DELIVERABLE D6.3
3 ORC UNITS READY TO BE SHIPPED
WP6: DEMONSTRATION OF ELECTRICITY AND POWER GENERATION

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PUBLIC SUMMARY

One of the objectives of the MEET project is to demonstrate the feasibility of producing heat and electricity from low-temperature and/or low-flow geothermal resources from various geological contexts (sedimentary, volcanic, granitic). Indeed, there is a high potential for electricity production from geothermal energy with low temperature supply. In Europe, the geothermal energy potential is estimated at 19 233 MWe for spring temperatures between 65-150°C (Karytsas, 2007).

The difficulty in exploiting geothermal energy lies mainly with the problems of corrosion due to aggressiveness of geothermal fluids and the economic profitability of the installations. Thus, the work carried out at this stage of the project was to test and select adapted materials to the different geological contexts identified. Then, technical heat recovery solutions had to be adapted for the selected demonstration sites. This document explains the various steps taken to produce this equipment.

1 EXECUTIVE SUMMARY

1.1 DESCRIPTION OF THE DELIVERABLE CONTENT AND PURPOSE

This deliverable D6.3 is done in the framework of the Horizon 2020 MEET project aiming at boosting and upscaling the development of geothermal energy in Europe. Indeed, there are a lot of wells across Europe producing water between 65 and 100°C which are not valorised energetically. Typically, mature oil wells produce 95% of water from which thermal energy could be extracted. Additionally, in naturally 'hot' regions, many wells provide water for local usage, but the heat is often lost. The idea of this work is to show the feasibility of electricity production in various geological environments (sedimentary, volcanic, granitic) with low flow and/or low temperature geothermal resource (Trullenque et al., 2018; Dalmais et al., 2019). Having a plug and play solution adapted to various geological environments will thus boost the usage of geothermal electricity in many spots where is it currently under-exploited.
Based on the results obtained from several material testing experiments in different reservoirs, three ORCs (Organic Rankine Cycle) have been designed and manufactured to fit with each selected site.
This document presents the manufacturing process followed to produce three ORC units adapted to three geological contexts: sedimentary oil field, granitic and volcanic areas.
These ORC units will be shipped and installed in three first demonstration sites matching each geological setting. It is currently planned to test them for 4 months.

1.2 BRIEF DESCRIPTION OF THE STATE OF THE ART AND THE INNOVATION BREAKTHROUGHS

In general, for low temperature heat to electricity conversion, the ORC power systems are used. This Organic Rankine Cycle uses organic fluids that have a low boiling point in comparison with water, which is an advantage to use low to medium temperature resources (Steven Lecompte, 2015).
From 2015 to 2020, the world power generation increased from 12.3 GWe to 16 GWe. In 2019, European geothermal electricity generation capacity represents to 3.3 GWe for a total of 130 geothermal power plants across Europe. About 80 binary plants using ORC technology are running in Europe in 2019 (EGEC, 2020). Additionally, 20 ORC units are under development in Europe (EGEC, 2020). Continuing a sustained trend over the past years, binary turbines are the almost exclusive solution in almost all European markets except for Iceland.
Today's European geothermal powerplants produce from a few MWe (EGS power plants) to more than 50 MWe in most favourable area (Iceland, Italy, Turkey) (IGA, 2020). Exploiting a low thermal power capacity makes the cost effectiveness of the facility questionable. On the one hand there is the risk of not finding the resources while the drilling costs are considerable, on the other hand the low efficiency of low temperature ORC cycles can present a low profitability. That is why many low-flow and low temperature resources (70°C-120°C) are untapped. In addition, the corrosion and scaling problems can make the operation of geothermal wells complicated.
The innovation consists in producing a small-scale ORC power plant (20-40 kW) which is adapted to geothermal challenges (corrosion and scaling) and able to produce electricity

with low-flow and low temperature resources at a competitive cost by connecting it on already existing wells.

1.3 CORRECTIVE ACTION (IF RELEVANT)

The deliverable D6.3 was initially planned for M12 (April 2019) but finally delivered at M30 (October 2020). Indeed, the tasks leading to the delivery of the 3 ORC units faced many delays, mainly for the following reasons:

1- The design of the ORCs depends on the results of the corrosion analyses performed by ICI from onsite data and samples testing which were only available in September 2019 (see Deliverable D6.6)

2- In the production phase, there were many incidents that delayed the ORC units manufacturing. They concerned mainly the Heat exchanger delivery (3 weeks late) and various noncompliance due to the supplier (2 months lost).

3- The heat exchangers were delivered full of water, which is unusual. As a result, they had to be dried and emptied. This took a considerable amount of time (around two weeks per heat exchanger).

4- The first volcanic demonstration site in Iceland (Reykjanes) needed to be changed due to evolution in the site owner top management who no longer wanted to hold the test. Therefore, it has been decided to install the machine on the second volcanic site (Grásteinn) and to identify other potential sites in Iceland to cover the volcanic geological context. This induced one-month delay for the volcanic site.

5- At M22 (February 2020), one ORC unit was already installed in the sedimentary demo site, the other machines were ready to go to the test phase, one after the other. But the situation in France regarding Covid-19 stopped the testing protocols. Activities could be resumed only in M25 (May 2020).

6- During the factory tests, it has been found that the configuration of the exchangers adapted for geothermal contexts had a significant impact on the ORC operation. It was therefore necessary to spend more time than expected to adapt the machine control to achieve the desired performance.

Regarding the accumulated delays observed within WP6, it has been decided to reduce the test duration from 6 months to 4 months in order to provide the expected experiments and information within the course of the project, given that a second set of tests on other demo-sites is expected after this first set.

1.4 IPR ISSUES (IF RELEVANT)

N/A

2 DELIVERABLE REPORT

2.1 CONTEXT

The Global warming issues have highlighted the necessity to enhance the use of renewable energy. Among these energies, geothermal energy is one of the most promising in terms of stable power production. While solar and wind energies are intermittent, geothermal installations have a constant production throughout the year and can partake in producing a baseload power. In geothermal installations, a hot fluid from underground reservoir is used in an energy conversion system (steam train, Organic Rankine Cycle, etc.).

In Europe, geothermal energy is an under-exploited renewable energy source. In 2020, the geothermal electricity installed capacity reaches 0.94 Mtoe, while solar Photovoltaics is 7 Mtoe, Wind energy is 45 MToe and Biomass 13 Mtoe (European Environment Agency, European Topic Centre on Climate change mitigation and energy, 2019). The MEET project was created to boost the development of geothermal energy, mainly the Enhanced Geothermal System (EGS). A part of the MEET project is to demonstrate the conversion of the heat to electricity at low temperature (from 60°C to 120°C) and in three geological contexts: sedimentary, volcanic, and granitic (Trullenque et al., 2018).

The geothermal exploitation is subjected to several challenges, such as corrosion problems related to the chemistry of the geothermal fluid, but also the management of scaling at low temperature and low flow. The issue of converting oil wells into electricity-producing geothermal wells also arises. Thus, to cover a wide panel of situation, 6 demonstration sites were selected. Three geological settings have been chosen to cover different operating conditions and shared among 2 sedimentary sites, 2 granites sites and 2 volcanic sites. These different contexts represent geothermal fluids with quite different chemical compositions, therefore different corrosion stresses to which the ORC will have to adapt. Temperature, pressure, and flow conditions are also different for each site, so the tests can cover temperatures between 60°C to 120°C, which is representative of many geothermal fields in Europe. The Table 1 summarizes the characteristics of the various demonstration sites for the first set of tests.

In order to adapt the ENOGIA standard ORC to a geothermal context, it is necessary to look at the component in contact with the geothermal fluid, the evaporator. Indeed, the only part subjected to brine stresses is the heat exchanger connected directly to the well. This component must be able to resist to the corrosive properties of the hot fluid.

The ORC must also be able to adapt to the existing operating conditions of the various geothermal sites. Therefore the machine will be adapted to an existing geothermal power plant (Soultz-Sous-Forêts, France, an EGS Power Plant), an oil field (Chaunoy and Cazaux, France, Vermilion oil production field) and small private facilities in Iceland (Grásteinn, a farm and Krauma, a natural hot spring used for recreation activities). The location of the different demosites are represented on Figure 1. A last demosite is currently under discussion to test a second granitic setting and will probably be located in Turkey.

Figure 1: Map of the various MEET ORC demo sites.

Table 1: Features of the first demonstration sites.

Name		**Chaunoy**	**Grásteinn**	**Soultz-sous-Forêts**
Geological Context	-	Sedimentary	Volcanic	Granitic
Temperature	°C	90	115	65
Pressure	Bar	11	10	25
Flow	m^3/h	20.16	25.2	108
Fluid	-	Mixture of water (98%), oil and gas	Water, total dissolved solids (20 g/l)	Water, total dissolved solids (100 g/l)

2.2 BACKGROUND

2.2.1 Organic rankine cycle

The Organic Rankine Cycle unit is a heat to power conversion system, based on the closed-loop thermodynamic Rankine cycle. The difference with the basic Rankine cycle is that an ORC uses an organic fluid as a working fluid instead of water. ORC systems can generate electric power exploiting various resources, such as renewables (geothermal energy, solar energy, biogas, etc.), traditional fuels and waste heat from industrial processes.

The ORC, which principle is presented in Figure 2, consists of a pump which pressurizes the working fluid and transports it to the evaporator. In the evaporator, the working fluid is heated to the superheated vapor. The vapor goes through the turbine where it expands and transfers a mechanical work to a shaft that drives a generator where this energy is converted into electricity. At the outlet of the expander, the working fluid is condensed in the condenser. At the outlet of the condenser, the saturated working fluid goes to the pump where it is again pressurized, closing the cycle. ENOGIA's ORC units are designed with a cooling loop extracting the condensing heat from the working fluid through the condenser. This cooling loop is filled with a mixture of water and glycol and it is connected to a dry cooler to evacuate the heat into the ambient air.

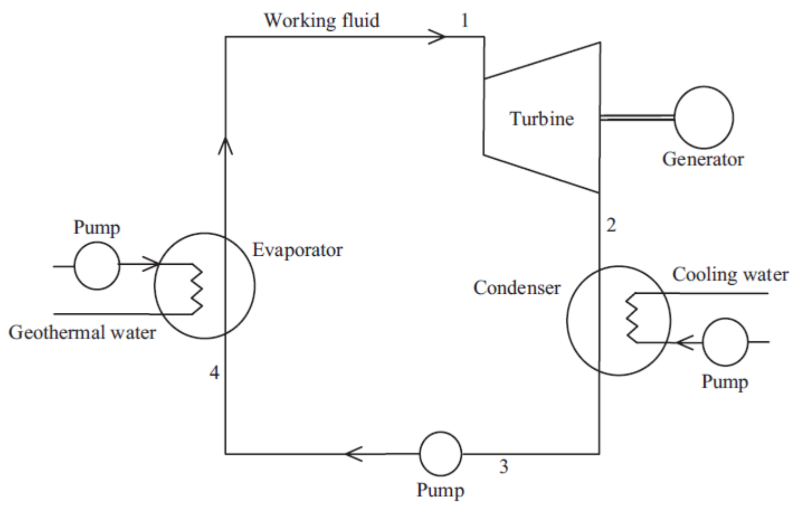


Figure 2: Schematic diagram of the Rankine cycle (Hettiarachchi, 2007).

The performance of the ORC depends on the supply temperature, the load and the system size. The efficiency can be up to 7% with a resource at 90°C, and 12% at 120°C supply temperature (Karytsas, 2007).
The main components of the basic ORC are the expander, the feed pump and two heat exchangers, the evaporator and the condenser. In geothermal applications, the evaporator is the most critical part of the system as it is the only components of the system in direct contact with the geothermal fluid.

2.2.2 Heat exchanger

The heat exchangers are primordial for the Organic Rankine cycle. The role of this equipment is to transfer heat from a hot fluid to a cold fluid. For the evaporator, the heat is transferred from the geothermal fluid to the working fluid, while the condenser transfers heat from the working fluid to cold water.
There are various technologies of heat exchangers, but for small ORC applications, the heat plate exchanger is quite common. Heat plate exchanger, or PHE, primarily consists of thin rectangular pressed sheet metal plates that are sandwiched between full peripheral gaskets and clamped together (Figure 3).

