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Solar thermal collectors for medium temperature applications: a comprehensive review and updated database

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Abstract

Although the technology of solar thermal collectors for medium temperature applications is not new, few collectors and commercial installations were available worldwide. Presently the sector is growing rapidly, new technologies have been developed and real installations using these technologies are already being built all around the world for different applications, especially for the generation of heat required by industrial applications.

Considering the increasing number of available products and the importance of disseminating this information among system designers and end-users, a database of the available solar collectors for medium temperature applications is under development. The information has been gathered from the different collector manufacturers and suppliers and the available technical information published on the different collector models. Aiming a thorough insight into these new commercially available solutions, the database includes the most relevant technical information of the different existing collectors.

This work is being done within the framework of the European project STAGE-STE (Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy) (<http://www.stage-ste.eu/>). The information gathered will also be used within the Task 49, the working group for Solar Heat Integration in Industrial Process (SHIP) of the Solar Heating and Cooling program (SHC) by the International Energy Agency (IEA) (<http://task49.iea-shc.org/>).

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1. Introduction

Solar energy is widely used worldwide to supply thermal needs [1]. Medium temperature solar collectors represent an interesting solution to cover specific demands. According to the definition proposed within Task 49 [2], medium temperature solar thermal collectors refer to collectors whose power output exceeds 300 W/m^2 (referred to gross collector area) for the following conditions: 1000 W/m^2 hemispherical irradiance, 15 % diffuse fraction and 20°C ambient temperature at an operating temperature above 100°C .

Although the development of medium temperature collector technologies technology started more or less at the same time as the Concentrating Solar Power (CSP) systems (some examples are available from the seventies and eighties of last century [3]), until now their market development has not been as relevant as in CSP, due more to the lack of financial support than to the technology itself. Currently these technologies are developing very fast. Possible uses of these collectors are mainly solar process heat but also solar cooling, desalination, electricity generation using Organic Rankine cycle (ORC), pumping irrigation water, water heating for high consumptions, etc. In Task 49, a database for applications of solar heat integration in industrial processes was created (<http://ship-plants.info/>).

Existing collectors are based on different technologies (Parabolic-Trough Collectors PTC, Linear Fresnel Collectors LFC, parabolic dishes, ultra-high vacuum flat plate collectors, fixed mirror solar concentrator FMSC, etc...), different designs, concepts, sizes and materials, etc. Therefore, no standardized designs of collector-components are still available. The database herein presented will serve as a reference survey of available products in the medium temperature solar thermal collectors market.

2. Methodology

The methodology followed for developing the medium temperature solar thermal collectors database was accomplished in three main steps:

- The first one consisted on defining the most important technical parameters of the collectors to be gathered, such as the main materials, collector designs, certifications (if any) and geometrical, optical and thermal behavior information. The selected parameters are the following: manufacturing information, collector type, component materials and dimensions, optical properties, tracking system information and other specifications. For a clearer understanding of the parameters selected to be included in the database, details are presented in section 3.1.
- Secondly, the existing information on solar thermal collectors was collected and the defined technical information was extracted. It was noted that the information on different existing collectors varies depending on the sources. In addition, it should be mentioned that the different suppliers have different collector models and their products are continuously evolving.
- Finally, the different suppliers were contacted to check the validity of the available information. With all the information collected a statistical analysis was performed to achieve important conclusions such as market distribution among the different collector types, specific relevant parameters that are not typically reported, component materials typically used, etc.

Aiming a permanent update of the gathered information, a public online form was created. Following the same format and data parameters of the original database, such form will enable the introduction of information on new collector technologies by manufacturers. Such information will then be screened by the core database technical commission and, upon approval, will be made available to the general public online.

3. Medium temperature solar collectors database

3.1. Thermal collector technical parameters

In the medium temperature solar thermal collectors database each collector is identified by the model, type, manufacturer (including name, location and website), and they are characterized by technical parameters. In this section the definition of these technical parameters about medium temperature solar thermal collectors included in the database is given:

