DELIVERABLE NO WP4.D2
DRAFT PROCEDURES AND RESOURCE DOCUMENTS
Subtask 6: Solar Desalination

Dissemination level: Public

August 2007

New Generation of Solar Thermal Systems

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In total this Deliverable consists of 16 pages.

The task of WP4.D2 “draft procedures and resource documents” was divided into the following 9 subtasks:

1. advanced collectors
2. advanced stores
3. advanced controllers
4. combisystems
5. solar cooling
6. solar desalination
7. fluids
8. LCA (Life Cycle Assessment)
9. m² -> power and energy

The resource documents of subtask 6 “solar desalination” (subtask leader: Demokritos) are included in this report.

Guidelines for the selection of materials for solar thermal desalination plants

1. Introduction

The contact of saline water to the materials used at solar thermal desalination plants, principally referring to the heat exchanger for the heating of saline water, potentially causes problems. These problems are mainly related to corrosion phenomena. The following analysis examines the basic characteristics of the undesirable phenomena, the behaviour of candidate materials to these phenomena and suggests guidelines for the selection of appropriate materials for the various components of solar thermal desalination plants. Consequently, a list of proposed materials is suggested.

2. Corrosion

Corrosion is a phenomenon that might occur in various types, nevertheless not necessary connected to thermal desalination (e.g. corrosion due to mechanical fatigue or due to fluid motion). The most significant types of corrosion, connected to thermal desalination, and their basic characteristics are:

a. Usual surface corrosion in stagnation conditions

The corrosion rate of various materials is presented in figure 1. The materials with the most resistant behaviour are brass, bronze, copper, Cu-Ni alloys, and mainly stainless steel and nickelmolybdeniumchromium.

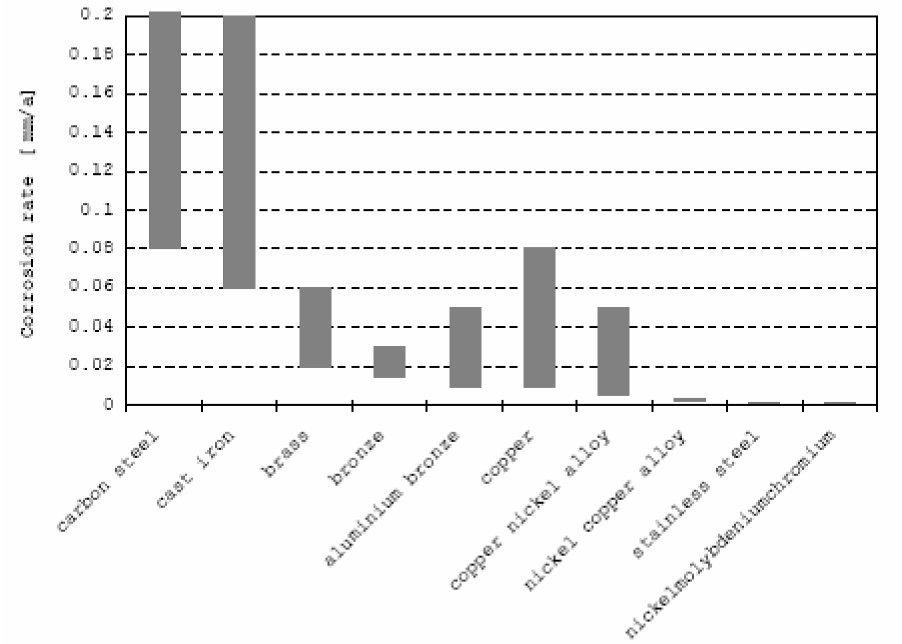

Figure 1: Corrosion rate of various materials under stable conditions

b. Pitting corrosion

This type of corrosion is developed under stagnation conditions or low velocities of fluid, in areas with lack of oxygen. It is favoured by existing surface particularities (cavities, cracks, etc.). Typical areas that present this kind of corrosion are interface of metals to screws, rivets, shims or even local welding.

