

Thermal Performance Rating of Solar Water Heating Systems in ASEAN

E. Halawa

Abstract—Solar water heating (SWH) systems are gaining popularity in ASEAN in the midst of increasing number of affluent population in society and environmental concerns from seemingly unchanged reliance on fossil-based fuels. The penetration of these systems and technologies into ASEAN markets is a welcome development; however there is a need for the method of assessment of their thermal performances. This paper discusses the reasons for this need and a suitable method for thermal performance evaluation of SWH systems in ASEAN. The paper also calls on research to be focused on the establishment of reliable data to be entered into the performance rating software. The establishment of accredited solar systems testing facilities can help boost the competitiveness of ASEAN solar industry.

Keywords—ASEAN, Solar Industry, Solar Water Heating Systems, Thermal Performance Rating

I. INTRODUCTION

THE environmental concerns due to the constantly increasing demand for fossil-based fuel have been in the centre of global attention for some time now despite different pace of response of individual countries. ASEAN has witnessed increasing proliferation of solar water heating systems due to increased percentage of affluent group in society in this region. While there has been no reliable official figure on the number of SWH units that have been installed in each ASEAN country members, anecdotal evidences have seen the introduction of these units in existing and new housing complex of middle class groups. Local solar water heating system manufacturers or suppliers have kept introducing their systems in the market and their existence is evidence of the existence of potentially lucrative market of this 'green' business. This is further boosted by the fact that environmental issues which constantly remind us of the threat posed to our planet from our reliance on fossil fuels have become people's daily vocabulary and everyone seems to want to contribute to the solution.

While the introduction of these 'green' systems / technologies into the market is a welcome endeavour, it is also crucial to ensure that its goal to contribute to sustainability is guaranteed through the proper design, construction, installation and rating. As the energy sustainability and environmental concerns are already becoming 'hot' issues involving the whole world, ASEAN countries should consider these issues seriously by starting developing a reliable

sustainability and environmental assessment method for this 'green technology'. There are a number of evaluations (tests) applicable to solar collectors including solar hot water systems [1]. These are: internal pressure, high temperature resistance, exposure, external and internal shock, rain penetration or ingress, freeze resistance, thermal performance, impact resistance and final inspection tests. Most of these tests relate to the quality of materials used for the construction of the collector [1].

In this paper, the focus is on the thermal performance evaluation method of the solar hot water systems. This thermal performance rating is directly related to the energy consumption and greenhouse gas emissions from these systems. The testing can be performed outdoor or indoor using solar simulators [2]. However, limited access of many countries to solar simulators makes the outdoor test a more preferred option [3].

This paper discusses two methods for evaluating the thermal performance of SWH systems with the specific focus on the mixed experimental and computer modelling / simulation method. The paper also discusses research activities that need to be carried out for the realisation of the performance evaluation in ASEAN.

II. CURRENT STATUS OF THE ASEAN ENERGY LABELLING AND MINIMUM ENERGY PERFORMANCE STANDARDS (MEPS)

In an effort to tackle the sustainability issues related to the introduction and use of appliances, two schemes have been developed worldwide, namely: energy labelling and minimum energy performance standard [4]. Energy labelling relates to the energy consumption and hence the cost of running an appliance. Energy label provides a useful guide to consumers in deciding to procure an energy consuming appliance – a much more affordable appliance with potentially high running cost or a rather expensive appliance with low running cost. The MEPS limits the maximum energy an appliance can consume and therefore aims to increase the average efficiency of a product that is allowed to enter the market.

A report by Harrington and Damnic [4] and ICF International [5] revealed that several ASEAN countries have already introduced energy labelling program and MEPS for a number of appliances. Similar programs for water heating appliances (including solar water heating systems) are yet to be developed.

The development of a method for evaluating the thermal performance of the SWH systems is an initial and crucial step leading to the realisation of the energy labelling program and MEPS for this type of energy consuming appliance.

