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A total cost perspective on use of polymeric materials in solar collectors – Importance of environmental performance on suitability

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HIGHLIGHTS

- A polymeric solar collector system was compared with two traditional ones.
- It was found the best in terms of climatic performance per solar heat collected.
- The differences in climatic cost between the systems compared however are small.
- The low climatic cost makes solar heating better compared to natural gas heating.
- Use of Ecoindicator 99 for environmental cost makes solar heating even better.

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ABSTRACT

To assess the suitability of solar collector systems in which polymeric materials are used versus those in which more traditional materials are used, a case study was undertaken. In this case study a solar heating system with polymeric solar collectors was compared with two equivalent but more traditional solar heating systems: one with flat plate solar collectors and one with evacuated tube solar collectors. To make the comparison, a total cost accounting approach was adopted. The life cycle assessment (LCA) results clearly indicated that the polymeric solar collector system is the best as regards climatic and environmental performance when they are expressed in terms of the IPPC 100 a indicator and the Ecoindicator 99, H/A indicator, respectively. In terms of climatic and environmental costs per amount of solar heat collected, the differences between the three kinds of collector systems were small when compared with existing energy prices. With the present tax rates, it seems unlikely that the differences in environmental and climatic costs will have any significant influence on which system is the most favoured, from a total cost point of view. In the choice between a renewable heat source and a heat source based on the use of a fossil fuel, the conclusion was that for climatic performance to be an important economic factor, the tax or trade rate of carbon dioxide emissions must be increased significantly, given the initial EU carbon dioxide emission trade rate. The rate would need to be at least of the same order of magnitude as the general carbon dioxide emission tax rate used in Sweden. If environmental costs took into account not only the greenhouse effect but also other mechanisms for damaging the environment as, for example, the environmental impact factor Ecoindicator 99 does, the viability of solar heating versus that of a natural gas heating system would be much higher.

1. Introduction

It has been pointed out that in many cases, polymeric materials would be a better alternative to materials currently used in solar thermal energy systems. Intense research and development is being conducted on this use of polymeric materials in Task 39 of the IEA Solar Heating and Cooling Programme [1,2]. The economic viability of solar collector systems is strongly linked to thermal performance and to investment costs, and an attractive approach to cost reduction would be to replace glass and metal parts with less expensive, lighter weight polymeric components. However, the use of polymeric materials in solar technologies is still very limited because the applicability and the durability of these materials are often questioned. Because today's solar heating systems

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need to function for a long period, at least 25 years, the requirements for adequate materials durability may be hard to meet. As environmental concern is the most important incentive for installing a solar heating system today, the design concept chosen for the system must also be environmentally friendly and, in this context, polymeric materials are in general considered more suitable than other materials such as metals.

To take into account all the relevant factors for materials selection in designing a solar heating system, it would be best to take a holistic view. This would allow for simultaneously considering not only functional quality and cost effectiveness, but also reliability, long-term performance, ecological soundness, and recoverability. Consequently, a total cost accounting approach could therefore preferably be adopted. Such an analysis has not, to the knowledge of the authors, been done before [2].

A total cost accounting approach takes the end-user or consumer perspective and the ecological long-term perspective as a basis for compiling the contributions from all the various factors that might be important to the life cycle of a functional unit of a product. The point of departure is not a particular design alternative of the functional unit and its life cycle, but its intended function over time. When adopting the total cost accounting approach, it is, however, not the absolute value of the total cost that is of main interest, but the difference in the total cost between two design alternatives of the functional unit of the product considered; see, for example, [3,4].

If one design alternative of the functional unit is chosen as reference, the model to be adopted can be described as follows: For a fixed service time, the difference in total cost (C_{RT}) associated with maintaining a specific function defined for the functional unit is estimated from

$$C_{RT} = C_{RP} + C_{RNIP} + C_{RO\&M} + C_{RF} + C_{REoL} + C_{RE} + C_{RD} \quad (1)$$

where C_{RP} = the difference in production cost between the two design alternatives; C_{RNIP} = the difference in cost associated with initial non-ideal function or performance between the two design alternatives; $C_{RO\&M}$ = the difference in operational and maintenance cost between the two design alternatives; C_{RF} = the difference in cost of probable failures and damage between the two design alternatives; C_{REoL} = the difference in end-of-life costs between the two design alternatives; C_{RE} = the difference in environmental cost associated with probable ecological damage between the two design alternatives; and C_{RD} = the difference in development cost between the two design alternatives.

