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SOCO – Storage Optimisation Concepts in Industries, Commerce and District Heating Businesses

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For the implementation of existing optimisation potentials in industry, commerce and district heating, it is important to expedite the reduction of waste energy and consequently of the primary energy demand as well as CO_2 emissions and additionally to integrate renewable energy technologies. To reach these goals, complex optimisation principles are needed, due to the fact that heat and cold demand and availability vary in time and need to be aligned. Furthermore, continuous as well as batch processes which can be found in all industry sectors have to be considered. For this reason heat and cold storages are indispensable and necessary for increasing the resource and energy efficiencies in complex energy systems.
It has been proven that the pinch analysis is a very suitable method for the design of an optimised overall energy system (Muster-Slawitsch et al., 2011a; Varbanov and Klemes, 2010; Brunner et al., 2008). This methodology has been already implemented in several tools used for continuous processes without storages (Klemes et al., 2010). For minimising the external energy demand of non-continuous processes some approaches for ideal scheduling including heat integration have been formulated. Several authors worked with algorithms including batch processes and storages in the pinch analysis which are able to deal with single storages and optimise them (Krummenacher and Farvat, 2001; Nemet and Klemes, 2011; Atkins et al., 2010; Majozi, 2009; Chen and Ciou, 2008). But until now no software tools for the purpose of designing complex storage systems under practical considerations are available.
To close this gap, a new planning tool SOCO (Storage Optimisation Concepts) is being developed that is able to plan and design complex storage systems on the basis of real life process data coming from the industries, commerce and district heating businesses. The application will enhance possibilities of demand reduction (heat integration), increases the measures on energy efficiency and boosts the implementation of economically and technically reasonable renewable energy technologies, with a special attention on solar process heat. Included in SOCO is a pinch analysis on the basis of real life data with varying heat load profiles and the possibility to create heat exchanger networks. Based on the illustration of the residual load profile with its different temperature levels the best possible way of integrating renewable energy technology (solar process heat) can be shown. Furthermore, one of its main topics is the design of storage systems with regards on the heat exchanger network, previously calculated within the pinch analysis, and with regards on the possibility to implement renewable energies. SOCO optimises the amount, style, dimension and design of these storage systems as type of storage, insulation, connections, charging and discharging of the storages. This way, a holistic optimisation concept for storage systems and heat exchangers and their energy saving potential are displayed. The main fields of application are industries where several complex heat and cold streams occur, like producing industry, commerce and district heating businesses.

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SOCO is being developed based on measurements and monitoring data of 10 storages and the connected processes in industrial plants and district heating networks with which the present state has been modelled and analysed. Three of these storages will be the basis for detailed analysis of processes where holistic energy concepts have been developed: In an Austrian brewery the existing interconnections of processes (continuous and batch) with heat and cold demand at varying temperature levels and operating times in a water storage as well as an energy storage have been modelled and evaluated. The results show that the processes have been generally well integrated. On the one hand hot water from the wort cooler supplied the water demand of the brew house, the heating net and the fresh water over a water storage tank. On the other hand the lautering process and the vapour condenser of the wort copper (Pfaduko) are connected in an energy storage. But the integration of the storages could have been optimised. Based on the data of the three case studies the SOCO tool will be tested, evaluated and improved. The paper will present the structure of the algorithm and results of the optimisation within the case studies. By this way, the potential of the SOCO tool for reducing the primary energy demand by an optimised storage concept can be shown.

1. Objectives

For the implementation of existing optimisation potentials in industry, commerce and district heating, it is important to expedite the reduction of energy demand as well as to integrate renewable energy technologies. For solving these two problems, complex optimisation principles are needed, due to the fact that heat demand and heat availability vary in time and need to be adjusted. For this reason heat storages are indispensable and necessary for increasing the resource and energy efficiencies in complex energy systems.

Till now software tools, which are able to deal not only with single storages and optimise them, but for the purpose of designing complex storage systems are not available. So the aim is to develop a software-based planning tool which is able to generate a holistic concept for the implementation of thermal storage systems. With the help of this tool it will be possible – based on a pinch analysis (current approaches, new approaches including storage optimization) using real process data with varying heat loads - to generate and implement concepts for the reduction of primary energy demand in industry and in other thermal energy systems. The applications of the tool should, on the basis of real data, provide the possibility to increase the measures on energy efficiency, as well as to boost the implementation of economically and technically reasonable renewable energy technologies, with a special attention on solar process heat. So the main challenges are: the design of an optimised heat recovery system combining suitable processes including heat exchangers and storages; the implementation of batch processes that are very common in the food industry; possible variation of time schedules of different processes; time schedule defined by operational reasons (e.g. delivery of raw material, working hours etc); processes in different compartments; consideration of turn-on and shut-down times of thermal energy supply (e.g. boilers) and possible link of thermal energy supply to other demands (CHP systems, waste heat of cooling machines); the placement and design of storages and heat exchangers and; different storage technologies.

