SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Task 39

Polymeric Materials for Solar Thermal Applications

SHC Polymeric Materials for Solar Thermal Applications

June 2015

Contents

SHC Polymeric Materials for Solar Thermal Applications– Position Paper

Aim of the Position Paper

This position paper describes the current state of the art for polymeric materials in solar thermal applications, shows the potential of polymers in solar thermal applications, and encourages further R&D activities.

Executive Summary

The major advantages of using polymeric materials in solar thermal systems are economical aspects, especially when taking into account the increasing solar thermal market and increasing raw material prices for metals. Although the cost of materials per mass unit might often be put forward as a major advantage of polymers relative to metals in conventional collectors, the entire picture is more complex.

Many successful applications of polymeric materials in solar thermal systems that perform equally well or better in terms of conventional energy savings, reduction of materials, as well as production, transport, installation and/or end-user costs have been demonstrated [Piekarczyk, 2014].

Good energy performance is reached especially when favorable applications and system designs for polymeric materials are chosen. These favorable designs may include heating systems with low and medium system temperature, low system pressure, optimized heat carrier flow, drain-back technology, overheating protection, suitable surface coating of collectors, etc.

Examples for such systems are pool heating systems, combined systems for solar domestic hot water preparation (DHW) and space heating, systems with large DHW consumption (sport centers, nursing homes, hospitals, multi-family buildings, etc.) and air heating systems in commercial or institutional buildings as well as façade systems and storage tanks.

Introduction and Relevance

While the energy delivered by the sun is free of charge, the installations for the technical conversion into heat and for the heat transport and storage require some investments. A considerable part of these system components consist of metals. The piping in the solar collectors and heat exchangers are made of copper, aluminum is used for the absorber and the casing, and steel is often used for the storage unit. If we continue to use these standard materials, the demand from the still growing solar thermal market [Mauthner, 2015] would lead to an annual copper consumption in the order of the yearly copper production worldwide. The price development we would have to face then is thus very obvious. Increasing prices against the political and environmental necessities would clearly jeopardize market deployment.

One way out of this dilemma is to use polymeric materials instead of metals. Seeing more and more successes of polymer technology development stabilizing material blends and cost-efficient production techniques for innovative designs, this is a palpable way to go. As the building blocks of polymers are hydrocarbons, about 10% of the oil consumption today goes into such technical use. In the future, biomass or even carbon dioxide and water could be substitutes for the by-then depleted oil resources. A variety of production technologies like extrusion, thermo-forming, vacuum-forming and injection molding could be applied to the product designs and the market volumes. Due to the economies of scale, mass production clearly facilitates an appreciable cost reduction. In addition, the accompanying design freedom opens the chance for the production of collectors with high geometrical flexibility that meet the aesthetical requirements of building integration better. With regard to the environmental performance of metal compared to polymeric solar thermal collectors, Life Cycle Assessments found the relative advantage of polymeric collectors due to the absence of harmful mining processes (Weiß, 2014; Weiß, 2015).

Numerous examples of solar thermal collectors and systems can be found on the market. Most of them are used without glazing and thermal insulation for swimming pool heating. Some are more advanced and able to reach a better performance and at higher operational temperature either as integrated storage collectors or as glazed flat-plate collectors with absorbers made of high-performance polymers. Although there are quite a number of solar thermal systems where polymers already are in use, the number and variety of possible applications of polymeric combinations is far greater than these examples suggest. For a more extensive integration of polymers in this area, however, targeted research on suitable materials and compounds as well as an extensive consideration of their characteristics and their special strengths and weaknesses is necessary.

System challenges for the use of polymeric materials is the limitation of the maximum temperatures of absorbers during stagnation (when no heat is extracted from the solar system) to values around 120°C and the lowering of the pressure of the heat transfer fluid to avoid mechanical damage. Such measures allow the use of less expensive, but also less durable polymeric materials. Another challenge is the long-term weathering of the polymers during operation, if the service life should be comparable to the conventional solar thermal systems. Although polymer technology has made significant progress in developing stabilizers and UV-absorbers, a demonstration of sufficient durability is needed to counteract the traditional image of polymers as one-way products with poor aging properties and sustainability.

