Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Hybrid Cooling Tower Retrofit in a Geothermal Power Plant: Outcomes from H2020 MATChING Project

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Keywords: hybrid cooling tower, wet cooling tower, dry cooling tower, geothermal power plant.

ABSTRACT

A cooling tower in a direct steam geothermal power unit behaves like a direct-contact heat exchanger, where geothermal condensed steam exchanges heat into the air. Heat is transferred by radiation from the surface of the droplets, by conduction and convection between water and air, by evaporation of part of water. The later represents the main part of heat transferred and this is the reason why the whole process is called an “evaporative cooling tower.” In the geothermal sector, the most diffused evaporative cooling towers belong to induced draught technology where a fan moves the air counter-currently with respect to the water. The water is distributed at the upper side of cooling tower, slides down the packing and is collected in the basin at the bottom. The amount of heat exchanged depends by various factors including the contact surface area, thus the filling media design plays a key role in increasing the cooling capability or in reducing the filling height with a fixed thermal load. The effective shape of the filling media affects the fouling behavior as well. In the geothermal evaporative cooling tower, most of the steam condensate that takes part in the cooling process escapes as water vapor from the fan stack, and only a small amount (blow down) is re-injected into the geothermal reservoir. Recently the use of a wet-dry hybrid cooling tower has been considered as an alternative to evaporative cooling towers in order to raise the amount of re-injected water and to avoid the typical visible plume. The increased water recovery is paid with a larger fan consumption but generally, the higher re-injection into the reservoir results in a higher steam flow rate available at production wells thus leading to a net power gain. In a MATChING EU H2020 funded project, one of the main goals was to assess the use of advanced/innovative material solutions to increase the robustness of hybrid cooling towers in high temperature geothermal power plants in order to make them a competitive alternative to currently wet cooling towers. After a pilot validation phase, one of six cells of the cooling tower of “Nuova San Martino” geothermal power plant (Monterotondo Marittimo, Italy) owned by Enel Green Power, was retrofitted with 4 heat exchangers designed and engineered by SPIG and operated in hybrid configuration. From experimental tests lasting 6 months, hybrid operation showed a water recovery up to 15% with respect to the wet operation. Moreover, the typical plume at the fan stack was avoided, improving the visual impact and the environmental sustainability of the plant. An economic evaluation considering a typical geothermal process equipped with a hybrid cooling tower was addressed and the profitability of this technology was assessed.

1. INTRODUCTION

In high temperature (HT) geothermal power plants no fresh water is used as cooling media, but the geothermal fluid itself is exploited in the cooling towers (CTs) once it has been condensed. CTs are among the most important components of geothermal power plants because their function is to keep as low as possible the condenser pressure downstream expansion thus increasing the generating power. In a CT, the hot fluid (water) is cooled down by another fluid (the air) through the exchange of latent or convective heat.
This different heat transfer approach discriminates CT into three different types: wet, dry, and hybrid (wet-dry).
Wet CTs operate upon latent heat transfer by means of evaporation promoted by direct contact of water with the air stream. The latent heat transfer is associated to mass transfer of water into the unsaturated air stream in vapor phase due to differences in water vapor pressure.
Dry CTs operate upon convective heat transfer among water and air through an exchange surface between the two streams thus not using evaporation as a means for cooling.
Hybrid (wet-dry) CTs operate upon both approaches with a split of heat load between evaporative and surface exchange.
In the wet CT the amount of evaporation which takes place depends upon process boundary conditions and engineering & design parameters.
The boundary process conditions that are involved in the CT operation are:

- flow rate of the water to be cooled (or circulation rate);
- ambient air wet bulb temperature WBT (determined by dry bulb temperature DBT and relative humidity RH);
- outlet and inlet water temperatures;

The engineering and design features of a CT are determined by the following parameters:

- the performance coefficient of the fill used;
- the volume and surface/volume ratio of filling media;
- the type of water distribution system;
- inlet air flow rate;

Based on the above data the typical design parameters used are:

- approach (difference between outlet water temperature and WBT);
- cooling range (difference between inlet and outlet water temperatures);
- liquid/gas ratio (L/G);
- heat load;

From Merkel theory CT performances can be estimated on the basis of two basic data: “tower demand” and “tower characteristic curve”. Typically, the first one is calculated from approach, cooling range, WBT temperature and L/G ratio; it is determined only by process constraints and is independent by the tower design. The second one serves as a measure of the capability of the cooling tower to which it applies and has nothing to with the physical characteristics of the tower. It deals with design requirements such as the characteristics of filling media, including the total surface area between water and air.

The main drawback of wet CT is that part of water to be cooled is lost by evaporation; moreover, the air leaving the tower through the fan stack becomes supersaturated and leads to the typical visible plume.

In dry CT there is no contact among air and water and evaporation doesn’t occur. The total amount of hot water is cooled with higher fan consumption and large surface heat exchangers (HEXs).

The hybrid (wet-dry) CT differs from wet one because the heat load is partially removed by means of surface HEXs taking care of limited fan consumption and exchange surfaces.

So far, the standard cooling technology in HT geothermal power plants has been the wet CT because of low energy penalty and small footprint; furthermore hybrid cooling tower technology has not found application in HT geothermal plants due to corrosion and fouling phenomena at the exchanging surface that can have a high impact on cooling tower performance and operation issues.

One of the main challenges of H2020 EU funded MATChING project has been the effective application of hybrid CTs in HT geothermal plants in order to enhance the sustainability of the process due to the reduced loss of evaporation, increasing the re-injection stream.

