Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2014.946722

55 (2015) 3506–3518
September

Taylor & Francis
Taylor & Francis Group

Techno-economic assessment of boiler feed water production by membrane distillation with reuse of thermal waste energy from cooling water

Norbert Kuipers[a,*], Robin van Leerdam[a], Jolanda van Medevoort[a], Willy van Tongeren[a], Bart Verhasselt[b], Lieve Verelst[b], Marnix Vermeersch[b], Dominique Corbisier[b]

[a]*TNO, Utrechtseweg 48, 3704 HE Zeist, The Netherlands, Tel. +31 (0)88 866 21 67; Fax: +31 (0)88 866 2049; email: norbert.kuipers@tno.nl (N. Kuipers)*
[b]*Laborelec/GDF Suez, Rodestraat 125, 1630 Linkebeek, Belgium, Tel. +32 (0)2 382 02 11; Fax: +32 (0)2 382 02 41*

Received 28 February 2014; Accepted 16 June 2014

ABSTRACT

The European KIC-Climate project Water and Energy for Climate Change (WE4CC) aims at the technical demonstration, business case evaluation and implementation of new value chains for the production of high-quality water using low-grade thermal waste energy from cooling water. A typical large-scale waste heat water network is the production of the boiler feed water from surface water using waste heat of temperatures below 60°C from power plants. Two innovative membrane distillation concepts for the production of high-quality water were evaluated for this case in terms of operational conditions, equipment size and costs which are dependent on the available amount of waste heat and its temperature.

- Memstill® (partial use of waste heat, by partially cooling down cooling water such that the remaining heat can be reused for other applications, e.g. for the recovery of desiccant solutions)
- MD-HEX, i.e. membrane distillation with an extra integrated heat envelope within the Memstill® module for full use of waste heat which is taken up by the produced water and/or the concentrate.

Both Memstill® and MD-HEX behave as a demineralised water (demi-water) producing once-through cooler. Due to the utilisation of waste heat, much less electricity is needed for the production of demi-water relative to other water production technologies. Memstill® also behaves as a waste heat-consuming demi-water producing technology. Thus, significant reductions in cooling water intake, costs and GHG emissions can be achieved.

Keywords: Low-grade heat; Waste heat; Desalination; Boiler feed water; Demi-water; Heat water networks; Membrane distillation; Memstill®

---

*Corresponding author.

Presented at the Conference on Desalination for the Environment: Clean Water and Energy 11–15 May 2014, Limassol, Cyprus

1. Introduction

In Europe, huge amounts of waste heat are lost. In the Netherlands alone, this already amounts to more than 250 PJ per year for low-grade heat with temperatures above 50˚C [1]. This amount of thermal energy loss represents the equivalent of 8,000 Mm^3 natural gas, the emission of 3.5 Mton CO_2 and a potential value exceeding 1,000 M€.

Often this waste heat is discharged via cooling water into the surface water via once-through coolers, or towards the atmosphere via cooling towers. This requires the intake of water and use of electricity and results in various emissions. Table 1 shows typical emission values per MW_{th} for these systems [2]. In addition, the specific costs of cooling are reported. They are in the range 0.06–0.16 €ct GJ^{-1}, as calculated from typical data reported in European reference documents [3]. Besides water and energy, also intake of specific chemicals is needed to prevent fouling and scaling. These are about 250 (chlorine), 1,000 (sulphuric acid) and 50 (phosphate) kg $year^{-1}$ MW^{-1}.

Reuse of thermal energy from cooling water would therefore involve a significant contribution to the climate change goals, prevent loss of economic damage and contribute to better welfare of people in the cities and facilitate current and new energy production systems.

In the European project Water and Energy for Climate Change (WE4CC), new value chains and concepts were identified and developed for effective recovery of low-grade heat up to 60˚C. Here, the heat from low-temperature aqueous resources such as cooling water and industrial water is used to drive the production of high-quality water (boiler feed water, drinking water and process water) from typical aqueous feedstocks using membrane distillation or for dehumidification of humid air using liquid desiccants. The latter case can be used for climate control and is described in the literature [4].

In this paper, the focus is on the production of demineralised water (demi-water) as feedstock for high-pressure boilers in power plants. The potential available heat sources are characterised by large streams of low temperature (35˚C) and small streams of higher temperature (industrial heat, 40–60˚C). In order to identify potential business cases for the power plant and industrial heat, two generic concepts of membrane distillation were evaluated for on-site or near-site production of pure water.

2. Waste heat driven membrane distillation

Membrane distillation is a relatively new but well-documented technology, which is on the brink

Table 1
Typical performance indicators indicating the climate effect of cooling water treatment in once-through and recirculation systems per MW_{th} [2,3]

	Intake		Emissions to atmosphere			Emissions to water		
System	Water [m^3 $year^{-1}$ MW^{-1}]	Electricity [kW_e MW^{-1}]	Water [m^3 $year^{-1}$ MW^{-1}]	CO2 [ton $year^{-1}$ MW^{-1}]	Heat [MW]	Water [m^3 $year^{-1}$ MW^{-1}]	Heat [MW]	Specific cooling costs [€ct.$GJ_{th}{}^{-1}$]
Once-through	700,000	10	0	50	0	700,000	1	0.06–0.16
Cooling tower	14,400	27	11,000	136	0.98	0.08	0.02	0.06–0.16

of commercialisation [5]. It refers to a thermally driven transport of vapour through non-wetted porous hydrophobic membranes, the driving force being the vapour pressure difference between the two sides of the membrane pores. It is particularly suited for the applications in which water is the major and most volatile component present in the feed solution.

Various modes and configurations exist for membrane distillation. A highly efficient counter-current flow process can be realised in the so-called Memstill® process. Here, a cold aqueous feedstock (sea water for the case shown in Fig. 1(a)) enters the module and takes up heat in the condenser channel through condensation of water vapour. Next, a small amount of low-grade heat or waste heat is added, and the stream flows in the counter-current direction back via the membrane channel. Driven by the small amount of added heat, water evaporates through the membrane, and is discharged as cold condensate. The brine is disposed of or further concentrated in a next module. A heat exchanger between the condenser and membrane envelope supplies the necessary heat to the module. Because a Memstill® module houses a continuum of evaporation stages in an almost ideal counter-current flow process, a very high recovery of evaporation heat is possible.