Typical pitting corrosion rates for various materials are presented in figure 2.

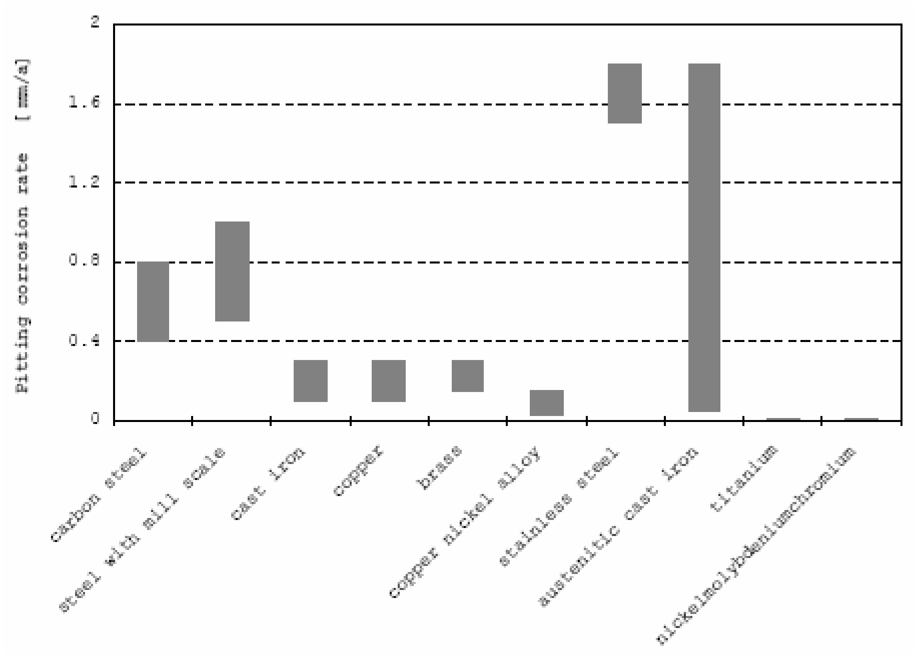

Figure 2: Pitting corrosion rate of various materials under stable conditions

In this figure, one may observe that stainless steel appears to be vulnerable in this type of corrosion, in contrast to its resistance to usual corrosion.

c. Galvanic corrosion

As it is known, this type of corrosion is related to different metals coming into contact in the presence of an electrolyte, and it becomes more intense as the distance of metals in the electrochemical series increases (fig.3).

Thus, and with reference to the processes involved in solar thermal desalination, it is important to select metals that present the less possible difference of electrochemical potential in contact to the oxygened saline water.

