed the automatic synchronisation has failed and the synchronisation will be switched to manual.
- *Operation*. When synchronisation is complete the shut down valve 1MAA10-AA010 is opened and the shut down valve bypass 1MAA10-AA210 is closed and cannot be opened again until the turbine has been reset after a stop. The governor switches from island operation to droop mode. The AVR panel switches from voltage to power factor control.

5.2. Turbine warm start

The turbine can be started once the pressure, measured by 1LBB10-CP001, is high enough, i.e. when the pressure is 22 bar_a. The turbine is started according to the following sequence:

- *Warm up*. No warm up is required. It is not required to drain condensate from the turbine.
- *Ramp up*. As the turbine start button is pushed the shut down valve bypass 1MAA10-AA210 is fully opened and simultaneously the inlet guide vanes opens and the turbine starts to rotate according to a start-up ramp preset in the governor. The generator fans

starts when the turbine is started. When the turbine reaches 85% speed a signal from the governor is sent to the AVR to initiate excitation. The auxiliary oil pump stops.

- *Synchronisation*. When the generator reaches 98% speed a synchronisation signal is sent to the synchronisation panel. If the generator breaker has not closed 5 minutes after reaching 98% of the speed the automatic synchronisation has failed and the synchronisation will be switched to manual.
- *Operation*. When synchronisation is complete the shut down valve 1MAA10-AA010 is opened and the shut down valve bypass 1MAA10-AA210 is closed and cannot be opened again until the turbine has been reset after a stop. The governor switches from island operation to droop mode. The AVR panel switches from voltage to power factor control.

6. *Preheater-reboiler set 2*

Preheater-reboiler set 2 is heated by the brine flowing from TR 2/9. Preheater-reboiler set 2 (1LAB10-AC011, 1LAB10-AC012 and 1LAB10-AC013) can be started once the isopentane cycle and the turbine is running. When control valve 2LBD20-AA010 is opened the brine starts to flow into preheaters and reboiler 1LAB10-AC011, 1LAB10-AC012 and 1LAB10-AC013. In the beginning bypass control valve 2LBD10-AA202 is also fully opened but as the bypass is gradually closed the flow through preheater-reboiler set 2 increases.

As the isopentane in reboiler 1LAB10-AC013 starts to boil the level in the reboiler, measured by 1LAB10-CL011, drops below the set point and control valve 1LAB10-AA011 opens. Thus the isopentane starts to flow through preheater-reboiler set 2.

5.4 Operation

In normal operation all available brine flow through the preheaters and reboilers i.e. control valves 1LBD20-AA010 and 2LBD20-AA010 are fully opened and bypass control valves for the brine 1LBD10-AA202 and 2LBD10-AA202 are fully closed. The flow through the turbine and the output depends on the pressure of the isopentane gas i.e. 1LBB10-CP001.

The valve controlling the bypass of the turbine 1LBB11-AA011 is controlled by the pressure of the isopentane gas i.e. 1LBB10-CP001. The set pressure is higher than the one controlling the turbine i.e. the bypass control valve only opens if the gas produced in the reboilers is more than the turbine can utilize.

It is possible to operate the turbine in part load. As the output from the turbine is lowered the gas pressure, measure by 1LBB10-CP001, will increase. This will cause the turbine bypass control valve 1LBB11-AA011 to open and if the pressure still increases the brine bypass control valve 1LBD10-AA202 will open, reducing the brine flow through preheater-reboiler set 1 (1LAB10-AC021, 1LAB10-AC022 and 1LAB10-AC023).

Flow of brine through preheaters and reboiler 1LAB10-AC011, 1LAB10-AC012 and 1LAB10-AC013 will only be on/off as described above in *start up*.

In normal operation isopentane control valves 1LAB10-AA021 and 1LAB10-AA011 are controlled by the level in reboilers 1LAB10-AC023 and 1LAB-AC013 respectively. These levels are measured by 1LAB10-CL021 and 1LAB-CL011. The temperature of the brine flowing from the preheaters is measured by 1LBD20-CT001 and 2LBD20-CT001. If the temperature drops below 140 °C the corresponding isopentane control valve, 1LAB10-AA021 or 1LAB10-AA011, closes.

5.5 Shut down

1. *Normal shut down*

   Normal shut down is reverse to start up. Preheater-reboiler set 2 (1LAB10-AC011, 1LAB10-AC012 and 1LAB10-AC013) is shut down first by opening brine bypass control valve 2LBD10-AA202 and then be closing brine control valve 2LBD020-AA010. The isopentane control valve 1LAB10-AA011 will be closed when the evaporation in the reboiler 1LAB10-AC013 stops. The output of the turbine will be reduced as a consequent of reduced heat input.

   The turbine output will then be reduced further causing turbine bypass valve 1LBB11-AA011 to open as well as the brine bypass valve 1LBD10-AA202. Eventually the turbine will be stopped and the flow of brine through preheater-reboiler set 1 (1LAB10-AC021, 1LAB10-AC022 and 1LAB10-AC023) will be stopped as the brine control valve 1LBD20-AA010 is closed. As the evaporation of isopentane in reboiler 1LAB10-AC023 stops the isopentane control valve 1LAB10-AA021 closes. At the same time the bypass valve 1LAB12-AA010 opens. The isopentane circulation pumps 1LAC10-AP011 and 1LAC10-AP021 are shut down.

   The cold end is shut down first by turning off the cooling tower fans 1PAB10-AN011 and 1PAB10-AN021 and thereafter the cooling water circulation pumps 1PAB10-AP011 and 1PAB10-AP021 are turned off.

2. *Emergency shut down*

   There are two types of emergency shut down. Firstly turbine trip only where the flow of isopentane in the cycle continues bypassing the turbine. Secondly a trip of the isopentane cycle when the isopentane circulation pumps are stopped and all the brine bypasses the heat exchangers.

   2.1. Turbine trip

   If the turbine trips the turbine stop valve 1MAA10-AA010 closes and the turbine bypass control valve 1LBB11-AA011 opens. The isopentane gas pressure, measured by 1LBB10-CP001, will raise and brine bypass control valve 1LBD10-AA202 will open. The isopentane gas which bypasses the turbine through valve 1LBB11-A011 flows into the recuperators 1LAB10-AC010 and 1LAB10-AC020 and the condensers 1MAG10-AC011 and 1MAG10-AC021. The temperature of the gas entering the recuperators will increase from approximately 95 °C to approximately 135 °C due to isenthalpic throttling in the turbine bypass valve 1LBB11-AA011.

   The isopentane cycle continues to run even though the turbine trips. Warm up is not needed when restarting the turbine in this case.

   2.2. Trip of the isopentane cycle

   If the isopentane cycle trips the turbine stop valve 1MAA10-AA010 will close and the turbine bypass control valve 1LBB11-AA011 opens. The isopentane circulation pumps 1LAC1-AP011 and 1LAC10-AP021 are stopped. The isopentane control valves 1LAB10-AA011 and 1LAB10-AA021 close and the bypass valve 1LAB12-AA010 opens. The brine bypass control valves 1LBD010-AA202 and 2LBD010-

AA202 open and finally the brine control valves 1LBD20-AA010 and 2LBD20-AA010 close. The cold end is shut down as described above i.e. the cooling tower fans 1PAB10-AN011 and 1PAB10-AN021 are turned off and thereafter the cooling water circulation pumps 1PAB10-AP011 and 1PAB10-AP021 are turned off.

Restarting the power plant after a trip of the isopentane cycle requires the procedure described in “Start up” above.

In the following table, trip signals and type of trip are listed

Signal	*Code (KKS)*	*Type of trip*
Low water level in cooling tower basin	1PAB10-CL101	Isopentane cycle
Low liquid level in condensers	1LAA10-CL001 1LAA10-CL101 1LAA10-CL102	Isopentane cycle
High level in reboiler 1 (1LAB10-AC023)	1LAB10-CL021 1LAB10-CL122 1LAB10-CL123	Turbine trip
High level in reboiler 2 (1LAB10-AC013)	1LAB10-CL011 1LAB10-CL112 1LAB10-CL113	Turbine trip
High back pressure	1MAA20-CP001 1MAA20-CP101 1MAA20-CP102	Isopentane cycle
High gas pressure	1LBB10-CP001 1LBB10-CP101 1 LBB10-CP102	Isopentane cycle
Low pneumatic system pressure		Isopentane cycle
Signals from turbine protection system		Turbine trip
Signals from electrical system		Turbine trip

5.6 Initial Fill of ORC

The procedure for initial filling of isopentane is as follows:

- The pneumatic system is in operation as well as the nitrogen generation system.
- Air is drawn from the cycle using a portable vacuum pump. All valves in the isopentane cycle are open. When the pressure in the cycle is below 0,005 bar_a the cycle is considered to be sufficiently free of air.
- Isopentane control valves 1LAB10-AA021 and 1LAB10-AA011 and turbine bypass valve 1LBB11-AA011 are closed. Bypass valve 1LAB12-AA010 is open.
- Isopentane is pumped from the isopentane storage tank using pump 1LAJ10-AP011. The isopentane is piped to various parts of the cycle using the drainage piping.
- The isopentane filling of the cycle is complete when the following liquid levels are correct.

1LAA10-CL001	Liquid level in condensers
1LAB10-CL101	Liquid level in recuperators, tube side
1LAB10-CL011	Liquid in reboiler 1, shell side
1LAB10-CL021	Liquid in reboiler 2, shell side

6 Control System

7 Equipment and Systems Description

7.1 Genset

The genset is designed for the expansion and power recovery of the isopentane medium and consists of a turbine, gearbox, generator, and lube oil console. The turboexpander-gearbox-generator unit is mounted on a structural steel skid, and is serviced by the lube oil console, which consists of a water-cooled lubrication system mounted on an adjacent skid.

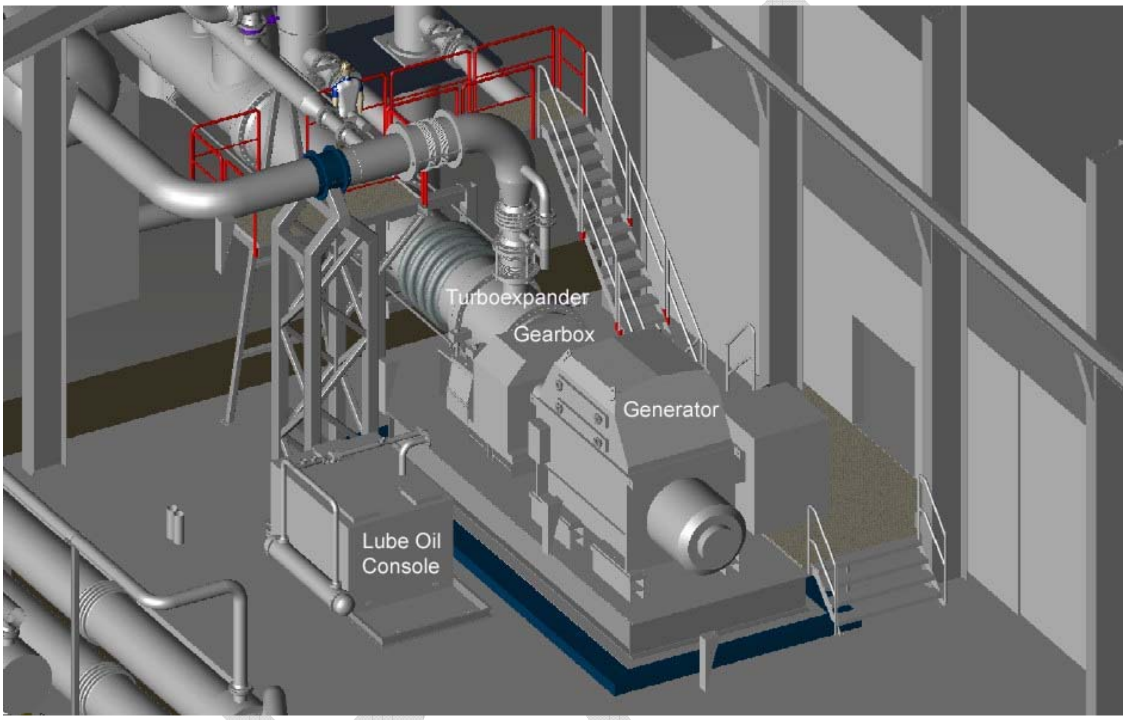

Figure 7: Genset.

