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Solar Heat in Industrial Processes

IEA-SHC Task 49 Subtask A Leadership

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Abstract

Anfang 2012 wird neuer IEA-SHC Task mit dem Titel „Solar Process Heat for Production and Advanced Applications“ gestartet, der an den abgeschlossenen IEA SHC / Solar Paces Task 33/IV „Solar Heat in Industrial Processes“ anknüpft. Für diesen neuen Task wurde das SPF vom Operating Agent angefragt, die Leitung des Subtask A „Process Heat Collectors“ zu übernehmen. In diesem Subtask soll die Entwicklung von Prozesswärmekollektoren und ‚advanced heat exchangers and controllers‘ für den Einsatz in Prozesswärmeanlagen koordiniert werden. Es sollen ferner Testmethoden und Teststände für Prozesswärmekollektoren untersucht und entwickelt werden. Die Herausforderung und der Aufwand für die Leitung des Subtask sind erheblich, da eine Vielzahl von Randbedingungen und technischen Details zu beachten sind, die für den angestrebten Temperaturbereich noch nicht definiert bzw. untersucht wurden.

2011 gab es zwei Task Definition Meetings (März 2011 in Graz/Österreich, September 2011 in Kassel/Deutschland) mit einer regen Beteiligung seitens der Industrie und von Forschungsinstituten aus verschiedenen Ländern (bislang waren 47 Teilnehmende bei den beiden Definition Meetings und es sind 10 Länder, 11 Firmen und 15 Forschungseinrichtungen beteiligt). Derzeit ist der Working Plan in der letzten Überarbeitung für die endgültige Verabschiedung beim SHC ExCo (November 2011). Die ersten beiden Task 49 Meetings sind für Anfang März 2012 (Freiburg/Deutschland) und Mitte September 2012 (Graz/Österreich) terminiert.

Das SPF war und ist 2011 massgeblich an der Erstellung des Working Plans, insbesondere für den Abschnitt zu Subtask A, beteiligt sowie im Rahmen der Subtask-Leitung an der Gesamtkoordination und -organisation des Task.

Generelles

Die Beschreibung des gesamten Tasks sind dem (vorläufigen, da noch nicht endgültig vom ExCo verabschiedeten) Work Programms zu entnehmen, das in Ausschnitten hier wiedergegeben wird:

Background

Solar Heat for Industrial Processes (SHIP) is currently at the early stages of development. Less than 100 operating solar thermal systems for process heat are reported worldwide, with a total capacity of about 24 MWth (34,000 m²). Most of these systems are of an experimental nature, and are relatively small scale. However, there is great potential for market and technological developments, as 28% of the overall energy demand in the EU27 countries originates in the industrial sector, majority of this is heat of below 250°C.

According to a study (Ecoheatcool 2006), around 30% of the total industrial heat demand is required at temperatures below 100°C and 57% of this demand is required at temperatures below 400°C. The heat demand below 100°C could theoretically be met with solar thermal systems using current technologies, if suitable integration of the solar thermal system can be identified. With technological development, more and more medium temperature applications, up to 400°C, will also become market feasible.

In several specific industry sectors, such as food, wine and beverages, transport equipment, machinery, textiles, pulp and paper, the share of heat demand at low and medium temperatures (below 250°C) is around 60% (POSHIP 2001). Tapping into this potential would provide a significant solar contribution to industrial energy requirements.

The methodology which has been developed in order to realize thermal energy supply in industry with minimal greenhouse gas emissions is based on a three step approach:

- Technological Optimization of the processes (e.g. increased heat and mass transfer, lower the process temperature) and solar thermal system (e.g. operation of solar field, integration schemes, control, safety issues etc.)
- System Optimization (enhancing energy efficiency using e.g. Pinch Analysis for heat exchanger network for a total production site)

- Integration of renewable energy/solar thermal energy (based on exergetic considerations)

In the last two years the awareness for solar process heat in the industry increased and some new solar thermal systems were installed. This positive development should be supported now by further research and development in the key research questions of solar process heat.

