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# Optimising the Temperature of Heat Storage to Serve Processes with Varying Supply and Demand - Captured Solar Energy Curve

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This work focuses on maximising the utilisation of solar thermal energy. The amount of energy supplied from solar radiation depends on the weather conditions, the available area and on the capture temperature. The weather conditions are difficult to account for. However, the collectors' area and temperature are design parameters. Usually there is an upper limit on the area of the collectors, both by available space and the cost. It determines the maximum energy that can be captured at different temperatures. The storage temperature should be the lowest possible to ensure maximum solar heat capture and minimum losses to the ambient. The resulting temperature level is determined by a trade off between the temperature levels of the process demands and the solar supply temperature. The higher is the temperature of the capture, the lower is the efficiency of the storage system and the amount of heat captured. Too low storage temperature may result in infeasibility of the heat transfer to processes. By constructing the Minimal Capture Temperature Curve (MCTC) and the Captured Solar Energy Curve (CSEC) the most favourable temperature of the storage and capture of energy from solar source is determined using simple targeting techniques.

## 1. Introduction

An important problem of heat integration of many renewables (in this study – solar energy) is the variation of their supply availability in time. On the side of the processes the heat demands usually vary as well. Different arrangements are possible to deal with this problem. One option is a heat storage, which stores surplus heat from renewable sources. Another option is to analyse and suggest possibilities to shift both supply and demand. Heat integration (Klemeš et al, 2010) using Time Slices developed originally for integration of batch processes can be a promising solution (Varbanov and Klemeš, 2010). Energy sources with constant supply availability (e.g. biomass, fossil fuels) are needed to ensure reliable operation.

## 2. Problem statement

The problem of many renewable sources of energy is their varying availability in time. An analogy from batch process integration is used to deal with this problem. For the heat integration of batch process are used two supplementary approaches. First is based

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on the Time Average Model (TAM) introduced by Kemp and Deakin (1989). In the TAM the time constraints are not included. To account for the time constraints the Time Slice Model was developed again by Kemp and Deakin (1989). Their paper suggests a basic procedure to determine storage size. It was extended by Sadr-Kazemi and Polley (1996). Several papers dealt with the storage system efficiency, e.g. (Kaygusuz, 1995; Zalba et al., 2003). This work deals with the temperature level of storage for energy from renewable sources. There is a general opportunity to improve the efficiency of the storage, due to smaller temperature difference between the storage media and surroundings. The other benefit is minimising the storage temperature and also the temperature of capture solar source could be decreased. With decreasing the temperature of the capture the efficiency increases. The amount of captured energy would increase as well. This paper offers a procedure to determine storage with minimal temperature required.

## 3. Suggested Methodology

A scheme of a solar system capture is in Fig. 1. The solar irradiation energy is transformed to heat energy and stored. From storage the heat energy can be used at the time needed. This allows the time constraints to be overcome. To cover the rest of the heat demand other source with constant availability is used e.g. biomass or fossil fuel.

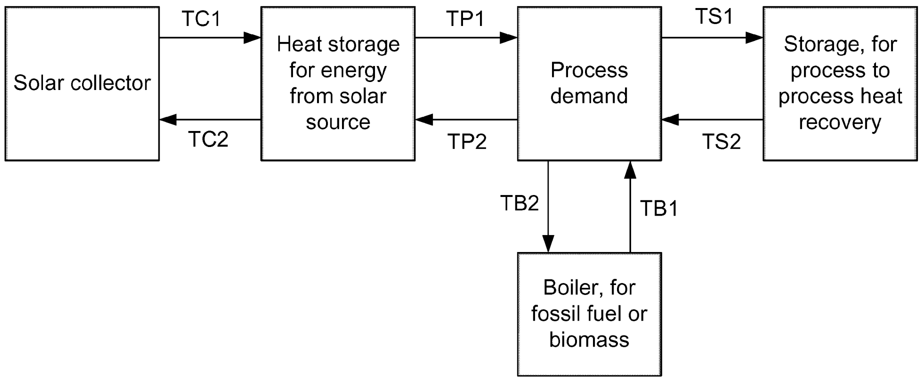


*Fig. 1: Schematic diagram of the whole process*

The heat storage for a process to process recovery has been added as well. For determining the optimal temperature for heat storage from solar source a construction of two curves has been suggested. The first curve is the Minimal Capture Temperature Curve (MCTC). This is a profile, derived from the part of the cold Composite Curve which needs heating utility shifting the latter up by a temperature difference with two components (Fig. 2): (i) Between the storage and process demand temperature ($TP_{min}$) and (ii) Between the capture and storage temperature ($TC_{min}$). When constructing a MCTC the possible temperature range of capture can be determined as well. The lowest temperature of the range of temperature of capture is evaluated. The lowest temperature range is a summation of the lowest heat demand summed up with both of minimum temperatures. The highest temperature of the range is a highest heat demand summed up with both of minimum temperatures.