Turboexpander Nozzle Assembly – Governor

The turboexpander is equipped with a variable nozzle assembly that controls the process gas flow so that a high efficiency is maintained over a wide range of flow rates. The nozzles are controlled by an electrically governed hydraulic amplifier, acting upon the assembly through an actuator rod. The actuator turns a low level electrical signal from the Woodward governor to a rotary mechanical output, exerting an opening or a closing force depending on the supplied oil pressure.

Turboexpander Case Seal

The process gas pressure in the expander case is sealed at the shaft by a dry face seal assembly, which has provision ports to inject the nitrogen seal and purge gas. The seal gas leaks through the dry face seal front labyrinth and mixes with the process gas flow, thereby ensuring that the process gas is retained in the expander casing. The purge gas is injected in the back labyrinth of the dry face seal and flows towards the vent cavity, thereby dissipating any heat generated by the dry face seal and ensuring that the lube oil mist does not migrate to the expander process side.

Monitoring System
A computerized vibrations monitoring system from Bently Nevada supplies the information necessary to assess the mechanical condition of the rotary components of the genset. A variety of supervisory parameters are continuously measured, providing crucial information of machinery problems such as imbalance, misalignment, shaft crack, and bearing failures. The data is then fed to the control system, which can shut down the machinery in case of abnormal readings.

Gearbox
The gearbox is connected to the turboexpander through a power shaft and acts as a speed reducer. It is connected to the generator through a low speed coupling.

Generator
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 at 13.8 kV and 60 Hz.

Lube Oil Console
The lubrication system circulates cooled, filtered, and pressurized lube oil through the genset, including gearbox and generator bearings.

Table 1: Genset KKS designation

Genset KKS designation	
Turbine	MAA
Lube oil console	
Gearbox	
Generator	MKA

See Appendix 11.1 and Drawings 12.1.1 for further information on the genset.

7.2 Heat Exchangers

Heat exchangers are used to transfer heat between the different media of the binary plant processes. The main ones are of the shell and tube type, in which one fluid is diverted into a number of tubes arranged in bundles and the second fluid, or fluid phase, flows in the shell in between the tubes. This arrangement ensures a large heat exchange area. If a phase change occurs in the heat exchanger, the fluid undergoing the change will be flowing on the shell side, as is the case with the reboilers and condensers.

The major heat exchangers have three basic functions:

1. Pre-heaters and reboilers transfer heat from brine to isopentane.
2. Recuperator transfers heat between two different phases of isopentane.
3. Condensers transfer heat from isopentane to cooling water.

In addition to the major heat exchangers of the binary plant process, other auxiliary heat exchangers exist in the plant, such as the cooling water loop heat exchanger.

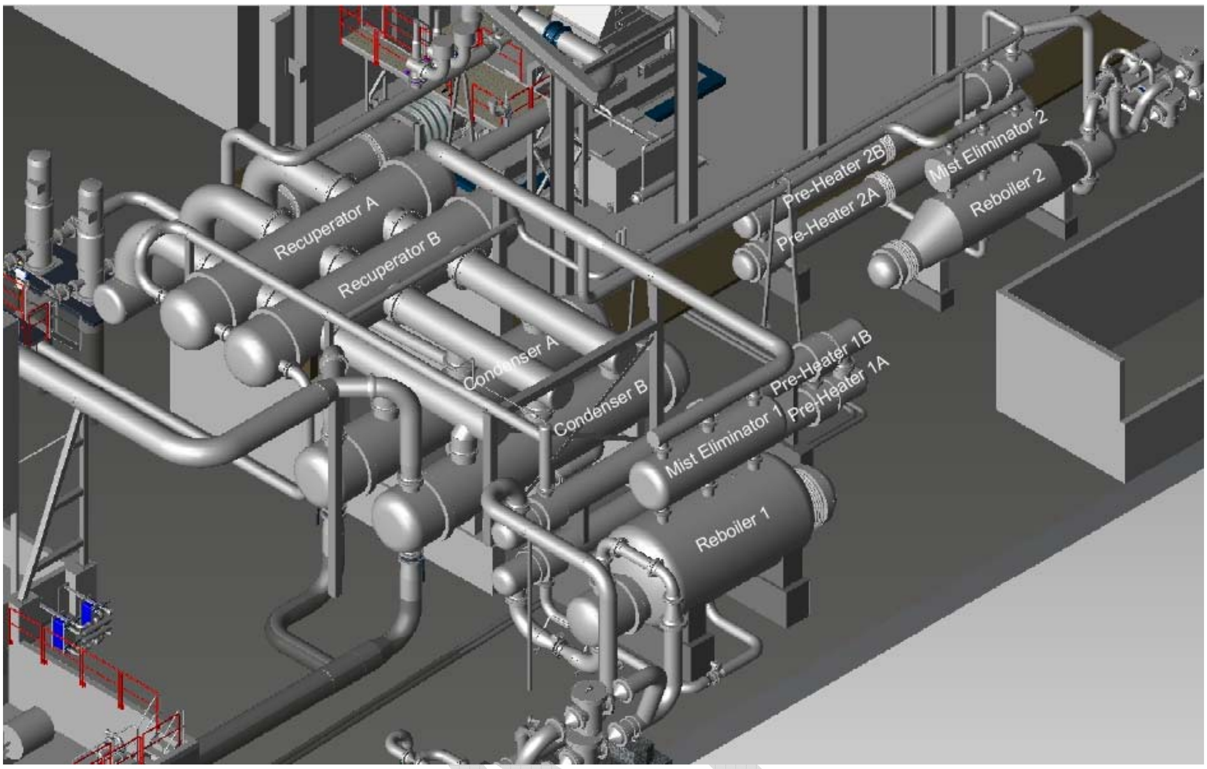

Figure 8: Heat exchangers

7.2.1 Pre-Heaters

Before reaching the reboilers, the isopentane is passed through two pre-heaters connected in series. The isopentane enters the first at approximately 77°C and exits the second at just under the boiling point temperature of 159.5°C at 22 bar_a. The brine enters at a temperature of approximately 164°C from the reboilers and flows out at around 140°C.

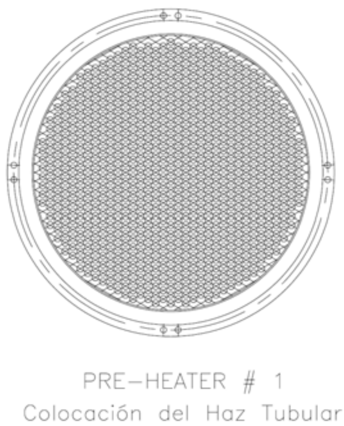

Figure 9: Pre-Heater tube bundle

Flow Arrangement – Tube Bundles

The pre-heaters are arranged so that one is seated on top of the other, which saves space and eliminates the need of connection pipes. As shown in figure 10, the brine enters the lower pre-heater at T1 (red), while the isopentane flows in the opposite direction and enters the upper pre-heater at S1 (blue). The brine flows through the pipe bundles, a cross-section of which is shown in figure 9, and the isopentane flows in the countering direction on the shell side.

Valves – Supports – Expansion Relief – Water Boxes – Lifting Lugs

Each pre-heater shell is provided with a drain valve (D) in case of the need for emptying or filling and vent valves (V) to allow the escape of gases. The pre-heaters´ supports rest on concrete foundations. One is fixed, whereas the other allows some movement due to thermal expansion/contraction. Stresses caused by differential expansion between the tube bundle and the shell are also relieved through expansion joints located near the centers of the pre-heaters. The water boxes at the end of each shell are detachable in case of the need for maintenance or cleaning of the pipe bundles. The upper shell of each pre-heater has two lifting lugs (A) to allow lifting during transport and each water box has two small lugs (B) for lifting in case of detachment.

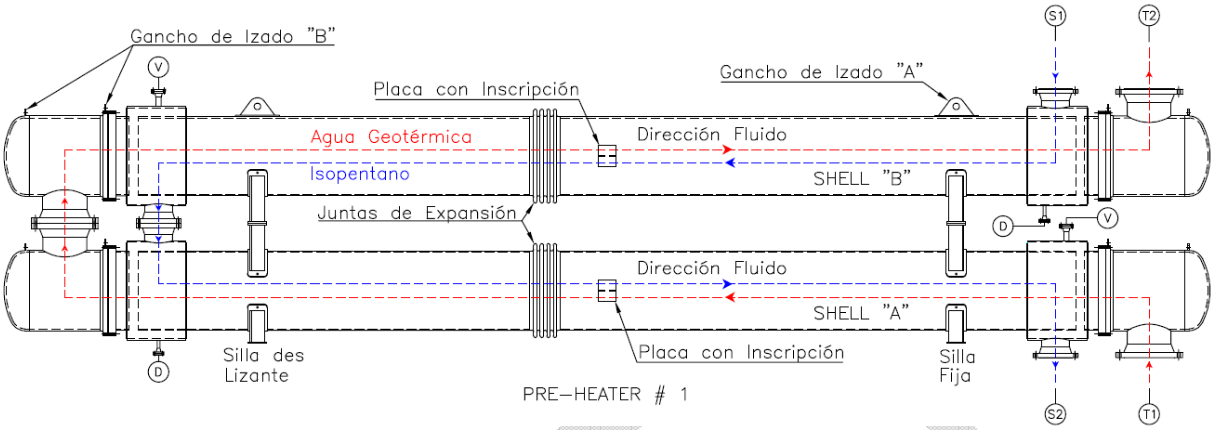

Figure 10: Pre-Heater flow arrangement

Table 2: Pre-Heaters KKS codes

Pre-Heaters KKS codes	
Pre-Heater 1A	1LAB10-AC021
Pre-Heater 1B	1LAB10-AC022
Pre-Heater 2A	1LAB10-AC011
Pre-Heater 2B	1LAB10-AC012

7.2.2 Reboilers

After passing through the pre-heaters, the isopentane reaches the reboilers at just under the boiling point. The brine enters at 180°C and flows out at approximately 164°C, after which it enters the pre-heaters. The extracted thermal energy changes the phase of the isopentane from liquid to gas. Due to the expansion in volume accompanying the phase change, there are three outlets at the top compared to just one inlet at the bottom.

7.2.2.1 Reboiler 1

Flow – Volume – Flow Arrangement

Reboiler 1 receives approximately ¾ of the brine flow (221 kg/s), and has a volume of 47.3 m^3. The brine enters the larger water box on the top at T1 and flows through the tube bundle in four passes to be returned at T2 as seen in figure 12. The isopentane enters through a single inlet (S1) at the bottom, from pre-heater 1, and evaporates as it flows past the tubes. The gas then bubbles to the surface and exits to the mist eliminator through the three outlets on top (S2, S3, S4).

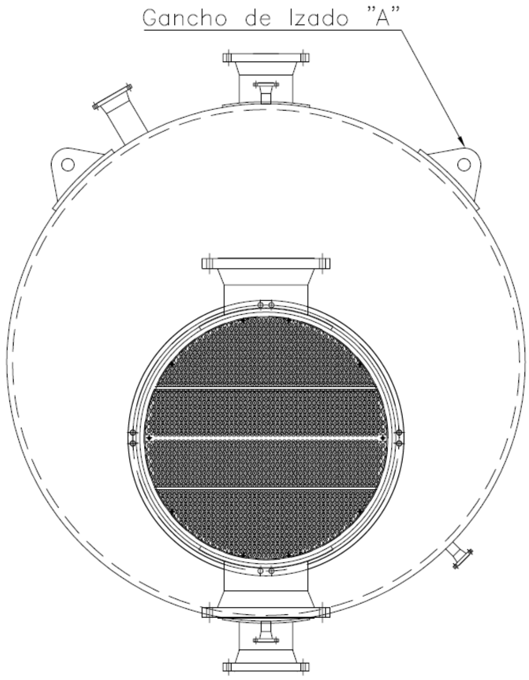

Figure 11: Reboiler 1 tube bundle

Valves – Supports – Expansion Relief – Water Boxes – Lifting Lugs

Reboiler 1 is provided with a drain valve on the low side (X1) and another on the bottom at the lowest point (X). A vent valve is likewise placed on the upper side (D) and another on the top at the highest point (X). The lower drain valve and upper vent valve are used for level sensor attachment (see drawing 20-04-1097). The reboiler's supports rest on concrete foundations, where one is fixed and the other is free to slide as a result of thermal expansion/contraction. Stresses caused by differential expansion between the tube bundle and the shell are also relieved through a bellows expansion joint near the smaller waterbox. The water boxes are detachable in case of the need for maintenance or cleaning of the pipe bundles and lifting lugs are provided to facilitate removal (B). Four lifting lugs are also attached to the shell to allow lifting during transport (A).