Detailed information on the assessment of how the different cost terms that contribute to the total cost can be found in a previous work by Carlsson [3,4].

Comparing different design alternatives using the total cost accounting approach required systematic suitability analysis. This requires that the design alternatives be clearly defined and suitability analysis be conducted, preferably in the form of a case study.

Within the framework of the IEA Solar Heating and Cooling Program Task 39 Polymeric Materials for Solar Thermal Applications, a case study therefore was undertaken to assess the suitability of solar collector systems with polymeric materials against solar collector systems using more traditional materials.

Three solar heating systems were selected for study:

- a solar heating system with polymeric flat plate solar collectors manufactured by Aventa [5] (system A);
- a solar heating system with flat plate collector with copper absorber, the New Nr. 2 system according to [6] (system B); and
- a solar heating system with evacuated tube collector, the New Nr. 8 system according to [6] (system C).

Data on the characteristics of system A were gathered mainly from the company Aventa [5], which participates in the work of Task 39. A general description of the polymeric collector and the corresponding solar heating system design is given in [2]. One of the main characteristics of the polymeric solar heating concept is that the collector loop contains pure water without additives, is not pressurised but open to atmospheric pressure. The collectors are part of a drain-back system. Favourable applications for this concept are combined solar heating systems for domestic hot water (DHW) preparation and space heating or DHW systems with large heat demand and relative low system temperature.

Systems B and C were chosen as reference systems because their characteristics are well described in the report by Stucki and Jungbluth [6].

To make a total costs comparison between the systems, it is essential first to adjust the size of the different systems so that their functional capability in the initial phase will be the same, in other words, C_{RNIP} becomes equal to zero in Eq. (1). This means that the different systems have to be compared when placed at the same location delivering the same amount of solar heat to cover the energy demand for the same kind of building. Resizing the three systems was therefore the first step in the analysis.

The next steps were (1) assessment of the difference in environmental and climatic performance of the three systems by life cycle analysis (LCA); (2) analysis of the three systems with respect to differences in investment costs, O&M costs, and end-of-life costs; and (3) analysis of the three systems with respect to differences in reliability and long-term performance.

2. Dimensioning of an equivalent set of solar combi systems with respect to functional capability

For the analysis, a typical Swedish one-family house from 1980 in Stockholm was used. The yearly heat demand for space heating was set at 30 MW h and the yearly hot water demand was set at 4.57 MW h, corresponding to 200 l of hot water a day. A wood pellet heating system was selected as an auxiliary heat source.

For assessment of thermal performance, the system simulation tool TRNSYS, developed by Klein et al. at the Solar Energy Laboratory at the University of Wisconsin, USA, was used [7]. TRNSYS contains a number of types (previously written programs that describe components) that can be connected to each other to form complete heating systems. Types representing a variety of components for modelling of heating systems are presently available from TRNSYS [8]. To fulfil the purpose of the present study, a set of suitable types and connections between them were selected to form a solar heating system.

The relatively simple type 12c was considered most suitable to describe the house based on the results of a previous study [9]. Type 12 is a simple degree-day, single-zone, single capacitance building model with internal gains. The model creates a heating need by using an effective heat capacity for the entire building together with the difference between indoor and outdoor climate.

The tank was modelled by use of Type 534; see [8]. For all solar heating systems studied, the same kind of tank was used with a volume of 1000 litre and a heat loss coefficient of 3 kJ/h,m^2,K. The tank is treated as stratified with five nodes or temperature zones interacting adiabatically with each other. To model the hot water system, Type 38-2 was used [8]. Weather data file from Meteonorm, modelled by use of Type 15, and valid for Stockholm was adopted. Within Type 15, the angle to the horizontal plane and the azimuth of the solar collector were defined as 45 degrees and 0 degrees, respectively. The model used for the solar collector was Type 136 [10]. Type 136 is a further development of the earlier Type 132 in TRNSYS 15. It takes into account the contribution of