

## Optimised Storage and Energy Efficiency Concepts in Industries, Commerce and District Heating Business: Based on Tool SOCO – Model and Measures Identified

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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<sub>2</sub> 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 also including continuous as well as batch processes which can be found in all industry. 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. This has been shown for renewable energy integration at total sites (Varbanov and Klemeš, 2010) and specifically for solar thermal integration (Brunner et al., 2008). Recently the approach has been applied for energy efficiency and renewable energy integration in breweries (Muster-Slawitsch et al., 2011). Several authors worked with algorithms including batch processes and storages in the pinch analysis but until now no software tools for the purpose of designing complex storage systems under practical considerations are available. To close this gap, the tool SOCO (Storage Optimisation Concepts) has been 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 (Fluch et al., 2012). The application enhances possibilities of demand reduction (heat integration), increases the measures on energy efficiency and boosts the implementation of economically and technically reasonable renewable energy technologies (focus 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 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. Therefore, the storage itself is simulated using a node model adapted for storages with a fixed level and a varying level. Based on these simulations SOCO optimises the amount, style, dimension and design of the storage systems as type of storage, insulation, connections, charging and discharging of the storages.

Within the project data of 10 storage systems have been evaluated and out of these three detailed case studies have been performed (two integrated in a production process, one storage system of a district heating network). It can be stated that based on the evaluation of the status quo significant optimisation can be reached by an optimised combination of processes with heating and cooling demand, an optimised storage management including the control systems and the charging and discharging strategies and an optimised design of the storage itself. The thereby achievable increase of efficiency of the storage and respectively the increase of the total energy efficiency in the production process is up to 20 %.

It can be stated that the developed SOCO tool is a very useful software and methodology for the optimisation of energy efficiency in industry, commerce and district heating. The user is able to design the status quo and based on real data the developed algorithms for heat integration including the storage

system and management suggest an optimised solution with the target of energy efficiency and integration of renewable energy sources.

## 1. Objectives

The reduction of energy demand as well as the integration of renewable energy technologies are important measures for the implementation of existing optimisation potentials in industry, commerce and district heating. 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.

Until 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 e.g. 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 of the project was 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 exchangers and a simulation algorithm for storage networks based on time varying load profiles.

### 2.1 Pinch algorithm

It has been proven that the pinch analysis is a very suitable method for the design of an optimised overall energy system. This has been shown for renewable energy integration at total sites (Varbanov and Klemeš, 2010) and specifically for solar thermal integration (Brunner et al., 2008). Recently the approach has been applied for energy efficiency and renewable energy integration in breweries (Muster-Slawitsch et al., 2011). This methodology has been already implemented in several tools used for continuous processes without storages (Klemeš 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 presented a graphical storage pinch approach for storage design (Krummenacher and Farvat, 2001), while other authors worked on MILP approaches with defined superstructures for storage placement and design (Majozi, 2009; Chen and Ciou, 2008). Recently Nement and Klemes (2011) presented a design approach for optimised temperature in a solar storage tank and Atkins and coworkers worked on ideal design of a central heat storage for heat integration of batch processes in dairies (Atkins et al., 2010). But until now no software tools for the purpose of designing complex storage systems under practical considerations are available.

Existing pinch analysis algorithm based on the time slice model (Muster-Slawitsch et al., 2011b) have been extended to the needs of time depending load profiles including batch processes. Before it had 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. The algorithm developed was verified using real data of the 10 case studies and based on results achieved with pinch tools as PE2.

## 2.2 Storage algorithm

Within the SOCO tool it is necessary to simulate the performance of storages as e.g. charging and discharging, heat losses, etc. as this directly influences the heat exchanger network and energy system. In order to avoid the integration of expensive TRNSYS models an algorithm was developed using a node model for mass and energy balances (Moser, 2012). The algorithm itself was optimised based on the verification with real data as well as results of the TRNSYS model types available for storages with fixed and varying levels (type 38-plugflow - Puschnig, 2005, type 840 - Schranzhofer, 2006 and 844 - Heinz, 2012)– fixed and varying levels. Based on these results the storage efficiency was calculated.

## 2.3 SOCO tool

The modules developed (pinch analysis and storage optimization) have been combined in the SOCO tool. This has been realised using the programming language of C# based on a MS Visio GUI. The development started from the scratch and was accompanied with test examples that had been checked for every development step. As the improvement of such algorithm depends on the variability of the code a stretched mockup was set up offering different approaches.

## 3. Results

### 3.1 Pinch algorithm

Figure 1 gives an overview of the basic structure of the algorithm used in the SOCO tool which extends the previous work and past development steps (Fluch et al., 2012, Muster-Slawitsch et al., 2011). The details of the algorithm vary depending on type of processes and type of storages. 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 based on the developed storage algorithm including the calculation of heat losses and the simulation of the overall energy system.