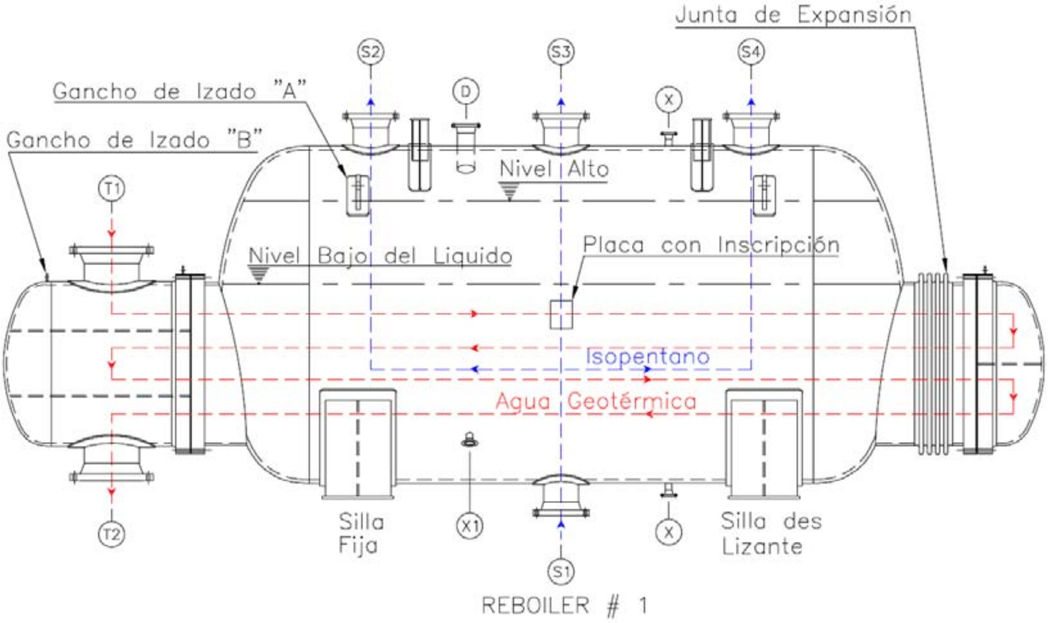

Figure 12: Reboiler 1 flow arrangement

KKS code: 1LAB10-AC023.

7.2.2.2 Reboiler 2

Flow – Volume – Flow Arrangement

Reboiler 2 receives about ¼ of the brine flow (79 kg/s) and has a total volume of 13.0 m^3. The brine enters the larger water box on the top at T1 and flows through the tube bundle in four passes to be returned at T2 as seen in figure 14. The isopentane enters through a single inlet (S1) at the bottom, from pre-heater 2, and evaporates as it flows past the tubes. The gas then bubbles to the surface and exits to the mist eliminator through the three outlets on top (S2, S3, S4).

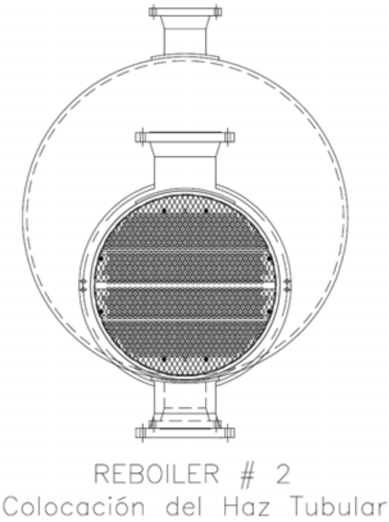

Figure 13: Reboiler 2 tube bundle

Valves – Supports – Expansion Relief – Water Boxes – Lifting Lugs

Reboiler 2 is provided with a drain valve on the low side (X) and another at the lowest point (D). A vent valve is likewise placed on the upper side (S5) and another on the top at the highest point (S6). The lower drain valve and upper vent valve are used for level sensor attachment (see drawing 20-04-1097). The reboiler's supports rest on concrete foundations, where one is fixed and the other is free to slide as a result of thermal expansion/contraction. Stresses caused by differential expansion between the tube bundle and the shell are also relieved through a bellows expansion joint near the smaller waterbox. The water boxes are detachable in case of the need for maintenance or cleaning of the pipe bundles and lifting lugs are provided to facilitate removal (B). Two lifting lugs are also attached to the shell to allow lifting during transport (A).

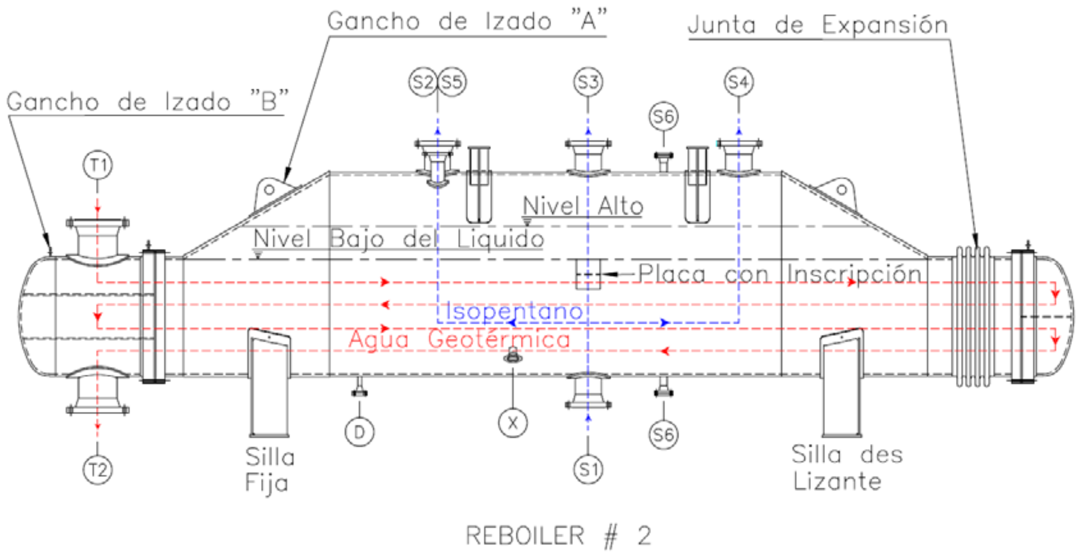

Figure 14: Reboiler 2 flow arrangement

KKS code: 1LAB10-AC013.

7.2.3 Recuperator

Flow Arrangement

The function of the recuperator is to increase the efficiency of the energy recovery process. Isopentane flows in on the shell side as a superheated gas at approximately 93°C and cools down to about 53°C before exiting to the condensers. After condensation, the pressure is raised in the isopentane feed pumps and the fluid returns to the recuperator. On the tube side, liquid isopentane enters at approximately 47°C and exits at around 77°C. The recuperator can therefore be looked upon as a pre-preheater.

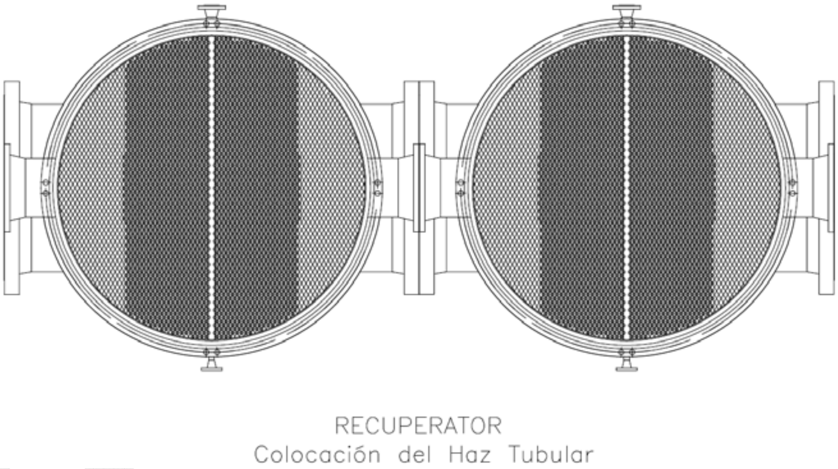

Figure 15: Recuperator tube bundles

Valves – Supports – Water Boxes – Lifting Lugs

The recuperator is provided with four drain valves at the lowest point, with two on the shell side (D_S) and two on the tube side (D_T). Four vent valves are likewise provided at the highest point, with two on the shell side (V_S) and two on the tube side (V_T). The recuperator's supports rest on concrete foundations, where one is fixed and the other is free to slide as a result of thermal expansion/contraction. The water boxes are detachable in case of the need for maintenance or cleaning of the pipe bundles and lifting lugs are provided to facilitate removal (B). Two lifting lugs are also attached to the shell of each unit to allow lifting during transport (A).

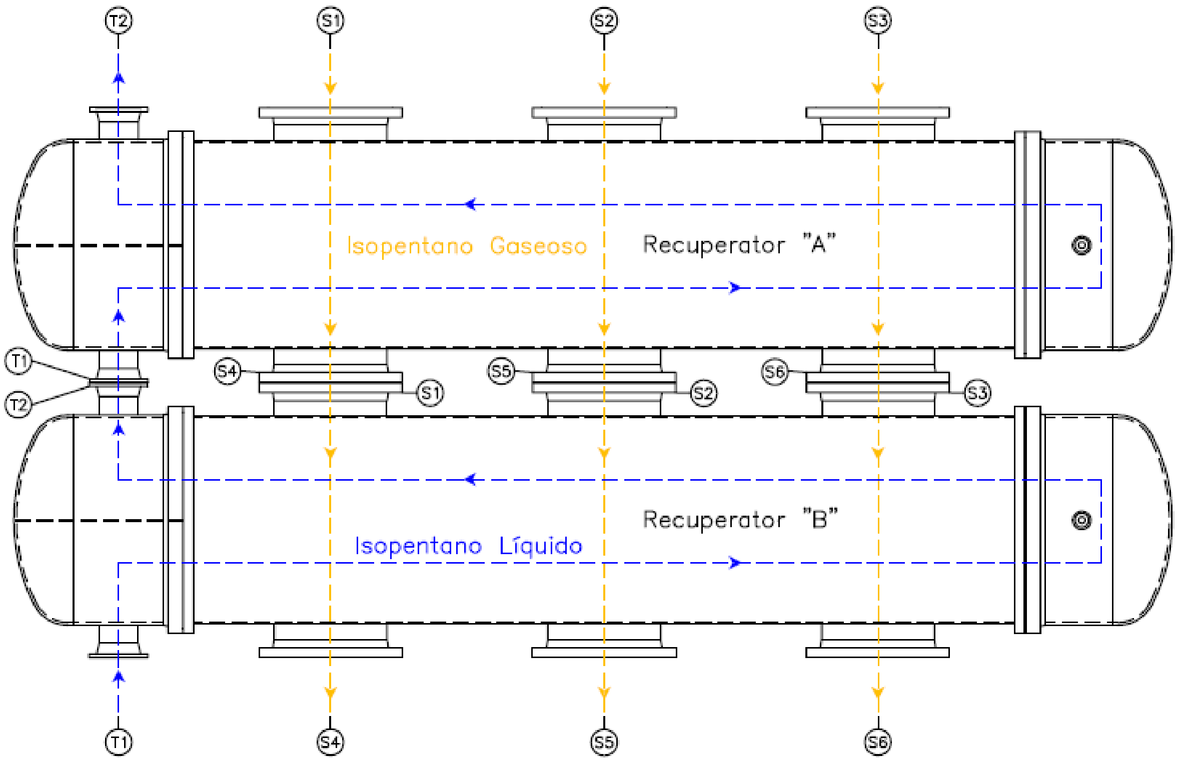

Figure 16: Recuperator flow arrangement – Plan view

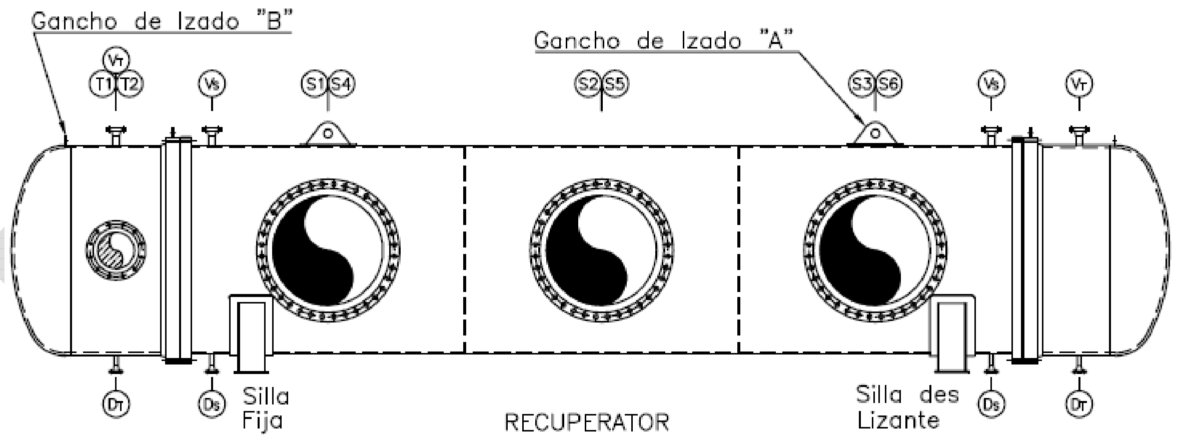

Figure 17: Recuperator – Side View

Table 3: Recuperator KKS codes

Recuperator KKS codes	
Recuperator A	1LAB10-AC020
Recuperator B	1LAB10-AC010

7.2.4 Condensers

Flow Arrangement

The isopentane gas received from the recuperator flows in on the shell side of the condenser and liquefies upon cooling. The gas enters through three inlets on the top at approximately 53°C and exits through a single outlet on the bottom at around 45°C. The cooling water on the tube side comes from the cooling tower and is circulated by the cooling water pumps. It enters the water boxes on the bottom side at about 28°C and exits through an outlet on the upper side at approximately 38°C after two passes through the condenser.