Another configuration is characterised by the presence of an additional heat envelope, see Fig. 1(b). Instead of adding the heat at the top of the system, the heat is added over the full length of the membrane by allowing hot cooling water to flow parallel with the brine.

Both configurations can be characterised as a water-producing heat exchanger, where high-quality water (demi-water) and a concentrate (brine) are produced from an aqueous feedstock. From the point of view of heat transfer, there are some differences between both processes:

- Memstill®. It makes partial use of the waste heat source (hot cooling water), by partially cooling down cooling water such that its remaining heat can be used for other waste heat-driven applications or for discharge.
- Membrane distillation with an extra heat envelope (MD-HEX). Here the waste heat source is fully exploited and its heat is taken up by the produced water and/or the concentrate.

Concerning climate effects, Memstill® and MD-HEX behave as a (demi-) water-producing once-through cooler with emissions as reported in Table 1. Due to the use of waste heat, much less electricity is needed for the production of (demi-) water relative to alternative technologies such as reverse osmosis. The savings in CO_2-emissions are about 1 kg CO_2 m^{-3} water produced (seawater as feedstock). Additional savings can be realised by recycling the brine, preferably after cooling it down towards feedstock conditions or by using feedstock with higher salt contents.

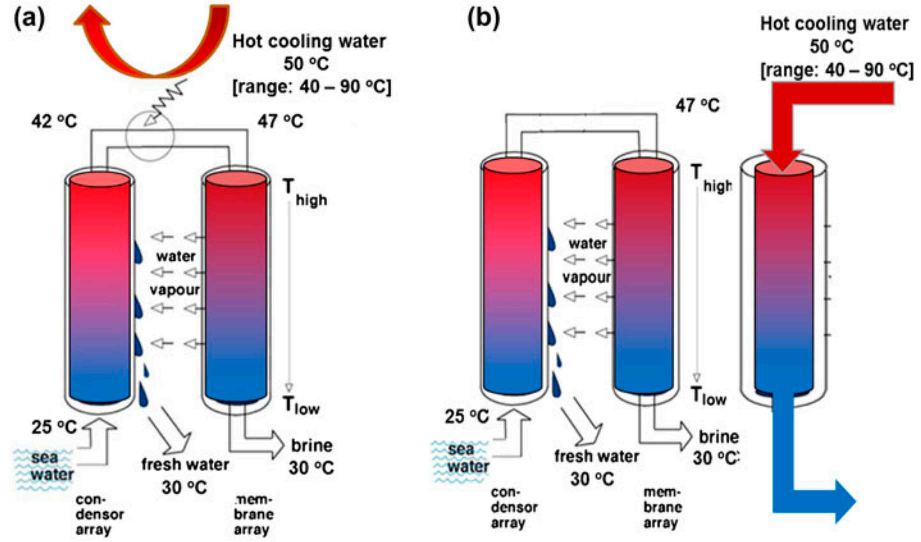

Fig. 1. Memstill® (a) and Memstill® with heat envelope (MD-HEX, b) using waste heat from cooling water (here at 50°C). For Memstill® the cooling water is partially cooled down (here ΔT = 5°C) by local heating of the feedstock with ΔT (°C) after passing the condenser array and heating of the fresh water and brine with the same ΔT (°C) relative to the feedstock. For Memstill® with heat envelope, all waste heat from the cooling water is utilised due to continuous heating of the brine in the membrane array which flows cocurrently.

3. Identification of potential business cases for the power industry

3.1. Identification, selection and evaluation of waste heat resources for power plants

In a market evaluation for the power industry, 10 residual heat streams in a power plant were identified and characterised. Based on the experience from existing (power) plants, temperature and flow ranges for each heat source are defined. These temperature and flow values should be considered as indicative values, as they are highly location- and design-specific. Special attention is also given to the availability of the heat source (continuous vs. discontinuous). Table 2 gives an overview of the results.

3.2. Screening and characterisation of demi-water needs for power plants

Power plants and other industrial plants produce and consume significant quantities of demi-water as boiler feed for their water steam circuits. The actual need for demi-water mainly depends on the type of plant.

The process of water loss in the water steam cycle for conventional fossil power plants is approximately 1%. For a plant of about 200 MW_e, this represents roughly estimated 100 m^3 of demi-water per day. If steam soot blowing is applied, the need for demi-water can rise up to roughly estimated another 100 m^3 per day more. The most recent gas-fired combined-cycle power plants consume less boiler feed water. For a 400 MW_e power plant, a consumption of approximately 30 m^3 d^{-1} can be expected. For plants with a direct steam delivery to industrial clients (e.g. cogeneration plants), high needs for demi-water should be taken into account.

The required demi-water quality is depending on several parameters such as the pressure of the boiler system and the design of the water steam cycle. Table 3 shows the specifications for high pressure boiler water systems (>100 bar) according to international guidelines [6].

Based on available distillate data from the Memstill® pilot test at the Rotterdam Maasvlakte as

Table 2
Summary table for heat sources in industrial environments with a focus on power plants (CCGT = combined cycle gas turbine; LTHE = low temperature heat exchanger)

Heat source	Temperature range	Flow range	Availability
Boiler water blow down	Max. 100°C	• Max. 2.5 m^3/week (CCGT 450 MW_e) • Max. 10 m^3/week (conventional high pressure power plant 180 MW_e)	Discontinuous
Condenser cooling water	15–40°C	Max. 86 m^3 h^{-1} MW_{th}^{-1} (3)	Continuous
Turbine lubricating and control oil circuit	52–65°C	50 m^3 h^{-1} (CCGT 450 MW_e)	Continuous
Closed cooling circuits	5–50°C	• 150 m^3 h^{-1} (fossil power plant 180 MW_e) • 480 m^3 h^{-1} (CCGT 450 MW_e)	Continuous
Bottom ash process water	Max. 100°C	10 m^3 d^{-1}	Continuous
Waste water from flue gas desulfurisation (FGD) unit	40–45°C (with LTHE) 50°C (without LTHE)		Continuous
Purified FGD effluents	40°C	2–10 m^3 h^{-1}	Continuous
Heat recovery from flue gases	70–80°C (CCGT) 40–50°C; 80–100–120°C (coal fired plants)	External cooling flow necessary	Continuous
Return condensates	80–100°C		Continuous
Condensates from district heating	70–100°C		Continuous

represented in the last column of Table 3, it can be concluded that the membrane permeate quality does not fully comply with the water quality needs for high-pressure boiler feed water. Therefore, it is imperative to design a post-treatment after the Memstill® module to obtain demi-water for high-pressure boiler systems. A mixed-bed (MB) unit or an electro deionization (EDI) unit is recommended as final polishing step. In order to avoid (ir)reversible damage to the resins (especially the anion resins) present in the MB or EDI units, it is recommended to use only cold Memstill®/MD-HEX distillate. After all, condensate polishing applications in the power plants are currently limited to temperatures around 35–40˚C. Referring to the limited data-set of the pilot test at the Rotterdam Maasvlakte, it can be expected that only small-scale post-treatment will be necessary for high-pressure boiler systems.