Plastics are one key material for reliable and cost-efficient warm water preparation around the world. Less expensive manufacturing processes and material combinations lead to cost-efficient manufacturing of completely innovative collector designs that are competitive to standard solutions in cost, efficiency and durability. They also open up possibilities for aesthetical innovations in building integration and low-cost systems for Sunbelt regions.

IEA SHC Task 39: Polymeric Materials for Solar-thermal Applications was started in order to work on these issues and to create space for the extensive use of polymeric materials in solar thermal systems.

Status of the Technology/Industry

The status of the application of polymeric materials in solar thermal systems is described by looking at the technical maturity, energy and cost performance, and market deployment.

Technical Maturity

Traditionally, solar thermal (ST) technologies have been dominated by the materials metal and glass, except for pool heating systems where polymeric materials have been applied from the beginning. Hence, the technical maturity has to be seen in connection with the application:

- Absorbers for solar heating of (outdoor) swimming pool systems have been produced from polymeric materials since the early 1970s. The technology is straightforward and ideal for using commodity plastics with low material costs and high production volume. Pool absorbers exist in various designs produced by different polymer processing techniques. They represent a mature technology with the largest capacity installed in the USA and Australia in terms of GW_{th} ([Mauthner, 2014]). These unglazed polymer collectors are nowadays promoted for domestic hot water systems in the sunny regions of USA.

- Complete solar collectors of polymeric materials with a high performance are most challenging from a technology point of view and most interesting due to the potential market volume. There are all plastic solar collectors available, which are or are at least close to being technical mature. A real market breakthrough is expected in the coming 10 years. Market introduction now needs other strong partners besides the established HVAC industry in the start-up phase.

- Smaller key components of polymeric materials are already implemented in ST applications where the unique advantages of polymers exceed the conventional material properties and the costs or functional design of conventional components. Established ST actors usually initiate such substitution measures after thorough evaluation of cost performance (e.g., frame corners by BBT, manifold header by Kingspan, solar insulation by Viessmann).

- The technical maturity of polymers in heat storage technology is basically reached with different polymer storage designs currently on the market.

Energy Performance

Many successful applications of polymeric materials in solar thermal systems that perform equally well or better in terms of conventional energy savings, the reduction of materials, production, transport, installation and/or end-user costs have been demonstrated.

Good energy performance is obtained when favorable applications and system designs for polymeric materials are chosen. Favorable designs may include heating systems with low and medium system temperature, low system pressure, optimized heat carrier flow, drain-back technology, overheating protection, suitable surface coating of collectors, etc.

Examples for such systems are pool heating systems, combined systems for solar domestic hot water preparation (DHW) and space heating, systems with large DHW consumption (sport centers, nursing homes, hospitals, multi-family buildings, etc.) and air heating systems in commercial and institutional buildings.

Potential

The major advantage of using polymeric materials in solar thermal systems is economics, especially when the solar thermal market is growing. Although material costs per mass unit might often be put forward as a major advantage of polymers relative to metals in conventional collectors, the entire picture is more complex (and in favor of polymers). The following aspects normally contribute positively when the total cost scenario of polymers and conventional materials is compared:

- material costs when large volumes are considered,
- production costs considering mass production technologies for polymeric materials,
- reduction of installation time and costs due to smart integrated design,
- significant environmental advantage due to highly harmful mining conditions of metals,
- multi-functional design of polymeric collectors replacing conventional roofs and facades, and
- cost reduction due to the weight reduction of the final product: handling, transport and installation.

It should be pointed out that crude oil price fluctuations have a larger impact on commodity plastics produced in large volumes and less on high temperature performance plastics.

When evaluating the overall picture and considering all the positive impacts when using polymeric materials, as described above, the life cycle of solar thermal technology/products needs to be analyzed as it considers among others costs, CO_2 emissions and used energy for:

- material production and transport,
- maintenance, and
- end of life disposal.

Introducing polymeric materials in solar thermal applications offers great potential, which could provide significant advantages and benefits for manufacturers, installers as well as end-users.

Technical Potential

The technical potential of polymeric materials for solar thermal applications can mainly be addressed by two major items: manufacturing process and technical properties of materials. Manufacturing processes of polymeric materials are significantly different from that of most manufacturing processes known up to now in the solar thermal industry, where metallic materials are used most of the time. These manufacturing processes allow for an innovative approach in the design of products and components, which can lead to significant advantages as illustrated by the two following examples.