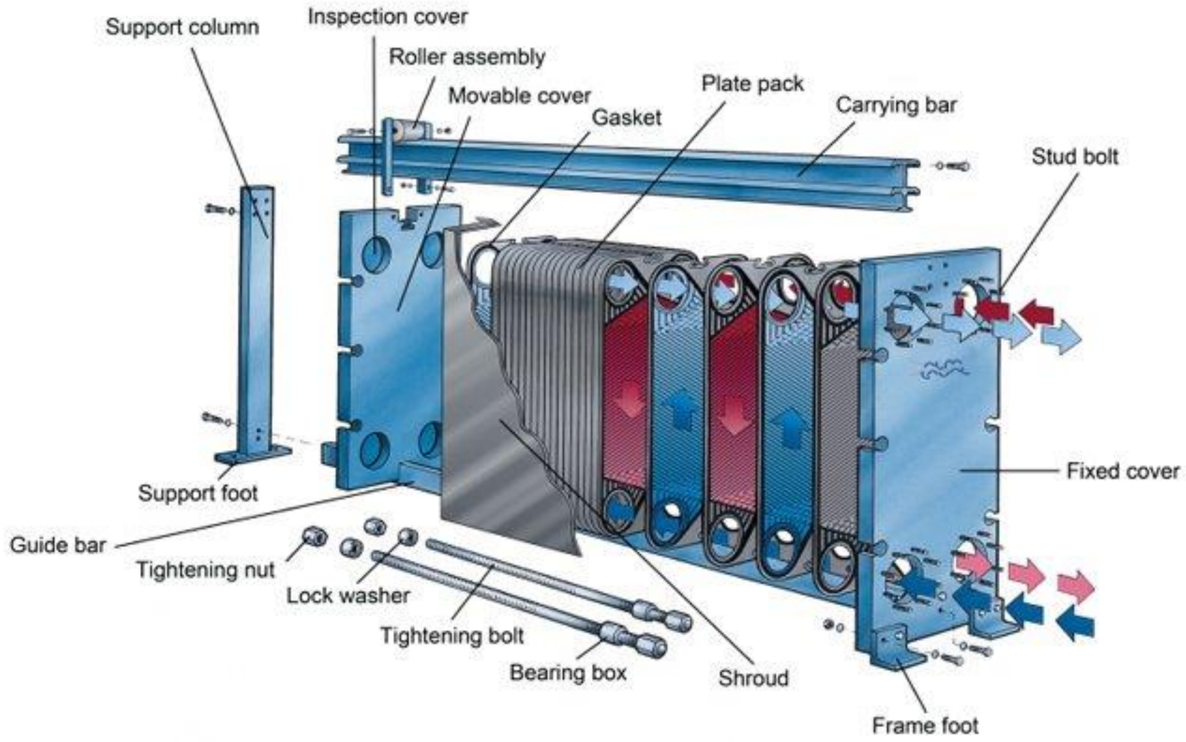


Figure 3: Gasketed plate heat exchanger (Alfa Laval).

There are some PHE sub families: brazed plate heat exchanger (BPHE), Semi-welded PHE and fully welded PHE. The BPHE is generally used in ENOGIA standard ORCs. This exchanger is essentially made of a pack of thin corrugated stainless-steel plates that are brazed together using copper as brazing material. This configuration eliminates the need of gaskets and it is very compact. With the brazed plates, there are no frames or gaskets, BPHE can therefor handle important pressures and temperatures (around 30 bar and up to 400°C). In the MEET project, this type of exchanger has been used as condenser, because no maintenance is needed with the cold loop.
The Semi-Welded PHE (Figure 4) is produced by assembling pairs of plates welded together in a plate-and-frame pack with gaskets only in the plate channels that handle the secondary fluid stream. This design is useful for handling corrosive media which is why the Semi-welded PHE was the chosen solution for the geothermal application. With this design, the maintenance is easy, the plates pack can be removed easily, and it can withstand pressures up to 30 bar.

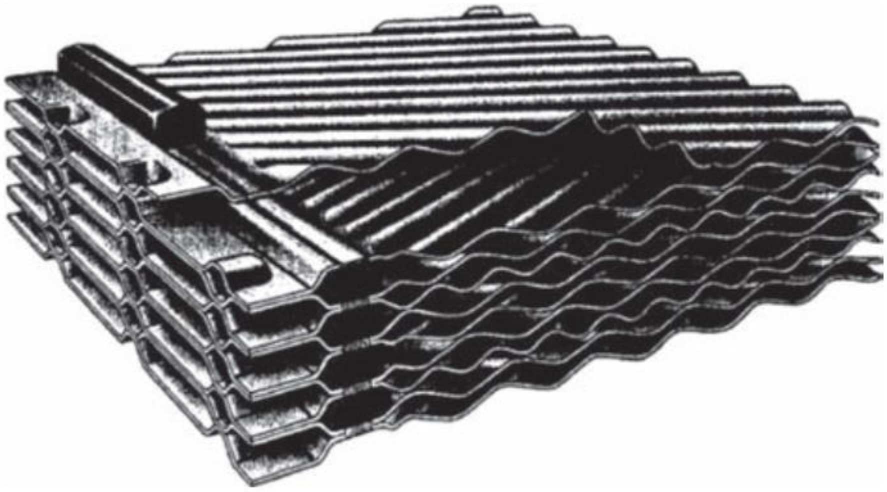


Figure 4: The semi-welded PHE (Alfa Laval).

2.3 HEAT EXCHANGER SELECTION

The choice of a heat exchanger material depends on the geothermal context. A preliminary work has been performed by ICI and ESG to find the optimal material for each first demonstration site. Conclusion of this study is detailed in D6.6 and D6.5. This work has been used to select the appropriate materials for the heat exchangers: for the volcanic and the granitic sites, the selected material is 254 SMO, but for the sedimentary sites, the titanium has been chosen.
The following sections deal with the Heat exchanger characteristics for the various demonstration sites.

2.3.1 Sedimentary

The sedimentary ORC unit was designed for the first sedimentary demo site located on Vermillion facilities in the Paris Basin. The well is called CNY40 and it is located near the city of Blandy. The design of this unit is detailed in the D6.2. It is a 20 kWe ORC with a heat exchanger made with titanium.
The titanium was selected for safety reasons without prior corrosion test on this particular well as it was important to launch the design and manufacturing of this first ORC as early as possible to handle all tests within the timeframe of MEET project. It is safer to use titanium as it had already been tested and validated in the past. Regarding the fluid composition, and especially the presence of H_2S, the risk of corrosion and leakage associated with material degradation is well handled with the use of titanium.
The heat exchanger connected to the brine has the characteristics described in Table 2 (more detail are available in the Appendix 1: SEDIMENTARY HEAT EXCHANGER DATASHEET).

Table 2: Heat Exchanger characteristics (Chaunoy ORC Units).

		Inlet	Outlet
Fluid		Water	R1233zd
Exchanged Heat	**kW**	**350**	
mass flow	kg/h	20038	5832
Steam quality		0	1
Temperature inlet	°C	90	32
Temperature outlet	°C	75	75.72
Saturated temperature	°C		75.72
Pressure drops	mbar	55	129
Volume	m^3	0.07409	0.07223
Fluid quantity per circuit	Kg	41.7	10.8
LMTD (logarithmic mean temperature difference)	K	7.89	
Heat transfer coefficient (required)	W/m^2K	816	

2.3.2 Volcanic

The volcanic ORC unit was designed for two sites in Iceland: Reykjanes and Grásteinn. The fluids characteristics are similar on these two sites. The geothermal fluid temperature is around 110-115°C with a flow of around 7-10 l/s. A brine analysis and the material compatibility have been made by ICI in the D6.6, the material advised in this report is the 254 SMO. The stainless-steel grade 254 SMO is a very high end austenitic stainless steel. This material is designed to have a combination of impact toughness resistance to chloride stress corrosion cracking and pitting and crevice corrosion with strength that is twice that of the stainless steel 300 series.
Figure 5 and Figure 6 present the characteristics of the brine heat exchanger for the two volcanic demo sites (Appendix 2: VOLCANIC HEAT EXCHANGER DATASHEET).

Customer : **ENOGIA**
Model : **MK15-BWFG**
Project: : **19POMPa102**
Item : **Evap. Reykjanes (cas design)** **Date** : **07/08/2019**

Fluid		**Water**	**R1233zd**
Mass flow rate	kg/s	7.000	2.819
Fluid vapourized	kg/s	0.000	2.819
Inlet temperature	°C	115.0	37.8
Dew point	°C		95.7
Outlet temperature (vapor/liquid)	°C	93.3	98.2
Operating pressure (In/Out)	bara		9.40/9.30
Pressure drop	kPa	3.69	10.5
Velocity connection (In/Out)	m/s	0.418/0.411	0.130/3.40
Heat Exchanged	kW	640.2	
Mean Temperature Difference	K	12.0	
Relative directions of fluids		Countercurrent	
Nozzle orientation		S1 -> S2	S4 <- S3
Connections S1, S2, S3, S4:		Flange EN1092-1 DN150 PN16, lining SMO	

Figure 5: The characteristics of the heat exchanger for Reykjanes.

Customer	: **ENOGIA**			
Model	: **MK15-BWFG**			
Project:	: **19POMPa102**			
Item	: **Evap. Grasteinn**		**Date**	: **07/08/2019**

Fluid		**Water**	**R1233zd**
Mass flow rate	kg/s	7.000	2.511
Fluid vapourized	kg/s	0.000	2.511
Inlet temperature	°C	110.0	29.8
Dew point	°C		92.0
Outlet temperature (vapor/liquid)	°C	90.0	94.5
Operating pressure (In/Out)	bara		8.66/8.56
Pressure drop	kPa	3.70	9.72
Velocity connection (In/Out)	m/s	0.416/0.410	0.114/3.29
Heat Exchanged	kW	589.2	
Mean Temperature Difference	K	12.2	
Relative directions of fluids		Countercurrent	
Nozzle orientation		S1 -> S2	S4 <- S3
Connections S1, S2, S3, S4:		Flange EN1092-1 DN150 PN16, lining SMO	
Plate material / thickness		ALLOY 254 / 0.60 mm	
Sealing material		NBRP Clip-on	Welded
Ring Gasket			NBRP

Figure 6: The characteristics of the heat exchanger for Grásteinn.

2.3.3 Granitic

The Granitic heat exchanger was designed for two sites, Soultz-sous-Forêts in France and Vranjska Banja in Southern Serbia. The brine conditions are different on these sites. For Soultz-sous-Forêts the temperature harnessed for this test varies between 60°C and 70°C and the flow is above 25 l/s. For Vranjska Banja, the wellhead temperature is 120°C and the flows is 20 l/s. The ORC has been designed upon Vranjska Banja because the conditions are more restrictive than Soultz regarding the operating conditions (high temperature and high pressure). Figure 7 and Figure 8 present the heat exchanger characteristics (Appendix 3: GRANITIC HEAT EXCHANGER DATASHEET).

Technical specification

Customer	: **ENOGIA**		
Model	: **MK15-BWFG**		
Project:	: **19POMPa102**		
Item	: **Evap. Soultz**	**Date**	: **07/08/2019**

Fluid		**Water**	**R1233zd**
Mass flow rate	kg/s	30.00	2.071
Fluid vapourized	kg/s	0.000	2.071
Inlet temperature	°C	70.0	29.8
Dew point	°C		59.4
Outlet temperature (vapor/liquid)	°C	66.5	61.7
Operating pressure (In/Out)	bara		3.84/3.76
Pressure drop	kPa	33.1	8.18
Velocity connection (In/Out)	m/s	1.74/1.73	0.0937/6.11
Heat Exchanged	kW	438.6	
Mean Temperature Difference	K	9.0	
Relative directions of fluids		Countercurrent	
Nozzle orientation		S1 -> S2	S4 <- S3
Connections S1, S2, S3, S4:		Flange EN1092-1 DN150 PN16, lining SMO	
Plate material / thickness		ALLOY 254 / 0.60 mm	
Sealing material		NBRP Clip-on	Welded
Ring Gasket			NBRP

Figure 7: The characteristics of the heat exchanger for Soultz-sous-Forêts.

Customer	: **ENOGIA**		
Model	: **MK15-BWFG**		
Project:	: **19POMPa102**		
Item	: **Evap. Vranska (cas design)**	**Date**	: **07/08/2019**

Fluid		**Water**	**R1233zd**
Mass flow rate	kg/s	20.00	2.391
Fluid vapourized	kg/s	0.000	2.391
Inlet temperature	°C	120.0	29.8
Dew point	°C		111.8
Outlet temperature (vapor/liquid)	°C	113.0	114.5
Operating pressure (In/Out)	bara		13.1/13.1
Pressure drop	kPa	15.0	7.02
Velocity connection (In/Out)	m/s	1.20/1.19	0.108/2.02
Heat Exchanged	kW	593.1	
Mean Temperature Difference	K	10.3	
Relative directions of fluids		Countercurrent	
Nozzle orientation		S1 -> S2	S4 <- S3
Connections S1, S2, S3, S4:		Flange EN1092-1 DN150 PN16, lining SMO	
Plate material / thickness		ALLOY 254 / 0.60 mm	
Sealing material		NBRP Clip-on	Welded
Ring Gasket			NBRP

Figure 8: The characteristics of the heat exchanger for Vranjska Banja.

However, the Vranjska Banja site could not be secured for a test within MEET as the well owner changed recently and is not willing to proceed. Thus, another granitic site is under investigations in Turkey.

2.4 MANUFACTURING PROCESS

The 3 ORC units followed the same manufacturing process, which can be divided into 4 phases. The first step is the subcontracting of the welded structure, the control cabinet manufacturing and the precision machining of the turbine parts. The second step is the final assembly, this phase consists in the integration of the cooling turbine pipework, the sensors integration and the wiring. The third step is the manufacturing tests and the final phase is the quality check. When all these phases are validated, the ORC can then be prepared for its expedition.

2.4.1 Subcontracting

2.4.1.1 Container

Since the ORC units are integrated into a 20 feet dry container, a big part of the manufacturing process consists in modifying the container. The containers are mainly used to facilitate their transport and installation on site. A brand-new container was bought and sent to ENOGIA's subcontractor.
The modification consists in opening the right side of the container (Figure 9) and installing a metal wall in the middle of the container to create an inner room. Other elements are also added such as openings for the piping and the support of the exchanger (Figure 10).

Figure 9: Container modification, opening in the right flank of the container.