2. Methodology

The overall goal is to develop the planning tool SOCO including the optimisation of storage concepts in complex thermal energy systems based on the Pinch analyses for the design of heat exchanger and storage networks based on time varying load profiles.

2.1 Optimised Storage Systems

To achieve the targets defined, as a first step storage systems have been evaluated, where necessary supported by measurements of mass flows and temperatures (input and output), time depending load profiles, storage volumes and technology, heat losses and hydraulic integration of the storage in the overall system. The development of the automatic optimization algorithm was based on the storage evaluation with a focus on the connection of different profiles of storage charging and discharging and heat losses, optimized control strategies depending on the variation of storage sizes targeting at an energetic and economical optimum. This algorithm is also implemented in the SOCO tool. Additionally, for the development of the storage optimization algorithm it has been necessary to generate models for the simulation of different storage types (hot water storage, cold storage, energy storage, PCM storage).

2.2 Pinch Analysis

Existing pinch analysis algorithm based on the time slice model (Muster-Slawitsch et al., 2011b) has been extended to the needs of time depending load profiles including batch processes. Before it has been necessary to simplify process parameters including the risk of a loss of information e.g. load peaks that can't be taken into account.

2.3 SOCO planning tool

The modules developed (pinch analysis and storage optimization) have been and will be combined in the SOCO tool. Thereby, the two combinatorial optimization algorithms (for heat exchanger networks and storages) will be connected. The overall target is to maximize the efficiency (minimizing the energy demand) of the production process including minimized heat losses including economic constraints based on the case studies. The further development of the tool will be based on the verification of the mentioned case studies where detailed implementation concepts will be generated.

2.4 Main challenges and solution

The main problems and constraints identified in existing optimization algorithms (Majozi, 2009; Chen and Ciou, 2008) are: direct heat integration can only involve one pair of units (one source and one sink); if there is no heat integration between a process unit and the storage tank, the storage temperature remains constant; only one unit can be integrated with the storage tank at any given point in time; if a process unit is heat integrated with another process unit, it cannot be simultaneously integrated with the heat storage; storage tanks have one temperature level, multiple tanks are necessary for storing the heat transfer medium at various temperatures; only one inlet and outlet connection is allowed for each heat exchanger that uses the heat transfer medium; all heat integration happens over the heat transfer medium (no direct heat exchange between processes)

The initial stages for a solution are e.g.: the storage possibility is defined by the maximum accumulated energy within the time period; Storage temperature at the end of each time slice is calculated over the loss coefficient k and the storage surface; streams are modelled as matrices to map real process schedule (mass flow and temperature can vary for each time step) and these can be mixed and split; connections between heat exchangers, storages and streams are possible; different storage types are included (with various inlets/outlets)

3. Storage data acquisition

As shown in Table 1, 10 storages have been analyzed. The size varies from 20 up to 2,150 m³. By this the wide range of possible storages in the industry can be covered. Additionally, hot water and energy storages have been considered and in the development of the SOCO tool PCM (phase changing materials) storages will be implemented.

Table 1: Evaluated storage systems

Storage	Storage type	Storage size, m³
1	Hot water storage	220
2	Energy storage	96
3	Hot water storage	2,150
4	Hot water storage	54
5	Hot water storage	250
6	Hot water storage	320
7	Hot water storage	100
8	Hot water storage	44
9	Hot water storage	20
10	Hot water storage	40

4. Optimisation potentials identified

For two storages the evaluation of the present state and optimisation potentials identified are displayed in Figure 1 and Figure 2. Both of them are installed in a brewery. On the one hand the lautering process and the vapour condenser of the wort copper (Pfaduko) are connected in an energy storage. On the other hand hot water from the wort cooler supplied the water demand of the brew house, the heating net and the fresh water over a water storage tank.