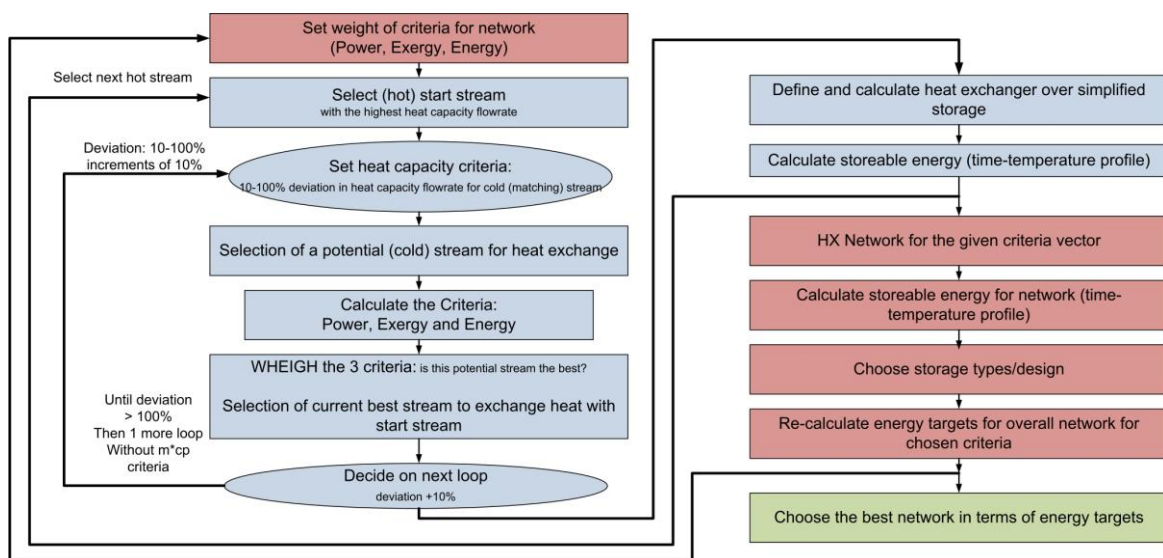


Figure 1: Structure of the algorithm of the SOCO tool

### 3.2 Storage algorithm

The development of the storage simulation algorithm as well as 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) based on TRNSYS storage types (type 38-plugflow - Puschnig, 2005, type 840 - Schranzhofer, 2006 - , type 844 - Heinz, 2012). The basics are shown in Figure 2. For each node of the storage a mass and energy balance is performed based on the input data and performance parameters leading to results that are then the new input data for the next node. After finishing the calculation the results are compared to the input data of the whole storage and if necessary the algorithm starts again till the final results fulfil the convergence criteria.

In order to verify the algorithm as well as to optimise and further develop the structure the results of the model were compared on the one hand to the measured data of the storages (10 case studies) and on the other hand to the results of the suitable TRNSYS models. It can be highlighted that the results of the SOCO algorithm differ only in a range of 0.3 % to 1.4 % from real data and proved TRNSYS model depending on the size and type of the storage (Moser, 2012).

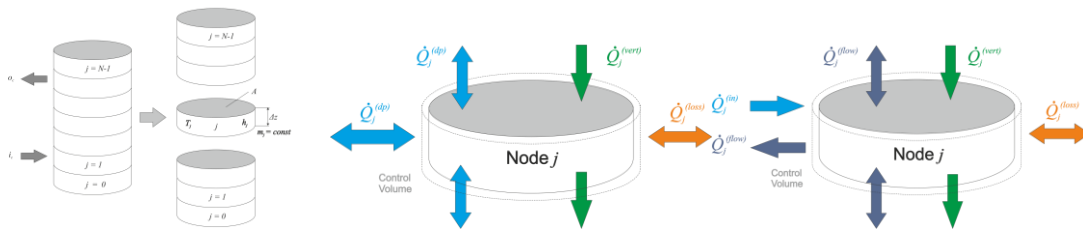


Figure 2: Basics of the storage algorithm node model for storages with fixed and varying level (Moser, 2012)

### 3.3 SOCO tool

The overall target of the SOCO tool is to maximize the efficiency (minimize the energy demand) of the production process including minimized heat losses as well as the evaluation of the integration of renewable energy sources as e.g. solar thermal. As a first step the user defines the structure of the production process (flow sheet) including definition of streams and filling them with data, existing heat exchangers and storages using the developed GUI based on MS Visio (see Figure 3). Based on this data SOCO tool performs a system simulation resulting in a statistic evaluation of the status quo (see Figure 4) and the pinch curves.