Figure 10: Container modification: (1) opening for aeration, (2) metal wall with door and holes for piping, (3) opening for cold pipe connection.

All these parts are welded to the container, each wall connection has been sealed with a silicone seal. Once all the operations were carried out, the container was painted in leafy green (RAL 6002), as this colour is usually used in industrial sites.

2.4.1.2 The skid

The skid is the structure that contains all the standard components (pump, electrical cabinet, turbine…) of the ORC. It is a semi-welded assembly. This part is based on the standard ORC layout. The skid is made of steel bars which are welded together. When all the bars are welded and the various supports and other accessories are placed, the skid is painted (Figure 11).

Figure 11: 40 kW ORC unit welded structure (Skid).

2.4.1.3 Pipework

The pipework is an important part of the manufacturing process. The main ORC pipework is made with stainless steel and all pipes and fittings are welded together. There are two mains pipes: the working fluid pipe, and the brine pipe.

The first step of this part is the production of the working fluid pipe integrated to the skid. The pipe starts at the outlet of the tank receiver and goes to the feed pump with flanged connections. After the flange, the pipe goes to the evaporator with flanged connections as well, and then to the expander. For the 20 kW ORC there is only one turbine, but for the 40 kW, there are two 20 kW turbines in parallel. The connection between the turbines and the condenser is also done with the stainless-steel pipe (Figure 12 and Figure 13).

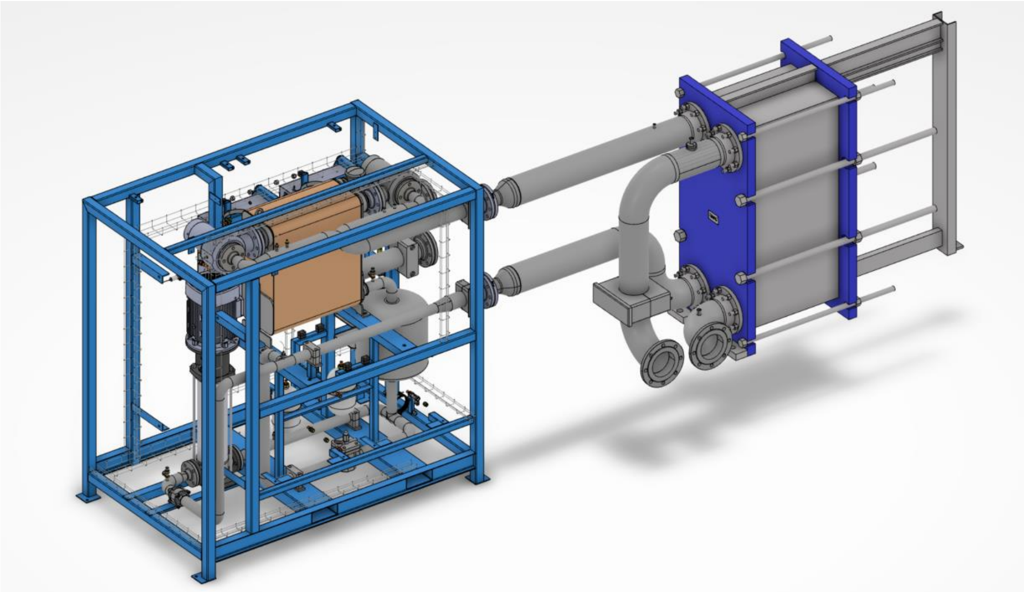


Figure 12: Stainless steel pipework 40 kW ORC unit (designed for volcanic and granitic demo sites).

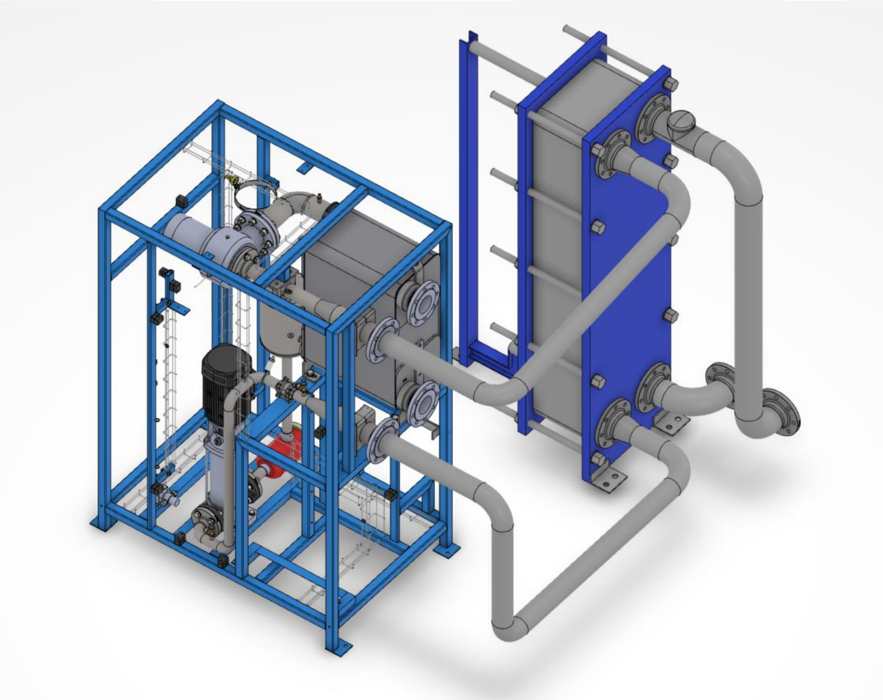


Figure 13: Stainless steel pipework 20 kW ORC unit (designed for sedimentary demo sites).

A special attention was paid to the realization of the brine pipe. The welding was carried out respecting the oil and gas standards for the 20 kW ORC unit. The brine pipe was made with pipe and fitting in schedule 40 and in stainless steel 316 L, which means that the thickness of the pipes is larger. The schedule 40 was also used for the 40 kW ORC units because of pressure conditions in the Soultz-sous-Forêts wells (25 barg).
Figure 14 illustrates the welding process performed to manufacture the pipes necessary for the ORC.

Figure 14: Welding process, brine pipe welding.

A part of this welding process has been made directly in the container (Figure 15). This part concerns the connections between the skid and the evaporator.

Figure 15: Pipework inside the modified container.

2.4.2 Assembly

This step of the manufacturing consists in integrating all the components, sensors, cooling loop and electrical cabinet on the skid (Figure 16). It is also necessary to change all the gaskets of the system to ensure having the right material regarding fluid compatibility.

Figure 16: Pictures of the assembled skid.

The assembly starts with the lubrication turbine loop and cooling loop integration (Figure 17). The circuits are made of coper pipework and accessories.

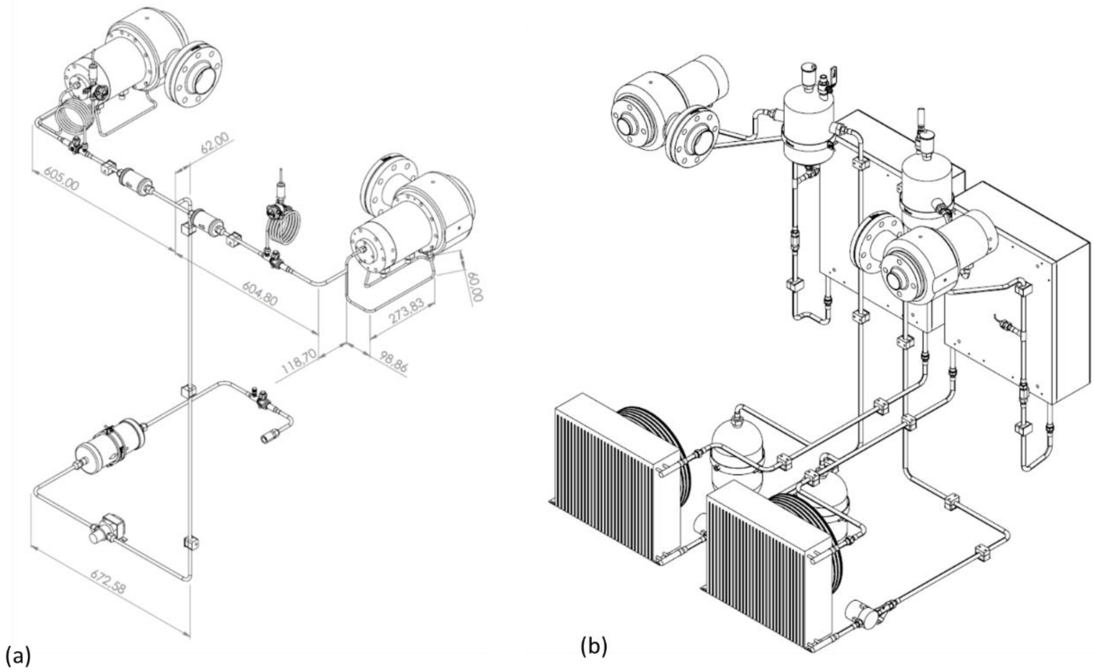


Figure 17: (a) Lubrication turbine loop, (b) cooling turbine loop.

The next step is the sensors integration and electrical wiring. Each sensor is installed on the pipes and connected to the main control cabinet. The Skid is also connected to the container electrical cabinet (Figure 18).

Figure 18: Skid control cabinet.

The final step of this process was the final integration into the container. The skid was installed in the container, all connection made (hydraulic, electrical) (Figure 19). The final completions are carried out: the skid is fixed to the container; the painting is finalized, and some general cleaning is performed. The machine is then ready to undergo the pressure and electrical tests.

Figure 19: Assembled ORC units. (A) Granitic ORC module, (B) Sedimentary ORC module and (C) Volcanic ORC unit.

2.4.3 Manufacturing tests

The manufacturing tests include the pressure test, electric test, leak test and PLC (programmable logic controller) debugging. Each machine is tested before the functional test.
The pressure test is a regulatory test imposed by the PED (Pressure Equipment Directive); it consists in pressurizing the ORC at 1.5 times the service pressure.
The pressure test is followed by the leak test, with the unit steel pressurized while the operator checks if the pressure inside the equipment decreases. If the pressure decreases, the operator looks for the leaks with a traditional leak detector. The leak test is validated only when the pressure remains steady for at least half a day.
The electrical test consists of a continuity test. This test is important to determine damaged components or broken conductors in a circuit. It can also help to determine if the connections are good or if the resistance is too high. It allows verifying the conformity of the electrical circuit or connection.
The goal of the PLC debugging is to check the consistency between the sensors values and the real values, validating the scaling of the measurement equipment.

2.4.4 Functional test

The functional test aims to validate the primary functions of the machine. These functions are:

- The stop/start procedures.
- The regulation.
- The communication;
- The safety shutdown

All these functions need to be validated before the performance test.
The tests are performed on a test bench, with the ORC connected to a heat source (oil boiler) and a cold source (dry cooler).

The stop/start procedures
This test consists in starting the ORC with low temperature and checking the behaviour of the unit. Some faults are simulated to see if the machine reacts well and stops as expected.

The regulation
To have optimal power production and to avoid some risky conditions, the system needs to be finely regulated. The system is controlled with a PID (Proportional Integral Derivative) and safety rules. A PID controller is used to control an output and regulates a process value to the desired set point. In this case, the set points are the temperature and the pressure at the inlet of the turbine.
The fluid at the turbine inlet needs to be saturated to avoid droplets in the equipment. Droplets in the turbine will considerably affect the turbine lifetime. The regulation test consists in checking the PID and optimising it (speed and precision).

The communication
This is to check if the HMI (Human Machine Interface) works properly, but also if the data is sent correctly.

The safety shutdown:
The safety shutdown is to stop the production of electricity, to let the actuator run to cool the system. After 5 minutes, the system will stop completely.

2.4.5 Factory Test

The factory performance tests consist in connecting the ORC module to the ENOGIA Test Bench and operating the machine under similar conditions as the demo site where it will operate. The test bench is composed of two oil boilers with a total thermal output of 14 000 kW and a hot loop pump circulating hot water at a maximum flow rate of 85 m^3/h. The test bench also has a cold-water loop made of a dry cooler and a water circulation pump.
The hot loop circuit is equipped with a flow meter and temperature sensors at the inlet and outlet of the evaporator. These sensors are connected to a Calorimeter that measures heat consumed by the ORC.
The HMI interface provides a real-time view of the ORC's behaviour. Figure 20 shows the ORC HMI and the test bench HMI.

