EFFICIENCY TESTING OF PARABOLIC TROUGH COLLECTORS USING THE QUASI-DYNAMIC TEST PROCEDURE ACCORDING TO THE EUROPEAN STANDARD EN 12975

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Abstract

The collector efficiency of a parabolic trough collector prototype has been tested according to the European Standard EN 12975. The Standard includes, apart from the well known steady state parameters, an incident angle modifier for diffuse irradiation and an effective collector thermal capacity. The addition of these two collector parameters allows the evaluation of continuous measurements over several hours even under irradiance fluctuations and changing sun position.

Keywords: Parabolic Trough Collector, Testing, Standards, Thermal Efficiency

Introduction

The thermal performance of a solar collector is of major interest to all parties, e.g. designer, investor, operator and last but not least collector manufacturer, involved in the setup of a solar thermal system. In order to be able to compare the thermal performance of different collectors a standardized test method must be available. Standardized test methods have been published in international normative documents for decades[1,2]. These Standards are well accepted for the test of flat plate collectors and evacuated tubular collectors. However if it comes to collectors with a significant concentration ratio the stipulated use of the hemispherical solar irradiance as reference irradiance does not meet the requirement for the performance characterization anymore. To overcome this difficulty the “concentrating community” uses the direct irradiance as reference irradiance together with the test procedures[1,2] to characterize the thermal performance of concentrating collectors. This non normative approach leads to a variety of collector models as well as differing nomenclatures and methodologies. The first attempt to standardize these different approaches was done by all mayor institutions involved in the performance testing of tracking concentrating collectors[3].

With the implementation of the European Standard EN 12975[4] an alternative test method under so called quasi-dynamic conditions has been introduced. This test method, in contrast to previous ones takes into account direct irradiance as well as diffuse irradiance and thus permits the performance measurement of tracking concentrating collectors.

In the frame work of a collaborative research project (Solar Heat for Industrial Processes) of the IEA Solar Heating and Cooling Program (Task 33) and the IEA SolarPACES Program (Task 4) a parabolic trough collector has been tested according to this test method under quasi dynamic conditions. For the purpose of this work the test identity was eliminated by introducing an arbitrary scale factor.

Collector model

The collector output is modeled with 6 parameters using the following equation[4].

$$\frac{\dot{Q}}{A} = \eta_0 K_{\theta b}(\theta) G_b + \eta_0 K_{\theta d} G_d - c_1(\vartheta_m - \vartheta_a) - c_2(\vartheta_m - \vartheta_a)^2 - c_3 \frac{d\vartheta_m}{dt}$$

In contrast to the Standard[1,2] the hemispherical irradiance G is divided into the direct G_b and diffuse G_d parts. For both irradiances an incident angle modifier is used. $K_{\theta b}(\theta)$ being a function of the angle of incidence of the direct irradiance and the constant $K_{\theta d}$ for the diffuse irradiance. The conversion factor η_0 is the efficiency of the collector at ambient temperature under steady state conditions. The thermal losses are modeled by a 2nd order polynomial approach, c_1 and c_2 being the heat loss coefficients corresponding to the temperature difference between the mean fluid and ambient temperature and the square of the temperature difference respectively. The effective collector capacity c_3 accounts for the transient behavior of the solar collector and permits measurements under changing levels of irradiance. The introduced effective thermal capacity permits continuous measurements even under scattered cloud conditions.

Collector test

A prototype collector test was carried out on the test facility of the German Aerospace Center (DLR) in Cologne. The test facility allows for testing up to a temperature of 250°C. Two axis normal tracking ($K_{\theta b} = 1$) was active throughout all sequences of the test. In order to operate the collector array at different conditions five test sequences have been used covering clear sky conditions as well as scattered clouds. The mean fluid temperature varied from close to ambient up to 175 °C. The length of the test sequences varied between four and seven hours. Table 1 summarizes the conditions of the five test sequences used for the parameter identification.

