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Solar energy — Water heating systems — Guide to material selection with regard to internal corrosion

Énergie solaire — Système de production d'eau chaude — Guide pour le choix de matériaux vis-à-vis de la corrosion interne

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Foreword

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ISO/TR 10217, which is a technical report of type 3, was prepared by Technical Committee ISO/TC 180, *Solar energy.*

Annex A of this Technical Report is for information only.

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Solar energy — Water heating systems — Guide to material selection with regard to internal corrosion

1 Scope

This Technical Report provides a discussion of the parameters that have a bearing on the internal corrosion of solar water heating systems.

The following topics are not dealt with in this Technical Report:

- problems of compatibility between polymeric materials (plastics and rubber) and fluids;
- corrosion risks concerning the enclosure and the external surface of the absorber;
- safety and health questions, especially the toxicity of heat-transfer fluids.

In many fields, the corrosion problem is hard to deal with, because it overlaps several matters. As far as solar systems are concerned, corrosion prevention cannot be treated only in respect of a component, or only as a durability problem, or only as a design problem. It cannot be solved only by specific tests, or only by design recommendations.

This Technical Report addresses the question of which requirements are necessary, to predict with confidence long failure-free lifetimes in active solar systems, from the point of view of internal corrosion. It gathers information provided in previous papers on this subject (especially bibliography references 2, 3 and 4) while staying in agreement with them.

2 Corrosion risk statement

If corrosion effects are considered as a reliability problem for the system, because corrosion can reduce the quality of the system, the following points may be detailed.

2.1 The **degrading agent** is internal corrosion. Its effects are different according to

- materials;
- couples of materials;
- temperature;
- fluid circulation;
- fluid oxygen content;
- fluid aggressive ions content.

2.2 The **materials** concerned are

- absorber materials;
- pipes and fitting materials;
- fluids;
- welding materials.

2.3 The **functional characteristics** of the system are

- pressure resistance;
- efficiency of thermal transfer between the sun and the storage;
- high and low temperature resistance.

2.4 The **failure modes** (i.e. the ways for the degradating agent to act on the materials to weaken their functional characteristics or those of the system) are

- bad design choice (materials and conditions of use of the system);
- degradation of materials during service life;
- bad maintenance.

3 Discussion

Internal corrosion damage in solar systems is generally detected too late: it is reported as a serious problem, which requires replacement of significant parts of the system [3], but inspection studies [12, 13] give little information on this subject; a visual inspection, even completed by user-consultation, is not able to show the growing effects of internal corrosion before the first pitting occurs.

Among the types of damage reported, most are related to the use of aluminium absorbers without precautions [5].

Several documents treat the corrosion problem as presented previously: it is a whole-system problem, and initial design and material-choice recommendations are emphasized as a way to prevent corrosion damage [2, 11]. Even in standards, the problem is sometimes left to expert advice [10]. A table of acceptable or unacceptable conditions can summarize all the data given about installation parameters, metal/fluid pairs and metal association [1, 4].

Nevertheless, there exists the need to envisage specific tests to predict with greater confidence the service life of the system. Classic laboratory corrosion tests may be used to study the metal and fluid compatibility[14], and specific ones are used experimentally to simulate solar system characteristics[5, 8]. In the USA, such specific laboratory tests are standardized[6].

Another type of test is also performed in several laboratories, which simulates service conditions, generally based on test loops[7, 8] and even real systems[9].

However, most of the papers[2, 3, 4, 5, 10, 11, 15] emphasize the usefulness of a good maintenance programme to prevent fluid degradation (closed loops), and/or water (organic fluids) entry, effects of erosion, etc.

4 Proposal for a procedure to prevent internal corrosion damage

4.1 General

After viewing the literature, it appears clear that a procedure to prevent internal corrosion damage has to include two steps, namely:

a) recommendations concerning the design of the installation;

b) recommendations concerning the maintenance.

The first step must give indications on the acceptable conditions concerning working modes of the installation, metal and fluid combinations, etc. Sometimes, tests may be necessary to draw firm conclusions, and some recommended test methods have already been standardized.

The second step gathers maintenance advice in order to ensure continuation of the good conditions selected following the indications of the first step.

4.2 Recommendations concerning design

When the installation design has been determined, including loop type (closed or open), absorber material, pipe material, fluid type and composition, fluid velocity, etc., tables 1 and 2 are used to check whether the system parameters give acceptable or unacceptable conditions for the prevention of internal corrosion damage.

These two tables gather information previously produced in bibliography references 1 and 4.

The tables given are probably sufficient to check the good design of the system, but they do not provide information on the reliability of the materials over their service life (absorber materials, pipe materials and fluids).

It is therefore proposed to use some existing tests to appreciate the effect of time on the materials in use. These tests, which have been developed in various laboratories[5, 8, 9], may also be used in the cases of design choices for which tables recommend a detailed study.

4.2.1 Test for the fluid/metal pair

To appreciate the behaviour of the fluid at high temperature, laboratory tests have been mentioned[5, 8]: a metal/fluid pair can be submitted to high temperature, up to 100 °C, in a glass container at atmospheric pressure, or in an autoclave to reach higher temperatures. After this ageing, corrosion of the metal is measured by **mass losses** and **visual inspection**, and the **fluid is analysed**. Ageing processes are described in ASTM Standard E 745[7], and the qualification tests are traditional.

It is possible to perform electrochemical measurements on some kinds of metals, especially those which are sensitive to pitting corrosion, using the degradated fluid as liquid medium. This type of test is not specific to solar applications, and it is possible to use traditional procedures. Where the pipe material is brass, dezincification resistance may be determined using the test method given in ISO 6509[16].

