IMPROVING THE COMPATIBILITY BETWEEN STEADY STATE AND QUASI DYNAMIC TESTING FOR NEW COLLECTOR DESIGNS

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Abstract

The European standard for solar collector testing, EN 12975-2 (CEN 2006) offers two different methods for characterizing the thermal performance of solar thermal collectors: The steady state (SS) method and the quasi dynamic method (QDT). When the QDT method first was introduced in the standard, a “steady state reference case” was defined. This way QDT parameters could be converted into a power curve that corresponded well to one delivered by applying the steady state method. However, as concentrating technologies and vacuum tube collectors are gaining market shares, it has become apparent that the steady state test method is not able to fully characterize the performance of these products.

This paper presents an approach to overcome this problem temporarily, by calculating essential “missing” QDT parameters from steady state model parameters. In a longer perspective, the steady state test method should be replaced by the QDT method in order to give accurate results in system simulations and in predictions of annual collector gains, at least when testing collectors of the types mentioned here. With an example of an evacuated tube collector (ETC), it is shown how the method improves the accuracy of predicted energy yield based on steady state testing by 5-15 % depending on which weather conditions that occurred during the steady state test.

1. INTRODUCTION

The European standard for solar collector testing (EN 12975-2) offers two different methods for characterizing the thermal performance of solar thermal collectors: The steady state method (SS) and the quasi dynamic method (QDT). The first one originates from the Ashrae 93-77 and ISO 9806 standards where the performance model parameters are determined under clear sky conditions (maximum 20 % diffuse fraction allowed, however EN 12975 states maximum 30 %) and at high irradiance levels (minimum 800 W/m^2, however EN 12975 states 700 W/m^2). The QDT method was developed and introduced in the EN standard in 2001, as this standard was first published. Compared to the SS method, the QDT method offers the following main advantages:

- It allows for accurate characterization of a wide range of collector types
- It allows for testing under a wide range of operating and ambient conditions
- It gives a more complete characterization of the collector through an extended parameter set as compared to steady state testing

In the QDT collector model (Perers 1993, Perers 1995, Perers 1997, Fischer 2004), see equation below, the original steady state equation has been modified and extended with some correction terms. A single incidence angle modifier for hemispherical irradiance has thereby been divided into incidence angle modifiers for direct ($K_{\theta b}(\theta)$) and diffuse ($K_{\theta d}$) irradiance and the thermal capacitance term (c_5) is integrated in the equation. Furthermore, terms for the heat loss dependence on long wave irradiance (c_4) and wind speed (c_3) and wind speed dependence of the zero loss coefficients (c_6) have been added.

$$\dot{Q}/A = F'(\tau\alpha)_{en} K_{\theta b}(\theta)\, Gb + F'(\tau\alpha)_{en} K_{\theta d}\, Gd - c_6\, u\, G^* - c_1 (t_m - t_a) - c_2 (t_m - t_a)^2$$
$$- c_3\, u\, (t_m - t_a) + c_4 (E_L - \sigma T_a{}^4) - c_5\, dt_m/dt$$

These generalizations make it possible to test a wide range of collectors under the most varying weather conditions and in fact, a certain variation in the weather during testing is desirable in order to have all relevant parameters properly identified. This feature is a great advantage in some European locations where steady state testing can be very time consuming. On the contrary, applying QDT can be difficult in other locations where the weather is very stable or where diffuse fractions are constantly very low (Alfonso el al 2008). There is thus a need for further development of the QDT in order to make it fully applicable also at such locations.

The other very advantageous feature of QDT is its applicability to a wide range of collector designs, including ETC:s, concentrating, semiconcentrating (Rönnelid, Perers, Karlsson 1996, 1997) and unglazed collectors (Perers1987). A proposal for a further extension of the QDT method for test of unglazed collectors operating under the dew point of the air (for heat pump applications) is also available, but not yet validated (Perers 2006). As the market now grows, these types are becoming increasingly common and it is essential that performance testing within reasonable effort can deliver results that are not biased by unique features of a single collector type. Recent experiences from testing of these products however tell us that steady state testing in this respect is not powerful enough, which is shown in the following example. A correction method for increasing accuracy of the steady state method and the compatibility between the two performance test methods is also outlined. The example focuses on an ETC collector of the Dewar type, i.e. with a cylindrical absorber, as this is the most obvious case where the accuracy of the steady state method can be improved. However, the correction method may also be possible to use in order to generalize the steady state method to concentrating designs even though QDT seems to be the most appropriate method for these collectors.

