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Collector Efficiency Calculation Tool For Polymer Collectors with Temperature Limitation

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Summary

The goal of several projects in Europe is to develop and design collectors made out of polymers. A main boundary condition for such polymer collectors is the possibility to use as cheap as possible polymer material, which can typically withstand temperatures only up to about 90°C. Therefore solutions for limiting the temperatures during stagnation are looked for. One possible solution is a collector with integrated thermosiphon cooling, which limits the temperature during stagnation, but also allows the design of a collector with highest possible efficiency during operation. For supporting the development work a calculation tool is under development. It is a 1-D model which calculates all heat flows within a collector for a finite number of elements along the manifolds and strips in the absorber resulting in a theoretical efficiency curve. Actually the tool is validated against collector test certificates and can be used for parametric studies changing geometry and materials of the collector. This paper presents the validation results compared to a tested collector and some parametric studies. The possible influence of simulations on the design process is emphasized.

Keywords: Solar Thermal, Solar Collector, Polymer Collectors, Collector Efficiency, Simulation Tool

1. Introduction

The development of cost efficient polymer collectors is strongly depending on the possibility to use low-cost polymer material, which typically has temperature limitations of about 90 to 95 °C. Good flat plate polymer collectors reach stagnation temperatures of at least 160 °C.

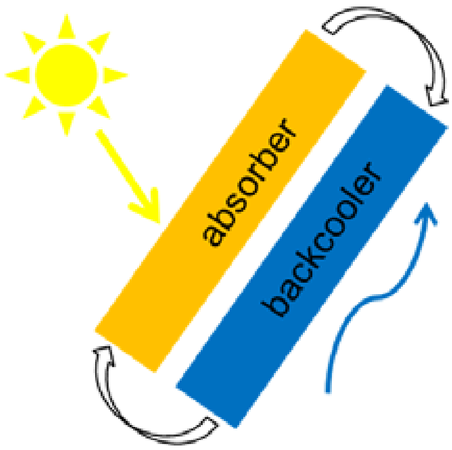

Fig. 1: Principle of the thermosiphon cooling concept of a flat plate collector

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One proposed solution is to design a best possible collector for operation and to integrate a thermosiphon cooling element for stagnation periods which is intrinsically save and keeps the temperature within acceptable limits. This concept enables highest possible collector efficiency and also the possibility to switch on and off the collector loop at any time without evaporation of the collector fluid. Fig. 1 shows the principle concept of the thermosiphon cooling concept. In fact it works like a solar thermal thermosiphon heating system, but instead of the hot water tank an additional absorber is mounted on the rear and operates as a cooler. Depending on the collector temperature and/or the operational status of the solar heating system a special valve activates or closes the connection to the backcooler. Otherwise the collector operates as an ordinary flat plate collector in a pumped solar heating system. This type of collector was developed within the project SolPol (www.solpol.at) (Hintringer 2012, 2013).

2. Calculation Model

For supporting the design of this concept a calculation tool is under development (Thür, 2013, 2014). It is a 1-D model, which calculates all heat flows within a collector for a finite number of elements along the manifolds and strips in the absorber (Fig. 2) resulting in a theoretical efficiency curve. Thanks to the sequential calculation method the temperature along the fluid flow can be calculated in detail for each register and used for further calculations of buoyancy forces and further on for a detailed flow distribution inside the absorber (but not yet implemented).

The description of the collector in terms of geometric data and material properties is done by an input list consisting of about 50 parameters. Also the parameter of ambient conditions like sky-temperature, ambient temperature, global solar irradiation and wind speed above and under the collector can be defined. Actually the solar irradiation is taken into account as a homogeneous radiation perpendicular to the transparent collector cover. Also long wave radiation from transparent collector cover back to the environment is calculated homogeneous to the sky temperature, where long wave radiation from collector casing back to the environment is calculated homogeneous to the ambient temperature.