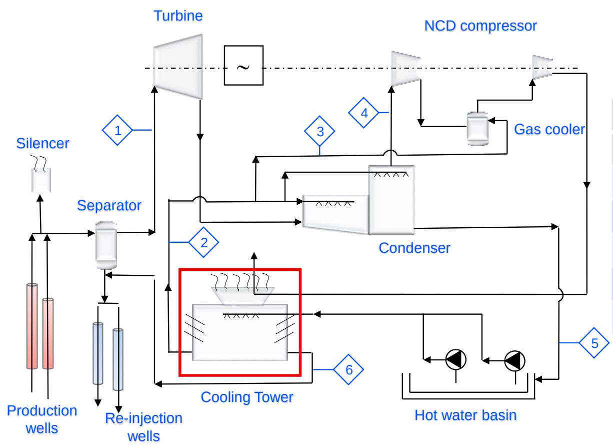
2. MATChING PROJECT

The focus of this project was the selection and demonstration of technological solutions to improve the performance of cooling systems for geothermal and fossil-fueled power plants through the use of advanced materials, with the final aim to reduce the overall amount of fresh water abstraction.

In the working package WP4 related to HT geothermal power production, one module of existing wet CT of N.va San Martino power plant (Monterotondo Marittimo, Italy) was converted in hybrid configuration in order to demonstrate an effective water saving during a significant operation period. In the retrofitting works advanced CT filling media was installed and validated with the aim to reduce the volume of packing while maintaining a high heat transfer efficiency. Furthermore, a dry section made by 4 HEXs was installed on the lateral sides of the tower to balance the evaporative heat exchange with the convective one. The design of the dry section was strengthened using new coating materials with anti-fouling and anti-corrosion properties in order to increase the robustness and reliability of this equipment exposed to geothermal fluid.

2.1 Demo Site

The geothermal power plant that had hosted the demonstration test of a hybrid module is Nuova San Martino in Monterotondo Marittimo (Grosseto, Italy) - one of 34 geothermal plants owned by Enel Green Power in Tuscany. The plant is fed by 265 tonnes/h of dry (superheated) steam at 8-9 bar coming from wells that belong to San Martino geothermal field.



Process flow data							
Stream		**1**	**2**	**3**	**4**	**5**	**6**
Flow rate	*[t/h]*	*265*	*12.500*	*60*	*8,75*	*12.756*	*60*
Temperature	*[°C]*	*175*	*25*	*25*	*26*	*35*	*25*
Pressure	*[kPa]*	*850*	*100*	*100*	*6*	*100*	*100*
Enthalpy	*[kJ/kg]*	*2697*	*105*	*105*	*383*	*146*	*105*

Figure 1: Process data of N.va S. Martino geothermal plant.

The feature of this field is a gas/steam ratio of about 2-3% by weight mainly composed by carbon dioxide (CO_2), hydrogen sulfide (H_2S), boric acid (H_3BO_3) and other minor Non-Condensable Gases (NCGs). The field is characterized by several re-injection wells that mitigate the typical pressure decline due to steam exploitation[1].

The plant is constituted by 2 generating units of 20 MWe each: the steam enthalpy drop across the turbines generates power and the outlet of saturated steam is condensed in a direct contact condenser by-means of subcooled water supplied by 2 cooling towers that cool down the condensed steam itself (see Figure 1). The turbine is directly coupled with a compressor that takes NCGs from condenser toward the AMIS[2] plant to remove H_2S and mercury (Hg). In Nuova San Martino there are 2 cooling towers (one made of structural wooden beams, one in concrete) composed of three induced-draft wet cells each, with a total cooling water flow rate of about 12.000 m^3/hr. Hot water coming from the condenser is cooled and returned to the condenser. In this stream a blowdown of about 60 tonnes/hr is taken out and sent to the re-injection wells so that most of inlet steam is lost by evaporation in the cooling towers and only 20% is returned to reservoir.

Hot water coming from the condenser is collected downward in the warm pool by gravity and 3 pumps send it toward the cooling towers. Each cooling tower has 3 cells with a separate basin at the bottom. The water collected in each basin is evacuated in a common floodway by means of a gateway (Figure 2).

Figure 2: Basin at the bottom of wooden cell with the gateway.

One module of wooden tower was chosen as a candidate for retrofitting and demonstration tests in the MATChING project (see Figure 3).

Figure 3: CT module retrofitted in MATChING project.

2.2 Existing CT Data

The cooling tower modules cool down water from 35°C to 25°C (design range of 10°C) with a design air WBT of 18,5°C. The performance curves at the design flow rate are reported in Figure 4.

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1 This geothermal field in Monterotondo Marittimo is characterized by low elapsing recharging time that is the time between re-injection point and reservoir recharge.

