MATChING
MATERIALS & TECHNOLOGIES FOR PERFORMANCE IMPROVEMENT OF COOLING SYSTEMS IN POWER PLANTS

Final MATChING Workshop

June 25-26, 2019

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Edited by Elena TOCCI, Francesca MACEDONIO, Adele BRUNETTI

The Final MATChING Workshop

MATChING "Materials & Technologies for Performance Improvement of Cooling Systems performance in Power Plants" is a collaborative project, funded by the EU Horizon 2020 programme, which aims to significantly reduce the demand of water and improve energy efficiency of cooling systems in the energy sector through the use of advanced materials and nano-technology based materials.

A broad set of technologies is proposed acting on intake, blowdown, make-up, and evaporated water. Hybrid cooling systems are proposed for the geothermal sector. For the thermal power sector, innovative materials are applied to steam condensers, and membrane-based solutions developed for water treatment and recovery.

A total of 8 test sites/facilities have been used within the project. The list of demonstrators includes 2 demo sites (Italy, Spain), 3 pilot sites (Belgium, Italy, France) and 3 existing facilities (France, Belgium, Spain), of which two are movable and have been brought on site to work in real power plants context.

The purpose of the workshop is to share the most relevant results of the Project and to engage an open discussion with the Stakeholders on the current and future scenarios related to the water availability and to technological measures for improving the performance of cooling systems in power plant, in Europe and abroad.

Organizing Committee

Enrico DRIOLI, ITM-CNR (Italy),

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The Workshop is organized by

Institute on Membrane Technology (ITM-CNR), National Research Council,
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Program

Tuesday June 25, 2019 – Morning

8:30 – 9:00	Registration	
09:00 – 9:30	**Introductory remarks & Welcome** Daniela GALLA, ENEL	
9:30 – 10:30	Session I Chairpersons: Daniela GALLA, Johan VAN BAEL	Plenary Lecture Thirst for Power: Energy, Water and Human Survival Michael WEBBER (ENGIE)
10:30 – 11:00		Success indicators, techno-economical targets, and establishment of scenarios for advanced cooling technologies cost-benefit analysis Han HUYNH (ENGIE LBE)
11:00 – 11:30		Coffee break
11:30 – 12:00		Pilot plant results water treatment technologies applied for recirculating cooling system Christophe VANSCHEPDAEL (ENGIE LBE)
12:00 – 12:30		Implementation of water treatment technologies for new built cooling towers within Europe Sofie VAN ERMEN /Leo DE NOCKER (VITO)
12:30 – 13:00		Hybrid cooling with ATES of Geothermal plants: simulation results and feasibility Johan VAN BAEL (VITO)
13:00 – 14:30	***Lunch***	

Program

Tuesday June 25, 2019 – Afternoon

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Program

Wednesday June 26, 2019 – Morning

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09:30 – 10:00		Coatings and surface texturing pilot tests in MATCHING for improving the performance of condensers Andres SANCHEZ- BIEZMA SACRISTAN (ENDESA)
10:00 – 10:30		Hybrid Cooling tower retrofit in a geothermal power plants: outcomes from H2020 Matching project Alessio BARDI (EGP)
10:30 – 11:00		Coffee break
11:00 – 11:30		Water innovation in a renewable world Ludwin DAAL (BLUE EXPERT)
11:30 – 12:45		Round table - Post Matching: new scenarios and new projects for the water energy nexus Moderator – Daniela GALLA (Enel) Participants - Sara MONTOMOLI (EGP), Han HYUNH (LBE), Enrico DRIOLI (ITM), Loic CHARPENTIER (WSSTP), Marco BRUGNONI (SPIG)
12:45 – 13:00		Q&A and Closing remarks All
	Lunch	

Oral presentations

Session I

Chairpersons

Daniela GALLA, Johan VAN BAEL

Thirst for Power: Energy, Water and Human Survival

Michael Webber
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This talk offers a big picture perspective that reveals the interdependence of the world's two most critical resources - energy and water. In addition to identifying the seriousness of the challenges, it lays out an optimistic approach with an array of solutions.