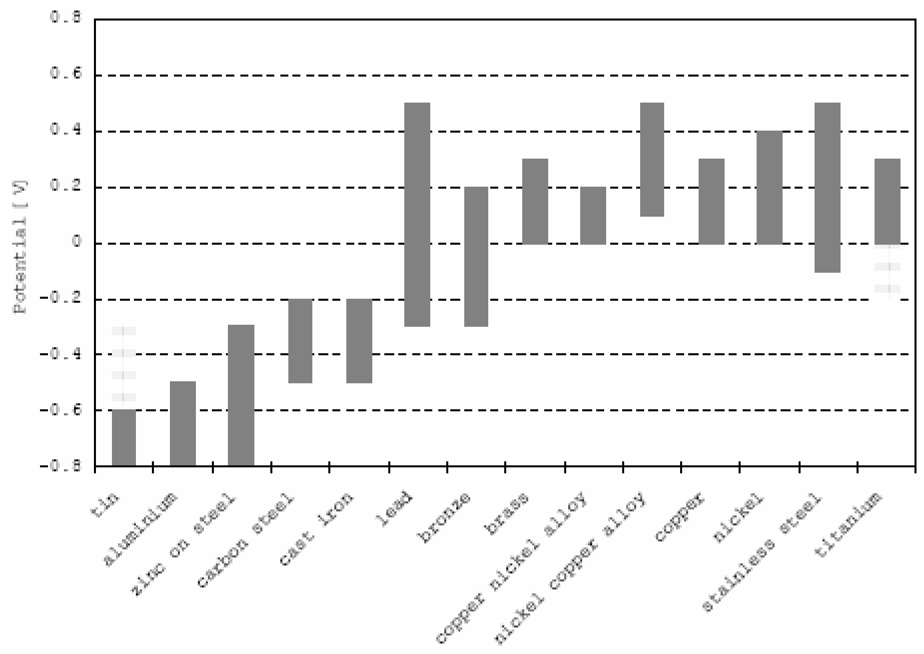

Figure 3: Electrochemical potential of metals in oxygened saline water

3. Formation of organic depositions

In conditions of low fluid velocities and high temperature, the deposition of organic by-products is possible, resulting to the decrease of heat transfer coefficients and pressure loss in piping. Metals that present toxic salts, as Cu or Pb, are less vulnerable to this problem, comparing to others as steel, aluminum and titanium.

4. Material processing problems

An important parameter during the selection of materials for solar thermal desalination plants is the potential/susceptibility they present to specific processing, during the various phases of the desalination plant construction. In fig.4, one may observe the behaviour of specific alloys.

						Fusion welding				
							metal arc welding			
								shielded arc welding		
	thermoform	cold form	free-machining	soft soldering	hard soldering	gas-welding	arc welding	WIG welding	MIG welding	resistance spot welding and seam weld
CuZn 28 Sn	+	+/-	+/-	++	+/-	-	-	+	+/-	+
CuZn 30	+	-	+/-	o	o	o	o	o	o	o
CuZn 20 Al	+	+/-	+/-	-	+/-	-	-	+	+/-	+/-
CuZn 40	++	+/-	+/-	++	+	+	-	+/-	+/-	+/-
CuZn 39 Sn	+	+/-	+/-	++	+/-	-	+	+/-	+/-	+
G-CuAl 9	+	+/-	+	+/-	+/-	-	+/-	+	+	+
G-CuSn 10	+/-	++	+/-	+	+	+/-	+/-	+	-/	+
CuSn 6	+	+/-	+	o	o	o	o	o	o	o
CuNi 10 Fe 1 Mn	+	++	-	++	++	-	+	++	++	++
CuNi 30 Fe	+	+	+/-	++	++	-	++	++	++	++
CuNi 30 Fe 2 Mn 2	+	+	+/-	++	++	-	++	++	++	++
AlMn	++	+	++	+	+	o	++	o	o	o
AlMg 1 bis AlMg 5	++	++	++	-	+/-	o	++	o	o	o

Figure 4: Behaviour of alloys as regards specific processing

++: satisfactory, --:non satisfactory, o: non implementable

5. Evaluation of materials for solar thermal desalination plants

With reference to the above analysis, the candidate materials (mainly metals) are:

- Cu-Ni alloys: The 90/10 copper-titanium alloy seems to satisfy most of requirements in thermal distillation. In addition, there is significant experience by the use of this material in sea related applications.
- Steel with or without surface protection: The basic advantage of the common steel, the low price, compensates to the weak resistance in corrosion. The use of steel with coating (galvanization, special paint), solves some of the corrosion problems but increases significantly the cost without ensuring long life of the installation
- Stainless steel: traditional ferrite and austenite stainless steels, including 304 and 316, are not readily for use in sea water, due to the problems in pitting corrosion and organic depositions. There are though specific types that present improved characteristics, as ferrite including 25-29% Cr, 3-4% molybdenum and 4% Ni or austenite with 18-25% Ni, 20% Cr, 6% molubdenum and 0.1-0.2% nitrogen.
- Titanium: the excellent behaviour of Ti in thermal desalination conditions, becomes moderate by the high cost of materials and processing, as well as to the cause of galvanic corrosion to other metals.
- Plastic: even though plastic can be an alternative to metals, it presents problems related to limited life-time, organic depositions, low heat transfer coefficients and difficulty to achieve resistant to the plant operation conditions assembling.