3.3. Screening and characterisation of available water sources

In order to produce demi-water, industrial plants use different kinds of water sources. More and more, special attention is given to the use of lower quality water streams like surface water, seawater, recuperated water and waste water. After all, the actual cost and future cost for tap water and well water become less and less beneficial. Furthermore, in the framework of the European water directive, it will become more and more difficult to obtain permits for the production of demi-water from tap water or well water. All of these water streams contain a certain amount of dissolved gases. These gases will pass the Memstill® (or MD-HEX) membrane during operation resulting in a decrease of the vapour flux and consequently the overall recovery of the unit. Therefore, it is recommended to install a degasser (membrane contactor or vacuum degasser) upstream the membrane distillation unit. Furthermore, it has to be remarked that some types of water have particular disadvantages in terms of water quality:

- Surface water and seawater

  Surface water and seawater are characterised by a high variability in terms of water quality. Suspended solids, biological organisms, salts, etc. could be high and vary a lot with respect to the season, the specific location and the rainfall density. This type of water has a high fouling potential, both microbiological and colloidal. In the framework of a potential use of these kinds of water flows in Memstill® (or MD-HEX) applications, it is recommended to foresee an advanced pre-filtration. Based on pilot tests it can be expected that at least a pre-filter of 40–100 μm should be foreseen in front of the membrane distillation module in order to prevent the module from fouling. Furthermore, it is advised to install a pre-filter of 200–500 μm in front of the filter in order to protect the first filter.
- Well water

  In order to prevent the deposit of iron- or manganese oxides, often present in shallow well water, it is recommended to install a sand filter with oxidation step (or other treatments) upstream the Memstill (or MD-HEX) unit. Considering the use of deep well water, it can be expected that no additional pre-treatment will be necessary.
- Waste water

  The exact composition of waste water depends a lot on the application where the waste is produced. Considering concentrated waste water streams (e.g. with salt concentrations exceeding those of the brine from a reversed osmosis unit), it should be emphasised that the warming up of these streams in the

Table 3
Required demi-water quality for high-pressure boiler water systems (>100 bar) [6] and Memstill® distillate specification from desalinated North Sea water in a pilot plant at E.ON Benelux (Maasvlakte, Rotterdam) [7]

Parameter	Unit	Normal value for high pressure boiler water	Memstill® distillate
Specific conductivity	$\mu S\ cm^{-1}$ (25 ˚C)	<0.10	0.75
Silica—SiO_2	$\mu g\ kg^{-1}$	<10	0.0275
Sodium—Na	$\mu g\ kg^{-1}$	<3	0.011
Chloride—Cl	$\mu g\ kg^{-1}$	<3	0.13
Sulfate—SO_4	$\mu g\ kg^{-1}$	<3	<0.02
Iron—Fe	$\mu g\ kg^{-1}$	<5	n.a.
Total organic carbon—TOC	$\mu g\ kg^{-1}$ ˚C^{-1}	<300	0.3

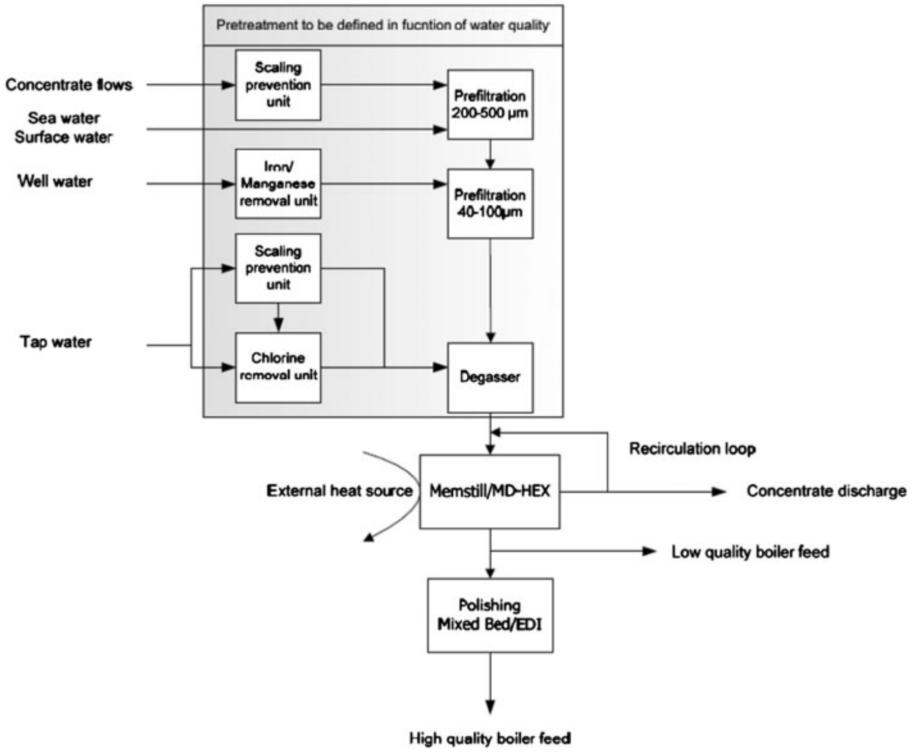

Fig. 2. Overall process flow diagram for the integration of Memstill®/MD-HEX in the production process of high-pressure boiler feed water.

Memstill® (or MD-HEX) units implicates high risks of fouling and scaling of the integrated heat exchanger and the membrane. In such cases, it is recommended to foresee an anti-scalant dosing (or softening unit) upstream the pre-filter unit of the Memstill® (or MD-HEX) unit.

