Task 39: Polymeric Materials for Solar Thermal Applications

CONTENTS

NEWS

October 13-15, 2008

The **5th IEA-SHC Task 39 Experts Meeting** was hosted by and took place at Instituto de Technologias Energeticas (INETI) - Department de Energias Renovavaeis in Lisbon, Portugal from October 13-15, 2008. 39 experts were present at the meeting. 11 participants were industry partners. Most of the presentations and the results from group work are included in this newsletter.

On October 14, an excursion was arranged to both the solar collector test facility, an Accreditated Test Laboratory under Standard EN ISO/IEC 17025:2005, and to the Solar XXI building at INETI.

(a)-(d): Pictures of the experts meeting at INETI and excursion to the solar collector test facility, an Accreditated Test Laboratory under Standard EN ISO/IEC 17025:2005.

(c+d) Visit of the *Solar XXI building* at INETI, an energy-efficient building, with passive cooling; further an active system with PV modules integrated in the façade, with thermal gain, natural ventilation and lighting systems (http://www.ineti.pt/). It results from an optimization compromise between surrounding environment and incorporation of solar active and passive systems.

October 7-10, 2008

Eleven presentations of Task 39-related topics were presented by our experts at the EUROSUN conference in Lisboa, Oct. 7-10, 2008 (www.eurosun2008.org). The presentations&posters are listed on the Task 39 website under Publications/Outcomes.

April 27-29, 2009

The next and 6th Experts Meeting will be hosted by SPF in Rapperswil, Switzerland.

TASK 39 - PARTICIPANT STATUS by October 2008

The experts in Task 39 are represented by 17 research institutions and 15 industrial companies from 11 countries worldwide. Seven industrial companies are Active Supporters of Task 39: BASF (D), Bosch Thermotechnik (D), EDF - Électricité de France (F), EMS-Chemie (CH), Roth Werke GmbH (D), Solvay Solexis (B) and Söhner Kunststofftechnik GmbH (D).

Active Supporters of Task 39 are:

BASF The Chemical Company · BOSCH · EDF R&D · EMS-GRIVORY · Roth · Solvay Solexis · SOLVAY · SÖHNER

Operating agent: Michael Köhl, E-mail: michael.koehl@ise.fraunhofer.de, Fraunhofer Institute for Solar Energy Systems, Germany

Taskforce: Making solar thermal systems more desirable

Two first outcomes could be drafted from the work of this Taskforce within market communication after the Lisbon meeting:

1) A new definition of solar thermal**: High-tech renewable energy with great performance!** The core element of a solar thermal installation is solar collectors that convert the energy in sunlight directly into usable heat. These collectors can be aesthetically integrated into the building envelope or they can be mounted onto a building.
Solar thermal installations have high energy capacity, and end users therefore benefit of an attractive pay back on their investment. The systems are sophisticated, but very user friendly. Solar thermal is worldwide the second largest technology (after wind) considering energy production from new renewable resources, and its importance within the global energy system will continue to increase in the future.

2) A new database presenting the best solar thermal projects considering aesthetics and function will be built up - a source of inspiration for architects and others (draft illustrated to the right).

Do you know a project that could be shown – please contact is@aventa.no.

Ingvild Skjelland, Aventa AS, Norway, is@aventa.no

Polymer Solar Water Heaters Introduced into the U.S. Market

The United States Department of Energy (DOE)/Solar Heating and Cooling Program started an initiative to develop low-cost polymer-based solar water heaters for mild climates in 1999. The restriction to mild climates was based on the perceived need to focus the efforts narrowly due to low funding levels (~$1.2 M/year total R&D budget!). All concepts were to be industry-originated, with the DOE labs and universities providing support to the industry teams. Six industry teams started with conceptual development, and the program down-selected to two teams in year 2. Both successful teams changed their system concept at least once during development, not surprising given the inexperience with polymer SWH. Both teams have introduced product to the US market.

FAFCO developed an unglazed drainback system using their pool collectors, and the system can be packaged in a small box facilitating big-box outlet and stocking on repair trucks of plumbing firms for adventitious sales during repair of conventional systems. DEG/Harperis Energy have developed an ICS consisting of a rotomolded water-storage tank with an immersed, in-mold heat exchanger. The system can be glazed or unglazed. Both systems will reduce installed system cost to under US $2000, more than 60% savings versus conventional systems.

Fig. 1. The FAFCO drainback system is shown schematically on the left. It uses unglazed collectors in a drainback system, and the system sans storage is shipped in a small UPS container. The DEG/Harperis Energy system is shown on the right. It has an immersed heat exchanger in a glazed or unglazed polymer tank.

Jay Burch, NREL - National Renewable Energy Laboratory, Golden, USA; jay_burch@nrel.gov

Polymeric collectors: offering colour freedom?

