PinCH: An Analysis Tool for the Process Industries

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Abstract: This paper describes a newly developed software application called PinCH. The software is designed to support the application of process integration through the use of the pinch method. The project has been developed in cooperation with several partners from industry and has been funded by the Swiss Federal Office of Energy (SFOE). The product is a replacement of the original PinchLENI application developed in early 1990's at the Swiss Federal Institute of Technology Lausanne (EPFL). A key goal in this project has been to continue to provide and extend the foundation for the teaching and the transfer of skills and knowledge of process integration to industry. Therefore, the target group of users includes both students and teachers in academia as well as design engineers in the praxis. An overview of the project methodology, application design and several of the main visualization components are presented.

Keywords: Process Integration, Pinch Analysis, Process Optimization, Heat Exchanger Network, Software.

1. Introduction

Energy use in the world today is important for the world's economic and innovation progress. However, the increasing cost of energy and stricter environmental legislation require industrial firms to seek ways to reduce their energy needs. Process integration has played an important role in seeking ways to improve resource utilization. A mature but somewhat under utilized method used in process integration studies is pinch analysis [1, 2]. This method provides a relatively practical interpretation of the second law of thermodynamics and seeks to determine energy targets that distinguish between the inevitable and avoidable exergetic losses. To help promote the use of the pinch analysis method, a software tool called PinCH (CH stands for the Latin name "Confoederatio Helvetica", i.e. Switzerland) is being developed to provide a sound basis for the application and support of the pinch method.

2. Project Description

The project has been supported by the Swiss Federal Office of Energy SFOE to replace and provide additional features to the PinchLENI software developed at Swiss Federal Institute of Technology Lausanne (EPFL) in the early 1990's [3]. This software tool allowed students and practicing engineers to learn and apply the pinch method in the praxis successfully. However, it was requested to upgrade the code base and implement additional features and algorithms that have since matured. Information exchange and support from present and previous academic staff at the EPFL was initiated in order to ensure appropriate knowledge transfer of the existing PinchLENI program implementation as well as associated literature available within the department.

Inherent in the overall project goals is the need to continue to provide a user friendly foundation for the teaching of the pinch method and for the easy application in industry. In addition, the internal structure is to provide the flexibility to allow further development and extension of more advanced algorithms and techniques. Finally, the present specific improvements are as follows:

1. Dynamic stream table data specification
2. Humid air auto-segmentation
3. Scenario management of targeting and heat exchanger design results
4. Soft stream handling in targeting and heat exchanger network design
5. Stream merging in heat exchanger network design
6. Split grand composite curve visualization
7. Driving force plot visualization

Compared to existing commercially or scientifically available software, the project goals are limited primarily to the implementation of the

classical pinch method for the targeting and design of heat exchanger networks. There are no present plans for implementing automated heat exchange network optimization design algorithms outside batch and multiple base case optimization.

Notwithstanding the importance of the software product, a fundamental initiative of the project is to support the transfer of skills based on the principles of process integration and the pinch method to industry through teaching and application. A key distinction is the recognized importance of enhancing the skill of new engineers in the analysis procedures and thinking processes of overall system design along side the development of skills in process engineering and unit operation design and optimization. This foundation building is important for continued improvements in industrial energy system optimization providing a basis for the application of more advanced techniques.