2 AMIS Abbattimento Mercurio Idrogeno Solforato. It is a plant patented by ENEL designed to remove H_2S and Hg from NCG

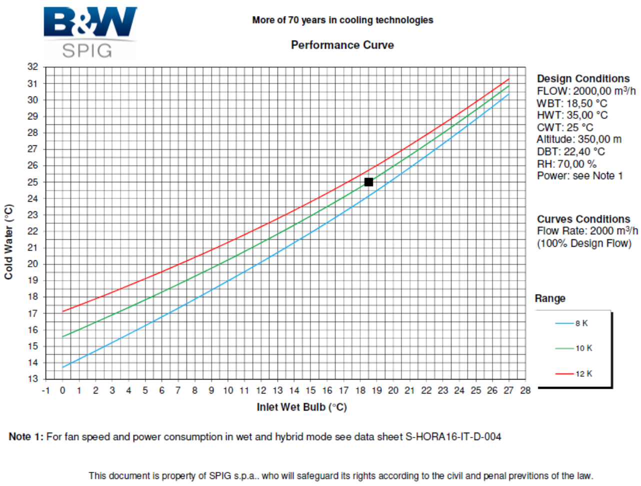
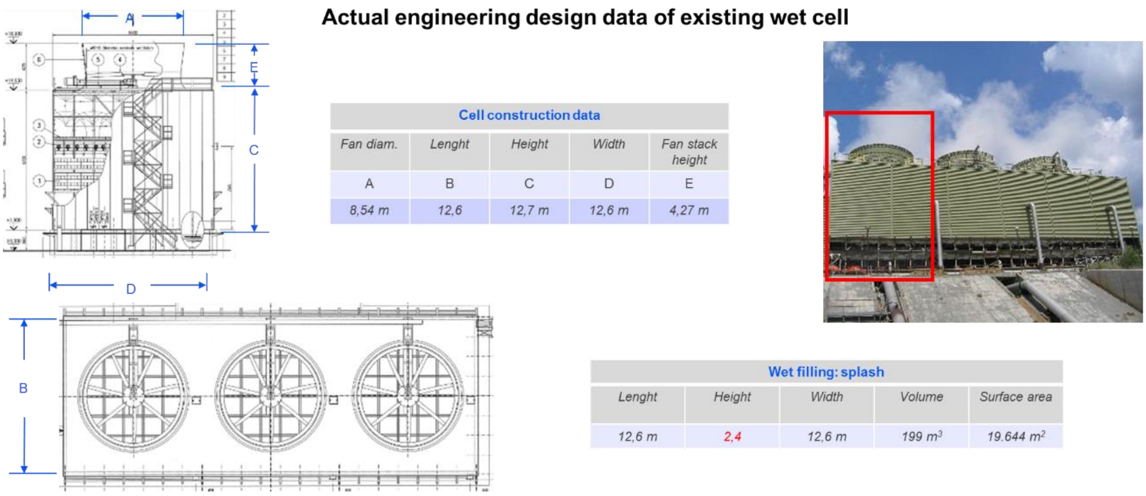


Figure 4: Performance curve of existing CT.

The fan data sheet of each 3 cells reports a volumetric air flow rate of 472 m^3/s with an absorbed power of 111 kWe (145 kWe nominal power). The size of the existing cell is reported in Figure 5 and does not change in hybrid configuration except for the height of filling pack.

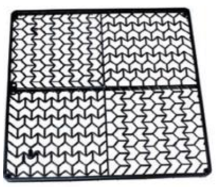


Cell construction data				
Fan diam.	Lenght	Height	Width	Fan stack height
A	B	C	D	E
8,54 m	12,6	12,7 m	12,6 m	4,27 m

Wet filling: splash				
Lenght	Height	Width	Volume	Surface area
12,6 m	2,4	12,6 m	199 m^3	19.644 m^2

Figure 5: Actual engineering design data of existing CT.

The existing filling pack is a traditional splash one with the following characteristics:



Specific water consumption[3]	~1.23 m^3 H_2O/hr/MWth.
Number of Transfer Units (NTU)	~ 0.268 @ L/G equal 1 and per each meter of filling.

Figure 6: Features of existing splash filling.

2.3 Retrofit of Existing Wet Module in Hybrid Configuration

The module was retrofitted with the replacement of existing filling pack with new innovative one (splash 3D) and with the installation of a dry section composed of 4 HEXs. With the installation of the dry section, the retrofitted module became "Hybrid" or "wet-dry" (see Figure 7).

[3] Evaporation loss evaluated in a typical geothermal installation at following design condition: WBT 18,5°C, RH 70%, Altitude 450 m

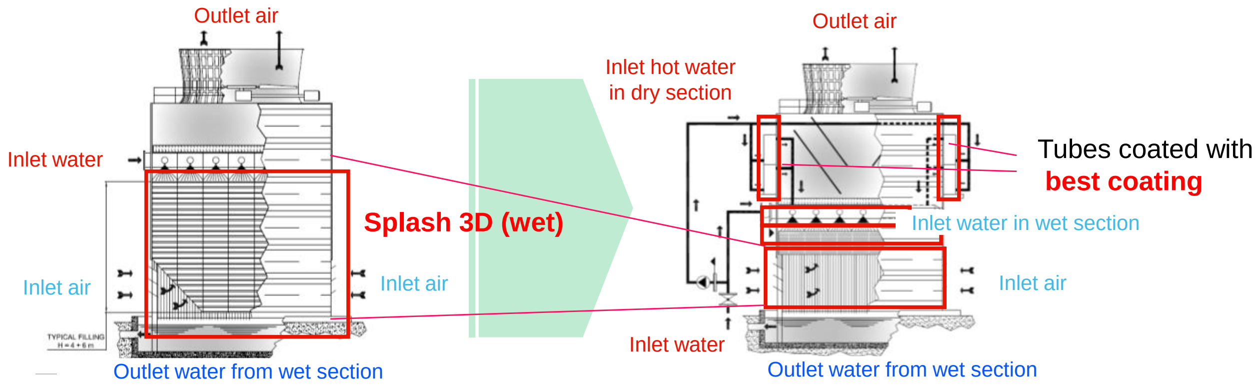


Figure 7: Retrofitting of the standard wet cooling tower.