After completion of the IEA SHC/Solar Paces Task 33, key areas for further technological development, which should be treaded in the context of a new Task, have been identified:

- Process heat collector development with heat loss control and maximization of energy collection
- Material research with improvement of components on a higher temperature level and better materials for concentrated optics
- Process heat collector testing for working temperatures above 100°C

The content of this new proposed project were defined based on this knowledge out of IEA SHC 33/Solar Paces Task IV and other position papers like the strategic research agenda of the European Solar Thermal Technology Platform and the experience of several national projects in the field of solar process heat.

Main activities to be undertaken

- Design and definition of general requirements and relevant parameters for process heat collectors and their improvement
- Definition of high temperature behaviour of process heat collectors and solar loop components
- Improvement of process heat collectors and solar loop components
- Based on the results of IEA SHC Task 33 / Task 4 a basis for the standardized comparison of collectors under certain conditions will be provided
- Recommendations for testing procedures
- Development of advanced pinch and heat storage management tools
- Survey on heat integration methodologies
- Develop System concepts and integration guidelines for solar process heat in different industry sectors and temperature levels
- Survey and dedicated Workshop on new process technologies
- Compendium of ongoing activities and existing pilot plants/case studies in the field of process intensification and solar thermal systems
- Identification of the increasing potentials for solar thermal process heat through combination with PI technologies
- Development of Design Guidelines for integration of solar thermal systems in industrial processes
- Further development and adaptation of numerical simulation tools for the improved design of solar thermal systems
- Performance assessment methodology for process heat collector types in different industrial application scenarios
- Case studies and monitoring of existing and during the next years realized demonstration projects (within parallel demonstration projects)
- Dissemination activities of task results
- Development of programs for a broader market deployment
- Carrying out of a potential study for solar process heat considering the integration of process intensification technologies and “new applications”

Scope of the Task

Applications, systems and technologies which are included in the scope of this task are:

- All industrial processes which are thermal driven and running in a temperature range up to 400°C

- Solar thermal systems using air, water, low pressure steam or oil as a heat carrier, i.e. not limited to a certain heat transfer medium in the solar loop.
- All types of solar thermal collectors for an operating temperature level up to 400°C are addressed: uncovered collectors, flat-plate collectors, improved flat-plate collectors - for example hermetically sealed collectors with inert gas fillings, evacuated tube collectors with and without reflectors, CPC collectors, MaReCos (Maximum Reflector Collectors), parabolic trough collectors.
- Technologies for industrial application which can be driven by sunlight or specific spectrums (e.g. UV)

Specific process engineering technologies to which solar heat has to be supplied, such as the technologies for desalination of sea water, industrial cooling applications and electricity generation, are not the main focus of the Task. They may be considered to a certain extent if there is strong interest from industry.

For cooling applications, for instance, the work will be restricted to the adaptation of the results of IEA SHC Task 38 to industrial applications. The foreseen activities in the field of heat storage management will not deal with the development of storage technologies and the application of new storage materials. This work will be addressed in the IEA SHC Task 42 and its follow up activities. There is also a link of this IEA SHC Task to the activities in IEA SHC Task 45 “Large scale systems” due to the size of the solar thermal systems and the challenges faced by both applications.

Objectives and subtasks’ organisation

The main goals of the activity will be to:

1. Further develop and improve solar process heat collectors and components
2. analyze and provide new knowledge on high temperature behavior of process heat collectors and solar loops
3. develop a testing procedure and to provide a basis for the comparison of collectors under certain conditions
4. provide engineering tools for optimized heat integration and optimized planning of solar thermal integration by advanced pinch analysis and storage management.
5. identify new applications for solar thermal energy in several production processes through the combination of process intensification technologies
6. develop planning tools, calculation tools for solar yields in large scale plants
7. gain proven solutions for stagnations behavior
8. install and monitor large-scale demonstration systems
9. develop guidelines for solar process heat
10. to lower the barriers for market deployment