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III. THE NEED FOR SHW THERMAL PERFORMANCE RATING

A hot water heating system is one of energy intensive appliances and the 'solar' attribute attached to it may lead to an inference that it must be environmentally friendly or 'green' which is not always the case. Its ultimate performance will be dictated by various factors such as design, materials, construction, installation, the environment, climatic conditions, etc. For instance, a well designed SHW unit may not be able to deliver the optimum (near optimum) performance if not properly oriented or installed under the shadow. Mismatch between the collector size and storage tank capacity will also affect the system performance significantly.

Thus, a proper performance rating is required to (1) provide helpful information to consumers, (2) verify the claimed energy performance and greenhouse gas offsets of the system, (3) provide basis for comparison of greenhouse impact of all forms of water heating appliances (4) provide the reference for supporting program such as subsidy or rebate schemes [6].

The proposed rating program - when implemented through a standard and enacted through a regulation - will certainly affect the SWH industry in terms of an additional cost associated with the rating compliance. This additional cost relates to the component testing, system modeling and verification. The proposed scheme may also result in the lengthy approval process for the introduction of a SWH product into the market. Without proper planning this proposed scheme will send the SWH industry into debacle. On the other hand, the current situation is also unsustainable; it will eventually hurt the SWH industry in the long run. The global push for internationally standardised performance rating of environmental goods and services cannot be avoided. The international competitiveness of the ASEAN solar industry hinges on their ability to adapt to this global imperative.

IV. METHODS OF ASSESSMENT

In theory, there are two methods of rating the solar hot water systems: (1) onsite evaluation; (2) combined direct measurement and modelling/simulation methods.

Onsite evaluation: In this method, thermal performance is assessed during the utilisation period of the system. Assessment is based on the various data recorded during the operation of the system. The outcome of the assessment only comes at the end of the system's lifetime. Although this method is more reliable in terms of its outcome, it is not practical, very expensive and cannot be used to 'regulate' the market. To the best of the author knowledge, this approach has never been adopted. However, it may still be relevant for research purposes.

Combined direct measurement and computer modeling / simulation: In this approach, the actual thermal performance of the main components of a SWH system (solar collector, tank and pump) is tested using a standardised methods in laboratory or test field while the system performance is assessed using rating software developed for that purpose [7].

This second option - with its associated strengths and drawbacks - is the most widely used. It is easier to adopt and can be used to 'regulate' the proliferation of the systems into the market by establishing the minimum performance requirements of the systems. It can also be used to estimate the system's contribution to the reduction of conventional energy use and the greenhouse gas abatement. Its main drawback is the need for strict observation of the implementation in the field. Its reliability or accuracy also very much depends on the input data and various assumptions behind the method. This approach also entails the need for competent computer modellers that help establish reliable computer models of each of the systems to be checked for compliance. It also entails the need for competent auditors who help the regulatory body in verifying the validity of such models.

Of the two methods mentioned above, the combined experimental evaluation and computer based modelling/and simulation is the most practical and easiest to implement and is discussed in detail in this paper.

V. THE MIXED EXPERIMENTAL AND COMPUTER MODELLING - SIMULATION METHOD

Fig. 1 shows the typical components of a SWH system. The collector, which can be of a flat plate or evacuated tube type, is connected to a storage tank that stores the hot water heated by the collector. Depending on the solar collector capacity and prevailing weather conditions, the water may need further heating either in the tank (by an electrical element) or before being delivered to the hot water use point. For a thermosyphon system, the tank is placed on top of the collector where the water in the tank is heated by natural convection or thermosyphoning [1].

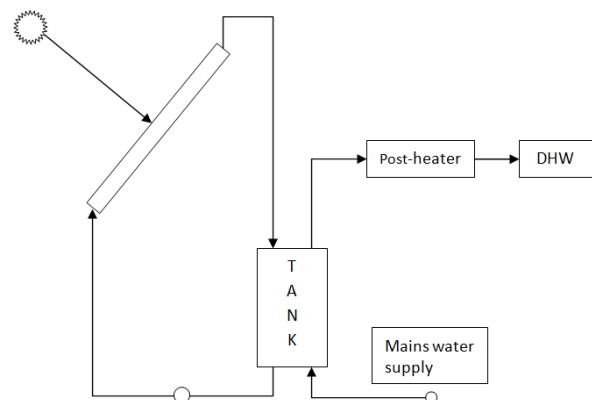


Fig. 1 A typical solar hot water system

A. The experimental assessment of the components

1. Solar thermal collector

The existing standards for evaluating the thermal performance of solar collectors such as ISO 9806-1:1994 [2], the ANSI/ASHRAE Standard 93:2003 [8] and AS/ANZ 2535.1:2007 [9] can be used as the basis for developing such a standard in ASEAN.