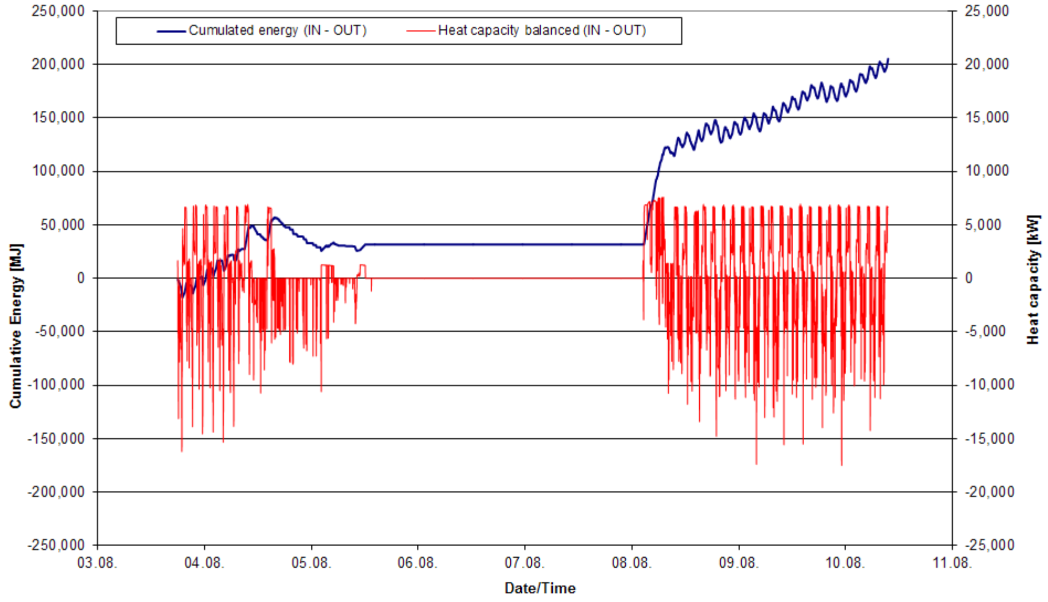

Figure 1: Evaluation of ingoing and outgoing energy and the cumulated energy in the energy storage evaluated (96 m³)

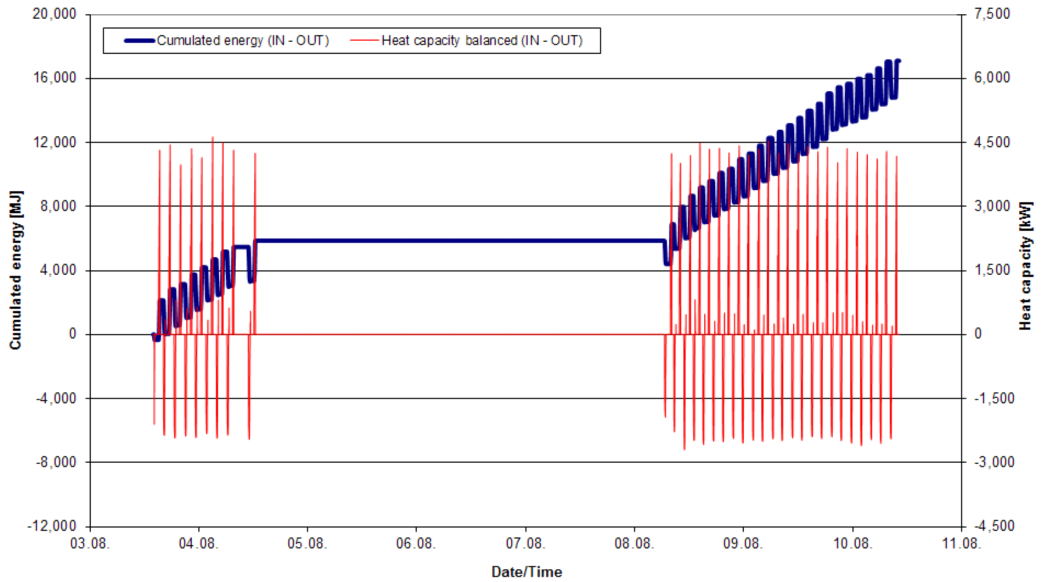

Figure 2: Evaluation of ingoing and outgoing energy and the cumulated energy in the hot water storage evaluated (220 m³)

5. Algorithm structure

Figure 3 gives an overview of the basic structure of the algorithm used in the SOCO tool which extends our previous work (Muster-Slawitsch et al., 2011b). The main target is to increase the energy efficiency by the reduction of waste energy and consequently of the primary energy. This can be reached by the design of optimised heat exchanger networks connected to storages as already mentioned above.
Based on the present state (processes, streams, heat exchangers, storages, operating schedules, etc.) the algorithm defines criteria (power, exergy and energy) and performs a pinch analyses to detect the theoretical potential of heat recovery. Hot streams are compared to cold streams calculating heat exchangers and the storable energy with a time-temperature profile. Using the weight of the criteria the most efficient system is generated and simulated. The optimised system is then compared to the present state detecting optimisation potentials. Finally, the storage type and design is suggested.