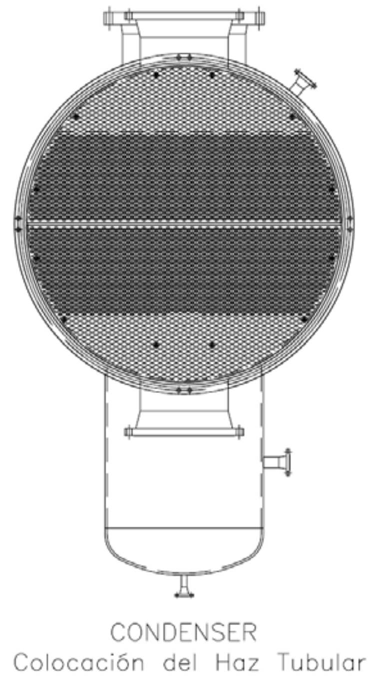

Figure 18: Condenser tube bundle

Valves – Supports – Water Boxes – Lifting Lugs

The condenser is provided with two drain valves (D), one on the shell side and one on the tube side. Two vent valves (V) are likewise provided at the highest point, one on the shell side and another on the tube side. The condenser's supports rest on concrete foundations, where one is fixed and the other is free to slide as a result of thermal expansion/contraction. The water boxes are detachable in case of the need for maintenance or cleaning of the pipe bundles and lifting lugs are provided to facilitate removal (B). Two lifting lugs are also attached to the shell of each unit to allow lifting during transport (A).

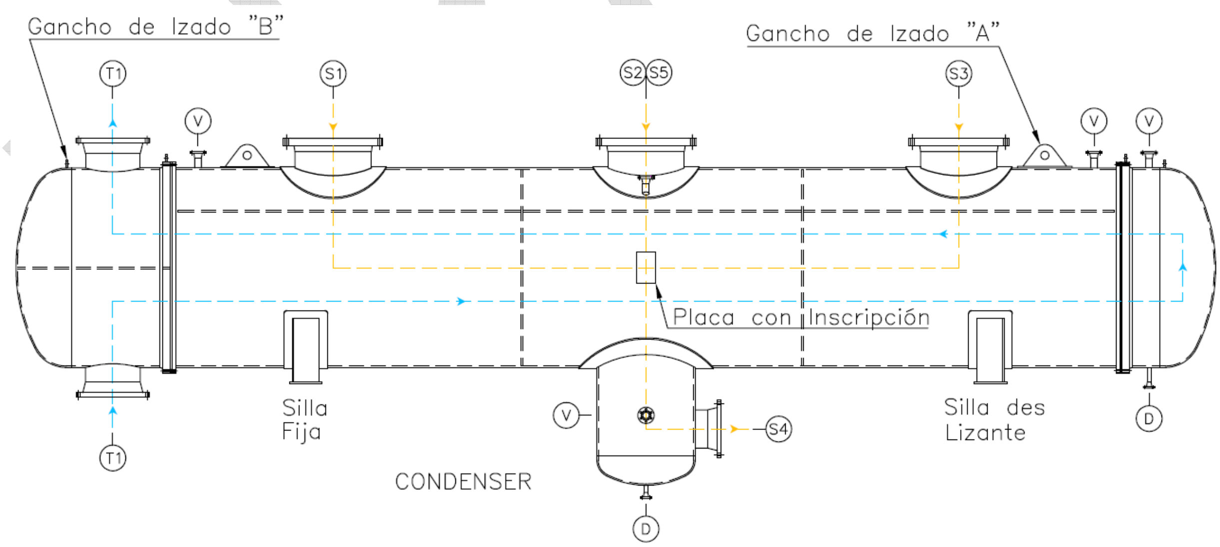

Figure 19: Condenser flow arrangement

Table 4: Condensers KKS codes

Condensers KKS codes	
Condenser A	1MAG10-AC021

Condenser B	1MAG10-AC011

7.2.5 Mist Eliminators

Mist eliminators, or droplet separators, are mounted on top of the reboilers to separate small droplets from the gaseous isopentane. These droplets are generated at the rigorously bubbling surfaces inside the reboilers and move upward with the gas stream. The gas is made to pass through strainers within the mist eliminators, which catch most of the droplets, thereby greatly decreasing erosion threat to the turbine nozzle assembly. The liquid isopentane then drains back to the reboilers.

Table 5: Mist Eliminators KKS codes

Mist Eliminators KKS codes	
Mist Eliminator 1	1LBJ10-AT021
Mist Eliminator 2	1LBJ10-AT011

7.2.6 Auxiliary Cooling Loop Heat Exchangers

The lube oil console is cooled by a closed water loop, which discards the heat through two semi-welded plate heat exchangers. Water from the cooling tower is used as the cooling medium.

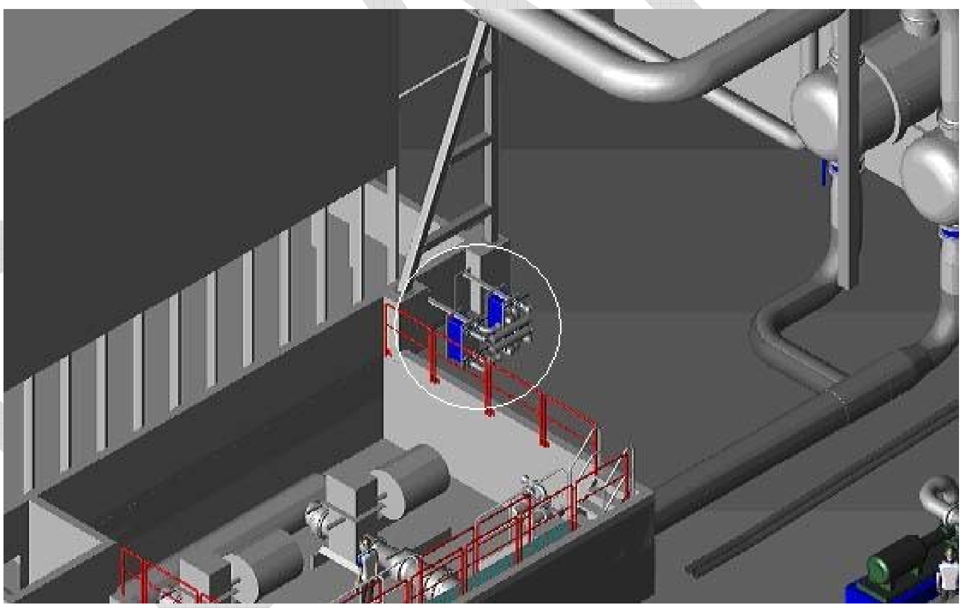

Figure 20: Auxiliary cooling loop heat exchangers.

KKS code: 1PCC10-AC001.

See Appendix 11.2 and Drawings 12.1.2 for further information on heat exchangers.

7.3 Pumps

7.3.1 Isopentane Circulation Pumps

The isopentane circulation pumps are large vertical, multistage, centrifugal pumps which elevate 123.3 kg/s of isopentane liquid from approximately 1.8 bar_a to 23.8 bar_a under normal operating conditions.

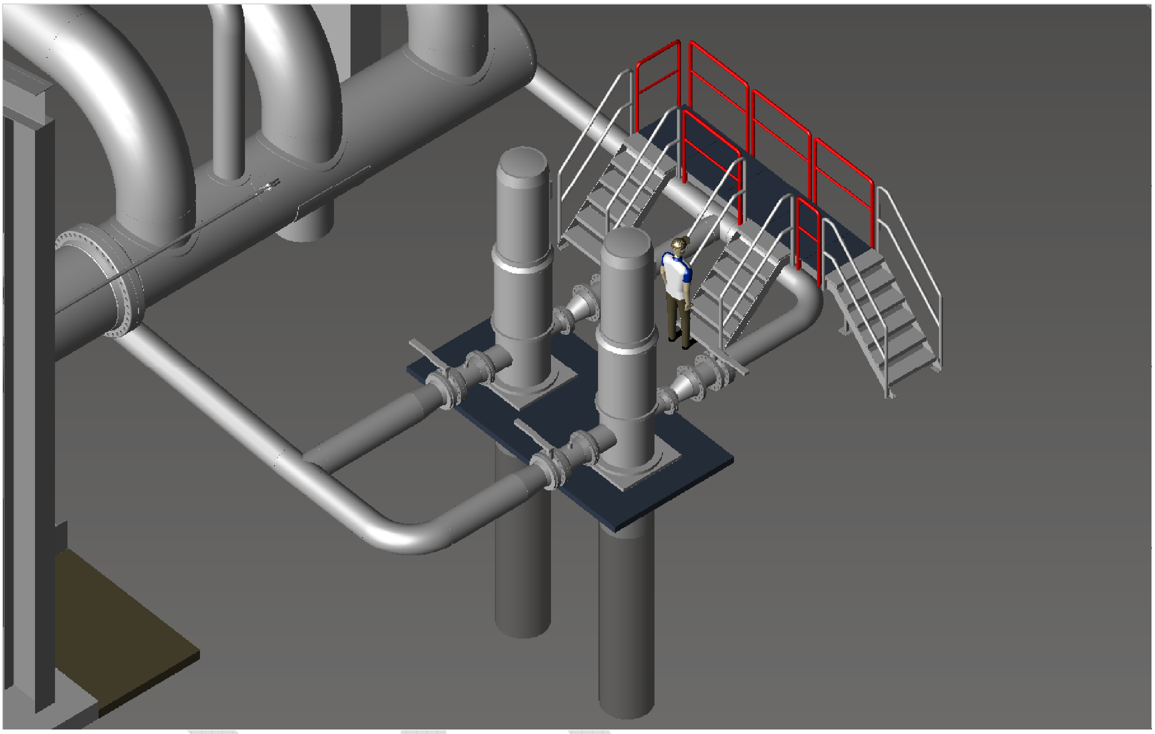

Figure 21: Isopentane circulation pumps.

Table 6: Isopentane Circulation Pumps KKS codes

Isopentane Circulation Pumps KKS codes	
Pump A	1LAC10-AP011
Pump B	1LAC10-AP021

7.3.2 Isopentane Fill Pumps

The isopentane fill pumps are single stage, in-line, close-coupled type pumps used to fill the process pipes and equipment either initially or after maintenance, when the isopentane is stored in the isopentane tank.

KKS code: 1LAJ10-AP011.

7.3.3 Isopentane Drain (Vacuum) Pump

The isopentane drain pump is an oil flooded rotary vane vacuum pump used to drain the process pipes and equipment of isopentane and transfer it to storage in the isopentane tank before maintenance.

KKS code: 2LAJ10-AP001

7.3.4 Cooling Water Circulation Pumps

The cooling water circulation pumps are between-bearing, axially split, single stage, double suction pumps used to circulate 1013 kg/s of cooling water, under normal operating conditions, from the cooling tower to the condenser and back.