3. Methodology

The application of the pinch method is manual in nature; however, it provides a systematic and structured approach to the difficult problem of overall system design [4]. The method places a considerable amount of responsibility on the user to fully understand the process they are focused on optimizing. However, this action in itself provides a strong benefit as the design engineer speaks in terms of his or her process on a practical concrete level of understanding. Figure 1 shows the project flow diagram for a typical pinch study in industry [5]. The flow involves 3 major phases 1) mass and energy balance validation, 2) pinch method calculations and 3) new design change recommendations. The PinCH software mainly focuses on supporting the second phase involving targeting and heat exchanger network design calculations. The skills involved in the first and third steps can only be minimally supported and require the design engineer to develop the necessary skills in process engineering and unit operation design through learning and experience.
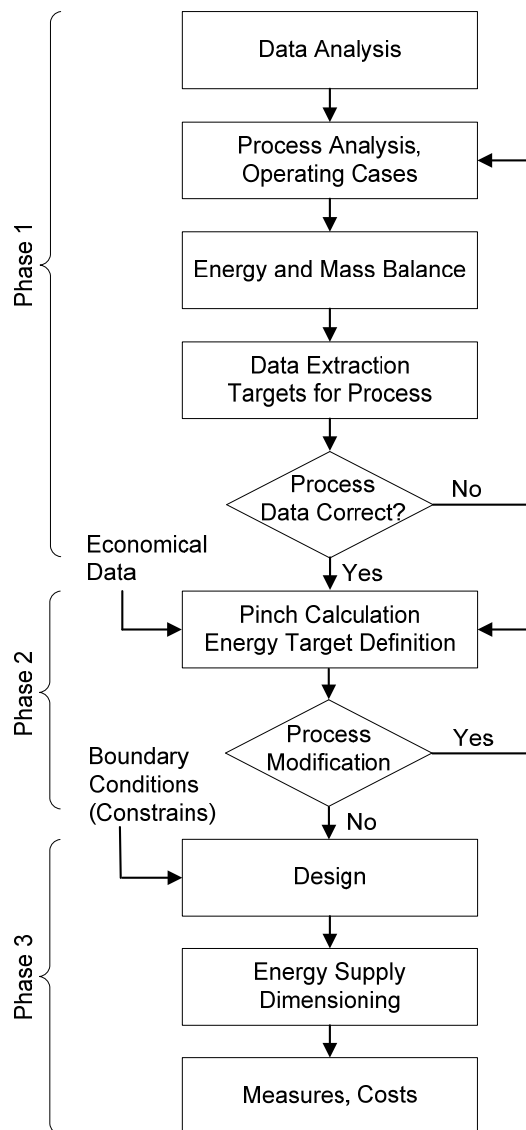

Fig.1. Pinch Study Process [5]

However, within the context of the pinch study calculations, ten major processing steps were identified that are typically done and are directly supported in the PinCH software. They are as follows:

1. Entering Stream Data
2. Creating Processes
3. Assigning Streams to Processes
4. Setting Economic Data (Global and Utility Stream Specific)
5. Creating an Operating Cases Schedule
6. Creating a Target Group
7. Calculating a Target Result (e.g. Separate Design or Time Average Model (TAM) Design)

8. Calculating Target Results Based on Variations of ΔTmin Values or other parameters (e.g. economic data and scheduling data)

9. Adding Energy Conversion Units

10. Creating Heat Exchanger Network (HEN) Designs for Specific Target Results

Each of these steps is managed within PinCH through the use of graphical user interface object visualizers. The key features include the ability to create complex plant design scenarios for the analysis of single continuous, multiple base case and single product batch processes. Once standard targeting calculations are complete detailed heat exchanger network grid diagrams can be created to produce minimum energy or relaxed designs.

4. Visualization Components

In order to support the ten steps identified for completing a pinch study, user interface visualizer components were created. These components represent individual objects encapsulated to provide separate and enclosed feature behaviour. To manage these components, the overall system architecture was based on the well established n-tier design. The implementation specifically used the Model-View-ViewModel pattern [6], but with the addition of controllers to separate out specific visual controlling behaviour. This design provides the necessary flexibility for future extensions. An event notification system has been implemented that is used to handle communication between the different layers as well as the different visualizers.

