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Task 2.1: Definition of Key Performance Indicators (KPI) and success indicators

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V0.1	30/09/2016	Author	KPIs for laboratory tests

Distribution List

Classification Code	Distribution list	Dissemination Level
PU	Partners + Project officer + Project Monitor + User's Group	Public

Summary

The report, in its first version, provides all the necessary KPIs for the laboratory screening of technologies and configurations in WP3 to 6. An update of the deliverable is foreseen for M18 to provide all the operational and global KPIs for the pilot and demo testing. The development of KPIs is a living process and will evolve along the project.

First of all the methodology followed to establish these KPIs is described in section 1. Then a global overview of the KPIs is given in section 2 with a table summarizing all the KPIs defined by technology solution together with target values when available. The core of this report in section 3 is a booklet in power point format with one slide per KPI definition.

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1 Methodology

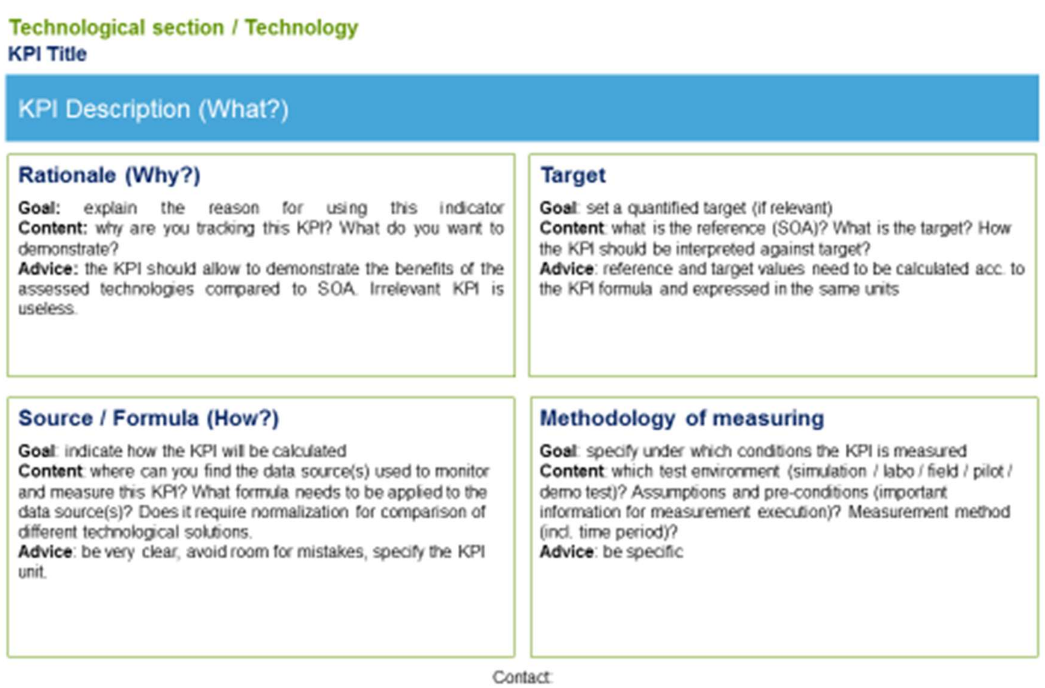
A Key Performance Indicator or KPI is an objective to track in order to demonstrate the performance of a technological solution in this case. In order to be evaluated, KPIs are linked to target values, so that the value of the measure can be assessed as meeting expectations or not.

One way to evaluate the relevance of a KPI is to use the SMART criteria. The letters are typically taken to stand for specific, measurable, attainable, relevant, time-bound. In other words:

- Is the objective **S**pecific (clearly defined and identified)?
- Can we **M**easure progress towards that goal?
- Is the goal realistically **A**ttainable?
- How **R**elevant is the goal to the success of the technological solution?
- It must be **T**ime phased, which means the value or outcomes are shown for a predefined and relevant period.

A template (one slide power point format) was prepared containing the main elements that needed to be developed for each KPI. The KPI description should answer the following basic questions: what? (definition), why? (rationale) and how? (calculation methodology). It also mentions the expected target compared to the reference (state of the art) and gives information on test conditions.

Success indicators are defined for some KPIs giving a minimum threshold for the technological solutions.



This template was completed by the technology providers and R&D centres and discussions were held to clarify KPI definition, request missing information, challenge the number of KPIs, harmonize definitions among work packages…

A draft version was afterwards distributed for validation by the contributors and review by the utilities and by SWECO. Finally, a workshop was organized in September 2016 during which a final validation and consolidation was performed within each work package.

Methodology for the KPIs establishment for the pilot/demo phase still needs to be discussed.

Several remarks can be made on KPI definition and were discussed during the workshop in September 2016:

For some KPIs, the state of the art and/or target is missing. Indeed, the state of the art is not always mentioned because it refers to a technology that cannot be compared with the one under investigation or because the field of application is too different. Besides, it is sometimes difficult to define a clear target depending on the technology maturity level.

Success indicators are not defined for all technological solutions. At laboratory scale, these should not be considered as criteria to exclude a material or a technology because some aspects cannot be evaluated at this scale.

Some KPIs are based on estimation (instead of measurement). All parameters cannot be measured or depend on several assumptions. In order to take this uncertainty into account, sensitivity analyses will be performed during the techno-economic evaluation (WP7).

Cost is sometimes defined as KPI for laboratory phase. It will be used with caution in the comparison of the technological solutions. Indeed, a complete techno-economic evaluation taking into account material costs but also maintenance costs, operational costs, energy/cooling water savings… is necessary to have a global overview of the technology.

2 Global overview

This report presents the different KPIs that will be used for technologies evaluation and benchmarking along the project. The table on next page gives an overview of the indicators selected for each technological solution.

KPIs are defined at different levels:

- KPIs at technology level: Specific KPIs are defined to characterize innovative technologies and to allow comparison between the innovative technologies and the benchmarked commercial solutions (state of the art). Examples of such KPIs are: electrical consumption, heat transfer coefficient, fouling, corrosion...
  The definitions of these KPIs are essential for the laboratory screening process of WP3-6. They will be used as criteria/decision parameters for the material/technology selection.
  They will be reviewed for pilot and demonstration activities to properly measure operational performances of the technological solutions.
- KPIs at global level: Overall targets are defined to characterize the success of the innovative technology on cooling systems for fossil fuelled and geothermal plants. Examples of such KPIs are: reduction of fresh water abstraction, net efficiency, CAPEX and OPEX retrofit/new built…
  These KPIs will be used for evaluation and ranking during pilot and demo activities.
- Non-technical KPIs: According to EC environmental and educational objectives, general KPIs are also defined at business, education, and dissemination levels.

This first version of the report only contains **the KPIs at technology level for the laboratory screening**.

D2.1 Key Performance and Success Indicators - Overview
Technical KPIs for laboratory screening of technologies and configurations