Test sequence	Duration [min]	Mean fluid temp [°C]	Sky condition
1	360	35	Clear sky
2	420	35	Scattered clouds
3	240	115	Clear sky
4	290	150	Mainly clear sky
5	300	175	Clear sky

Table 1: Test sequences used for parameter identification

Figures 1 and 2 show the direct irradiance G_b, diffuse irradiance G_d and the specific collector output P_{col} per aperture area during two test sequences (data in arbitrary scale, to eliminate original test identity).

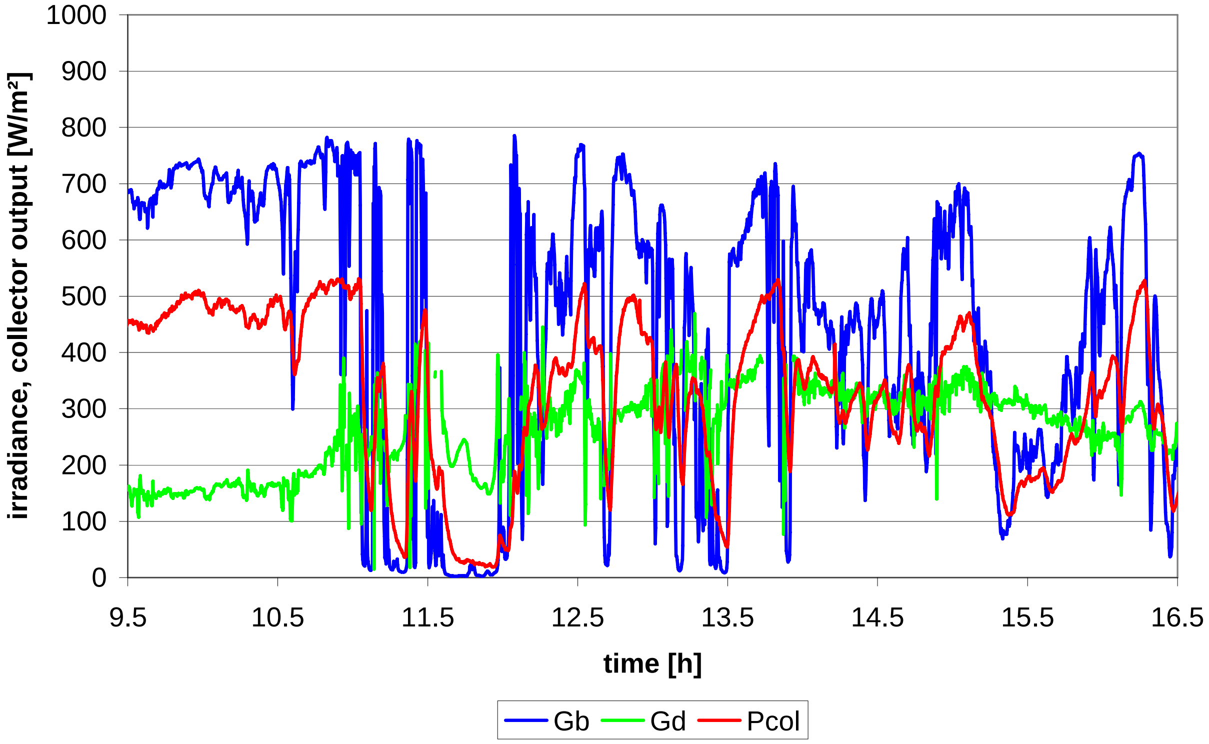

Figure 1: Test sequence 2, unstable irradiance

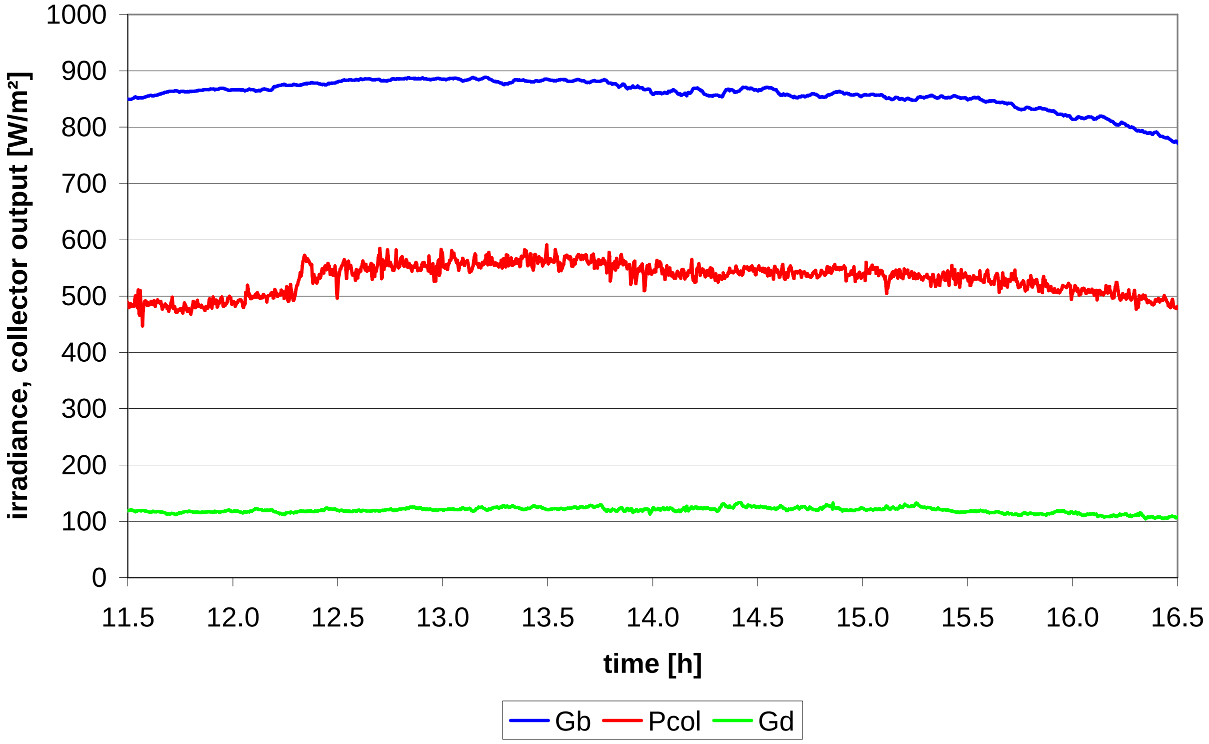

Figure 2: Test sequence 5, on a clear day

Parameter identification and results

For the evaluation of the measured data Multiple Linear Regression (MLR) as the parameter identification tool is foreseen[4]. MLR uses a fast, non-iterative matrix method. However, other algorithms, mainly used for non-linear models, lead to the same results and will be allowed as parameter identification tool in the next review of the Standard. A comparison of the MLR method and the iterative method has been published[7]. The advantage of the iterative method is a high flexibility with respect to the input data as well as to the collector model. For this study the DF program[5] was used. It uses the Levenberg–Marquardt algorithm[6] for the parameter identification process. .

Table 2 shows the parameter set determined from five test data series. In Figure 3 the measured and calculated collector output for test sequence 1 is plotted. The dynamics of the measured collector output are very well described by the five collector parameters.

η_0 [-]	$K_{\theta d}$ [-]	c_1 [W/(m²K)]	c_2 [W/(m²K²)]	c_3 [J/(m²K)]
0.674	0.179	0.211	0.002	12680