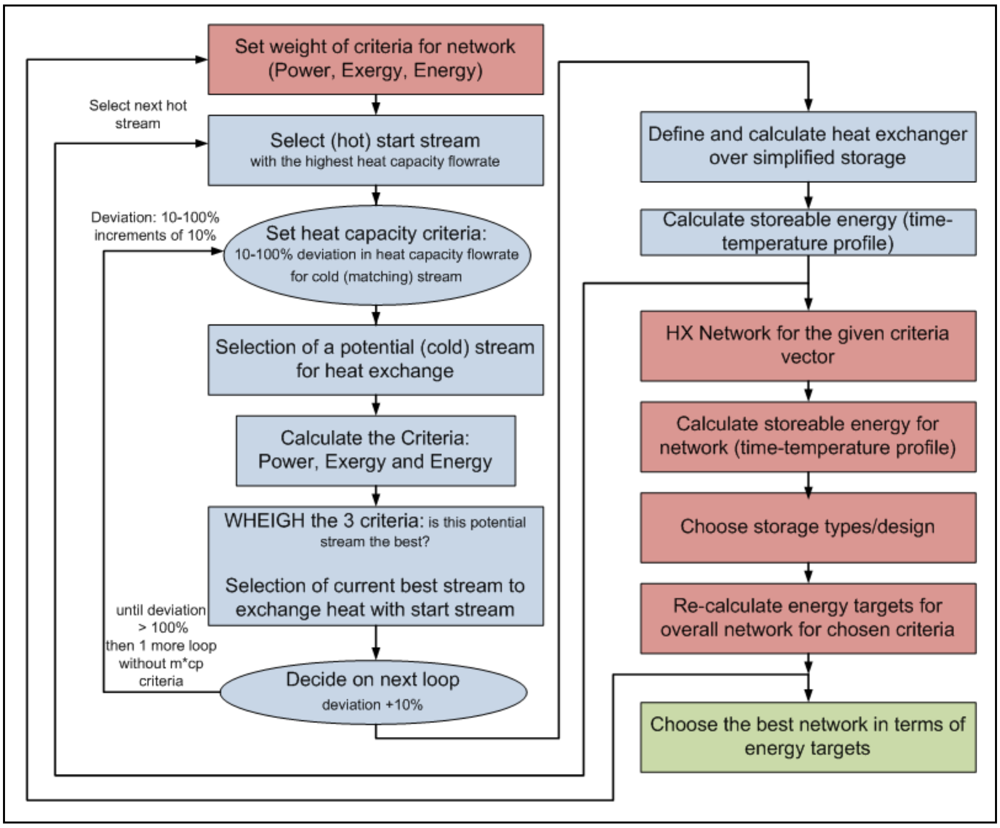

Figure 3: Structure of the algorithm of the SOCO tool

6. Conclusions

Based on the development of the algorithms for the storage optimisation and the pinch analyses including batch processes as well as the measurements and concepts developed for the systems evaluated the development of the software tool named “SOCO tool” will be finished within the next months. This will include the following functions:

- Pinch analysis on the basis of real life data with varying heat load profiles and the possibility to create heat exchanger networks
- illustration of the residual load profile with its different temperature levels, to provide the best possible way of integrating renewable energy technology (solar process heat)

- design of storage systems with regards on the heat exchanger network, previously calculated within the pinch analysis, and with regards on the possibility to implement renewable energies at its best (solar process heat)
- illustration of a holistic optimisation concept for storage systems and heat exchangers and their energy saving potential

The SOCO tool is specially designed for energy managers and consultants, plant engineering and construction enterprises, as well as for engineers dealing with solar integration. The main fields of application are industries where several complex heat and cold streams occur, like producing industry, commerce and district heating businesses.

The project achievements are:

- The acquisition and treatment of real life data from large storages for generating the calculation and simulation algorithms.
- Design tool for developing heat exchanger networks on the basis of real life process data, and optimising thermal storage systems. The design tool will optimise the amount, style and dimension of these storages in a complex industrial environment, with a simultaneous integration of renewable energy technologies like solar heat.
- Optimised heat concepts for three case studies (best practice examples)
- Illustration of the improvement potential of ideally designed heat storage systems
- The results will be used as a basis to derive further optimisation potential by the implemented solution principles for further applications.

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