Each of the visualizer components are dynamically displayed and managed on the main application user interface Workbench (Fig. 2). The details of the major visualization components are presented next.
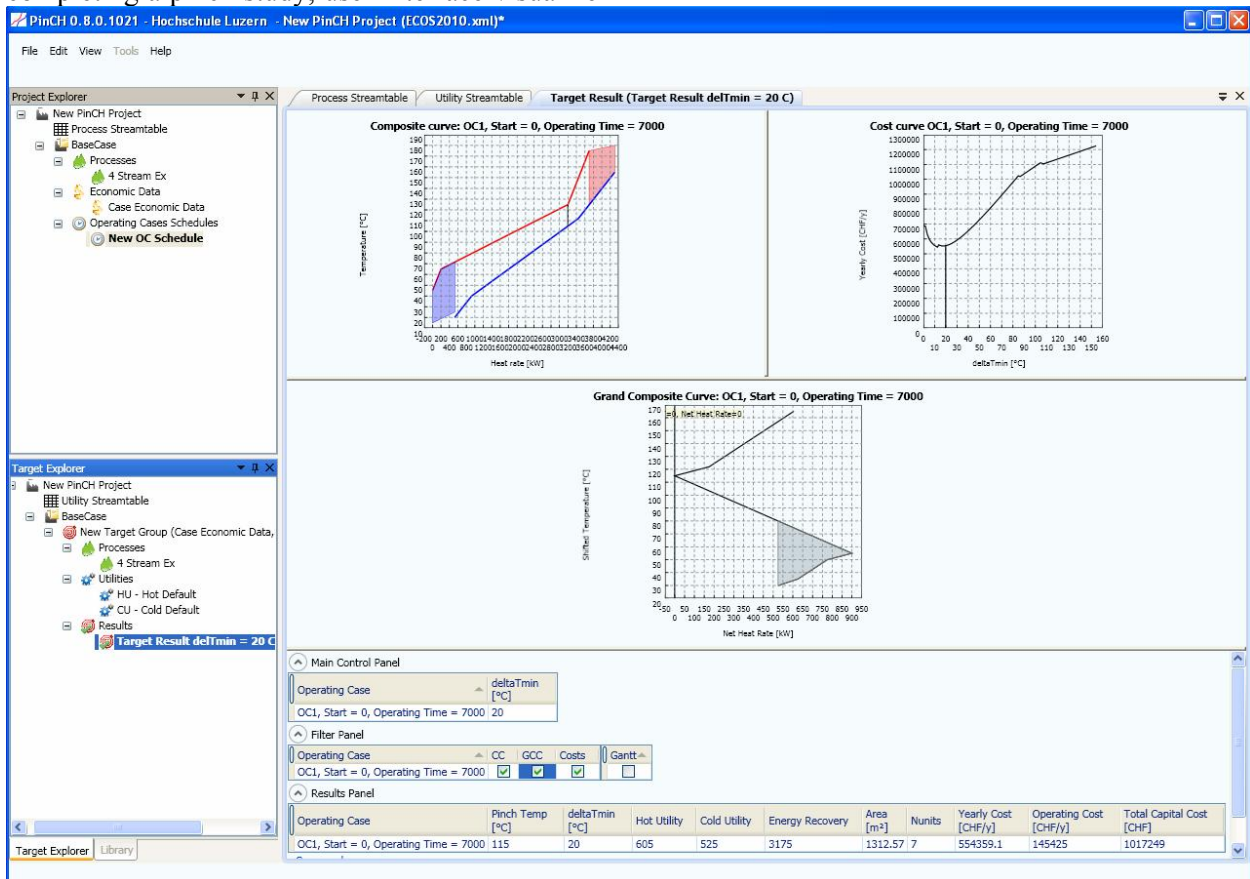

Fig.2. Workbench User Interface of PinCH

4.1 Project Scenario Management

The management of project scenarios is done within the project explorer (Fig 3). This visualizer provides configuration capabilities necessary to define continuous, batch and multiple base case processes. The configuration

features include the steps 1 to 5 of the major processing steps and are linked to the project explorer through additional interface objects. The user is able to import and export data to and from the stream table. The stream table supports simple streams as well as standard refrigerants based on rigorously calculated physical property data using [7]. The steam table and the humid air models are also supported allowing the automatic segmentation of streams. Once the stream table information is imported, the streams can be grouped into processes or areas based on any logical separation the design engineer requires.
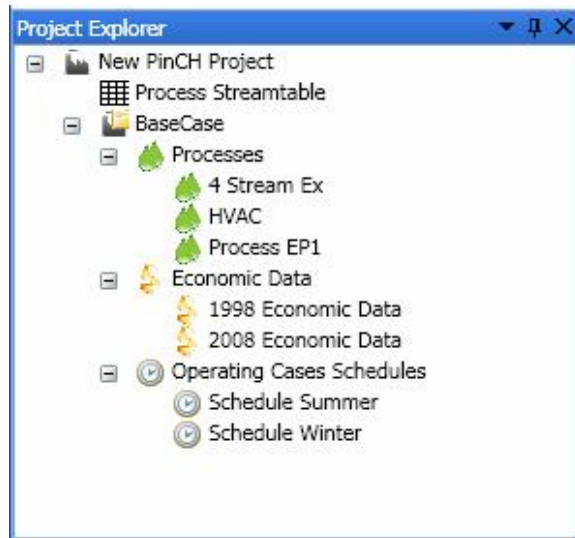