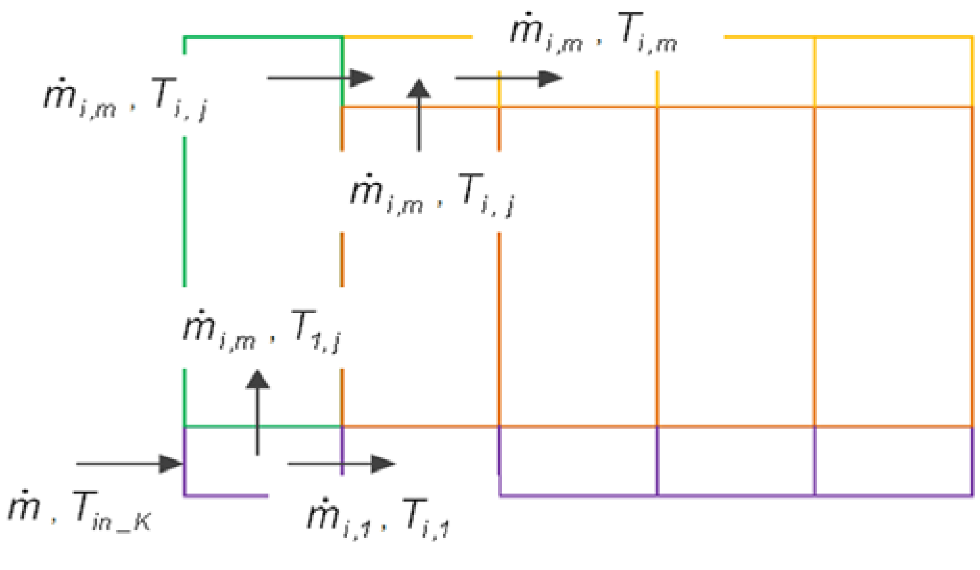

Fig. 2: Sequential calculation concept of the collector divided in n x m elements

Each element (Fig. 2) includes transparent cover, absorber, absorber pipe, insulation and rear cover. All heat flows as shown in Fig. 3 are calculated by an iteration process starting with a calculated guess of initial temperatures at all surfaces. Based on these temperatures all heat transfer coefficients for radiation, convection and conduction are calculated. All fluid characteristics (air and collector fluid) like density, heat capacity, viscosity, etc. are calculated with local temperature dependency.

In the next step all heat flows are calculated. For the absorber sheet also in detail the fin efficiency is calculated resulting in the heat flow to the absorber pipe and further on to the fluid. Heat conductivity along the absorber sheet from one element to the surrounding elements is neglected. For the collector casing at the side and the collector edges an overall, linear heat loss coefficient is determined. The heat losses therefore are taken into account for each element in the heat balance accordingly to the share of the element area. In the next step the new temperatures are determined and used for the next iteration loop. Actually the difference of the fluid outlet temperature of the calculated element between two iteration loops is the criteria for finishing the iteration loop.

This procedure is done for each element until the final fluid outlet temperature in the last manifold element is determined. Based on the inlet temperature, the outlet temperature and the total mass flow of the complete collector the gained heat and further the overall collector efficiency can be determined. Repeating this whole procedure for the complete collector for increasing inlet temperatures leads in the end to the efficiency curve of the collector.