2. METHOD

When testing ETC:s with cylindrical absorber according to the steady state method, the ability to utilize irradiance coming from non-normal incidence angles, a specific feature of this collector type, can result in a significant bias in the resulting model parameters. This is due to the following two effects:

- The impact of the incidence angle modifier for direct irradiance in the transverse direction $\mathrm{K}_{\theta\mathrm{b}}(\theta_L)$ is positive (i.e. $\mathrm{F}'(\tau\alpha)_{\mathrm{e}} > \mathrm{F}'(\tau\alpha)_{\mathrm{en}}$) and much more pronounced compared to e.g. flat plate collectors. This makes the "acceptance angle" for determining $\mathrm{F}'(\tau\alpha)_{\mathrm{en}}$ by steady state measurements very small (often below ±5 degrees). This should be further stressed in the EN 12975 standard as measurements at higher angles can lead to significant over estimation of the $\mathrm{F}'(\tau\alpha)_{\mathrm{en}}$ parameter. From a practical point of view it means that a solar tracker should be used in testing unless very stable weather conditions are guaranteed at the test site. If the collector is mounted on a fixed structure the acceptance angle of ± 5 degrees corresponds to a time window of only ± 20 minutes around solar noon.

- The incidence angle modifier for diffuse irradiance is normally in the range of $1{,}0 < \mathrm{K}_{\theta\mathrm{d}} < 1{,}5$ for this kind of collector i.e. giving a strong, positive contribution to the yield as compared to e.g. flat plate collectors where it is normally between 0,85 and 1,0 i.e. giving a weaker and negative contribution. Determination of $\mathrm{F}'(\tau\alpha)_{\mathrm{en}}$ that should represent direct irradiance at normal incidence will therefore be positively biased even at relatively low diffuse fractions. As $\mathrm{K}_{\theta\mathrm{d}}$ is not identified through the steady state test, this effect cannot be directly corrected for. If different diffuse fractions occur when $\mathrm{F}'(\tau\alpha)_{\mathrm{en}}$ and

$F'(\tau\alpha)_e$ are measured this will probably also give a bias in the values of $K_{\theta bL}$ and $K_{\theta bT}$.

The impact of these two effects are shown below by calculating the zero loss coefficient $\eta 0$ (which is effectively what is determined as $F'(\tau\alpha)_{en}$ in the steady state measurement) for a set of incidence angles and diffuse fractions, according to equation (1). Here, a zero loss coefficient for hemispherical irradiance is weighted together by the corresponding coefficients for direct and for diffuse irradiance.

$$\eta_0 = F'(\tau\alpha)_{en} * K_{\theta b}(\theta=\theta_i) * a + F'(\tau\alpha)_{en} * K_{\theta d} * (1-a) \quad [--] \qquad (1)$$

Where $K_{\theta b} = K_{\theta bL} * K_{\theta bT}$, a=fraction of direct irradiance, (1-a)= fraction of diffuse irradiance. η_0= zero loss efficiency from stationary testing.

Now, if $K_{\theta d}$ can be determined, equation (1) can be used to calculate $F'(\tau\alpha)_{en}$ from measured values of $\eta 0$ and measured (or default) values of $K_{\theta b}(\theta_i)$ and a.

$$F'(\tau\alpha)_{en} = \eta_0 / [K_{\theta b}(\theta=\theta_i) * a + K_{\theta d} * (1-a)] \qquad (2)$$

In the proposed method for adjusting steady state parameters to better accuracy, $K_{\theta d}$ is first determined from the measured values of $K_{\theta bL} * K_{\theta bT}$, by integrating them over a hemisphere, assuming isotropic sky conditions (Perers 1995). Thereafter, $F'(\tau\alpha)_{en}$ is calculated according to equation (2).

3. RESULTS

A typical evacuated tube collector with cylindrical absorber tested according to the steady state method is characterized by the following parameters:

η_0= 0,65

Table 1. Incidence angle modifiers for direct hemispherical irradiance in the transverse and longitudinal directions for the example collector

Angle of incidence [º]	0	10	20	30	40	50	60	70	80	90
$K_{\theta bL}$	1.000	1.000	1.000	0.985	0.970	0.920	0.840	0.700	0.350	0.000
$K_{\theta bT}$	1.000	1.070	1.140	1.275	1.410	1.730	1.760	1.760	0.880	0.000