Original installation

Green shade

Yellow shade

Blue shade

While polymeric collectors can use the flexibility in design offered by the material to propose products specifically addressed to building integration, an important limit to their spread still lies in the lack of colour choice (only black).
A development originally designed to standard flat plate collectors using glass could be used for these polymeric collectors. The principle is to apply a selective filter reflecting only a specific narrow band of the solar spectrum in the visible range to give a coloured appearance.
Photographic tests have been made to check the validity of the concept, and the results have been applied to illustrate the potential of this technology.
A Photoshop simulation, using real colours obtained during the tests, shows the variety of appearances a building integrated system could take (Figs. left).

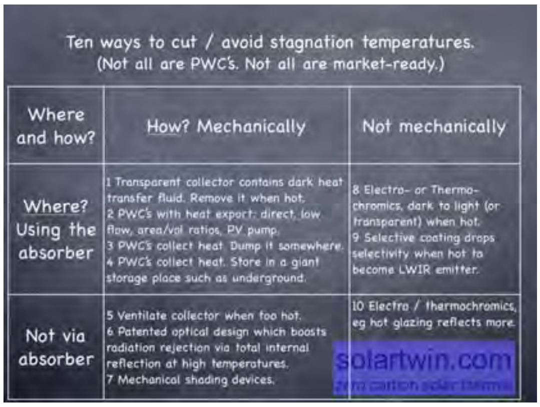
Christian Roecker, EPFL, Lausanne, Switzerland; christian.roecker@epfl.ch

Heat export delivers reliable overtemperature control in direct plumbed polymer collector

The freeze tolerant Solartwin system (produced since 1999) controls overheating by exporting heat via a double glazed matt black absorber which has a stagnation temperature of 152 °C. Somewhat surprisingly, in normal operation, the water in it does not boil, because the panel does not stagnate due to a very specific system design. Independently collected field data on the system showed a peak water temperature of 87 °C in a midsummer heat wave with zero hot water consumption. Solartwin's specific combination of design characteristics required for this overheat control method to operate effectively include:

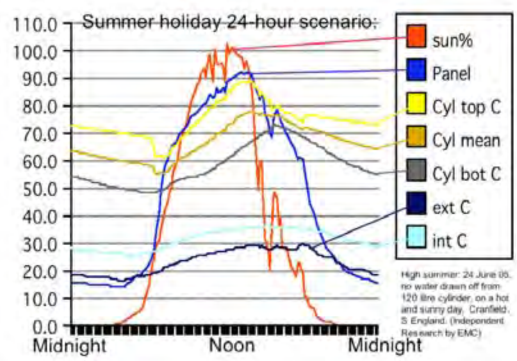
- Use of a matt black-coated absorber as a long wave infrared emitter.
- The water store volume to panel area ratio must be above a minimum, for any climate zone.
- Direct heating is required, with no heat exchangers on the solar loop. The controller set to run the pump continuously above a preset temperature, such as 65°C.
- Photovoltaic pumping is used to eliminate the risk of mains electric power cuts.

The field test data showing no boiling were re-validated by simulation. Because stagnation is thereby limited to non-operation conditions only, the time of exposure to stagnation is reduced to less than 1% of normal levels, or even to zero. Thus heat export design has significant positive impacts on polymer life expectancy and polymer selection. However, to remove barriers to innovation, today's narrow conceptual starting points in existing solar thermal standards require significant expansion to fully include new means of overtemperature control. In this context, heat export was only one of ten such means, which were identified as being of possible benefit to polymeric solar thermal systems.



Ten ways to cut / avoid stagnation temperatures.
(Not all are PWC's. Not all are market-ready.)

Where and how?	How? Mechanically	Not mechanically
Where? Using the absorber	1 Transparent collector contains dark heat transfer fluid. Remove it when hot. 2 PWC's with heat export: direct, low flow, area/vol ratios, PV pump. 3 PWC's collect heat. Dump it somewhere. 4 PWC's collect heat. Store in a giant storage place such as underground.	8 Electro- or Thermo-chromics, dark to light (or transparent) when hot. 9 Selective coating drops selectivity when hot to become LWIR emitter.
Not via absorber	5 Ventilate collector when too hot. 6 Patented optical design which boosts radiation rejection via total internal reflection at high temperatures. 7 Mechanical shading devices.	10 Electro / thermochromics, eg hot glazing reflects more.



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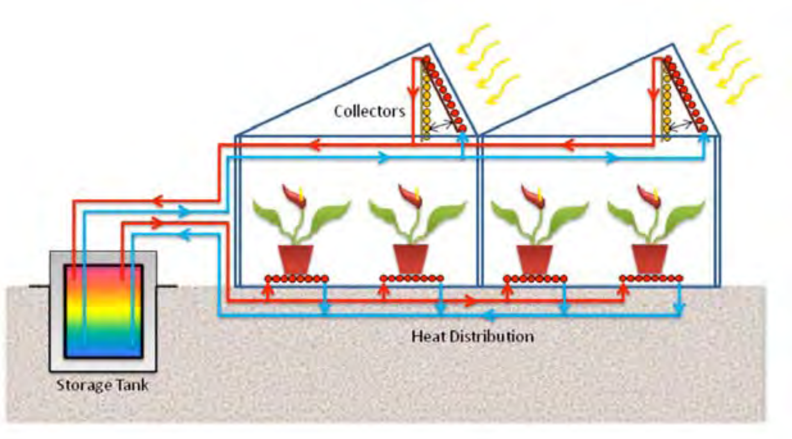
Making greenhouses greener