Subtask A: Process Heat Collectors

Lead Country: Switzerland (Dr. Elimar Frank - SPF)

In this Subtask, the further development, improvement and testing of collectors, collector components and collector loop components is investigated. All types of solar thermal collectors for an operating temperature level up to 400°C are addressed: Uncovered collectors, flat-plate collectors, improved flat-plate collectors (for example hermetically sealed collectors with inert gas fillings or vacuum) with and without reflectors, evacuated tubular collectors with and without reflectors, CPC collectors, parabolic trough collectors, Fresnel collectors, air collectors etc. Furthermore, to identify and select the most suitable collector technology for specific boundary conditions an overview of collector output and key figures will be compiled. It is assumed that for all activities of this subtask the temperature range will have to be separated in several segments. For instance, up to around 200°C water and steam can be used as heat carriers with acceptable pressure. With higher temperatures and with choosing another heat carrier (e.g. oil) the boundary conditions change substantially. A simple up-scaling of the results from the investigations and recommendations for the temperature range up to 200°C or 250°C will not be possible. This is true both for the investigations aiming at improvements of the solar loop as well as for recommendations with regards to test rigs, testing procedures and standardization.

Based on existing approaches, methods and parameters for the assessment of the collector and collector loop performance as well as of the impact of the properties of materials and components will be developed and identified. Appropriate durability tests will be applied to specific materials / components to allow the deep understanding of the collector and collector loop behaviour for a wide range of operation conditions and the prediction of service life time.

Based on the investigation of the dynamic behaviour of solar process heat collectors and loops (both experimentally and theoretically), recommendations for process heat collector testing procedures will be worked out.

Subtask A has three main objectives:

1. Improving solar process heat collectors and collector loop components
2. Providing a basis for the comparison of collectors with respect to technical and economical conditions
3. Giving comprehensive recommendations for standardized testing procedures

The participants will achieve the objectives by

- updating the IEA SHC Task 33 state of the art survey of process heat collectors
- increasing the knowledge of general requirements and relevant parameters for process heat collectors and their improvement
- determining parameters for
- modelling collectors in simulation programs to reflect the realistic performance of medium temperature collectors in process heat systems and
- comparable measurement data evaluation also from dynamic data for different locations, applications etc.
- developing and/or improving collectors, components and solar loops for process heat applications in co-operation with the involved industry. The main aspects are performance, reliability and cost effectiveness. Both new or improved collector or component/solar loop concepts and design details will be addressed
- investigating the collector behaviour by collector testing at high temperatures and by the evaluation of measurement data from existing plants
- investigating material aspects for collectors with up to 400°C operating temperature and system components
- investigating the overheating behaviour of large medium temperature collector fields
- measurements on the thermal performance of other components and solar loops of solar thermal systems operating at high temperatures
- elaboration of recommendations for collector testing standards for the medium temperature level

Special effort will be made to involve the solar industry in the analysis of all working fields, e.g. through industry-dedicated workshops.

Proposed activities in this subtask are the following:

A1. Improvement of solar process heat collectors and collector loop components

In order to support the development and improvement of cost effective and at the same time well-performing and reliable process heat collectors, the appropriate requirements are investigated. It shall be described and evaluated which parameters have to be taken into account for the development and improvement, which ones are more important than others and which kind of measurements can enhance the development/improvement. Also material topics and the accuracy that is necessary will be discussed and described.

Characteristic parameters will be determined for both modeling collectors in simulation programs to reflect the realistic performance of medium temperature collectors in process heat systems and comparable measurement data evaluation for different locations, applications etc.

