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Evaluation of the Test Method for Efficiency for Flat Plate Solar Collectors

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Abstract

The test method of the standard EN12975-2 (European Committee for Standardization, 2004) is used by European test laboratories to determine the efficiency of solar collectors. The aim of this work is to present an evaluation of the test method for a 12.5 m² flat plate solar collector panel from Arcon Solvarme A/S. CFD (Computational Fluid Dynamics) simulations, calculations with a solar collector simulation program SOLEFF and thermal experiments are carried out in the investigation. The influences of the method to determine the mean solar collector fluid temperature, the approximation used to determine the specific heat of the solar collector fluid, the temperature levels used in the tests and the weather conditions on the collector efficiency are elucidated. Based on the investigations, it is recommended that the maximum temperature level used in the tests is not higher than the maximum operation temperature of the collector. Further, if the solar collector efficiency for low flow rates are measured in future test methods there is a need to change the method used to determine the mean solar collector fluid temperature.

Keywords: Flat-plate solar collector, Test method, Computational fluid dynamics(CFD), Thermal experiments.

1. Introduction

In the test method of the standard EN12975-2 [1], the mean solar collector fluid temperature in the solar collector, T_m is determined by the approximate equation: $T_m = (T_{in} + T_{out})/2$, where T_{in} is the inlet temperature to the collector and T_{out} is the outlet temperature from the collector. The specific heat of the solar collector fluid is a function of the temperature of the fluid. In the test method the specific heat of the solar collector fluid is an approximation for each measuring period determined as a constant equal to the specific heat of the solar collector fluid at the temperature T_m.

The power produced by the solar collector in a steady state test period is determined by the product of the specific heat, the mass flow rate and the temperature increase of the solar collector fluid. The solar collector efficiency is determined by measurements at different temperature levels. Based on these efficiencies, an efficiency equation is determined by regression analysis. In the test method, there are no requirements on the ambient air temperature and the sky temperature.

The paper will present an evaluation of the test method for a 12.5 m² flat plate solar collector panel from Arcon Solvarme A/S. The investigations will elucidate:

- How the mean solar collector fluid temperature T_m is underestimated by the approximate equation in the test standard and how the collector efficiency equation is influenced by the underestimation of T_m. The dependence of the volume flow rate is shown.
- How the use of the approximate specific heat of the solar collector fluid is influencing the collector efficiency.
- How the temperature levels used in the tests are influencing the collector efficiency expression.

· How the measured collector efficiency is influenced by the weather conditions such as the ambient air temperature and the sky temperature.

2. Investigated solar collectors

The investigated solar collectors are 12.5 m² solar collector panels, type HTU and HT from Arcon Solvarme A/S, designed for medium and large solar heating systems. Fig. 1 shows the design of the HTU solar collector. The HTU solar collector is tested side-by-side with the similar collector HT, which includes a Teflon foil between the absorber and the cover glass. Each collector consists of two manifolds, one dividing and one combining manifold, and 16 parallel connected horizontal fins.

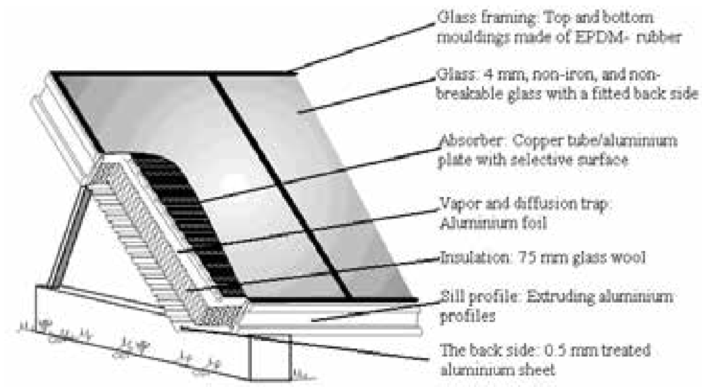


Fig. 1. Design and dimensions of the investigated HTU collector

3. Evaluation of test method for a flat plate collector

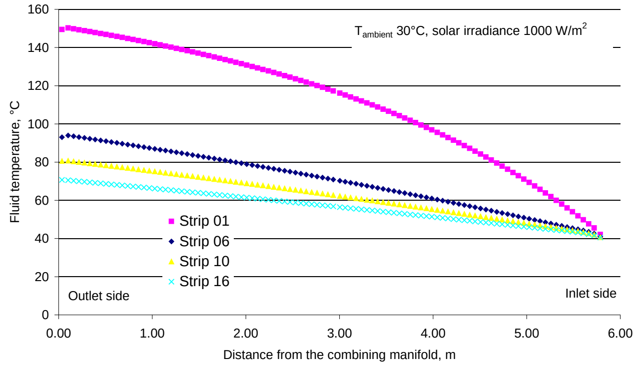
Investigations on how the test conditions and the approximate methods used in the test method to determine the collector efficiency will influence the efficiency and the efficiency expression for the HTU and HT collector will be described in the following sections. A 40% propylene glycol/water mixture is assumed to be the solar collector fluid. A collector tilt of 40° is assumed.