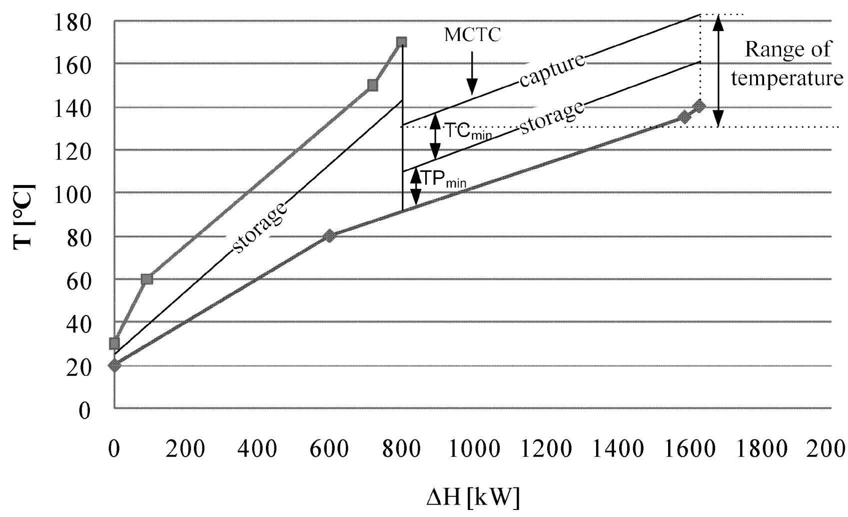


*Fig. 2: CCs and MCTC for the whole process for all Time Slice together*

The second newly developed curve is a Captured Solar Energy Curve (CSEC). To construct CSEC the captured solar energy is determined by multiplying (i) The amount of solar irradiation, (ii) The available area and (iii) The efficiency of the solar system in the temperature range determined by MCTC.

The first step in constructing CSEC is the determination of the amount of solar irradiation. The amount of solar irradiation is calculated from the integration of a fitted function e.g. polynomial to the measured/forecasted data points. The area of solar panels is usually considered as a constraint. The maximum collector area is determined mostly by the available space and cost limits. Efficiency is evaluated for the determined temperature range. From the three variables a CSEC for the range of temperature can be constructed. The aim of the method is to find the intersection between two curves – CSEC and MCTC. This crossing point of the curves represents a minimal feasible temperature of the capture. The maximum amount of energy covered by solar source is determined by this point as well. With assumption that there is no heat loss in the storage the temperature of storage can be concluded, see Fig 3. More accurate temperature of the storage can be found if the efficiency of the storage is known.

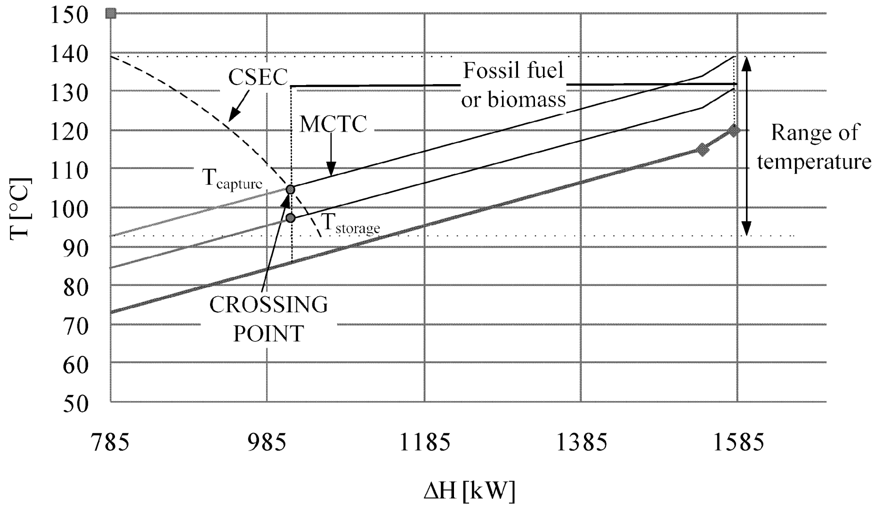


*Fig. 3: Determination of minimum temperature of solar capture and storage using MCTC and CSEC*

## 4. Illustrative case study

It has been based on a case study described by Kemp (1989). The streams are presented in Tab. 1. For the case study a typical summer day solar irradiation in Central Europe is used (Fig. 2). A polynomial function is fitted to the measured/forecasted data (Fig 4). The area below the fitted curve is calculated from Eq. 1 and Eq. 2.