Success indicators, techno-economical targets, and establishment of scenarios for advanced cooling technologies cost-benefit analysis

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Within the MATChING project, multiple promising technologies to reduce the freshwater abstraction for water cooling are investigated. First investigations are conducted through laboratory experiments, and some involve mock-ups at pilot or demonstration scale. Many technologies will be tested in different environment, at different scale under a multiple ranges of conditions. It was therefore necessary to develop a reference frame. The Work Package 2 aims at providing methodology and tools to guide and support lab, pilot and desmonstration in the execution of their work and in the techno-economical assessment of the technology, through the definition of Key Performance Indicators (KPI) and the necessary context, framework and scenario hypotheses for the Cost/benefits analysis.

A Key Performance Indicator or KPI is an objective to track in order to demonstrate the performance of a technological solution in this case. In order to be evaluated, KPIs are linked to target values, so that the value of the measure can be assessed as meeting expectations or not.

Cost-benefit analysis must be assessed at the end of the project for the most promising technologies for scale-up. This investigation, requires the definition of assumptions and scenarios for cooling system, as well as coupling scenarios with water saving technologies taking into account the impact of climate scenarios on the cost-benefit analysis in order to capture the complexity of the water-energy nexus for (geo)-thermal power plants. These scenarios are established on the basis of historical data collection from the utilities and from the open literature, review of studies from European and international organizations (ONU, IEA, Joint Research Center…) and scientific literature. These scenarios serve as the basis for the technologies coupling cost benefit analysis.

The approach, strategy, data collection, parameters definition together with all the project partners as well as the final outcome of this methodological Work Package 2 will be presented.

This work was supported by National Grant no. 6860312

Keywords: Key Performance Indicator, scenario, water-energy nexus, methodology, cost-benefit analysis

Pilot plant results water treatment technologies applied for recirculating cooling systems

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In the framework of the MATChING project, ENGIE Laborelec in collaboration with VITO, Pathema and Aquastill tested different water treatment technologies applied to recirculating cooling system. The aim is to demonstrate at pilot scale how innovative water treatments can decrease water withdrawal.

Three strategies for reducing cooling water abstraction were studied at pilot scale:

- Reduction and reuse of blowdown water. Membrane distillation was coupled with the cooling water the blowdown to reuse the high quality water as make-up water for the cooling circuit allowing an increase of the cycle of concentration and consequently, a reduction in freshwater abstraction.
- Circulation water treatment to reduce scaling. The second technology tested is the Vortex Process Technology from Pathema. This technology actually induces calcium carbonate precipitation under a form that the deposition of this scale in the cooling water circuit is avoided.
- Make-up water treatment to reduce scaling. The last technology tested is the membrane captive deionization (MCDI). MCDI treated the make-up to reduce salinity of the water and to allow an increase of the cycle of concentration.

To compare these technologies, ENGIE Laborelec used MERADES. MERADES is a mobile installation simulating semi-open cooling circuits, made of two parallel and independent circuits allowing the comparison between different treatments under the same conditions. Each circuit is a miniaturized cooling circuit with one simulated heat exchanger and a forced-draft cooling tower. In the frameworks of MATChING, the same water quality was used and for each tested technology, and comparison between technology and reference with acid injection was made. The tests highlights that the technology can reach the objective of MATChING project saving the water withdrawal of 30% during the pilot test.

Implementation of water treatment technologies for new built cooling towers within Europe

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In the framework of the MATChING project, VITO in collaboration with ENGIE Laborelec, evaluated the implementation of different water treatment technologies for new built recirculating cooling system based on the pilot plant results demonstrated within the MATChING project.