Fig.3.PinCH Project Explorer for Managing Static Scenarios

To complete the static configuration of the project, global economic data and process operating case schedule information must be provided. Versions of each type of data can be managed on the project explorer as shown in Fig. 3.

Economic data can be defined on a global, HEN or utility stream basis. Separate heat exchanger costs can be defined in order to provide a separate breakdown of cold and hot utility exchanger costs as well as process to process exchanger costs. Scheduling information can be used to define overlapping batches, number of batches in a cycle and number of repeat batch sequences. Finally, utility costs are defined separately for each utility stream providing the ability to explore the cost effects of multiple utilities.

4.2 Targeting Scenario Management

Targeting result creation and management is made possible using the target explorer (Fig. 4). This visualizer is the main location to configure new targeting groups involved in the more dynamic processing steps 6 to 9. Each target group requires the assignment of a process, an economic data and an operating case schedule configured on the project explorer. In addition, as a minimum, a default cold and hot utility must be assigned before a target result can be calculated. Multiple processes can be selected to facilitate zonal targeting analysis when compared to the processes on an individual basis.
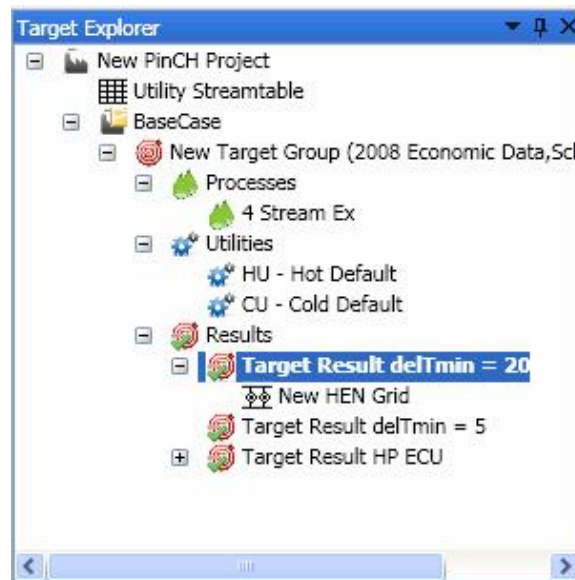

Fig.4.PinCH Target Explorer for Dynamic Targeting Scenario Management Visualization

The target result can be created using either the separate design tool or the TAM tool. The separate design tool decomposes the time data to create operating cases based on the process schedules and the individual stream existence times for pure batch streams. A Gantt chart is available to illustrate both the process and stream existence time dependencies (Fig. 5). Once the tool has completed calculation, the results are viewed in a targeting result visualizer. In this location the user can view and interact with the composite curve (CC), grand composite curve (GCC), balanced composite curve (BCC), and the cost curves (Fig. 2).
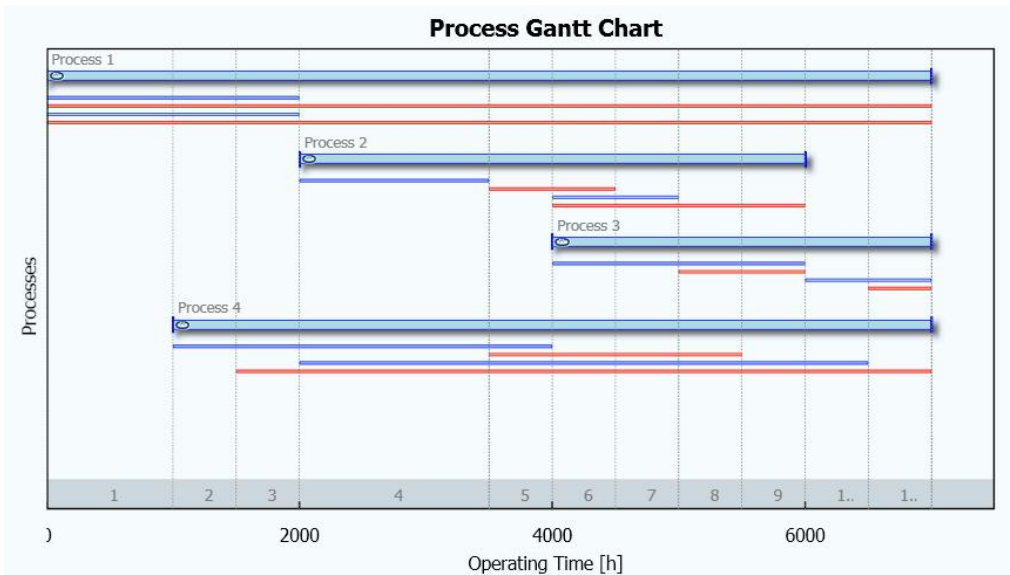
Fig.5.Gantt Chart Illustrating Process Schedules and Individual Stream Existence Times