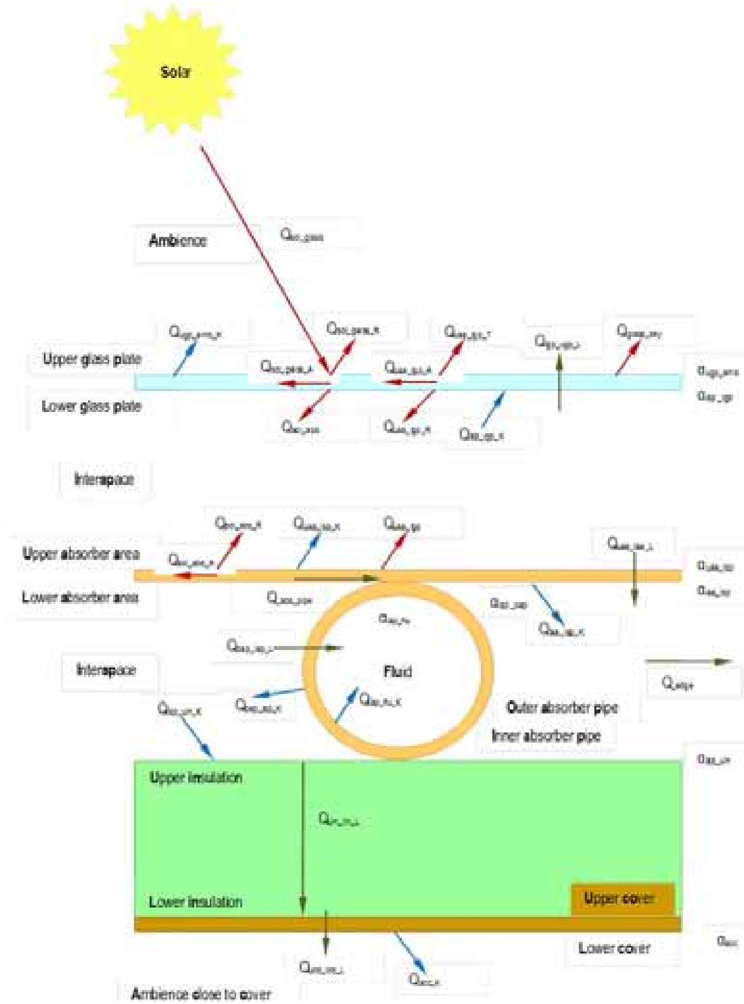

Fig. 3: Heat flow scheme across the flat plate collector

3. Model Validation

In order to validate the calculation model a standard flat plate collector with detailed description based on a test certificate was chosen. The reference collector is the Sunmaster SWK25 with the Test Report ITW-SWT: 05COL425 (ITW-SWT, 2005) reporting the following main performance figures: conversion factor $\eta_0 = 0.766$, and the heat loss coefficients $a_1 = 3.562$ W/m^{2}K and $a_2 = 0.01$ W/m^{2}K^2 at global solar radiation of G = 800 W/m^2. Volume flow rate of 214 l/m^{2}h with pure water is used for both the collector test and the theoretical calculations. Fig. 4 displays the simulation results (symbol ▲) compared with the measured data of the reference collector (symbol ■).

In this example the linear heat loss coefficient of the collector edge and the collector boundary casing heat losses is fitted by tripling the value compared to a simple calculation approach. In this simple calculation approach only the heat conductivity through the collector side casing is calculated, neglecting any geometrically collector edge effects or any thermal bridges of the casing. The calculation concept of the linear heat loss coefficient still is under investigation and under development for further improvement of the model.

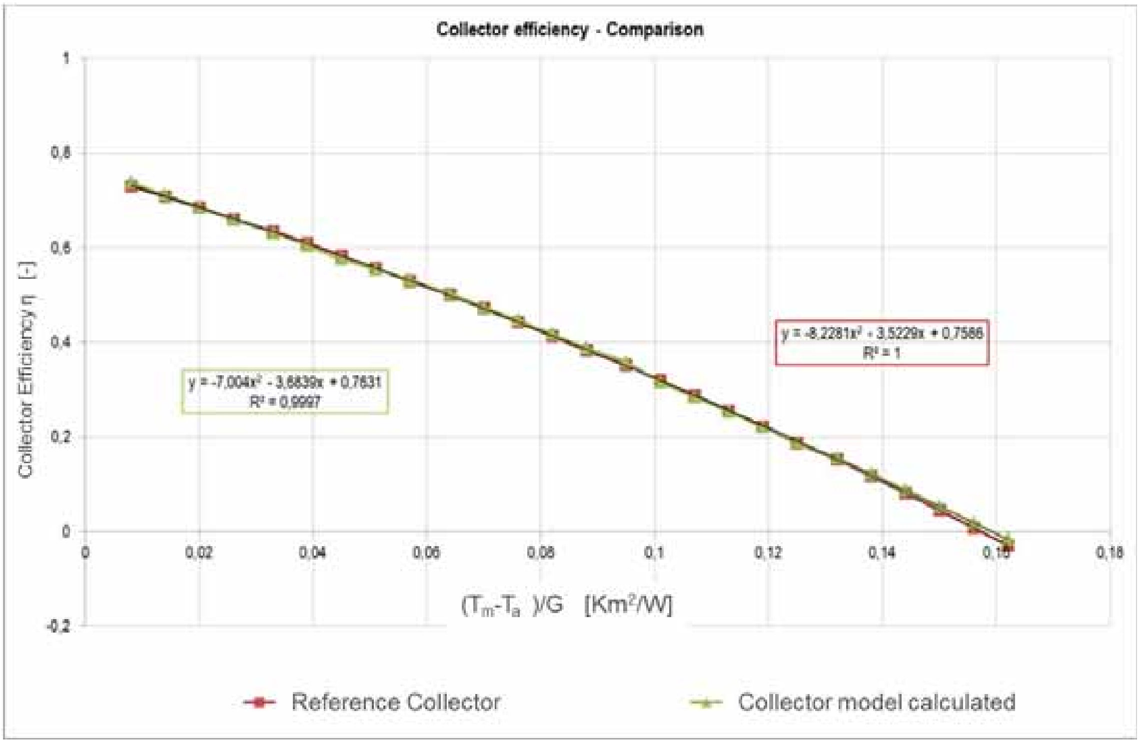

Fig. 4: Validation of the calculated collector efficiency against measurements based on the tested reference collector: Sunmaster SWK25 (Test Report ITW-SWT: 05COL425: η_0= 0.766, a_1=3.562 W/m^{2}K, a_2=0.01 W/m^{2}K^2, G = 800 W/m^2)

For comparison the reference collector was also calculated with “Collector Design Program – CoDePro“ (Klein, 1992-2005), using the same input data as known from the test certificate “05COL425”. The result of the calculation is shown in Fig 5.