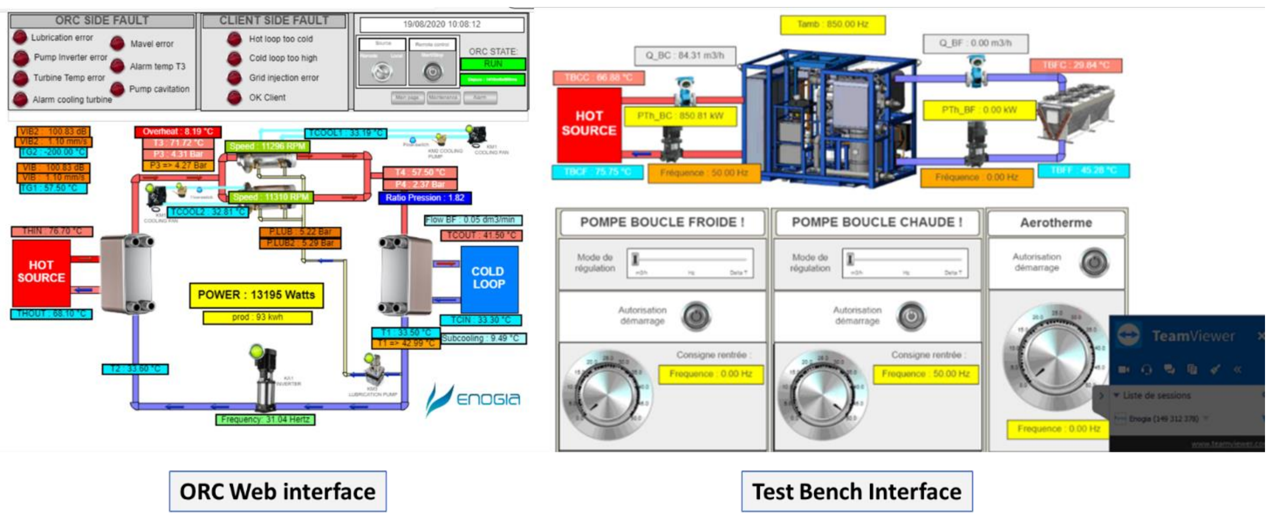


Figure 20: ORC web interface and test bench interface.

The important values for evaluating the performance of the ORC unit are:
- The electrical power generated by the ORC unit, given by the inverter;
- The pressure ratio (High Pressure/Low pressure);
- The thermal power given by the calorimeter.

The electrical power and the thermal power make it possible to calculate the gross efficiency of the cycle.

$$Gross\ efficiency = \frac{Electrical\ Power\ production}{Thermal\ Power}$$

2.4.5.1 Factory tests results of the Chaunoy's ORC

The Chaunoy ORC unit was designed for the CNY40 wells at Vermillion facilities in Paris basin. During the first visit in Vermillion, the temperature of the hot brine pipe was 90°C, the data from the site indicated that the daily flow of CNY40 was around 456 m^3/day. The theorical performance of the unit are resumed in Table 3.

Table 3: Performance of Chaunoy ORC unit. (Nearest point of brine conditions).

		Design Point	Test
Brine			
Temperature Inlet	°C	90	90.48
Temperature Outlet	°C	76.4	78.23
Flow	m^3/h	20.16	20
Thermal Power	kWth	319.51	313.95
Cold Loop			
Temperature Inlet	°C	21.3	32.6
Temperature Outlet	°C	31.3	38.8
Flow	m^3/h	27.51	32.8
Thermal Power	kWth	319.51	295.07
Working Fluid (R1233ZD)			
Temperature Evaporator Outlet (T3)	°C	79.8	87.01
Pressure Evaporator Outlet (P3)	bar	6.08	6.22
Temperature Condenser Outlet (T1)	°C	31.3	38.37
Pressure condenser Outlet (P4)	bar	1.44	2.2
Turbine			
Turbine Output power	kW	16.98	14.72
Efficiency	%	5.31	4.7
Pressure ratio		4.22	2.82

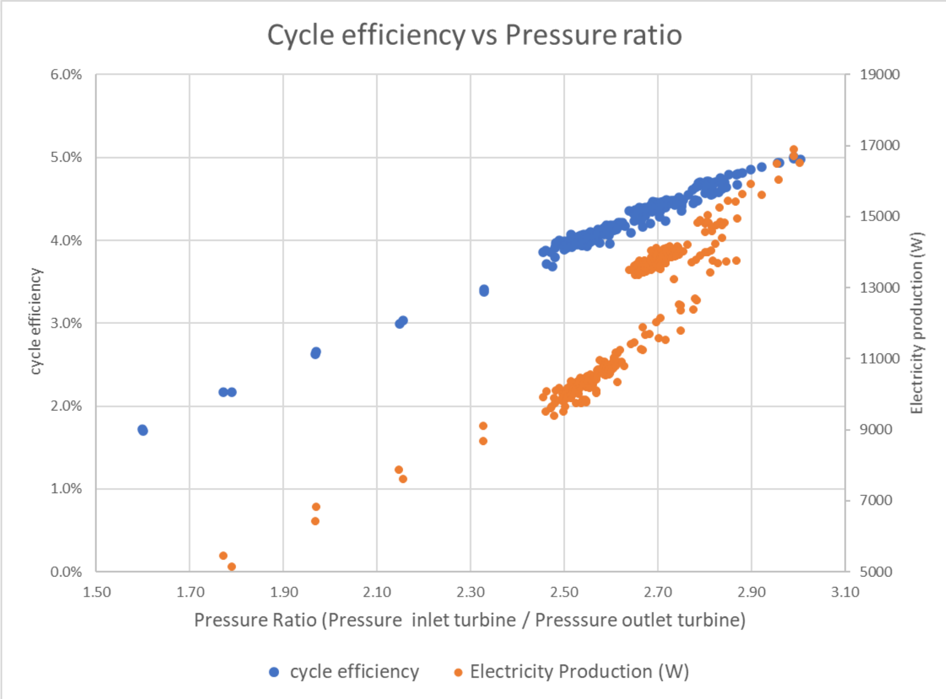


Figure 21: Graph of the efficiency versus pressure ratio (Factory test for Chaunoy ORC).

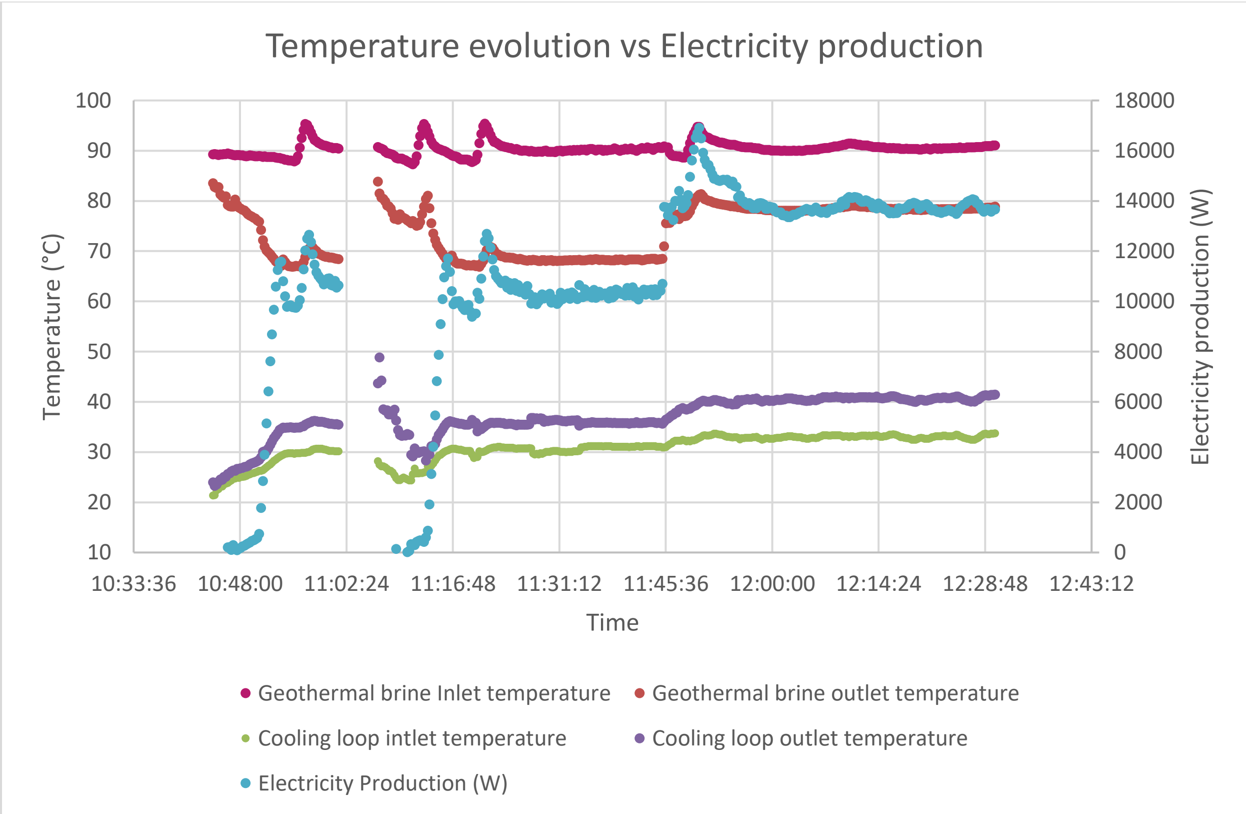


Figure 22: Evolution of the temperature loop temperature and Electricity power production (Factory test for Chaunoy ORC).

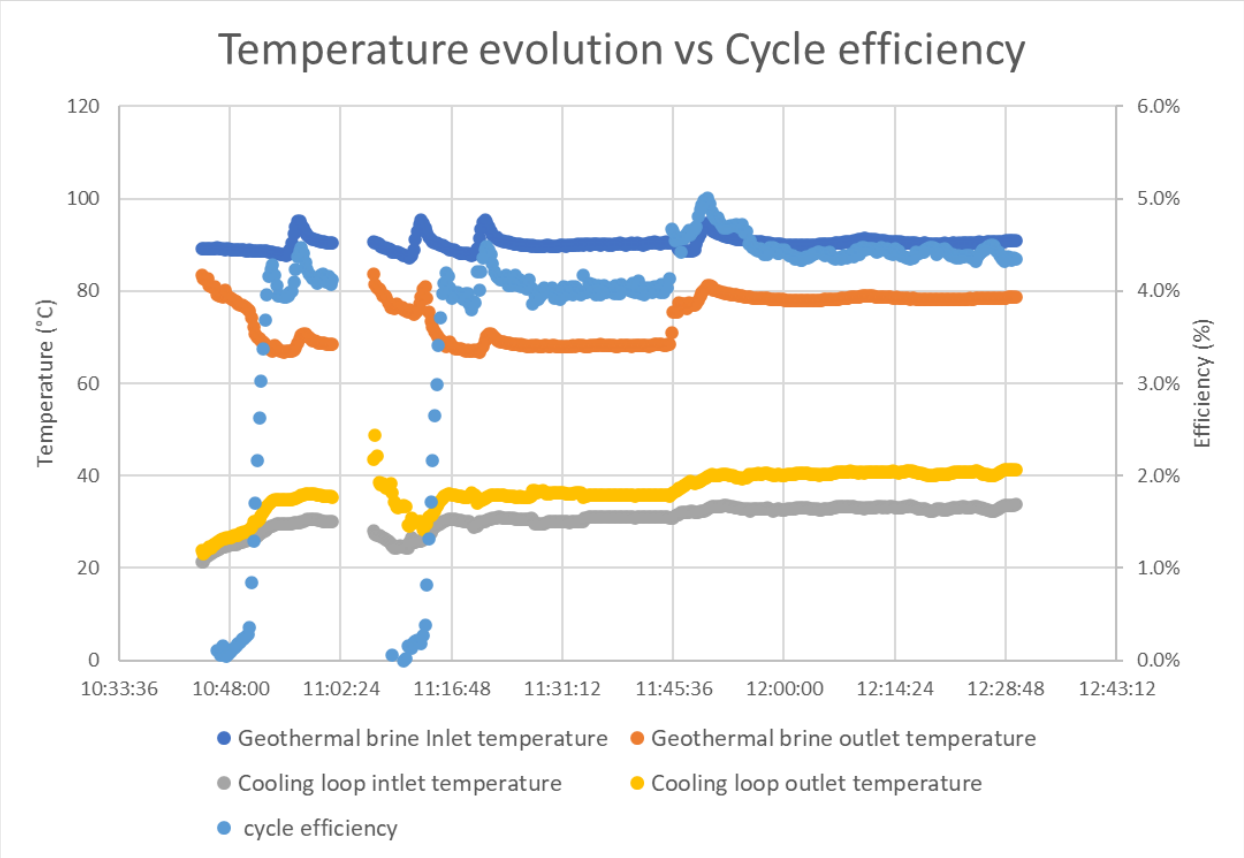


Figure 23: Evolution of the temperature loop temperature and cycle efficiency (Factory test for Chaunoy ORC).

Regarding the factory test results, the performance of the Chaunoy ORC is satisfactory. On the nearest point of the brine conditions, the machine's performances are good, the unit is able to produce 14 kW instead of 16 kW on the same hot fluid temperature (Table 3). This difference may be explained by the fact that the nominal pressure ratio was never reached because of the high temperature on the cold loop. The Figure 21 shows the influence of the pressure ratio on the cycle efficiency, the maximum value that could be reached remains less that 3. In fact, the tests were carried out in November in Marseille with outside temperatures around 25-30°C, but on the design point the temperature input condenser is 20°C (Figure 22).

During the test, some parameters were optimized to have better production. Indeed, in Figure 22, despite the increase in the cooling loop temperature, there is also an increase of electricity production. At 11:45 a.m., the superheating instruction was reduced, which increased the pump's flow and the heat exchange at the evaporator.

During the test, the gross efficiency was around 5%, which was close to the theoretical gross efficiency (Figure 23).

In conclusion, the Chaunoy ORC unit performance was validated and has been sent to the demonstration site.

2.4.5.2 Grásteinn ORC units

The volcanic ORC unit has an electrical capacity of 40 kW. The unit was designed to run with a geothermal fluid at 115°C. However, the ENOGIA test bench has a temperature limitation and the testing with hot water cannot exceed 100°C.