Basically, greenhouses are solar collectors with poor heat storage capacity. Using EPDM tubes, not only as collectors to absorb solar thermal energy but also to release the heat inside the greenhouse, preferably near the root zone, HeliAgro is a project being implemented in Portugal. The heat carrier is pure water and the heat is stored at relatively low temperature (up to 60 ºC) in inexpensive underground storage tanks made from EPS blocks with a watertight reinforced PVC inner bag.
Results from preliminary analysis show that, for thermal optimized greenhouses under typical local weather conditions, one hundred square meters of collectors may supply enough energy to keep more than 500 m^2 of planted greenhouse soil warm though cold winter nights.
This is an example of eco-innovation, leading to a decrease in pollution and to a more efficient management of the resources.

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Polymeric Solar Thermal Collectors: Requirements, Concepts and Feasibility Evaluation

In the field of polymeric solar thermal collector development within Task 39, a research project is carried out at Ingolstadt University of Applied Sciences (Germany). Based on a detailed component analysis in existing solar systems, the component as well as the system designs are adopted to polymer needs. This first major project phase ends up with consolidated specifications for the development of polymeric flat plate collectors, i.e. a detailed requirements list. Subsequently, collector concepts are developed with regard to both polymeric materials and adequate production processes. Finally, a feasibility investigation concerning technical and economic issues will conclude the project.

Collectors and measurement equipment in the field testing object

For the requirements definition with regard to the application of polymeric materials in solar thermal collectors, a conventional solar system is currently analysed in a field-testing building. The building is a single-family house inhabited by four persons. It is equipped with a modern 20 m² solar hot water and space heating system with customary flat plate collectors. Measurement equipment was applied to both the system and a collector to specify the thermal and pressure loads on the collector at casing, absorber, glazing, and insulation in a state-of-the-art system in detail. Furthermore, a collector without connection to the solar system was installed to refer to maximum loads during stagnation. The next step to be taken is the derivation of characteristic annual load profiles for collectors, being the basis for an adoption of systems and designs to polymer needs.

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

The project is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

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Material development: Thermal stress on collector components

To develop new polymer materials for solar thermal systems the knowledge of exposure time of thermal stresses is of great interest.
Collector materials have to withstand occasionally long periods of stagnation, particularly in the case of the construction of new houses where the collector on the roof can be one of the first parts, which is finished, and a lot of months elapse till the system can start to work.
Simulations of examples of collector configurations with temperature limiting measures give an impression of thermal stress and exposure times of worst case temperature loads to collector components.
In the examples shown to the right, one can see the cumulative frequency of temperatures for the absorber and the thermotropic layer if the collector is one year in stagnation only (location: Graz, orientation: south, slope 45°). In the comparison collector configurations (PC-twin wall sheet cover, non selective absorber) without temperature limiting measures and with two different kinds of thermotropic layers (ttL) located on the inner side of the cover (solar transparency clear state: 85%, transparency opaque state: 60% and 40 %, switching temperature range: 75 /80 °C and 55/60 °C, respectively) are shown.

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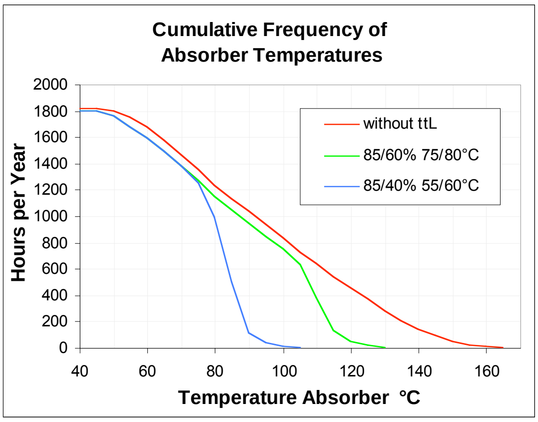