- Stationary/tracking: stationary option is marked when the collector does not present a movement system, while tracking is selected when the collector include a movement system to track the Sun direction along the day;
- Primary reflector (material, reflectance, ρ , dimensions and other specifications): description of the main features of the primary reflector, which is the element that concentrates the solar radiation onto the receiver. The typical material types are silvered-glass (thick or thin), aluminum (several kinds of protective layers) and polymer film. The material model and manufacturer is also specified, when known. The reflectance, ρ , is the ratio of the energy flux reflected by a surface to the radiation incident on it [4]. Dimensions include width, length and thickness. Concentrator characteristics are also mentioned in some cases;
- Secondary reflector (material, reflectance, ρ , dimensions and other specifications): description of the main features of the secondary reflector, which is an element located around the receiver to re-concentrate on it the radiation reflected by the primary reflector;
- Flat cover if any (material, transmittance, τ , dimensions and other specifications): description of the main features of the flat cover, which is an element located on the aperture plane of some collectors to protect the rest of the components (reflector, receiver, etc.) and to decrease the thermal losses. The transmittance, τ , is the ratio of the energy flux transmitted by a material to the incident radiation on it [4]. Dimensions include width, length and thickness;
- Receiver (material, absorptance, α , emittance, ε , inlet diameter, outlet diameter, evacuated or non-evacuated and other specifications): description of the main features of the receiver, which is the element of a solar collector absorbing radiant solar energy and transferring it to a fluid in the form of heat. The absorptance, α , is the ratio of the energy flux absorbed by a surface element to the radiation incident on it [4]. The emittance, ε , is the ratio of the radiant energy emitted by a material from its surface to the radiant energy emitted by a black body under the same conditions [4];
- Receiver cover (material, transmittance, inlet diameter, outlet diameter and other specifications): description of the main features of the receiver cover, which is an element located around receiver in some solar collectors to protect it and decrease the thermal losses;
- Tracking system (type, accuracy and other specifications): description of the main features of the sun-tracker, which is the element of a solar collector that permits it to follow the Sun direction along the day. Some common types of tracking systems are: sun (electro-optical) sensor, sun position algorithm (date/time based, open loop system), and hybrid sun-tracker (combination of sensor and date/time based); the orientation of the tracking mode (East-West EW or North-South-NS);
- Stagnation protection: method to avoid the collector reaching the stagnation temperature. In tracking collectors, the stagnation protection is to defocus it;
- Gross area (width and length): main dimensions of the collector; the width corresponds to width of the flat surface which accepts the solar radiation (aperture plane), including the gaps between adjacent reflectors. The length also includes the gaps between adjacent reflectors composing the collector unit;
- Focal length: distance between the vertex of the parabola and the focus. In parabolic-trough collectors, the receiver is located in the focal line;
- Geometric concentration ratio C : is defined as the ratio of solar collector aperture area to the receiver aperture area;
- Rim angle: in the cross section of a parabolic-trough collector, is the angle between the optical axis and the line between the focus (focal point) and one of the edges of the reflector (mirror rim);

- Acceptance angle: the angular range over which all or almost all rays are accepted without moving all or part of the collector [5];
- Certification: type of certification scheme fulfilled by the collector (typically exist in Europe SolarKeyMark and SRCC in USA);
- Operating pressure: pressure range that may be covered by the collector –inside the receiver- during normal operation;
- Operating temperature: temperature range that may be covered by the collector -inside the receiver- during normal operation;
- Performance: the global or overall collector efficiency (or performance) is the ratio of the thermal power transferred to the heat transfer fluid in the collector to the available radiant solar power [4]. If possible, the performance is indicated by the following terms: η_0 (peak collector efficiency [4]), a_1 (heat loss coefficient [6]) and a_2 (temperature dependence of the heat loss coefficient [6]), following the Eq. 1:

$$\eta = \eta_0 - a_1 \cdot \frac{(t_m - t_a)}{G} - a_2 \cdot \frac{(t_m - t_a)^2}{G} \quad (1)$$

For concentrating collector the testing method used according to ISO 9806:2013 is under quasi-dynamic conditions (QDT). The collector model is described by the Eq. 2 (3 additional parameters, c_3 , c_4 and c_6 , are defined in this method but could neglected for the concentrating collectors), with $\eta_{0,b}$ (optical efficiency based on beam irradiance G_b); c_1 (heat loss coefficient); K_b and K_d the incidence angle modifier for direct and diffuse radiation respectively; c_2 (temperature dependence of the heat loss coefficient) and c_5 effective thermal capacity.

$$\frac{\dot{Q}}{A_G} = \eta_{0,b} \cdot K_b(\theta_T, \theta_L) \cdot G_b + \eta_{0,b} \cdot K_d G_d - c_1 \cdot (t_m - t_a) - c_2 \cdot (t_m - t_a)^2 - c_5 \cdot \frac{dT_m}{dt} \quad (2)$$

In order to compare both methods results under steady-state and quasi-dynamic conditions, ISO 9806:2013 define how to calculate the parameters and represent into a thermal curve graph. The optical efficiency shall be calculated from the power function, Eq. 2, using the value of $G = 1000 \text{ W/m}^2$ and a diffuse fraction of 15 %, i.e. $G_d = 150 \text{ W/m}^2$. The parameter dT_m/dt is set to zero. The incidence angles are set to 0° so the IAM K_b is set to 1. Both heat losses coefficients under quasi-dynamic conditions (c_1 and c_2) are then equal to the heat losses coefficients under steady-state conditions (a_1 and a_2).


