Task 39 - Polymeric Materials for Solar Thermal Applications

Meetings

10th Experts meeting, Sept. 27-28, 2010

The 10th IEA-SHC Task 39 Experts meeting was hosted by Johannes Kepler University Linz, supported by the Polymer Competence Center (PCCL) and took place in Blumau (Austria). 24 experts particpated in the meeting among them six from industry. Most of the presentations from day one are summarised in this newsletter. A major part of the agenda on day two was to discuss and define the workplan for the planned extension of Task 39 for the period 2011-2014.

Task 39 experts meeting in Blumau, Sept. 2010

EUROSUN 2010 in Graz

The 10th Task 39 Experts meeting was arranged in conjunction to the EuroSun 2010 conference in Graz, Austria, from Sept. 29 - Oct. 01, 2010. Eleven contributions related to Task 39 were presented at the EuroSun 2010 conference. The abstract are presented in this newsletter (pp. 7-10).

Next Task 39 meeting

The next Task 39 meeting will take place in Slovenia, May 19-20, 2011 hosted by the National Institute of Chemistry, Ljubljana.

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Task 39 Active Supporters:

Recent Task 39-related graduations

Website and abstracts: [www.iea-shc.org/task39кƎ⃒ǀ·ŘăŭdžŘŜýűă](www.iea-shc.org/task39)

Miriam Falk, Spectroscopic analysis of the aging behavior of polymers for solar thermal applications. Diploma thesis, University of Ulm, Germany, Oct. 2010 (in co-operation with Fraunhofer ISE).

Matjaž Koželj, Synthesis of substituted trialkoxysilanes and their use for preparation of materials via sol-gel route. PhD thesis, National Institute of Chemistry, Ljubljana, Slovenia, 2010.

Markus Mikl, Fabrication and characterization of thermotropic systems with fixed domains. Master Thesis, University of Leoben, Austria, September 2010 (in cooperation with PCCL).

Christoph Stöver - AFM aging analysis of polymeric materials for solar thermal applications. Diploma thesis, University of Ulm, Germany, Oct. 2010 (in co-operation with Fraunhofer ISE).

Andreas Weber - Analysis of morphology and switching process of thermotropic polymers by atomic force microscopy, Master thesis, University of Leoben, Austria, June 2010 (in cooperation with PCCL).

Solar-thermal Systems based on Polymeric Materials (SolPol)

Based on the available scientific and industrial expertise in the field of solar-thermal technologies and polymer technologies in Austria, which so far are not sufficiently interlinked, it is the overall visionary goal of the 3 years (2010 to 2013) research program SolPol to foster and strengthen the worldwide leading position of the Austrian solar thermal industry by novel polymer based product developments and innovations. For this purpose these two fields of expertise and competences are combined in two associated projects, one accounting for the scientific research needs (SolPol-1), the other for the industrial research needs (SolPol-2). While the fundamental research project SolPol-1, carried out by 5 Scientific Partners, is addressing some basic scientific and methodological aspects and requirements for the development of novel plastics based thermal collector systems, including an assessment of ecological and economical impacts of such collector systems upon market penetration on a regional and worldwide scale, the collaborative project SolPol-2, carried out by a consortium of 8 Scientific Partners und 10 Company Partners, focuses on industrial research aiming at the development of novel polymeric materials and all-polymeric model collectors of various designs as well as of other polymeric solar-thermal model components.

