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Review

Advanced solar flat plate collectors with full area absorber, front side film and rear side vacuum super insulation

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ABSTRACT

For solar process heat production up to 150 °C, advanced insulation methods for flat plate collectors are presented. The collector front losses have been reduced by transparent insulation materials, the rear losses by an integrated vacuum super insulation (VSI). Four front side insulations have been developed and investigated at laboratory and outdoor test facility: double skin sheet and polymer honeycomb show good insulation properties, but under collector stagnation the maximum temperature still narrowly leave the range for long term stability of the used state of the art materials. Single and double highly transparent film insulations (ETFE and FEP with solar transmission of 94% and 96%, respectively) combined with a full area (direct flow) absorber are especially promising. They reduce the *U*-value by 1.3 and 1.7 W/m^2 K at additional costs of below 10 and 20 €/m^2, respectively, while the optical efficiency, as a consequence of the full area absorber, nearly remains unchanged compared to high-end series collectors. Totally the efficiency of flat plate collectors for a reduced temperature of 0.1 K m^2/W is augmented by 21% and 29%, equivalent to evacuated tube collectors at only about 60% of their costs. The new film insulations for the front side turned out to be very efficient, practicable and long-term stable. Additionally, a VSI rear side insulation has been developed. Heat loss coefficients (*U*-values) for different VSI rear sides (core with expanded perlite and highly dispersed silica, envelope with 0.8 mm and 0.1 mm stainless steel film, welded by hand, by laser and glued) have been measured. With low priced perlite, $p < 0.1$ mbar at 40 mm insulation thickness and 70–120 °C absorber temperature rear *U*-values of 0.5–0.8 W/m^2 K can be achieved. With more expensive highly dispersed silica at $p < 10$ mbar even lower values of 0.25–0.45 W/m^2 K have been measured. Outdoor measurements showed that using a VSI, total collector losses can be reduced by 0.5 W/m^2 K compared to dry mineral wool insulation. Open problems are the long term vacuum tightness and mechanical stability of the VSI envelope. Double film insulation combined with a VSI rear side would lower the total collector heat losses by more than 2 W/m^2 K. At a reduced temperature of 0.1 K m^2/W such a collector could reach efficiencies over 50%, comparable to high-end evacuated tube collectors. Costs for a collector with double film insulation and perlite VSI filling would be 70% of the costs of a vacuum tube collector, for a VSI filling with highly dispersed silica plates it would be 90%.

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1. Introduction

In future regenerative energy scenarios, solar thermal collectors need to deliver temperatures between 100 and 150 °C with higher efficiencies at affordable costs for applications like process heat, district heating and process cooling. Those collectors need to be able to economically compete with new emerging technologies like the combination of PV and heat pump. Vacuum tube collectors can supply heat at these temperatures. But with production costs of about 175–250 €/m^2 they are more than twice as expensive as flat plate collectors.

The aim is to lower the total *U*-value of flat plate collectors to about 2–2.5 W/m^2 K to be comparable with vacuum tube collectors in the range of elevated reduced temperature (0.1 K m^2/W) and to be competitive with other technologies at additional costs of only 10 to max. 30 €/m^2 referred to standard flat plate collectors, which are produced typically at 70–100 €/m^2. Both solar process heat up to 150 °C (laundries, food industry [1]) and solar cooling (single and double effect absorption chiller at 90 and 130 °C, respectively [2]) should be economically provided.