Part of the hot water (about 60% of inlet flow rate) is cooled in series starting in the dry section (tube bundles) located outside of cooling tower casing just above the drift eliminators, then fed to the distribution system and discharged on the filling media (wet section) where it mixes with the rest of inlet hot water (see Figure 8, right side). Heat dissipation through dry section makes possible the reduction of evaporation process through wet section thus reducing water consumption. The air streams come across both systems (dry section and wet section) in parallel paths leaving them with different thermodynamic properties, then they mix themselves in the plenum just above the drift eliminators. The air stream from the dry section dries out the saturated stream coming from wet section preventing the condensation of humidity at the exit of fan stack thus avoiding the typical plume (see Figure 8, left side).

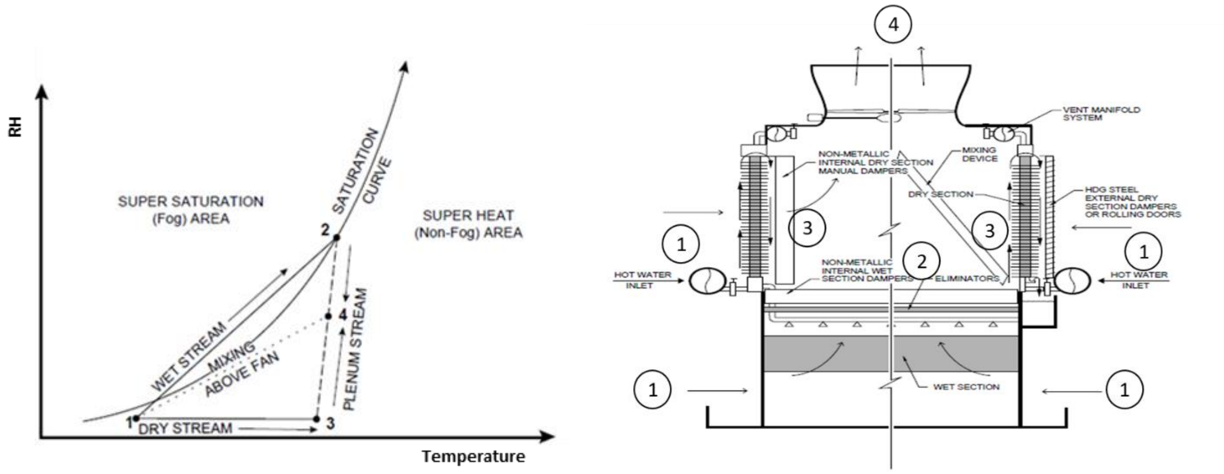


Figure 8: Thermodynamic state of the air leaving the CT with the plume abatement.

The design of new hybrid module was carried out following 2 main criteria: CT demand of a standard Enel Green Power geothermal plant (70 MW_{th} for a unit of 20 MW_e), no plume condition in the winter season (see Figure 9).

The first criterion takes into account the following design parameters:

- range temperature difference of 10°C;
- water flow rate of 2.000 tonne/hr (standard water flow rate for a CT module) ;
- inlet air WBT of 18,5°C;
- approach temperature of 6,5°C;

The second criterion was not a process constraint but aimed at avoiding the visibility of plume at the stack in the worst ambient conditions (winter season). This corresponds to air DBT of 5°C associated to RH of 90%. The design WBT and no plume condition arise from a statistical ambient data (see Figure 9).

PROCESS DATA - DESIGN CONDITION	
Cell Waterflow WF (m^3/h)	2000
Hot water temperature HWT (°C)	35.0 (wet mode)
Cold water temperature CWT (°C)	25.0 (wet mode)
Range HWT-CWT (°C)	10.0 (wet mode)
Entering Wet bulb temperature WBT (°C)	18.5
Approach (°C)	6.5
No plume condition	5°C / 90%
Drift loss (%)	≤ 0.0005
Evaporation loss (%)	1.40% wet mode / 1.25% hybrid mode
Water specific load ($m^3/h*m^2$)	11.02

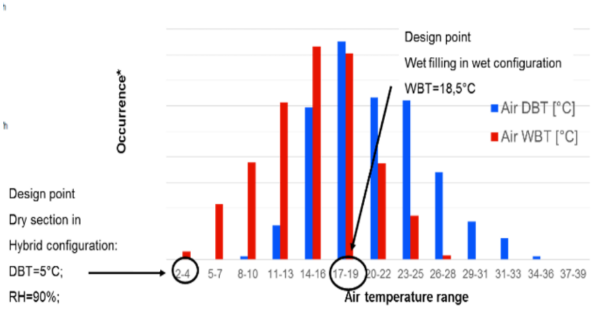


Figure 9: Process Data – design condition of hybrid module.

The innovative filling media STAR X20 3D grid type installed in demo module (see Figure 10) was tested in the SPIG R&D facility during preliminary assessment and then was selected for the demonstration tests. It features special geometries to maximize the thermal efficiency, reduce the packing volume, and improve clogging resistance. Part of the water to be cooled goes down as droplets and the other forms a film around the elements of each module. The heat exchange packs are made of modular multi-layer non-deformable elements with grid structures, which resists the working temperature, remaining unchanged, without clogging.

Material	Polypropilene
Standard size [mm]	905x604x450
Manufacturing procedure	Injection Moluling

Figure 10: Feature of typical SPLASH filling media.