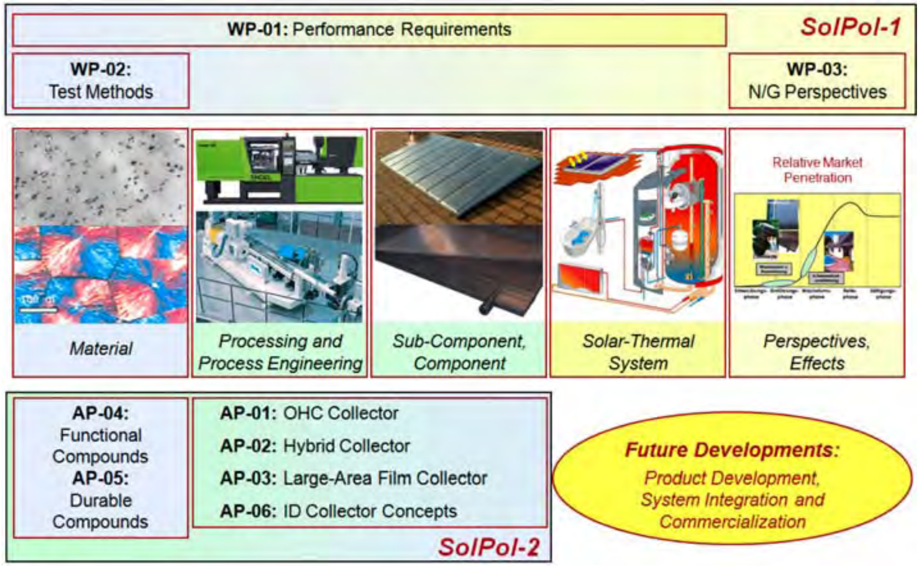

Fig. 1. Overview of the SolPol research program with positioning of the 3 work packages of SolPol-1 and the 6 work packages ("Arbeitspakete (AP)") of SolPol-2 along the value creation chain.

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Presentation of Technoform Kunststoffprofile GmbH (TKP) at the Task 39 conference in Blumau

Mrs. Jasmin Koch introduced TKP, which is a company in the Technoform Group. Technoform is one of the world's most renowned suppliers in the area of plastics extrusion.

As the development specialist in the Group, TKP specialises in developing and producing complex plastic profiles which meet extremely demanding requirements in terms of geometry, material and function. Core competences of the company include the realisation of high-precision tolerances (± 0.05 mm) and the achievement of exceedingly smooth surfaces – and this both inside and outside the profile.

After naming industries where TKP is already a leading supplier of extruded technical profiles, Mrs Koch went on to point out the advantages of using plastics in the solar industry and how TKP's strengths can contend with these challenges:

- Colour: Profiles can be made of all sorts of colours to blend into the background colours of roofs or facades.
- Weight: Plastic profiles weigh approximately 50% less than aluminium profiles.
- Material: TKP produces reinforced plastic profiles that provide high tensile strength as well as high temperature performance.

The company sees considerable potential for the use of plastic materials in the solar industry and is therefore willing to support initiatives like Task39.

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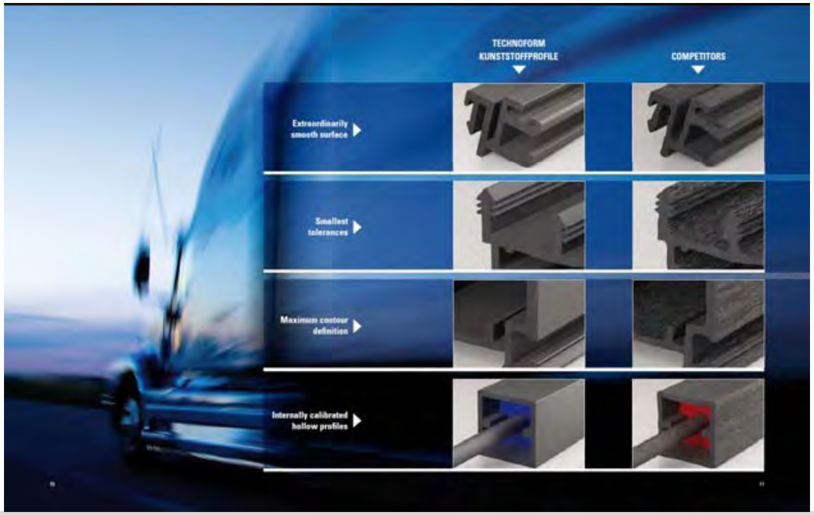
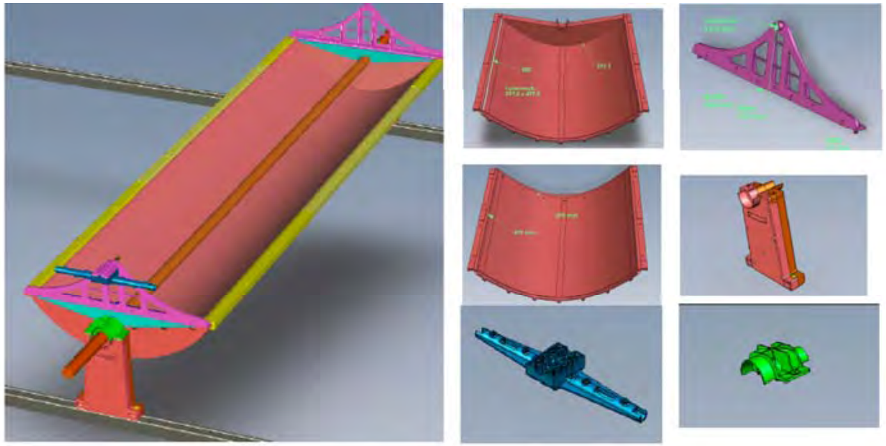