- Stagnation temperature (non-tracking collectors): the temperature reached when stagnation persists until the losses of the solar thermal collectors equal the absorbed energy [2];
- Weather conditions for normal operation (wind speed, temperature, humidity, other specifications): description of the weather parameters at which the collector is kept in operation under safety conditions;
- Stow conditions (tracking collectors): maximum wind speed admissible during collector operation, above which the collector is sent to the stow position;
- Heat transfer medium: description of the heat transfer medium to be used inside the collector;
- Applications: typical applications susceptible to be covered by the solar collector;

3.2. Online database on solar collectors

Considering the interest on having a permanent update of this information, a publicly available online form was created, enabling new inputs from technology suppliers, researchers, engineers or general public.

The application is a google form where the requesting form is structured in 9 pages following the contents of the original database. New inputs on available solar collectors include:

1. Collector identification: manufacturer name, location and website, collector type, collector model, adoption of stagnation protection strategy;
2. Reflector(s) characterization: for both primary and secondary reflectors (when existing), reflectance values, reflectance measurement parameters and additional (material) specifications;
3. Glazing characterization: for both external flat and/or tubular receiver covers (when existing), transmittance values, transmittance measurement parameters and additional (material) specifications;
4. Receiver characterization: material, absorptance value and measurement parameters, emittance value and measurement parameters, diameter (inner or outer), wall thickness, atmosphere and additional (material) information;
5. Tracking system characterization: tracking type, moving element, system type, tracking accuracy and additional information;
6. Geometrical characterization: aperture width, aperture length, collector height, focal distance, rim angle, acceptance angle, concentration factor;
7. Optical and thermal characterization: certification (standard, testing lab, certification scheme, status), optical efficiency, heat loss and temperature dependent heat loss coefficients, stagnation temperature;
8. Operating conditions: maximum operating temperature, maximum operating pressure, weather conditions for normal operation, stow conditions, heat transfer media, suitable applications;
9. Additional resources: the user might indicate up to five additional resources (technical specification sheets, presentations, videos, etc.) by adding a short description and the corresponding link for download/consultation.


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Solar Collectors Database

Manufacturer
Please provide the manufacturing company name

Manufacturer location
Please provide the manufacturer company location: City (Country)

Collector Type

Flat Plate
 Evacuated Tubes
 CPC
 Parabolic Trough
 Linear Fresnel
 Otro:

Collector Model
Please provide the collector model designation

Website
Please provide the link for the manufacturer (or collector) website

Stagnation protection

No protection
 Otro:

if "Otro", please specify

11% completado

Fig. 1. Medium temperature collectors online form first page.

The contents of new inputs will be reviewed by a technical committee in charge of maintaining and publishing the database results. This technical committee is currently composed by researchers from Tecnalia, Fraunhofer-ISE, CIEMAT, University of Evora and CENER. Upon validation of the information inserted by the user, the information will be added to the database and included in the statistical results. Database statistics will be published every three months.

The online form for addition of new collectors, the existing information in the collectors' database, and database statistics are available on the following link:

- www.stage-ste.eu/keydocuments/solarthermalcollectors.php

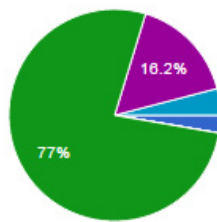
4. Results and discussion

4.1. Database statistics: Summary of the existing information in the database of solar collectors

The current contents of the database cover the review on available information on existing solar collectors and enquiries performed among solar collector manufacturers. 39 manufacturers were contacted covering in total 74 collectors.

Direct statistical information is available e.g. on collector type, stagnation protection, existence of primary and secondary reflector, tracking type or suitable HTF, as illustrated in Figs. 2 to 7. †

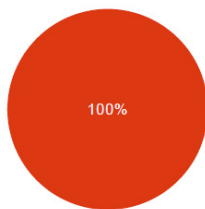
Collector Type



Flat Plate	2	2.7%
Evacuated Tubes	0	0%
CPC	0	0%
Parabolic Trough	57	77%
Linear Fresnel	12	16.2%
Other	3	4.1%

Fig. 2. Medium temperature collectors database statistics: Collector type.