About 75% of the total losses (about 6 W/m^2 K at 0.1 K m^2/W) of a standard flat plate collector arise to the front. A reduction of the front losses can be achieved by a transparent barrier to suppress air convection in this gap. The challenge is to lower the thermal losses, but not deteriorate the solar transmission and the optical collector efficiency. The transparent barrier can be a polymer film, thin glass or a honeycomb structure. Several papers have been published examining different front side insulations theoretically and experimentally, for instance [3–6]. Principally all the portrayed technologies are market available: Danish company Arcon has an FEP film stretched in the space between absorber and glass [7]. Nevertheless, the film in the collector is clamped at two sides only with small tension insufficient to prevent sagging and wrinkles during operation. However this does not lower the efficiency but the appearance of the collector is affected of which some customers are sensitive. Austrian company Oekotech has a collector with a double-glass design at the front [8]. Although the collector efficiency rises, it makes the collector quite heavy and expensive. The Israeli company Tigi sells an efficient collector with a polymer honeycomb structure [9]. Unfortunately, this material is only temperature stable up to 100 °C and requires a sumptuous cooling device integrated in the collector. Summarizing, no significant market penetration has been achieved so far due to various reasons.

In this paper, four new prototype collectors with transparent barriers are described. The first uses a double-skin sheet, the second a single ETFE (ethylene tetrafluorethylene) film clamped at four sides. The third is combined of a polymer honeycomb transparent heat insulation with an ETFE film tensed under, whereas the fourth uses a double FEP (fluorinated ethylene-propylene) film air tightly fixed at four sides. To guarantee a high optical efficiency, despite the lower transmission due to the second cover, a full area direct flow absorber with multiport extrusion profile (MPE) of the Finnish company Savosolar is incorporated [10]. It has an absorber efficiency factor of 0.97 and therefore shows an excellent η_0 [11]. If the front losses are appropriately reduced by 1–2 W/m^2 K, like shown in this paper, the back losses amount to 30–40% of the total losses and should be addressed as well, to result in combination with an optimized front insulation to an outstanding advanced collector performance. Standard insulations like mineral wool or PU foam with typical thickness of 40–50 mm normally exhibit *U*-values of about 0.9–1.1 W/m^2 K in new and dry state at 100 K over ambient temperature. This paper presents the first integrated rear side vacuum super insulation in a solar flat plate collector. Thus, rear side losses between 0.25 and 0.8 W/m^2 K can be reached, depending on the VSI filling and the envelope material.

2. Transparent front insulations and films

2.1. Theoretical considerations on multiple covers

To reduce convective losses, the gap between glass and absorber is subdivided by additional transparent layers of parallel glasses or films. The principle is like in an insulated glazing where two or more parallel panes are combined for a better thermal performance. The single panes have optimized positions to reach the minimum of the *U*-value of free convection between two parallel plates [12]. This minimum is realized at the largest distance where still pure heat conduction governs, free convection has just not yet occurred and the viscosity forces in the fluid still prevail over the buoyancy forces (see Fig. 1). The optimal gap width is dependent on tilt angle and temperature difference of the panes. It can be seen that a slightly larger gap, starting from the optimal gap width, leads to only a small rise in the convective *U*-value in the gap. As a rule of thumb, gap widths larger than 10 mm have to be chosen for typical collector operation conditions.

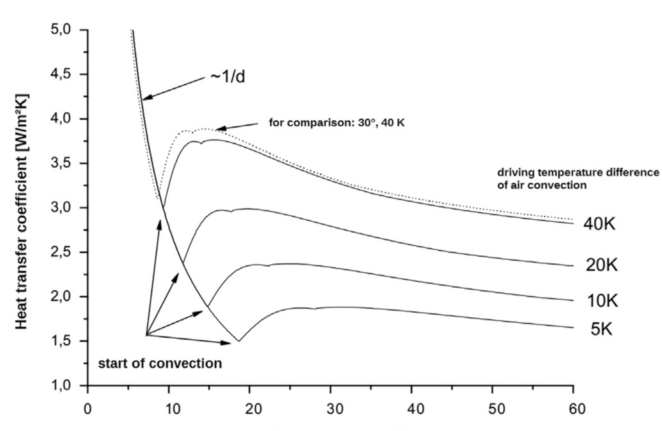

Fig. 1. Convective front *U*-value as a function of distance *d* between absorber and glass cover. One-dimensional calculation neglecting side losses. Mean air temperature in between the planes is 50 °C. Tilt angle is 45°, except for the dotted line (30°).