Parabolic trough collector mainly made from polymeric materials



A parabolic trough collector mainly made from polymeric materials was designed by Dr. Vetter Gesellschaft für Medizinische Datentechnik, Bio- und Umwelttechnik mbH. All major parts like the parabolic trough, the support and most of the smaller components are made out of polyamide, polyoxymethylene and polyvinyl chloride. The reflector is made from MIRO® reflective 90 and the absorber from stainless steel with selective black chrome coating. The concentration ratio of approx. 5 allows for temperatures of more than 120°C with reasonable collector efficiency.

The dimensions of the standard modules are 2 m long and 0.5 m wide. However the modular approach for building up the trough also allows other dimensions in length.

The first performance measurements conducted at the Institute of Thermo-dynamics and Thermal Engineering (ITW) of University Stuttgart showed very promising results.

In the next development phase the stainless steel absorber will be replaced by a copper absorber within an evacuated glass tube to reduce the heat losses to reach even higher temperatures.

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Solar collectors for the building industry

- Largest Nordic housing assocation OBOS invests in solar thermal energy

The production of the Aventa Solar collector has started, and the first pilot and demonstration projects are in operation. The first solar collector model is designed as a modular building element, applicable as facade elements or roof covers. The absorber is an extruded twin wall sheet in high temperature resistant PPS delivered by Chevron Phillips Chemicals, closed by means of molded en caps that are welded to the sheet. The transparent cover is a twin wall PC sheet, and the two layers are fixed together by means of aluminum profiles.
One of the main arguments for introduction of polymer materials in solar collectors is the potential for reducing costs due to different processing and manufacturing methods compared to conventional flat plate collectors. Aventa aims to reduce the processing cost by introduction of a new extrusion die enabling simultaneous extrusion of three absorbers. The new triple die is under construction.
The market acceptance of the product is depending on a good match between the collector design and the building industry. The mounting should be at least as simple and cost effective as the mounting of those elements that are replaced by the collector, and should be managed with tools familiar to the builders. A new profile concept has been designed in order to simplify the mounting and approach wishes and opinions from architects.
The cooperation with the building industry has recently got a major step forward since the largest Norwegian housing company, OBOS, is engaged as a significant shareholder in Aventa AS. OBOS has decided to create two identical passive houses (figure above) one with an air–water heat pump, the other with an Aventa solar thermal system. The two houses will be thoroughly monitored and the target is to declare a winner based on energy performance, costs and other factor that determine how well the systems are adapted to the market requests.

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HELIOSYS

This project will run for two years and aims to develop and to industrialize a universal solar thermal system for domestic hot water and room heating, thought primarily for small to medium sized housing and for easy integration into collective solar thermal systems for buildings. Being a low-pressure and low-temperature, operating under the drainback principle, this system can be used with almost any type of thermal solar collector, including the new generation of polymeric collectors that allow easy external integration, both on roofs and facades, and can even be used as structural and / or decorative elements. Heliosys also allows better inner integration because it can be sold just with the thermal insulation plates. The outer shell of the heat storage tank may be the responsibility of kitchen furniture manufacturers, giving them the freedom to design a cover to match the furniture style. A new patented circuit that reverses the heat flow through the wall of the inner DHW heat-exchanger using the same auxiliary heating system for DHW and room heating is expected to simplify and to lower production costs.

