PinCH Tutorial 3

Welcome! The PinCH team of the Lucerne University of Applied Sciences and Arts offers tutorials for the PinCH software to present to you the possibilities of the software and how to use it. In five tutorials, you will learn the basics of using PinCH for energy and cost optimization in industrial processes:

PinCH Tutorial 0	Quick Overview
PinCH Tutorial 1	Continuous Production Plant
PinCH Tutorial 2	Production Plant with Multiple Operating Cases
PinCH Tutorial 3	**Discontinuous Production Plant**
PinCH Tutorial 4	Integration of Thermal Energy Storage

The tutorials are sequential. If you are using PinCH for the first time, we recommend that you start with Tutorial 0 entitled "Quick Overview".

The tutorials and the associated "finished" PinCH files can be downloaded from the website www.pinch-analyse.ch. The tutorials can be solved with the trial version of PinCH (full version, but limited to eight process streams). To obtain the trial version, please send an E-Mail to pinch@hslu.ch.

The tutorials are available in German, English and French. The labels in process flow charts and the names of processes, streams, etc., as well as software-related terms, are always kept in English. The used currency is Euro.

Energy and cost optimization with PinCH is carried out in 10 Steps. You will find an overview of the 10 Steps and a list of symbols and abbreviations in Tutorial 0.

The tutorials focus on using the PinCH software. It is assumed that you are familiar with the basic principles of the pinch analysis. We recommend the following books as an introduction or for a deeper insight into the pinch method:

- F. Brunner, P. Krummenacher: Einführung in die Prozessintegration mit der Pinch-Methode – Handbuch für die Analyse von kontinuierlichen Prozessen und Batch-Prozessen. Swiss Federal Office of Energy SFOE, 2017 (available from www.pinch-analyse.ch)

- R. Smith: Chemical Process Design and Integration. 2nd Edition, John Wiley & Sons, 2016; Pinch Analysis from Chapter 15 onwards (ISBN 9781119990130)

- I. C. Kemp: Pinch Analysis and Process Integration – A User Guide on Process Integration for the Efficient Use of Energy. 2nd Edition, Elsevier Butterworth-Heinemann, 2007 (ISBN 978-0-7506-8260-2)

You are currently working on PinCH Tutorial 3. It is about analyzing and optimizing a production plant in the chemical industry. The production plant is a discontinuous production plant. Tutorial 3 is structured as follows:

Contents

I Introduction to Tutorial 3

Learning objective:	To perform a pinch analysis for a discontinuous production plant with PinCH.
Duration:	2-3 hours

While optimizing the energy and costs of discontinuous processes, further aspects are presented in PinCH. These include the definition of pre-processing and post-processing of equipment and the optimization of the schedule of discontinuous processes in PinCH. In this Tutorial 3, you will be guided through the optimization process in the following steps (Step 9 is not required for this case study):

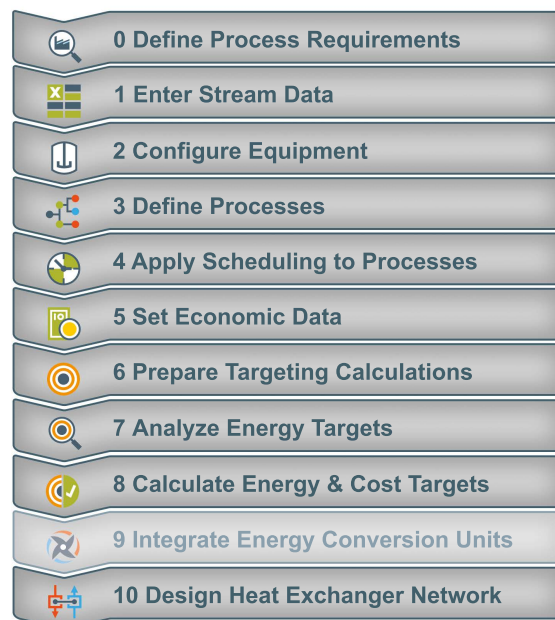Figure 1: Sequence in PinCH for optimizing a discontinuous process

The PinCH team of Lucerne University of Applied Sciences and Arts hopes you find this tutorial instructive and wishes you every success!

II Case Study: Producing Nutrient Salt

Process Description

In a production plant, a batch reactor with subsequent cooling crystallization is operated to produce nutrient salt (fertilizer industry, see Figure 2). The inorganic salt, which is dissolved in the aqueous solvent, is used as the starting raw material. The solvent ($6\,t$ per batch) is pre-heated to $80°C$ for this purpose and put in the B100 stirrer tank. $1.5\,t$ of inorganic salt is endothermically dissolved during the stirring process, whereby the solution is cooled to $60°C$. The ready-mixed salt solution is then put in the C100 reactor. The additive ($2\,t$) is added to the nutrient salt formation and the solution is then evaporated in the reactor with heating steam. The reactor is heated with heating steam on the shell side for this purpose. $2\,t$ of water in total is vaporized due to the evaporation process, and the vapor is condensed with cooling water at present. The solution, which has a temperature of $100°C$ following evaporation, is cooled to $60°C$ with cooling water via the shell and added to the B101 intermediate container. The nutrient salt is then extracted as a pure substance through a crystallization stage (cooling crystallization). The B102 crystallizer is first of all filled with solution ($1\,t$) from the B101 intermediate container for this purpose. Cooling crystallization is started when seed crystals are added while recirculation cooling is taking place.
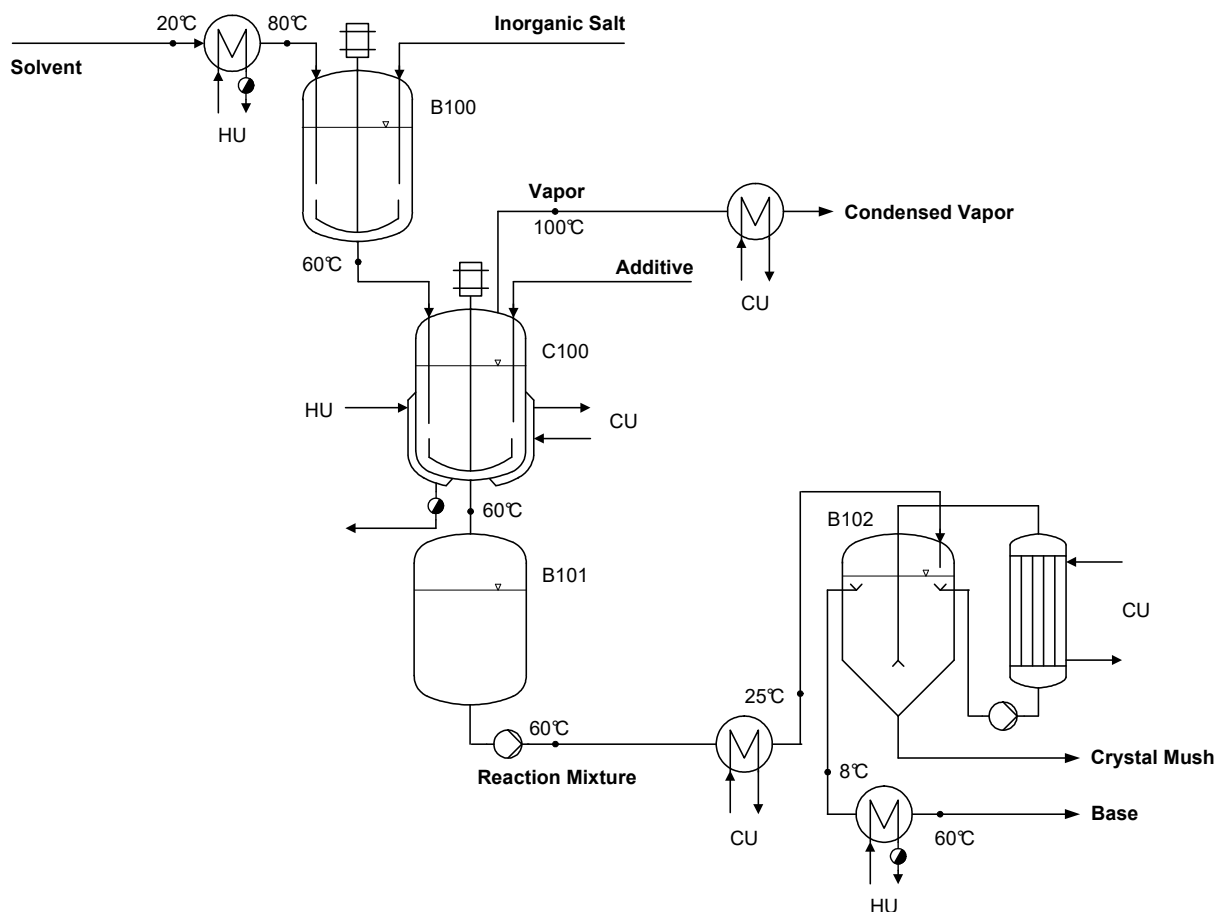

Figure 2: Process flow chart of the existing production plant

Following the growth of growable crystals, cooling is intensified and, at the same time, fresh solution is added from the intermediate container. The fresh solution is pre-cooled to $25°C$ before entering the

crystallizer. Meanwhile, the base and crystal mush are removed from the crystallizer. Once all of the solution from the intermediate container has been used up, crystallization is stopped, but the base and crystal mush are still removed (to empty the crystallizer). The base (5 t per batch) must be heated from 8°C to 60°C for further processing throughout the removal process. To simplify matters, we will refrain from discussing subsequent washing of the crystal mush and processing of the base in this tutorial.