Three technologies for reducing cooling water abstraction are studied:
- Reduction and reuse of blowdown water using membrane distillation
- Vortex Process Technology from Pathema for circulation water treatment to reduce scaling and reduce intake water
- Make-up water treatment using MCDI to reduce scaling

The study aims to identify the market potential for implementation of new technologies in wet tower cooling, accounting for different factors that determine costs and benefits. To this purpose, different implementation scenario's of the new technologies (designs and management options) are compared against a reference case and against current practises. The study looks in detail on the effect of on water intake for cooling, blowdown discharge and acid dosing, and distinguish for three different climate conditions and two different surface water types representative for the European situation.
The study calculates the additional investment and operational costs of the new technologies, and the costs savings related to a reduction of required water intake. In addition, we estimate the impact of the technology scenario's on the drought risks in the reference scenario. Drought risks are based on the risk of water shortage and consequent limitations for water intake for cooling. This leads to loss temporary reduction of electricity production and loss of income. We built on the literature related to water shortages, the impact on availabity of water for cooling and the impact of droughts on electricity prices.
Finally, we assess the costs and benefits of the technologies on the costs of electricity production and how it relates to the cost of dry cooling.

The study shows that a good understanding of all costs and benefits is required in order to select the optimal design for the new technologies, and to identify under which conditions the reduction of drought risks justify the investments.

Hybrid cooling with ATES of Geothermal plants: simulation results and feasibility

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The electrical efficiency to valorize low-temperature (100°C-150°C) geothermal heat to electricity with binary plants (ORC) is often low, in the order of 8% to 15%. The efficiency is highly depending on the temperature of the heat sources, but also the condensing temperature in the ORC plays an important role and this temperature is for most of the installations depending on the ambient conditions. In combined heat and power plants the effect of the ambient conditions is even amplified. The heat available for electricity production is much higher in summer months compared to winter months. Unfortunately, the ambient conditions for cooling of the ORC are less favorable at that period. Most used cooling systems for ORC are 1) air cooled condensers, 2) direct water cooling or 3) mechanical-draft cooling towers. To reduce the impact of high ambient temperatures on the electricity output a new hybrid cooling system is proposed based on shallow aquifer as medium to store cooling (ATES – Aquifer Thermal Energy Storage). As groundwater with a constant temperature is used in a closed loop even the net water consumption for cooling is reduced compared to classical wet systems.
The proposed hybrid cooling system is being the subject of extensive numerical simulations by VITO in the framework of the European project MATChING. The results described in this paper indicate as optimal strategy the use of groundwater only in the case of high ambient temperatures. Moreover, during cold periods, the groundwater used to cool down the binary plant has to be re-extracted, cooled in the dry cooler and reinjected at a temperature close to that of the original aquifer. The benefit quantified in this paper is an increase in the plant conversion efficiency, without any water consumption and at the cost of a limited temperature anomaly in the wells field.

The work within the MATChING project has received funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement N° 686031.

Keywords: Underground Thermal Energy Storage, Aquifer Thermal Energy Storage, ORC, geothermal energy, seasonal storage, cold storage

Session II

Chairpersons

Sofie VAN ERMEN, Enrico DRIOLI

Water treatments with Membrane Systems

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Membrane engineering has already provided interesting solutions to some of the major problems of our modern industrialized society. Membrane techniques are essential to a wide range of applications including the production of potable water, energy generation, tissue repair, pharmaceutical production, food packaging and the separations needed for the manufacture of chemicals, electronics and a range of other products. However, water treatment is the sector that account for the majority membrane application. Actually, growing global demand for **WATER** makes membrane filtration the prominent technology in desalination and wastewater treatment: the global cumulative contracted capacity, dominated by Reverse Osmosis (SWRO), reached 99.8 million m3/day in 2017 [1], and membrane desalination technologies account for more than 90% of all desalination plants [2]. Despite the enormous success of membrane desalination technology, improvements are still required in terms of desalted water cost, higher productivity (that means higher water recovery factors), better water quality and enhanced eco-sustainability of the desalination process. A solution is offered by ***membrane distillation (MD)*** [3]. The latter belongs to the class of membrane contactors in which microporous hydrophobic membranes are used not as selective barriers but to promote the mass transfer between phases on the basis of the principles of phase equilibrium. MD presents interesting advantages with respect to conventional distillation processes from one side, and compared to RO from another side, such as: (i) lower operating temperatures and pressure; (ii) 100% (theoretical) rejection of non-volatile solute; (iii) performance not limited by high osmotic pressure or concentration polarization (thus allowing to reach elevated permeate recovery factors); (iv) lower membrane fouling problems.