- Components with complex shapes, including multiple functions, can be easily produced based on injection molding processes. This could be a major advantage for the manufacturing of complete hydraulic units including most of the components required (pumps, valves, flow and temperature sensors) with a significant reduction in fittings, piping and components as well as a minimization of weight and space requirements. The design of specific components, such as the casing, can include additional functions for venting (overheating protection) and installation.

- Extrusion process can provide significant advantages for the production of solar absorbers. The design of the flow channels can be improved in order to reach a very high efficiency despite the low conductivity of polymeric materials. This process allows also for the flexible production of absorber lengths that can be adjusted to the required dimension for building integration purposes.

Other production processes for polymers can be advantageously used for solar thermal applications, such as thermoforming (components of collectors, heat storage) and rotational molding (shell tank storage) thus providing a significant technical potential.

From commodity/standards to high performance plastics, a wide range of technical properties are available on the market that allow finding the right material from commodity/standards to high performance plastics for most of the applications.

Additional functionality of the components can be developed to provide specific properties or additional functions for components. This is the case for:

- thermotropic materials for overheating protection, and
- absorber coatings for enhanced performance.

Economic Potential

Solar thermal systems will have to make a major contribution to the worldwide targets of renewable energy contribution. For example, to cover 4% of the low temperature heat (in this case defined as < 250°C) in Europe (EU-27 countries) by 2020, the installation of 388 million square meters of collector area would be needed (ESTIF, 2009). According to the Full R&D and Policy Scenario, a potential of 1,400 million square meters of collector area by 2030 and 3, 880 million square meters of collector area (corresponding to 2,717 GWth) by 2050 is estimated for Europe. While worldwide scenarios are currently not available, it is obvious that the potential on a worldwide scale is significantly higher (factor of 10 to 20).

To achieve the ESTIF goals, the rapid growth in production is needed – the average growth rate of the last decade has to be doubled. Simultaneously, it is quite apparent that such growth rates will not be achievable with current collector manufacturing technologies.

Current solar collector and system technology relies on the use of copper or aluminum for absorbers and steel for storage tanks. The copper content in conventional flat plate collectors varies between 2 and 6 kg/m². Taking into account the copper used in piping and heat exchangers/heat stores, 5 kg/m² of copper can be assumed. According to the above growth scenario for Europe, this would imply that by 2050 the annual copper demand for solar thermal systems would be about 4.7 million tons annually. This figure corresponds to 31%(!) of the annual world copper mining production in 2006, and it underlines the need for alternative material solutions.

Compared to other materials, polymeric materials are characterized by their tailored multi-functional property profiles, their highly flexible ability to be processed to complex components and their low density or weight. Based on these and other specific advantages, an increased use of polymeric materials in solar thermal applications could lead to the following improvements:

- Polymer based components in solar thermal systems will exhibit a substantial improvement in functionality and functional integration and thus significantly reduce the number of individual part counts compared to the conventional metal based solutions.

- Collectors and heat stores in proper plastics design will lead to a significant reduction in installation costs simply due to their lower weight, but also as a result of more innovative connecting and mounting techniques (plug & play elements).

- In correlation to other fields of application (e.g., interior design of vehicles), the use of plastics in solar thermal components and systems will offer significantly more freedom of design and better meet aesthetic needs. For example, colors and shapes may be varied so that future collector designs are not necessarily always flat or cylindrical, but may also by freely shaped as architectural roof and facade surfaces.

- A special feature of polymer processing technologies is the ease of production of large numbers of complex parts. As in other areas, these technologies offer mass production capability coupled with a high degree of functional integration. This in turn acts to reduce costs while simultaneously guaranteeing that the high market growth rates needed to cover a significant portion of the low-temperature heat demand can be achieved and sustained. One of the key innovative elements is likely to be related to advanced polymer processing technologies.

Current polymer based collector solutions do not meet the above described criteria, as they were primarily developed by simple substitution considerations. To exploit the full potential of innovative designs with plastics, a joint development effort is needed involving experts from the entire value generation chain in polymer technologies and experts from the field of solar thermal technologies. Only such an approach can ensure the synergies needed for leap frogging innovations, which are a prerequisite to achieve the ESTIF market growths objectives.