Table 1: Quantities per batch, specific heat capacities and heat transfer coefficients

Substance	m [t]	c_p [kJ/(kg K)]	α [W/(m² K)]
Solvent	6.0	4.20	2'000
Inorganic Salt	1.5	1.60	200
Additive	2.0	1.65	1'000
Reaction Mixture	7.5	3.50	500
Vapor*	2.0	2.00	4'000
Crystal Mush	2.5	3.00	300
Base	5.0	3.00	500

* The vapor's condensation enthalpy at 1 bar(a) is 2'257 kW/kg

Scheduling

Nutrient salt is made in a batch process. One batch is produced twice per day from Monday to Saturday all year round (48 weeks). The operating time of one batch is 11 h. The Gantt chart for one batch is shown in Figure 3. The associated process steps are listed in Table 2.
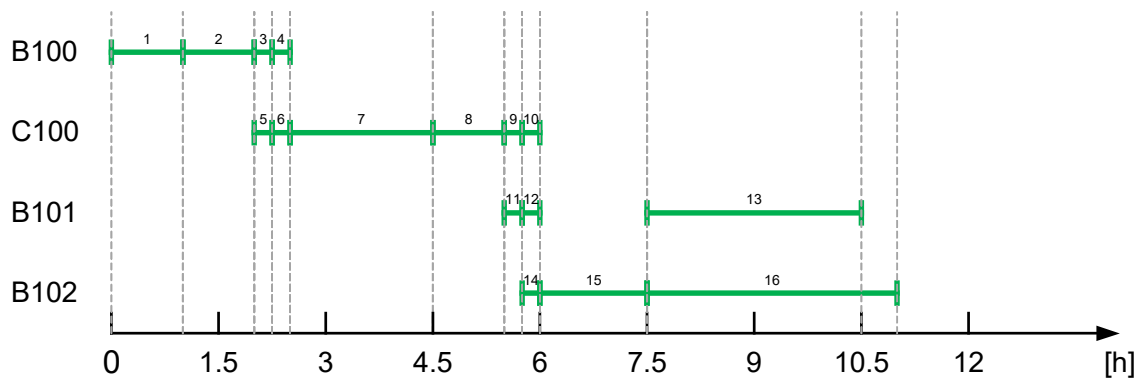

Figure 3: Gantt chart of one batch for producing nutrient salt

Table 2: Process steps per batch

Equip.	#	Process Description	Operating Mode	Start	Duration
B100	1	Pre-heating of the solvent, filling (6 t)	Processing	0 h 00′	1 h 00′
	2	Addition of salt, dissolving while stirring (1.5 t)	Postprocessing	1 h 00′	1 h 00′
	3	Emptying (7.5 t)	Postprocessing	2 h 00′	0 h 15′
	4	Cleaning	Postprocessing	2 h 15′	0 h 15′
C100	5	Filling (7.5 t)	Preprocessing	2 h 00′	0 h 15′
	6	Addition of Additive (2 t)	Preprocessing	2 h 15′	0 h 15′
	7	Evaporation of Solution, condensation of Base (2 t)	Processing	2 h 30′	2 h 00′
	8	Shell cooling	Postprocessing	4 h 30′	1 h 00′
	9	Emptying (7.5 t)	Postprocessing	5 h 30′	0 h 15′
	10	Cleaning	Postprocessing	5 h 45′	0 h 15′
B101	11	Filling (7.5 t)	Preprocessing	5 h 30′	0 h 15′
	12	Emptying (1 t)	Preprocessing	5 h 45′	0 h 15′
	13	Emptying, cooling of the Reaction Mixture (6.5 t)	Processing	7 h 30′	3 h 00′
B102	14	Filling (1 t)	Preprocessing	5 h 45′	0 h 15′
	15	Start of crystallization	Preprocessing	6 h 00′	1 h 30′
	16	Crystallization, emptying of Crystal Mush (7.5 t)	Processing	7 h 30′	3 h 30′

Note: From a process engineering standpoint, the described crystallization process is strictly a continuous process integrated in a batch process. As a result of "embedding" in a batch process, the entire process must be considered a batch process for a pinch analysis.

Utilities

The Utilities from Table 3 are available for heating and cooling the process streams. Heating steam is used as a hot utility (HU). The heating steam is available as saturated steam, so the pressure p and – instead of the inlet temperature (T_{in}) and the outlet temperature (T_{out}) – the steam content x are specified. The cold utility (CU) is made up of cooling water, which is provided from a refrigeration plant.

Table 3: Utility data

Utility Stream	T_{in} [°C]	T_{out} [°C]	p [bar(a)]	α [W/(m² K)]	c [€/kWh]
Heating Steam (HU)	x=1	x=0	2.5	5'000	0.08
Cooling Water (CU)	8	14	1.0	2'000	0.03

The annual operating costs C_{Op} [€/a] are made up of the annual operating costs per time slice (TS).

Note: A time slice is a period of time in which there is a heating and/or cooling requirement. The transition from one time slice to another is characterized by the fact that changes to the heating or cooling requirement occur.

Using the annual operating hours τ [h/a], the HU / CU requirement $\dot{Q}$ [kW] and the specific HU / CU costs c_{HU}, c_{CU} [€/kWh], the annual operating costs are calculated as follows:

$$C_{Op} = \sum_{TS} C_{Op,TS} = \sum_{TS} \tau_{TS} \cdot \left(\dot{Q}_{HU,TS} \cdot c_{HU,TS} + \dot{Q}_{CU,TS} \cdot c_{CU,TS} \right) \tag{1}$$

To calculate the annual operating costs, the process requirements must be assigned to the respective TSs first of all. Because the process requirements have not yet been extracted at the present time, nothing can be said yet about the operating costs. The production plant's operating costs are calculated in Step 0.

Investment Costs

You are already familiar with the process of calculating investment costs from Tutorial 1. Since only the investment costs C_{HEX} of the heat exchangers (HEX) for heat recovery (HR) and the utilities have to be taken into account, the following applies for the total investment costs C_{Inv}:

$$C_{Inv} = \sum_{HEX} C_{HEX} = \sum_{HEX} \left(C_0 + C_b \cdot \left(\frac{A_{HEX}}{A_b} \right)^m \right) \tag{2}$$

whereby $C_0 = 0$, $C_b = 110'000\,€$, $A_b = 100\,\mathrm{m}^2$ and $m = 0.71$ (see Tutorial 1). These values are used to calculate the costs of all the heat exchangers based on the specific heat transfer area A.

Total Costs

The annual total costs C_{tot} [€/a] are made up of the annual investment costs (a is the annuity factor) and the annual operating costs:

$$C_{tot} = a \cdot C_{Inv} + C_{Op} \quad \text{mit} \quad a = \frac{Z \cdot (1 + Z)^n}{(1 + Z)^n - 1} \tag{3}$$

In this case study, we are using the following values:

- Interest Rate: $Z = 6\,\%$

- Pay off Period: $n = 5\,\mathrm{a}$

Since we are considering an existing production plant and are assuming that the plant has already been depreciated, only operating costs are incurred before the optimization measures are implemented, so $C_{tot} = C_{Op}$ applies. The total costs can only be calculated in Step 0 due to the data which has not been extracted yet.

Problem

In this tutorial, you will learn how to systematically and purposefully perform a pinch analysis for a batch process with PinCH. First of all, the maximum HR potential (direct and indirect HR) should be determined. Additionally, the process scheduling should be optimized and therefore the direct HR potential and the productivity should be increased. With the help of energy and cost targets, HR measures should be specifically implemented in the heat exchanger network.

Step 0: Define Process Requirements

Define the process requirements by extracting the relevant data (for data extraction, see Tutorial 1).

Note: Process requirements are not necessarily linked to "streaming" fluids. The heating or cooling of a solution in a container is also a process requirement. You must carefully consider what type of energetic modeling is expedient in these cases (see references on page 1).

The reactor's heating jacket must not be "overlooked" from a process engineering standpoint. While the modeling of the reactor content itself (the solution to be heated up and evaporated) reflects the actual energetic requirements, this approach would be based on the assumption that heating could take place using any process stream (which has a heat level at a sufficiently high temperature level). External heating, where you pump the reactor content through a loop with heat exchangers, is often not possible.

Note: Also, heating via any process stream in the existing reactor shell is in most cases unfeasible from a process engineering standpoint (uneven heating, temperature peaks and limited heat exchanger areas).