4.2.2 Test for the loop

Another test method uses an experimental loop where metal samples are tubes making part of the loop, and where the fluid is circulating in the loop. Temperature and liquid velocity are parameters of the test, and corrosion is measured by mass losses or possibly by an electrochemical test[8]. The loop is described in ASTM Standard E 745[7].

4.3 Recommendations concerning maintenance

Recommendations for maintenance have to take into account the field information collected, in addition to scientific knowledge on metal and fluid compatibility, and on heat-transfer fluid degradation. The following procedure summarizes the indications of several documents[2, 3, 4, 5, 11, 15].

4.3.1 Starting operation

The system and its components must be protected against contamination and overheating during storage and assembly, and before being filled.

If the heat-transfer fluid is aqueous, flush the unit out with water; if the heat-transfer fluid is organic, flush the unit out using the correct organic fluid. Immediately after this flushing operation, a pressure test is carried out. The flushing out and pressure test are immediately followed by filling with heat-transfer fluid.

It is recommended that ready-diluted antifreeze fluids be used, under the manufacturer's recommendations.

4.3.2 Operation and shutdown of the solar system

The circulatory system must always remain filled ready for operation, even during the winter months. Components in the heat-transfer fluid can concentrate in systems which are partly or completely empty as a result of vaporization of the remaining heat-transfer fluid. In this case, protection against corrosion provided by inhibitors can fail, so that pitting is possible.

Should a shutdown or emptying of the system become necessary, for instance because of repair work, it is advisable to cover the collector surfaces to avoid over-heating. Repairs have to be carried out in such a way that boiling of the heat-transfer fluid is effectively prevented, and the system should be refilled as soon as possible.

Should losses in the amount of fluid occur because of leakage, then these have to be compensated for by addition of the same heat-transfer fluid as that used initially.

Losses caused by evaporation of water can be compensated for by addition of ordinary water, as long as the supplier of the fluid does not stipulate any other requirements.

4.3.3 Annual inspection

An annual inspection of the installation has to be made by a qualified person. During these inspections, the following operations should be performed:

a) check the fluid level;

b) check the air vents;

c) take a sample of the heat-transfer fluid in order to check

- the pH value;
- the freezing point;
- the alkaline reserve;
- the metallic traces in suspension.

For aluminium absorbers, it is recommended that the fluid be replaced after 2 years.

Table 1 — Material/fluid combinations for closed systems

Absorber material	Aqueous fluid (with or without addition of glycol)					Organic fluid	Pipes and fittings materials			
	Untreated	With inhibitors	Velocity m/s	pH	Temp. °C		Copper	Steel	Galv. steel	Polymer
Aluminium	☒	no Cu^{++} no Fe^{++} no Cl^-	$< 1{,}22$	> 5 < 9		no H_2O	☒	● 1)		● 2), 7)
Galvanized steel				> 8 < 12	6) < 55	no H_2O	☒			● 2), 7)
Steel			$< 1{,}83$	> 8 < 12		no H_2O				● 2), 7)
Stainless steel	● 3) Cl^- < 50 ppm	● 3) Cl^- < 50 ppm								● 2), 7)
Copper	no NH_4^+		$< 1{,}22$						☒	● 2), 7)
Polymer					● 4)	● 5)				● 2), 7)

Legend

☐ Acceptable condition (if any limitations indicated are respected)

● Special study or test necessary

☒ Unacceptable condition

1) Avoid direct contact in fittings. Use the appropriate inhibitor.

2) For collector output fittings, take into account the stagnation temperature of the collector.

3) The stainless steel grade must resist all types of corrosion. Special attention has to be paid to welded zones.

4) Maximum service temperature of the polymer must exceed the stagnation temperature of the collector.

5) Check the chemical compatibility between absorber and fluid.

6) This condition effectively excludes galvanized steel.

7) Polymer used must avoid oxygen diffusion.

NOTE — "No xxx" means that the amount of "xxx" shall not be detectable by usual laboratory analytical equipment.

Table 2 — Material/fluid combinations for open systems

Absorber material	**Aqueous fluid** (with or without addition of glycol)						Organic fluid	Pipes and fittings materials			
	Drinkable water	Untreated	With inhibitors	Velocity m/s	pH	Temp. °C		Copper	Steel	Galv. steel	Polymer
Aluminium	☒	☒	no Cu^{++} no Fe^{++} no Cl^-	< 1,22	> 5 < 9		no H_2O	☒	● 1)		● 2)
Galvanized steel	☒	☒	no Cu^{++}		> 8 < 12	6) < 55	no H_2O	☒			● 2)
Steel	☒	☒		< 1,83	> 8 < 12		no H_2O				● 2)
Stainless steel	● 3), 7) Cl^- < 50 ppm	● 3) Cl^- < 150 ppm	● 3) Cl^- < 50 ppm								● 2)
Copper	Cl^- < 100 ppm SO_4^{--} < 150 ppm no NH_4^+	Cl^- < 100 ppm SO_4^{--} < 150 ppm no NH_4^+		< 1,22	> 5					☒	● 2)
Polymer						● 4)	● 5)				● 2)

Legend

☐	Acceptable condition (if any limitations indicated are respected)
●	Special study or test necessary
☒	Unacceptable condition

1) Avoid direct contact in fittings. Use the appropriate inhibitor.

2) For collector output fittings, take into account the stagnation temperature of the collector.

3) The stainless steel grade must resist all types of corrosion. Special attention has to be paid to welded zones.

4) Maximum service temperature of the polymer must exceed the stagnation temperature of the collector.

5) Check the chemical compatibility between absorber and fluid.

6) This condition effectively excludes galvanized steel.

7) Check safety and health regulations.

NOTE — "No xxx" means that the amount of "xxx" shall not be detectable by usual laboratory analytical equipment.

Annex A
(informative)

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