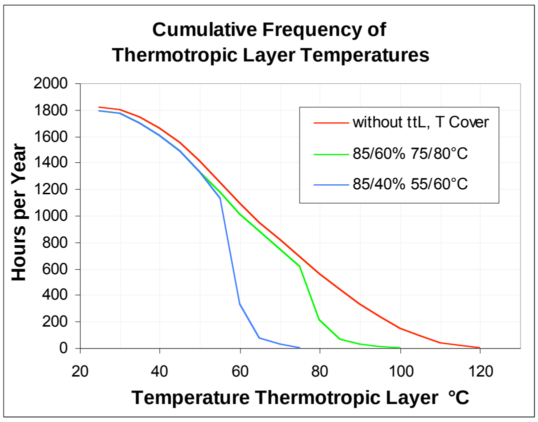

Ensuring efficiency and stability of polymer collectors

Numerical simulation tools were used to analyze solar thermal collectors considering an integrated polymer collector design. A triple wall sheet was defined as the basic geometry. Various material and geometry parameters were varied to compare their influence on efficiency and mechanical stability.
By varying parameters as fluid flow and position of absorbing layer the heat transfer capability of the absorber and the collector efficiency were calculated. The most promising configurations have been identified by comparison of the fluid heat gain. The simulations show that collector efficiency can be even higher than of conventional flat plate collectors.
Further mechanical stresses and deformation during operation were studied. These loads occur due to temperature gradients in the collector and induced uneven expansions. The mechanical stresses are in acceptable ranges for most of the considered collector configurations. Deformations of the collector geometry have to be considered. For polymer material combinations, the bending of the geometry will only be in acceptable range for identical and low thermal expansion coefficients. The simulation of snow loads identifies that the bend-proof triple wall sheet geometry will resist occurring snow loads. The simulations show that the considered integrated design can resist steady state mechanical loads during operation.

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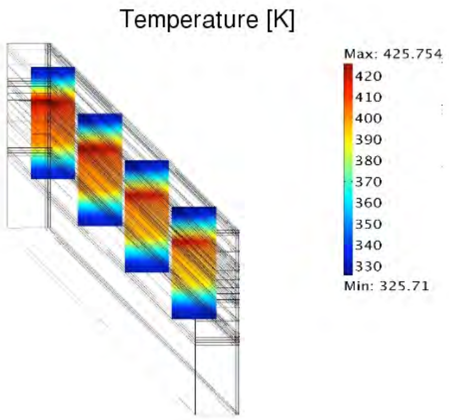
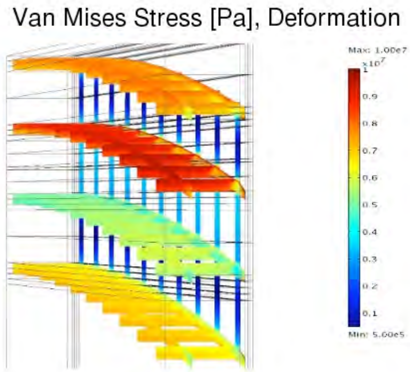


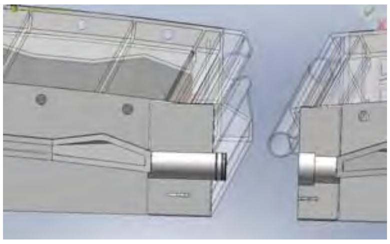
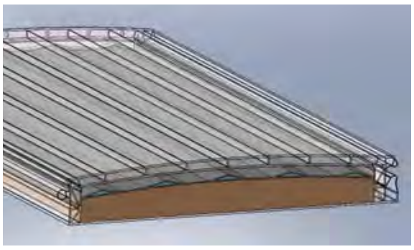
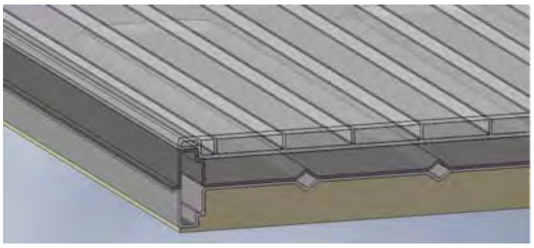


Collector design at INES

Polymeric collector must be different than a simple copy of metallic collector in order to use the full potential of polymeric process. This is the basic idea used by INES in order to suggest new concepts for polymeric collector.
Two concepts have been suggested:

- One collector based on extrusion/co-extrusion with end-caps produced by injection moulding
- One collector based on thermoforming/blow molding

These two concepts are in a early stage of design. Improvements, as well as feasibility and thermal analysis will be performed next year.

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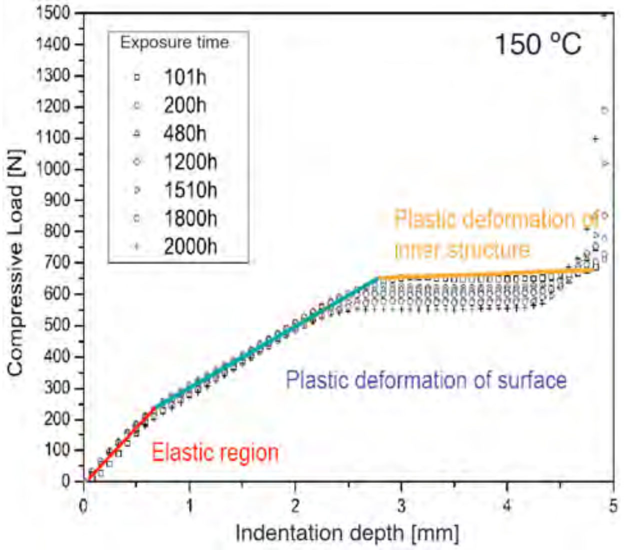
Toward an all-polymer solar collector