For the integration of solar heat into industrial processes it is compulsive that the systems operate totally reliable in all the operation modes that may occur. In this respect, special emphasis has to be put on the aim that the solar thermal systems can handle stagnation or overheating situations without any danger of failure and without the need for additional maintenance works. Whereas for collectors with stagnation temperatures lower than e.g. 250°C stagnation has to be regarded as a normal operation mode of solar thermal systems, this has to be investigated and analyzed for collector concepts leading to higher temperatures when there is no sink for the solar heat (e.g. times without industrial production because of weekends or vacation times, but also technical faults like the breakdown of a pump etc.). In this context, also the terminology "stagnation" will have to be discussed and adapted with respect to process heat collectors as for collectors aiming at high usual operation conditions overheating will lead to severe material problems. The influences and consequences of stagnation/overheating on the collector loop fluids and components will also be addressed and solutions (avoidance of overheating/stagnation by conceptual approaches, coolers, …) will be developed. The aim is to develop techniques to handle stagnation situations also in large medium temperature collector fields.

Not only stagnation, but also the (dynamic) behavior of the collectors and the collector loop is of interest. Investigating the collector behavior will be done by collector testing at high temperatures and by the evaluation of measurement data from existing plants. Also, material problems for medium temperature collectors up to 400°C operating temperature and system components will be investigated, such as heat carriers, insulation etc. If possible, these measurements will be carried out in existing systems and in laboratory measurements in order to be able to realistically model medium temperature systems and to give recommendations for testing procedures.

With all the knowledge gained, even some of the collectors already available on the market for up to around 100°C could be modified to be used for higher temperatures. Furthermore, there is a considerable potential for the improvement of existing process heat collectors in many aspects. New collector developments and improvements will lead to a better cost/performance ratio as is presently achieved for medium temperature systems. The collectors to be investigated are for example, double glazed flat plate collectors with anti-reflection coated glazing, hermetically sealed collectors with inert gas fillings or vacuum (with and without reflectors), CPC collectors, evacuated tubular collectors with and without reflectors, parabolic trough collectors, Fresnel collectors etc...). In these activities, investigations on materials suitable for medium temperature collectors will play an important role.

Beside developing and/or improving collectors, also other components and whole collector loops for process heat applications will be analysed and further developed in co-operation with the involved industry. The main aspects are performance, reliability and cost effectiveness. Both new or improved collector concepts and design details will be addressed and improved peripheral devices are aimed at (e.g. tracking with high accuracy, collector connections, …).

In order to achieve an improved performance / cost ratio for collectors for industrial processes, the reliability of collectors and their service life time is important. Moreover, in the development of medium temperature collectors, new materials and components will be used. This concerns the full width of collector technologies from flat-plate collectors to vacuum tubular collectors and parabolic trough collectors, e.g. reflectors (including their mechanical support), tracking devices, glazing and absorbers addressed.

Representative and realistic test samples will be identified and prepared. Relevant performance parameters will be defined and characterisation procedures will be established. Existing durability test procedures will be investigated and adapted where required. Adequate accelerated ageing tests will be developed as a basis for longevity assessments.

Summarizing, the overall aim of this activity is to achieve improvements optimizing the combination of thermal performance, collector costs and durability for process heat collectors.

A2. Comparison of collectors with respect to technical and economical conditions

In this activity, the results of A1 are used and extended. Areas and suitable boundary conditions and parameters will be discussed to find out if and how a comparison of different collector types is possible. This part is strongly connected with Subtask C (system simulation and assessment). An overview of collector output and key figures for defined conditions will be developed depending e.g. on climate, temperature range. The aim is to prepare the basis for a first choice of collector as some restrictions may be unfeasible for some collector concepts (required temperature level, heat carrier, pressure etc.).

A3. Comprehensive recommendations for standardized testing procedures

There is a broad range of experience in collector testing for operating temperatures below 100°C. Most of the testing laboratories carry out the tests with water as the fluid and up to a maximum temperature of less than 100°C. Therefore, only very few test results are available for higher operating temperatures. In simulation programs, an extrapolation of the collector performance determined at moderate temperature levels (up to 100°C) is made to describe the collector performance at higher temperatures. These extrapolations often have a high uncertainty resulting in system design calculations with uncertain component dimensioning results. The present situation is undoubtedly a major obstacle in designing medium temperature process heat systems with the needed accuracy for successful pilot systems.