The thermal performance of the collector, the tank and the pump can be evaluated individually. The results of these evaluation will later be used in the thermal performance evaluation of the whole system using the computer modelling and simulation (Section V.2). For the collector, the aim of the experimental evaluation is to obtain the coefficients of the collector characteristic equation which is normally expressed in either a linear form.

$$\eta_{\text{coll}} = c_0 - c_1 \frac{\Delta T}{G} \quad (1)$$

or a quadratic form:

$$\eta_{\text{coll}} = c_0 - c_1 \frac{\Delta T}{G} - c_2 \frac{(\Delta T)^2}{G} \quad (2)$$

where:

η_{coll} = collector efficiency, percent

c_0 = maximum (intercept) efficiency

= $F_R(\tau\alpha)$

c_1 = negative of the slope of the efficiency curve, $\text{kJ}/(\text{hr}\cdot\text{m}^2\cdot\text{K})$

c_2 = negative of the second order efficiency coefficient, $\text{kJ}/(\text{hr}\cdot\text{m}^2\cdot\text{K}^2)$

ΔT = collector temperature difference, either $(T_i - T_a)$ or $(T_m - T_a)$, K

T_i = collector fluid inlet temperature, $^{\circ}\text{C}$

T_a = ambient temperature, $^{\circ}\text{C}$

T_m = $0.5 * (T_i + T_o)$, K

F_R = collector heat removal factor, fraction

$(\tau\alpha)_n$ = transmittance-absorptance product at normal incidence, fraction.

G = solar irradiance on the collector surface, $\text{kJ}/\text{hr}\cdot\text{m}^2$.

Thus the development the collector characteristic equation requires the measurements of fluid inlet and outlet temperatures (T_i and T_o), ambient temperature (T_a) and solar irradiance (G) on the collector surface at the constant fluid mass flow rate.

The thermal performance of the solar collector is affected by collector materials (through $(\tau\alpha)$ product), insulation, collector orientation and slope and the environment (wind, dust, etc.). The incidence angle modifier (IAM) is important in the performance of the evacuated tube collectors and therefore must be measured for a number of longitudinal and transversal angles.

2. Storage Tank

The thermal performance of the storage tank depends on the tank dimension and material of tank wall and tank insulation. The most important parameter is the tank standing heat loss, defined as the heat loss during a day (24 hours) from a tank without water draw-off [10]; it is expressed in $\text{kWh}/24 \text{ h}$.

3. Pump

For a forced circulation solar water heating system a pump is required to recirculate the water between the collector and the tank.

B. The modelling/simulation of the system (assembled components)

In order to evaluate the thermal performance of the system, a computer model is employed where the various components whose relevant technical specifications have been established through the testing program discussed earlier are interconnected in the model. One of the most widely used packages for this task is the transient simulation package TRNSYS [11]. The program has a number of relevant subroutines to perform simulation. The main subroutines include: solar collector models (for flat plate, evacuated tube, and special model for thermosiphon collector), tank models, pump model, heater model. This computer model can also be used to optimise the system's performance. Fig. 2 shows typical connections of the various components in TRNSYS.