The main barrier for making an all polymer solar collector is the high temperature during thermal stagnation when the solar heating system is not in operation. Two solutions have been proposed, either to introduce an overheat protection mechanism that prohibits temperature to increase above a predefined upper limit, or to apply polymers which can sustain the highest possible collector temperatures. Aventa has chosen the last approach, and through a close collaboration with Chevron Phillips Chemicals (CHPH) a new all-polymer collector design has been developed with an absorber made of a specially adapted PPS-material from CHPH.
A number of high temperature resistant polymers are known, but most of these are not suitable for an industrial extrusion into multi-wall sheets. Extrusion is considered to be a necessary processing step in order to make a product that is competitive with conventional flat plate collectors. With important assistance from Kaysersberg Plastics, successful processing has been demonstrated.
Long lasting exposures at high temperatures have been carried out at the Department of Physics, University of Oslo, and the mechanical, optical and physical properties of absorber sheets have been investigated. These investigations conclude that the absorbers in the actual PPS-blend are able to sustain temperatures in the range of 170 – 180 ºC. These temperatures represent the expected upper limit for a highly selective polymer collector with one layer of transparent plastic cover. Different methods for application of selective coatings have been successfully demonstrated.
The pilot production of the new collector will be started soon, and a comprehensive test program is planned for the spring and summer 2009 in collaboration with key participants in the IEA-SHC, Task 39.



Indentation tests of PPS structured sheets after exposure to thermal load at 150ºC for various exposure times.

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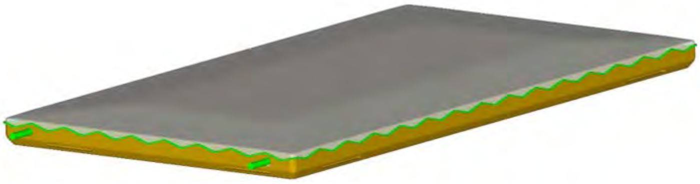
Söhner Kunststofftechnik - an expert in the thermoforming technology

For 40 years the Söhner Kunststofftechnik GmbH is an expert in the thermoforming technology.
With the twin sheet technology, two parts can be thermoformed and welded together in one process step. This is a promising technology, which can be used for the production of a polymer based solar thermal system. The picture shows a development for a housing, which is made of polycarbonate. The front is a transparent, the backside is a colored polycarbonate-sheet. Both parts are molded and welded together in one step.
The twin sheet technology can be used to make absorbers and housing for polymer solar thermal systems.



T. Doll, General Manager SÖHNER Kunststofftechnik GmbH, Germany, t.doll@soehner-worldwide.com

CFD-Optimization of the Shape of the Absorber

The thermal efficiency of polymeric collectors is strongly related to the efficiency of the absorber itself. The latter is dependent not only on the capability to absorb solar energy (e.g. selective coating) but also on the capability to transfer this energy into the carrier fluid. In conventional shapes such as plat plates or tubes the heat exchange is restricted by a stable boundary layer between the absorber surface and the flow region (see the velocity distribution in Fig. 1). In order to overcome this constraint and enhance the heat transfer significantly a turbulent flow with recirculating eddies has to be formed. Therefore new geometrical shapes of the absorbing layer have to be designed which influence the fluid behavior at the contact surface (see Fig. 2).

For the purpose of developing a new type of highly efficient collector polymeric materials have the key advantage that they can be formed unconventionally. Dr. Axel Müller - HTCO - a company specialized in the field of fluid dynamics and heat transfer simulation (CFD) for over 20 years – contributes to Task 39 by designing and optimizing absorber shapes by means of computer simulations.

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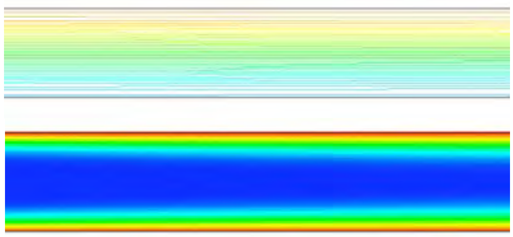