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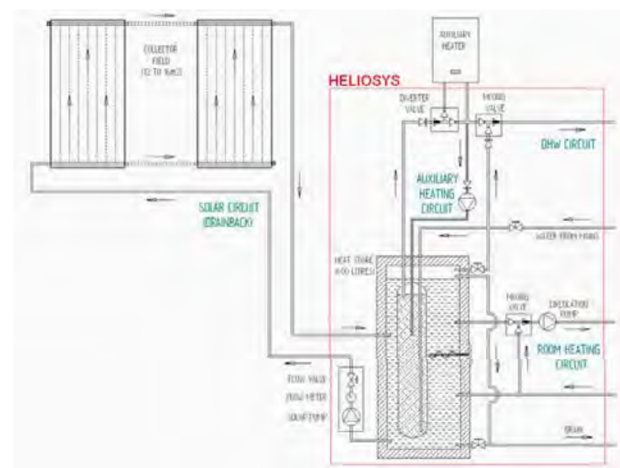
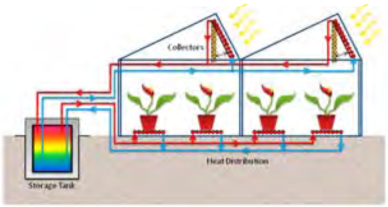


HELIOAGRO

The main purpose of a greenhouse is to create and maintain a controlled artificial environment that will favor the crop production with the maximum profit. Late increase on fuel prices, together with colder than normal seasons, make heating costs a significant burden on greenhouse operations. Therefore, the use of renewed energy systems, namely solar thermal systems, to control the inner environment of agricultural greenhouses becomes an economical and technological topic of unquestionable interest. Preliminary calculations on the possibility of using a solar thermal system to control the climate environment of a greenhouse show that, in certain climate conditions, a solar greenhouse can collect sufficient solar energy to feed, at least, another standard thermally optimized



greenhouse of the same size. The implementation of this project, which is based on Portuguese Utility Model nº10218 – “Thermal Solar System for Collection, Storage and Distribution of Heat at Low Temperature”, considers the construction of a prototype and, later, of a larger industrial greenhouse, to verify the technological and economical viability of the patented idea.

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Review: Structural Polymeric Materials for Solar Thermal Applications

Polymers are gaining increasingly importance in the solar thermal collector market mainly due to their low cost and light-weight properties and their flexibility in processing. Hence, the purpose of this study was to evaluate various plastic material types including commodity plastics, engineering plastics and high-performance plastics as to their performance in solar thermal absorbers. Based on the experiences of the all-polymeric Solarnor® collector designed for Northern climates, maximum operation temperatures in hot water (80 °C) and maximum stagnation temperatures in hot air (140 °C) were assumed. To characterize the chemical and physical aging behavior after exposure to hot water and hot air of selected plastics, tensile tests, differential scanning calorimetry (DSC) and size exclusion chromatography (SEC) were carried out.

Compared to the reference material used in the Solarnor® absorber (a poly-phenylene ether polystyrene blend (PPE+PS)), two other polymers, a random co-polymer polypropylene (PP) and a heat impact modified polyamide 12 (PA12) turned out to be the most promising candidates for the application in a solar thermal absorber. However, hot water had a stronger impact on the PA12 grade most probably due to a loss in antioxidant concentration indicated by a decrease in the oxidation temperature.

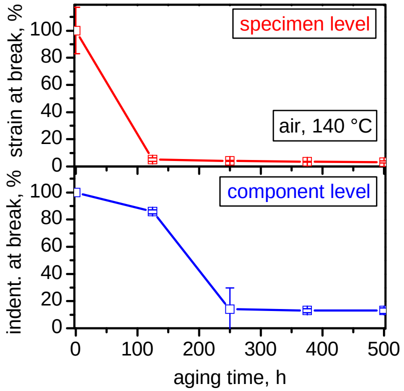

Fig.2: Relative strain at break values (specimen level) and indendation at break values (component level) versus aging time.

In general, for all polymers tested, proper devices are needed to prevent overheating above temperatures of approximately 120 – 140 °C.

Finally, mechanical performance properties on the specimen (ultimate strain) and on the component level (ultimate indentation) most sensitive for chemical aging were compared. A good correlation between the results on the components and the specimens (s. Fig. 2) was found, indicating that efficient material screening for solar-thermal absorbers is possible on specimen level.

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Numerical values based on AFM-measurements describe material degradation

***Abstract* -** Researchers at Fraunhofer ISE analyzed the aging behavior of three different polymeric materials (PPS, PPE-PS and PP with graphite) for solar thermal applications. Accelerated aging tests have been performed in climatic cabinets and solar simulators. The variation of UV irradiation, temperature and humidity allows analyzing the effects of defined combinations of these factors with Raman Microscopy and Atomic Force Microscopy (AFM).