3.1 Influence of the method to determine the mean solar collector fluid temperature

CFD calculations have been carried out in order to determine the flow distribution as well as the solar collector fluid temperatures in the HTU collector for different conditions [2]. The CFD model has been validated by temperature measurements. By means of the calculations the mean solar collector fluid temperature in the solar collector can be determined. Figure 2-5 show results from the calculations. In these calculations, the solar irradiance is 1000 W/m² and the ambient air temperature is 30°C.

From Fig. 2 it can be seen that for a low flow rate there are large temperature differences inside the collector and that the fluid temperatures are much higher in the upper strips than in the lower strips of the collector. The temperature profile in the strips from the inlet side to the outlet side is not linear. Fig. 3 shows that the mean solar collector temperature is higher than $(T_{in}+T_{out})/2$ which in the test method is used as the mean solar collector fluid temperature, due to the nonlinear temperature profile in the strips. For decreasing flow rate the underestimation of the mean solar collector fluid temperature is increasing.

Fig. 4-5 show efficiency data points and efficiency expressions for different collector fluid flow rates. The efficiency expressions are obtained by regression based on the data points. From fig. 4 it is seen that for a low flow rate the use of $(T_{in}+T_{out})/2$ as the mean solar collector fluid temperature results in a too low efficiency, especially at high temperature levels. From fig. 5, it is seen that the error caused by the approximate equation is of no importance if the flow rate is 6 l/min.



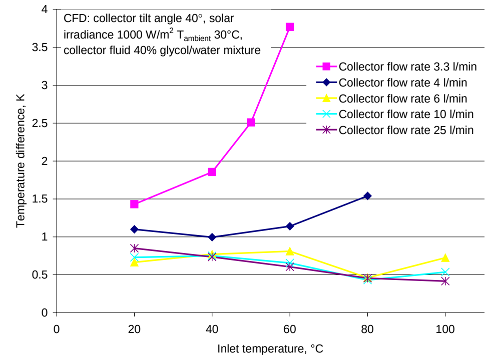
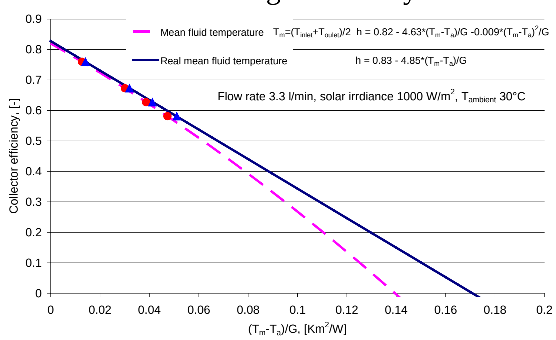


Fig. 2. Calculated solar collector fluid temperatures inside 4 strips: The top strip, strip no. 6 from the top, strip no. 10 from the top and the bottom strip for an inlet temperature of 40°C and a flow rate of 2.9 l/min.

Fig. 3. Difference between mean solar collector fluid temperature determined by CFD calculations and $(T_{in}+T_{out})/2$ for different flow rates and inlet temperatures.

It can be concluded that the normally used approximation $T_m = (T_{in} + T_{out})/2$ only will result in a wrong efficiency expression if the flow rate is lower than 6 l/min, corresponding to 0.48 l/min per m² collector. For low flow rates the approximation will result in too low efficiencies especially at high temperature levels. In the test method a recommended flow rate of 1.2 l/min per m² collector is normally used. Consequently, the approximation does not require any changes of the test method. Changes will only be needed if low flow rates will be used in future test methods.