The dry section is constituted by 4 finned tube HEXs positioned instead of enclosure panels of the opposite lateral sides of module (2 at north and 2 at south sides) in the upper part of module at the level of plenum just below the fan (see Figure 11). HEXs are equipped with 140 finned tubes each with different combinations of base material (metallic) and coating material. Based on Key Performance Indicators (KPI) at lab scale, the selected base materials were aluminium alloy and carbon steel A179 whereas the best inner protective layer resulted an epoxy resin based coating that was selected for the aluminium and carbon steel tubes. The others HEXs are equipped with uncoated tubes in Aluminium alloy and stainless steel AISI316L that represent the state of the art (SOA) used in a Enel Green Power, power plant.

HEX-1	HEX-2	HEX-3	HEX-4
Carbon Steel A179 + Coating layer	Aluminium alloy + Coating Layer	AISI 316 (not coated) (SOA)	Aluminium alloy (not coated)

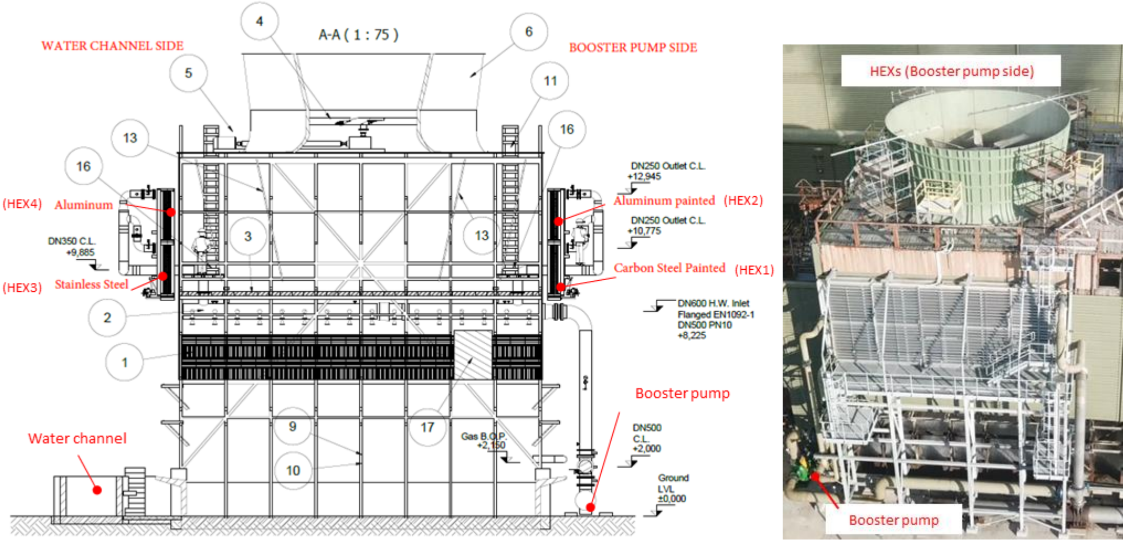


Figure 11: Lay out of HEXs of dry section.

Each HEX is equipped with motorized louvers able to allow or avoid air to exchange heat with water. The opening louvers are remotely controlled in order to easly switch from wet to hybrid operation (see Figure 12).

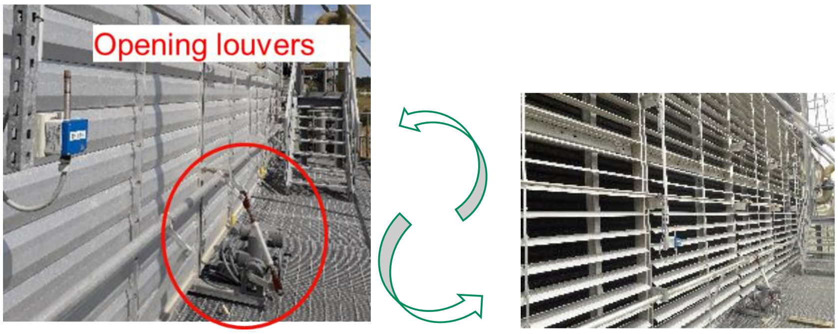


Figure 12: Remotely controlled motor driven louvers.

The whole demo hybrid CT module is equipped with a redundant instrumentation in order to monitor and process ambient variables necessary for KPIs evaluation.

2.4 Performance and Material Assessment

The retrofitting works were completed at the beginning of March 2018 and wet operation had last up to October 2018. November 2018 marked the beginning of the combined operation in hybrid/wet configurations with a switch every 3 days by opening louvers in front of HEXs and by regulating the fan speed by means of variable frequency drive (VFD). The assessment of performances and the reliability of the new equipment had been carried out by means of KPIs defined at the beginning of the project (see Figure 13). Dedicated instrumentation had measured input data that had been continuously and simultaneously recorded by "UNICO" system (provided by SPIG).

Before the execution of the tests, the pitch angle of fan blades was set in the hybrid configuration in order to have the design fan power consumption; moreover it was necessary to set up the instrumentation to measure the air flow in wet and hybrid mode (only at the beginning, keeping this values constant throughout the testing). A specific set up of the inlet valves of HEX carried out to assure the same water flow through each of the four HEXs.

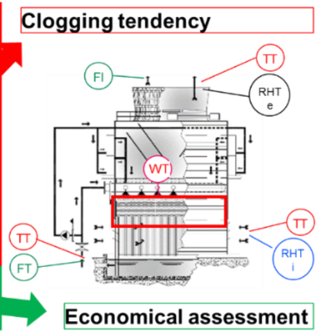
Data had collected each minute and had been analyzed through SPIG in-house thermal software. The post processing elaboration consisted of a validation process that excluded data recorded in non stable conditions (as depicted by CTI guidelines). The adopted criterion to select acceptable measurements were the threshold of 3% in the difference between mean values every 5 minutes (cooling range, water flow, etc). Additional boundary conditions were wind speed equal or lower than 3 m/s, and inlet relative humidity equal to or lower than 95%.