After weathering with UV irradiation @ 85°C and 85% relative humidity a brown condensate was detected on the surface of PPS. The analysis of the Raman-Spectra shows an increasing fluorescence with the exposure time which can be explained with photo-degradation. Additionally changes of the typical spectra are recognized with increasing exposure time. Differences of the spectra of the surface scans show that an inhomogeneous degradation has to be assumed.

The weathering of PPS at 85°C and UV irradiation leads to strong blooming effects as can be seen in Fig. 3.
After 250h the surface area increases by approximately 17% and the Root Mean Square value by 103%. These quantitative values based on AFM measurements make trends and time dependences visible and support the interpretation of the qualitative surface images. This leads together with Raman Spectroscopic measurements to a broad understanding of materials degradation and durability.

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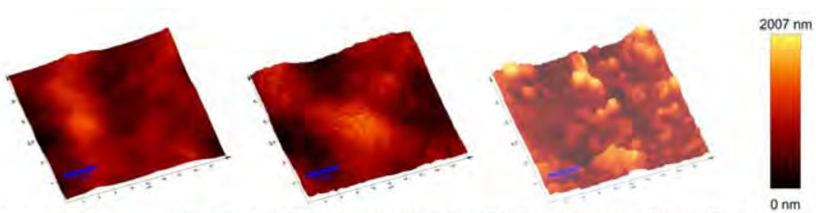

Fig. 3: AFM topography images of PPS exposed to heat (85°C) and UV irradiation. The surface topography shows significant changes during the expsoure tests. Strong blooming can be seen after 125 h (middle) and 250 h (right) shows up which is not found at the reference (left).

Fluorescence as an usefool tool for observation of polymer aging

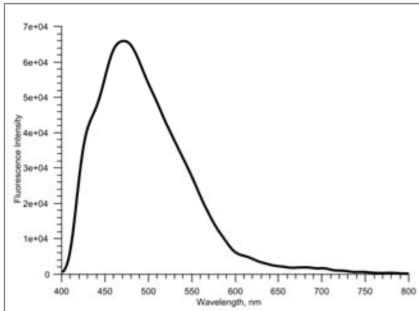

Fig. 4a: Typical fluorescence spectrum after DH ageing

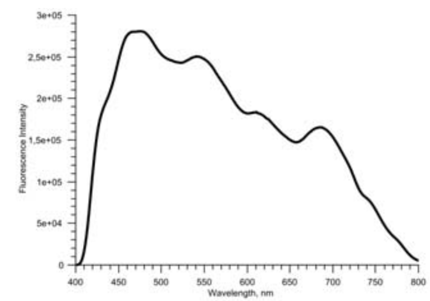

Fig. 4b: Typical fluorescence spectrum after UV ageing

Photovoltaic (PV) modules are designed to have a service lifetime of more than 20 years. It is hard to follow suitable degradation indicators during service life testing with sufficient accuracy for comparison with real outdoor aging during operation. Often the polymeric encapsulation material, mostly ethylene vinyl acetate (EVA), shows degradation effects. The detection of small changes of the material in a non-destructive manner helps to follow the changes over time.

We started our work with small model PV modules with crystalline Si-wafers and different back sheet materials, which were analyzed after accelerated indoor aging. Systematic spectral luminescence studies of polymer degradation of EVA were carried out. The laminated test modules were exposed to ultraviolet radiation (UV) or aged under damp-heat (DH) conditions (85% r.h./85°C). We found characteristic differences in polymer luminescence for the two ageing procedures (see Fig.4a,b).

Further we investigated PV modules with crystalline Si-cells of seven German manufacturers after 2 years outdoor weathering. For the first time we reported spatially resolved fluorescence spectroscopic images (FL) of complete modules. This is an upcoming new technology which allows non-destructive measurements of the encapsulation material through the glazing so that the degradation of the samples can be followed by measuring after or during exposure. In these studies we found characteristic differences in the EVA degradation depending on the location of the the weathering site and on the module.

Now we started with the application of this method to polymeric absorber material.