*Tab :1 Streams of the case study*

| No. | $T_s$ [°C] | $T_t$ [°C] | CP [kW/°C ] | ΔH [kW] | Time interval [h] |
|---|---|---|---|---|---|
| 1 | 5 | 115 | 10 | 1150 | 0.5–0.7 |
| 2 | 150 | 40 | 4 | 440 | 0.25–1 |
| 3 | 60 | 120 | 8 | 480 | 0–0.5 |
| 4 | 135 | 15 | 3 | 360 | 0.3–0.8 |

The minimum temperature for the feasible heat exchange was determined as $TP_{min}$=10 °C and $TS_{min}$=5 °C. The temperature range according to data is 88 –130 °C.

$$A=\int_{18.867}^{5.367}(0.2183\cdot x^4-10.689\cdot x^3+171.56\cdot x^2-996.85\cdot x+1889.9)\ W/m^2 \tag{1}$$

$$A= 5469.366\ W/m^2 \tag{2}$$

The maximal average daily temperature for a summer day is considered as 25 °C (EU, 2010). The efficiency for a collector in the temperature range is between 10-58% (SolarUK, 2010). The area of the solar collectors is 150 m$^2$.

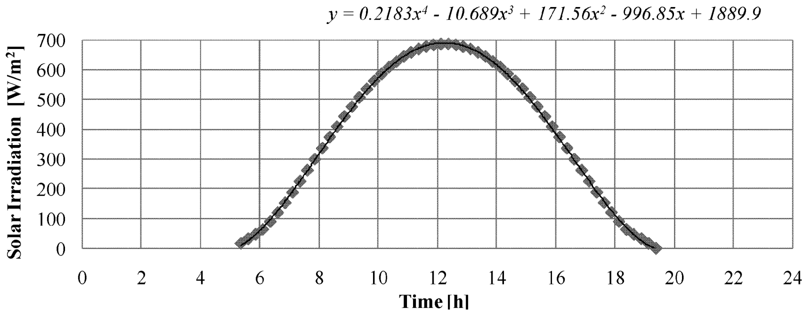


*Fig. 4: Daily solar irradiation on a typical summer day in Central Europe (EU, 2010)*

To determine the exact intersect of the CSEC and MCTC, both are presented with linear function (Fig. 5). For the CSEC the linear approximation is reasonably good, due to small temperature range. The shape of the efficiency curve is nearly linear. The linear approximation of the CSEC is Eq. 3. For the MCTC the slope is same as for the cold part of the CC in the range where the MCTC curve is. This is represented in Eq. 4

$$y=-0.1219 \cdot x+240.68 \tag{3}$$

$$y=0.0556 \cdot x+44.444 \tag{4}$$

The crossing point value is calculated from this set of equations, where are two variables and two equations.

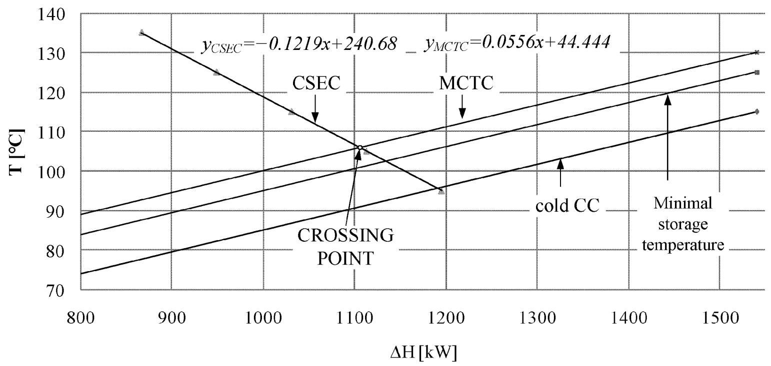


*Fig. 5: Result for the illustrative case study*

The crossing point is at 105.9 °C, which represents the value of solar capture temperature. The amount of the enthalpy at the crossing point is 1105 kW. The minimal storage temperature should be 95.9 °C. This is determined as 105.9 °C minus 5 °C. The amount of energy demand which can be covered ideally from solar energy source is 320 kW. The rest 475 kW should be covered from other sources e.g. fossil fuel or biomass.

## 5. Conclusions and future work

Finding the optimal storage temperature is important. For this purpose the Captured Solar Energy Curve (CSEC) is constructed. To obtain feasible solution the Minimal Capture Temperature Curve (MCTC) is introduced. The crossing point of the two curves represents the minimal temperature of the capture, which is still feasible. After determining the minimal temperature of the capture, also the minimal temperature for the storage can be identified. Also the amount of energy demand covered from solar source is determined with the crossing point. The further steps include the evaluation which streams are involved in the process to process heat recovery, in to covering the demand from solar sources of energy and which stream´s heat demand is covered from the fossil fuel or biomass (Varbanov and Friedler, 2008 and 2009).

This work represents a simple and efficient targeting for a minimal temperature of storage. In the procedure there are considered two heat storages. In the future a procedure for combining the heat storages should be evaluated.

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