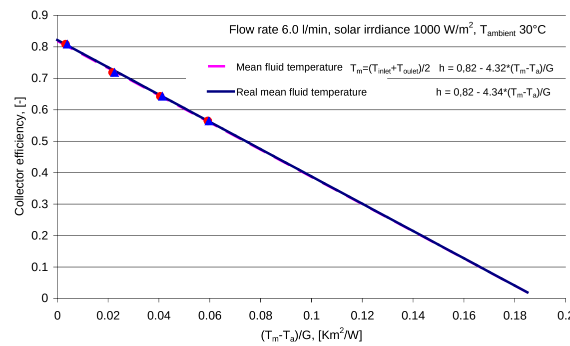


Fig. 4. Efficiency expression based on T_{mean} as the real mean solar collector fluid temperature and as $(T_{in}+T_{out})/2$ for a flow rate of 3.3 l/min.

Fig. 5. Efficiency expression based on T_{mean} as the real mean solar collector fluid temperature and as $(T_{in}+T_{out})/2$ for a flow rate of 6.0 l/min.

3.2 Influence of the method to determine the specific heat of the solar collector fluid

The specific heat of a 40 % propylene glycol/water mixture is determined by [3]:

$$C_p(T) = 3721.4 + 1.629 * T + 0.0101132 * T^2 \text{ , [J/kg *K]}$$

where T is the fluid temperature, [°C]

The power produced by the solar collector is found by: $Q_1 = \rho * v * \int_{Tinlet}^{Toutlet} C_p(T) dT$, [W]

where ρ is the density of the fluid at the temperature of the fluid in the flow meter, [kg/m³] and v is the volume flow rate, [m³/s]

The test method makes use of the following approximate equation by calculation of the power from the solar collector: $Q_2 = \rho * v * C_{p,\bar{T}}$, [W]

where $C_{p,\bar{T}}$ is the specific heat of the fluid at the temperature $(T_{in}+T_{out})/2$, [J/kg *K]

Table 1 shows measured collector efficiencies found by both methods for different temperature levels and flow rates.

Table 1. Collector efficiencies calculated by two different methods to determine the specific heat of the solar collector fluid for the HTU collector.

Flow rate	T_{inlet}	T_{outlet}	T_{mean}	Q_2	η_2	Q_1	η_1
l/min	°C	°C	°C	W	%	W	%
2.71	19.4	64.3	41.9	7962.8	71.32	7959.2	71.35
3.36	20.0	57.6	38.8	8256.7	75.46	8256.4	75.48
4.04	41.2	70.2	55.7	7649.9	70.71	7648.4	70.72
4.94	41.2	69.1	55.2	8995.6	71.00	8994	71.01
4.87	68.7	89.9	79.3	6738.2	58.08	6737.5	58.09
10.18	85.9	93.4	89.7	4960.4	47.56	4960.4	47.56
24.32	86.7	91.3	89	7259.4	56.83	7259.4	56.83

From the table it is concluded that the error introduced by the approximate method used to determine the specific heat of the solar collector fluid is insignificant.

3.3 Influence of the temperature levels used in the test

Thermal measurements have been carried out to investigate how the temperature levels used in the test will influence the efficiency expression. Fig. 6 shows results of the measurements with the HTU collector and a similar collector, type HT which includes a Teflon foil between the absorber and the cover glass. Five temperature levels are used in the test: Group 1 (29°C), group 2 (45°C), group 3 (64°C), group 4 (84°C) and group 5 (94°C). The collector fluid volume flow rate is 25.0 l/min, corresponding to 2.0 l/min per m^2 collector. The full curves show efficiency expressions of the HT and HTU solar collectors determined by means of regression analysis based on the temperature levels 1, 2, 3, 4, while the dashed curves show the efficiency expressions determined based on the temperature levels 1, 2, 3, 5. It can be seen that the efficiency expression determined by the high temperature levels has a higher heat loss coefficient than that determined by the temperature levels 1, 2, 3, 4. This is due to the fact that there is a sharp decrease of the measured collector efficiency at the high temperature level 5, caused by boiling in one of the strips. The boiling is only discovered by means of temperature sensors placed inside the solar collector.