3.4. Overall process flow diagram

Assuming boiler feed as the most important water need in power plants, cogeneration plants and other steam-producing plants, the following overall process flow diagram for the integration of a Memstill® (or MD-HEX) unit was considered, see Fig. 2. It has to be remarked that the design of the pre-treatment highly depends on the quality of the water sources. In order to increase the Memstill®/MD-HEX recovery, the possibility of concentrate recirculation is added to the flow diagram.

4. Design assumptions for potential business cases

In order to evaluate the feasibility of potential Memstill®/MD-HEX applications, a theoretical business case for power plants was defined, based on the assumptions as summarised in Table 4. It has to be emphasised that this business case will only be used as an evaluation tool. After all, the pilot and/or final implementation of a Memstill®/MD-HEX application will be highly location- and sector-specific.

Table 4
Most important assumptions for the techno-economic evaluation of potential business cases

Assumption	Value	Unit
Distillate flow	10	t h^{-1}
Expected recovery	5	%
Maximum outlet temperature Memstill®/ MD-HEX	30	°C
Temperature gradient over Memstill®/ MD-HEX	5	°C
Cost brine disposal as cooling water	0.01	€ m^{-3}
Estimated pre-treatment costs as % of total costs	10	%
Estimated polishing costs	0.15	€ m^{-3}
Estimated costs for heat recuperation	0–2	€ GJ^{-1}
Estimated cost for demi-water (UFRO)	3	€ m^{-3}

4.1. Demi-water quantity and quality need

As theoretical business case, a coal fired power plant with a consumption around 10 t h^{-1} of high quality boiler feed water is assumed. Furthermore it is considered that this quantity of water is currently produced by the help of an UFRO-MB demineralisation unit (ultrafiltration/reverse osmosis-mixed-bed) fed by surface water. The production of this water quantity should be (partially) replaced in the future by help of a Memstill®/MD-HEX unit. As high quality boiler feed water is needed, it can be expected that the Memstill®/MD-HEX distillate has to be polished in a mixed-bed/EDI unit. Considering an existing UFRO-MB demineralisation plant, the mixed-bed unit can still be used as a polishing unit for the distillate. So, for the total cost calculation of the polishing step of the Memstill®/MD-HEX unit, only the OPEX of the mixed bed should be taken into account. This is estimated to be around 0.1–0.15 € m^{-3}.

4.2. Raw water quantity and quality needs

Assuming a recovery around 5% of the future Memstill®/MD-HEX unit, it can be expected that 200 t h^{-1} of "raw water" will be necessary in order to obtain 10 t h^{-1} of distillate. In the framework of the "European water framework directive" and from the economical point of view, use of tap water or well

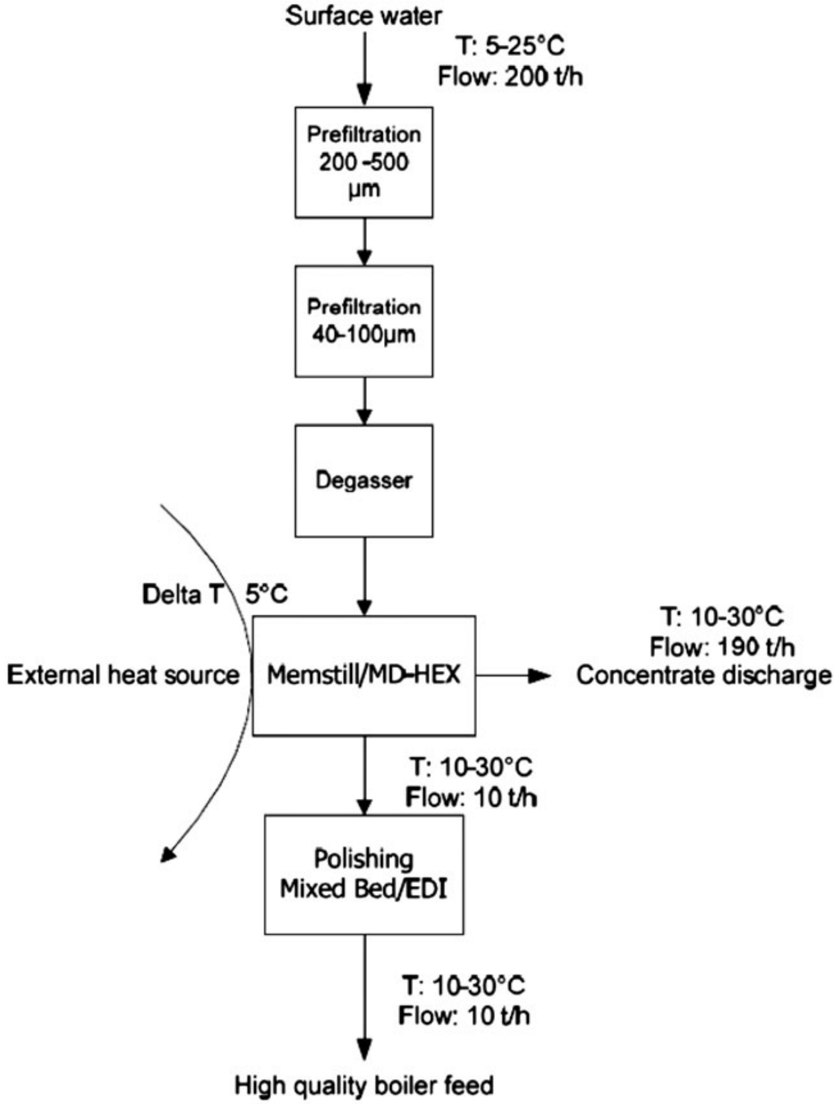

Fig. 3. Basic design of Memstill®/MD-HEX case.

water is excluded as the “raw water” source. After all, only 5% of the inlet flow will be useful. So, in this theoretical business case, surface water (fresh/brackish/seawater) is considered as the only potential “raw water” source.

As surface water is used, a pre-treatment consisting of a pre-filtration (200–500 μm and 40–100 μm) and a degasser should be foreseen in front of the Memstill®/MD-HEX unit. Concerning the pre-treatment, an additional cost of 2–10% of the Memstill®/MD-HEX distillate cost (in € m^{-3}) is considered. This implies, in further economical evaluations, an additional cost of 0.2 € for an estimated distillate cost of 2 € m^{-3}.