The heating of the reactor is forced heating with heating steam. You can model the heating requirement using the heating steam if need be.
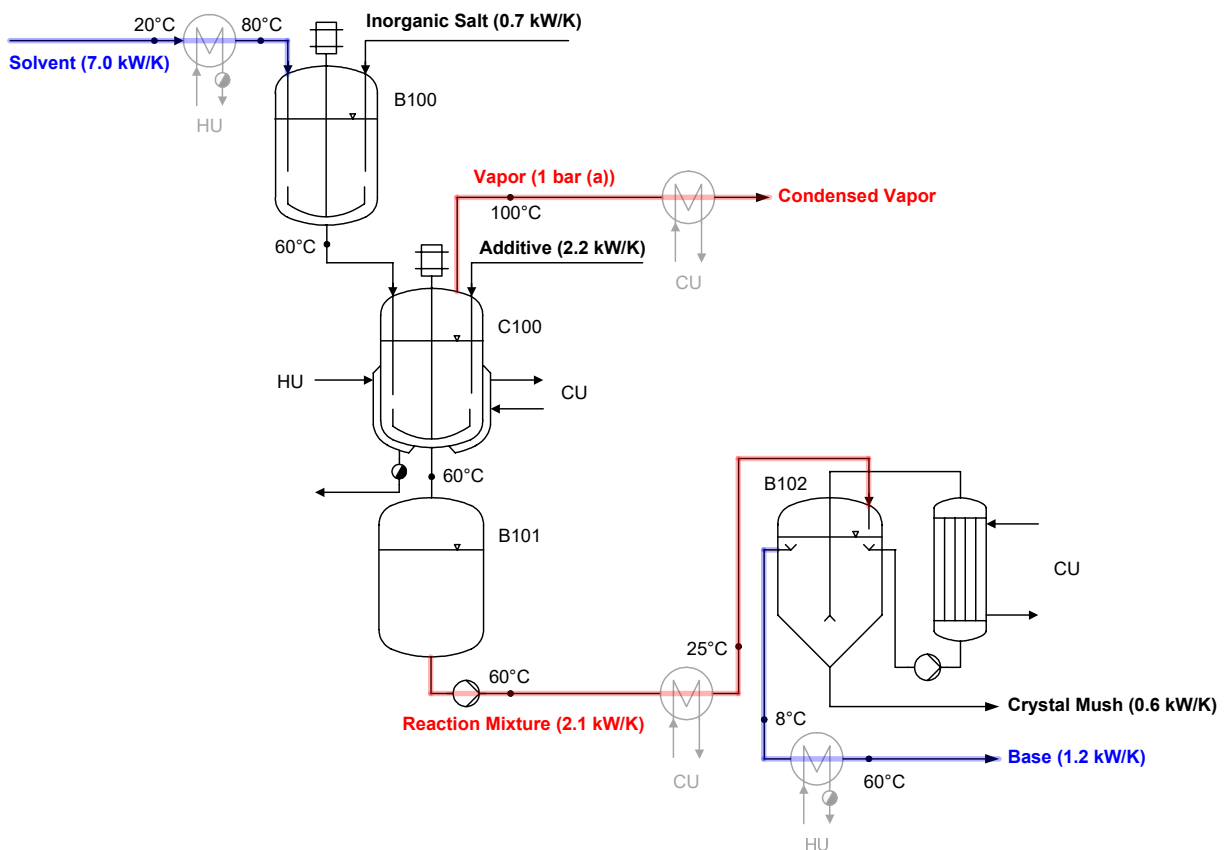
Figure 4: Process requirements

Summary: The (re-)evaporation of the condensate occurring in the shell must be defined as a backup stream if heating in the reactor is to be modeled. In this tutorial, a description of modeling of the reactor heating and reactor cooling (forced shell cooling with cooling water) and the recirculation cooling of the crystallizer is not provided, because the provision of utilities is not the subject matter of this tutorial. For the condensation of the base, the cooling of the crystallizer feed (reaction mixture) and the heating of the removed crystal mush, utilities do not necessarily need to be used, and so they must be modeled as process requirements. The process requirements for nutrient salt production are shown in Figure 4.

By extracting the process requirements, a new Gantt chart is created in which the heating and cooling requirements are shown over time:
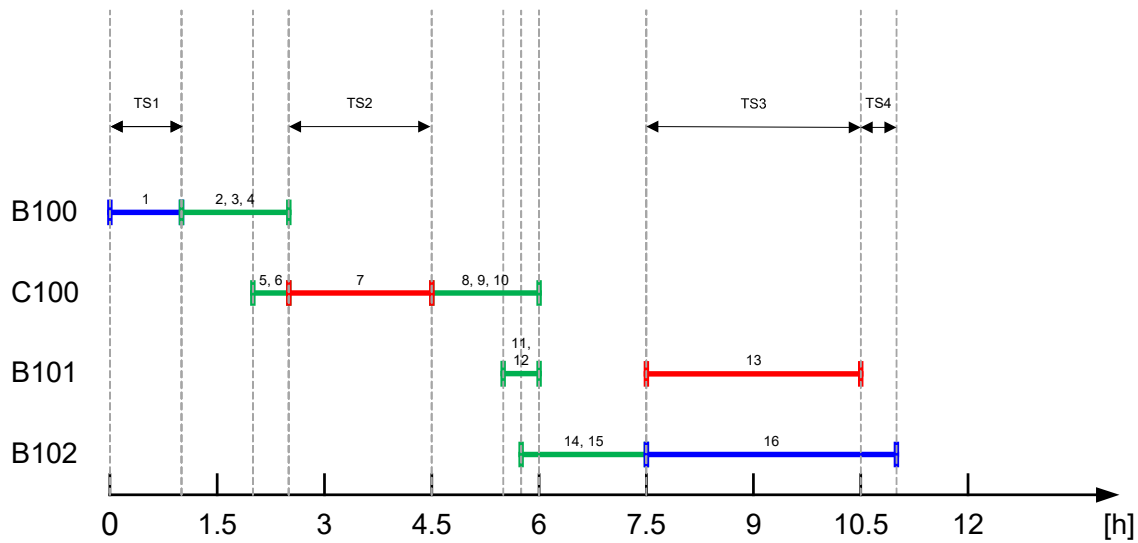

Figure 5: Heating and cooling requirements of one batch

The heating requirement (cold stream) is blue in the Gantt chart, the cooling requirement (hot stream) is red, and the pre-processing and post-processing (process steps which "block" the equipment but do not have any heating or cooling requirements, e.g. cleaning a reactor) are shown in green. It is clear that internal HR is only possible in TS3. In TS1, TS2 and TS4, there is only one heating or cooling requirement, which has to be covered with utilities. The utility requirement and the resulting annual operating costs C_{Op} are shown in Table 4.

Table 4: Utility demand and operating costs of the existing production plant for 576 batches per year in total

TSs	Δt [h/batch]	τ [h/a]	$\dot{Q}_{HU}$ [kW]	$\dot{Q}_{CU}$ [kW]	C_{Op} [€/a]
TS1	1.0	576	420	-	19'354
TS2	2.0	1'152	-	627	21'670
TS3	3.0	1'728	74	62	12'407
TS4	0.5	288	74	-	1'427
Total	**6.5**	**3'774**	**-**	**-**	**54'858**

III   10 Steps in PinCH

Let's get started!

To start, open PinCH. Before we start with the actual project, it is advisable to check and, if necessary, adjust the basic settings in PinCH. Because the costs are specified in euro in our tutorials, you may under certain circumstances have to adjust the currency settings before you start. The units kW and kWh are also used in this tutorial. An explanation of how to proceed is provided in Tutorial 0.

The tutorial follows the 10 PinCH Steps (cf. Tutorial 0). In Steps 1-5, the process-related data is recorded in the Project Explorer. In Steps 5-10, the plant is optimized in the Target Explorer. Create a new project and rename it "Fine Chemistry AG".

Step 1: Enter Stream Data

Enter the process requirements in the Process Stream Table.

☞ Open the Process Stream Table.

Add a discontinuous process stream (hereinafter referred to as a "batch process stream") by

☞ Clicking on

or:

☞ Right-clicking into the empty field of the Process Stream Table tab

☞ Select Add Batch Process Stream

Name the process streams and change the default values according to the extracted data. You must calculate the mass stream $\dot{m}$ "manually" using the mass to be heated or cooled and the duration of the process. A batch process stream's tstart and tstop times specify the time at which a stream exists relative to the beginning of the batch process. The complete Process Stream Table looks like this:
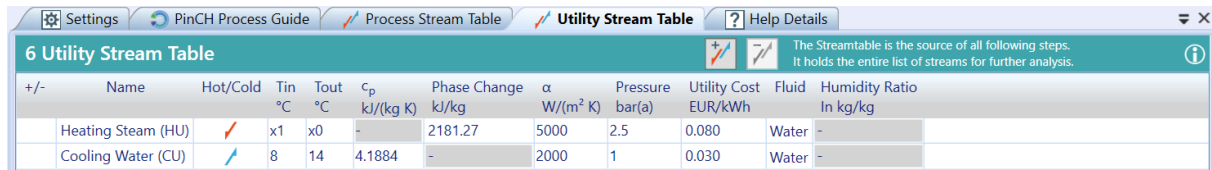
+/-	Name	Hot/Cold	Tin °C	Tout °C	ṁ kg/s	c_p kJ/(kg K)	Phase Change kJ/kg	α W/(m² K)	Pressure bar(a)	CP kW/K	ΔḢ kW	Fluid	Humidity Ratio In kg/kg	Soft	tstart h	tstop h
	Solvent		20	80	1.66667	4.2	-	2000	-	7	420	Simple	-	☐	0	1
	Vapor		x1	x0	0.2778	-	2257.08	4000	1	-	627.02	Water	-	☐	2.5	4.5
	Reaction Mixture		60	25	0.602	3.5	-	500	-	2.11	73.74	Simple	-	☐	7.5	10.5
	Base		8	60	0.397	3	-	500	-	1.19	61.93	Simple	-	☐	7.5	11

Figure 6: Process Stream Table

In a second step, the utilities (heating and cooling media) available to the process must be defined.