Work packages	Technological sections	KPI n°	KPI name	KPI definition	Test environment	SOA (ref. value)	Target (success indicator)
WP3: Hybrid Cooling Systems for Low-T Geothermal Sources	Coatings for geothermal pipes (T3.1)	3.1.1.	Coating adhesion	Adhesion rating after immersion in a corrosive environment (-)	Lab	Non-coated expensive materials (Ni and Ti alloys or high grade SS)	≥ 2
		3.1.2.	Coating corrosion resistance	Average corrosion rate (mm/year) (mock-up test)	Lab	Non-coated expensive materials (Ni and Ti alloys or high grade SS) with high corrosion resistance	≤ ~0.01 mm/year (≤ 0.1 mm/year)
		3.1.3.	Coating adhesion (after mock-up test)	Adhesion rating after mock-up test (-)	Lab	Non-coated expensive materials (Ni and Ti alloys or high grade SS)	≥ 2
	Closed loop groundwater (GWC) integrated in a binary cycle (T3.2)	3.2.1.	Water consumption reduction	Reduction in net water consumption of ORC hybrid cooled compared to cooling towers (%)	Simulation	Cooling with cooling towers	> 30%
		3.2.2.	Electricity production increase	Increase in electricity production of ORC hybrid cooled compared to cooling towers (%)	Simulation		> 0.5%
WP4: Hybrid CTs for High-T Geothermal Sources	New Filling Media	4.1.1.	Filling thermal performance	Filling cooling capability for filling height of 1 meter (-)	Lab / Demo	High efficiency film filling (0.27 @L/G=1 and filling height 1 m)	> 1.4 @L/G=1 and filling height 1 m
		4.1.2.	Filling specific thermal performance	Filling cooling capability of demo module per fan power consumption (kW^{-1})	Lab / Demo	High efficiency film filling (0.012 kW^{-1})	> 0.020 kW^{-1}
		4.1.3.	Material cost	Material costs of innovative fillings per MW (€/MW)	Lab	Innovative fillings under development	? (proven applicability)
	Coatings for dry section modules	4.2.1.	Pipe thermal conductivity	Thermal conductivity of coated plate (W/m-K)	Lab	Bare steel (53 W/m-K) and aluminium (210 W/m-K)	?
		4.2.2.	Coating corrosion resistance	Average corrosion rate (mm/year)	Lab	Non-coated expensive materials (Ni and Ti alloys or high grade SS) with high corrosion resistance	≤ ~0.01 mm/year (≤ 0.1 mm/year)
		4.2.3.	Water repellence	Static water contact angle, after exposure (degree)	Lab	Uncoated/untreated stainless steel (~0-30°)	70-90°
		4.2.4.	Coating adhesion	Adhesion rating after immersion in a corrosive environment (-)	Lab	Non-coated expensive materials (Ni and Ti alloys or high grade SS)	≥ 2
		4.2.5.	Dry section costs	Cost increase compared to standard dry module sections (%)	Lab	AISI 316L dry section not coated	? (proven applicability)
WP5: Steam condenser and CT water circuits	Condenser steam side - Coatings and surface texturing (T5.1)	5.1.1.	Water repellence	Receding water contact angle under condensation, after exposure (degree)	Lab	Uncoated/untreated stainless steel (~0-30°)	70-90°
		5.1.2.	Coating adhesion	Adhesion rating after immersion in water (-)	Lab	No coating/treatment	≥ 2
		5.1.3.	Thermal conductance	Thermal conductance estimation (W/m²-K)	Lab		?
		5.1.4.	Applicability / costs	Application costs per unit of surface (€/m²)	Lab		? (proven applicability)
		5.1.5.	Steam cycle contamination	To be defined for next revision of the deliverable	Lab		
	Condenser cooling water side - Stainless steel with biocide properties (T5.2)	5.2.1.	Bacterial inhibition performance	Biocidal efficiency of stainless steels (%)	Lab	AISI 304, with 0.5% Cu (0.01%)	> 90%
		5.2.2.	Copper release	Cu^{2+} release from antimicrobial stainless steels (ppm)	Lab	Cu-Ni alloy 90-10, 0.09 ppm (after 24h) measured in the effluent of a condenser	< 0.05 ppm
		5.2.3.	Corrosion performance of Cu-bearing SS	Corrosion rate of Cu-bearing stainless steels in presence of bacteria	Lab	304L in E.Coli culture Icorr = 0.01mm/year after 2 days and Icorr= 0.06mm/year after 21 days of immersion. Cu-Ni Icorr= 0.02 mm/year at short term exposures.	≤ 0.01 mm/year
	Condenser cooling water side - Anti-fouling and fouling-release coatings (T5.3)	5.3.1.	Bacteria adhesion	Bacteria content in the biofilm of coated surface compared to reference (%)	Lab	Non-treated surface / surface treated with a biocide-free commercial paint	0%
		5.3.2.	Bacteria adhesion after a bleach shock	Bacteria content in the biofilm of coated surface compared to ref. after a bleach shock (%)	Lab	Non-treated surface / surface treated with a biocide-free commercial paint	0%
		5.3.3.	Thermal conductance	Thermal conductance estimation (W/m²-K)	Lab	No coating	?
		5.3.4.	Coating adhesion after a bleach shock	Adhesion rating after a bleach shock (-)	Lab	Non-treated surface	≥ 2
WP6: Cooling water treatment and water recovery	Membrane Capacitive Deionization (MCDI) for CT feed pre-treatment (T6.1)	6.1.1.	Water recovery	Ratio of product water flow to feed water flow (%)	Lab / Pilot	Commercially available MCDI (70-90%)	80-95%
		6.1.2.	Charge efficiency	Ratio of salt adsorption (desorption) over corresponding charges (%)	Lab / Pilot	Commercially available MCDI (50-80%)	90%
		6.1.3.	Salt adsorption capacity	Amount of salt or specific ions adsorbed per mass of electrodes (mg NaCl/g electrode)	Lab	Commercially available MCDI (10mg NaCl/g)	10mg NaCl/g
		6.1.4.	Salt adsorption rate	Average rate of salt adsorption for 90% saturation (mg NaCl/min-g)	Lab	Commercially available MCDI (1mg NaCl/min.g)	1mg NaCl/min.g
		6.1.5.	Ions removal efficiency	Percentage of total ions removed (%)	Lab / Pilot	Commercially available MCDI (50-70%)	80%
		6.1.6.	Specific energy consumption per cycle	Energy used by the technology (adsorption & desorption) per m³ of product water (kWh/m³)	Lab / Pilot	Commercially available MCDI (0.05-5 kWh/m³)	< 2 kWh/m³ (< 1-5 kWh/m³)
	IVG-C CoolWater to reduce blowdown through operation at high COC (T6.2)			The technology for circulation water treatment will not be evaluated at lab scale. KPIs will be defined for pilot/demo phase.			
	Membrane distillation (MD) for blow-down water recovery (T6.3)	6.3.1.	Water recovery	Ratio of product water flow to feedwater flow (%)	Lab / Pilot	(CT blowdown: evaporation, RO)	?
		6.3.2.	Separation efficiency	Separation efficiency (%)	Lab / Pilot	(CT blowdown: evaporation, RO)	99.99%
	Thermally driven membranes (MD) for the recovery of water from	6.4.1.	Water recovery	Ratio of product water flow to feedwater flow (%)	Lab / Pilot	(FGD wastewater: evaporation)	?
		6.4.2.	Separation efficiency	Separation efficiency (%)	Lab / Pilot	(FGD wastewater: evaporation)	99.99%
	Pressure driven membranes for reuse of waste water streams - Nanofiltration/RO (T6.5)	6.5.1.1.	Water recovery	Ratio of product water flow to feedwater flow (%)	Lab / Pilot	(FGD wastewater: evaporation)	?
		6.5.1.2.	Ions removal efficiency	Percentage of total ions removed (%)	Lab / Pilot	(FGD wastewater: evaporation)	? (conductivity < 800 µS/cm)
	Pressure driven membranes for reuse of waste water streams - Integrated membrane system (T6.5)	6.5.2.1.	Water recovery	Ratio of product water flow to feedwater flow (%)	Lab / Pilot	(FGD wastewater: evaporation)	?
		6.5.2.2.	Ions removal efficiency	Percentage of total ions removed (%)	Lab / Pilot	(FGD wastewater: evaporation)	? (conductivity < 800 µS/cm)
	Membrane Condenser (MC) for the recovery of water vapour from CT (T6.6)	6.6.1.	Water recovery	Ratio of product water flow to feedwater flow (%)	Lab	Liquid and solid sorption: 22-62% Dense membranes: 20-40% Not applied in power industry	20% with ΔT<6°C and around 50% at ΔT equal to 16°C
		6.6.2.	Water quality	Water quality (ppm)	Lab	Liquid and solid sorption Dense membranes Membrane condenser Not applied in power industry	Sufficient for cooling tower make-up

3 KPIs booklet

D2.1 Key Performance and Success Indicators

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30/09/2016

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

Introduction

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- This report establishes the different KPIs that will be used for technologies evaluation and benchmarking along the project. An Excel file is also associated to this report for an easy overview of the indicators.
- This first version includes KPIs for **laboratory screening** of technologies and configurations and will be reviewed for pilot/demo test activities.