6. Final selection of materials

With regard to the operation conditions and requirements of a solar thermal desalination system, and considering the analysis of the material properties and their behaviour in the specific environment, following materials are proposed for such an installation:

- 90/10 Cu-Ni alloy for the heating (evaporation) and condensation exchangers
- Stainless AISI 316 Ti for the walls
- Bronze for hydraulic connections
- EPDM for water-tightness
- Polyethylene tissues or evaporation paper for the evaporation surface (if any)

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New Generation of Solar Thermal Systems

WP4-D2.7.b: Guidelines for performance testing of solar systems with desalination units

Dissemination level: Public

Authors: G. Fiorenza, D. Marano, V. Sabatelli (ENEA)

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CONTENTS:

SUMMARY

The overall objective of the present report, concerning pre-normative work for solar desalination standards, is the definition of some simple guidelines for the monitoring and the performance testing of a generic solar desalination system, intended as a system where the thermal energy supplied by common low to medium temperature solar thermal collectors is used as the driving heat of a generic thermal desalination process.

In order to achieve the above-mentioned goal the following actions have been carried out:

- a general scheme of the solar desalination system for performance monitoring and testing has been defined;
- a set of suitable indicators able to completely characterize the system performance has been introduced;
- subsequently, the most relevant parameters to be monitored have been identified;
- finally, same simplified correlations for the prediction of the output of the system in different operational conditions have been proposed.

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1. INTRODUCTION

The current application of low to medium solar thermal collectors to drive seawater desalination processes in Europe is limited to some 10 small capacity systems, mostly operated for experimental or demonstrative purposes [1]. On the other hand, this technology has a great potential for remote areas located in Southern Europe [2]. In effect industry is showing a rising interest in it and novel desalination processes suitable for the use of the driving heat provided by solar collectors have been developed.
Presently desalination units with capacity ranging from 1 to 50 m³/d and driving heat temperature of 80-90°C are available on the market [3]. However solar collectors and desalination process are still to be considered as two separate units of the same system, while pre-assembled systems, similar to factory-made system for DHW preparation, are not commercially available. Furthermore, a large number of combinations between solar collectors and desalination processes are in principle possible, since it does not exist yet a prevailing technology. Therefore, the definition of detailed test methods does not make sense at this stage of development of the use of solar systems in combination with desalination units.

2. OBJECTIVES OF THE PRE-NORMATIVE WORK

The overall goal of the present pre-normative work for solar desalination standards is the definition of the guidelines for the monitoring and testing of the performances of a generic solar desalination system, intended as a system where the thermal energy supplied by a generic type of low to medium temperature solar thermal collector is used as the driving heat of a generic thermal desalination process.
The achievement of this final objective includes the following steps:

a) definition of the general scheme of the solar desalination system for performance monitoring and testing;
b) introduction of a set of indicators able to completely characterize the system performance;
c) identification of the influential parameters to be monitored;
d) development of simplified correlations for the prediction of the output of the system in different operational conditions.

3. SCHEMATIZATION OF THE SOLAR DESALINATION SYSTEM

The present guidelines are applicable to the generic solar desalination system described in Figure 1. According to this scheme, the heat is supplied by the collector to the desalination unit via a storage tank. In effect, solar energy could be in theory directly stored as distilled water. However the storage tank is included in order to optimize the system operation. In fact, if correctly sized, it allows the continuous running of the system, even if under a minor load, when solar energy is not available, thus avoiding the recurrent starting up and shutting down of the system, which will dramatically reduce its efficiency.