> **Note:** No distinction is made between continuous and discontinuous utility streams. Utilities must be available at all times. There is no need for a start time and a stop time.

The complete Utility Stream Table looks like this:

+/-	Name	Hot/Cold	Tin °C	Tout °C	c_p kJ/(kg K)	Phase Change kJ/kg	α W/(m² K)	Pressure bar(a)	Utility Cost EUR/kWh	Fluid	Humidity Ratio In kg/kg
	Heating Steam (HU)	⟋	x1	x0	-	2181.27	5000	2.5	0.080	Water	-
	Cooling Water (CU)	⟋	8	14	4.1884	-	2000	1	0.030	Water	-

Figure 7: Utility Stream Table

Step 2: Configure Equipment

So that the individual batches can be overlapped (the productivity and the direct HR potential can be increased), it must be guaranteed that no equipment is being used at the same time in two different batches. Otherwise, several instances of this equipment will be required. In this regard, it is important that the equipment cannot be used in another batch during pre-processing and post-processing (e.g. cleaning).
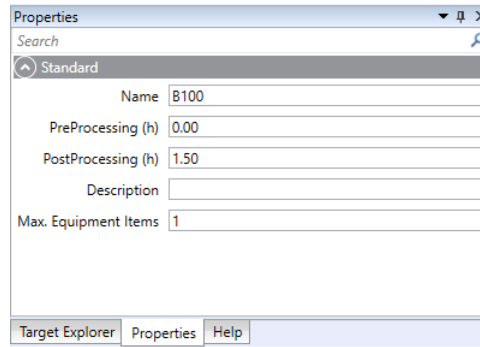
In a first step, name the default equipment according to the actual labels. While doing so, think about what process stream belongs to which piece of equipment (B100, C100, B101, B102). If, for example, the solution flows into B100 during pre-heating, this piece of equipment is blocked during the pre-heating time and cannot be emptied, for example. The following affiliation results:

- Solvent → B100

- Vapor → C100

- Reaction Mixture → B101

- Base → B102

Now add the pre-processing and post-processing times defined in Table 2 to the respective pieces of equipment. Proceed as follows here:

☞ Select a piece of equipment

☞ Click on Properties in the Target Explorer

☞ Specify the pre-processing and post-processing durations of the respective piece of equipment according to Table 2

The properties of the B100 equipment are shown in Figure 8. In the "Max. Equipment Items" field, it can be specified how many times this piece of equipment is available, i.e. for how many purposes it can be used simultaneously. Because the plant already exists in the case study and therefore only one piece of equipment is available, enter the number 1 for each piece of equipment.

Figure 8: Properties of the B100 equipment

Step 3: Define Processes

In our case study, we have to create a "batch process". Proceed as follows here:

☞ Right-click on "Process 1" in the Project Explorer

☞ Select Remove Process

☞ Right-click on "Processes"

☞ Select Add Batch Process

Now rename the batch process "Nutrient Salt Production" (F2) and assign all the defined process streams to it.

Step 4: Apply Scheduling to Processes

Schedules are required to define the chronological sequence of the processes defined in Step 3. If there are multiple processes, at least some of which run in parallel, operating cases may occur during which heat transfer is possible between the processes. In these cases, an operating case schedule must be described in appropriate detail. Rename "OC Schedule 1" to "Non-Overlapping" and open the tab.

Enter the annual operating hours according to the specifications.

☞ Select "Batch Daily" in the Timebase column

☞ Select Mon – Sat as the operating days

☞ Adjust the Daytime Start: 00:00

☞ CW start: Enter 1

☞ # weeks: Enter 48

☞ Batch Cycle Duration (BCD): Enter 11 h

☞ # batches: Enter 2

Note: The Batch Cycle Duration (BCD) is the time until the next batch starts. In the case of staggering / overlapping, the BCD is correspondingly shorter than the Batch Processing Duration (BPD), which corresponds to a batch's production time.

PinCH creates a batch Gantt chart from the entered data, see Figure 9. Please refer to this chart for the chronological sequence of the processes. Please refer to the horizontal axis for the time (the daily time in our case study) and the number and duration of TSs. You can click on any TS in the gray bar at the bottom (Figure 9 TS3 or time period 5).
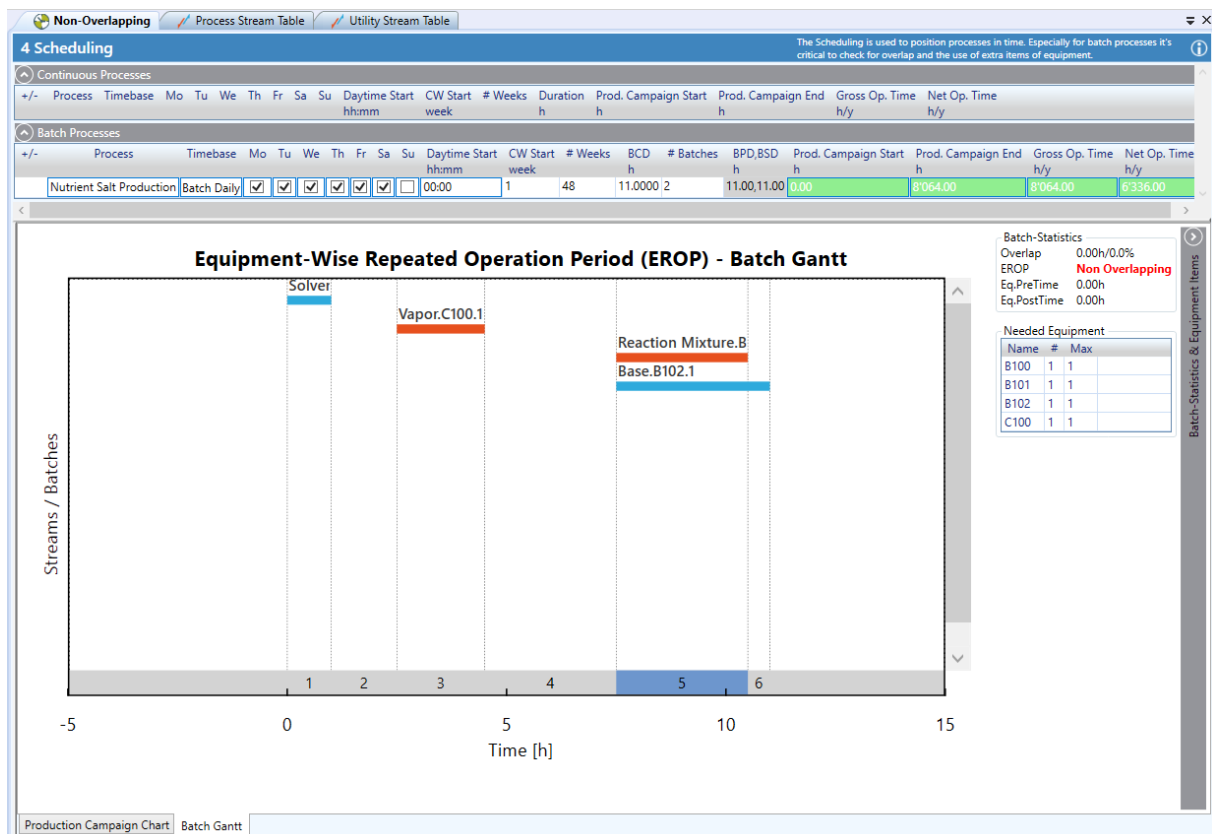
Figure 9: Equipment-Wise Repeated Operation Period (EROP) of the non-overlapping batch process

The Equipment-Wise Repeated Operation Period (EROP) specifies after what amount of time the identified TSs periodically reoccur. In our case, one batch process exactly is shown, because there is no overlapping.

Now create a second OC schedule and name it "Overlapping". In this schedule, we will overlap the same batch process by shortening the BCD from $11\,\mathrm{h}$ to $5.5\,\mathrm{h}$ and increasing the number of batches per day from 2 to 3. The number of production weeks can therefore be reduced from 48 weeks to 32, without the production volume changing. The EROP of the overlapping batch process is illustrated in Figure 10. It is clear that the Vapor, Reaction Mixture and Base process streams exist simultaneously and that the direct HR potential increases as a result.