4.3. Concentrate water quantity and quality

Assuming a recovery around 5% of the future Memstill®/MD-HEX unit, it can be expected that 190 t h^{-1} of concentrate will be produced in order to obtain 10 t h^{-1} of distillate. So, in comparison to a traditional UFRO-MB (assumption of an overall recovery around 65%), more than 180 t h^{-1} of additional concentrate can be expected for the Memstill®/MD-HEX configuration. This indicates an additional discharge cost for the Memstill®/MD-HEX configuration. When the local legislator considers this water flow as cooling water (roughly estimated at 0.01 € m^{-3}), a discharge cost of 1.9 € h^{-1} should be taken into account for this example. This cost will be much higher in case the concentrate is considered as waste water (0.03–0.7 € m^{-3}). During operation of the Memstill®/MD-HEX, the concentrate flow will gradually increase in temperature. So it will be important, in the framework of the local environmental legislation, to configure the Memstill®/MD-HEX unit in compliance with the applicable thermal discharge limits. In many European countries, 30°C is considered as the absolute thermal discharge limit in surface water. This means, assuming surface water temperatures between 5 and 25°C, that the concentrate may only increase with 5°C during the hottest period of the year. Therefore, it was decided to design the Memstill®/MD-HEX case for a temperature difference of 5°C (which can be considered as conservative).

4.4. Defined parameters and basic design of Memstill®/MD-HEX case

Fig. 3 schematically shows the basic design and the range of values for the operation parameters as based on the above assumptions.

4.5. Benchmark demi-water

The design and consequently the overall cost of a demineralisation unit for the production of demi-water from surface water depend a lot on the quality of the surface water and operational mode. The cost price for 1 m^3 of demi-water (high-quality boiler feed)

Table 5
Typical values of the techno-economic parameters for Memstill®/MD-HEX

Parameter	Value	Unit
Operation hours per year	8,000	hours $year^{-1}$
Savings MD + HEX relative to Memstill® with external exchanger	15	%
Heat consumption	72	kWh m^{-3} distillate
Cost waste heat (cost hot cooling water)	1 (0.0036)	€ GJ^{-1} (€ kWh^{-1})
Discharge cost cold cooling water	0.000	€ kWh^{-1}
Intake cost feedstock	0.000	€ m^{-3} feedstock
Discharge cost concentrate	0.000	€ m^{-3} concentrate
Electricity consumption	0.0278	kWh m^{-3} feedstock
Electricity costs	0.1	€ kWh^{-1}
Membrane module costs (current)	100	€ m^{-2} (Memstill®)
	110	€ m^{-2} (MD-HEX)
Membrane module costs (2,020)	30	€ m^{-2} (Memstill®)
	35	€ m^{-2} (MD-HEX)
Annual depreciation installation	10	%
Annual depreciation membrane module	25	%
Maintenance installation	3	%
Interest	5	%

will increase by the presence of high loads of salts in the surface water. In order to define a benchmark value, experience from power plants was collected, resulting in an estimated cost of 3 € m^{-3} of demi-water (for a production around 12 $m^3 h^{-1}$ by membrane technology). In order to evaluate the feasibility of a future Memstill®/MD-HEX application, the total estimated distillate cost should be lower than 3 € m^{-3}. In the calculation of the Memstill®/MD-HEX distillate cost, attention was given to the integration of the energy benefits resulting from the temperature reduction of the external heat source and the energy requirements for cooling down the brine flow in order to comply with the local discharge limit. As the simulations are made for a maximum temperature of 30℃ (=discharge limit in many European countries) for the brine flow, only a net energy profit can be expected.

4.6. *Memstill®/MD-HEX*

Table 5 schematically shows the assumptions for the techno-economic evaluation of membrane distillation by Memstill® and MD-HEX. Estimates of both the