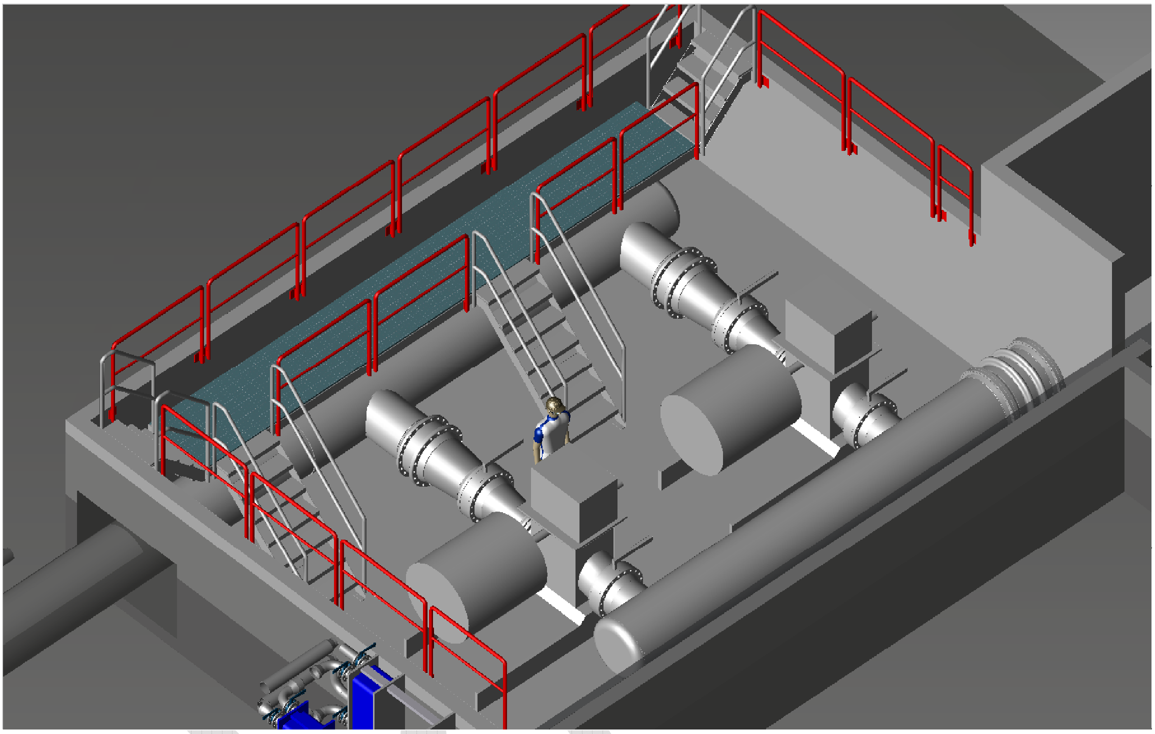

Figure 22: Cooling water pumps.

Table 7: Cooling Water Pumps KKS codes

Cooling Water Pumps KKS codes	
Pump A	1PAB10-AP011
Pump B	1PAB10-AP021

7.3.5 Cooling Water Make-up Pumps

The cooling water make-up pumps are single stage centrifugal pumps used to deliver 20.3 kg/s of make-up water over a distance of approximately 700 m from the Berlin Power Plant condensate pond to the Binary Plant Berlin cooling tower basin. The elevation difference between the condensate pond and the highest point of the pipeline is around 23 m and the cooling tower basin lies approximately 10 m higher than the surface of the condensate pond.

Table 8: Cooling Water Make-up Pumps KKS codes

Cooling Water Make-up Pumps KKS codes	
Pump A	1GHE10-AP011
Pump B	1GHE10-AP021

7.3.6 Auxiliary Cooling Water Pumps

The auxiliary cooling water pumps are single stage, in-line, close-coupled type pumps used to circulate 29 kg/s of water in the closed cooling loop of the lube oil console.

Table 9: Auxiliary Cooling Water Pumps KKS codes

Auxiliary Cooling Water Pumps KKS codes	
Pump A	1PCC10-AP011
Pump B	1PCC10-AP021

7.3.7 Brine Booster Pumps

The brine booster pumps are in-line, recessed impeller, sealmatic and unitized self-primer pumps used to elevate the pressure of the brine after flowing through the reboilers and pre-heaters in order to ensure successful reinjection.

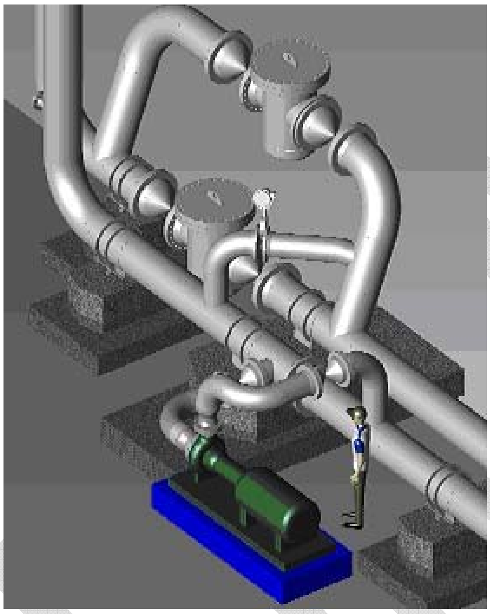
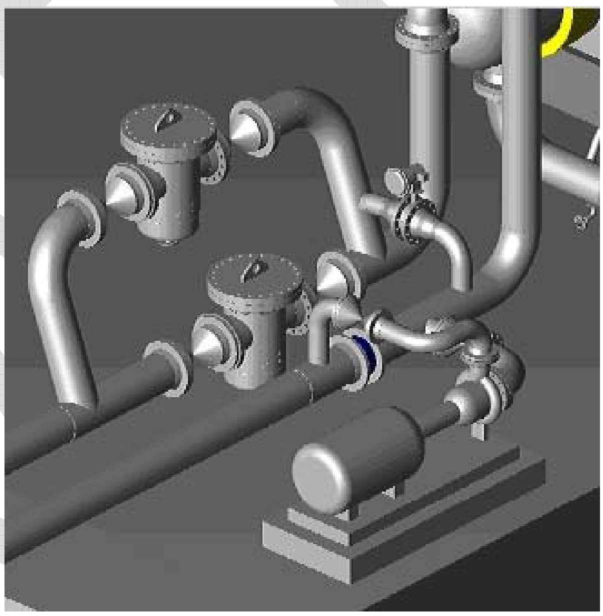

Figure 23: Brine booster pumps for TR-4/5 and TR-2/9.

Table 10: Brine Booster Pumps KKS codes

Brine Booster Pumps KKS codes	
Pump A	1LBD20-AP010
Pump B	2LBD20-AP010

See Appendix 11.3 and Drawings 12.1.3 for further information on pumps.

7.4 Cooling Tower

Function – Capacity

The cooling tower has the function of cooling the water from the condensers and thus acting as the final heat sink in the generation process by delivering waste heat into the environment. The two fans of the tower draw air upward against the water, which trickles down through the fill material. This cools the water down from 38.3°C to 28.3°C through conduction and evaporation. Operating under these conditions, the tower can handle a flow of up to 4,122 m^3/hr.

Water losses – Make-up Water
Due to losses from evaporation, blowdown, and drift, a supply of 20.3 kg/s of make-up water is guaranteed to the tower. The water is pumped through a 700 m pipeline, which originates in the Berlin Power Plant condensate pond.

Structure – Water Basin
The tower structure consists of pressure treated Douglas fir resting on a concrete water basin. The structure is clad with fiberglass reinforced panels, and windwalls and partitions are made of Douglas fir plywood. The water basin is coated with Interseal 670HS to guard against leaks and protect the concrete.

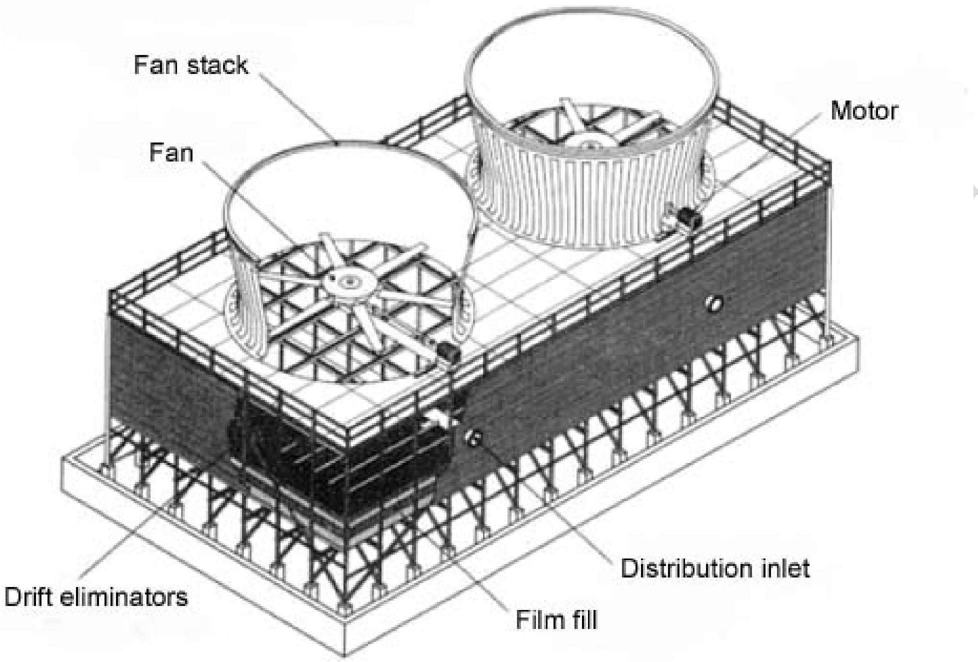

Figure 24: Counterflow cooling tower.

KKS designation: PAB

See Appendix 11.4 and Dawings 12.1.4 for further information on the cooling tower.

7.5 Transformers

There are two main power transformers in Binary Plant Berlin. The larger one is a step-up transformer that increases the potential of the output (7.8 MW) of the plant before the electricity is delivered to the power transmission line connecting Binary Plant Berlin to the Berlin Power Plant. The smaller one is a step-down transformer that decreases the potential of the electricity that is used by the plant itself (1.4 MW).

In addition, two smaller transformers are used to decrease the 480 V output from the smaller power transformer to 240 V.

7.5.1 12.5 MVA Transformer

The 12.5 MVA power transformer increases the potential of the net output of the plant from a voltage of 13.8 kV delivered by the generator to 115 kV used for transmitting the electricity over the power line. The main characteristics of the transformer are as follows:

- Number of phases: 3
- Frequency: 60 Hz
- Nominal Power: 12,5 MVA
- Cooling: ONAN[1]
- Total Weight: 32850 kg

Table 11: Tension and nominal intensities

Winding	Voltage (V)	Current (A)	Connection
High Voltage	115,000	62.8	Wye
Low Voltage	13,800	522.9	Delta

The transformer is an integral part of the substation of the binary plant and is located a short distance outside the electrical room. It rests on rails that extend into the road adjoining the substation to facilitate removal. This makes it possible to move the transformer to an easily accessible location where it can be placed on a truck without complications.

KKS designation: 0AET10

7.5.2 2 MVA Transformer

The 2 MVA power transformer decreases the voltage of the electricity needed for the operation of the plant from a potential of 13.8 kV delivered by the generator to 480 V used by the various equipment of the plant. The main characteristics of the transformer are as follows:

- Number of phases: 3
- Frequency: 60 Hz
- Nominal Power: 2 MVA
- Cooling: ONAN
- Total Weight: 5246 kg

Table 12: Tension and nominal intensities

Winding	Voltage (V)	Current (A)	Connection
High Voltage	13,800	83,7	Delta
Low Voltage	480	2406	Wye

The transformer is located outside the ventilation room of the binary plant and is fixed to its foundation. The produced voltage of 480 V is used for equipments that require high power, such as the building crane, pumps, and cooling tower motors.

[1] O: Oil; N: Natural flow; A: Air

KKS designation: 0BFT10

7.5.3 30 KVA and 10 KVA Transformers

Two small transformers are used to decrease the voltage of electricity from the 2 MVA transformer from 480 V to 240 V and 120 V. These voltages are used for various building electrical needs, such as lighting, parts of the ventilation system, and electrical outlets. Under normal plant operating conditions, both of the transformers are in service. The advantage of using two units is that a degree of redundancy is attained.