List of acronyms

AISI: American Iron and Steel Institute
BREF: BAT (Best Available Techniques) REFerence document
COC: Cycle Of Concentration
CT: Cooling Tower
CTI: Cooling Tower Institute
EC: Electrical Conductivity
EIS: Electrochemical Impedance Spectroscopy
EQS: Environmental Quality Standard
FGD: Flue Gas Desulfurization
GWC: Ground Water Cooling
IC: Ion Chromatography
ICP: Inductively Coupled Plasma mass spectroscopy
ISO: International Organization for Standardization
IVG-C: Industrial Vortex Generator - Circulation
KPI: Key Performance Indicator
LPR: Linear Polarization Resistance
MC: Membrane Condenser
MCDI: Membrane Capacitive Deionization
MD: Membrane Distillation
MF: Micro Filtration
NF: Nano Filtration
ORC: Organic Rankine Cycle
PREN: Pitting Resistance Equivalent Number
PS: Polystyrene
RO: Reverse Osmosis
SOA: State Of the Art
SS: Stainless Steel
UF: Ultra Filtration
WP: Work Package

TECHNICAL KPIs

for laboratory screening of technologies and configurations

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WP3: Low-T Geothermal Source

3.1. Coatings for geothermal pipes

3.1.1. Coating adhesion

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Adhesion rating after immersion in a corrosive environment (-)

Rationale

The KPI evaluates the coating adhesion. Adhesion is viewed as the strength of the bonds between the coating material and the substrate. Coating adhesion provides a tool to evaluate the integrity of the coating and its potential for the intended performance. The adhesion will be tested by a common cross-cut and tape test. The tape test will be performed after immersion in a highly corrosive environment. The cross cut will simulate defects in the coating, that are expected to be not completely avoidable. The exposure is milder than the real conditions, but suitable as an experimentally simple pre-selection.

Source / Formula

Measurement data:
The test is performed according to the ISO 2409

Formula:
The KPI is the rating of samples between 0 (best) and 5 (worst) according to ISO 2409

Unit: -

Target

SOA: No coating, utilization of expensive materials (high grade stainless steels, Ni and Ti alloys) with high corrosion resistance (very high PREN)

Success criteria: A rating of 2 or better

Methodology of measuring

Test environment: Laboratory
Substrates: AISI 316L and P265GH
Test conditions:
Coated samples immersed in corrosive environment

- Media: aerated NaCl 3.5 wt.%
- Temperature: 90 °C
- Exposure time: 72 hr

Method:
ISO 2409, but three tear-offs instead of one.

Contact: rlm@teknologisk.dk

3.1. Low-T geothermal source / Coatings

3.1.2. Coating corrosion resistance

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Average corrosion rate (mm/year) (Mock-up test)

Rationale

The KPI evaluates the ability of different coatings in mitigating corrosion on low-grade materials exposed to low temperature geothermal fluid sources. Objective is to replace expensive materials by cheaper combinations of lower grade SS or carbon steel with coatings.

Target

SOA: No coating, utilization of expensive materials (high grade stainless steels, Ni and Ti alloys) with high corrosion resistance (very high PREN)

Target: ~0.01 mm/year

Success criteria: ≤ 0.1 mm/year

Source / Formula

Measurement data:
Corrosion current density

Formula:
$I_{corr} = B / R_p$
B is a constant and R_p is the polarization resistance
The corrosion current is calculated from the polarization resistance (R_p) and converted to average corrosion rate according to standard procedure for LPR and/or EIS measurements (1 A/m² corresponds to 1.16 mm/year)

Unit: mm/year

Methodology of measuring

Test environment: Laboratory
Substrates: AISI 316L and P265GH
Test conditions:
Coated samples exposed to brines (Mock testing)

- Media: synthetic brines with equivalent composition to Balmatts brines
- Exposure time: 570 h (24 days)
- Temperature: 125 °C
- Pressure: 30 bar

Method:
The corrosion current density is determined through electrochemical analysis (LPR and/or EIS in aerated NaCl 1M) of the coated samples before and after exposure tests in the LOTU device.

Contact: afernandez@aimen.es / rlm@teknologisk.dk

3.1. Low-T geothermal source / Coatings

3.1.3. Coating adhesion (after mock-up test)

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Adhesion rating after mock-up test (-)

Rationale

The KPI evaluates the coating adhesion after the mock up test. Coating adhesion provides a tool to evaluate the integrity. The adhesion will be tested by a common cross-cut and tape test. The tape test will be performed after the mock-up test. The cross cut will simulate defects in the coating, that are expected to be not completely avoidable.

Target

SOA: No coating, utilization of expensive materials (high grade stainless steels, Ni and Ti alloys) with high corrosion resistance (very high PREN)

Success criteria: A rating of 2 or better

Source / Formula

Measurement data:
The test is performed according to the ISO 2409

Formula:
The KPI is the rating of samples between 0 (best) and 5 (worst) according to ISO 2409

Unit: -

Methodology of measuring

Test environment: Laboratory
Substrates: AISI 316L and P265GH
Test conditions:
Coated samples exposed to brines (Mock testing)

- Media: synthetic brines with equivalent composition to Balmatts brines
- Exposure time: 570 h (24 days)
- Temperature: 125 °C
- Pressure: 30 bar

Method:
ISO 2409, but three tear-offs instead of one.

Contact: rlm@teknologisk.dk

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WP3: Low-T Geothermal Source

3.2. Closed loop groundwater (GWC) integrated in a binary cycle

3.2. Low-T geothermal source / GWC hybrid cooling

3.2.1. Water consumption reduction

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Reduction in net water consumption of ORC hybrid cooled compared to cooling towers (%)

Rationale

The goal is to reduce the net water consumption for electricity production with low temperature geothermal sources by using hybrid cooling with groundwater. In theory the water consumption by using groundwater can be zero, but only if you can store enough cold in the groundwater layer during colder days.
The KPI evaluates the reduction of water consumption over one year compared to operation with wet cooling towers only.

Source / Formula

Measurement data: (results from simulation)
- Net water consumption (hybrid cooling) G_{hybrid} = water for flushing (m³/year) + CT water evaporation (m³/year)
- Net water consumption (wet cooling tower) G_{CT} = CT water evaporation (m³/year) (make-up flow – blowdown flow)

Formula:
$(G_{CT} - G_{hybrid}) / G_{CT} * 100$

Unit: %

Target

SOA: Cooling with cooling towers

Target: > 30% reduction in net water consumption
We expect that some water has to be used to cool the groundwater in colder days. The groundwater can be cooled with a dry cooler (no water consumption), but also with a wet cooling tower (with water consumption). We try to use as much as possible the dry coolers, but if the outside temperature (dry bulb) is not low enough, we need to include also a wet cooling tower.

Methodology of measuring

Test environment:
Task 3.2 is based on simulations. There will be no measurements, lab tests or demo.

Contact: johan.vanbael@vito.be

3.2. Low-T geothermal source / GWC hybrid cooling

3.2.2. Electricity production increase

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Increase in electricity production of ORC hybrid cooled compared to cooling towers (%)

Rationale

The KPI evaluates the increase in annual electricity production compared to operation with wet cooling towers only. In summer efficiency of the plant is higher (as we use groundwater). However, the energy consumption of the groundwater pumps and the cooling tower fans over the year should be included in the evaluation.

Target

SOA: Cooling with cooling towers

Target: > 0.5% increase in electricity production

Source / Formula

Measurement data: (results from simulation)
- Net electricity production (hybrid cooling) E_{hybrid} (MWh/year)
- Net electricity production (wet cooling tower) E_{CT} (MWh/year)

According to water temperature and dry/wet bulb ambient air temperature

Formula:
$(E_{hybrid} – E_{CT}) / E_{CT} * 100$

Unit: %

Methodology of measuring

Test environment:
Task 3.2 is based on simulations. There will be no measurements, lab tests or demo.

Contact: johan.vanbael@vito.be

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WP4: High-T Geothermal Source – Hybrid CT

New filling media

4. High-T geothermal source / New filling media

4.1.1. Filling thermal performance

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Filling cooling capability for filling height of 1 meter (-)

Rationale

The KPI calculates the cooling capability of the advanced high-efficiency filling for one meter of filling, which can be compared to the cooling capability of the standard filling.

Source / Formula

Measurement data:
- Cold and Hot water temperature
- Wet Bulb Temperature of entering air
- Circulating water flow

Formula:
Calculation according to CTI (Cooling Technology Institute) standard: ATC-105 (Acceptance Test Code for cooling towers)

Unit:
- dimensionless

Target

SOA: High efficiency film filling
KaV/L = 0.27 (calculated for L/G=1 and filling height 1m)

Target: KaV/L > 1.40 (calculated for L/G=1 and filling height 1m)

Methodology of measuring

Test environment:
SPIG facility and Demo site

Test conditions:
- Circulating water flow rate and range at design conditions
- Absorbed fan power at design condition

Method:
Continuous and accurate monitoring of cooling capability

Contact: protopapa@spig-int.com / bertocchi@spig-int.com

4. High-T geothermal source / New filling media

4.1.2. Filling specific thermal performance (for total height)

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Filling cooling capability of demo module per fan power consumption (kW^{-1})

Rationale

The KPI calculates the cooling capability of the advanced high-efficiency filling for the height of the demo module divided by the power consumption of the fans.