As a next step the pinch algorithm and the storage respectively optimisation algorithm is started. This includes the design of an optimised heat exchanger network including the storage demand for all processes. Furthermore, the design of the storages is suggested based on basic parameters and default values defined by the user. This includes the dimensions, fixed or varying levels, heat losses, insulation, charging and discharging ports, etc. As a result the user gets a list of heat exchangers and storages suggested and the possibility to design the new flow sheet supported by the SOCO features and add-ons. The user is guided through this process. At the end a simulation of the designed system is performed in order to be able to evaluate the optimisation potential (energetic and ecologic) and further to enable an economic evaluation.

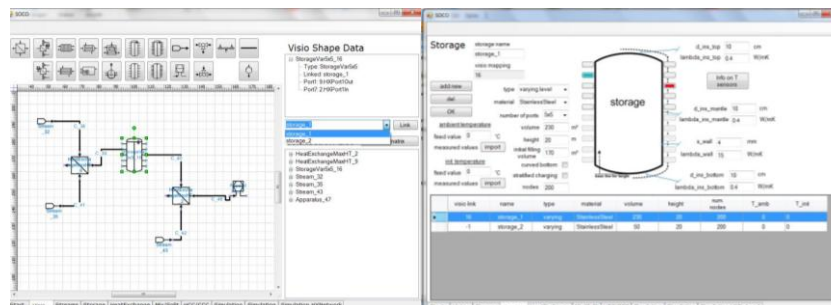


Figure 3: Start in SOCO tool – designing flow sheet and definition of storage

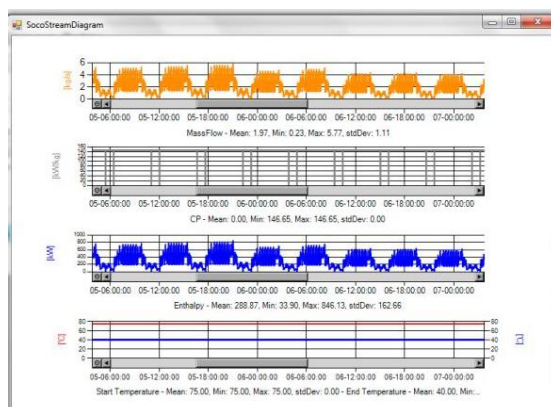


Figure 4: Statistic evaluation of status quo

The final results are displayed in clearly arranged charts and tables as e.g. displayed in Figure 5 for a suggested heat exchanger and storage.

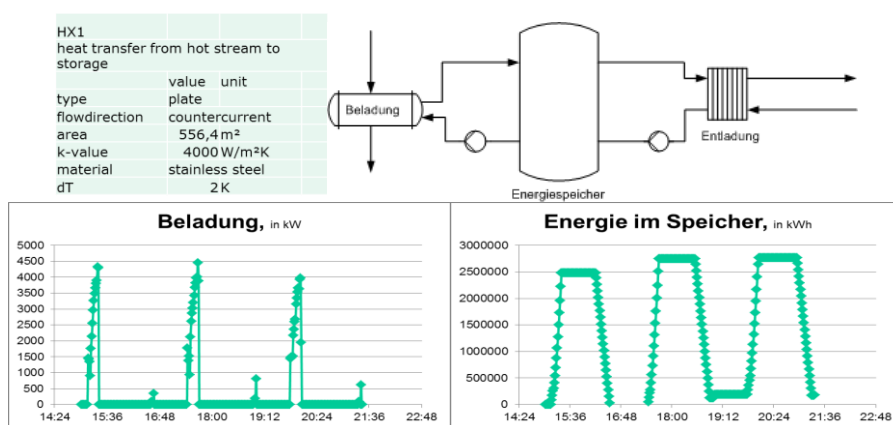


Figure 5: Evaluation designed storage and heat exchanger (heat exchange, loading, stored energy)

### 3.4 Case studies

Based on the data evaluation in 10 case studies in three of them a detailed evaluation of identified optimization potential has been performed including a verification of the algorithms developed. The results show that the processes have been generally well integrated based on the temperature levels of the processes. But the integration and the design of the storages could have been optimised. The most important optimisation measure identified is the reduction of the very large heat losses. The amount of energy charged in the storages is much higher than the energy discharged explainable by the heat losses of the whole system. This can and has partly already been realised in the storages evaluated. Additionally, the design of the ports has to be optimised avoiding charging/discharging in inappropriate temperature zones of the storages. The best solution would be charging pipes that can hardly be realised in big tanks. So therefore even more important are well-developed temperature layers in storages that have to be ensured.

### 4. 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 the software tool named "SOCO tool" has been developed. This includes 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 and a storage system
- 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)

- 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 main project achievements are the acquisition and treatment of real life data from large storages for generating the calculation and simulation algorithms and the development of the design tool for developing heat exchanger networks and optimising thermal storage systems. The tool optimises the amount, style and dimension of these storages in a complex industrial environment, with a simultaneous integration of renewable energy technologies like solar heat. The SOCO tool is available in a first version and will be further developed regarding optimised consideration of e.g. condensation of process media, improvements retrofit and economic evaluation. 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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