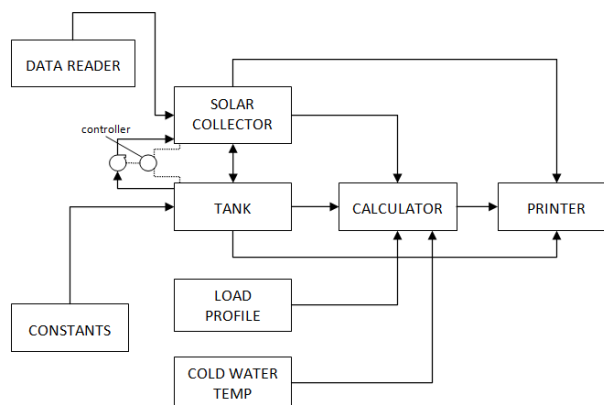


Fig. 2 TRNSYS Typical Configuration of a SWH Model

C. Data requirement

For the successful evaluation of the system's thermal performance using the TRNSYS [11], all the inputs required needs to be supplied. These include solar collector characteristic coefficients and related quantities such as solar collector orientation, collector slope, fluid flow rate at test conditions, fluid properties, tank parameters such as tank dimensions, standing heat loss, wall and insulation thicknesses, boosting type, etc. [11]. In addition to the system's components specification, the load profile in terms of hourly water draw-off pattern for a specific season and peak load for the coldest month needs to be supplied. The monthly cold water temperature profiles need also to be established. To compare the performance of the system to that of the standard water heating system, a reference load also needs to be established [12].

D. The Assessment Outcome

The energy saving delivered by the SWH system can be estimated by comparing its energy consumption with that of the reference system for a particular period. This should form the basis for SWH energy labelling. This can also be used by the jurisdiction as guide for encouraging high efficient systems to enter the market through various subsidies or rebate schemes. The outcome of this rating can also be used as the basis for establishing the MEPS for the SWH systems.

VI. RESEARCH FOCUS

The successful realisation of the development of this evaluation method depends mainly on: (1) the establishment of reliable input data to the rating software to be employed, (2) the availability of solar testing facilities for testing the main components of the systems, i.e. the collector and the storage tank. Reliable data of solar radiation, water draw-off profiles, cold water temperatures are crucial as they affect directly the results of the evaluation. While rating software such as TRNSYS [11] has built-in radiation data for many locations including several locations in ASEAN, development of a more reliable ASEAN radiation database is worth pursuing. The establishment of reliable water draw-off and mains water temperature profiles entail rigorous research. The fact that these systems will likely to be found or installed in housing complex of affluent groups in society justifies focussing the data collection for this research on these groups. Establishment of accredited solar testing facilities enable ASEAN countries to provide services to local manufacturers which helps boost their competitiveness on regional and world market.

VII. THE ESTABLISHMENT OF STANDARD

The role of the respective ASEAN government in realising this program and running it smoothly is crucial. ASEAN countries – individually or as an Association – need to develop a framework to assist their SWH industry to sustain in the increasingly tough global competition. However, to avoid unnecessary ‘panic’ within the SWH industry, the gradual and smooth introduction of the proposed scheme in ASEAN should be well planned. This can be realised through the formulation of immediate, mid- and long-term action plans. The immediate plan should include briefing to SWH industry on the importance, potential benefits and impacts of a rating program on the industry and the government policy to minimise the impacts.

In the immediate plan, a committee representing relevant government department and SWH industry should be established to discuss matters related to the establishment of the rating scheme. The committee can also be commissioned to identify various issues and actions to address them. Voluntary rating scheme can be introduced as a way of making the SWH industry familiarise themselves with the rating. In the mid-term plan, the committee can also be commissioned to establish the Standard Committee whose members should come from relevant government department, SWH industry representative and research institutions. This committee drafts the Standard, invites comments from the public and refines the draft accordingly. The enactment of the Standard should be the main action of the long term plan.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Two method for rating the thermal performance SHW systems have been presented with the detailed discussion on the mixed experimental and computer modelling / simulation method. The development of the rating method is the first and

crucial step leading to the establishment of energy labelling and minimum energy performance programs for the SWH systems. The research is called on the developing reliable solar radiation data, water draw-off and cold water temperature profiles required by the rating software. The establishment of accredited testing facilities in ASEAN should further boost the competitiveness of ASEAN solar industry.

ACKNOWLEDGEMENT

The author would like to acknowledge the supports of the Research and Innovation of Office (RIO), and Mission Oriented Research (MoR) Hybrid Energy - Universiti Teknologi PETRONAS, to this research endeavour.

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