Source / Formula

Measurement data:
- Filling cooling capability of demo module, KaV/L (see previous KPI)
- Power absorption (at fan motor shaft), P (kW)

Formula:

$$\frac{KaV/L}{P}$$

Unit:
kW^{-1}

Target

SOA: High efficiency film filling (0.012 kW^{-1})

Target: > 0.020 kW^{-1}

Methodology of measuring

Test environment:
SPIG facility and Demo site

Test conditions:
- Circulating water flow rate and range at design conditions
- Absorbed fan power at design condition

Method:
Continuous and accurate monitoring of cooling capability

Contact: protopapa@spig-int.com / bertocchi@spig-int.com

4. High-T geothermal source / New filling media

4.1.3. Material cost

Material costs of innovative fillings per MW (€/MW)

Rationale

The KPI measures the cost of the innovative filling for each MW of heat load discharged at design condition by the demo module.

An attempt shall be made to foresee the product costs considering mass production (10 demo modules).

Target

SOA: N/A (comparison among the innovative fillings under development)

Target: Costs to be specified in comparison to expected savings.
Success criteria: proven applicability

Source / Formula

Measurement data:
No direct measurement will be performed.
Costs will be estimated based on information gathered during the high efficiency filling development.

Formula:
Estimated costs / Demo Module Design Heat Load

Unit:
€/MW

Methodology of measuring

Evaluation of filling cost will be performed considering mass production for 10 demo modules.

Contact: protopapa@spig-int.com / bertocchi@spig-int.com

WP4: High-T Geothermal Source – Hybrid CT

Coatings for dry section modules

4. High-T geothermal source / Coatings for dry section modules

4.2.1. Pipe thermal conductivity

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Thermal conductivity of coated plate (W/(m-K))

Rationale

The applied coating shall not significantly decrease the heat transfer as this would be counterproductive to the effect of the air/water heat exchange.

Target

SOA: bare steel 53 W/(m-K) and aluminium 210 W/(m-K)

Target: as low as possible with respect to not coated material

Source / Formula

Measurement data / formula:
The KPI is directly determined by the measurement of the thermal conductivity of a coated plate for each material (Aluminium AL6082T and Carbon Steel S275JR) provided as average of at least 2 measurements (n° of measurements to be confirmed).

- Thermal conductivity of coated plate λ (in $Wm^{-1}K^{-1}$)

Unit: $Wm^{-1}K^{-1}$

Methodology of measuring

Test environment:
Laboratory

Method:
- Transient plane heat source (hot disc) method

Contact: protopapa@spig-int.com / bertocchi@spig-int.com

4. High-T geothermal source / Coatings for dry section modules

4.2.2. Coating corrosion resistance

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Average corrosion rate (mm/year)

Rationale

The KPI evaluates the ability of different coatings in mitigating corrosion on low-grade materials exposed to high temperature geothermal fluid sources. Objective is to replace expensive materials by cheaper combinations of lower grade SS or carbon steel with coatings.

Target

SOA: No coating, utilization of expensive materials (high grade stainless steels, Ni and Ti alloys) with high corrosion resistance.

Target: <~0.01 mm/year
Success criteria: < 0.1 mm/year

Source / Formula

Measurement data:
Corrosion current density

Formula:
$I_{corr} = B/ R_p$
B is a constant and R_p is the polarization resistance
The corrosion current is calculated from the polarization resistance (R_p) and converted to average corrosion rate according to standard procedure for LPR measurements (1 A/m² corresponds to 1.16 mm/year)

Unit: mm/year

Methodology of measuring

Test environment: high-temperature geothermal plant
Test conditions:

- Media: brine/liquid from high-temperature geothermal site (alternatively, synthetic brines/liquid with equivalent composition) (according to guidelines from T2.2)
- Exposure time: 1 month minimum
- Temperature: 20-40 °C

Method:
The corrosion current density is determined through electrochemical analysis (LPR/EIS) of the coated samples.

Contact: protopapa@spig-int.com / bertocchi@spig-int.com

4.2.3. Water repellence

Static water contact angle, after exposure (degree)

Rationale

The KPI quantifies the ability of a surface to repel water. The action of repelling water that is already in contact with the surface is quantified by the static contact angle.

Inner surface of the pipes of the dry module are coated to increase the water repellence and increase resistance against fouling.

Target

SOA: uncoated/untreated stainless steel (yet to be measured ; expected in the range of 0 - 30°)
Target: not specific, the higher the better (expected 70 - 90°)

Source / Formula

Measurement data / Formula:
The KPI is directly determined by the measurement of the water contact angle and provided as average and standard deviation of at least 5 measurements (n° of measurements to be confirmed).

Unit: °

Methodology of measuring

Test environment: Laboratory

Test conditions:
The contact angle is measured on a flat coupon after exposure in a dry bundle mock-up simulating the cooling tower application.

1) Exposure of the flat coupons in dry module mock-up: Temperature approx. 35 °C, exposure time: 1000 hr.
2) Laboratory test on a flat coupon after exposure.

Method: static water contact angle.

Contact: protopapa@spig-int.com / bertocchi@spig-int.com

4.2.4. Coating adhesion

Adhesion rating after immersion in a corrosive environment (-)

Rationale

The KPI evaluates the coating adhesion. Adhesion is viewed as the strength of the bonds between the coating material and the substrate. Coating adhesion provides a tool to evaluate the integrity of the coating and its potential for the intended performance. The adhesion will be tested by a common cross-cut and tape test. The tape test will be performed after exposure. The cross cut will simulate defects in the coating, that are expected to be not completely avoidable. The exposure is milder than the real conditions, but suitable as an experimentally simple pre-selection.

Target

SOA: No coating, utilization of expensive materials (high grade stainless steels, Ni and Ti alloys) with high corrosion resistance (very high PREN)

Success criteria: A rating of 2 or better (to be confirmed)

Source / Formula

Measurement data:
The test is performed according to the ISO 2409

Formula:
The KPI is the rating of samples between 0 (best) and 5 (worst) according to ISO 2409

Unit: -

Methodology of measuring

Test environment: Laboratory
Substrates: Aluminium AL6060 and Carbon steel ASTM A 214

Test conditions:
The test is performed after the installation of the pipe in a dry bundle mock-up simulating the cooling tower application. Pipe will have to be cut in half to perform the test.

1) Exposure of the pipe in dry module mock-up: Temperature approx. 35 °C, exposure time: 1000 hr.
2) Laboratory test on cut pipe after exposure.

Method:
ISO 2409, but three tear-offs instead of one (to be confirmed).

Contact: protopapa@spig-int.com / bertocchi@spig-int.com

4. High-T geothermal source / Coatings for dry section modules

4.2.5. Dry section costs

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Cost increase compared to standard dry module sections (%)

Rationale

The KPI evaluates the cost increase due to new material and inner surface coating of the dry section.

Target

SOA: AISI 316L dry section not coated

Target:

Success criteria: proven applicability

Source / Formula

Measurement data:
No direct measurement will be performed.
Costs will be estimated based on information gathered during new dry section development.

Formula:
New dry section costs / Standard dry section cost

Unit:
%

Methodology of measuring

Evaluation of filling cost will be performed considering mass production for 20 dry sections demo modules.

Contact: protopapa@spig-int.com / bertocchi@spig-int.com

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WP5: Steam condenser and CT water circuit

5.1. Condenser steam side – Coatings and surface texturing

5.1. Condenser steam side / Coatings and surface texturing

5.1.1. Water repellence

Receding water contact angle under condensation, after exposure (degree)

Rationale

The KPI quantifies the ability of a surface to repel water. The action of repelling water that is already in contact with the surface, either due to condensation or drainage from upper pipes, is quantified by the receding contact angle.
On the pipes of SOA steam condensers, the condensing water forms a continuous film. This film is heat-insulating and reduces the heat transfer. Water repellent surfaces shall ensure, that condensing water contracts and part of the condenser's pipe surface stays free of water to improve efficiency.