Another innovative membrane operation allowing, at the same time, water and crystals extraction from seawater/produced water/industrial wastewater is **membrane assisted crystallization (MCr)** [4]. As membrane distillation, also membrane crystallization is a membrane contactor operation. In a membrane crystallizer the evaporative mass transfer of volatile solvents through microporous hydrophobic membranes is used in order to concentrate feed solutions above their saturation limit, thus attaining a supersaturated environment where crystals may nucleate and grow. MCr is an innovative technology with some important advantages with respect to traditional crystallization processes: well-controlled nucleation and growth kinetics, fast crystallization rates and reduced induction time, membrane surface promoting heterogeneous nucleation and control of supersaturation level and rate.
In the present work, the latest progresses of membrane distillation in water treatment and reuse sector, as well as the potentialities of membrane assisted crystallization are presented.

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Remediation of flue gas desulfurization wastewaters by integrated membrane systems

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Discharge of flue gas desulfurization (FGD) wastewaters without sufficient treatment pose serious environmental issues because of its detrimental impact on human health and ecological system. The use of membrane operations has been increasingly implemented in the recent years in the purification of groundwater and surface water as well as for decontamination of wastewater streams of very diverse sources [1].
In this work the use of ultrafiltration (UF) and reverse osmosis (RO) membranes has been investigated on laboratory scale in the treatment of FGD wastewaters before a final step of membrane distillation (MD). The lab scale plant included: (1) a pre-treatment (chemical softening and UF) for reducing Ca^{2+}, Mg^{2+}, and total organic carbon (TOC) in the raw wastewater, (2) a RO unit for reducing the salt content of UF permeate.
The performance of commercial RO membranes was evaluated in terms of salts rejection, permeate flux, fouling index and water recovery [2].
A total recovery factor of about 94% was reached by treating the RO retentate by MD [3]. The permeate stream, with an electrical conductivity of 80 μS/cm, is suitable to be reused in the power plant with a saving in fresh water demand.
According to the experimental results, the combination of membrane operations in sequential design is a viable approach for the treatment of FGD wastewaters with significant benefits in terms of reduction of water demand in the plant, minimization of wastewater to be discharged in the environment, and overall improvement in the sustainability of the process.

Keywords: Flue gas desulfurization (FGD) wastewaters; reverse osmosis (RO); membrane distillation; desalination; integrated membrane systems.

Acknowledgements: *This work was performed within the Project "Materials Technologies for performance improvement of Cooling Systems in Power Plants" (MATChING) which received funding from the European Union's Horizon 2020 research and innovation program under the grant agreement number 686031.*

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Wastewater treatment with innovative membrane technologies

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Plume of cooling tower: source of water and chemicals

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Minimizing fresh water requirements is necessary in industrial processes for reducing their demand of water and increasing their sustainability. In particular, in the energy sector, one of the major waters consuming unit is cooling tower. This device removes the heat absorbed in the circulating cooling water used in power plants. In doing this, a portion of the water evaporates, and the energy required to evaporate that portion of the water is taken from the remaining mass of water, thus reducing its temperature. It has been estimated that approximately 970 BTU of heat energy is absorbed for each pound of evaporated water (2 MJ/kg). Therefore, fresh water make-up has to be supplied to the tower to compensate for the loss of evaporated water. In this work, membrane condenser has been utilized for the recovery of the water contained in the evaporated water stream (also called plume) exiting from the cooling tower. Moreover, considering that plume can contain also salts (in particular when seawater is utilized as make-up water), biocides and algaecides (such as chlorine and ammonia, dosed to the circulating cooling water to prevent growths of micro-organisms), in the present work the potentialities of membrane condenser for chemicals recovery is also illustrated.