Yearly thermal performance of the HT collector is calculated with the two efficiency expressions: One determined based on the temperature level 1, 2, 3, 4 and one determined based on the temperature levels 1, 2, 3, 5. The collector is facing south and the collector tilt is 40°. The calculations are based on the weather data from the Danish Design Reference Year. Fig. 7 shows yearly thermal performance of the HT collector as a function of a constant mean solar collector fluid temperature throughout the year. The yearly thermal performance calculated with the efficiency expression determined by 1, 2, 3, 5 is lower than that with the efficiency expression determined by temperature levels 1, 2, 3, 4 except for a mean solar collector fluid temperature less than 10°C. Fig. 8 shows the relative thermal performance of the HT solar collector defined as the ratio of the yearly thermal performance of the solar collector with an efficiency determined at the temperature levels in question during the collector tests and the yearly thermal performance of the solar collector with an efficiency determined at the temperature levels 1, 2, 3 and 4 during the collector tests. It can be seen that the HT collector with efficiency expression determined at the high temperature levels will reduce thermal performance by 5% - 16% comparable to the efficiency expression determined at temperature levels 1, 2, 3 and 4 for a mean solar collector fluid temperature from 45°C to 86°C. It can be concluded that for a solar collector operating with a solar collector fluid temperature lower than 86 °C, the collector efficiency and the thermal performance of the collector will be underestimated by up to 16% if a high temperature level like 94°C is used in the test to determine the collector efficiency. It is therefore recommended that the maximum temperature level used in the tests is not higher than the maximum operation temperature of the collector.

3.4 Influence of the weather conditions used in the test

Calculations with the program SOLEFF [4] are carried out in order to determine the collector efficiency for the HTU collector and the HT collector for different weather conditions. A collector fluid volume flow rate of 25.0 l/min, corresponding to 2.0 l/min per m^2 collector, is used in the calculations. Fig. 9 shows the calculated efficiencies for the HTU collector for different ambient air temperatures and sky temperatures. The sky temperature is assumed to be 15 K lower than the air temperature. It is seen that the efficiency for high temperature levels is decreased for increased temperature levels of the ambient air and the sky.

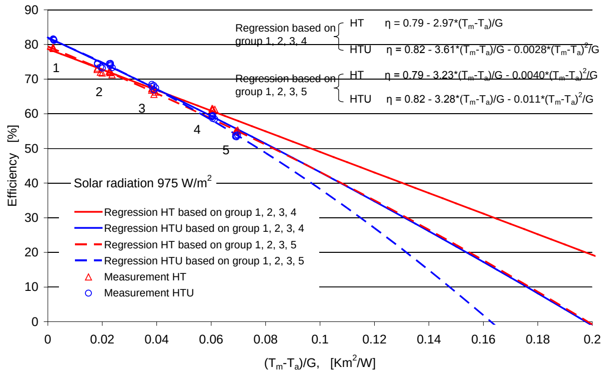


Fig. 6. Efficiency expressions of the HT and HTU solar collectors determined by tests at different temperature levels.

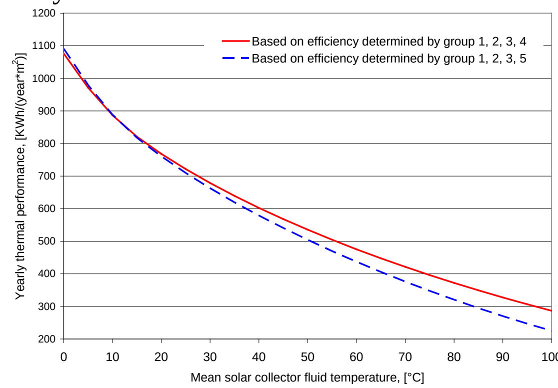


Fig. 7. Yearly thermal performance of the HT collector for efficiency expressions determined at different temperature levels.

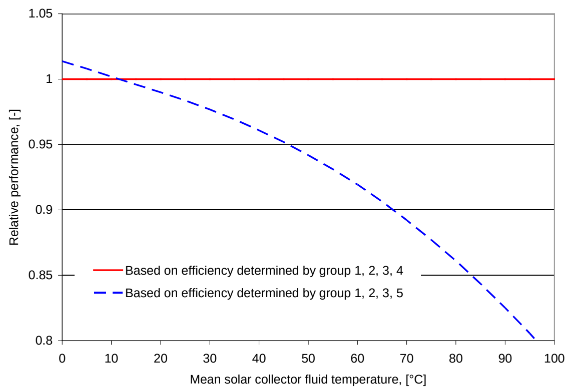


Fig. 8. Relative thermal performance of the HT collector for efficiency expressions determined at different temperature levels.

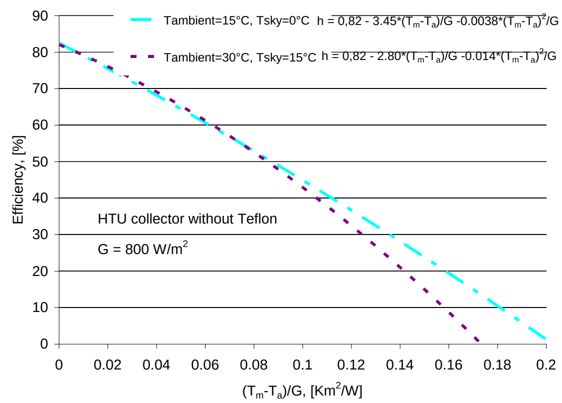


Fig. 9. Calculated efficiency for the HTU collector for different ambient air and sky temperatures for a solar irradiance of 800 W/m² and an incidence angle of 0°.