Fig. 1 Velocity contours and temperature distribution in a plat plate collector

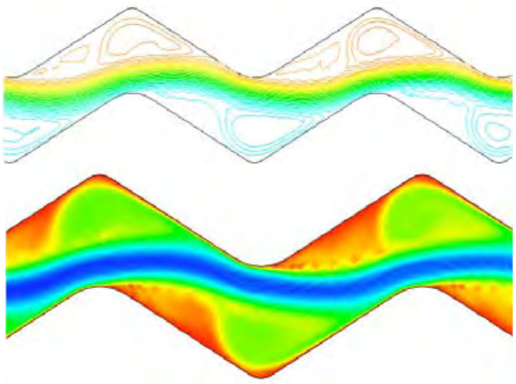


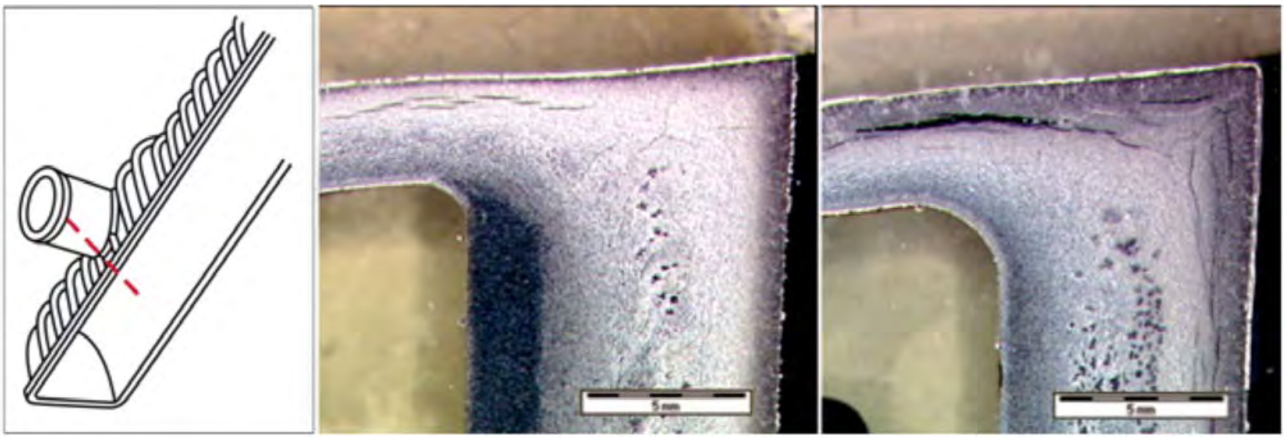
Fig. 2 Velocity contours and temperature distribution in a collector with formed absorber surface

Even when the water boils

Recently, BASF has added two new hydrolysis-resistant polyamides (PA 66) to its product range. These plastic grades are called Ultramid® A3WG6 HRX and A3WG7 HRX and are reinforced with 30% and 35% glass fibers, respectively. The products were developed for applications in coolant circuits. Additionally, they also exhibit outstanding heat-ageing resistance in hot air.
Today, such components also need to be resistant to hot water and glycol. Tests were conducted with all of the standard water-glycol mixtures.

Tested in hot cooling water: weld line strength and crack formation

BASF developers had a real close look at the weld line strength: the weld line of tanks and caps made of the new A3WG7 HRX grades is much stronger than that of commercially available reference plastics. Tests were carried out on welded containers that had been exposed on one side and on both sides to hot coolant at a temperature of 130°C [266°F]. The new Ultramid grades are considerably less prone to crack formation. This lower tendency to form cracks – a very advantageous aspect for components with weld lines – was also confirmed in the swelling test in pure glycol at high temperatures.



Andreas Maegerlein, BASF SE, Germany, andreas.maegerlein@basf.com

Measuring water vapour diffusion of polymeric materials

Flexible polymeric materials can be used as a sealing device for hot water tanks. Apart from temperature/mechanical stability and water tightness, the water vapour diffusion through the membrane is of major interest. Especially when using elastomeric materials, the high water vapour diffusion can lead to water loss in the tank and a moisturization of the thermal insulation.
In the scope of IEA Task 39, a test rig for measuring water vapour diffusion on application level was developed.

The water vapour diffusion resistance factor μ was carried out for PE, PP, EPDM, IIR and FPO polymers. Furthermore, composite materials with vapour barriers (PE and aluminium) have been examined.

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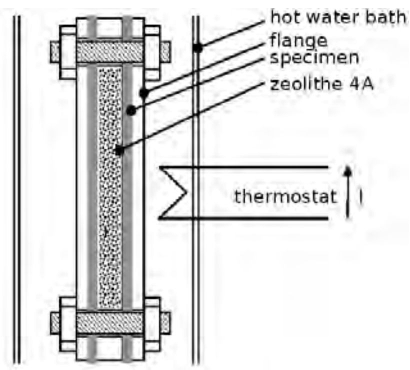
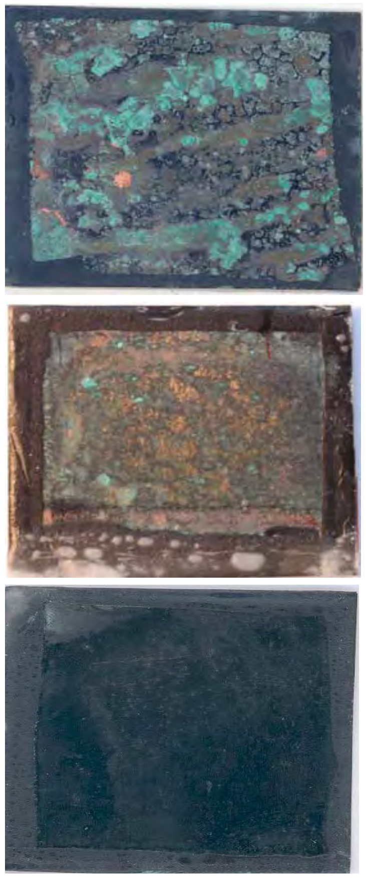


Schematic of test flange with mounted membranes on each side and sorption material inside.

Spectrally selective cermets deposited on polymeric absorbers.