KKS designations:

See Appendix 11.5 and Drawings 12.1.5 for detailed operation and maintenance instructions on transformers.

7.6 Substations

7.6.1 115 kV Substation

The 115 kV substation is located on the north side of the power plant building and includes the following equipment:

- Surge arresters
- Current transformers
- Disconnecting switch (S2DAT)
- Potential transformer
- Supporting insulator

7.6.2 Berlin Power Plant Substation

A substation is located at the Berlin Power Plant, for which Enex supplies the following equipment:

- Disconnecting Switches
    - S2DAT
    - S2DA
    - Semi-Pantograph type SPV
- Circuit Breakers

See Appendix 11.6 and Drawings 12.1.6 for further information on the substations.

7.7 Auxiliary Systems

7.7.1 Nitrogen Generation System

The nitrogen generation system supplies the nitrogen for the expander seal system of the turbine (see section 7.1). The first step of the proces is achieved by compressing, cooling, filtering, and drying supply air. The air then enters one of two adsorber beds in the generator, where oxygen and water vapor are adsorbed faster than nitrogen. This increases the nitrogen purity of the product gas stream to 99.9%. The product flows through a 30 gallon tank before it is delivered to a 400 gallon storage tank. Together, these tanks act as a buffer to ensure a reliable continuous flow of nitrogen to the turboexpander.

Alternating Adsorber Beds
A portion of the intermediate nitrogen product produced is allowed to flow back through the adsorber sieve bed which is not in use. This action purges the bed of the oxygen that was adsorbed in a previous cycle, and prepares it for the next one. One adsorber bed is operated for about two minutes before the next cycle starts.

Figure 25: Nitrogen generator with a buffer tank

The nitrogen generation system is located by the southwestern wall of the machine hall.

See Appendix 11.7.1 and Drawings 12.1.7.1 for further information on the nitrogen generation system.

7.7.2 Nitrogen Extraction System

The nitrogen extraction system has the function of separating non-condensable nitrogen, which escapes into the process cycle from the turboexpander case seal, from isopentane to avoid accumulation of the former in the condenser. The isopentane-nitrogen mixture enters the system from the condenser and passes through a heat exchanger, where the isopentane liquefies. The nitrogen remains in the gas phase and is ejected to the atmosphere from a gas separator.

KKS code: 1MAJ10-GH010[2]

See Appendix 11.7.2 and Drawings 12.1.7.2 for further information on the nitrogen extraction system.

7.7.3 Compressed Air System

The compressed air system delivers pressurized air to various equipment, where it is used to carry out mechanical functions initiated by the plant control system.

Compressors
Intake air from the ventilation room enters two screw compressor units, which then feed the air to a drying unit.

Dryer
A heatless desiccant dryer removes moisture from the compressed air. The dryer consists of two towers filled with a bed of activated alumina desiccant, which adsorbs the moisture in the air as it flows upward through the towers. Cleanable, stainless steel, flow diffusers ensure even flow distribution through the bed.

One tower dries the compressed air while the second is purged of the moisture adsorbed in a previous drying stage. A portion of the dried air flows at a reduced pressure over to the tower being purged, regenerating the activated alumina by carrying off moisture to the atmosphere. After a set period, the towers switch roles.

Figure 26: Compressor and desiccant dryer

See Appendix 11.7.3 and Drawings 12.1.7.3 for further information on the compressed air system.

7.7.4 Ventilation System

The ventilation system consists of the following parts:

- **Circulation and cooling unit**: circulates and cools building air in addition to filtering out H_2S. Located in the ventilation room.
- **Pressurization and drying unit**: pressurizes and dries supply air from the outside in addition to filtering out H_2S. Located in the ventilation room.
- **Water chiller**: discards heat from the cooling unit to the atmosphere. Located outside the ventilation room beside the 2.0 MVA power transformer.
- **Auxiliary cooling unit**: cools air inside the control room. The chiller is located on the hallway roof.
- **Fire and smoke dampers**: keep fire and smoke from spreading over fire barriers. Close upon a signal from the control system. Located in transfer ducts in the wall separating the control room and ventilation room from the hallway.
- **Gravity dampers**: keep a set differential pressure level between spaces by providing an appropriate resistance to air flow. Located in the wall separating the control room and ventilation room from the hallway.
- **Instrumentation**: sensors detect pressure, temperature, and humidity levels inside the ventilated spaces.

Control Room Pressurization

The supply duct from the ventilation units opens into the space underneath the modular floor of the control room and the air flows through perforations in the tiles of the floor. The control room is kept at an overpressure of 60 Pa, whereas the hallway, side entrance, bathroom, and storage space are kept at 30 Pa (see drawing 60-07-1011). This is to ensure that outside air does not enter the control room as electrical equipment is sensitive to hydrogen sulfate and air impurities.

As a result of the required overpressure inside the control room, it is very important to keep doors closed and the building as tight as possible so that the system will function as intended. It is also of utmost importance to keep door P-10 (see drawing 60-09-6000) closed and locked at all times except when absolutely required during unit maintenance. Outside air which enters through the door will not undergo a filtering process as the air entering through the pressurization and drying unit. A greater burden would therefore be placed on the circulation and cooling unit and the possibility of impurities entering the control room cannot be disregarded.

See Appendix 11.7.4 and Drawings 12.1.7.4 for further information on the ventilation system.

7.7.5 Fire Protection System

The fire protection control system consists of the following:

- Sensors and control system.
- Electric pump, diesel pump, jockey pump.
- Cooling tower sprinkler system.
- Cooling water pumps sprinklers.

- Heat exchangers foam sprinkler system.
- Booster pumps sprinklers.
- Isopentane tank foam sprinkler system.
- Isopentane circulation pumps sprinklers.
- Lube oil console and turbine foam sprinkler system.
- Generator clean agent suppression system.
- 12.0 MVA transformer foam sprinkler system.
- 2.0 MVA transformer sprinkler system
- Fire Alarm and Automatic Clean Agent Suppression for Control Room.
- Fire hydrants located around the plant.
- Fire department connection.

Two 450 m^3 tanks that are located southeast of the main platform area supply the fire protection system with water in case of activation. The fire mains are kept full and are maintained at approximately 120 psi by a jockey pump. An electric pump provides the necessary pressure to convey 1250 GPM of water through the system and a diesel pump is installed for redundancy in case of electrical failure. They are designed to start automatically, but also have provisions for a manual start. The pumps are located in a shed next to the water tanks, along with a 300 gal fuel tank, and controls.

Pumps

The pumps are automatically started by a pump controller when the pressure in the mains drops as shown in table 13.

Table 13: Pumps control pressure values

Pump	Start pressure (psi)	Stop pressure (psi)
Jockey	110	125
Electric	95	N/A
Diesel	100	N/A

Note: Every six months switch main fire pump pressure switch setting so other pump starts first.

Fire Pump Controllers

Fire Pump controllers are self contained units with several special features:

- Motor and controller isolating device.
- Automatic start from internal pressure switch.
- Manual electric start by pushbutton on face of controller.
- Manual mechanical start by emergency operating handle on face of controller.
- Minimum running timer to avoid short cycling and motor over-heating on water pressure fluctuations.
- Power "on" light.
- Power failure alarm (indicates power failure on the annunciator on the main control board).
- Provision for testing voltage and current.

In addition, a pump operation alarm is included on the annunciator, on the instrument controller panel.

Jockey Pump Controller

The jockey pump is controlled through an automatic control switch located by the pump. The pump can be placed in continuous operation when the switch is in the “hand” position or intermittent operation through the pressure switch when the switch is in the “auto” position. The motor controller is located in the fire protection pumps shed.

Hydrants

A total of four 4” hydrants are located outdoors in the perimeter of plant area. The hydrants are fed by the underground fire protection water loop mains surrounding the cooling towers and the control room. Every hydrant has a fire hose cabinet containing fire hoses for outdoor use.

Fire Department Connection

A fire department connection is located in front of the building, through which the fire department can supply water to the system.

Main Transformer Sprinkler System

The 12.5 MVA transformer sprinkler system consists of deluge type sprinklers with closed sprinkler wet heads actuation. The system includes an AFFF 3% foam tank with foam supply for 10 minutes and the design density is 0.25 gpm/ft² (10.2 l/min/m2).

Turbine

The turbine is protected by a deluge type sprinkler system with closed sprinkler wet heads actuation. The system includes an AFFF 3% foam tank with foam supply for 10 minutes and the design density is 0.30 gpm/ft² (12 l/min/m2).

Lube Oil Reservoir

The lube oil console is protected by a deluge type sprinkler system with closed sprinkler wet heads actuation. The system includes an AFFF 3% foam tank with foam supply for 10 minutes and the design density is 0.30 gpm/ft² (12 l/min/m2).

Fire Alarm

Smoke detectors are located beneath and above the modular floor of the control room. These detectors report to a fire alarm control panel within the control room. The panel is also connected to the fire protection pumps, waterflow switches, and the heat detectors of the turbine generator.

The control room is protected by an automatic fire suppression system using ECARO 25 clean agent with an 8% design concentration and a 10 seconds discharge time. The clean agent will be discharged both above and below the modular floor in the case of system activation.

Cooling Tower

The cooling tower is protected by a wet type closed head sprinkler system with a 200°F activation temperature. The design density of the system is 0.49 gpm/ft2 (20 l/min/m2).

Isopentane Tank

The isopentane tank is protected by a deluge type sprinkler system with closed sprinkler wet heads actuation. The system includes an AFFF 3% foam tank with foam supply for 10 minutes and the design density is 0.25 gpm/ft² (10.2 l/min/m2).

Generator
The generator temperature is monitored by heat detector heads that are connected to the fire alarm control panel. At 300°F, an ECARO 25 clean agent system is automatically activated by the panel. The design clean agent concentration is 8% and the system has a 10 seconds discharge time.

See Appendix 11.7.5 and Drawings 12.1.7.5 for further information on the fire protection system.

7.7.6 Inhibitor System

The concentration of dissolved solids in the utilized brine is nearly 27,000 ppm by weight, which makes scaling inside the reboilers, pre-heaters, and reinjection pipes a major concern. The inhibitor system has the function of reducing this scaling to acceptable rates by increasing the acidity of the fluid.

Structure and Function
The inhibitor system comprises an acid mixing station and two injection stations.

- **Mixing station** consisting of a concrete basin enclosing the following:
  - 2 hydrochloric acid (HCl) containers with a 33% concentration. The tanks are replaced or refilled approximately once a week.
  - A water container connected to the local water supply of the plant, which act as buffers in case of temporary flow disruptions.
  - Mixing pump shed, where the acid is diluted to the appropriate concentrations for each injection station.

- **Injection station 1** injects the inhibitor into the brine line from TR-4/5 upstream of reboiler 1. It consists of a shed enclosing the following:
  - Buffer tank with a 6.6% hydrochloric acid concentration.
  - High pressure dosing pump
  - pH control
  - Sampling system

- **Injection station 2** injects the inhibitor into the brine line from TR-2/9 upstream of reboiler 2. It consists of a shed enclosing the following:
  - Buffer tank with a 2.3% hydrochloric acid concentration.
  - High pressure dosing pump
  - pH control
  - Sampling system

Safety Equipment
Safety showers and eyewashes are located near the mixing station and injection stations in case of emergencies (see general layout drawing 00-02-0003).