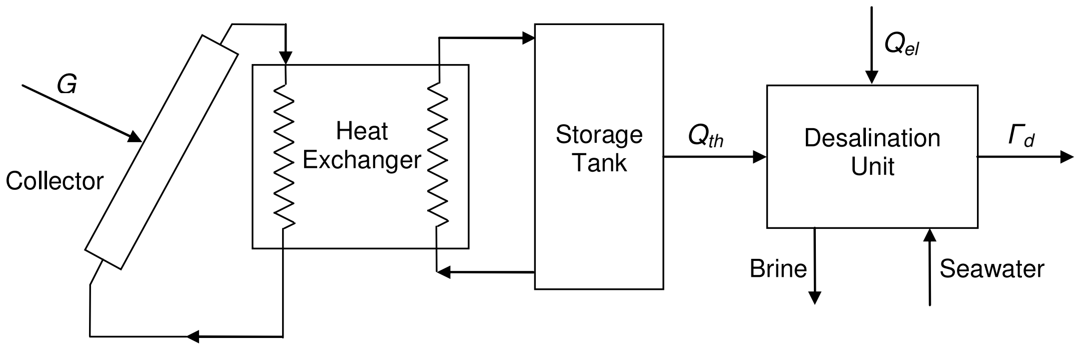

Figure 1: Scheme of a general solar desalination system

As it can be noticed, a black box approach is followed, considering both solar and desalination unit, as systems which can be fully characterized by the received inputs and the produced outputs, without any regard to their internal configuration. Since no specific hypothesis is made, the field of application includes any type of low to medium temperature solar collector coupled to one of the following desalination thermal processes:

- multi-stage flash evaporation;
- multiple effect evaporation;
- multiple effect humidification.

The impact of possible factors correlated to the specific technology, for instance the number of effects for the multi-stage flash and multiple effect evaporation, the system layout (forward feed, parallel feed, cross flow) for multiple effect evaporation, etc., will be not considered for now, provided that the great variety of combinations and the resulting analysis complexity would be outside of the objectives of the present work. Similarly the range of variation of the parameters to be monitored, which are related to the specific process (for example the driving heat temperature) will be not fixed.

4. PERFORMANCE INDICATORS FOR SOLAR DESALINATION SYSTEMS

The following main indicators for solar desalination systems performance, which can be applied to a general level, have been identified:

1) thermal performance ratio, characterizing the desalination unit efficiency related to a given driving heat temperature ;
2) specific electrical energy consumption, characterizing the efficiency of the desalination unit with respect to the auxiliary energy demand;
3) solar performance ratio, characterizing the overall productivity of the solar desalination system;
4) distilled salt concentration, characterizing the quality of the desalination unit output.

The meaning of the last parameter is manifest, while the rigorous definition of the remaining performance indicators is presented in the following points.

4.1 Thermal performance ratio

The thermal performance ratio of the solar desalination system is defined as the total produced distillate to the total heat input ratio in a given time range [T_0, T].

$$PR_{th} = \frac{\int_{T_0}^{T} \Gamma_d dt}{\int_{T_0}^{T} Q_{th} dt}$$

The heat supplied to the desalination unit can be inferred by the collector fluid flow rate and the difference between inlet and outlet collector fluid temperature.
This indicator aims at the characterization of the desalination unit efficiency only, without any influence from the solar system unit.

4.2 Specific electrical energy consumption

The specific electrical energy consumption is defined as the total electrical energy consumed by the desalination process to the total produced distillate ratio in a given time range [T_0, T].

$$C_{el} = \frac{\int_{T_0}^{T} Q_{el} dt}{\int_{T_0}^{T} \Gamma_d dt}$$

The power demand of the desalination unit is mostly due to the pumps for seawater feed and circulation, distilled and brine circulation, driving vapour feed. The consumptions of other auxiliary devices must be included. This indicator plays a crucial role above all when assessing the feasibility of stand-alone installation for remote areas [2].