Fig. 10 shows the calculated yearly thermal performance of the HTU collector without Teflon foil as a function of a constant mean solar collector fluid temperature throughout the year. The calculations are carried out with weather data from the Danish Design Reference Year based on two efficiency expressions: One determined by means of collector tests with an ambient air temperature of 15°C and a sky temperature of 0°C and one determined by means of collector tests with an ambient air temperature of 30°C and a sky temperature of 15°C.

Fig. 11 shows the calculated relative performance of the HTU collector as a function of the mean solar collector fluid temperature. The relative performance is the ratio between the yearly thermal performance of the collector determined with an efficiency expression determined at the ambient air/sky temperatures in question and the yearly thermal performance of the collector determined with an efficiency expression tested at an ambient air temperature of 15°C and a sky temperature of 0°C. For solar collector fluid temperature levels between 15°C and 85°C the difference between the yearly thermal performances of the collector determined by means of the tests at the different weather conditions is lower than 3%.

The calculations are carried out with the HT solar collector as well. It is shown that for solar collector fluid temperature levels between 15°C and 100°C the difference between the yearly thermal performances of this collector determined by means of the tests at the different weather conditions is lower than 4%. Consequently, taken the measuring accuracy into consideration, the weather conditions used in the tests will not significantly influence the calculated thermal performance of the collector.

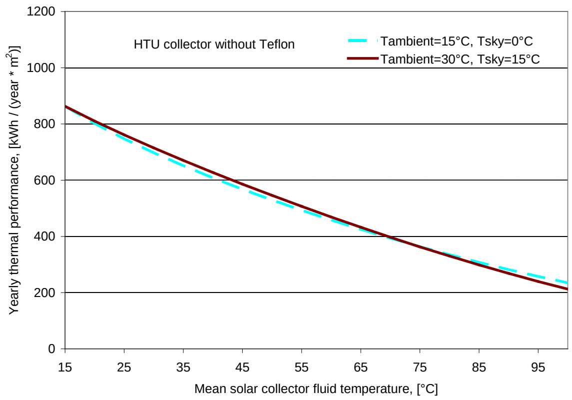


Fig. 10. Yearly thermal performance of the HTU collector for efficiency expressions determined with two different ambient and sky temperatures.

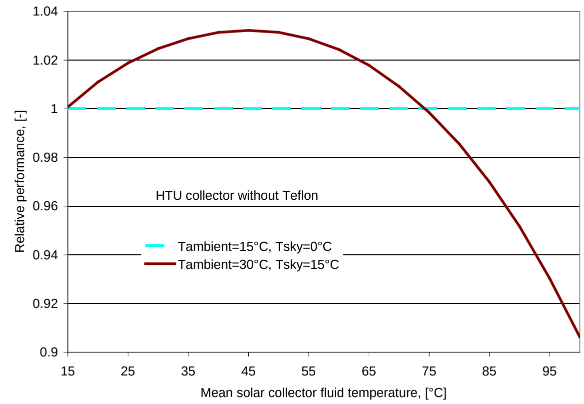


Fig. 11. Relative thermal performance of the HTU collector at different mean solar collector fluid temperatures.

4. Conclusions and recommendations

Investigations on the suitability of collector test methods have been carried out for two collectors from Arcon Solvarme A/S: The HTU collector without a Teflon layer and the HT collector with a Teflon layer. For the HT solar collector operating at a collector fluid volume flow rate of 25.0 l/min and at solar collector fluid temperatures lower than 86 °C, the thermal performance of the collector will be underestimated by up to 16% if a high temperature level like 94°C is used in the test to determine the collector efficiency. It is recommended that the maximum temperature level used in the tests is not higher than the maximum operation temperature of the collector. Further, if the solar collector efficiency for low flow rates is measured in future test methods there is a need to change the method used to determine the mean solar collector fluid temperature. The weather conditions like the ambient air temperature and the sky temperature used in the tests will not significantly influence the calculated thermal performance of the collector. The error introduced by the approximate method used to determine the specific heat of the solar collector fluid is insignificant.

Acknowledgement

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