Further analysis can be done through the use of additional features such as integrating energy conversion units (ECU), designating soft-stream segments and performing continuous targeting based on the cold composite curve shifting. In addition, creation of additional targeting results for specific ΔTmin values can also be made and saved in the scenario manager of the explorer. The BCC is created based on predefined utilities and sized using the GCC. A split grand composite curve is also available to display an extracted process mirrored against a background process.

Details of several of these features mentioned features are presented next.

4.2.1 Energy Conversion Units

The energy conversion units (ECU) are unit operating models that can be integrated into the stream table population to investigate the effects of additional utility streams. The implemented ECUs include a standard Heat Pump, Mechanical Vapour Recompression (MVR) unit, Organic Rankine Cycle (ORC) and a standard combined heat and power (CHP) engine. Each ECU thermodynamic cycle is solved based on input sizing information such as energy loads fitted to the grand composite curve or the required electrical power generation. The algorithm calculates the necessary refrigerant or waste heat streams and automatically integrates them into the stream table. The targeting result is

recalculated to see the effects on energy and cost targets which can be compared with a base case result.

4.2.2 Area Calculation

The targeting area calculation produces a breakdown of the area on a match-wise basis [8] as shown in (1) and (2).

$$A \min, L =$$

$$\sum_{k=1}^{Ni} \frac{1}{LMTD, k} * \sum_{i=1}^{NH_L} \sum_{j=1}^{NC_L} Q_{(i,j)k,L} \left(\frac{1}{\alpha_{i,j}} + \frac{1}{\alpha_{j,i}} \right) \quad (1)$$

$$A \min = \sum_{L=1}^{NE} A \min, L \quad (2)$$

This approach gives the flexibility to calculate the area distribution based on either a single stream or a particular heat exchanger specification match. The flexibility provides the ability to calculate the area distribution for different heat exchanger specifications such as the individual utility exchanger costs. The unit distribution for different heat exchanger designs is also calculated individually [8].

4.2.3 Continuous Graphical Targeting Technique

The ability to shift the composite curves relative to one another was implemented using a digital form of the graphical technique. The technique was originally developed in the predecessor PinchLENI [3] application and the same procedure is used internally. Each composite curve interval is stored internally and simply

shifted according to the offset utility required for a given ΔTmin value. All bound target result values such as area, cost and units are dynamically updated and plotted to show the effects of such movement in the cold composite curve relative to the hot composite curve [9].

4.2.4 Operating Cases Decomposition

This functionality is used in creating the operating cases that exist in batch or multiple base case scheduling scenarios. The internal algorithm uses the schedule and stream information for batch processes or continuous process to decompose the time dependent model into separate operating cases. Each operating case can then be analyzed individually or together to provide insight into the HEN design optimization opportunities between time periods.

4.2.5 Soft Stream Integration

This feature implementation allows the definition of soft stream segment. Both process and utility streams can be marked as soft from which the user can split the stream into hard and soft parts. Internally the soft parts are automatically excluded from the supertarting calculation and the CC is updated to reflect the new optimum. The user is able to see the effects on the pinch temperature and determine how much of a stream can be used in heat exchange and how much can be ignored. All dependent targeting visualizers are updated dynamically. However, in the HEN Grid the user is given the opportunity to ignore the soft energy parts or use the pool of soft energy in order to exchange with other process streams.