The tests were carried out with a temperature of about 100°C, therefore, the test conditions were far from the operating conditions of the demonstration site. Moreover, the cold loop temperature was 20°C, higher than expected. Despite these disadvantageous conditions, the results were relatively positive (Figure 24 and Figure 26). With 82% of the theoretical heat, the machine produced 70% of the expected electrical power (Table 4 and Figure 25).

Table 4: Performance of Grásteinn ORC unit. (Nearest point of brine conditions).

		Design Point	Test
Brine			
Temperature Inlet	°C	115	99
Temperature Outlet	°C	93.3	86.9
Flow	m^3/h	25.2	27
Thermal Power	kWth	640.52	526.65
Cold Loop			
Temperature Inlet	°C	10	31.37
Temperature Outlet	°C	38	39.6
Flow	m^3/h	19.69	20
Thermal Power	kWth	640.52	487.16
Working Fluid (R1233ZD)			
Temperature Evaporator Outlet (T3)	°C	98.73	96
Pressure Evaporator Outlet (P3)	bar	9.49	7.36
Temperature Condenser Outlet (T1)	°C	37.83	33.4
Pressure condenser Outlet (P4)	bar	2.22	2.18
Turbine			
Turbine Output power	kW	40.23	27.75
Efficiency	%	6.28	5.3
Pressure ratio		4.27	3.38

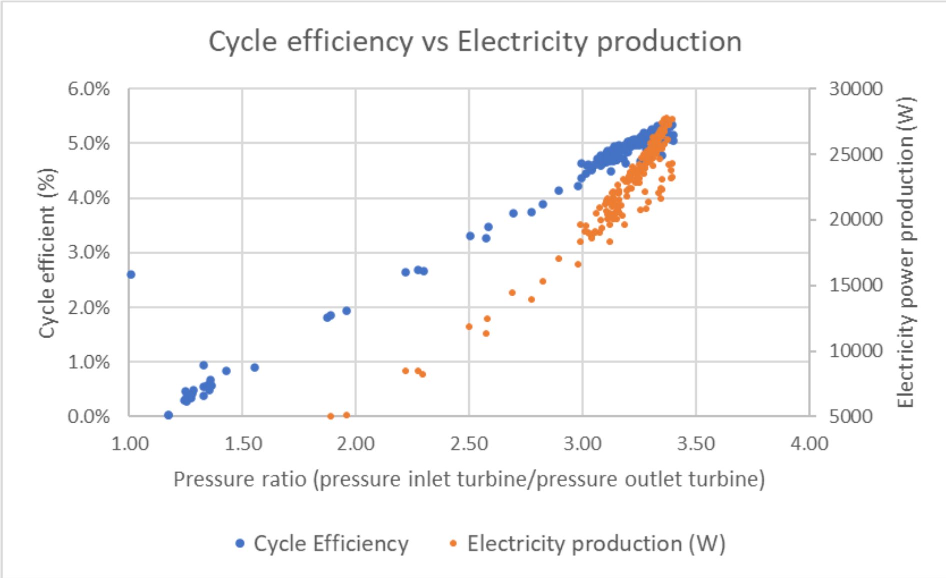


Figure 24: Graph of the efficiency versus pressure ratio (Factory test for Grásteinn ORC).

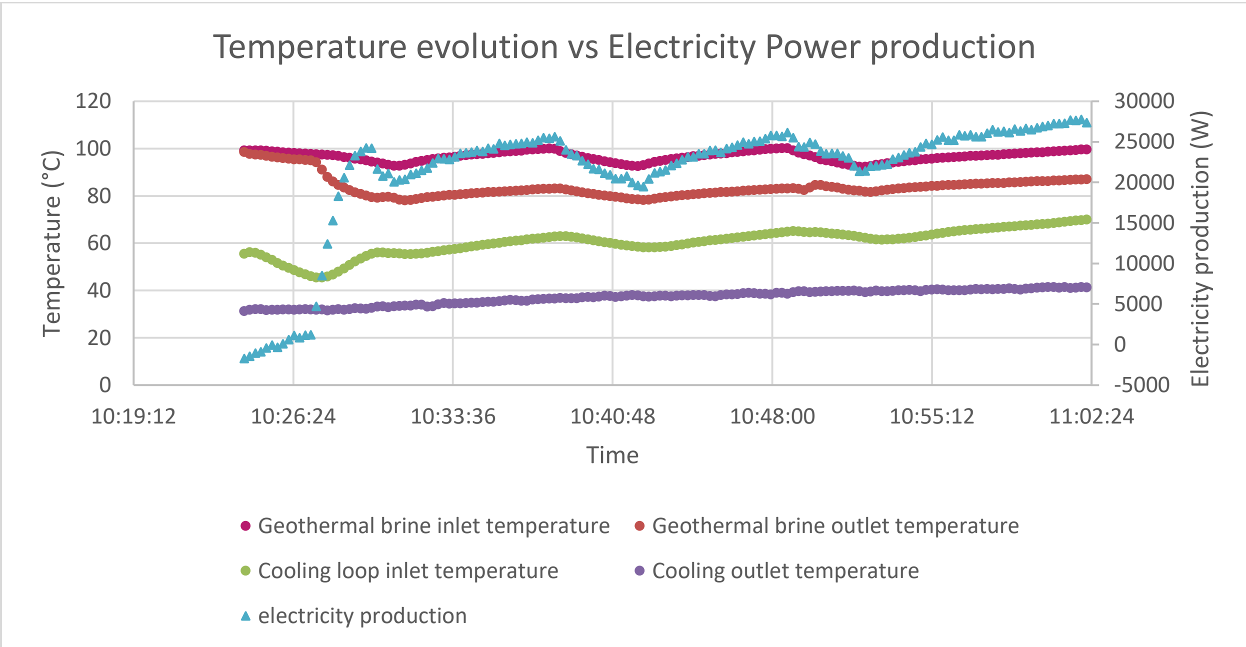


Figure 25: Evolution of the temperature loop temperature and Electricity power production (Factory test for Grásteinn ORC).

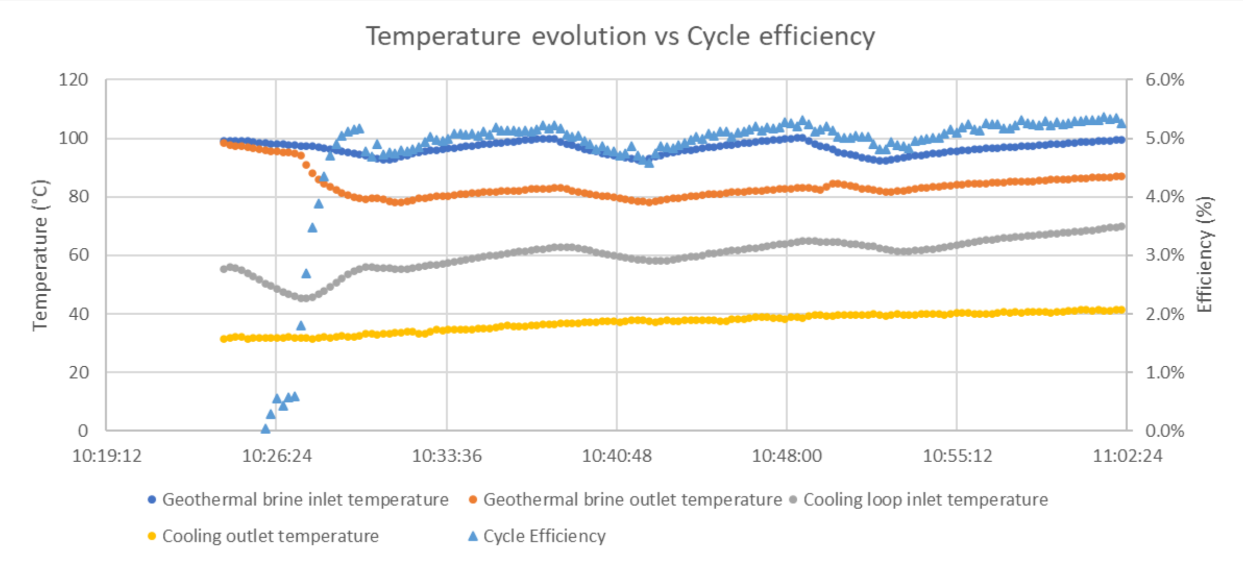


Figure 26: Evolution of the temperature loop temperature and cycle efficiency (Factory test for Grásteinn ORC).

2.4.5.3 Soultz-sous-Forêts ORC unit

The Soultz-sous-Forêts ORC is special regarding the temperature of the fluid, as it is low compared to what is usually done. The hot fluid temperature varies between 60 and 75°C depending on the 1.7 MW ORC unit operated on site, which implies in the organic Rankine cycle a high pressure between 3 and 4 bar, with the low pressure around 2 bar. The pressure ratio being low (Figure 25), the ORC unit is very sensitive to the slightest variations on the hot side as well as the cold side. The regulation of this machine is therefore finer, and the safety thresholds must be optimized to ensure a good lifetime of the machine.

Here, too, the test conditions were unfavourable, as the tests were carried out in the middle of summer with an ambient temperature around 30°C. Thus, the cold loop remained high, which greatly impacted the efficiency especially for a low temperature machine (Figure 25 and Figure 26). Moreover, the test conditions at the site could not be fully met as the flow of hot water is limited to 85 m^3/h on the test bench while it could reach 108 m^3/h on site.

The results are presented in Table 5: with 61% of the expected pressure ratio the turbines produce 53% of the electricity estimated at the nominal point. This is due to poor testing conditions. But by projecting the pressure ratio, the machine will be able to produce what has been designed.

Table 5: Performance of Soultz-sous-Forêts ORC unit.

		Design point	Test
Brine			
Temperature Inlet	°C	65	65.6
Temperature Outlet	°C	61.5	58.9
Flow	m^3/h	108	83
Thermal Power	kWth	439.56	383.22
Cold Loop			
Temperature Inlet	°C	25	29.7
Temperature Outlet	°C	30	36.1
Flow	m^3/h	37.85	
Thermal Power	kWth	439.56	371.1
Working Fluid (R1233ZD)			
Temperature Evaporator Outlet (T3)	°C	62.38	60.74
Pressure Evaporator Outlet (P3)	bar	3.84	3.34
Temperature Condenser Outlet (T1)	°C	29.95	29.7
Pressure condenser Outlet (P4)	bar	1.71	1.98
Turbine			
Turbine Output power	kW	15.92	8.45
Efficiency	%	3.62	2.2
Pressure ratio		2.25	1.69

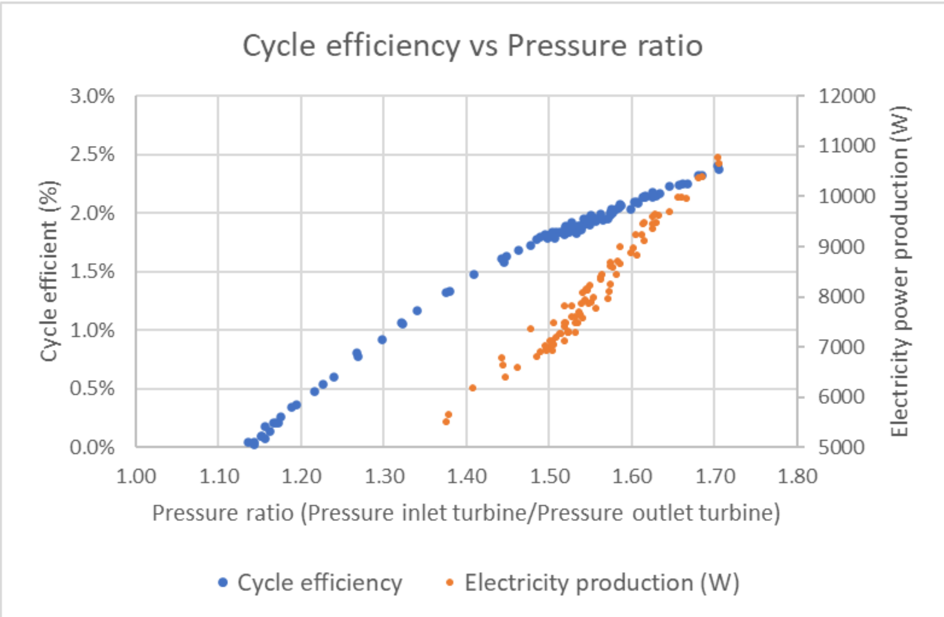


Figure 27:Graph of the efficiency versus pressure ratio (Factory test for Soultz-sous-Forêts ORC).