Note: On the right-hand side, in addition to the EROP it is specified how many times each piece of equipment is required and how many times it can be used at most (this was configured in Step 2). The number of pieces of equipment is increased if the equipment is required in different batches at the same

> time. It is clear that, in both schedules (Non-Overlapping and Overlapping), each piece of equipment is only needed once.
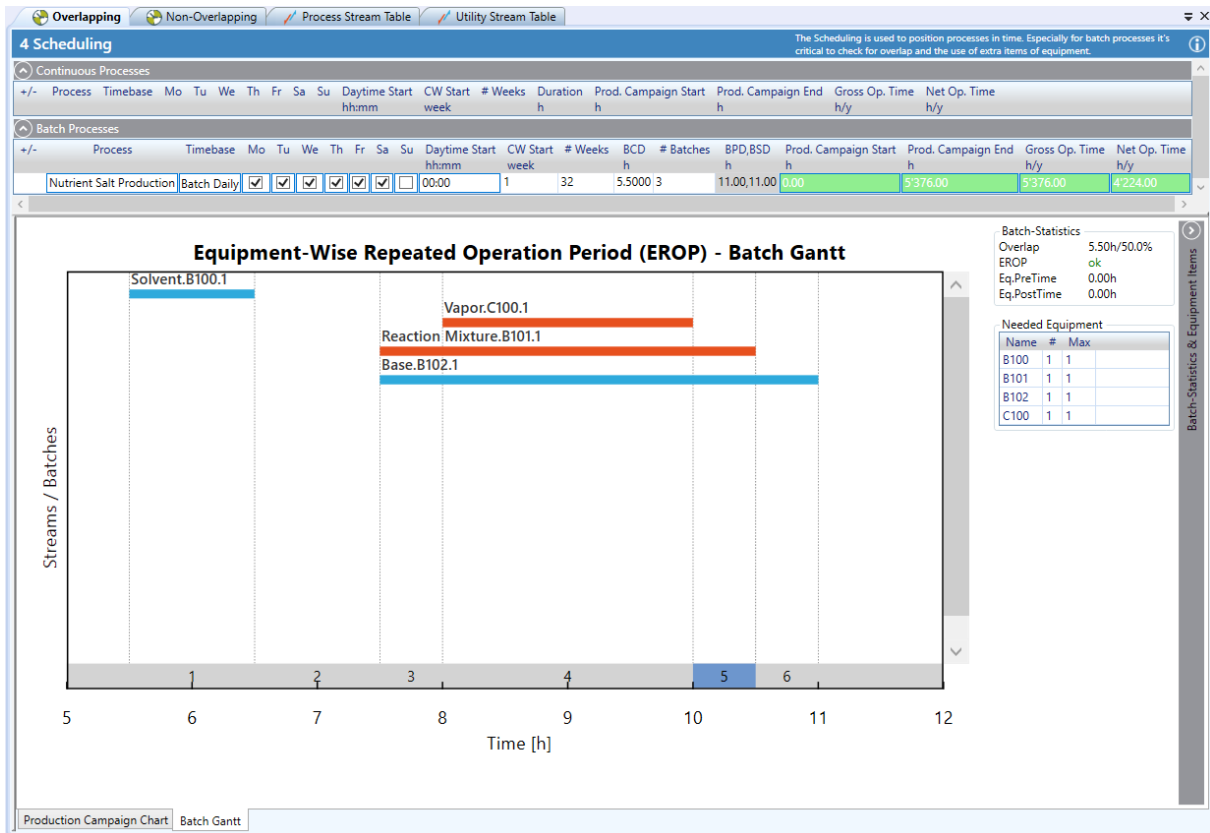

Figure 10: EROP of the overlapping batch process

Step 5: Set Economic Data

The economic parameters need to be specified to calculate the investment costs. The costs of the heat exchangers needed to meet the defined process requirements are calculated in PinCH. These include heat exchangers between two process streams (HR) and heat exchangers between one process stream and one utility system. Open the Economic Data tab and adjust the parameters according to the specifications in the section entitled "Investment Costs" on page 5. Because the plant already exists, the investment costs for the utility heat exchangers can be set to zero. The Economic Data tab should now look like this:

Figure 11: Economic Data

Once Step 1-5 have been carried out, your Project Explorer will be structured as follows:

Figure 12: Project Explorer

Step 6: Prepare Targeting Calculation

Once Steps 1-5 have been processed, all of the data required for the pinch analysis is stored in the Project Explorer. You can now calculate the energy and cost targets by creating two target groups in the Target Explorer. Rename these groups to Non-Overlapping and Overlapping. For the Overlapping target group, select the Overlapping OC schedule:

☞ Right-click on the "Overlapping" in the target group

☞ Reassign Operating Case Schedule ☞ "Overlapping"
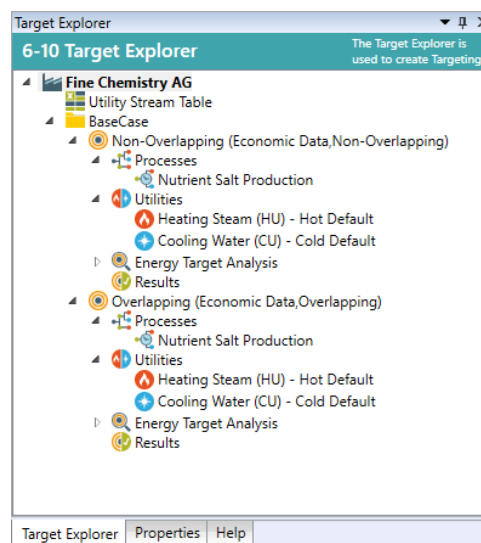
Your Target Explorer should now look like this:

Figure 13: Target Explorer

If you have problems creating the target group, please consult Tutorial 1. The process is described one step at a time in Step 6.

Step 7: Analyze Energy Targets

Once Step 6 has been processed, the preparations for calculating the energy and cost targets are complete. Before we calculate them in Step 8, we can use the Energy Target Analysis (ETA) tool to perform comprehensive analyses relating to HR potential for the scenario considered (target group).

> **Note:** The ETA is a tool for analyzing the HR potential, taking the chronological process sequence into account. In particular, individual process streams or TSs can be hidden to concentrate on the significant HR potential. Both direct and indirect HR potential (storage) can be examined in this regard. The maximum possible HR (direct and indirect) can be shown with the Time Average Model (TAM). Indirect HR potential can be visualized with the GCC-based Indirect Source Sink Profile (ISSP). During the Total Site Analysis (TSA) examination, HR potential can be analyzed between different processes with the Split GCC.

The direct and indirect HR potential can be compared for batch processes in the Energy Target Analysis tool. In this tutorial, the focus is on direct HR. Open the tool as follows:

☞ Right-click on Energy Target Analysis in the Target Explorer

☞ Select Open Energy Target Analysis

The new tab has three windows:

- **Time Charts**: The various Gantt charts can be viewed here. The EROP, in which the four relevant TSs are now highlighted in green, is illustrated again under Batch TS. You must select the desired process under Processes to make this clear.

- **TS Data**: The selected ΔT_{min}, the HR potential and the utilities requirement for each TS are listed in the table.

- **TS Charts**: The charts relating to the TSs selected in the TS Data table are shown here.

First of all, we consider the maximum possible HR potential of the "Non-Overlapping" operating mode. Proceed as follows here:

☞ Select "Batch TS" in the Time Charts window ("Nutrient Salt Production" must be selected under Processes)

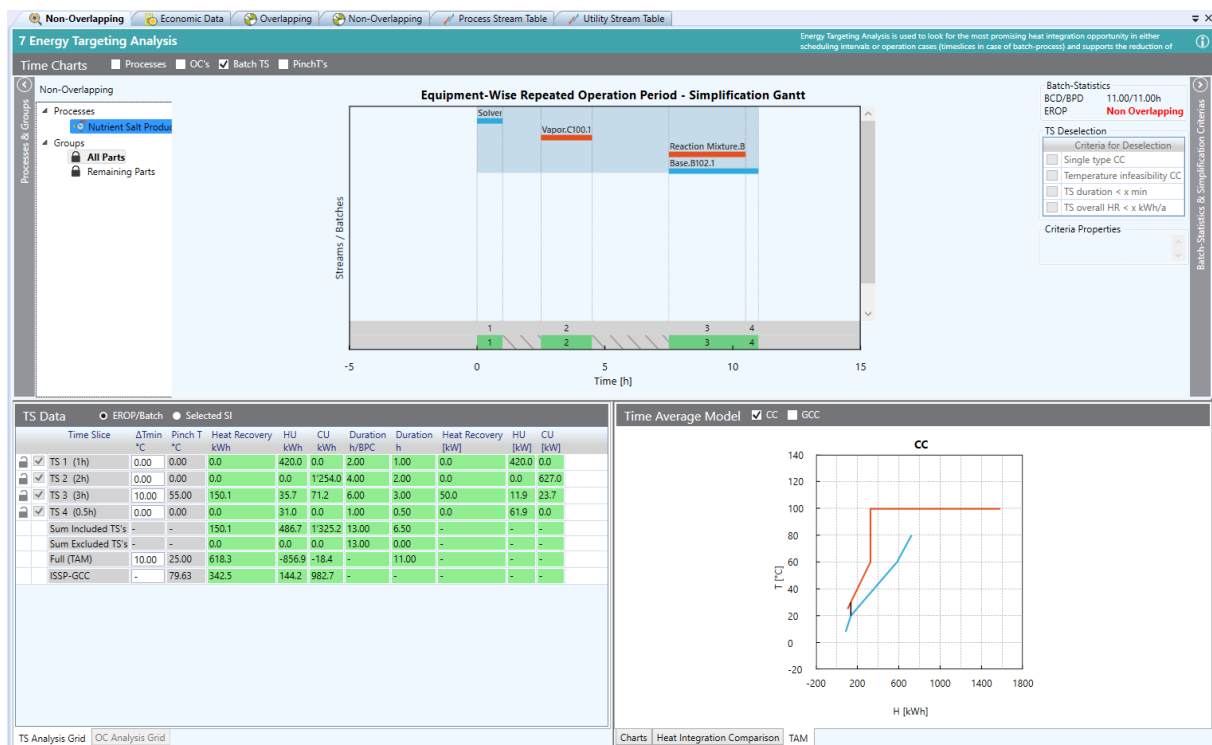☞ Select the "TAM" tab along the bottom edge of the TS Charts window

Figure 14: Energy Targeting Analysis of the non-overlapping operating mode with visualization of the maximum possible HR potential in the TAM

The overlapping of the Composite Curves in the TAM is the maximum possible HR potential (direct and indirect) in kWh/batch for a certain ΔT_{min} ($\Delta T_{min} = 10\,\mathrm{K}$ is a default value and is not based on a cost optimization process). In the TS Data window, the ΔT_{min} for the entire process can be adapted in the "Full (TAM)" row or for each individual TS.