Membrane condenser is an innovative membrane technology that exploits the hydrophobic nature of microporous membranes to promote water vapor condensation and recovery. In details, the waste gaseous stream (e.g., the plume of the cooling tower) at a certain temperature and, in most of the cases, water saturated, is fed to the membrane condenser kept at equal or lower temperature. Once this stream is brought into contact with the retentate side of a microporous membrane, its hydrophobic nature prevents the penetration of the water droplets into the pores letting pass the dehydrated gases through the membrane. Therefore, the liquid water is recovered at the retentate side, whereas the other gases at the permeate side of the membrane unit. A simulation study of the process has been developed for predicting the membrane-based process performance. A lab scale plant was realized to verify the results achieved by the simulation analysis. As humidified waste gases, streams simulating the plume of cooling tower were selected.

The simulation allowed predicting the process performance. In particular, it was found that the recovery of water can be increased with the grow of ΔT (temperature difference between the plume and the gas before entering the membrane module) (Figure 1), RHplume (relative humidity of the plume) and Q/A (ratio between feed flow rate and membrane area).

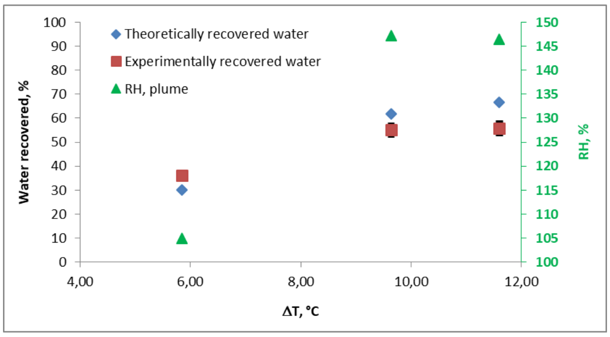

Figure 1 Water recovery vs ΔT at different RH_{Feed} (from 105 to 150%). T_{plume} ≈25°C, Q/A=1.2 m/h.

The experimental results showed good agreement with the simulation ones. Experiments proved that considering a plume at 25°C°C and utilizing Q/A =1.2 m/h, water recovery ranges from 36.24% (ΔT=5.84°C and RH=104.9%) to more than 55% (ΔT≈10°C, Tplume≈25°C and RH>140%). Moreover, experimental tests performed considering the presence of NH_3 in the fed gaseous stream revealed that the contaminants concentration increase with the growing temperature difference between fed plume and membrane module due to the dependence of gases solubility on temperature.

Acknowledgments
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Session III

Chairpersons

Ricardo LOSADA MATEO, Andrea GARAGIOLA

Si-based coating technologies for improving the performance of cooling systems in power plants

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Energy production requires large water volumes: worldwide increasing demand for energy and diminishing availability of freshwater pose challenges to ensure sustainability. For the thermal power sector, innovative materials are thus considered to enhance the heat transfer efficiency in the condenser both on the steam side and water side.
Si-based coatings are more and more used in a large field of applications thanks to its robustness and the easy way to modify their chemistry to tune the coating functionalities. Silica based coating can be obtained from different processes: the most common are sol gel (hydrolysis and condensation of alcoxysilanes), polydimethylsiloxane-based coatings or plasma enhanced chemical vapor deposition (under vacuum or at atmospheric pressure). The choice of the technology is mainly related on the targeted properties, the material to be treated or the industrial facilities.
In MATCHING project MATERIA NOVA and IONICS proposed two types of technologies to provide long-term efficient heat transfer.