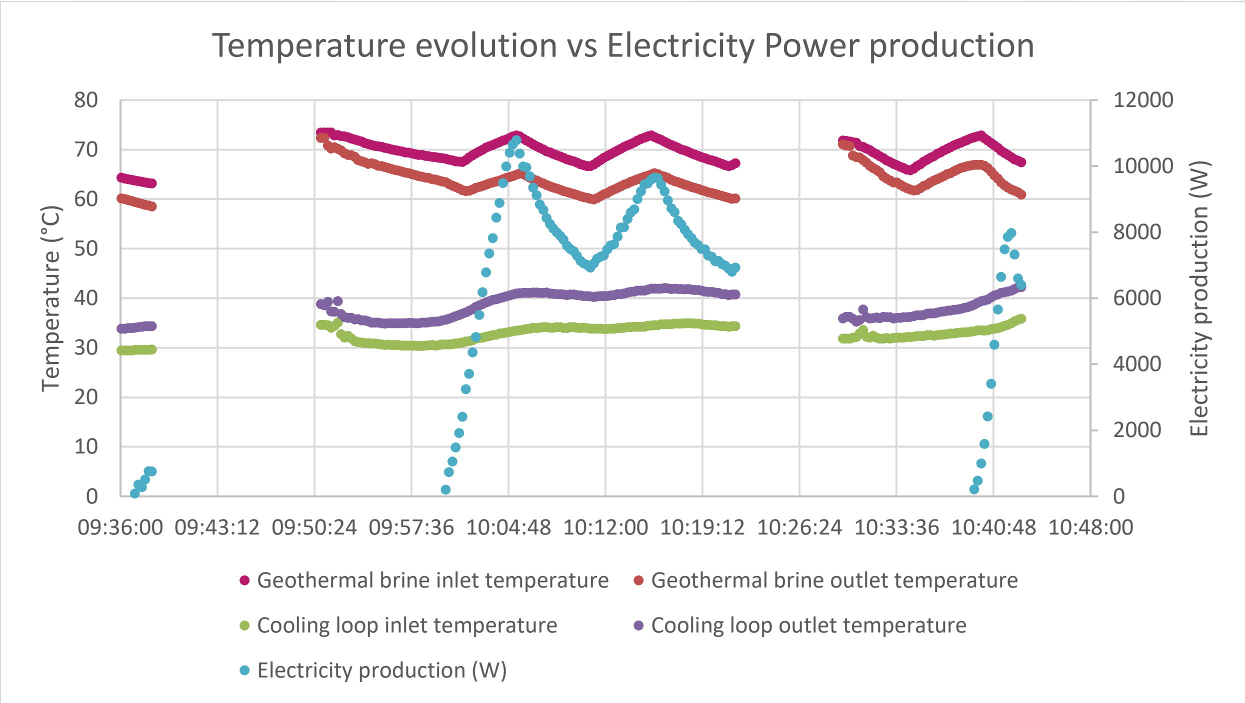


Figure 28: Evolution of the temperature loop temperature and Electricity power production (Factory test for Soultz-sous-Forêts ORC).

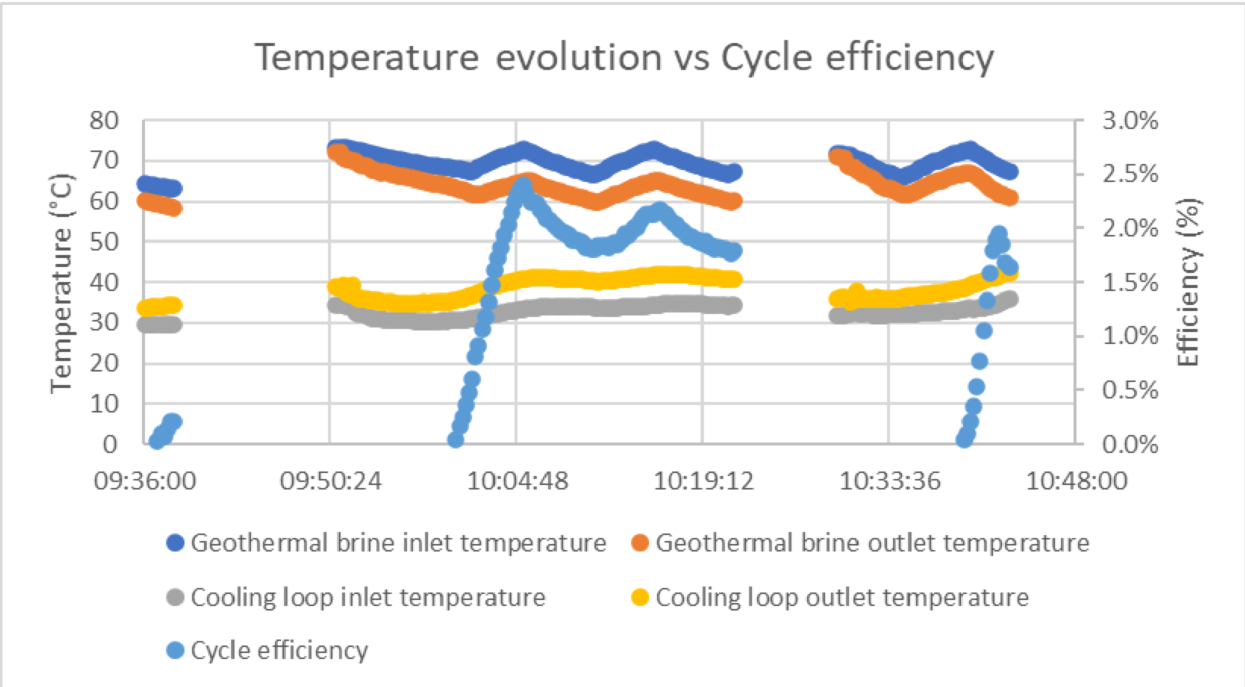


Figure 29:Evolution of the temperature loop temperature and cycle efficiency (Factory test for Soultz-sous-Forêts ORC).

2.5 CONCLUSION

The main objective of this task is to adapt the existing ORCs from ENOGIA to various geothermal applications. **The design and the production of 3 ORC units adapted to 3 geological contexts is successful.**

Three machines have been adapted for 3 different demonstration sites within different geological characteristics. Chaunoy, a sedimentary site with a fluid temperature between 90-94°C; Grásteinn, a volcanic demo site with 115°C of supply temperature and Soultz-sous-Forêts with a fluid temperature ranging from 60 to 75°C from granitic origins. Each unit was designed and the manufactured to meet the constraints of these different sites.

The ORC modules were also tested in the factory, the tests were carried out in such a way as to get as close as possible to each site's actual conditions. The results obtained are satisfactory, although the test conditions are not ideal for the performance of the ORC system. The ORC units are now delivered on the demonstration sites and the 4 months test can start.

3 REFERENCES

Dalmais E., Genter A., Trullenque G., Vidal J., Leoutre E., Leiss B., wagner B., Mintsa C.-A., Bar K., Rajsl I., (2019). MEET project: toward the spreading of EGS across Europe, European Geothermal Congress, EGC 2019, 11-14 June 2019, The Hague, The Netherlands.

EGEC, 2020. Geothermal Market report 2019, European Geothermal Energy Council June 2020, EGEC report, 60 pp.

European Environment Agency, European Topic Centre on Climate change mitigation and energy. (2019). *Renewable energy in Europe — 2019.* ETC/CME.

Hettiarachchi, H. M. (2007, Avril 17). Optimum design criteria for an Organic Rankine cycle using. *Energy*, pp. 1698-1706.

Karytsas, C. (2007). Project LOW-BIN “Efficient Low Temperature Geothermal Binary Power”. *Proceedings European Geothermal Congress 2007 .* Unterhaching, Germany.

Steven Lecompte, H. H. (2015). Review of organic Rankine cycle (ORC) architectures. *Renewable and Sustainable Energy Reviews*, 448-461.

Trullenque G., Genter A., Leiss B., Wagner B., Bouchet R., Leoutre E., Malnar B., Bär K., Rajšl I., (2018). Upscaling of EGS systems in different geological conditions: a European perspective, Stanford Geothermal Workshop 2018, Stanford, California, USA, 12-14 February 2018.

4 APPENDIX 1: SEDIMENTARY HEAT EXCHANGER DATASHEET

Devis 2605068-129 rev. 0 Client: Enogia

Client:	Enogia				
Devis n°	2605068-129	**Demande n°**	SUB017_Géothermie		
Contact:	Fuzel		**Poste:** 10	**Option:**	0
Référence client:	Evapo Géothermie cas n°1		**Date:**	13/02/2019	

Prix unitaire : **Prix total:** **Qté:** 1

ÉvaporateurEvaporateur à plaques LWC100X CDL-10
Kelvion: noyé

Données thermiques	**Côté chaud**		**Côté froid**		
		Entrée		**sortie**	
Fluide:	Eau		R1233zd		
Chaleur échangée:		350,56			kW
Débit massique:	20038		5832		kg/h
Débit volumique:	20,65	4,68		186,44	m³/h
Titre vapeur:		0,00		1,00	
Température d'entrée:	90,00		32,00		°C
Température de sortie:	75,00		75,72		°C
Température saturante:			75,72		°C
Pertes de charge:	55		129		mbar
Volume des circuits:	0,07409		0,07223		m³
Quantité de fluide par circuit:	41,7		10,8		kg
Pression de service à l'entrée:	4,98		4,99		barg
LMTD:		7,89			K
Coeff. d'échange (requis):		816			W/m²K

Propriétés du produit					
Masse volumique:	970,19	1245,64		31,28	kg/m³
Chaleur massique:	4198,80	1227,78		985,18	J/kgK
Conductibilité thermique:	0,66854	0,07319		0,01480	W/mK
Viscosité dynamique à l'entrée:	0,3142		0,4294		cP
Viscosité dynamique à la sortie:	0,3774		0,0130		cP

Caractéristiques techniques de l'appareil				
Type de plaques:		LWC 100X H – Cassette soudée		
Surface totale d'échange:		54,40		m²
Nombre total de plaques/cassettes:		82 / 40		
Epaisseur des plaques:		0.6		mm
Surface de réserve:		15,80		%
Coefficient d'encrassement:		167		m²K/W E-6
Matériau des plaques:		Titanium		
Matériau des joints de champ:	EPDM		Laser welded	
Matériau des joints de collecteur:	Laser welded		Neoprene	
Direction des fluides:		Contre courant parfait		
Circulation interne (passes x canaux):	1 x 41		1 x 40	
Nbre de bâtis (parallèle / série / total):	1		1	1
Matériau du bâti / Surface:	S355J2+N		Peint	RAL5002

Temp. de calcul (pri/sec):	**Min.:**	-10,00 / -10,00	**Max.:**	100,00 / 100,00	°C
Press. de calcul (pri/sec):	**Min.:**	0,00 / 0,00	**Max.:**	10,00 / 10,00	barg
Press. d'épreuve (pri/sec):	13,00 / 13,00	barg	**Code calcul:**	PED 2014/68/EU AD-2000 Checkfactor 1.3	
Catégorie:	Catégorie II		**Proc. d'évaluation de conformité:**	Modul A2	
Type/Remarques:	Marquage CE				

Limite de fourniture: La fourniture comprend les contre-brides (acier carbone), boulons et écrous galvanisés.

Remarque sur les joints Le matériau des joints annulaires Néoprène (CR) n'est pas compatible avec les huiles de polyolester (POE) et les huiles de polyvinylether (PVE). Veuillez vérifier le type d'huile utilisée.

Remarques:

Page 3

Devis 2605068-129 rev. 0 Client: Enogia

Client:	Enogia				
Devis n°	2605068-129	**Demande n°**	SUB017_Géothermie		
Contact:	Fuzel		**Poste:** 10	**Option:**	1
Référence client:	Evapo Géothermie cas n°2		**Date:**	13/02/2019	

Prix unitaire :	**Prix total:**	**Qté:**	1

ÉvaporateurEvaporateur à plaques Kelvion: noyé LWC100X CDL-10

Données thermiques	**Côté chaud**		**Côté froid**		
		Entrée		**sortie**	
Fluide:	Eau		R1233zd		
Chaleur échangée:		319,82			kW
Débit massique:	20160		5278		kg/h
Débit volumique:	20,79	4,23		163,42	m³/h
Titre vapeur:		0,00		1,00	
Température d'entrée:	90,00		31,19		°C
Température de sortie:	76,40		76,96		°C
Température saturante:			76,96		°C
Pertes de charge:	56		123		mbar
Volume des circuits:	0,07409		0,07223		m³
Quantité de fluide par circuit:	41,6		10,8		kg
Pression de service à l'entrée:	4,98		5,16		barg
LMTD:		7,57			K
Coeff. d'échange (requis):		776			W/m²K

Propriétés du produit				
Masse volumique:	969,75	1247,65	32,30	kg/m³
Chaleur massique:	4199,36	1226,37	990,36	J/kgK
Conductibilité thermique:	0,66897	0,07340	0,01492	W/mK
Viscosité dynamique à l'entrée:	0,3142	0,4338		cP
Viscosité dynamique à la sortie:	0,3706	0,0131		cP

Caractéristiques techniques de l'appareil				
Type de plaques:	LWC 100X H – Cassette soudée			
Surface totale d'échange:	54,40			m²
Nombre total de plaques/cassettes:	82 / 40			
Epaisseur des plaques:	0.6			mm
Surface de réserve:	15,07			%
Coefficient d'encrassement:	169			m²K/W E-6
Matériau des plaques:	Titanium			
Matériau des joints de champ:	EPDM	Laser welded		
Matériau des joints de collecteur:	Laser welded	Neoprene		
Direction des fluides:	Contre courant parfait			
Circulation interne (passes x canaux):	1 x 41	1 x 40		
Nbre de bâtis (parallèle / série / total):	1	1	1	
Matériau du bâti / Surface:	S355J2+N	Peint	RAL5002	

Temp. de calcul (pri/sec):	**Min.:**	-10,00 / -10,00	**Max.:**	100,00 / 100,00	°C
Press. de calcul (pri/sec):	**Min.:**	0,00 / 0,00	**Max.:**	10,00 / 10,00	barg
Press. d'épreuve (pri/sec):	13,00 / 13,00	barg	**Code calcul:**	PED 2014/68/EU AD-2000 Checkfactor 1.3	
Catégorie:	Catégorie II		**Proc. d'évaluation de conformité:**	Modul A2	
Type/Remarques:	Marquage CE				

Limite de fourniture: La fourniture comprend les contre-brides (acier carbone), boulons et écrous galvanisés.