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Summary and outlook on spectrally selective coatings for polymeric absorbers

Polymeric solar absorbers are suitable for solar thermal collector applications without extended modification because the solar radiation absorbing phase (i.e. black or coloured pigments), UV stabilizers and other surface modifiers (i.e., antisoiling additives), could be relatively easy to incorporate into the polymer itself before the extrusion process is done. At least for polymers with sufficiently high thermal stability (> 200°C) (for example PPS used by AVENTA), the application of spectrally selective coatings looks reasonable in order to enhance their light-to-heat conversion efficiency. Nowadays, PVD coatings dominate the market for metallic absorbers but their application on polymeric absorbers has not yet been realized mainly due to the need for additional metallic layers serving as a low emitting substrate for the subsequent deposition of Thickness Spectrally Selective cermet coatings. In contrast, Thickness Insensitive Spectrally Selective (TISS) paint coatings represent a much better option because the coatings' thickness does not need to be controlled. Moreover, they are thick (> 20µm), mechanically robust and can be made in different colours. In general, they also adhere excellently to most common polymers. The first generation of coloured TISS paint coatings, which were developed within the frame of a SOLABS EU project (2002-2006) (leader Michael Koehl) exhibit moderate spectral selectivity ($\alpha_s \approx 0.90$, $\varepsilon_T \approx 0.40$, black) and variety of colour shades but these lack antisoiling properties (low contact angles for water and oils). A new generation of coloured TISS paint coatings have been developed within the framework of Task 39 with higher selectivity ($\alpha_s \approx 0.9$ (black) and $\varepsilon_T \approx 0.25$) achieved by the use of silane based dispersants for pigments in the corresponding paints. Silane dispersants modified the pigment surface making them compatible with the paint polymeric binder and enabling the deposition of coatings that consisted of finely ground and uniformly distributed pigment particles. Also based on silane technology, an antisoiling TISS paint coating was prepared as described in Fig. 5.

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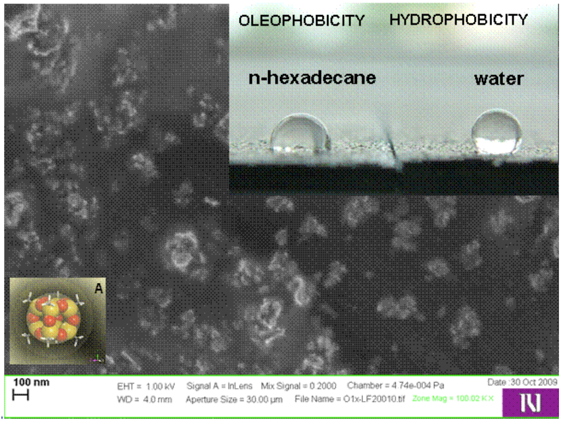

Fig.5 SEM micrograph of the surface of TISS paint coatings with separated pigment particles (~300 nm) achieved by using a dispersant based on fully condensed alkyltrialkoxy silane leading to molecules with a polyhedral structure as shown in (A). A structurally similar additive added to the paint imparts low water and oil contact angles to the coating, i.e. antisoiling properties.

Polymeric thermotrophic glazing for overheating protection of solar collectors

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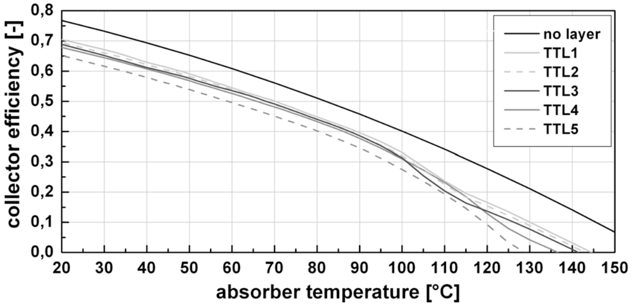

Fig.6 Effect of selected thermotropic prototype-layers on collector efficiency and maximum absorber temperature of a solar collector with twin-wall sheet glazing and black absorber (α=0.95, ε=0.90) at a solar irradiation of 1000W/m² and an ambient temperature of 20°C.

Synopsis - This paper focuses on thermotropic glazings based on polymeric materials for overheating protection of solar collectors. Thermotropic prototype-layers were developed and designed for solar collector applications considering aspects of polymer physics and characterized as to relevant morpho-logical parameters and performance properties. Structure-property relationships between the performance properties and the inner material structure and formulation parameters were established. Furthermore the effect of thermotropic prototype-layers on the efficiency and stagnation temperatures of an all-polymeric flat-plate collector was investigated and modeled. The investigations revealed a moderate reduction in the hemispheric solar transmittance of the thermotropic layers by maximum 18% above the switching threshold, which can be attributed to inappropriate scattering domain size and shape. Nevertheless, the use of these thermotropic prototype-layers in the glazing of a collector limits the maximum absorber temperatures to values between 129 and 146°C.