Source / Formula

Measurement data / Formula:
The KPI is directly determined by the measurement of the water contact angle and provided as average and standard deviation of at least 5 measurements.

Unit: °

Target

SOA: uncoated/untreated stainless steel (yet to be measured ; expected in the range of 0 - 30°)
Target: not specific, the higher the better (expected 70 - 90°)

Methodology of measuring

Test environment: Laboratory
Test conditions:
The contact angle is measured after exposure (simulating a power plant application) of test panels (microscope slide or larger) and under condensation conditions.

1) Exposure in condensation chamber: Panel temp. ~40°C, humidity > 100%, declination ~45°, duration 1000 h
2) In a normal laboratory atmosphere, the test panel is placed on a cooling block at ~1°C. After condensation has lead to visible drops (d at least 2 mm), a receding water contact angle is determined on at least 5 spots on the cold sample.

Method: the angle is determined with a cannula inside the drop, sucking up water.

Contact: Stefan Holberg, DTI, SHG@teknologisk.dk

5.1. Condenser steam side / Coatings and surface texturing

5.1.2. Coating adhesion

Adhesion rating after immersion in water (-)

Rationale

The KPI evaluates adhesion of the applied coatings and/or surface treatments to the condenser to provide drop-wise condensation.
The adhesion will be tested by a common cross-cut and tape test. The tape test will be performed after immersion in water at room temperature to simulate the humidity in the condenser. The cross cut will simulate defects in the coating, that are expected to be not completely avoidable. The exposure is milder than the real conditions, but suitable as a experimentally simple pre-selection. Each partner will test their own samples.

Source / Formula

Measurement data: see methodology

Formula:
The KPI is the rating of samples between 0 (best) and 5 (worst) according to ISO 2409

Unit: -

Target

SOA: No coating/treatment, thus no result available
Target: A rating of 2 or better

Methodology of measuring

Test environment: Laboratory
Test conditions / method:
Sample material: Duplex X2CrNiMoN22.5.3 (1.4462) stainless steel, either as flat panel (min. 2.5 x 5 cm) or as pipe. 3 samples or 3 test spots on one sample.
1) Cross cut: According to ISO 2409 but tolerance for the grit (1 mm to 1.5 mm) to allow cuts with a simple knife
2) Initial tape test: Acc. ISO 2409 (using Tesa Krepp 4331)
3) Immersion in demineralized water. Duration 67 to 77 h, temperature 18 to 16 C, thereafter wiping dry and testing within 5 min.
4) Final tape test: Acc. ISO 2409, but three tear-offs instead of one.

Contact: Stefan Holberg, DTI, SHG@teknologisk.dk

5.1. Condenser steam side / Coatings and surface texturing

5.1.3. Thermal conductance

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Thermal conductance estimation (W/m²-K)

Rationale

The applied coatings and/or surface treatments may not significantly decrease the heat transfer as this would be counterproductive to the effect of the desired drop-wise condensation.
To provide a simple evaluation at lab stage, the thermal conductance will be estimated by applying a published value of a similar material than the coating and dividing that value with the actual film thickness.
Each partner will evaluate their own samples.

Target

SOA: No coating/treatment, thus no result available.
Target: based on 10% additional heat transfer resistance for a condenser with an overall heat transfer coefficient U.

Cases	Thermal conductance	Thickness (with λ=0.2)
U = 3000 W/m²-K	> 30 000 W/m²-K	< 6.6 µm
U = 2000 W/m²-K	> 20 000 W/m²-K	< 10 µm

Treatments that solely render the structure, but not the surface chemistry, automatically pass this KPI.

Source / Formula

Measurement data:
- Thermal conductivity λ (in $Wm^{-1}K^{-1}$) (based on literature)
- Coating thickness d (in m)

Formula:
λ/d
A higher value indicates better heat conductance

Unit: $Wm^{-2}K^{-1}$

Methodology of measuring

Test environment: Laboratory
Method:
1) The thickness of the coating/treatment will be measured according to any method that is available and appropriate (e.g. inductive, profilometer, microscope)
2) The thermal conductivity of the material will be estimated by accessing published data on comparable materials. If no comparative materials, 0.2 W/(m*K) will be chosen.

Contact: Stefan Holberg, DTI, SHG@teknologisk.dk

5.1. Condenser steam side / Coatings and surface texturing

5.1.4. Applicability/costs

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Application costs per unit of surface (€/m²)

Rationale

Each partner shall state, whether they expect the respective coating/treatment to be suitable for real condensers (considering further development). An attempt shall be made to foresee the application costs considering mass production (10 condensers).

Target

SOA: No coating/treatment, thus no coating costs

Target: Costs to be specified in comparison to expected savings.
Success indicator: proven applicability

All partners will be aware, that such cost estimation is per se very unprecise and is solely used to point out expensive processes (more than 100 times more expensive than others). Coatings that differ by a factor of 10 or less should be regarded to be in the same order of magnitude.

Source / Formula

Measurement data:
No direct measurement will be performed
Costs will be estimated based on information gathered on application process

Formula:
Estimated costs / surface area

Unit: €/m²

Methodology of measuring

Each partner will perform evaluation of their coatings/treatments, considering to coat single pipes in mass production for 10 condensers (of 3000 m² surface area).
Length/no. of pipes to be specified.

Contact: Stefan Holberg, DTI, SHG@teknologisk.dk

5.1. Condenser steam side / Coatings and surface texturing

5.1.5. Steam cycle contamination

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Tests have still to be discussed and will occur in parallel to pilot/demo tests. KPI will be defined for the next revision of the deliverable.

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WP5: Steam condenser and CT water circuit

5.2. Condenser cooling water side – Stainless steel with biocide properties

5.2. Condenser cooling water side / SS with biocide properties

5.2.1. Bacterial inhibition performance

Biocidal efficiency of stainless steels (%)

Rationale

The KPI measures the effect of the bacterial inhibition on different stainless steels in order to optimize the condenser durability when alternative waters are employed.

Target

SOA: AISI 304, with 0.5% Cu, CR = 0.01%

Target: CR > 90% with ageing treatments
(= **success indicator**)

Source / Formula

Measurement data:
Colonization ratio (CR)

Formula:
CR= (A-B)/A×100
CR: indicates the percent decrease in viable cell number
A: number of microorganisms determined on a reference (standard stainless steel) after 24 h, (CFU cm^{-2}/ mL^{-1})
B: number of microorganisms on a tested stainless steel after 24 h (*CFU cm^{-2}/ mL^{-1})
*Colony forming unit

Unit: %

Methodology of measuring

Test environment: Laboratory

Test conditions:
- A specific viable cell number is deposited on both reference and tested stainless steel plates for a given incubation period
- Temperature: 30 - 40ºC
- Flow rate: 1.4 m/s

Method:
Viable bacteria counts are determined by automatic counting

Contact: a.fernandez@aimen.es

5.2. Condenser cooling water side / SS with biocide properties

5.2.2. Copper release

Cu^{2+} release from antimicrobial stainless steels (ppm)

Rationale

The KPI determines the trace amounts of Cu^{2+} ions released from the stainless steel alloys to the testing solution.

Target

SOA: Cu-Ni alloy 90-10, 0.09 ppm (after 24 h) measured in the effluent of a condenser

Target: Environmental regulations compliance
Regulations: BREF 0.01-0.05 ppm in water effluents
EQS (annual average) 0.001ppm

Source / Formula

Measurement data:
Amount of dissolved Cu^{2+} released from a specific surface of stainless steel per liter of testing solution (alternative water).

Formula:
Cu^{2+} concentration*= $\frac{mass\ of\ Cu^{2+}\ released\ (mg)}{Solution\ volume\ (L)}$
*referred to an specific area of the stainless steel

Unit: ppm

Methodology of measuring

Test environment: Laboratory

Test conditions:
- Medium: alternative water
- Temperature: 30 - 40ºC
- Time: 24 h

Method:
Concentration of dissolved copper in the alternative water is determined by inductively coupled plasma optical emission spectroscopy (ICP-OES) after 24 h of metal exposure.

Contact: a.fernandez@aimen.es

5.2. Condenser cooling water side / SS with biocide properties

5.2.3. Corrosion performance of Cu-bearing stainless steels

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Corrosion rate of Cu-bearing stainless steels in presence of bacteria

Rationale

The KPI evaluates the microbiologically-influenced corrosion (MIC) resistance of different bearing-Cu alloys in presence of alternative waters used in cooling systems.