> **Note:** It is advisable to select the same ΔT_{min} for all TSs. This permits designing of a heat exchanger network (MER HEN) with a similar structure for each TS. The HENs of the individual TSs can be merged into an overall network more easily later on.

The maximum possible HR, which is visualized in the TAM, can be read in the "Full (TAM)" row in the "Heat Recovery" column ($618.3 \, \text{kWh/Batch}$). The direct HR potential is listed individually for each TS in the same column. The indirect HR potential is listed in the "ISSP-GCC" row ($342.5 \, \text{kWh/Batch}$). This potential can be visualized with the ISSP-GCC. Proceed as follows:

☞ Select the "Charts" tab along the bottom edge in the TS Charts window

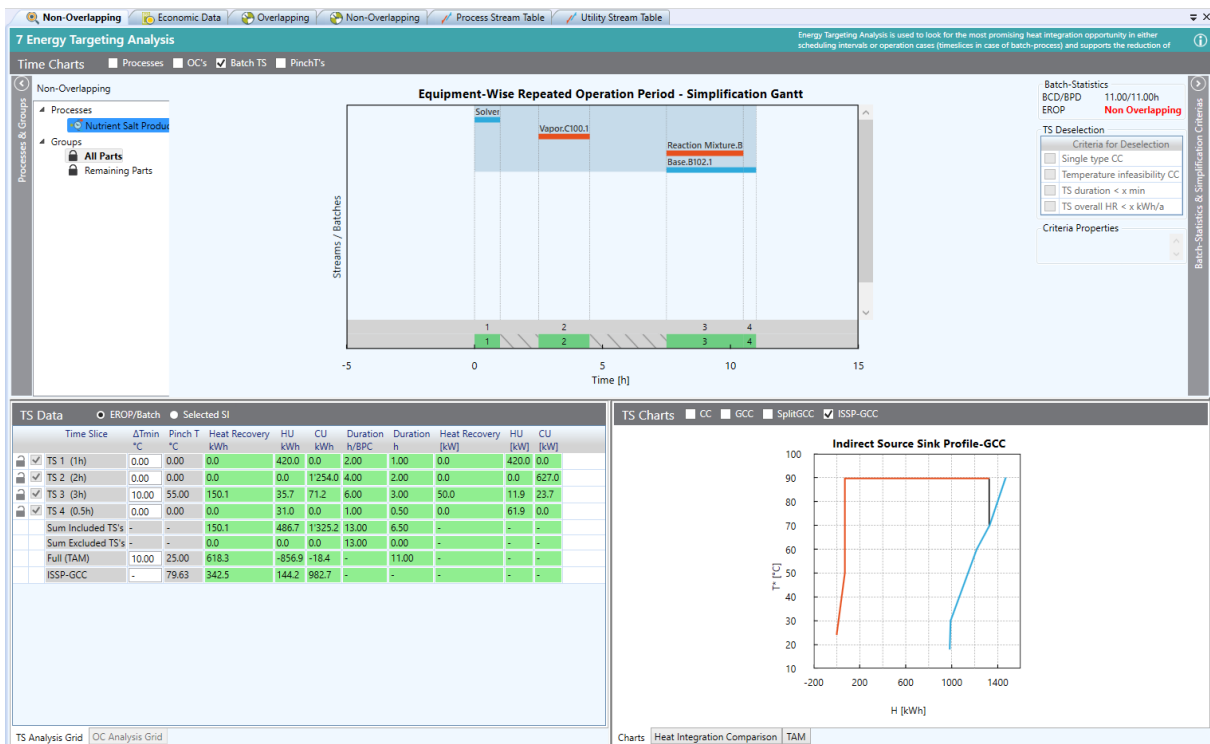☞ Select "ISSP-GCC" in the TS Charts window

Figure 15: Energy Targeting Analysis of the non-overlapping operating mode with visualization of the indirect HR potential in the ISSP-GCC

> **Note:** With the Time Average Model (TAM), the cyclically recurring period is taken into account and the heat level or the heat requirement of each stream is averaged over the entire duration of the period (see references on page 1). The ISSP-GCC shows the heating and cooling requirements which are left over after direct HR and can therefore be used indirectly with thermal energy storage (see references on page 1).

A Simplified Target Group is created to only take the direct HR potential into account. A Simplified Target Group is required whenever you want to hide individual TSs to simplify the problem. Proceed as follows:

☞ Right-click on "Groups" in the Time Charts window (Nutrient Salt Production must be selected in Processes)

☞ Select Add Simplified Target Group and rename the Simplified Target Group "Direct Heat Recovery".

☞ In the Overall Gantt Chart, click on the dashed bar (under Nutrient Salt Production)

☞ Deselect the Processes box and select Batch TS (in the Time Charts window)

☞ Select Single Type CC on the right-hand side of the window under TS Deselection. All of the TSs in which there is no direct HR potential are now hidden.

☞ Click on the padlock to be able to reuse the Simplified Target Group in Step 8. It now appears under Energy Target Analysis in the Target Explorer.

It is clear that only direct HR potential is available in TS3. In the TS Data window, the direct HR potential is specified under Sum Included TSs with $150.1 \, \text{kWh/batch}$. The HR potential of each individual TS can be read in the same row of the respective TS.

Because thermal energy storage, which incurs additional costs, is required for indirect HR, generally speaking direct HR is preferable over indirect HR. The direct HR potential can be increased by overlapping batches. Another advantage of overlapped batch processes is higher productivity. However, the overlap restricts flexibility in production planning. The various aspects must be considered and weighed up carefully.

Perform the same steps for the Overlapping target group. The Energy Target Analysis for the Overlapping target group should now look like this:
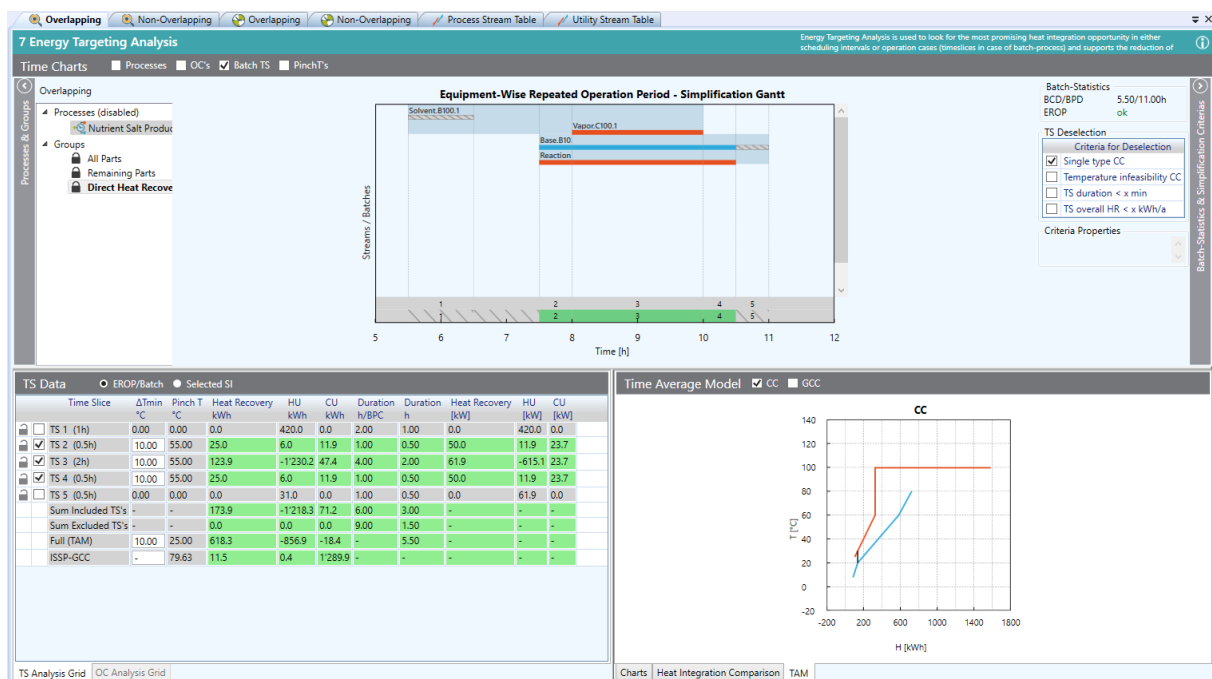

Figure 16: Energy Target Analysis of the overlapping operating mode

It is clear that an additional TS is created due to individual batches overlapping. Direct HR potential is also now available in TS2 and TS4. In Table 5, the HR potential of both the non-overlapping and the overlapping batch processes is compared. The maximum possible HR according to the TAM takes into account both direct and indirect HR, which is why the value is identical for both operating modes. It is

clear that the direct HR potential (Sum Included TSs) in the overlapping operating mode has increased by 16 % and the indirect HR potential has reduced by 7 %.