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Architecturally appealing solar thermal systems

– a great marketing tool in order to attract new customers and market segments

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Website: http://www.iea-shc.org/task39/projects/default.aspx

Abstract - Architectural integration is a major issue in the development and spreading of solar thermal technology. Unfortunately, the architectural quality of integrated solar thermal systems in many existing buildings is poor, which often discourages new potential users. Henning studied the attitude among people towards solar collectors and systems from a social anthropological point of view in 2000. Evidence showed that strengthened legitimacy and increased branch status is needed in order to attract new customers and market segments. As a contribution from IEA-SHC Task 39 to the challenge of making solar thermal systems more desirable, a database consisting of showcases where solar collectors have been successfully integrated into the architecture have been established. The idea is to make solar thermal more desirable by showing examples of visually appealing solar systems – something people really would want to put on their houses and something architects would want to implement in their design of new buildings.

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Pilot Plant of a Solar Thermal Energy Façade for Commercial and Industrial Buildings

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[3] ENERGY GLAS GmbH, Germany
[4] Kassel University, Germany

Abstract - How can solar thermal systems meet architectural and design needs? In commercial and industrial buildings solar thermal systems do not have great acceptance among architects and building owners yet. The reasons therefore are the optical appearance of standard collectors and a non holistic approach. It was therefore evident to create an attractive system, including all components, from the façade to the tank, including design and realization. Once this idea was born, the field of realization could easily be expanded not only to new build- ings, but as well to energetic improvement purposes of existing buildings. It was obvious that a pilot plant had to be erected, to gain experiences and to improve components. Thus the set goal was achieved to create an architectural solar thermal façade ready for the mar-ket.

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Aging behaviour of polymeric solar absorber materials: Aging on component level

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[3] University of Oslo, Norway

***Synopsis* -** Solar thermal collectors are evaluated and certificated according to EN 12975-2 [1]. In this standard testing procedures for polymer based absorbers are not implemented. Hence, the main objective of this study was to perform component tests of an existing solar thermal absorber made of polyphenylene ether polystyrene blend (PPE+PS) based on the test procedure proposed by Olivares et al. [2] and to correlate the results with aging data of PPE+PS on the specimen level (extruded film) [3]. In general, a good agreement between aging results on component and specimen was obtained. Hence, the implemented testing approach is applicable for the screening of novel polymeric materials for solar thermal absorber applications. It was also shown that the investigated PPE+PS grade may only be a proper material for solar absorber applications if suitable overheating protection is provided.

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Qualification of collectors and components by exposure to extreme climatic conditions

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Abstract - Solar thermal collectors and the used materials have to withstand outdoor weathering for very long periods of time; usually more than 20 years are expected. How do they cope with snow, salty ambience, desert climate, sea climate or tropical humidity? The Fraunhofer-ISE has access to 5 outdoor exposure sites where samples have to stand extreme climates: high temperatures with high daily differences in the Negev desert at Israel, snow, wind, extreme UV-irradiation and frost in the German Alps, high humidity at warm temperatures at Indonesia and high temperatures, wind and salt at Gran Canaria. The test sites are presently used for the exposure of PV-modules and will be extended for the testing of solar collectors and samples of collector components like absorbers, glazing and reflectors. The main aim is not only to collect data about the stresses on the samples, but the detection of reliability problems caused by salty atmosphere, high humidity, high wind loads and high temperature cycling, too. These activities are carried out in the next years within the German project SPEEDCOLL in a cooperation of Fraunhofer ISE with ITW (University of Stuttgart) and a number of quality-conscious companies (see list in the acknowledgements). UV- and solar-irradiation, ambient- and sample-temperature, ambient humidity and wind speed is measured and collected at a central server in Germany. Results of the first 24 months are compared. This data is the base for the calculation of integral loads for the comparison of different climatic regions and for the development of test procedures. The load differences for the different sites and the resulting test conditions for solar collectors and their impact on accelerated service life testing are discussed. This is important because regions close to the sea are usually highly populated and therefore have high potentials for solar thermal installations and CO_2 reductions.

The 5 different outdoor test facilities.