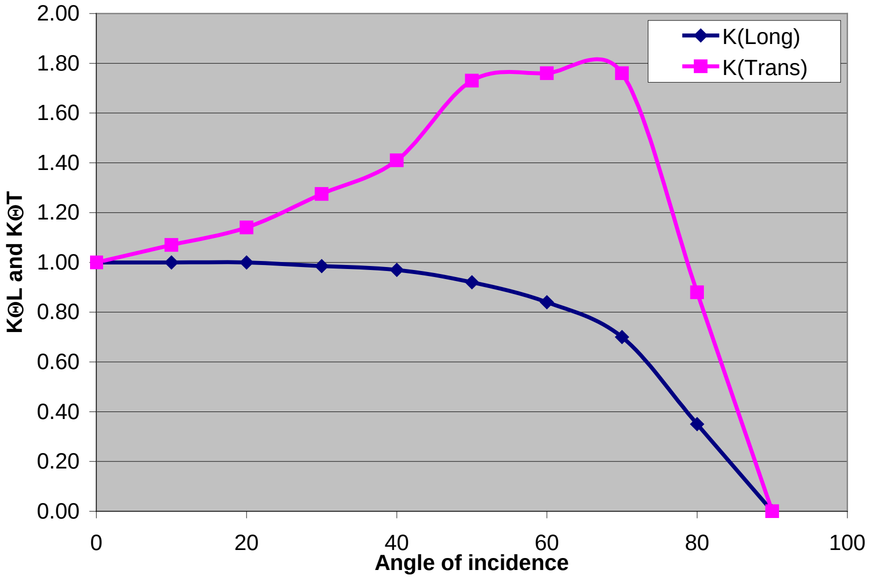

Figure 1. Incidence angle modifiers for direct hemispherical irradiance in the transverse and longitudinal directions for the example collector

Integrating the values of $K_{\theta bL}$ and $K_{\theta bT}$ over the hemisphere gives a calculated $K_{\theta d}$ equal to 1,22.

Depending on the diffuse fraction and any incidence angle offset from normal incidence during steady state measurements of this particular ETC, the "true" $F'(\tau\alpha)_{en}$ will deviate from the measured η_0- value (0,65) according to table 2. In other words, the conventional steady state test will only produce the "true" $F'(\tau\alpha)_{en}$ in the case represented in the first row of table 2 (for parallel light=beam radiation, at normal incidence, no diffuse radiation at all). The annual energy gain has been calculated using weather data from Meteonorm for Stockholm and an Excel tool developed within the Solar Keymark II project (Boverket 2009). The following collector model parameters have been used:

$F'(\tau\alpha)_{en}$= According to table 2
c1=1.5 $Wm^{-2}K^{-1}$
c2=0.01 $Wm^{-2}K^{-2}$
$K_{\theta d}$=1,22
IAM ($K_{\theta bL}$ and $K_{\theta bT}$)= According to table 1

Over estimation in energy gain is calculated as 710 kWh relative to each specific case e.g. (710-700)/700 in the second row.

Table 2. Bias in $F'(\tau\alpha)_{en}$ and annual energy gain due to deviations from optimum test conditions

Angle offset from normal incidence (longitudinal/ transverse) [degrees]	**Diffuse fraction [%]**	**True $F'(\tau\alpha)_{en}$ [-]**	**Annual energy gain [kWh/(m^2*a)]**	**Over estimation in energy gain [%]**
0/0	**0**	**0,65**	710	-
0/0	5	0,643	700	1.4
0/0	15	0,629	681	4.3
0/0	30	0,609	654	8.6
0/5	5	0,622	672	5.7
0/10	5	0,603	645	10.1
0/15	5	0,585	621	14.3

0/5	15	0,611	656	8.2
0/10	15	0,595	635	11.8
0/15	15	0,579	613	15.8
0/5	30	0,596	636	11.6
0/10	30	0,583	618	14.9
0/15	30	0,570	600	18.3

It shall be noted here that the proposed method for deriving $K_{\theta d}$, as a result of assuming isotropic sky conditions, tends to underestimate the value of $K_{\theta d}$. From QDT measurements on this type of collector, $K_{\theta d}$- values >1,4 has been determined. Applying steady state testing on a collector with an η_0- value= 0,65, a $K_{\theta d}$=1,4 and a diffuse fraction of 15 % would result in a “true” $F'(\tau\alpha)_{en}$=0,613 even with measurements carried out at normal incidence.

As a pragmatic approach to the issue of choosing incidence angles and diffuse fractions for a standardized correction procedure, it is suggested that normal incidence and a diffuse fraction of 15 % is applied in all calculations.

4. CONCLUSIONS

It has been shown that the zero loss coefficient and thus the energy performance of ETC:s with cylindrical absorbers when determined according to the steady state method described in EN 12975-2 is over estimated due to the specific characteristics of this collector type.

The proposed method will deliver a more accurate value of $F'(\tau\alpha)_{en}$ as well as a “new” parameter, $K_{\theta d}$ when steady state testing is applied to an ETC collector with cylindrical absorber. Considering that the diffuse fraction of annual irradiance for many European locations is in the order of 35-45 % it is essential that this dependency can be accurately modelled. System simulations and annual performance predictions based on the steady state test can thus be carried out with significantly improved accuracy for this type of collector. In particular the modelling of collector characteristics and system performance can be improved at low irradiance levels and high diffuse fractions, more often occurring during the heating season i.e. autumn to spring, where heat produced is generally more valuable than in the summer season.

The method tends to under estimate $K_{\theta d}$ and could thus be further refined. If the method could be shown to give good agreement between measured (using QDT) and calculated (based on steady state measurements) values of $K_{\theta d}$ it could open up for a wider application range also for steady state testing

The presented findings reveal a need for some further clarifications in the EN 12975 standard in order to avoid overestimation of collector performance for certain collector types

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