The flexibility is restricted due to batches overlapping: The various batches are highly dependent on one another due to heat transfer between them. Because overlapping would only cause an increase in direct HR potential of $23.8\,\mathrm{kWh/batch}$ and would restrict flexibility, the operating mode without overlapping is followed up in the case study.

Table 5: Comparison between overlapping and non-overlapping operating modes with regard to HR potential

Operation mode	Maximum HR [kWh/batch]	Direct HR [kWh/batch]	Indirect HR* [kWh/batch]
Non-overlapping (BCD = 11 h)	618.3	150.1	342.5
Overlapping (BCD = 5.5 h)	618.3	173.9	319.6

* To view the entire indirect HR potential of the process, All Parts must be selected under Groups in the Time Charts window.

Step 8: Calculate Energy & Cost Targets

One key aspect of the pinch analysis is the calculation of energy and cost targets *before* the (otherwise often subjectively influenced) examination of individual HR measures.

> **Note:** The guiding principle of the pinch method is Targets before Design!

The targeting carried out in Step 8 calculates the optimum use of utilities, the optimum HR potential, the optimum heat transfer area to be installed, the required number of heat exchangers to be installed and the associated minimum annual total costs.

The process for calculating the energy and cost targets for the non-overlapping operating mode is shown here. Start targeting for the Non-Overlapping target group:

☞ Right-click on Direct Heat Recovery (under Energy Target Analysis in the Non- Overlapping target group)

☞ Calculate Target Result with... ☞ Select Separate Design

☞ Right-click on Sep_Design 1_2 (Direct Heat Recovery)... ☞ Select Open Target Results (under Results in the Non-Overlapping target group)

In TS Data (bottommost window), all of the TSs which are taken into account for direct HR are listed. The barred TSs are shown by selecting "Show Ignored TSs". Since there is only direct HR potential in TS3 in the case study, the ΔT_{min} can be optimized with regard to total costs without the other TSs being influenced and therefore the entire heat exchanger network becoming more complicated. The cost optimum is shown in the Cost Curve diagram in the TS Data window. It is clear that the total costs are at their optimum at a $\Delta T_{min} = 15\,\mathrm{K}$. Therefore, adjust the value for ΔT_{min} in the TS Data table. You can now refer to the TS Data table from Figure 17 for the resulting energy and cost targets.
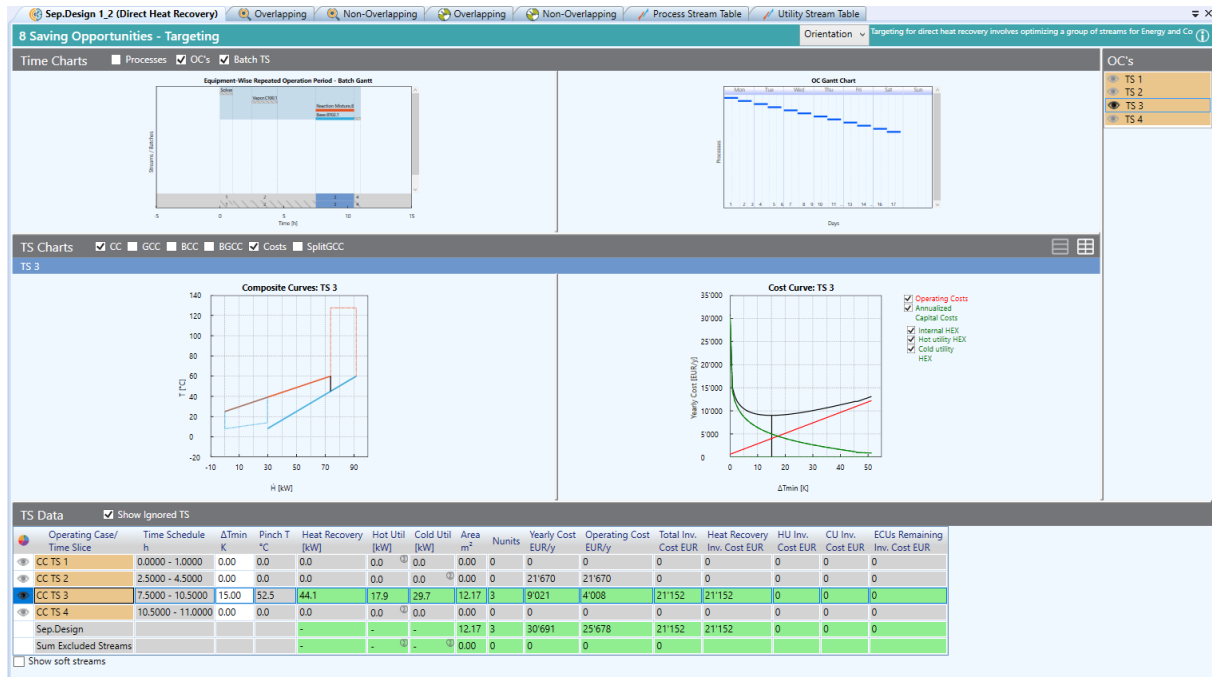
Figure 17: Energy and cost targets of the Non-Overlapping target group

Step 9: Integrate Energy Conversion Units (ECUs)

In many industrial processes, the heating and cooling requirements are large despite HR. In these cases, it is worthwhile reviewing the integration of an ECU. On the one hand, an ECU can be a heat engine whose waste heat is used in the process and therefore replaces HU. In most cases, the heat engine's mechanical energy is converted to electrical energy in a generator (e.g. combined heat and power plant, CHPP). On the other hand, an ECU can also be a heat pump which raises heat to a higher temperature level using electrical energy. The higher-value heat is, in turn, used to replace HU.

The pinch analysis is an excellent tool for analyzing the integration of an ECU. To optimize (and therefore reduce the costs of) the utilities, the correct integration of a heat pump, a mechanical or thermal base compressor, an ORC plant and a CHPP can be carried out in PinCH.

In this case study, base compression could be interesting in terms of reducing the utility requirement. In this regard, the CU for base condensation and the HU could be reduced. Since optimizing the utility system would go beyond the coverage of this tutorial, the integration of a base compressor is not examined any further here.

Step 10: Design Heat Exchanger Network (HEN)

Congratulations! You have successfully completed targeting as the basis of energy and cost optimization of the process. Now another important question needs to be answered: *How should the energy and cost targets be implemented in practice?* You can set up a HEN using PinCH. The HEN is less complex than a typical process flow chart. It shows what process streams are connected to heat exchangers and in what order. An optimized plant design can be developed based on this principle.

For a batch process, a MER HEN must be created for each TS in which there is direct HR potential. The only HR measure is possible in TS3. The resulting MER HEN for TS3 is shown in Figure 18. For all other TSs, the heating and cooling requirements must be covered with utilities (one heat exchanger each between process stream and HU or CU stream), which is already implemented in the existing production plant.
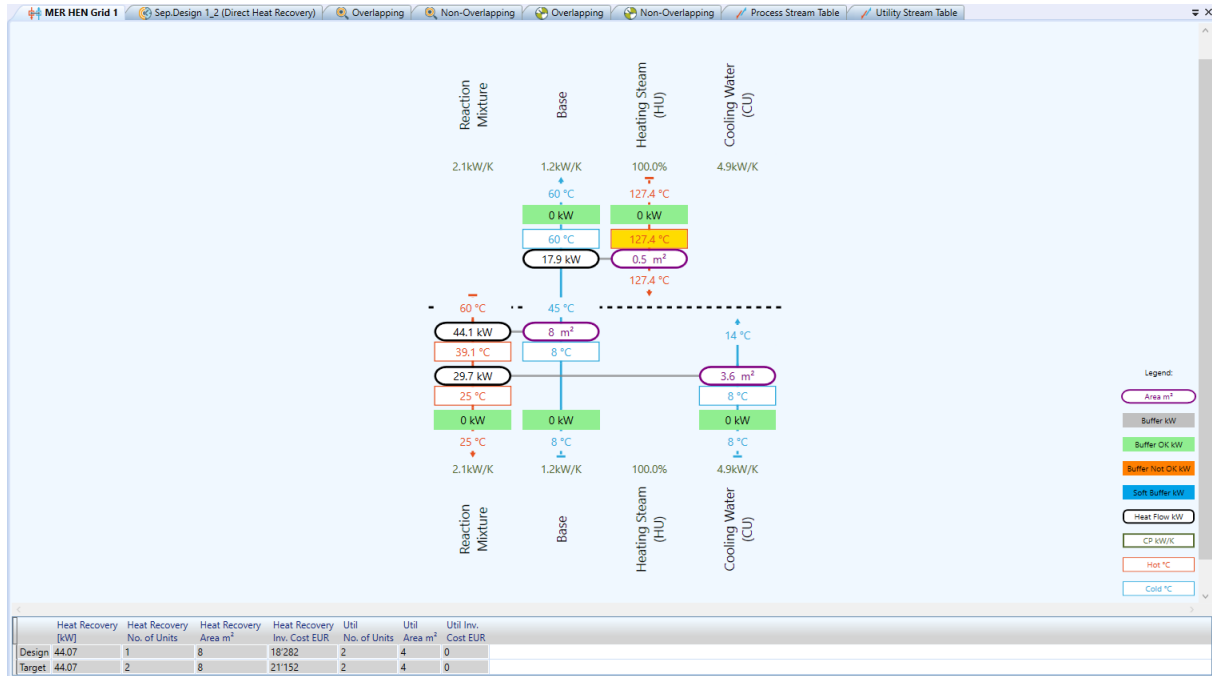