Since about 50% of the final energy consumption is used for low temperature heating, this energy market has also the largest potential for substituting fossil fuels with renewable energy, especially with solar thermal energy. The need for broader use of solar thermal energy also becomes increasingly obvious because of the prices of fossil fuels and threats of an upcoming shortage (e.g., “peak oil”).

Various scenarios on a national and European level assume significant growth potential for solar thermal technologies in the “low-temperature range” up to 90 °C. As a result of the low temperature difference between room temperature and outside environmental temperature (max. 40 K) and the maximum hot water temperature need of 80 to 90°C, a high degree of supply of these energy needs by solar thermal technologies is meaningful also for exergetic reasons. Thus, serving a large portion of the low temperature heat demand with solar thermal systems may also be argued based on this point of view.

The cost of a solar thermal system differs significantly depending on the type of collector, the storage tank and the market. For a thermosiphon water heater, the cost (excluding installation) ranges from about 150 €/m^2 to 1,000 €/m^2. The lowest cost is reported for open-looped thermosiphon systems for hot water preparation with rather low comfort demands; an average system lifetime below 5 years and high maintenance rates.

Overall systems costs for advanced pumped collector systems with separate storage tanks for domestic hot water preparation and space heating are in the range of 800 to 1,000 €/m^2. Interestingly, a high fraction of the costs are due to the installation of such systems (approximately 75%). Hence, a major disadvantage of advanced pumped collector systems for high comfort demands and a lifetime guarantee of 20 years is their complexity and the high level of effort needed to install the system. Furthermore, potential reductions in collector costs (currently about 60 €/m^2 for a flat-plate collector) will have a low impact on the overall system costs. These costs have to become fully competitive with fossil fuel based heating systems. Target costs are ranging from 150 €/m^2 for simple non-pumped, plug & play systems and about 300 to 400 €/m^2 for advanced pumped systems.

Current Barriers

The major producers of conventional ST collectors do – until now – not offer competing all-polymeric collector products. Innovative, all-polymeric collectors can be mainly found in small and relatively new companies. Hence, the challenge for such companies is to get their products established in the market and benefit from up scaling the production by the increasing sales volume aspect by using polymeric materials. A barrier for the introduction of new, all-plastic ST technology is to a certain extent, the protectionism of well-established installers of traditional technologies, whole-sellers and the HVAC sector. New approaches are to enter the market through companies that specialize in roofs or facades.

Monetary barrier:

- Upfront investment for suitable production units, such as extruders or injecting molding systems is relatively high and only viable for high production rates (requiring a corresponding big market).

Non-monetary barriers:

- Polymer technology suffers from the image of not being durable and sustainable.
- Awareness of the feasibility of polymeric materials for solar thermal systems is still too small.
- Overheating protection may be an issue for low-cost commodity plastics in certain collector designs.

Actions Needed

- *Stimulate the penetration of polymer applied in solar thermal applications.*

- *R&D efforts that stimulate a multi-disciplinary approach joining plastics and solar thermal experts.*

- *Quantify most relevant performance and material requirements of polymeric materials in solar thermal collector applications.*

- *Generate, improve and disseminate knowledge on the economic potential of different polymer based collector types in various world regions and climates.*

The research work on polymeric materials for solar thermal systems focused partly on the substitution of existing non-polymeric components of solar thermal systems by novel polymer based components (Meir et al., 2008). In many cases, the success of this research approach was limited and resulted in the current low market penetration of plastics based components in solar thermal systems.

The main reasons for the moderate market performance are related to a research and development approach that neglects fundamental research needs and the necessity of a multi-disciplinary and combined plastics and solar thermal experts approach. Further reasons are related to inappropriate collector or system design and improper material and process selection. A major problem in selecting appropriate materials and processing technology routes is related to the lack of well-defined performance requirements (component level) and material property requirements (specimen level).
There is a lack of knowledge in quantifying the most relevant material performance requirements and the material aging and degradation, which may occur under long-

term service conditions. For this purpose, proper accelerated test techniques are needed that allow for long-term extrapolations and lifetime estimations, but which are not yet available.

Finally, the economic potential of different polymer based collector types in various world regions and climates has not yet been systematically analyzed. The same is true for the environmental effects to be expected when transforming the conventional collector technology to a highly plastics based technology. A subject of special interest is related to the effect of various plastics based solar thermal systems growth scenarios on national and regional levels and global greenhouse gas reductions.

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