Therefore the testing of suitable collectors at medium temperatures and the exchange of experiences amongst different testing laboratories is very important. The possibilities for round-robin tests on a medium temperature collector with efficiency measurements at 160°C or higher will be evaluated. Depending on the findings and the respective financing, such tests will be carried out. The results will be discussed with respect to improving the testing procedures in the ISO 9806 and EN12975 standards. A comparison of outdoor and indoor measurements (using solar simulators) will be carried out.

An important task for the wide spread commercial application of solar collectors in industrial processes will be the development of test and qualification standards allowing to assess such different technologies as flat plate collectors (stationary, using global radiation) and parabolic troughs (tracking, using direct radiation) with a view to their respective suitability for a particular application (in terms of the degree of compliance with specific requirements). During the last years, the methods used for non- or low-concentrating collectors have been partially extended to concentrating systems. Different progress can be seen in different countries and for different aspects, but a comprehensive test standard is not yet in sight that includes also quality testing, tracking accuracy etc. Therefore, based on the measurements described above and the further work described in this Subtask, significant steps towards such a "unified" standard shall be achieved. This would be a major added value for the co-operation between IEA, SHC, and SolarPACES, helping potential customers and manufacturers to plan and operate solar process heat plants with high performance, reliability and safety. However, it has to be mentioned that this will be a challenging task due to the inherent differences of the technologies to be characterised. Also, specifications for suitable test rigs are needed and decisions which tests can be carried out in labs (indoor/outdoor) and/or field tests (e.g. mobile test rigs to be used for instance at demonstration sites). The aim is that two of those test environments shall be in operation during the time of this Task and different collector types shall be tested. The development of (recommendations for) testing procedures will be done in cooperation with other IEA SHC Tasks that also have the aim to develop testing standards (e.g. the follow-up Task of IEA SHC Task 38 (solar cooling) and IEA SHC Task 43).

For the collector tests, not only the thermal performance but also aspects such as safety (high temperatures and high pressure) and environmental safety will be important (e.g. in case of using oils as heat carriers).

Besides collector testing, also the testing of collector components and solar loop components will be addressed. This comprises sub components like mirrors, receivers etc. and also ageing behavior tests and tests for the optical accuracy. For these tests, not only test procedures but also specifications for suitable test rigs will be worked out.

The overall aim of this activity is to elaborate recommendations for collector testing standards for the medium temperature level and to contribute to a unified standard for medium temperature collectors.

Deliverables Subtask A

A1 Improvement of solar process heat collectors and collector loop components:

- A1-1 Definition of general requirements and relevant parameters for process heat collectors
- A1-2 Report on overheating/stagnation issues including the high temperature behavior of the investigated components
- A1-3 Brochure on State of the Art of process heat collectors

A2 Comparison of collectors with respect to technical and economical conditions:

- A2-1 An overview of collector output and key figures for defined conditions

A3 Comprehensive recommendations for standardized testing procedures:

- A3-1 Recommendations for different kind of test procedures, reports and test rig configurations, e.g.:
  a. Sub components (tracking, receiver, mirrors, glasses, …)
  b. Collector laboratory tests
  c. Collector field tests
  d. Service life time test procedures for collector components of medium temperature collectors.

A4 Subtask report.

Nächste Schritte

Zur Zeit wird das Working Program abschliessend bearbeitet, bei dem das SPF vor allem die Beschreibung von Subtask A vornimmt. Zudem werden Kontakte zu Industrie- und Forschungspartnern hergestellt bzw. vertieft, um die Arbeiten im Task 49 und speziell im Subtask A zu intensivieren und zu koordinieren.

Für das nächste Task Meeting sind einige Präsentationen des SPF vorgesehen zu den laufenden Aktivitäten, u.a. zum Messverfahren für α und ε an Absorberrohren. Dazu haben einige der im Task beteiligten Firmen Interesse angemeldet.