Before using data in the KPIs evaluation, the final criterion of thermal balances consistency was verified. In this procedure, heat balances calculated in the air and water streams had to be within a tolerance of ± 4 %.

The main KPI 4.2.6 had been calculated continuously by means of parametric functions correlating the ambient conditions (WBT and RH) and the evaporation rate. The parametric functions were used to compute the reduction of evaporation rate on the basis of monthly historical ambient data (RH and WBT).

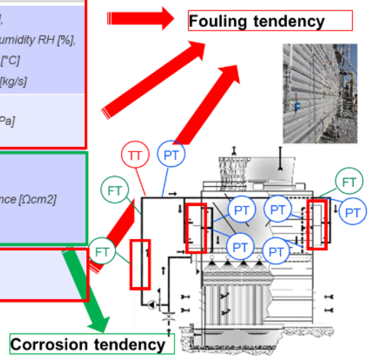
<u>KPIs at DEMO level related to WET operation</u>

Wet section KPIs	UoM	Description	Variable measured
4.1.1 Reduction of filling cooling capability over the time	[month^{-1}]	*The KPI measures the reduction of the filling cooling capability over the time, which is due to clogging.*	• *Inlet/out air DBT [°C],* • *Ilet relative humidity RH [%],* • *inlet/outlet water T [°C]* • *water Flow rate W [kg/s]*
4.1.2 Increase of pack weight due to clogging	[kg/month]	*The KPI measures the increase of the weight of the filling pack over the time*	• *weight [kg]*
4.1.3 Increase of air pressure drop through filling due to clogging	[Pa/month]	*The KPI measures the air pressure drop across filling pack over the time*	• *Air pressure [Pa]*
4.1.4 Filling cooling capability per fan power consumption at DEMO Module	[kW^{-1}]	*The KPI measures the air pressure drop across filling pack over the time*	• *Air pressure [Pa]*



<u>KPIs at DEMO level related to DRY SECTION during HYBRID OPERATION</u>

Dry section KPIs	UoM	Description	Variable measured
4.2.1 Reduction of dry module heat transfer coefficient due to fouling	[W/(m²*K*month)]]	The KPI measures the variation of the heat transfer coefficient of the dry module over the time due to increasing fouling	• Inlet/out air DBT [°C], • Inlet/outlet relative humidity RH [%], • inlet/outlet water Tw [°C] • water Flow rate Ww [kg/s]
4.2.2 Increase of dry module water pressure drop due to fouling	[Pa/month]	The KPI measures the in/out water delta pressure of the dry section	• Water pressure pw [Pa]
4.2.3 Coating corrosion resistance	[Ωcm2]	The KPI evaluates the corrosion protection of the different coatings applied on steel materials exposed to the real geothermal fluid conditions at San Martino facility	• Polarization Resistance [Ωcm2]
4.2.5 Fouling thickness growth	[mm/month]	The KPI evaluate the growth of the fouling over the time	• Thikness [mm]



KPIs at DEMO level related to performance of HYBRID operation

Dry section KPIs	UoM	Description	Variable measured
4.2.6 Evaporation reduction compared with traditional Wet Cooling Towers	[%]	***The KPI measures the evaporation during the operation of the cooling tower***	• Inlet/out air DBT [°C], • Inlet/outlet relative humidity RH [%], • inlet/outlet water T [°C] • Water flow rate Ww [kg/s] • **Air flow rate Wa [kg/s]** • Relative humidity RH [%], • inlet/outlet water Tw [°C] • **Fan, b. pump power P [kW]**
4.2.7 Water consumption related to Thermal Heat Duty	[m³/h/MW]	The KPI relates the volume of evaporated water to the thermal heat duty imposed on the cooling tower	
4.2.8 Water consumption related to Electrical Fan power absorbed	[m³/h/MW]	The KPI relates the evaporation rate and fan electric power consumption both in Hybrid and Wet mode.	

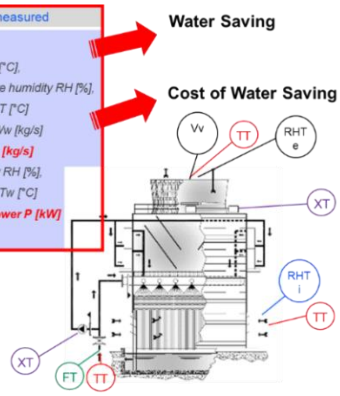


Figure 13: Sets of KPIs defined in the WP4 of MATChING project.

The assessment of filling media viability through the evaluation of KPIs related to wet operation, pointed out that the innovative STAR X20 works properly and is not affected by clogging issue (see Figure 14). Since the STAR X20 reduced the height of the filling pack, the retrofitting of existing wet CT allowed the installation of the dry section without changing the overall sizes.

Figure 14: Inspection of STAR X20 3D filling media after about 1 year of operation.

The assessment of HEXs material through the evaluation of KPIs related to dry operation was carried out by microscope observation (SEM EDS) of pipe sections after several months of operation (see Figure 15). Furthermore, an investigation of material samples had been carried out by means of a dedicated monitoring system based on Electrochemical Impedance Spectroscopy (EIS) measurements in order to follow onsite corrosion rates and the fouling tendency of the selected materials under real operational conditions. Impedance was measured in the frequency range between 100 kHz and 0.1 Hz (5 points per decade) with an AC potential perturbation of 200 mV (rms) amplitude each 8 hours during 6 months. The performance of the coatings was evaluated from the magnitude of the impedance modulus |Z| at low frequency as a Polarization Resistance (Rp) to compare its protective properties.