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Qualification of new polymeric materials for solar thermal applications

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Abstract - Polymers can offer additional degrees of freedom for collector design and access to cost-effective mass-production technologies for solar thermal applications, like collectors for example. But they have to stand harsh operational conditions. They are exposed to high temperatures, humidity and UV- irradiation. We exposed different types of polymeric materials to accelerated ageing tests. Samples were based on commodity plastics like poly-propylene (PP) with different stabilization systems, technical polymers like polyamide (PA) and cyclic olefin copolymers (COC), some with nano-fillers like glass-fiber (GF) or carbon-nano-tubes (CNT). Different compounds of high-performance polymers like polyphenylene sulfide (PPS) have been exposed, too. Some of the materials have been coated with optical selective coatings. The ageing conditions were different levels of high temperatures, high humidity and high UV-irradiation as well as combined tests. Optical, non-destructive methods like FFT-IR spectroscopy and Raman microscopy have been used for the characterization of the samples as well as atomic force microscopy (AFM). The results show a very strong influence of humidity at high temperatures on the degradation while UV exposure didn't lead to significant changes of the surfaces.

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The long, but successful way from development of coloured selective absorber coatings to application

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Abstract - Highly efficient selective solar absorber coatings are produced by coil-coating on thin metal substrates (usually copper or aluminium) either by PVD/CVD processes or by electro-plating. Rigid substrates or absorbers which were mechanically processed, like aluminium rollbond or polymeric twin wall sheets, cannot be coated in this manner. A number of projects had been dedicated to the development of coatings, which could be applied after the production of the absorber. Basically sol-gel coatings or paints could be applied. Additional features were the aesthetically acceptance for large area applications in the building envelope, especially by introducing colour shades, corrosion resistance for less expensive substrates as steel or plastic, high efficiency by decrease of the thermal radiation losses, potential use as unglazed facades, which requires anti-soiling properties and low costs.

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Thermal Load Analysis of a Solar-Thermal Flat-Plate Collector in a Domestic Heating System

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Abstract - Considering the significantly increased costs for aluminium and copper that are at present primarily used in the solar thermal flat-plate collector design, polymeric materials show a remarkable potential for cost reduction. Apart from moderate material costs especially for commodity plastics, highly efficient production processes provide an interesting prospective for the use of poly-meric materials. However, several technologi-cal challenges have to be met prior to the use of polymeric materials in a wide range of applications for collectors. This is especially the limited thermal property of various polymers in comparison to copper, aluminium or glass. Focussing on the evaluation of the thermal loads on the components of a flat-plate collector, an experimental analysis in combination with a simulation study of a state-of-the-art collector is carried out considering the aspects: max. temperatures of the collector components, dynamic behaviour of thermal loads and accumulated exposition times, i.e. thermal load profiles. The in-situ field-testing and the calculations show high thermal loads for the absorber and moderate temperatures for the other collector parts.

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Solar collector absorbers in high-temperature performance materials

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Abstract - The aim was to find and explore a material belonging to the class of high-temperature performance polymers, which is robust to sustain temperatures in a glazed solar collector during stagnation. The chosen material is a polyphenylene sulfide (PPS) - based blend from Chevron Phillips Chemicals adapted to the particular requirements related to the application as a solar collector absorber. If the solar collector is designed for a maximum stagnation temperature of the absorber of approximately 160 °C, the material will sustain this temperature for nearly 2000 hours. This thermal dose corresponds to approximately 20 years service life of a collector in south of Europe. Other factors than temperature can influence the material properties. The temperature variations during real operation can also cause effects different from those that are revealed in the present experiments. Still it is fair to conclude that the results indicate PPS as a promising candidate as an absorber material.

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Novel polypropylene compounds for solar thermal applications

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Abstract - Polypropylene (PP) is already in use for various components of solar thermal systems with a special relevance in polymer based heat storage tanks. For large or seasonal storage tanks an enhanced service temperature up to 95°C is required. Hence, the main objective of this work was to develop novel polypropylene compounds and to characterize their aging behavior in hot water and air environment. A reference and twelve novel compounds were prepared and exposed in hot water or hot air at 115, 125 and 135 °C at specimen level. To describe the aging behavior thermoanalytical and ultimate mechanical values were determined and evaluated. Especially for the novel grade P8 a significantly improved aging behavior was deduced for both environmental conditions hot water and hot air. Further work will focus on the continuation of the exposure tests and on the deduction of endurance limits under maximum operating temperature (95°C).

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