Spectral selectivity is a key property which enables widening the use of polymeric solar absorbers to high temperature solar thermal systems and on the other hand, to spread solar thermal applications also on unglazed solar facade collector systems. One possibility to make polymeric absorbers selective is to paint polymeric absorbers with thickness insensitive spectrally selective (TISSS) paint coatings, while the second option is to deposit on the surface of the polymer thin layer of metal, which serves as a low thermal emittance substrate for the depositing Thickness Sensitive Spectrally Selective (TSSS) cermet coatings (i.e. SUNSELECT (Alanod, DE)), produced via the vacuum deposition technique. However, the main hindrance for using SUNSELECT for polymeric solar absorbers lies in their poor corrosion stability leading to the deterioration of coatings in few hours in salt environment.
Accordingly, we developed sol-gel corrosion inhibition coatings by careful selection of trialkoxysilane mixture, enabling the deposition of protective coating form the corresponding solutions. The coated SUNSELECT, showed increased mechanical stability (easier handling, no finger print marks), prolonged corrosion stability (> 20 days in salt spray), and practically the same spectral selectivity (ε_T increases from 6 to 9 % but α_S also increases from 93.5 to 94%).
Further studies are planned to ensure long term UV and thermal stability of the sol-gel corrosion inhibition coatings and to check the applicability of the coatings on large scale.

The pictures to the right illustrate salt spray results; bad protected samples were destroyed after a 120 h exposure (picture 1 and 2 from top to bottom) and well protected sample was not changed after a 480 h exposure (the bottom picture).

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Accelerated tests for failure time assessment of organic spectrally selective paint coatings for polymeric absorbers.

TISS paint coatings based on a polyurethane polymeric binder deposited on copper substrates was investigated to obtain information about their service life-time. The degradation of the TISS paint coatings was performed according to the methodology worked out within Task 10 of the IEA's Solar Heating and Cooling Programme. The activation energy (E_a) for the degradation process was derived from the vibrational band changes of the polyurethane binder recorded in the infrared hemispherical reflectance spectra of the TISS paint coatings exposed to different thermal loads. The results of the vibrational band analysis were correlated with cross-cut tests, showing that the coatings started to loose integrity at 190 °C but protected the copper substrate against oxidation perfectly even at 200 °C (15 days). An accelerated test procedure confirmed that TISS coatings could be safely used in solar collectors for at least 45 years.

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Roman Kunic, Fragmat, Slovenia
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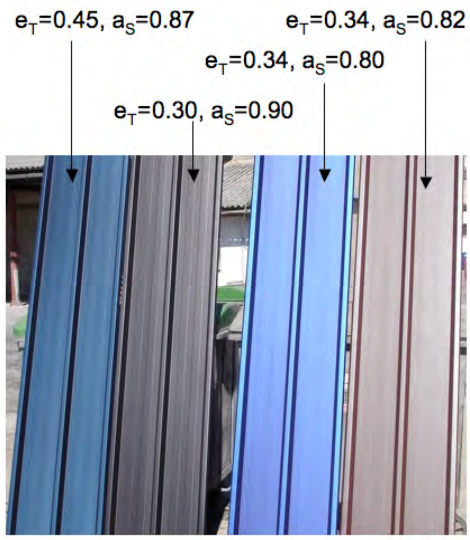

TISS paint coatings with diffferent thermal emittance e_T and solar absorptance a_S.

Thermotropic Materials for Overheating Protection of Solar Collectors

At the Polymer Competence Center Leoben GmbH a research project focusing on the development of thermotropic layers for overheating protection of solar thermal collectors is carried out. Numerous prototype-layers of thermotropic systems with fixed domains TSFD (i.e. additive embedded in a resin matrix) are prepared, which are analyzed as to morphological parameters and their light-shielding efficiency.

The thermotropic layers show a hemispheric solar transmittance between 76 and 87% in clear state. Above the switching threshold the transmittance changes by 1 to 18% to values between 62 and 85%. The layers exhibit switching temperatures between 40 and 80 °C and transition temperature ranges between 10 and 25 K. The comparison of the additives thermal transitions with the switching performance of the thermotropic layer revealed a good correlation (Fig. 1). This enables the development of thermotropic materials exhibiting tailor-made switching temperatures by selecting adequate additives.

Current investigations deal with the establishment of relationships between formulation parameters and the inner material structure and the light-shielding properties of TSFD, which shall provide fundamental knowledge and scientific basis for further developments.

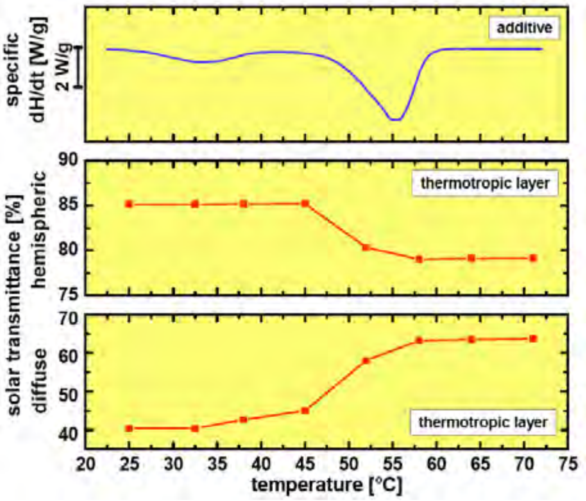

Fig.1: Thermogram of the additive (top), and hemispheric (middle) and diffuse solar transmittance (bottom) of a thermotropic prototype-layer as a function of temperature.