Stagnation protection

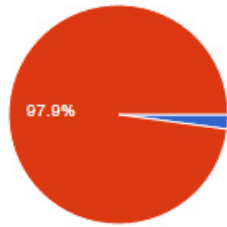


No protection	0	0%
Other	68	91.9%

Fig. 3. Medium temperature collectors database statistics: Stagnation protection.

* In the right side of the figures appears the number of answers received for each option and the percentage that this number represents referred to the total number of collectors. However the percentage that appears in the graphs are referred to the total number of answers received. As example in the Stagnation protection graph (Fig. 3) from the 74 collectors actually included in the database there is only this information for 68, that is, the 91.9% of the collectors. But the graphs represent the 100% because from the available responses, 100% indicate "other" and 0% indicates "no protection". The Collector type graph's (Fig 2) percentages are the same of the percentages showed in the right side of the figure, because this information is available for all collectors.

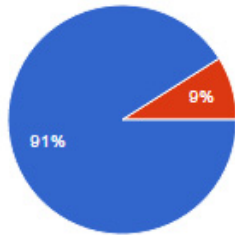
Primary reflector



No primary	1	1.4%
Other	46	62.2%

Fig. 4. Medium temperature collectors database statistics: Primary reflector.

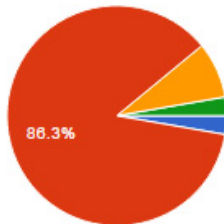
Secondary reflector



No secondary	61	82.4%
Other	6	8.1%

Fig. 5. Medium temperature collectors database statistics: Secondary reflector.

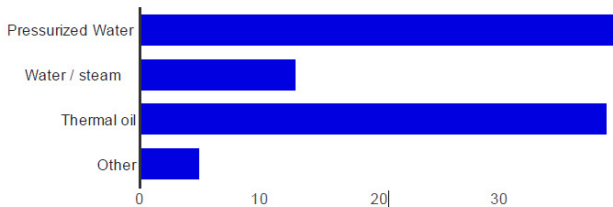
Tracking type



Stationary	2	2.7%
1-axis tracking	63	85.1%
2-axis tracking	6	8.1%
Other	2	2.7%

Fig. 6. Medium temperature collectors' database statistics: Tracking type.

Heat transfer media



Pressurized Water (w/ or w/out glycol)	40	54.1%
Water / steam (DSG)	13	17.6%
Thermal oil	39	52.7%
Other	5	6.8%

Fig. 7. Medium temperature collectors database statistics: Heat transfer media.

4.2. Analysis of results

Most of the collectors, (see Fig 2) 77%, are PTC, followed by 16.2% of LFC and 2.7 % FPC and 4.1% others (Dish, Enclosed-Fresnel and FMSC type with curved mirror). In the information collected, 9 collectors were identified with a flat glass cover, protecting the reflective surfaces and/or the receiver. Analyzing the geometrical information and employed materials and components, it is clearly noticed that there is a great diversity in the adopted solutions.

In this sense, considering the geometrical information on the difference collectors (sizes, focal length, geometrical concentration, rim angle, acceptance angle, etc.), there are important differences between the different collectors. The smallest collector has an aperture of 0.5 m and a length of 2.1 m and is based on the PTC geometry. On the other hand, the biggest collectors are Fresnel type solutions with sizes up to 25*110 m².

When observing the employed components and materials, big differences are detected between the different collectors. This is especially visible when analyzing the reflectors and the absorber tubes where several technologies are being used. Regarding the reflectors, the lack of standardized mass produced curved thick glass reflectors for this small scale concentrating collectors make that other solutions, such as the aluminum and silvered-polymer reflectors, are used in many of the collectors, e.g. more than 35% of the collectors included in the database use aluminum reflectors.

Finally, when discussing the applications for these collectors, most of the suppliers consider that the applications with highest potential for their collectors are industrial process heat, solar cooling, power generation with ORC and desalination. Related to this, most of the collectors use heat transfer fluids (HTF) based on pressurized water and thermal oil, depending on the temperature limitations, although some collectors can also be used in direct steam generation applications using water-vapor as HTF.

5. Conclusions

A detailed database of existing collectors for medium temperature applications has been created and the gathered information has been revised by manufacturers. Aiming the availability of a comprehensive overview of the existing technologies to system designers and end-users, the database has been fed through an online form, enabling a permanent update by technology suppliers, to achieve a live database gathering the most updated and relevant technical information on solar concentrating collectors for medium temperature applications.

The existing information in the collectors' database, database statistics and the online form for addition of new collectors, are available on the following link:

- www.stage-ste.eu/keydocuments/solarthermalcollectors.php

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