Fig 1. Matching's concept for coatings on internal and external parts of tubes

More precisely, coatings with high hydrophobic functionality were applied on the steam side of condenser tube bundles to promote drop-wise condensation. MATERIA NOVA developed a SiOxCy type-coating applied by PECVD at atmospheric pressure. The surface energy of the films is controlled by means of the decomposition of the precursor (here hexamethyldisiloxane) in the plasma. The coating parameters were tuned to control the amount of carbon in the coating composition and the coating roughness directly influencing the hydrophobic character as well as the sliding angle.
On the other hand, antifouling coatings were applied on the cooling water side of condenser tube bundles, allowing alternative water source usage. The coatings are based on sol-gel process combining hydrophobic character (for anti-adherence) and the use of peptoids as anti-fouling agent. The coatings were compared in terms of hydrophobicity, biofilm adhesion and microstructure.

This work was supported by Horizon 2020 research and innovation program (grant agreement n° 686031

Keywords: PECVD, sol gel, hydrophobicity, anti-fouling, cooling water

Coatings and surface texturing pilot tests in MATCHING for improving the performance of condensers

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It is well known that condensation efficiency is significantly affected by the type of condensation suffered in the tubes of the condenser and in the removal speed of the water layer created during the process. In the Matching project different technical solutions based on this concept had been tested in order to improve the efficiency of the condensation. Two main possibilities have been explored. The first one based on the modification of the surface of the tubes, using different laser texturing patterns. The second one, though the use of hydrophofic coatings used in the external surface of the tubes, with the aim to remove the condensated water much faster.
The presentation shows the main results obtained during the tests carry out and identify criticalities of this approach.

The second main factor that affects to the condenser efficiency is the heat rate penalty due to lack of cleanliness in the inner surface of the tubes, both because the accumulation of mineral deposits and biologic material. The use of antifouling coatings is an interesting option as an alternative to the periodic cleaning of the condenser. The presentation shows the main achievements of the Matching project in this area.

Hybrid Cooling tower retrofit in a geothermal power plants: outcomes from H2020 Matching project

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A cooling tower (CT) 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 latest represents the main part of heat transferred and this is the reason why the whole process is named "Evaporative CT". In geothermal sector the most diffused evaporative CTs 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 CT, 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 CT, 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 wet-dry hybrid CT has been considered an alternative to evaporative CT in order to raise the re-injection water amount 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 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 CTs in high temperature geothermal power plants in order to make them a competitive alternative to currently wet CTs. After a pilot validation phase, one of six cells of the CT of "Nuova San Martino" geothermal power plant (Monterotondo Marittimo, Italy) owned by Enel Green Power, was retrofitted by SPIG (B&W group) and operated in hybrid configuration. After the experimental tests lasted 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.

Water innovation in a renewable world

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Over the past decade the use of renewable energy in Europe has significantly changed the energy generation landscape. Predictable (high) returns are now more difficult to assess, and different governmental policies make it a challenging future for power plant operation. As a result of these uncertainties, investments in power plant improvements and new developments are scarce. The changing landscape has also had a high impact in the loss of expertise within generation assets and suppliers due to retirement and/or multiple roles and tasks for operators and chemists. The current energy landscape demands that assets must be more flexible in use.

Currently the most efficient means of cooling is once-through cooling, however developments in cooling water availability and more stringent environmental legislation make it increasingly challenging to adopt this cooling method and the trend is to adopt hybrid or air cooling as an alternative. Yet there are some cost beneficial opportunities to improve and increase uptime and efficiency with large once-through cooling water systems not previously identified by power plant operators. On the process water side chemical conditioning strategies of the water/steam cycle has become more challenging over the years as a result of cycling mode and unknown periods of standstill.

This paper describes the present situation in the Netherlands and the cooling water situation in the Middle East with current developments and an outlook to process- and cooling water use. The associated risks, challenges and opportunities for power plant operators going ahead will be particularly highlighted. In particular, the innovative opportunities worth investigating to offer flexible and holistic multi-propose generation asset will be presented.

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