The following criterion was applied: coatings with Rp >108 Ωcm2 provide excellent protection without noticeable penetration of electrolyte. Coatings with Rp between 107Ωcm2 and 108 Ωcm2 provide good protection with minimal electrolyte absorption into the coating. Rp >106-107 Ωcm2, the electrolyte penetrates the coating and creates a path to the surface of the metal substrate, there is not active corrosion yet and the degree of protection is ranked as doubtful. Rp <106 Ωcm2, the coating is deemed as non-protective, the electrolyte penetrates the coating and there is active corrosion process underneath. Figure 15, presents the Rp values for the tested materials combinations.

The section of not coated aluminium pipe shows a layer of passivating oxide with the presence of deposits of sulphur compounds. Local pitting evidences were found on the inner surface, confirmed by EIS analysis and obtaining low Rp values indicating poor corrosion resistance properties of the material (see Figure 16). The section of coated carbon steel pipe shows a diffused detachment of coating layer and a slight decrease of resistance was detected at the end of the experiment (Jan-Feb) due to a loss of adherence in the ring edges. However, a generalized corrosion process underneath was not found by EIS analysis. The section of coated aluminium pipe shows, locally, a limited detachment of coating layer, however, no corrosion process occurred on the materials monitored by EIS. Finally, the section of stainless steel 316L shows extensive superficial corrosion evidences confirmed by EIS analysis.

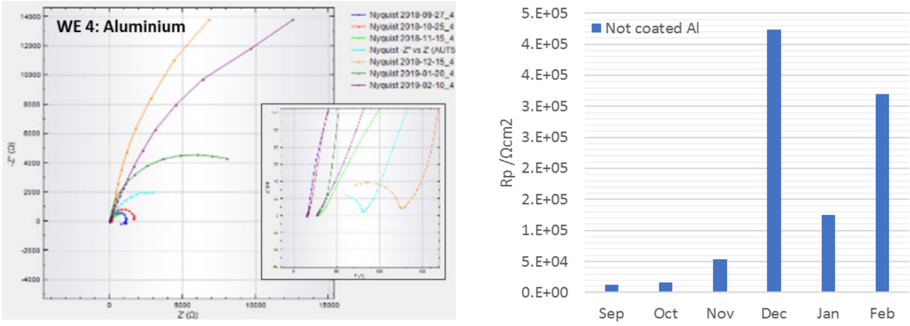


Figure 15: Impedance spectra (Nyquist diagrams) and Rp values obtained for not coated Al section monitored in the plant.

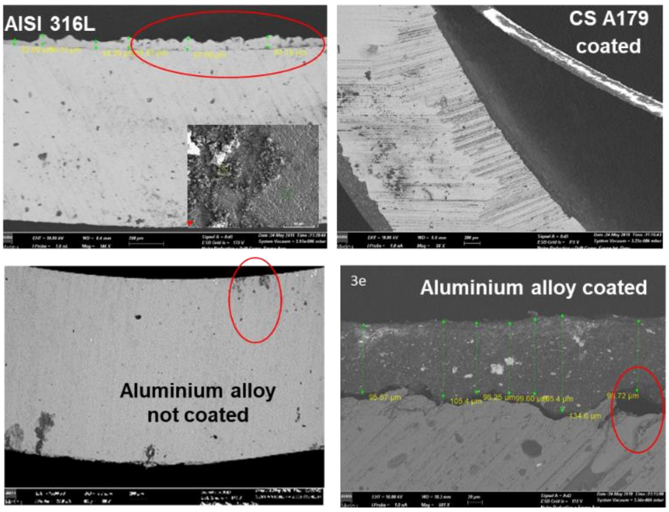
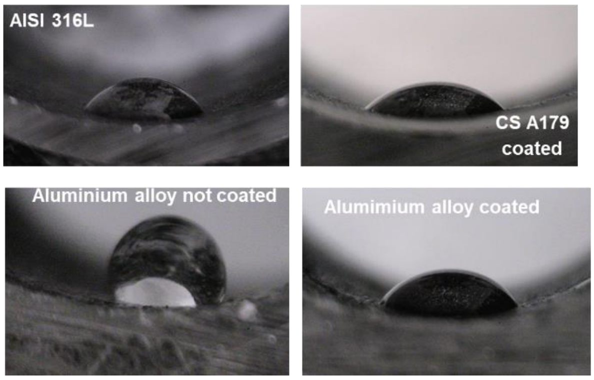


Figure 16: SEM EDS analysis of tubes of each HEX.

In order to assess the fouling tendency of the inner surface, a water contact angle (WCA) analysis was carried out comparing the morphology of droplets after and before exposure.

The WCA analysis revealed that the best behavior (highest final angles and little changes from the beginning of operation) comes up from not coated aluminium pipe. Although results from WCA analysis suggest aluminum as the best material, limited fouling behavior occurred in all of the other pipes.



	AISI316L	CS A179 coated	Aluminium alloy (not coated)	Aluminium alloy (coated)
Before exposure	75°	97°	89°	96°
After DEMO tests	**40°**	**35°**	**65°**	**43°**
Δ before-after	**35°**	**62°**	**24°**	**53°**

Figure 17: WCA analysis of pipe sections.