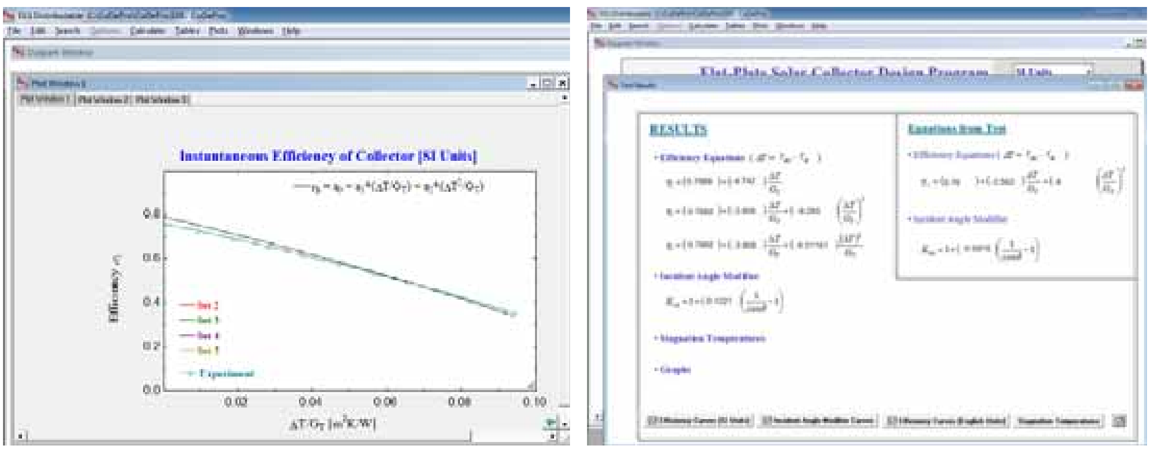

Fig. 5: Calculation of the reference collector with the program CoDePro: “Experiment” equates to the reference collector (with green line and ◊ symbols), the calculated collector equates to the black line.

4. Parameter Variation

In the following section some examples are shown how the program calculates with different parameter variations. Mass flow and absorber material parameters were varied and are explained subsequently. In Fig. 6 the result of the comparison of different flow rates is shown. The reference collector according to the test certificate (ITW-SWT, 2005) was measured as "high flow" with about 214 L/m^{2}h. Alternatively the collector was calculated as a "low flow" collector with a flow rate of only 21 L/m^{2}h. The result shows a difference of the collector efficiency at low temperatures of about 2 to 3 % relative, where at high temperatures the difference is getting smaller and reaching zero close to stagnation temperature. The difference can be explained by higher heat transfer coefficients at higher flow rates, which has decreasing influence at higher temperatures due to significant decreasing in viscosity of the water glycol mixture.