Target

SOA: 304L in E.Coli culture I_{corr} = 0.01mm/year after 2 days and I_{corr}= 0.06mm/year after 21 days of immersion.
Cu-Ni I_{corr}= 0.02 mm/year at short term exposures

Target: 0.01mm/year

Source / Formula

Measurement data:
Equivalent corrosion current density (I_{corr})

Formula:
$I_{corr} = B/ R_p$
B is a constant and R_p is the polarization resistance
The corrosion current is calculated from the polarization resistance (R_p) and converted to average corrosion rate according to standard procedure for LPR and/or EIS measurements (1 A/m² corresponds to 1.16 mm/year)

Unit: mm/year

Methodology of measuring

Test environment: Laboratory

Test conditions:
- Media: alternative water (composition to be defined)
- Temperature: 30 - 40º C
- Time: 24 h

Method:
The corrosion current density is determined through electrochemical analysis (LPR and/or EIS) of the samples exposed to alternative water.

Contact: a.fernandez@aimen.es

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WP5: Steam condenser and CT water circuit

5.3. Condenser cooling water side – Anti-fouling coatings

5.3. Condenser cooling water side / Antifouling coatings

5.3.1. Bacteria adhesion

Bacteria content in the biofilm of coated surface compared to reference (%)

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Rationale

Bacteria are the first organisms to attach to the surface leading to further fouling. Bacterial biofilm can be formed quickly (<24h) and quantified by absorbance measurement. Ideal for laboratory evaluation of efficiency of an antifouling coating.

Target

SOA: Non-treated surface / surface treated with a biocide-free commercial paint (not applicable on condenser because of thickness)
Target: 0% bacteria

Source / Formula

Measurement data:
- Absorbance of coated surface
- Absorbance of reference surface (non-treated / treated with a commercial paint)

Formula:
Absorbance of coated surface / Absorbance of reference surface * 100

Unit: %

Methodology of measuring

Test environment: Laboratory

Test conditions / Method:
Known quantity of a stationary culture of a specific strain is exposed to the surface of the well of a PS 96-well plate treated with the test compound.
- Vial is filled with known quantity of a stationary culture of a specific strain
- Incubation 24h at 37°C
- Biofilm formation
- Removal of non-adhering bacteria
- Living cells coloration with Crystal Violet or MTT (to form a formazan dye)
- Measurement of absorbance of dye at 540 nm

Contact: sophie.peeterbroeck@materianova.be

5.3. Condenser cooling water side / Antifouling coatings

5.3.2. Bacteria adhesion after a bleach shock

Bacteria content in the biofilm of coated surface compared to ref. after a bleach shock (%)

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Rationale

The coatings should be able to resist to bleach shocks that will occur in industrial installations (e.g. for pathogens). Furthermore, if the condenser will be protected by the coating, it will not be the case for the rest of the circuit and use of bleach will be necessary. Objective of this KPI is to verify that these conditions do not lead to a degradation of surface properties and thus to an increase of fouling adhesion.

Target

SOA: Non-treated surface / surface treated with a biocide-free commercial paint (not applicable on condenser because of thickness)
Target: 0% bacteria

Source / Formula

Measurement data:
- Absorbance of coated surface after a bleach shock
- Absorbance of reference surface (non-treated / treated with a commercial paint)

Formula:
Absorbance of coated surface / Absorbance of reference surface * 100

Unit: %

Methodology of measuring

Test environment: Laboratory

Test conditions / Method:
Cf. 'Bacteria adhesion' KPI

Bleach shock simulation:
3 hours in water with 5 ppm free Cl at pH 7,5 and 42°C

Contact: sophie.peeterbroeck@materianova.be

5.3. Condenser cooling water side / Antifouling coatings

5.3.3. Thermal conductance

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Thermal conductance estimation (W/m²-K)

Rationale

The applied coatings may not significantly decrease the heat transfer in the condenser as this would be counterproductive to the effect of protection against fouling.
To provide a simple evaluation at lab stage, the thermal conductance will be estimated by applying a published value of a similar material than the coating and dividing that value with the actual film thickness.

Target

SOA: No coating
Target: based on 10% additional heat transfer resistance for a condenser with an overall heat transfer coefficient U.

Cases	Thermal conductance	Thickness (with λ=0.2)
U = 3000 W/m²-K	> 30 000 W/m²-K	< 6.6 µm
U = 2000 W/m²-K	> 20 000 W/m²-K	< 10 µm

Source / Formula

Measurement data:
- Thermal conductivity λ (in $Wm^{-1}K^{-1}$) (based on literature)
- Coating thickness d (in m)

Formula:
λ/d
A higher value indicates better heat conductance

Unit: $Wm^{-2}K^{-1}$

Methodology of measuring

Test environment: Laboratory
Method:
1) The thickness of the coating will be measured according to any method that is available and appropriate (e.g. inductive, profilometer, microscope)
2) The thermal conductivity of the material will be estimated by accessing published data on comparable materials. If no comparative materials are available, a value of 0.2 W/(m*K) will be chosen, as this is a typical value for many polymers

Contact: sophie.peeterbroeck@materianova.be

5.3. Condenser cooling water side / Antifouling coatings

5.3.4. Coating adhesion after a bleach shock

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Adhesion rating after a bleach shock (-)

Rationale

The KPI evaluates adhesion of the applied coatings to the condenser cooling water side after a bleach shock.
The adhesion will be tested by a common cross-cut and tape test. The tape test will be performed after a bleach shock. The cross cut will simulate defects in the coating, that are expected to be not completely avoidable. The exposure is milder than the real conditions, but suitable as a experimentally simple pre-selection.

Target

SOA: Non-treated surface

Target: A rating of 2 or better

Source / Formula

Measurement data: see methodology

Formula:
The KPI is the rating of samples between 0 (best) and 5 (worst) according to ISO 2409

Unit: -

Methodology of measuring

Test environment: Laboratory
Test conditions / method:
Sample material: Duplex X2CrNiMoN22.5.3 (1.4462) stainless steel, either as flat panel (min. 2.5 x 5 cm) or as pipe. 3 samples or 3 test spots on one sample.
1) Cross cut: According to ISO 2409 but tolerance for the grit (1 mm to 1.5 mm) to allow cuts with a simple knife
2) Initial tape test: Acc. ISO 2409 (using Tesa Krepp 4331)
3) Immersion in demineralized water. Duration 67 to 77 h, temperature 18 to 16 C, thereafter wiping dry and testing within 5 min. **Bleach shock simulation:** 3 hours in water with 5 ppm free Cl at pH 7,5 and 42°C.
4) Final tape test: Acc. ISO 2409, but three tear-offs instead of one.

Contact: sophie.peeterbroeck@materianova.be

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WP6: Cooling water treatment and water recovery

6.1. Membrane Capacitive Deionization

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6.1. Cooling water treatment / MCDI for feedwater

6.1.1. Water recovery

Ratio of product water flow to feed water flow (%)

Rationale

The KPI measures the ratio of purified water that can be recovered from feed water. It therefore also quantifies the water efficiency of the technology.

Source / Formula

Measurement data:
- Product water flow rate
- Feedwater flow rate

Formula:
product water flow rate (l/h) / feedwater flow rate (l/h) x 100

Unit:
%

Target

SOA: 70-90% (commercially available MCDI technology)
(SOA for surface water used as CT intake water: no or limited treatment (sand filtration, de-ironing, chemical softening,…)

Target: 80-95%, depending on the nature of the feed stream, specifically the concentration range.