Remarque sur les joints Le matériau des joints annulaires Néoprène (CR) n'est pas compatible avec les huiles de polyolester (POE) et les huiles de polyvinylether (PVE). Veuillez vérifier le type d'huile utilisée.

Remarques:

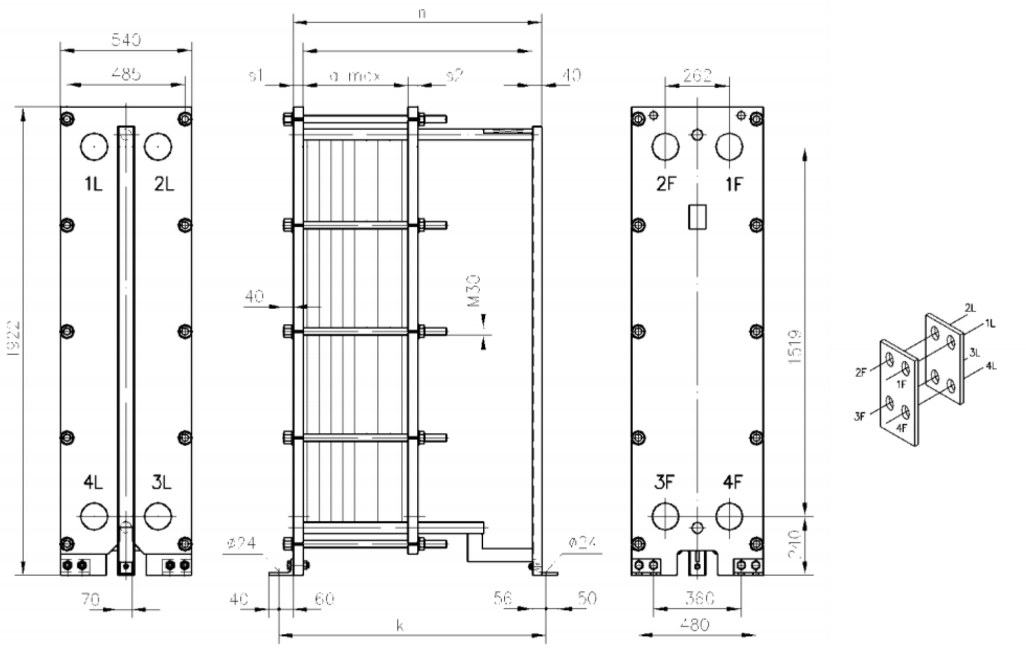
Page 4

Devis 2605068-129 rev. 0 Client: Enogia

Plan Dimensionnel Echangeur de chaleur

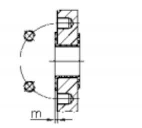
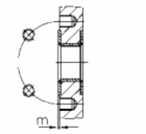
Client :	Enogia		
Devis :	**2605068-129**	**Elément n° : 10**	**Option n° : 0**
Référence client :	Evapo Géothermie		

Type: LWC100X CDL-10 Dimensions en mm 0100-108-Model.tif



n:	845 mm	s_1:	40,00 mm	a-max bâti :	404 mm	Poids:	873 kg
k:	921 mm	s_2:	40,00 mm	a-max:	287 mm	Poids en service:	912 kg
l:	765 mm	h:	1922 mm			long. max. de boulon	750 mm

Pos	DN	Type	Fluide	Circuit/Sens	m
1F	DN100	Insert caoutchouc EN1092-1-PN16	Eau	chaud - entrée	4 mm
2F	DN100	Insert métallique à gorge EN1092-1-	R1233zd	froid - sortie	0 mm
3F	DN100	Insert métallique à gorge EN1092-1-	R1233zd	froid - entrée	0 mm
4F	DN100	Insert caoutchouc EN1092-1-PN16	Eau	chaud - sortie	4 mm

			
Insert caoutchouc	Insert métallique à gorge		
EN1092-1-PN16	EN1092-1-PN16		
EPDM	AISI316Ti		
PN 16	PN 16		
1F;4F	2F;3F		

Sous réserve de modifications techniques. Pour les bâtis peints, épaisseur de couche de peinture selon DIN EN ISO 12944-5. Etat de surface des plaques fixes et mobiles selon DIN EN 10029.
Informations valables uniquement pour les échangeurs fabriqués par Kelvion PHE GmbH/Sarstedt.

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5 APPENDIX 2: VOLCANIC HEAT EXCHANGER DATASHEET

Plate Heat Exchanger

Technical specification

Customer : **ENOGIA**
Model : **MK15-BWFG**
Project: : **19POMPa102**
Item : **Evap. Reykjanes (cas design)** **Date** : **07/08/2019**

Fluid		**Water**	**R1233zd**
Mass flow rate	kg/s	7.000	2.819
Fluid vapourized	kg/s	0.000	2.819
Inlet temperature	°C	115.0	37.8
Dew point	°C		95.7
Outlet temperature (vapor/liquid)	°C	93.3	98.2
Operating pressure (In/Out)	bara		9.40/9.30
Pressure drop	kPa	3.69	10.5
Velocity connection (In/Out)	m/s	0.418/0.411	0.130/3.40
Heat Exchanged	kW	640.2	
Mean Temperature Difference	K	12.0	
Relative directions of fluids		Countercurrent	
Nozzle orientation		S1 -> S2	S4 <- S3
Connections S1, S2, S3, S4:		Flange EN1092-1 DN150 PN16, lining SMO	
Plate material / thickness		ALLOY 254 / 0.60 mm	
Sealing material		NBRP Clip-on	Welded
Ring Gasket			NBRP
Pressure vessel code		PED, Category 3	
Fluid danger group		No Danger	No Danger
Has risky vapour pressure		Yes	Yes
Design pressure	bar	15.0	15.0
Test pressure	bar	21.5	21.5
Design temperature	°C	120.0	100.0
Overall length x width x height	mm	1498 x 650 x 1486	
Flooded weight	kg	1540	
Packed weight	kg	1380	
Type of package		SKID BASE LYING	
length x width x height	mm	2080 x 800 x 1770	

The performance of the equipment is conditioned by the process media and process parameters being consistent with the provided customer data.

Fluid Composition

Hot side		**Cold side**	
Water		**R1233zd**	
Liquid Cooling		Vapourizing	
Water	**= 7.000 kg/s**	**R1233zd**	**= 2.819 kg/s**
inlet v/l	0.000/7.000	inlet v/l	0.000/2.819
outlet v/l	0.000/7.000	outlet v/l	2.819/0.000

Physical Properties

	Hot side		**Cold side**	
(inlet/outlet)	**Liquid**	**Vapour**	**Liquid**	**Vapour**
Dens	947.9/963.3		1231/1066	70.59/46.92
Sp.heat	4.234/4.199		1.257/1.370	0.8610/1.047
Visc	0.244/0.303		0.397/0.210	0.0115/0.0137
Th.Cond	0.687/0.678		0.0717/0.0580	0.0115/0.0166
Bub. p.				/95.7
Dew point				/95.7
Mol.W.				130.50/130.50
Cr.pr.				35.71/35.71
Cr.Temp.				165.6/165.6
Lat.heat				184.6/146.6

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Plate Heat Exchanger

Technical specification

Customer	**: ENOGIA**			
Model	**: MK15-BWFG**			
Project:	**: 19POMPa102**			
Item	**: Evap. Grasteinn**		**Date**	**: 07/08/2019**

Fluid		**Water**	**R1233zd**
Mass flow rate	kg/s	7.000	2.511
Fluid vapourized	kg/s	0.000	2.511
Inlet temperature	°C	110.0	29.8
Dew point	°C		92.0
Outlet temperature (vapor/liquid)	°C	90.0	94.5
Operating pressure (In/Out)	bara		8.66/8.56
Pressure drop	kPa	3.70	9.72
Velocity connection (In/Out)	m/s	0.416/0.410	0.114/3.29
Heat Exchanged	kW	589.2	
Mean Temperature Difference	K	12.2	
Relative directions of fluids		Countercurrent	
Nozzle orientation		S1 -> S2	S4 <- S3
Connections S1, S2, S3, S4:		Flange EN1092-1 DN150 PN16, lining SMO	
Plate material / thickness		ALLOY 254 / 0.60 mm	
Sealing material		NBRP Clip-on	Welded
Ring Gasket			NBRP
Pressure vessel code		PED, Category 3	
Fluid danger group		No Danger	No Danger
Has risky vapour pressure		Yes	Yes
Design pressure	bar	15.0	15.0
Test pressure	bar	21.5	21.5
Design temperature	°C	120.0	100.0
Overall length x width x height	mm	1498 x 650 x 1486	
Flooded weight	kg	1540	
Packed weight	kg	1380	
Type of package		SKID BASE LYING	
length x width x height	mm	2080 x 800 x 1770	

The performance of the equipment is conditioned by the process media and process parameters being consistent with the provided customer data.

Fluid Composition

Hot side		Cold side	
Water		**R1233zd**	
Liquid Cooling		Vapourizing	
Water	**= 7.000 kg/s**	**R1233zd**	**= 2.511 kg/s**
inlet v/l	0.000/7.000	inlet v/l	0.000/2.511
outlet v/l	0.000/7.000	outlet v/l	2.511/0.000

Physical Properties

	Hot side		**Cold side**	
(inlet/outlet)	**Liquid**	**Vapour**	**Liquid**	**Vapour**
Dens	951.7/965.4		1251/1077	66.26/43.14
Sp.heat	4.224/4.195		1.248/1.361	0.8428/1.030
Visc	0.255/0.314		0.440/0.217	0.0112/0.0136
Th.Cond	0.685/0.676		0.0738/0.0588	0.0109/0.0163
Bub. p.				/92.0
Dew point				/92.0
Mol.W.				130.50/130.50
Cr.pr.				35.71/35.71
Cr.Temp.				165.6/165.6
Lat.heat				189.1/149.3

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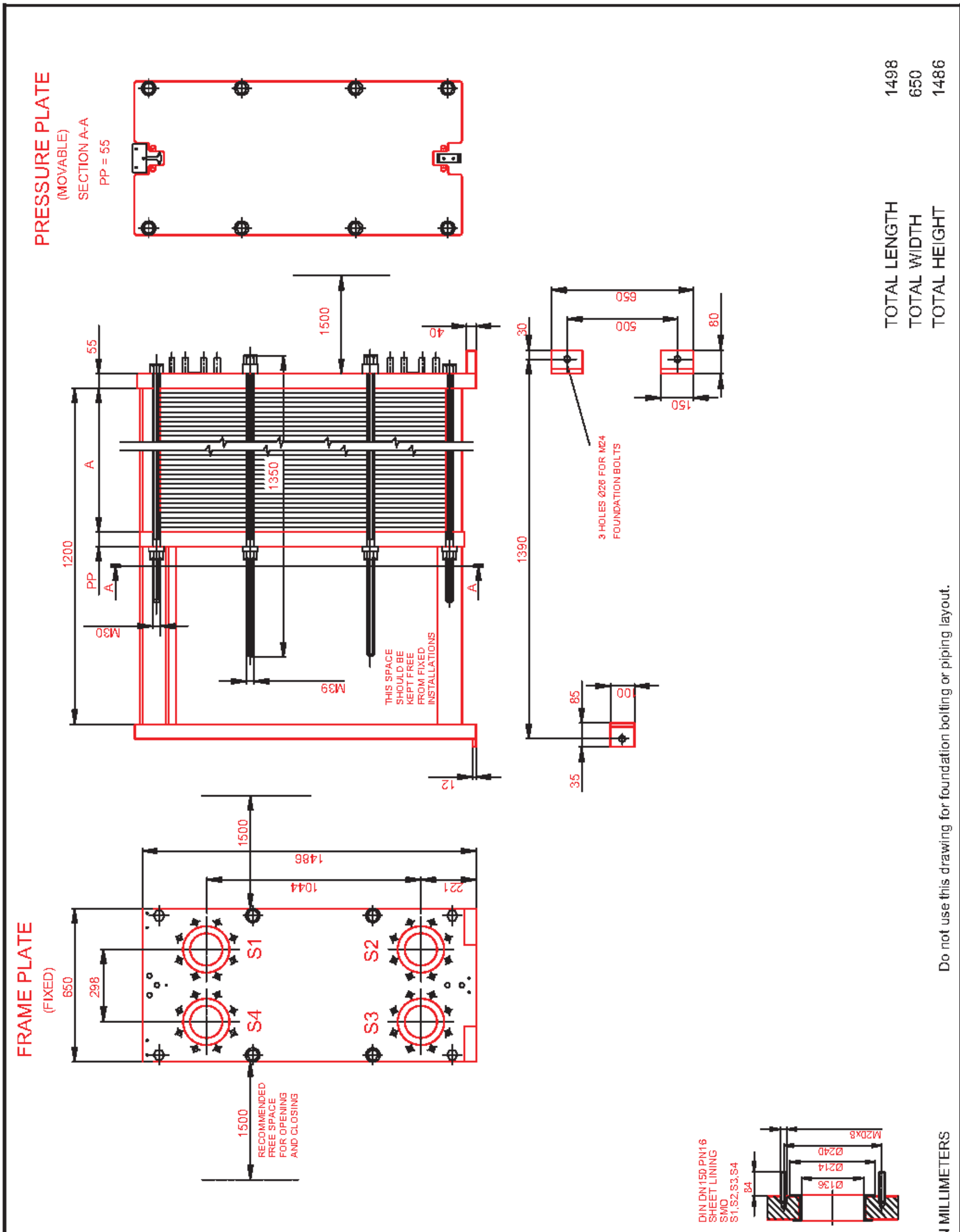

TOTAL LENGTH	1498	
TOTAL WIDTH	650	
TOTAL HEIGHT	1486	

Do not use this drawing for foundation bolting or piping layout.