4.2.6 Cost Calculation

The cost calculation is based on the well established cost formula that assumes equal distribution of area over the number of units. Different simple cost laws can be user for process-process or utility-process heat exchange. Additional costs such as personnel, maintenance and independent costs can also be included. The operating costs are assigned on a utility basis and are included in the overall operating cost for a given balanced composite curve.

4.4 Heat Exchanger Network Design Scenario Management

The creation of heat exchanger networks (HEN) is managed within the targeting explorer visualizer. Each HEN is bound to a particular

target result ΔTmin and is therefore displayed in an attached manner to the target result (Fig. 5). The detailed design of a HEN is done using the HEN grid design visualizer (Fig. 6). This graphical visualizer allows the user to build the minimum energy requirement (MER) network initialized from the associated targeting result. The pinch design rules are enforced ensuring the targeting constraints are maintained along with the graphical indication whenever the conservation of energy principle is violated.
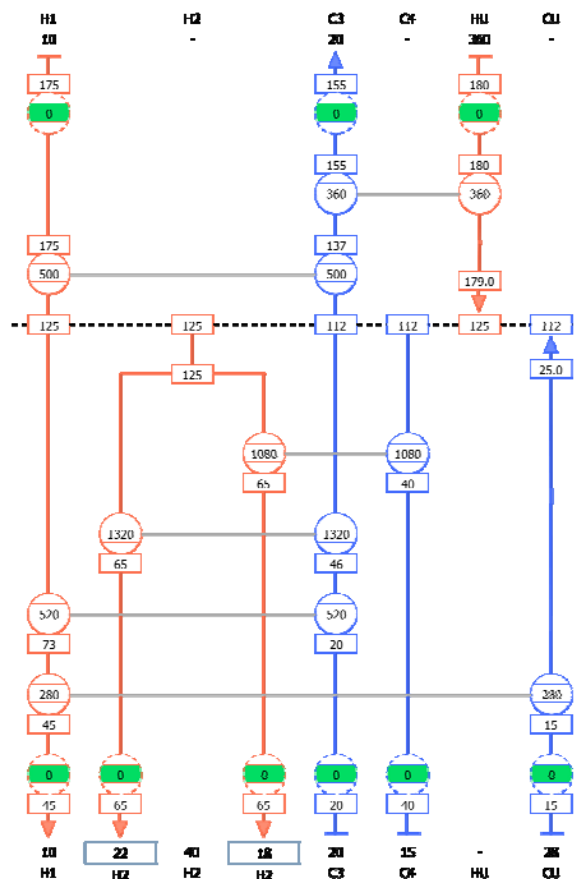

Fig.6.PinCH Heat Exchanger Design Visualization

The HEN grid allows the user to split or merge streams in order to complete a MER design. Several versions of the design can be created and compared to one another as well as with other versions from other targeting results. The network can also be relaxed in order to investigate possibilities to reduce the number of units or to see the effects of local heat exchanger approach temperatures that differ from the global ΔTmin. Multiple base cases and multiple batch operating cases are automatically created

and can be viewed and compared directly with the HEN Grid visualizer. This capability aids in the design of an optimum network valid over all time periods.

5. Conclusion

A software tool PinCH has been built to provide a foundation for the continued transfer of skills in process integration and in particular the pinch method. The software is a user friendly application designed to help and support new and experienced design engineers in academia and industry to apply the principles of pinch analysis. The project plans are for a version 1.0 release middle of 2010. Future plans include advancements in extensibility, MBC/Batch super-targeting, and remaining problem analysis techniques.

Nomenclature

Amin minimum area target for a entire network, m^2

Amin,L minimum area contribution of exchanger specification, m^2

i hot stream

j cold stream

k enthalpy interval

L exchanger specification

Ni number of enthalpy intervals

NE number of different exchanger specifications

NH_L number of hot streams with exchanger specification L

NC_L number of cold streams with exchanger specification L

$Q_{(i,j)}$ heat load between hot stream i and cold stream j

α heat transfer coefficient, $W/(m^2\ K)$

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