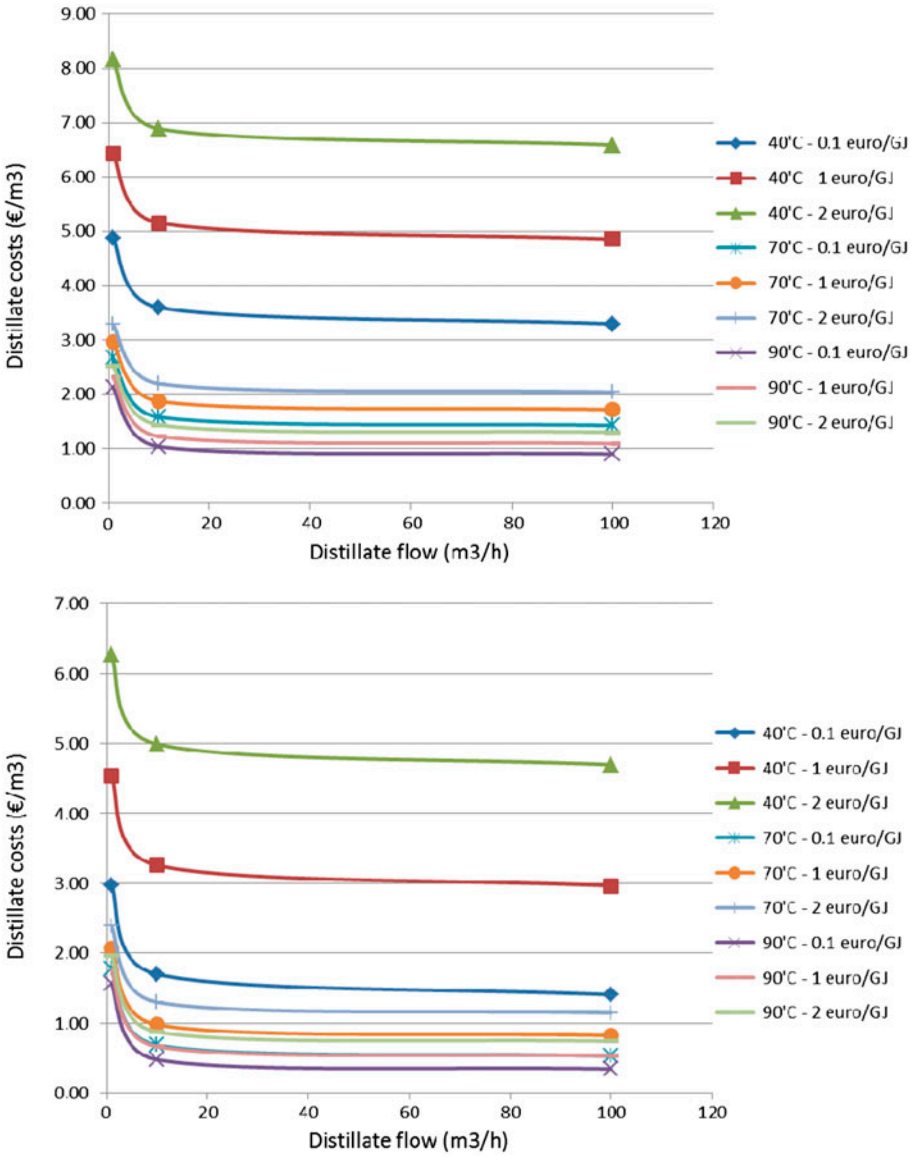

Fig. 4. Effect of temperature (40–90℃) and price (0.1, 1 and 2 € GJ^{-1}) of waste heat on the distillation production costs as a function of its capacity for Memstill® (assuming current membrane module prices of 100 € m^{-2}, in upper graph, and membrane module prices of 30 € m^{-2} for future commercial membranes, in lower graph).

current (non-commercial) membrane module prices and future commercial installations (2,020) are shown.

Based on the above assumptions, an estimate can be made of the current and future distillate production costs with respect to its production capacity, the temperature of the heat source and the costs of (waste) heat, see Fig. 4. Here, we assume heat prices of 0.1 (assuming the waste heat is available for free), 1 and 2 € GJ^{-1}. Also note that negative costs may be allocated to waste heat once it needs to be removed by cooling towers or other coolers (see Table 1).

The distillate costs range from about 1 to 8 € m^{-3}, where the lower limit is realised for high production capacities, a high waste heat temperature and low costs of waste heat. For the future, even lower prices are forecasted once membrane modules are commercially available. In general, the total capital costs depend on the size of the installation and thus on the feed flow. At a distillate production rate of 1 m^{-3} h^{-1}, these costs are substantial but at 10 and 100 m^{-3} h^{-1} they are not a significant part of the total production costs. The capital costs of the membrane modules decrease with increased waste heat temperatures. The reason is that at higher waste heat temperatures, fluxes are higher, and therefore less membrane surface is needed. Finally, it may be noticed that the price of waste heat might be the decisive factor for the application of Memstill® in a particular business case.

5. Business case evaluation for the power industry

After application of the design and operation constraints from Section 4 on the potential test systems as discussed in Section 3, a techno-economic analysis has resulted in the identification of three potential interesting business cases for the power industries:

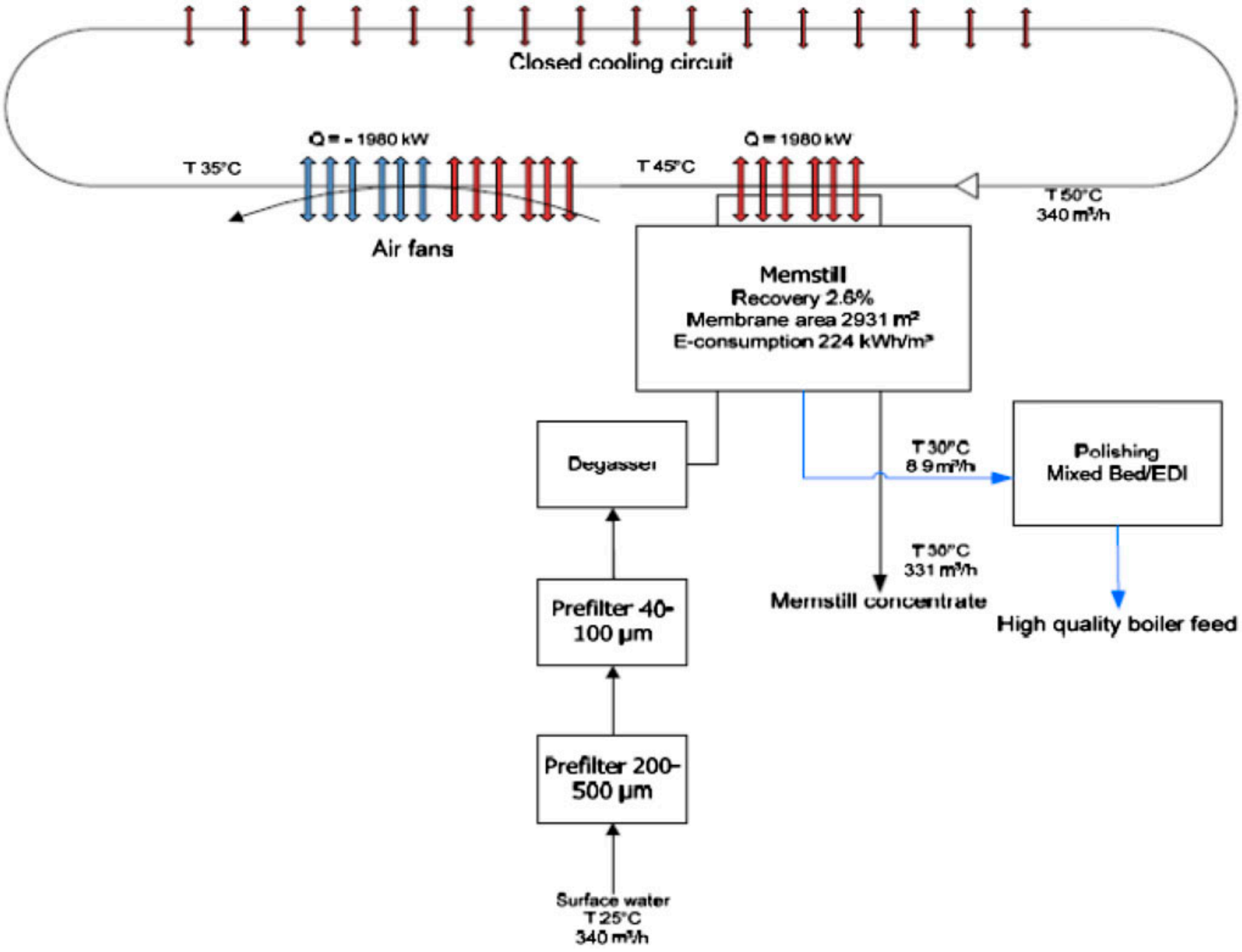

Fig. 5. Memstill® linked to a high-temperature closed cooling circuit.