ALL DIMENSIONS IN MILLIMETERS

SIDE	MEDIA	F.D.G.	INLET	TEMP.	OUTLET	TEMP.	FLOW RATE	PRESSURE DROP
1	Water	2	S1	115.0 °C	S2	93.3 °C	7.000 kg/s	3.695 kPa
2	R1233zd	2	S3	37.8 °C	S4	95.2 °C	2.819 kg/s	10.46 kPa

REMARKS:	SIDE 1	SIDE 2		
TEST PRESSURE	21,5 bar	21,5 bar	GASKET	NBRP Clip-on
DESIGN PRESSURE	15 bar	15 bar	PLATE MATERIAL	ALLOY 254
MAX TEMPERATURE	120 °C	100 °C	PLATE THICKNESS	0.60 mm
MIN TEMPERATURE	0 °C	0 °C		
WEIGHT WITH WATER	1537 kg		HEAT LOAD	640 kW

SUPPLIER	REF.	ITEM NO. Evap. Reykjanes (cas	PLATE HEAT EXCHANGER design)	ALFA LAVAL
AGENT / REF.			MK15-BWFG	
CUSTOMER NAME / REF. NO.				enogia
SIGN.	RISK CATEGORY 3		PED CE	DATE 2019-08-07 / REV NO. 0

6 APPENDIX 3: GRANITIC HEAT EXCHANGER DATASHEET

Plate Heat Exchanger

Technical specification

Customer : **ENOGIA**
Model : **MK15-BWFG**
Project: : **19POMPa102**
Item : **Evap. Vranska (cas design)** **Date** : **07/08/2019**

Fluid		**Water**	**R1233zd**
Mass flow rate	kg/s	20.00	2.391
Fluid vapourized	kg/s	0.000	2.391
Inlet temperature	°C	120.0	29.8
Dew point	°C		111.8
Outlet temperature (vapor/liquid)	°C	113.0	114.5
Operating pressure (In/Out)	bara		13.1/13.1
Pressure drop	kPa	15.0	7.02
Velocity connection (In/Out)	m/s	1.20/1.19	0.108/2.02
Heat Exchanged	kW	593.1	
Mean Temperature Difference	K	10.3	
Relative directions of fluids		Countercurrent	
Nozzle orientation		S1 -> S2	S4 <- S3
Connections S1, S2, S3, S4:		Flange EN1092-1 DN150 PN16, lining SMO	
Plate material / thickness		ALLOY 254 / 0.60 mm	
Sealing material		NBRP Clip-on	Welded
Ring Gasket			NBRP
Pressure vessel code		PED, Category 3	
Fluid danger group		No Danger	No Danger
Has risky vapour pressure		Yes	Yes
Design pressure	bar	15.0	15.0
Test pressure	bar	21.5	21.5
Design temperature	°C	130.0	120.0
Overall length x width x height	mm	1798 x 650 x 1486	
Flooded weight	kg	1800	
Packed weight	kg	1560	
Type of package		SKID BASE LYING	
length x width x height	mm	2080 x 800 x 2070	

The performance of the equipment is conditioned by the process media and process parameters being consistent with the provided customer data.

Fluid Composition

Hot side		**Cold side**	
Water		**R1233zd**	
Liquid Cooling		Vapourizing	
Water	**= 20.00 kg/s**	**R1233zd**	**= 2.391 kg/s**
inlet v/l	0.000/20.00	inlet v/l	0.000/2.391
outlet v/l	0.000/20.00	outlet v/l	2.391/0.000

Physical Properties

	Hot side		**Cold side**	
(inlet/outlet)	**Liquid**	**Vapour**	**Liquid**	**Vapour**
Dens	944.0/949.4		1251/1016	106.4/66.97
Sp.heat	4.244/4.230		1.248/1.413	0.8428/1.137
Visc	0.233/0.248		0.440/0.183	0.0112/0.0144
Th.Cond	0.688/0.686		0.0738/0.0550	0.0109/0.0181
Bub. p.				/111.8
Dew point				/111.8
Mol.W.				130.50/130.50
Cr.pr.				35.71/35.71
Cr.Temp.				165.6/165.6
Lat.heat				189.1/134.7

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Plate Heat Exchanger

ALFA LAVAL

Technical specification

Customer	**: ENOGIA**			
Model	**: MK15-BWFG**			
Project:	**: 19POMPa102**			
Item	**: Evap. Soultz**		**Date**	**: 07/08/2019**

Fluid		**Water**	**R1233zd**
Mass flow rate	kg/s	30.00	2.071
Fluid vapourized	kg/s	0.000	2.071
Inlet temperature	°C	70.0	29.8
Dew point	°C		59.4
Outlet temperature (vapor/liquid)	°C	66.5	61.7
Operating pressure (In/Out)	bara		3.84/3.76
Pressure drop	kPa	33.1	8.18
Velocity connection (In/Out)	m/s	1.74/1.73	0.0937/6.11
Heat Exchanged	kW	438.6	
Mean Temperature Difference	K	9.0	
Relative directions of fluids		Countercurrent	
Nozzle orientation		S1 -> S2	S4 <- S3
Connections S1, S2, S3, S4:		Flange EN1092-1 DN150 PN16, lining SMO	
Plate material / thickness		ALLOY 254 / 0.60 mm	
Sealing material		NBRP Clip-on	Welded
Ring Gasket			NBRP
Pressure vessel code		PED, Category 3	
Fluid danger group		No Danger	No Danger
Has risky vapour pressure		Yes	Yes
Design pressure	bar	15.0	15.0
Test pressure	bar	21.5	21.5
Design temperature	°C	130.0	120.0
Overall length x width x height	mm	1798 x 650 x 1486	
Flooded weight	kg	1800	
Packed weight	kg	1560	
Type of package		SKID BASE LYING	
length x width x height	mm	2080 x 800 x 2070	

The performance of the equipment is conditioned by the process media and process parameters being consistent with the provided customer data.

Fluid Composition

Hot side		**Cold side**	
Water		**R1233zd**	
Liquid Cooling		Vapourizing	
Water	**= 30.00 kg/s**	**R1233zd**	**= 2.071 kg/s**
inlet v/l	0.000/30.00	inlet v/l	0.000/2.071
outlet v/l	0.000/30.00	outlet v/l	2.071/0.000

Physical Properties

	Hot side		**Cold side**	
(inlet/outlet)	**Liquid**	**Vapour**	**Liquid**	**Vapour**
Dens	977.1/978.9		1251/1169	22.45/19.19
Sp.heat	4.178/4.176		1.248/1.293	0.8428/0.9159
Visc	0.403/0.423		0.440/0.301	0.0112/0.0124
Th.Cond	0.662/0.659		0.0738/0.0658	0.0109/0.0134
Bub. p.				/59.4
Dew point				/59.4
Mol.W.				130.50/130.50
Cr.pr.				35.71/35.71
Cr.Temp.				165.6/165.6
Lat.heat				189.1/170.6

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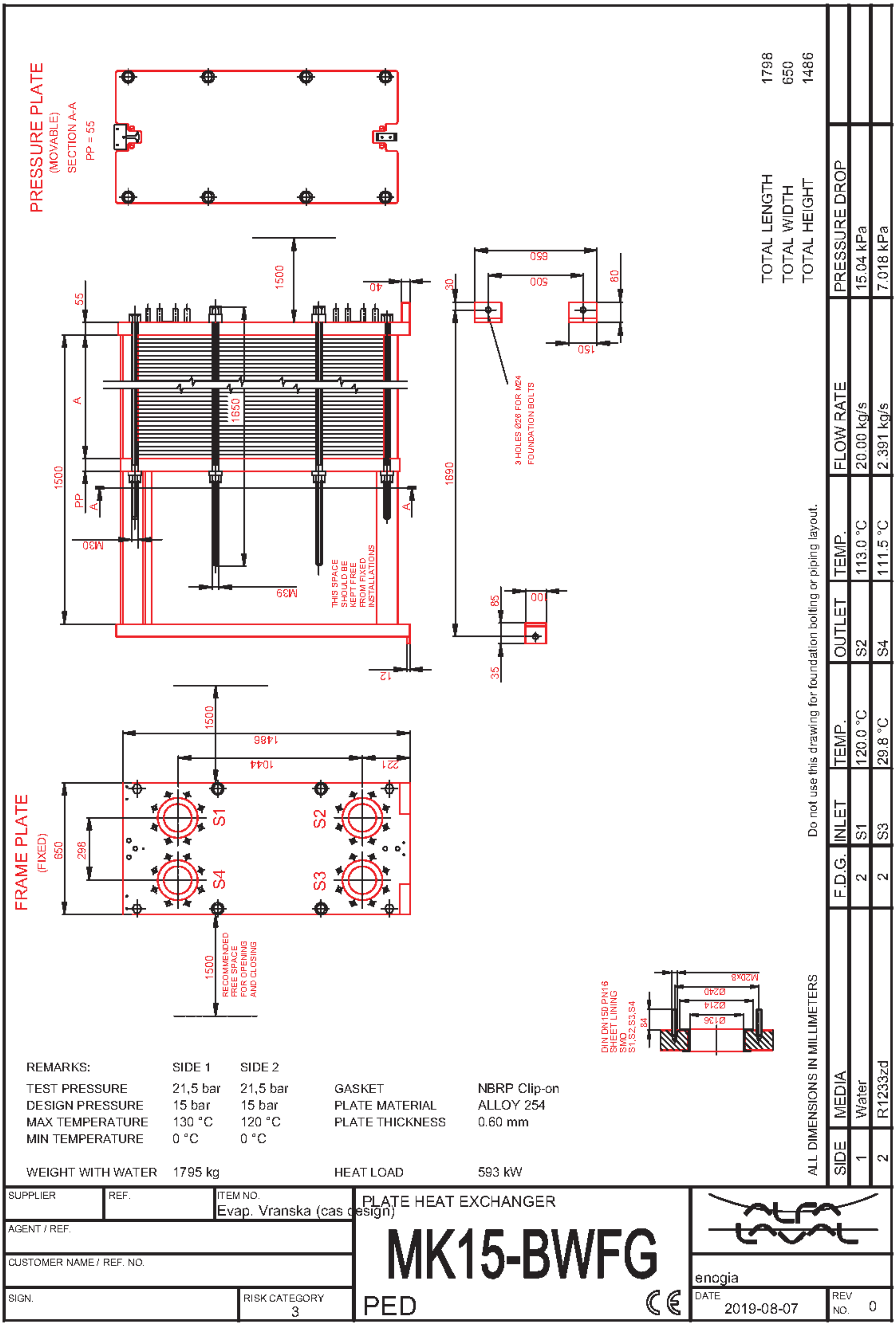
PRESSURE PLATE
(MOVABLE)
SECTION A-A
PP = 55
FRAME PLATE
(FIXED)
S1
S2
S3
S4
THIS SPACE SHOULD BE KEPT FREE FROM FIXED INSTALLATIONS
RECOMMENDED FREE SPACE FOR OPENING AND CLOSING
3 HOLES Ø26 FOR M24 FOUNDATION BOLTS
DIN DN150 PN16 SHEET LINING SMO S1,S2,S3,S4
TOTAL LENGTH 1798
TOTAL WIDTH 650
TOTAL HEIGHT 1486
Do not use this drawing for foundation bolting or piping layout.
ALL DIMENSIONS IN MILLIMETERS
SIDE | MEDIA | F.D.G. | INLET | TEMP. | OUTLET | TEMP. | FLOW RATE | PRESSURE DROP
1 | Water | 2 | S1 | 120.0 °C | S2 | 113.0 °C | 20.00 kg/s | 15.04 kPa
2 | R1233zd | 2 | S3 | 29.8 °C | S4 | 111.5 °C | 2.391 kg/s | 7.018 kPa
REMARKS: SIDE 1 SIDE 2
TEST PRESSURE 21,5 bar 21,5 bar
DESIGN PRESSURE 15 bar 15 bar
MAX TEMPERATURE 130 °C 120 °C
MIN TEMPERATURE 0 °C 0 °C
GASKET NBRP Clip-on
PLATE MATERIAL ALLOY 254
PLATE THICKNESS 0.60 mm
WEIGHT WITH WATER 1795 kg
HEAT LOAD 593 kW
SUPPLIER
REF.
ITEM NO.
Evap. Vranska (cas design)
AGENT / REF.
CUSTOMER NAME / REF. NO.
SIGN.
RISK CATEGORY 3
PLATE HEAT EXCHANGER
MK15-BWFG
PED
enogia
DATE 2019-08-07
REV NO. 0

Imprint

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LinkedIn page	https://www.linkedin.com/in/meet-eu-project/
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