4.3 Solar performance ratio

The solar performance ratio is defined as the total produced distillate to the total solar radiation incident on collector area ratio in a given time range [T_0, T].

$$PR_{sol} = \frac{\int_{T_0}^{T} \Gamma_d dt}{A \int_{T_0}^{T} G dt}$$

This indicator allows to estimate the solar desalination system productivity per m^2 of collector area, thus being crucial for the dimensioning of the solar system.

5. PERFORMANCE MONITORING OF THE SOLAR DESALINATION SYSTEM

According to the definitions reported above, a number of parameters related to the different units must be monitored in order to assess the solar desalination system performance.

5.1 Monitoring of solar system parameters

With reference to the solar field, the following parameters shall be monitored:

- collectors heat transfer fluid flow rate
- difference between the temperatures of the heat transfer fluid at the outlet and the inlet of the solar field.

With regard to the type of sensors, the required accuracy and the related settings for the measurements, the same requirements prescribed for testing solar thermal collectors and systems (according to EN 12975 and EN 12976) are recommended.
Moreover for collectors to be used for this type of application, the conformity to the standard EN 12975 is required.
Finally, due to the particular working conditions, it is advisable to perform additional specific tests able to check the reliability and the durability for solar collectors operating in maritime environments.

5.2 Monitoring of desalination parameters

With regards to the desalination unit, the following parameters shall be monitored:

- heat transfer fluid flow rate from the solar storage tank to the desalination unit
- difference between the temperatures of the heat transfer fluid at the outlet and the inlet of the desalination unit
- temperature, flow rate and salt concentration of the distillate water
- temperature, flow rate and salt concentration of the brine
- electrical energy consumption of the desalination unit pumps and auxiliaries.

5.3 Monitoring of ambient parameters

Finally, with reference to the ambient conditions, the following parameters shall be monitored:

- global solar irradiance on the collectors plane
- temperature of the surrounding air;
- wind speed;
- temperature, flow rate and the salt concentration of the seawater.

6. DEVELOPMENT OF SIMPLIFIED CORRELATIONS

The influence of the main variables on the outputs of seawater desalination processes has been broadly investigated and correlations are available in literature for the various cases. However, these equations referring to a specific desalination process with a defined layout are normally very complex and, therefore, unsuitable for a black-box approach.
A simple software tool, especially intended for cost analyses, is the DEEP (Desalination Economic Evaluation Program), which was developed by the IAEA-NPTDS (International Atomic Energy Agency, Nuclear Power Technology Development) in order to assess nuclear

desalination systems. However it can also be used for conventional power and heat production technologies coupled to different desalination processes [4], but the use of solar thermal collectors has driving heat source is not considered.
Basing upon the *PHIBAR f-Chart* method [5], a simple methodology to calculate the distillate production per m² of collector area is described in [2]. This approach is fully coherent with the one followed in the present paper.
Finally, it is to be emphasized that a simplified experimental correlation for the calculation of solar desalination system performance can be inferred by monitoring its outputs under different collector operating temperature. In principle, an approach similar to DHW preparation systems may be adopted to this purpose, but evidently the correlation would be applicable to the particular solar desalination system only. If mass produced solar desalination systems will be available, this could be the basis for a performance testing procedure.

NOMENCLATURE

PR_{th}: thermal performance ratio (m³/kWh);
C_{el}: specific electrical energy consumption (m³/kWh);
PR_{sol}: solar performance ratio (m³/kWh);
Γ_d: distillate flow rate (m³/h);
Q_{th}: heat supplied to the desalination unit (kW);
Q_{el}: power required by desalination unit pumps and auxiliaries (kW);
G: solar radiation on collector plane (kW/m²);
A: collector area (m²);
t: time (h);
T_0: lower limit of the given time range (h);
T: upper limit of the given time range (h).

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