- Memstill®/MD-HEX linked to a high temperature closed cooling circuit (see Fig. 5).

  As closed cooling circuits are widely spread within the power industry (and the industry in general), it can be expected that there is a potential market for industrial implementation. For further tests, they should be focused on high-temperature circuits.

- MD-HEX linked to a turbine lubricating oil circuit (see Fig. 6).

  This commonly used cooling circuit in power plants should be considered as a vital part for power plants. So, pilot tests and/or industrial implementation can only be approved after a series of successful lab tests and in accordance with the turbine supplier.

- Memstill® linked to the FGD waste water basin (see Fig. 7).

  There could be a potential market for coal fired power plants in Europe. Nevertheless, first of all the impact of fouling/scaling of the FGD water on the heat exchanger should be tested thoroughly on lab scale before further upscaling.

Based on the results of (some of) these test cases, the accomplishment of a detailed techno-economic evaluation will result in the final selection of a Memstill®/MD-HEX business case. Lab and pilot tests are needed in order to collect the indispensable(practical) input for the further development of the Memstill®/MD-HEX model, technical evaluation of Memstill®/MD-HEX applications and to be able to perform a detailed benchmark study.

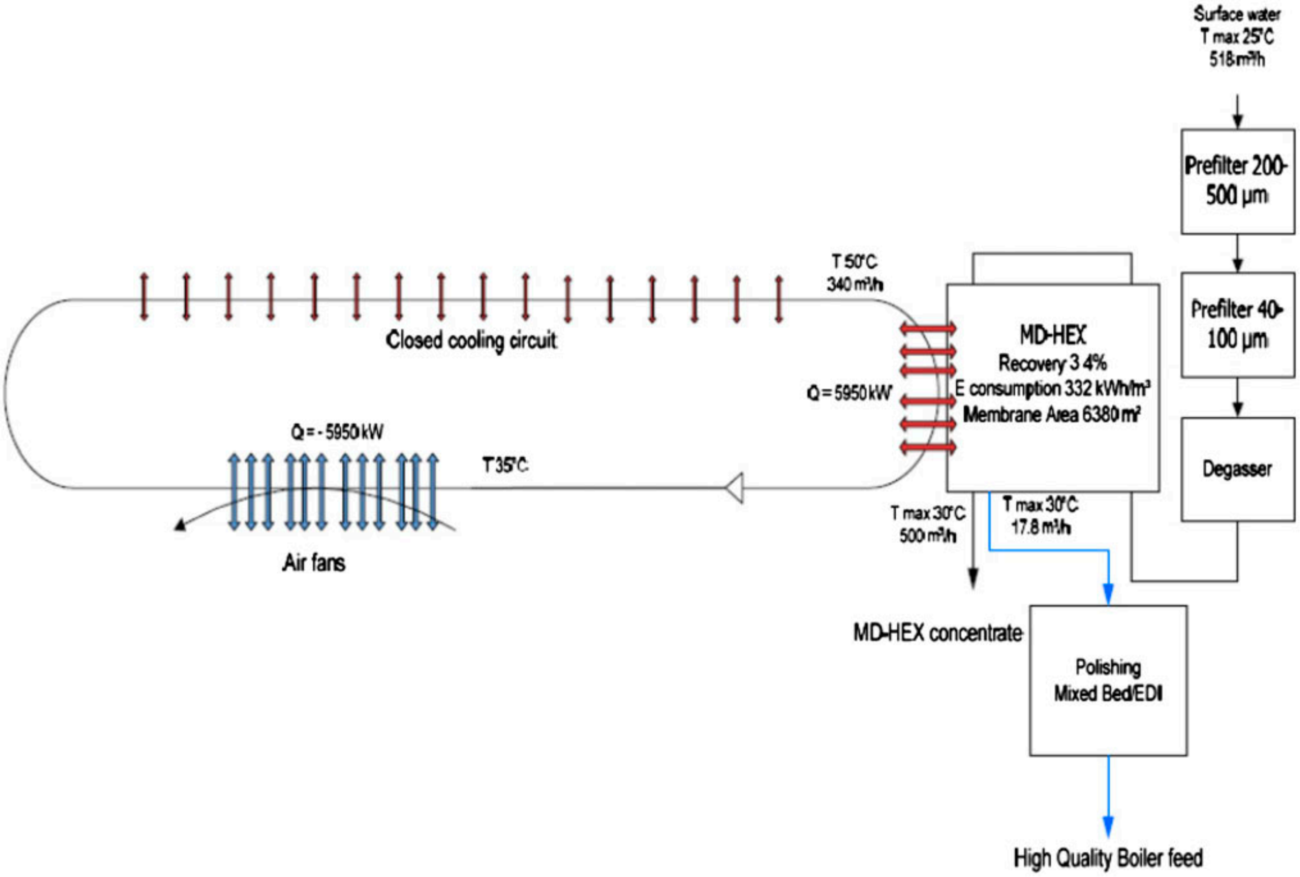

Fig. 6. MD-HEX linked to a high-temperature closed cooling circuit.