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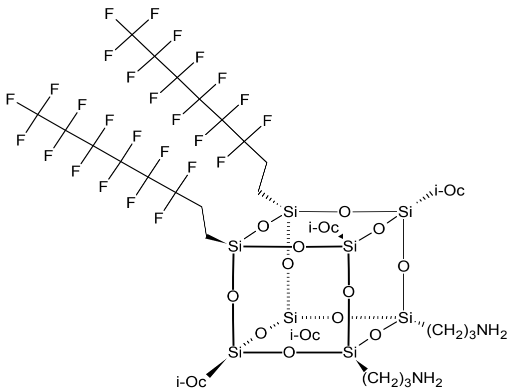
Easy- to- clean colored TISS paint coatings for polymeric absorbers

Unglazed solar collectors and solar façades are exposed to the rain which brought dust and dirt on the surface. Dirt deposited on the surfaces deteriorates aesthetic appearance of surfaces and -most importantly- decreases their optical properties leading to the loss of the solar radiation-to-heat conversion efficiency. Often cleaning usually with aggressive detergents is therefore needed even though this increases maintenance cost of the solar thermal collector systems.

Prevention of the dirt deposition by imparting solar absorbers' surfaces easy-to-clean properties represent viable route, which has not been exploited yet for solar thermal systems. Easy-to-clean surface are characterized with high contact angles for water (hydrophobic surfaces) and oils (oleophobic surfaces) and provide antisoiling properties to surfaces, trickling down of water drops collecting the dirt.



$IO_4AP_2PF_2$ POSS

Accordingly, we prepared novel adequately functionalized (heteroleptic) polyhedral oligomeric silsesquioxanes (POSS) materials having a well defined cage-like structure (3-5 nm) and organic inorganic hybrid composition. By the proper functionalization of POSS molecules (Figure above) we succeeded the incorporation of POSS into the organic resin binders suitable for the preparation of colored thickness insensitive spectrally selective (TISSS) coatings for plastic solar absorbers. TISS coatings, exhibit water and oil repellent properties and water sliding angles of few degrees. Through the nanotechnology the surfaces of the spectrally selective coatings were transformed providing advances properties to absorbers of solar unglazed polymeric collectors.

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Aging of polymeric materials - lifetime prediction

Lifetime prediction of plastics using accelerated aging data has always been a major challenge. For the use of plastics as an absorber in solar thermal systems a duration time of approximately 20 years is desired. According to the experiences with the Solarnor collector the wet load occurs up to 16000 hours and under stagnation a dry load of up to 500 hours. In this study 3 selected polymers including a polyphenylene ether polystyrene blend (PPE+PS), which is currently used in the Solarnor collector, a polycarbonate (PC) and a polypropylene (PP) were investigated as to their aging behavior in hot air and hot water.
Ultimate elongation data were chosen as the most sensitive indicator for aging. Hence, three different approaches were evaluated based on the Arrhenius relationship to predict lifetimes. Due to the constraints of the different methods, only PC was investigated, considering a useful lifetime (i.e. decrease in ultimate elongation by 50 %) for the operation in water at 60 °C (see Fig.1) and in air at 110 °C.

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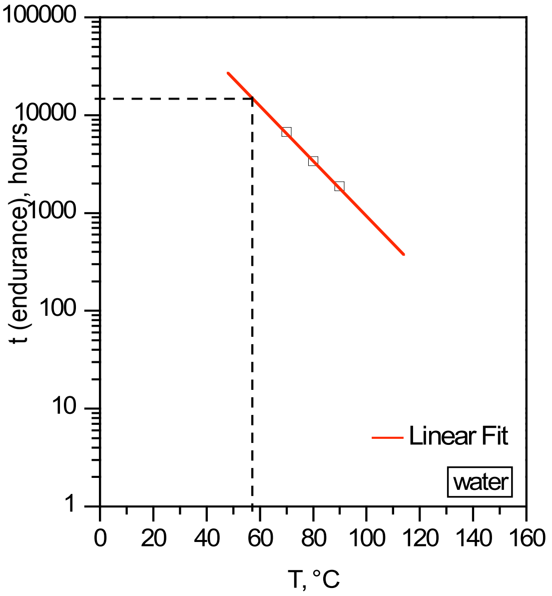

Fig.1. Logarithm of the endurance time to reach the 50 % end point criterion in ultimate elongation versus the reciprocal temperature after aging in hot water for PC.

The contributions of this newsletter were presented at the 5th IEA-SHC Task 39 experts meeting in Lisbon, Portugal, October 7-10, 2008. The authors are responsible for the content of their contributions. The newsletter is available as PDF-file under http://www.iea-shc.org/task39/whatsnew.htm. For more information on Task 39 visit the official website http://www.iea-shc.org/task39.