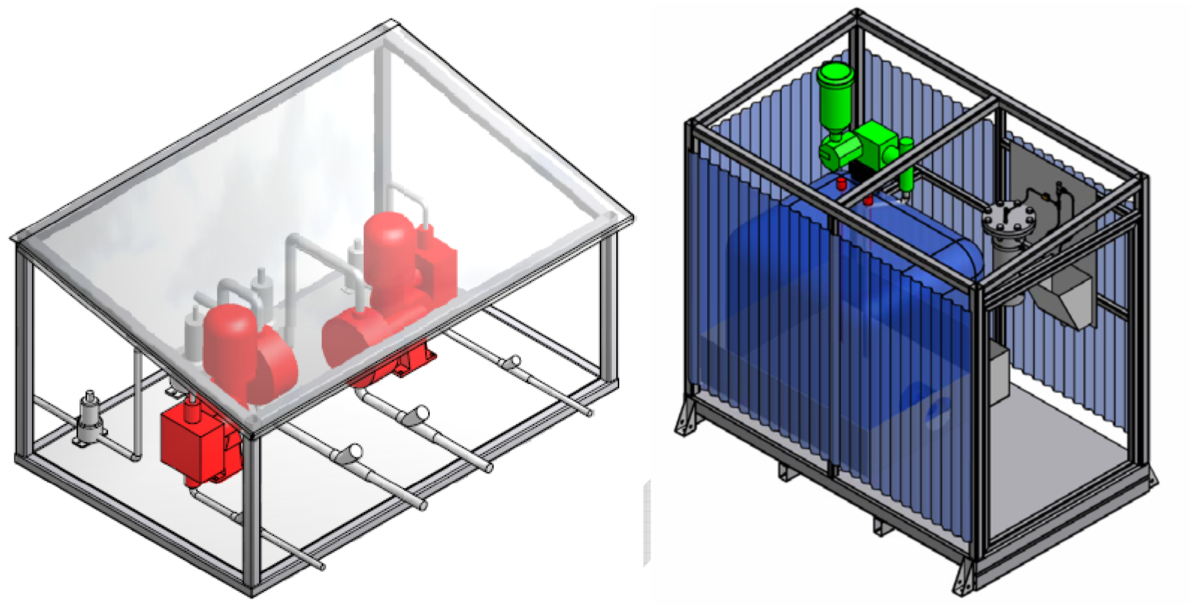

Figure 27: Inhibitor mixing pump shed and injection station

See Appendix 11.7.6 and Drawings 12.1.7.6 for further information on the inhibitor system.

7.7.7 Cooling Water Chemical Treatment System

Biocides

Two non-oxidizing biocides are used for the microbiological control of the cooling water:

- **Nalco H-130** is a non-oxidizing liquid organic biocide containing quaternary ammonium compounds, which controls the growth of bacteria and algae.
- **Nalco 2894** is a microbiocide used against a wide variety of algae, fungi, and cyanobacteria.

The biocides are slug dosed once per week as described in the dosing plan detailed in Appendix 11.7.7.

Testing

Water samples from the cooling tower need to be screened on a weekly basis. A one year supply of Hach paddle testers is provided for that purpose. The paddles are double-sided slides attached to a vial cap, where each side of a slide is used to perform a separate test. The slides have molded-in grids, which allow colony counting without opening the optically clear, leakproof vial.

A list of key customer contacts, a system survey, program administration manual, and service plan for the cooling water treatment system are included in Appendix 11.7.7 along with chemical safety data sheets.

See Appendix 11.7.7 and Drawings 12.1.7.7 for further information on the cooling water chemical treatment system.

7.7.8 Auxiliary Cooling System for Genset

The generator and lube oil console are cooled by a closed water loop, which discards heat through a semi-welded plate heat exchanger (section 7.2.6). Water from the cooling tower is used as the coolant. On the heat extracting end, the cooling water passes through 2 heat exchangers of the generator and 1 heat exchanger in the lube oil console.

The circulation is maintained by two single stage, in-line, close-coupled type pumps (section 7.3.6).

7.8 Tanks

The largest tanks used for Binary Plant Berlin are water storage tanks and a pressurized isopentane storage tank.

7.8.1 Fire Protection Tanks

The fire protection system relies on two water storage tanks for a steady supply of water in the case of system activation. The tanks hold enough water for use in all sectors of the plant simultaneously. In addition to their primary role in the fire protection system, they also function as reservoirs of potable water for the plant.

Geometry and Material
The main defining factors and material used for the tanks are the following:

- **Diameter**: 9.0 m
- **Volume**: 456 m^3
- **Water table** at approximately 7.2 m above the base under balanced conditions.
- **Cover sheet steel** is A36 with a thickness of 3/16”.

Accessories
The tanks are open to the atmosphere through a vent tube and include two manholes for inside inspection. They are equipped with a ladder to allow access to the top.

Coating
The tanks are coated with the following paint:

- **Interline 850** is ideal for potable water and is used on inside surfaces.
- **Interzinc 22** is a primer used on outside surfaces.
- **Interseal 670HS** is an overcoating paint used on outside surfaces.

The coating of the tanks should be checked regularly for integrity and remedial action taken if necessary, to prevent against corrosion. See section *7.16 Finishes* for further information on the tank paint.

7.8.2 Isopentane Tank

The isopentane tank functions as a storage vessel for the isopentane used in the process cycle of the plant. The volume division is as follows:

- **Total volume**: 85.9 m^3

- **Free space**: 2.9 m^3 to allow for thermal expansion of the fluid.
- **Operational volume**: 78 m^3 used in the process cycle.
- **Isopentane reserves**: 5 m^3 for replenishing the system if any leakages or other loss of isopentane from the process cycle should occur.

The tank is equipped with sensors to monitor liquid quantities.

See Appendix 11.8 and Drawings 12.1.8 for further information on tanks.

7.9 Cranes

7.9.1 Building Crane

The building crane is supplied to lift the generator, turbine, and other parts of the genset within the machine hall for installation and maintenance. The main defining features are the following:

- **Lifting capacity**: 25 metric tons
- **Maximum lifting height**: 5.7 m
- **Span**: 9.05 m

Genset Component Loads

The loads of the various components of the genset are given in table 14.

Table 14: Genset Component Weights

Component	Load [kg]
Generator	24,600
Gear Box	5,000
Expander case w/o diffuser cone	7,592
Skid (cannot be moved)	8,045
Diffuser Cone	567
Lube Oil Console (empty)	2,720
Lube Oil Console (full of oil)	3,230

See Appendix 11.9 and Drawings 12.1.9 for further information on the building crane.

7.9.2 Cooling Water Pumps Monorail Hoist

The cooling water pumps hoist is a hand operated chain hoist placed on a monorail beam. The monorail is placed directly above the central axis of the pumps, which allows the pumps to be lifted directly from their positions. After the pumps have been lifted, the hoist can be pushed along the rail to the outside of the pump pit where the pumps are accessible by transportation vehicles. The process is reversed when installing the pumps.

The main defining features of the hoist are the following:

- **Lifting capacity**: 2 metric tons
- **Maximum lifting height**: 2.2 m

7.9.3 Cooling Tower Strainers Monorail Hoist

The cooling tower strainers hoist is a hand operated chain hoist placed on a monorail beam with a lifting capacity of 500 kg. The concept is similar to that of the cooling water pumps monorail crane. The monorail runs along the center of the cooling water intake pit and extends outside the walls of the pit. This enables the lifting and transport of the cooling tower strainers from their functioning positions to a location where they can be picked up by transporting vehicles or cleaned. The process is reversed when installing the strainers.

7.9.4 Cooling Tower Jib Crane

The cooling tower jib crane, or davit, is located at the top of the cooling tower and has a lifting capacity of 900 kg. Its purpose is to facilitate maintenance of the tower by allowing the lifting or lowering of tools. The davit is operated by hand as the monorail cranes.

See Appendix 11.9 and Drawings 12.1.9 for further information on cranes.

7.10 Pipes and Fittings

All pipes and fittings follow ASME, ANSI, and ASTM standards and are of various material types, including carbon steel, stainless steel, PVC, and CPVC. Examples of the uses of each type follow:

- **Carbon steel:** primary and secondary loops.
- **Stainless steel:** cooling water circulation.
- **PVC**: potable water supply, make-up water supply, inhibitor system, and sewage.
- **CPVC**: fire protection system.

Steel Pipes
Steel pipes are divided into three main groups, depending on their material properties and dimensions as follows:

1. Carbon steel pipes with diameter lower than 20” (1/2” – 16”) are ASTM A 106 Gr. B.
2. Carbon steel pipes with a diameter of 20” or higher (20”, 24”, 40”, and 48”) are ASTM A 53 Gr. B ERW.
3. Stainless steel pipes are ASTM A 312 Gr. TP316L (4”, 6”, 24”, and 32”).

Steel Flanges
All steel flanges are of the raised face weld neck type. In general, flanges smaller than 24” follow the ASME A B 16.5 standard and flanges larger than 24” follow the ASME A B 16.47 Series A standard, with the exception of the flange connecting to the turbine’s diffuser, which is specified as Series B by the manufacturer.

Flanges are divided into three groups as follows:

1. Carbon steel flanges from 1” to 20” are ASTM A 105, class 300.
2. Carbon steel flanges of 28”, 40”, and 48” are ASTM A 105, class 150.
3. Stainless steel flanges of 2½”, 4”, 20”, 24”, and 32” are ASTM A 182 Gr F316L, class 150.

Steel Elbows
All steel elbows are in accordance with the ASME B 16.9 standard and can be grouped as follows:

1. Stainless steel elbows are ASTM A 182 Gr. F316L/A312 Gr. TP 316L with an angle of 90° and a bending radius of R=1.5D. Diameters range from 1/2" to 32".
2. Carbon steel elbows are A 234 Gr. WPD, class 125/150, with an angle of 90° and a bending radius of R=1.5D. Diameters range from 1" to 28".

Steel Reductions
All steel reductions are in accordance with the ASME B 16.9 standard and can be grouped as follows:

1. Stainless steel reductions are ASTM A 182 Gr.F 316L, class 125/150, of diameters Ø168,3mm - Ø 114,3, Ø 610x6,35 - Ø 508x6,35, Ø813x6,35 – Ø610x6,35.
2. Carbon steel reductions are A234 Gr. WPD, class 300, and diameters ranging from R2"-1" to R 24"-20".

Steel Tees
Steel tees follow the ASME B-16.9 standard, class 150/300, with a material classification of carbon steel A 234 Gr. WPB and a large range of diameters.

Butt Weld Caps
Butt weld caps are in accordance with the ASME B 16.9 standard and can be grouped as follows:

1. Stainless steel butt weld caps are ASTM A 182 Gr. F316L with diameters of Ø813x6,35 and Ø168,3x3,4.
2. Carbon steel butt weld caps are ASTM A 234 Gr. WPB with diameter ranging from 12" to 48".

7.11 Valves

The valves used in Binary Plant Berlin follow American ANSI standards and are of various types, including butterfly valves, check valves, gate valves, globe valves, and safety valves. Their sizes range by two orders of magnitude from small valves of ¼" used in the inhibitor system to large 24" valves used in the cooling water loop.

Control Valves
The control valves used in the plant are globe style and butterfly valve assemblies including pneumatic and diaphragm actuators, electrical position switches, and digitial controllers. The control valves and the associated by-pass valves are located at several points in the process structure (see P&I Diagram 00-07-1006):

- A control valve, with a fail safe to close, is located at the turbine intake to regulate flow. Valve 1LBB11-AA011 is the associated by-pass valve, with a fail safe to open.

- Control valves 1LAB10-AA021 and 1LAB10-AA011, with a fail safe to close, are located between the pre-heaters and reboilers to regulate isopentane flow. Control valve 1LAB12-AA010 is the associated by-pass valve, with a fail safe to open.

- Control valves 1LBD20-AA010 and 2LBD20-AA010, with a fail safe to close, are located between the reboilers and pre-heaters to regulate brine flow. Valves 1LBD10-AA202 and 2LBD10-AA202 are the respectively associated by-pass valves, with a fail safe to open.

Shut-down Valve
A shut-down valve, 1MAA10-AA010, is located in front of the turbine to shut down the flow of isopentane to the turbine in case of an emergency.

Relief Valves
As isopentane is a flammable fluid, leakages from the system must be avoided. Pressurized parts of the process system are therefore protected by relief valves and rupture disks installed in line. The rupture disks keep unnecessary leakages from occurring and in the case of excessive pressure, the relief valves will close when the pressure returns to normal. The valves and discs are located at strategic points in the process structure (see P&I Diagram 00-07-1006):

- Rupture disc 1LBB10-AA202 and relief valve 1LBB10-AA203 are located upstream of the turbine and vent isopentane to the atmosphere if the pressure rises too high.

- A pair of rupture discs, 1MAG10-AA212 and 1MAG10-AA222, and relief valves, 1MAG10-AA213 and 1MAG10-AA223, are located downstream of the control valve in the turbine by-pass pipe. They direct isopentane to the atmosphere if the pressure rises above 23,5 bar_a.

- Relief valve 1LAB10-AA202 is located downstream of the isopentane pumps and directs isopentane to the condensers if the pressure rises above 23,8 bar_a.

- Relief valve 1PCC10-AA211 is located upstream of the auxiliary cooling water pumps and vents water to the environment if the pressure rises too high.

See Appendix 11.11 and Drawings 12.1.11 for operation and maintenance instructions on valves.