Methodology of measuring

Test environment: Lab/pilot
Test conditions:
- Variable flow rate
- Variable voltage, current
- Variable concentration (feedwater quality)

Method:
- Most accurate measure between flow rates and volumes on test period

Contact: joost.helsen@vito.be

6.1. Cooling water treatment / MCDI for feedwater

6.1.2. Charge efficiency (CE)

Ratio of salt adsorption (desorption) over corresponding charges (%)

Rationale

The charge efficiency is the ratio of the amount of equivalents that are adsorbed onto the electrical double layer of the electrodes and the electrical charges for polarizing the electrode. It therefore expresses how efficient the electrical charges are used to remove ions from the feedwater

Target

SOA: 50-80% (commercially available MCDI technology)
(SOA for surface water used as CT intake water: no or limited treatment (sand filtration, de-ironing, chemical softening,…)

Target: 90%

Source / Formula

Measurement data:
- Time
- Current
- Feed water composition (as Electrical Conductivity) converted to equivalents (using a calibration curve)

Formula:
(Adsorbed equivalents/current x time) x 100

Unit: %

Methodology of measuring

Test environment: Lab/pilot
Test conditions:
- 25°C
- Variable flow rate
- Variable voltage, current
- Variable concentration (feedwater quality)

Method:
- Voltage and current over cell are measured continuously
- Electrical charge can be determined in each sample by multiplying current with time of sample
- Adsorbed equivalents can be determined based on changes in conductivity or analytically

Contact: joost.helsen@vito.be

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6.1. Cooling water treatment / MCDI for feedwater

6.1.3. Salt adsorption capacity (SAC)

Amount of salt or specific ions adsorbed per mass of electrodes (mg NaCl/g electrode)

Rationale

The salt adsorption capacity describes the maximum amount of salts or specific ions that can be adsorbed on to the electrical double layer of the microporous carbon structure of the electrodes.

Target

SOA: 10mg NaCl/g electrode (commercially available MCDI)
(SOA for surface water used as CT intake water: no or limited treatment (sand filtration, de-ironing, chemical softening,…)

Target: 10mg NaCl/g electrode

1-2g NaCl/m² electrode (assuming 100-200g/m² electrodes)

Source / Formula

Measurement data:
- Adsorbed ions (from EC measurement or analytical)
- Weight (m) /surface (S) electrodes
- Feedwater volume (V)
- Time (t)

Formula:

$$\frac{\sum_{t=t_0}^{t_{eq}} ([\text{NaCl}]_{\text{in, t}} - [\text{NaCl}]_{\text{out, t}}) * Vt}{\text{m (g)}}$$

with t_{eq}: time to reach equilibrium

Unit: mg NaCl/g

Methodology of measuring

Test environment: Lab
Test conditions:
25°C
1V

Method:
- CDI cell is continuously fed with fresh feed water
- Constant voltage adsorption at +1V
- Current and conductivity are continuously measured
- End of measurement when influent conductivity equals effluent conductivity

Contact: joost.helsen@vito.be

6.1. Cooling water treatment / MCDI for feedwater

6.1.4. Salt adsorption rate (ASAR90)

Average rate of salt adsorption for 90% saturation (mg NaCl/min-g)

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Rationale

Salt adsorption rate describes how fast ions are removed from the bulk liquid and adsorbed onto the electrical double layer of the electrodes. For CDI this rate depends on the saturation of the electrodes and therefore the ASAR90 is chosen. This is the average salt adsorption rate to achieve 90% adsorption of the electrodes.

Target

SOA: 1 mg NaCl/min.g (commercially available MCDI)
(SOA for surface water used as CT intake water: no or limited treatment (sand filtration, de-ironing, chemical softening,…)
Target: 1mg NaCl/min.g
0,1-0,2g/min.m² (assuming 100-200g/m² electrodes)

Source / Formula

Measurement data:
- Adsorbed ions (from EC measurement or analytical)
- Weight (m) /surface (S) electrodes
- Feedwater volume (V)
- Time (t)

Formula:

$$\frac{\sum_{t=t_0}^{t_{90}} ([\mathrm{NaCl}]_{in,\,t} - [\mathrm{NaCl}]_{out,\,t}) * Vt)}{\mathrm{m\ (g)} * t_{90}}$$

With t_{90}: time to reach 90% adsorption

Methodology of measuring

Test environment: Lab
Test conditions:
25°C
1V
Method:
- CDI cell is continuously fed with fresh feed water
- Constant voltage adsorption at +1V
- Current and conductivity are continuously measured
- End of measurement when influent conductivity equals effluent conductivity
- 90% adsorption is determined, corresponding time gives ASAR90

Contact: joost.helsen@vito.be

6.1. Cooling water treatment / MCDI for feedwater

6.1.5. Ions removal efficiency

Percentage of total ions removed (%)

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Rationale

The KPI measures the average quality of product water versus that of the feed water by measuring total ions concentration. This can be determined from EC or analytically (specific ion concentrations).

Target

SOA: 50-70% (commercially available MCDI)
(SOA for surface water used as CT intake water: no or limited treatment (sand filtration, de-ironing, chemical softening,…)

Target: 80%

Source / Formula

Measurement data:
- Product water total ions
- Feedwater total ions

Formula:
$[\text{total ions}]_{\text{product water}} / [\text{total ions}]_{\text{feedwater}} \times 100$

Unit:
%

Methodology of measuring

Test environment: Lab/pilot
Test conditions:
- Feedwater temperature and quality (Ca, suspended solids)
- Applied current, voltage, feed rate/module
- Module type and configuration

Method:
- Most accurate measure between flow rates and volumes on test period
- Voltage and current over cell are determined continuously
- Average product and feed samples are used

Contact: joost.helsen@vito.be

6.1. Cooling water treatment / MCDI for feedwater

6.1.6. Specific energy consumption per cycle

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Energy used by the technology (adsorption & desorption) per m³ of product water (kWh/m³)

Rationale

The energy consumption of the CDI cell is expressed in terms of produced effluent volume (EV), without accounting for differences in effluent quality. It consists of adsorption (ADS), desorption (DES) and pumping energy.

Target

SOA: 0.05-5 kWh/m³ (commercially available MCDI)
(SOA for surface water used as CT intake water: no or limited treatment (sand filtration, de-ironing, chemical softening,…)

Target: < 2 kWh/m³
Success criteria: < 1-5 kWh/m³ (reverse osmosis)

Source / Formula

Measurement data:
- produced water flow rate (Q)
- pressure drop across CDI module (Δp)
- current (I), voltage (U) and time (t)
- volume of treated water during adsorption phase (V)

Formula:

$$\frac{\left(\sum_{t=t_0}^{t_{ADS}} U_{t,ADS} \times I_{t,ADS} \times t\right) + \left(\sum_{t=t_0}^{t_{DES}} U_{t,DES} \times I_{t,DES} \times t\Delta\right) + \left(\sum_{t=t_0}^{t} \Delta p_t \times Q_t\right)}{V_{ADS}}$$

Unit:
kWh/m³ product water

Methodology of measuring

Test environment: Lab/pilot
Test conditions:
- Feedwater temperature and quality (Ca, suspended solids)
- % desalination, product water quality
- Applied feed rate/module
- Module type and configuration

Method:
- Most accurate measure between flow rates and volumes on test period
- voltage and current over cell are determined continuously

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WP6: Cooling water treatment and water recovery

6.2. IVG-C CoolWater

6.2. Cooling water treatment / IVG-C Coolwater

No KPI at laboratory scale

The IVG-C Coolwater technology for the treatment of cooling tower recirculation water will not be evaluated at laboratory scale.
(Tests will however be planned to evaluate the IVG-C Coolwater technology for use in combination with other water treatment technologies (RO, MD) to increase efficiency and reduce scaling during RO/MD treatment)

SOA for circulation water cooling tower: chemical dosing

WP6: Cooling water treatment and water recovery

6.3. Membrane distillation for blowdown

6.3. Cooling water treatment / MD for blowdown

6.3.1. Water recovery

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Ratio of product water flow to feedwater flow (%)

Rationale

The KPI measures the amount of high quality water that can be recovered from the blowdown and used as make-up water or for other scopes, thus reducing water withdrawal from the environment

Target

SOA for CT blowdown water: evaporation, RO treatment

Target: Water recovery should be as high as possible, depending on feed water quality

Source / Formula

Measurement data:
- Distillate flow rate (= product flow rate)
- Feedwater flow rate

Formula:
Distillate flow rate (l/h) / Feedwater flow rate (l/h) x 100

Unit:
%

Methodology of measuring

Test environment: Lab/Pilot
Test conditions: (to be specified)
- Heat source temperature and thermal power
- Feedwater temperature and quality (Ca, suspended solids)
- Recirculation ratio of the concentrate
- Module configuration (well insulated membrane module to avoid heat loss)
- Coolant temperature

Method:
Gravimetric

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6.3. Cooling water treatment / MD for blowdown

6.3.2. Separation efficiency

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Separation efficiency (%)

Rationale

The KPI measures the retention of non-volatile components in the feed solution.