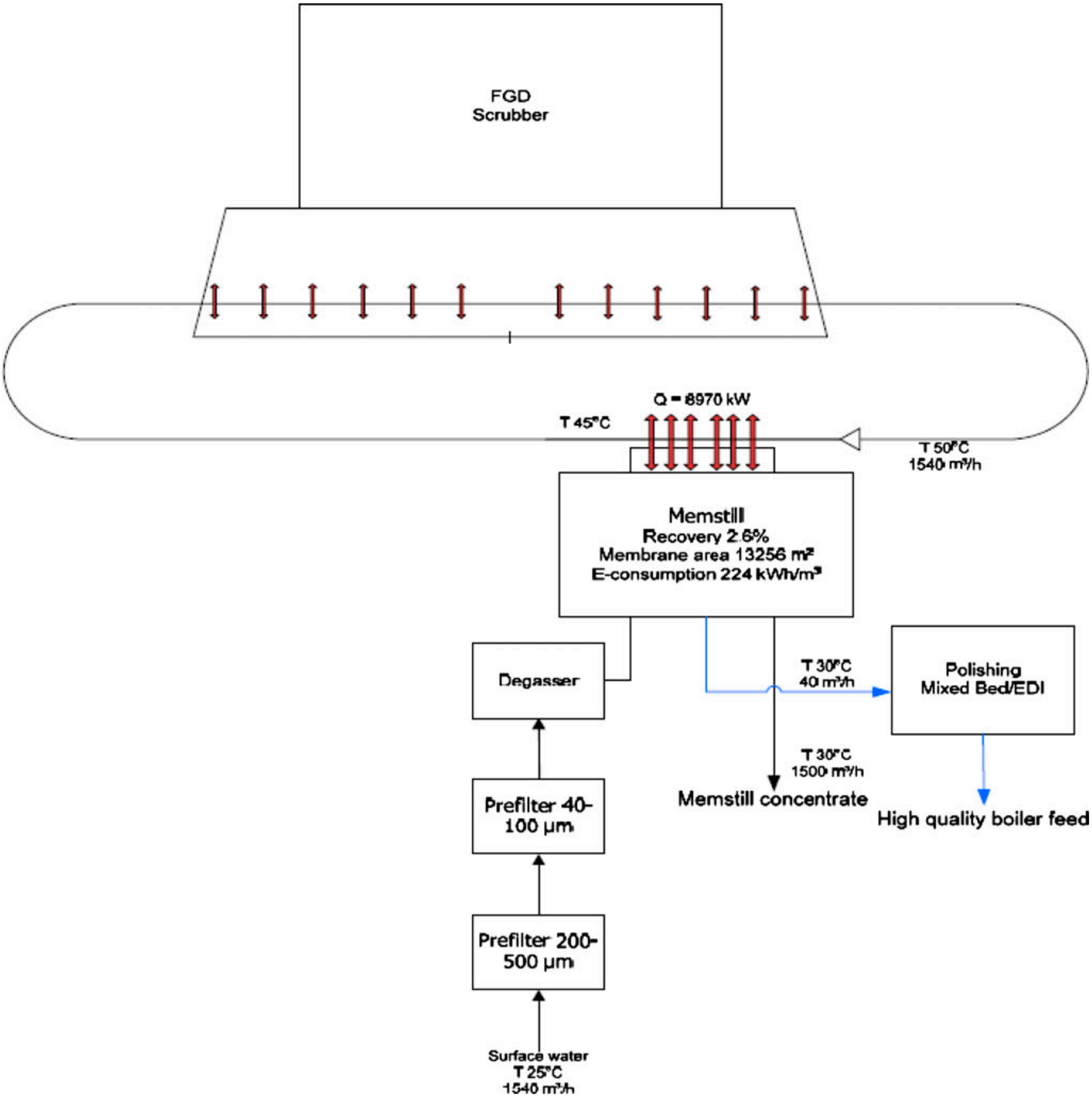

Fig. 7. Memstill® linked to FGD waste water basin.

6. Conclusions

Based on conceptual designs several potential business cases have been identified for power plants to utilise waste heat from cooling water to make high-pressure boiler feed water at costs below 3 € m^{-3} based on two innovative membrane distillation concepts: Memstill® and MD-HEX. These are:

(1) Memstill/MD-HEX linked to a high-temperature closed cooling circuit.
(2) MD-HEX linked to a turbine lubricating oil circuit.
(3) Memstill linked to the FGD waste water basin.

Memstill and MD-HEX behave as demi-water-producing once-through coolers. Due to utilisation of waste heat, much less electricity (0.75 kWh m^{-3}) is needed for the production of demi-water relative to other technologies (reverse osmosis: 2–3 kWh m^{-3}), i.e. the CO_2-emission for water production may be reduced to 50–75%, thus about 0.8 kg CO_2 m^{-3} water produced.

Memstill also behaves as a waste heat consuming demi-water producing technology. Thus, for cases where both high-quality water is required and waste heat has to be removed, less heat needs to be discharged for additional cooling. Then, the intake of additional cooling water can be reduced which also results in decreasing emissions of GHG and cooling water chemicals.

By utilising the remaining waste heat effluent stream from Memstill for other purposes, such as the recovery of desiccants for climate control, an additional 30–50% electricity reduction can be realised relative to climate control technologies driven by fossil energy. Thus, by cascading Memstill in new waste heat–water–desiccants networks, the overall utilisation of waste heat can be significantly increased.

A detailed techno-economic evaluation including technical demonstration of these cases is needed for the validation of these business cases. This asks for lab and pilot tests to collect the indispensable(practical) input to minimise the risks for technical demonstration, for further development of design models (Memstill/MD-HEX model), and to be able to perform a detailed benchmark study.

References

[1] S. Spoelstra, M.E.H. Tijani, Thermoacoustic heat pumps for energy savings, presented at the seminar “Boundary crossing acoustics” of the Acoustical Society of the Netherlands, 2005, http://intranet.energy.intra/publicaties/.

[2] Ministry of Infrastructure and the Environment of The Netherlands, Directorate General for Public Works and Water Management, CIW assessment system for discharging heat, 2004.

[3] European Commission, Integrated Pollution Prevention and Control (IPPC), Reference Document on the Application of Best Available Techniques to Industrial Cooling Systems, December, 2001.

[4] M. Buchholz, R. Buchholz, A. Hanßke, C. Paitazoglou und F. Ziegler, Nutzung von Sole als Energieträger und Speichermedium in einem urbanen Entwicklungsgebiet (Utilization of brines as energy sources and storage medium in urban areas), Third International Conference, Low Temperature and Waste Heat Use in Energy Supply Systems, October, 25–26, Bremen, 2012.

[5] M. Khayet, T. Matsuura, Membrane distillation—Principles and applications, Elsevier, Amsterdam, 2011.

[6] NEN-EN 12952-12 2003, Ketels met pijpen en hulpinstallaties—Deel 12: Eisen voor kwaliteit van boilervoedingswater en boilerwater (Water-tube boilers and auxiliary installation—Part 12: Requirements for boiler feed water and boiler water quality), 2003.

[7] A.E. Jansen, J.W. Assink, J.H. Hanemaaijer, J. van Medevoort, E. van Sonsbeek, Development and pilot testing of full-scale membrane distillation modules for deployment of waste heat, Desalination 323 (2013) 55–65.