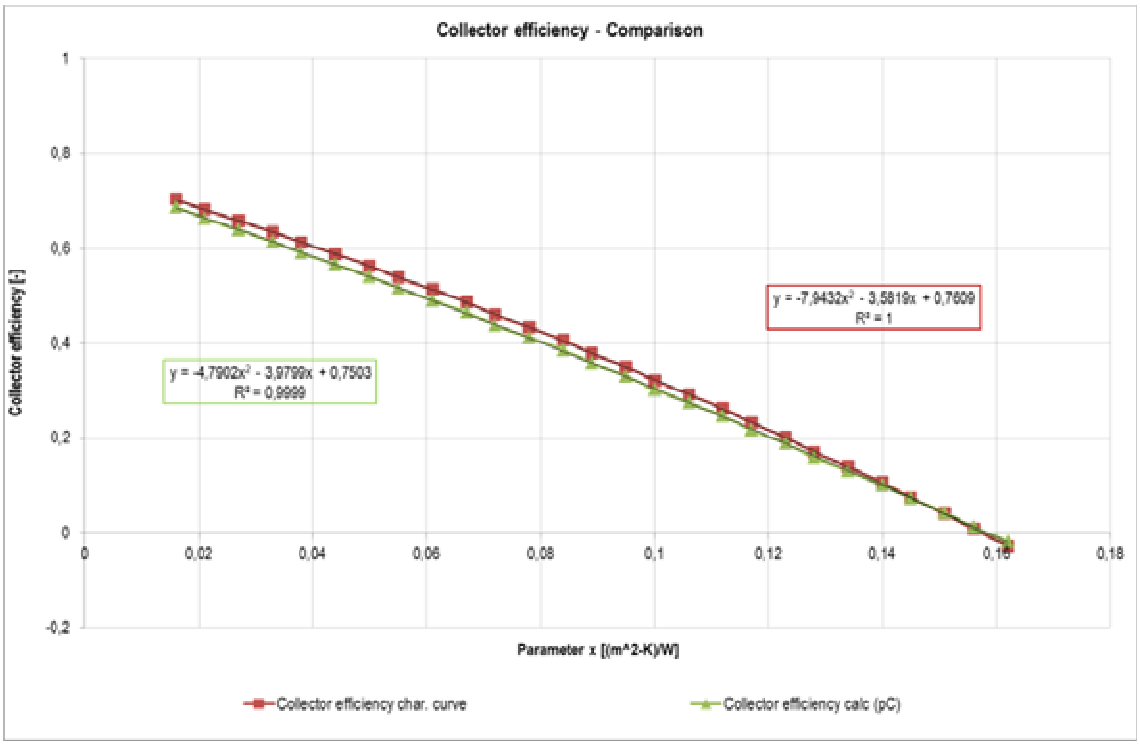

Fig. 6: Comparison of the reference collector: high flow (symbol ■) as measured vs. low flow (symbol ▲)

In Fig. 7 the influence of absorber material is investigated. The reference collector has a copper absorber (conductivity = 385 W/mK) with selective coating and distance between absorber pipes of about 106 mm. Only changing the absorber material from copper to aluminium (Fig. 7 left) with the same thickness (conductivity = 235 W/mK) shows only little decreasing efficiency. That's why aluminium absorbers with slightly thicker absorber sheets are absolutely competitive on the market. But as Fig. 7 right shows, if a polymer absorber (PP with conductivity = 0.235 W/mK) again with the same thickness and distance of absorber pipes is used, the efficiency is unacceptable low.

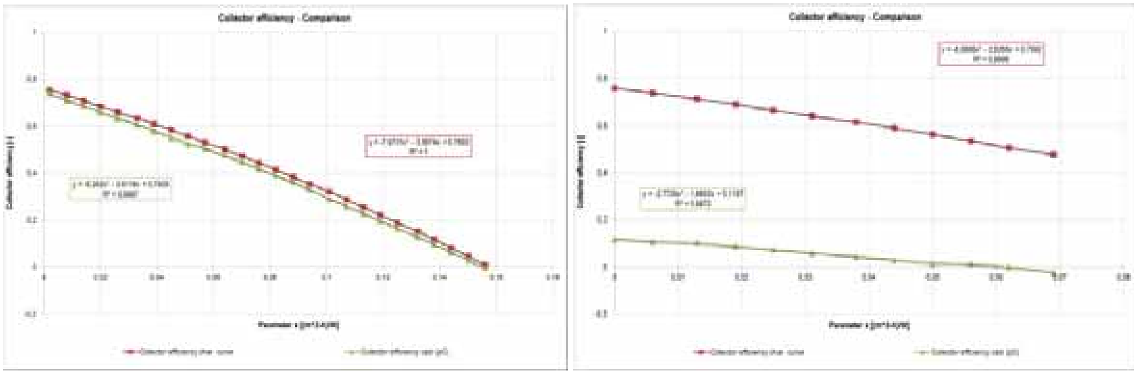

Fig. 7: Comparison of different absorber materials (left): reference collector with copper absorber (symbol ■) and calculated with aluminium absorber (symbol ▲); right: reference collector with copper absorber (symbol ■) and calculated with polymer absorber (symbol ▲)

Within the research project SolPol polymer collectors were developed, calculated and also measured at outdoor test facilities. In Fig. 8 the polymer collector is calculated ($\eta_0 = 0.75$, $a_1 = 7.9$ W/m^{2}K, $a_2 = 0.033$ W/m^{2}K^2) and compared with a standard flat plate collector with non-selective copper absorber ($\eta_0 = 0.75$, $a_1 = 5.4$ W/m^{2}K, $a_2 = 0.021$ W/m^{2}K^2) marketed from Solarverein Trier in Germany as the "K16" (Solarverein Trier, 2009). The result shows no significant difference at low temperatures which indicates equal optical efficiency, but increasing heat losses at higher temperatures indicating potential of improvement of the thermal quality of the collector casing. This can be explained by the fact, that the back insulation thickness of the calculated and tested polymer collector is only 20 mm.