Table 2: Determined collector parameter

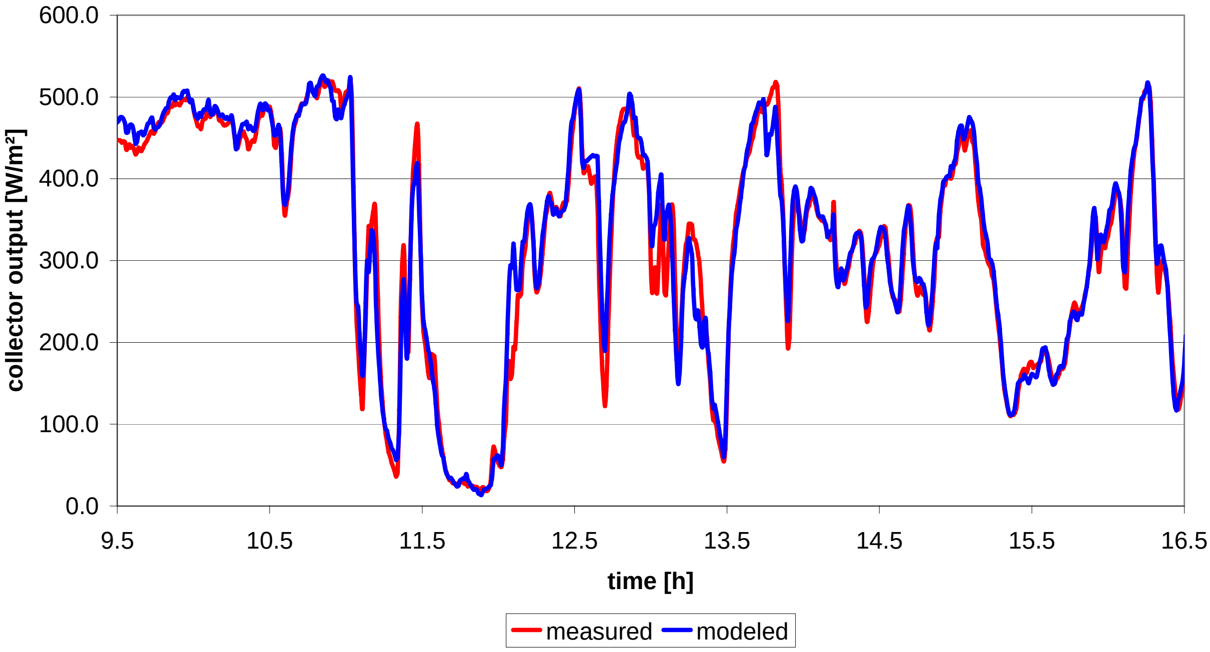

Figure 3: Measured and modeled collector output of test sequence 2

Conclusion

A parabolic trough collector prototype has been efficiency tested according to EN Standard 12975 using the test method under quasi dynamic conditions. This test method allows varying ambient conditions and continuous measurements over the day. This is possible because a collector model is used that takes into account the effective collector capacity as well as the diffuse irradiance on the aperture plane. The results show a very good agreement between measured and modelled collector output. An overall testing time of 5 days only in part under clear sky conditions, was sufficient to extract the relevant collector performance parameter set.

With the use of the European Standard EN 12975 a performance testing not only for flat plate or evacuated tubular collectors but also for all tracking and concentrating collectors is possible.

Nomenclature

Symbol	Unit	Description
A	m²	Area
b	m	Collector width
C_{geo}	-	Geometric concentration ratio $b/\pi d$
c_1	W/(m²K)	Heat loss coefficient at $(t_m - t_a) = 0$
c_2	W/(m²K²)	Temperature dependence of the heat loss coefficient
c_3	kJ/(m²K)	Effective thermal capacity
$d\vartheta_m/dt$	K/s	Time derivative of the mean fluid temperature
d	m	Absorber tube diameter
G	W/m²	Hemispherical solar irradiance
G_b	W/m²	Direct (beam) irradiance
G_d	W/m²	Diffuse irradiance
$K_{\theta b}(\theta)$	-	Incident angle modifier for beam irradiance
$K_{\theta d}$	-	Incident angle modifier for diffuse irradiance
P_{col}	W	Useful output power
Q	W	Useful output power
η_0	-	Conversion factor
ϑ_a	°C	Ambient temperature
ϑ_m	°C	Mean fluid temperature
θ	°	Incident angle of the beam irradiance

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