Target

SOA for CT blowdown water: evaporation, RO treatment

Target: 99.99 %

Source / Formula

Measurement data:
- Concentration of non-volatiles in the feed solution (c_f)
- Concentration of non-volatiles in the distillate (c_p)

Formula:

$$R = 1 - \frac{c_p}{c_f}$$

Unit:
%

Methodology of measuring

Test environment: Lab/Pilot
Test conditions: (to be specified)
- Module configuration (well insulated membrane module to avoid heat loss)
- Feed and distillate temperature (and thus temperature difference over membrane)
- Feed and permeate quality
- Crossflow velocity feed and distillate

Method:
?

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WP6: Cooling water treatment and water recovery

6.4. Membrane distillation for waste water

6.4. Cooling water treatment / MD for FGD wastewater

6.4.1. Water recovery

Ratio of product water flow to feedwater flow (%)

Rationale

The KPI measures the amount of high quality water that can be recovered from the FGD wastewater and used as make-up water or for other scopes, thus reducing water withdrawal from the environment

Target

SOA for FGD wastewater: evaporation

Target: Water recovery should be as high as possible depending on feedwater quality

Source / Formula

Measurement data:
- Distillate flow rate (= product flow rate)
- Feedwater flow rate

Formula:
Distillate flow rate (l/h) / Feedwater flow rate (l/h) x 100

Unit:
%

Methodology of measuring

Test environment: Labo/pilot
Test conditions:
- Heat source temperature and thermal power
- Feedwater temperature and quality (Ca, suspended solids)
- Recirculation ratio of the concentrate
- Module configuration (well insulated membrane module to avoid heat loss
- Coolant temperature

Method:
Gravimetric

Contact: francesca.macedonio@unical.it

6.4. Cooling water treatment / MD for FGD wastewater

6.4.2. Separation efficiency

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Separation efficiency (%)

Rationale

The KPI measures the retention of non-volatile components in the feed solution.

Target

SOA for FGD wastewater: evaporation

Target: 99.99 %

Source / Formula

Measurement data:
- Concentration of non-volatiles in the feed solution (c_f)
- Concentration of non-volatiles in the distillate (c_p)

Formula:

$$R = 1 - \frac{c_p}{c_f}$$

Unit:
%

Methodology of measuring

Test environment: Lab/Pilot
Test conditions: (to be specified)
- Module configuration (well insulated membrane module to avoid heat loss)
- Feed and distillate temperature (and thus temperature difference over membrane)
- Feed and permeate quality
- Crossflow velocity feed and distillate

Method:
?

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WP6: Cooling water treatment and water recovery

6.5. Pressure driven membranes

6.5.1.1. Water recovery

Ratio of product water flow to feedwater flow (%)

Rationale

The KPI measures the amount of high quality water that can be recovered from the FGD wastewater and used as make-up water or for other scopes, thus reducing water withdrawal from the environment

Target

SOA for FGD wastewater: evaporation

Target: water recovery should be as high as possible depending on feedwater quality

Source / Formula

Measurement data:
- Permeate flow rate
- Feedwater flow rate

Formula:
Permeate flow rate (l/h) / Feedwater flow rate (l/h) x 100

Unit:
%

Methodology of measuring

Test environment: Lab / pilot

Test conditions:
- Operative pressure: (around 55 atm)
- Feedwater quality (Ca, suspended solids): soften water

Method:
Gravimetric

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6.5.1.2. Ions removal efficiency

Percentage of total ions removed (%)

Rationale

The KPI measures the average quality of product water versus that of the feed water by measuring total ions concentration.

Target

SOA for FGD wastewater: evaporation

Target: conductivity < 800 microS/cm

Source / Formula

Measurement data:
- Product water total ions (conductivity)
- Feedwater total ions (conductivity)

Formula:
$[\text{total ions}]_{\text{product water}} / [\text{total ions}]_{\text{feedwater}} \times 100$

Unit:
%

Methodology of measuring

Test environment: Lab/pilot

Test conditions:
- Feedwater quality (Ca, Mg, Na, etc., total suspended solids)
- Conductivity

Method:
Conductivity meter, ICP or IC for Ca, Mg, Na, etc

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6.5. Cooling water treatment / Integrated membrane system MF/UF+NF/RO+MD for FGD wastewater

6.5.2.1. Water recovery

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Ratio of product water flow to feedwater flow (%)

Rationale

The KPI measures the amount of high quality water that can be recovered from the FGD wastewater and used as make-up water or for other scopes, thus reducing water withdrawal from the environment

Target

SOA for FGD wastewater: evaporation

Target: water recovery should be as high as possible depending on feedwater quality

Source / Formula

Measurement data:
- Distillate flow rate = RO Permeate flow rate + MD Distillate flow rate
- Feedwater flow rate

Formula:
Distillate flow rate (l/h) / Feedwater flow rate (l/h) x 100

Unit:
%

Methodology of measuring

Test environment: Lab / Pilot

Test conditions:
- Feedwater quality (Ca, suspended solids): soften water
- MD Operative temperature (around 40-60°C – to be decided after the experimental tests)
- Well insulated membrane module (to avoid heat loss)
- Module configuration

Method:
Gravimetric

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6.5. Cooling water treatment / Integrated membrane system MF/UF+NF/RO+MD for FGD wastewater

6.5.2.2. Ions removal efficiency

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Percentage of total ions removed (%)

Rationale

The KPI measures the average quality of product water versus that of the feed water by measuring total ions concentration.

Target

SOA for FGD wastewater: evaporation

Target: conductivity < 800 microS/cm

Source / Formula

Measurement data:
- Product water total ions (conductivity)
- Feedwater total ions (conductivity)

Formula:
$[\text{total ions}]_{\text{product water}}$ / $[\text{total ions}]_{\text{feedwater}}$ x 100

Unit:
%

Methodology of measuring

Test environment: Lab/pilot

Test conditions:
- Feedwater quality (Ca, Mg, Na, etc., total suspended solids)
- Conductivity

Method:
Conductivity meter, ICP or IC for Ca, Mg, Na, etc

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WP6: Cooling water treatment and water recovery

6.6. Membrane Condenser

6.6. Water recovery / Membrane condenser

6.6.1. Water recovery

Ratio of product water flow to feedwater flow (%)

Rationale

The KPI measures the amount of high quality water that can be recovered from the CT wastewater vapour and used as make-up water or for other scopes, thus reducing water withdrawal from the environment

Source / Formula

Measurement data:
- Liquid water flow rate
- Feedwater flow rate (evaporation flow of the cooling tower - water content in air stream in liquid and gaseous form)

Formula:
Liquid water flow rate / Feedwater flow rate x 100

Unit:
%

Target

SOA: In general Not applied in Power Industry. Possible technologies:
- liquid and solid sorption: 22-62%
- dense membranes: 20-40%
- membrane condenser (microporous hydrophobic membranes)

Target: 20% with $\Delta T<6°C$ and around 50% at ΔT equal to 16°C

Methodology of measuring

Test environment: Lab
Test conditions:
- RH (relative humidity) of the CT wastewater vapour: to be defined after the first experimental tests
- T of the CT wastewater vapour: to be defined after the first experimental tests
- DT: to be defined after the first experimental tests

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6.6. Water recovery / Membrane condenser

6.6.2. Water quality

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Water quality (ppm)

Rationale

The KPI measures the concentration of high quality water that can be recovered from the CT wastewater vapour and used as make-up water or for other scopes, thus reducing water withdrawal from the environment

Source / Formula

Measurement data:
- Treated water total ions (ppm)
- conductivity (μS/cm)

Unit:
- ppm
- μS/cm

Target

SOA: In general Not applied in Power Industry. Possible technologies:
- liquid and solid sorption
- dense membranes
- membrane condenser (microporous hydrophobic membranes)

Target: Sufficient for cooling tower make-up

Methodology of measuring

Test environment: Lab
Test conditions:
- RH of the CT wastewater vapour: to be defined after the first experimental tests
- T of the CT wastewater vapour: to be defined after the first experimental tests
- composition of the CT wastewater vapour: to be defined after the first experimental tests
- DT: to be defined after the first experimental tests

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4 Next steps

This first version of the report will be updated with KPIs at technical and global level for pilot and demonstration phase (Month 18). This document will be used as a starting point to support and validate laboratory / demonstration testing (WP7).