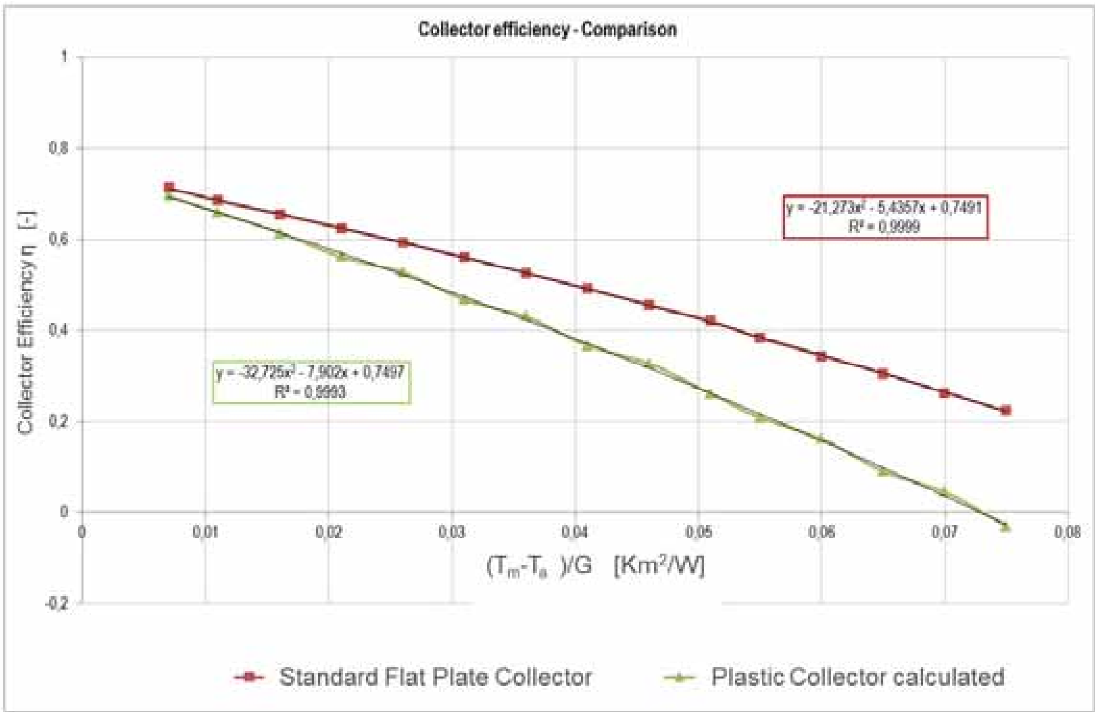

Fig. 8: Comparison of a polymer collector (symbol ▲) with a non-selective coated standard flat plate collector (symbol ■)

Nevertheless, as shown in the next section, it might be possible to use this „poor" collector in a favourite way under specific operation conditions.

5. Annual Simulations

The idea of the polymer collector with temperature limitation is to keep the absorber temperature below about 90 °C in order to be able to use cheap polymer material for the absorber and the complete collector as well. Additionally, due to the temperature limitation during stagnation the liquid in the collector does not evaporate. This allows to start the pump again at any time also during periods of full solar irradiation. In conventional high performance flat plate collectors the collector liquid vaporizes during stagnation with high solar irradiation, which means that it is impossible to start the pump in this situation. This can be a disadvantage during the day, when after hot water tapping solar energy could be used to heat the tank. In this case the system has to wait until the solar irradiation has decreased that much that the collector liquid has condensed again, which happens on nice days in the evening only. Only then the pump can start again.

For analyzing the potential of the temperature limited polymer collector annual simulations were performed with (Polysun, 2014) with the following boundary conditions. A solar domestic hot water system is defined with a daily hot water load of 200 L/day at 50 °C. The hot water storage is chosen for a "large" system with 295 liters (295L) and for a "small" system with 100 liters (100L). The maximum temperature allowed in the tank is 65 °C.

As solar collector on the one hand side a conventional flat plate collector (FK) with the efficiency parameter of $\eta_0 = 0.80$; a_1=3.0 W/m²K; $a_2 = 0.010$ W/m²K² is used. For this collector the maximum temperature is defined with 100 °C. This means that the pump is allowed to run only, if the collector temperature is below 100 °C. On the other hand a temperature limited polymer collector (OHC) with the efficiency parameter of $\eta_0 = 0.77$; $a_1 = 6.1$ W/m²K; $a_2 = 0.007$ W/m²K² is used. The solar heating system with this collector is allowed to run the pump at any time when the hot water storage needs energy.