7.12 Instrumentation

Instruments are essential for the control and safety of the plant. The instruments are placed at strategic locations for measuring critical input values to the plant control system. If the values fall outside specified ranges that are defined as normal under regular operating conditions, the system responds by sending appropriate alarm and control signals to rectify the situation.

The main types of instruments are the following:

- **Level indicators and transmitters** are used to continuously monitor liquid level values in the reboilers and condensers and transmit them to the control system.

- **Low level switches** are used to detect the passing of a liquid table past a pre-defined level. One low level switch is installed in each reboiler and two in the condensers in order to sense if the isopentane liquid table drops beneath set levels. A low level switch is also located in front of the cooling water pumps and isopentane fill pumps. In order for the control system to respond to low liquid level, at least two signals need to be in agreement in order to reduce the risk of a false detection.

- **High level switches** are used to detect the passing of a liquid table past a pre-defined level. Two high level switches are installed in each reboiler. In order for the control system to respond to high liquid level, at least two signals need to be in agreement in order to reduce the risk of a false detection.

- **Pressure indicators** are used to continuously monitor and display pressure, gauge or absolute, at various locations in pipes.

- **Pressure transmitters** are used to transmit pressure values at various locations in pipes to the control system.

- **Pressure switches** are used to detect when pressure levels pass pre-defined values at various locations in pipes and send appropriate event signals to the control system.

- **Differential pressure indicators** are used to continuously monitor and display pressure differences measured over fluid flow segments which impose restrictions on flow, such as strainers.

- **Differential pressure transmitters** are used to transmit pressure difference values to the control system.

- **Temperature indicators** are used to continuously monitor and display temperature values at various locations in pipes.

- **Temperature transmitters** are used to transmit temperature values at various locations in pipes to the control system.

- **Flow indicators** are used to continuously monitor and display flow rate values at various locations in pipes.

- **Flow transmitters** are used to transmit flow rate values at various locations in pipes to the control system.

- **pH sensors** are used to detect pH levels in the brine pipeline downstream of the inhibitor injection. The measured values are sent to the control systems which regulates the injection rate of the inhibitor.

- **Isopentane sensors** are located at various strategic locations within the plant in order to detect isopentane leakages. The sensors are located at low points due to the relatively high density of isopentane compared to air.

In addition to instrumentation directly related to the generation process, various other instruments are installed in the plant, such as those of the ventilation system and fire protection system.

See Appendix 11.12 and Drawings 12.1.12 for further information on instrumentation.

7.13 Communication System

7.14 Electricity

7.14.1 13.8 kV Switchgear

7.14.2 480 V Distribution

7.14.3 House Electricity

7.14.4 Directional Earth Fault – Over Current Protection

7.14.5 Energy Transductor

7.14.6 Batteries

7.15 Building

The plant building, designed by T.ark architects of Iceland, has a total floor area of 415 m^2 and includes the following subspaces and equipment (numbers and letters refer to figure 28):

- **Machine hall**: 222 m^2 (A)
  - ♦ Genset
    - ▪ Turboexpander (1)
    - ▪ Generator (2)
    - ▪ Gearbox (3)
    - ▪ Lube oil console (4)
  - ♦ Nitrogen generation system (5)
  - ♦ Maintenance floor (6)

- **Service building**: 193 m^2
  - o Main entrance: 34 m^2 (B)
  - o Hallway: 29 m^2 (C)
  - o Control room: 83 m^2 (D)
    - ♦ Control and electrical cabinets
      - ▪ 480 V MCC (7)
      - ▪ 240/120 V distribution (8)
      - ▪ Speed drive (9)
      - ▪ 13.8 kV switchgear (10)
      - ▪ 125 V DC distribution (11)

        - 125 V DC batteries (12)
        - Generator control and protection (13)
        - Heat process, control and protection (14)
        - Turbine, control and protection (15)
        - Switchgear, cooling process, HVAC, control & protection (16)
        - Transformer 1 480/240/120 V AC (17)
        - Transformer 2 480/240/120 V AC (18)
        - Generator backup protection (19)
    - Ventilation room: 26 m^2 (E)
        - Ventilation units (20)
        - Compressors (21)
        - Compressed air system dryer (22)
    - Visitors' restroom: 6.5 m^2 (F)
    - Operators' restroom: 2.5 m^2 (G)
    - Storage room: 3.7 m^2 (H)
    - Side entrance: 8.3 m^2 (I)

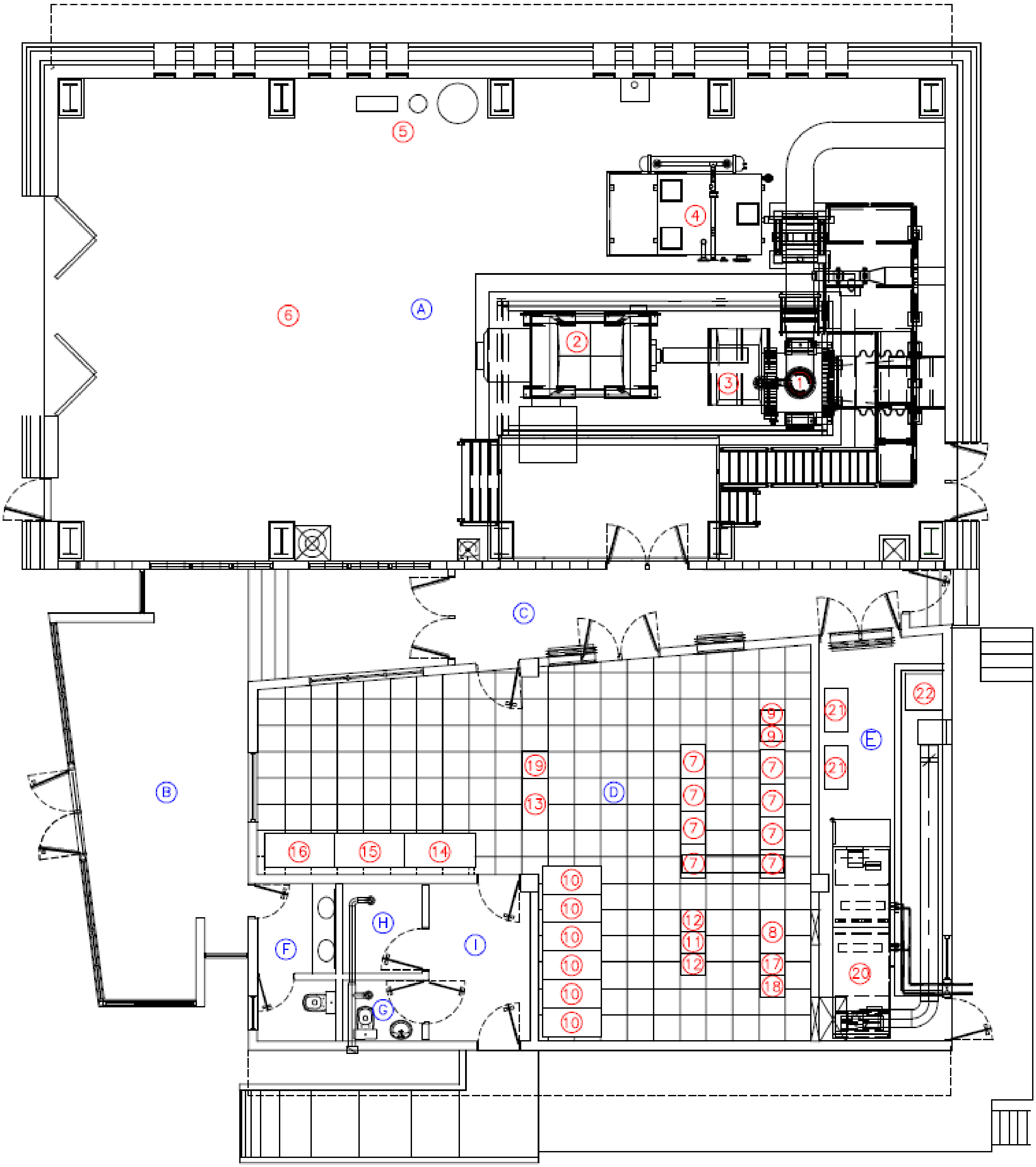

Figure 28: Binary Plant Berlin building and building equipment

See architectural and structural drawings for further information on the building.

7.15.1 Doors and Windows

Fire resistant steel doors can be found in the walls adjoining the hallway. Other doors are aluminum doors with a greater proportion of glass. Doors that form a part of a barrier between spaces with different pressure levels are provided with door closers.

The windows of the building are aluminum frame windows, many of which have a thickness of 6 mm for increased safety.

See Appendix 11.16.1 for further information on doors and windows.

7.15.2 Modular Floor

The modular floor of the control room consists of 60 cm x 60 cm tiles that rest on stringers supported by special pedestals in the interior of the room. On the edges, the tiles rest on L-profiles, which are bolted to the walls. A similar setup exists where the tiles meet cabinet supports. This gives the floor an enhanced stability in the lateral directions, in addition to supporting it vertically.

See Appendix 11.16.2 for further information on the modular floor.

7.15.3 Unipanels

The Unipanels that cover the building consist of galvalume metal plates separated by an insulating polyurethane foam of 2”. The insulation reduces the noise emanating from the genset and turbine by-pass valve to the outside of the machine hall and reduces the necessary work load of the ventilation system by acting as a thermal barrier. In addition, the panels are used to attain the desired geometry of the service building.

The composition of the panels increases their load carrying capacity while retaining relative lightness. This makes the panels an ideal material for the building shell.

See Appendix 11.16.3 for further information on the Unipanels.

7.16 Finishes

7.16.1 Paint

Most of the interior and exterior surfaces of the building are covered by standard paint. Steel surfaces, however, are to a large extent covered by the following special paint:

- **Interzinc 22** is a primer used on the machine hall steel structure and the outside surfaces of the fire protection water tanks.
- **Interzinc 72** is a primer used on steel supports.
- **Interseal 670HS** is an overcoating paint used on the machine hall steel structure, the outside surfaces of the fire protection water tanks, and as a coating for the cooling tower concrete basin.
- **Interline 850** is used for the inside lining of the fire protection water tanks.

Special attention should be paid to Interseal 670HS, which is a material applicable to concrete as well as steel, and is used to protect and seal the cooling tower basin in addition to its use as an external coating of steel surfaces.

See Appendix 11.17 for further information on paint.

8 Maintenance

9 Utilities

10 Safety Requirements

11 Emergencies

12 Warranty

12.1 Performance Guarantee

Enex hf. guarantees Binary Plant Berlin, when properly operated, applied and maintained in accordance with the instructions outlined in this manual, including appendices, to be free from defects in material, equipment, or workmanship for a period of one (1) year from the date of provisional plant acceptance, provided such defect is discovered and brought to Enex's attention during the foresaid Warranty Period.

Enex hf. furthermore guarantees the generator and excitation system, when properly operated, applied and maintained in accordance with the instructions outlined in this manual, including appendices, to be free from defects in material and workmanship for a period of two (2) years from the date of provisional plant acceptance, provided such defect is discovered and brought to Enex's attention during this period.

If a failure to meet the guarantee appears during the Warranty Period, LaGeo S.A. de C.V. shall promptly notify Enex hf. in writing and make the material or equipment available for inspection by Enex hf. Enex hf. will repair or replace any component it determines to be defective within the Warranty Period, provided such defect occurred in normal service and not as the result of misuse, abuse, neglect, accident, or use not in accordance with instructions. The repair or replacement will take place at Binary Plant Berlin, or elsewhere at Enex's sole discretion.

12.2 Limitation of Liability

Enex hf. is not liable for indirect, incidental, punitive, or consequential damages, costs, expenses, or for loss of profit or revenues arising from defects in equipment, material, or workmanship.

Enex hf. is not liable for damages or costs related to the cleanup, removal, release, remediation or disposal of, or any response to, any hazardous material.

Enex hf. does not warrant any component, part, material, equipment, or accessory that is not included in Enex's Scope of Work according to Contract.

Enex hf. shall not be liable for any personal injury or property damage connected with the operation and maintenance of Binary Plant Berlin.

Enex hf. shall not be liable for any personal injury or property damage caused by a Force Majeure, including fire, flood, earthquake, storm, hurricane or other natural disaster, war, invasion, act of foreign enemies, hostilities, civil war, rebellion, revolution, insurrection, military or usurped power or confiscation, terrorist activities, nationalization, government sanction, blockage, embargo, labor dispute, strike, and lockout or interruption or failure of electricity or communication.

13 Appendices

14 Drawings