Based on these observations, none of the new candidate materials (carbon steel and aluminium) seems to be suitable for this kind of application even though further investigations on deposition procedure should be done in the near future. Stainless steel (SOA) shows the best corrosion resistance although a superficial (intergranular corrosion) occurred. This consideration is confirmed by heat transfer coefficient behaviors reported in Figure 18.

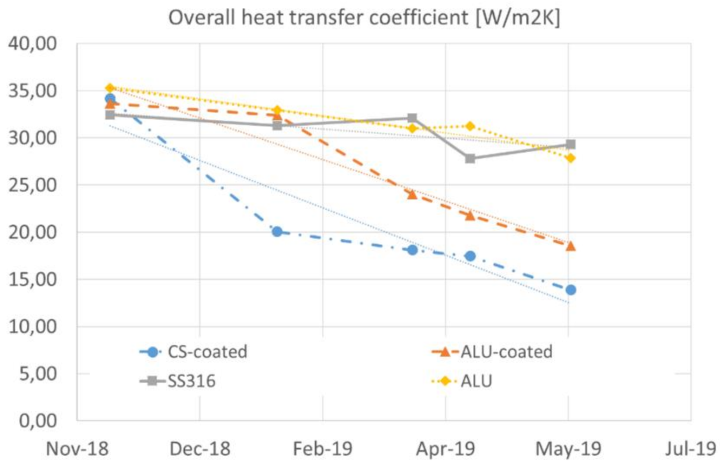


Figure 18: Overall heat transfer coefficient behaviors.

The comparison of heat exchange performances of hybrid and wet configurations were carried out by means of a third set of KPIs. The evaporation rate (self-explanatory parameters), defined as the difference between inlet and outlet water flow rate, was chosen as the best indicator of performance. The measurement is carried out indirectly by means of inlet/outlet air flow properties since outlet water flow rate cannot be measured across the gateway of the pool. The compared operations between wet and hybrid configurations showed a significant recovery of water evaporation rate corresponding to about 3 tonnes/hr. This recovery increases the re-injection capability up to 40% slowing down the usual decline of the geothermal field. The higher water recovery entails a higher air flow rate moved by the fan partially compensated by lower air head loss across the innovative wet filling. In particular the fan power consumption rose from 111 kWe to 136 kWe. On the basis of a slower decline of geothermal field and the small increase of power consumption, an economic evaluation of the retrofit investment was carried out with a pay back time lower than 10 years.

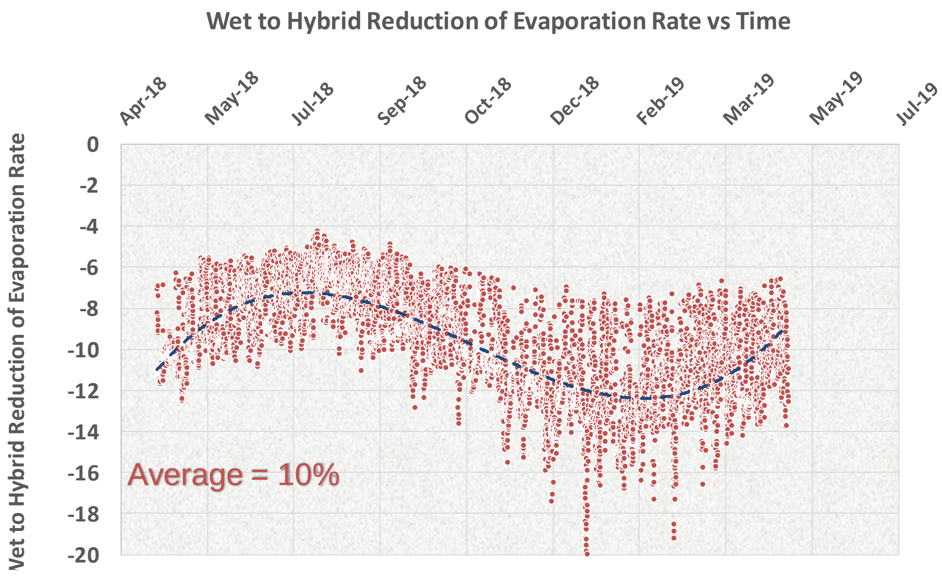


Figure 19: Wet to Hybrid Reduction of Evaporation Rate.

In addition to economic benefits, the wet cooling tower retrofit allows the avoidance of a visible plume at the stack due to the different thermodynamic state of the air leaving from the CT. This effect makes the existing geothermal power more environmentally sustainable, especially in those sites surrounded by tourist-frequented landscapes.

Figure 20: Avoidance of plume at the stack of CT.

3. CONCLUSIONS

In H2020 EU funded MATChING project, a retrofit of existing wet CT module in N.va San Martino geothermal plant was carried out in order to validate the first application of a hybrid CT in the HT geothermal sector. Demonstration tests had last for more than 1 year comparing performances of wet and hybrid configurations. Results clearly showed an average reduction of the evaporated water of about 10% of hybrid operation with respect to the wet one incurring a small energy penalty. This higher amount of water available for the reservoir recharge, together with the abatement of the typical visible plume from the stack, is economically viable and makes the hybrid CT application more sustainable. The assessment of new coatings and base materials did not confirm expected reliability and stainless steel (SOA) remained the acceptable design material for the HEXs even though deep investigation on deposition procedure is recommended in the coated aluminum and carbon steel pipes. The follow up of the project will take into account a different water split between wet and dry sections versus the ambient condition in order to enhance the yearly recovery of evaporated water.

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