The calculations are performed for 3 different climates: City of Innsbruck (IBK) in central Europe (Latitude: 47° N), Athens (ATH) in Mediterranean climate (Latitude: 38° N) and Johannesburg (JOH) in South Africa (Latitude: 27° S). The collector slope was chosen accordingly to the latitude with 45, 35 and 25 ° respectively. The annual global solar irradiation on the collector aperture area resulted in 1425 (IBK), 1709 (ATH) and 2285 kWh/m^2 (JOH) respectively. In Fig. 9, 10 and 11 the results are presented in terms of solar fraction as a function of collector area (one collector represents 2 m^2 collector area).

In Innsbruck climate (Fig. 9) the result shows clearly, that the solar hot water system with the high performing flat plate collector (FK) always reaches significant higher solar fraction. This is what is expected typically.

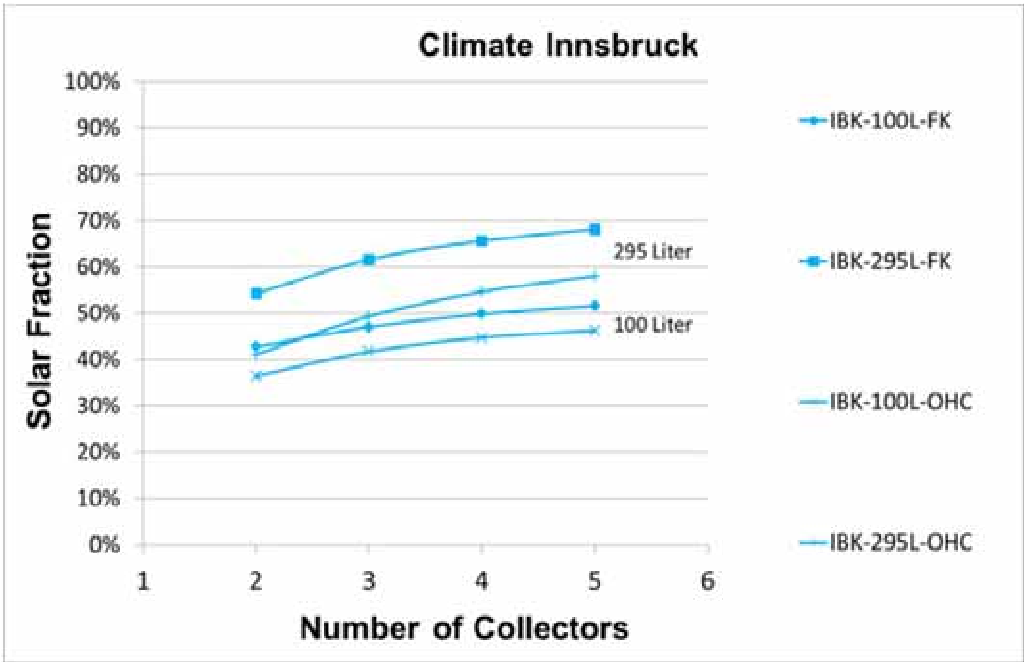

Fig. 9: Solar fraction of solar hot water systems with different collector types and hot water storage volumes for climate like in Innsbruck

In Athens the result is not that clear anymore, as Fig. 10 shows. For the solar hot water system in combination with the small 100 liter tank the temperature limited collector (OHC) can reach slightly higher solar fractions than the system with the high preforming flat plate collector. With the large tank still the system with the conventional flat plate collector (FK) is slightly better.

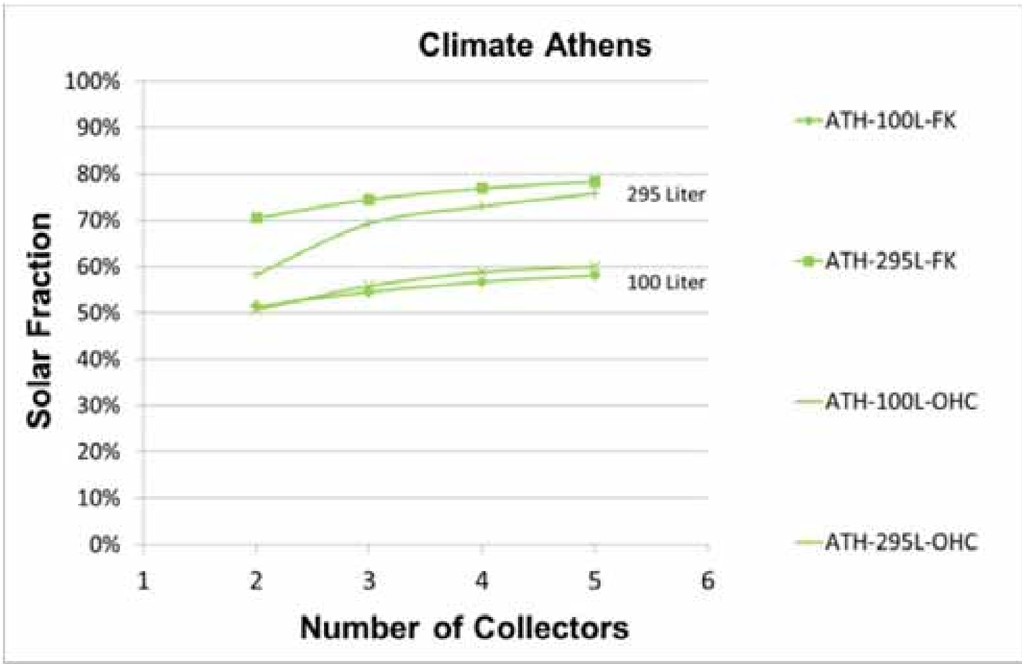

Fig. 10: Solar fraction of solar hot water systems with different collector types and hot water storage volumes for climate like in Athens.

Coming closer to the equator, in Johannesburg the result is almost completely different, as Fig. 11 shows. Especially the solar hot water system with the temperature limited collector (OHC) and the small hot water tank (100L) reaches a significant higher solar fraction than the system with the conventional collector (FK).

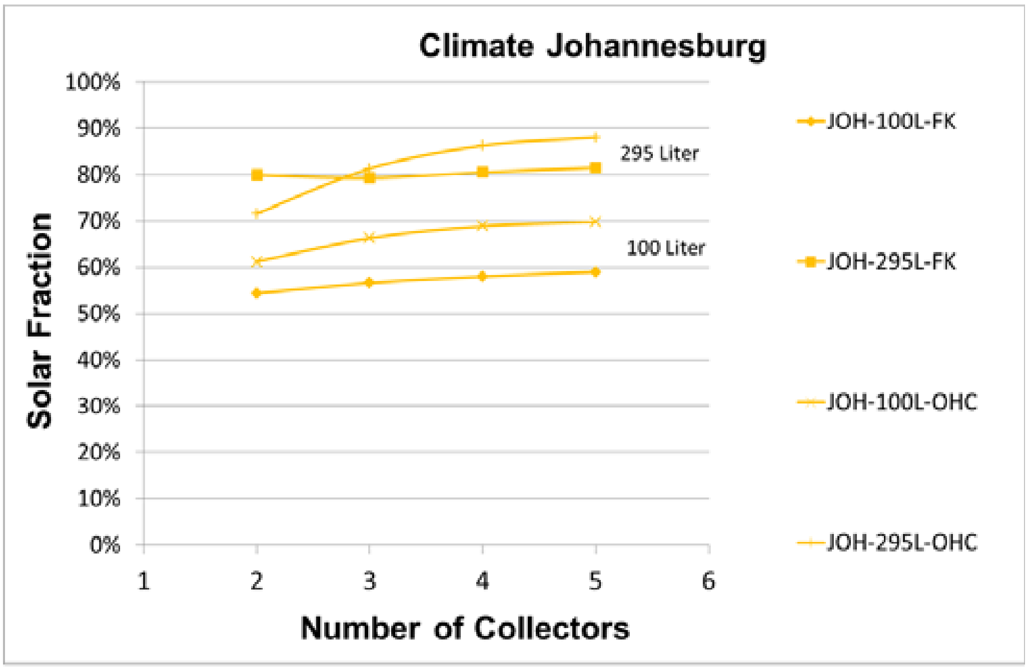

Fig. 11: Solar fraction of solar hot water systems with different collector types and hot water storage volumes for climate like in Johannesburg.

6. Conclusions

A tool for theoretical calculation of the collector efficiency curve was developed and validated against a reference collector with a recognized test certificate. The tool can be used for parametric studies changing geometry and materials of the collector. Parameters changed and investigated in the study as examples are flow rates, absorber material (copper, aluminium, polymer) and a calculation of a new developed polymer collector in comparison to a non-selective conventional flat plate collector.

Annual simulation studies of solar hot water systems in different climates showed that a temperature limited solar collector made out of low-cost polymer materials, which is temperature limited to below 90°C, can perform better than a high performing selective coated flat plate collector under specific operation conditions in regions near the equator (Latitude < 35 °).

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