Figure 18: MER HEN of the TS3

IV Optimized Process

Now, we transfer the created MER HEN to the process flow chart shown at the start of the tutorial. The process flow chart of the optimized process for the various TSs is shown in Figures 19 to 22.
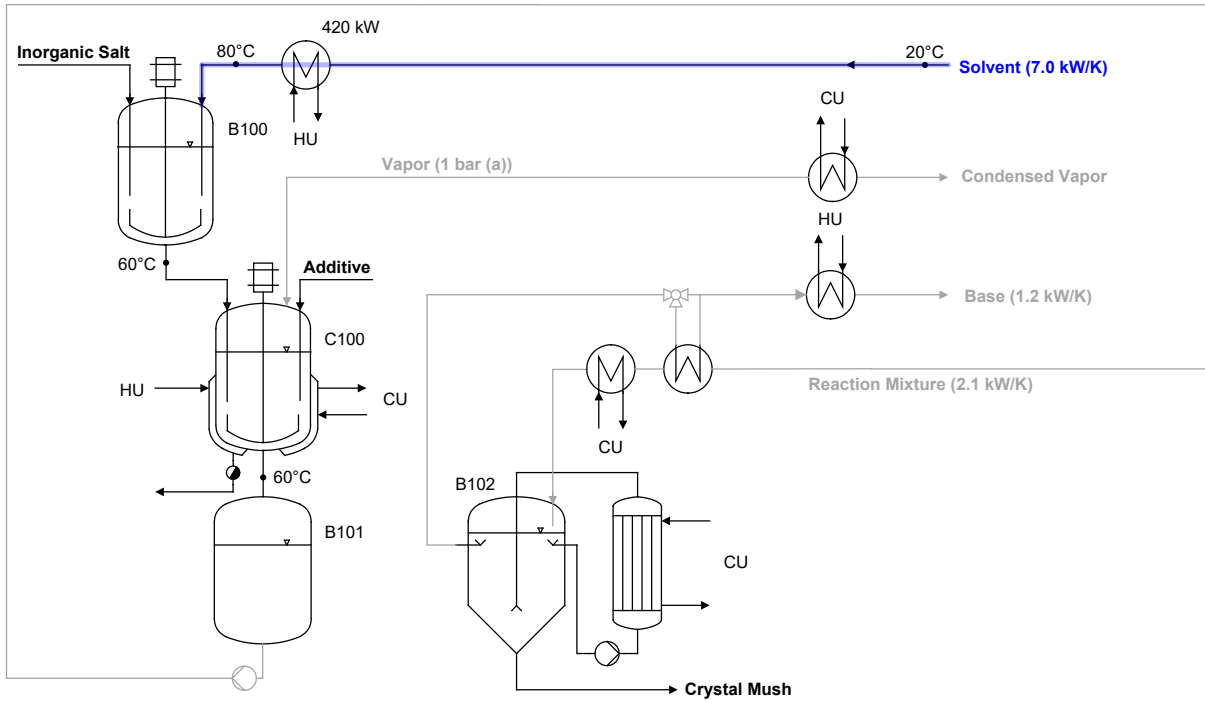
Figure 19: Process flow chart of the optimized production plant in TS1
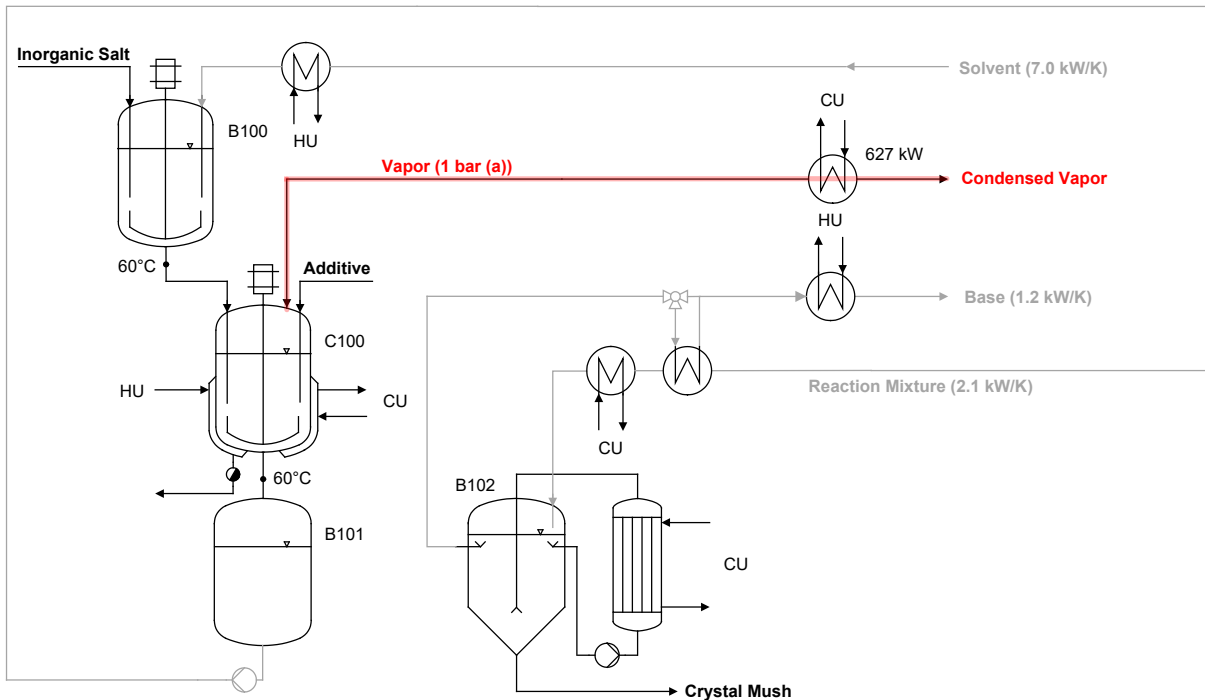

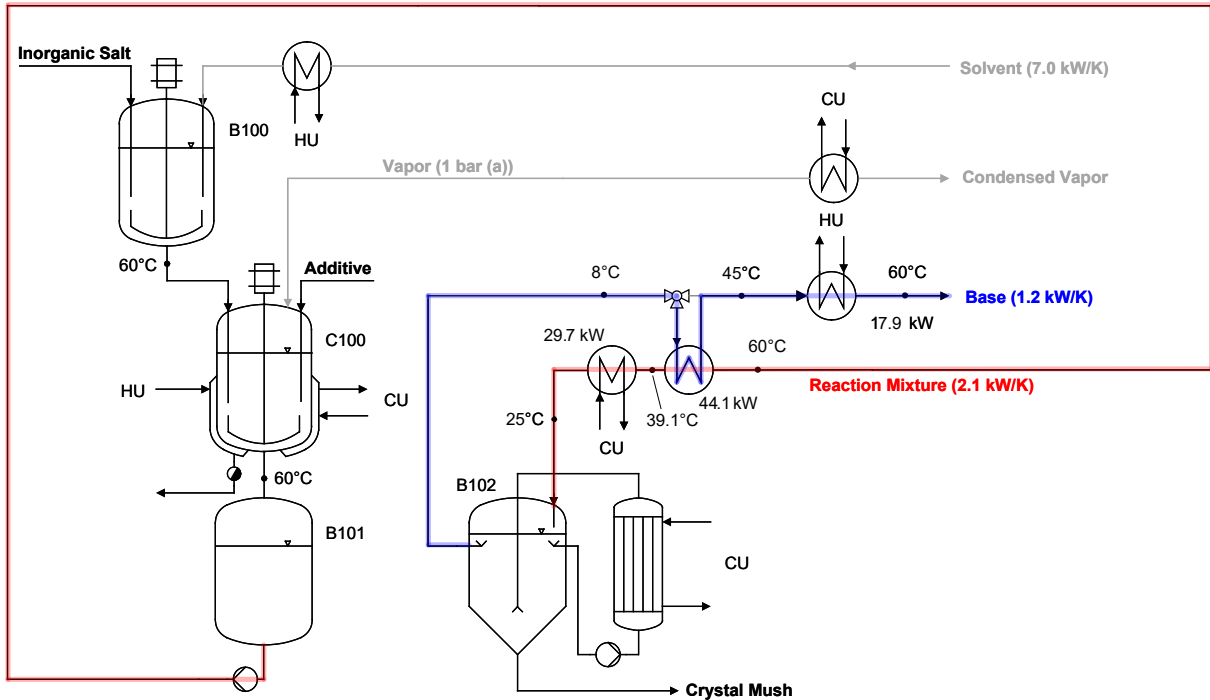Figure 20: Process flow chart of the optimized production plant in TS2

Figure 21: Process flow chart of the optimized production plant in TS3 with direct HR between the Reaction Mixture and Base
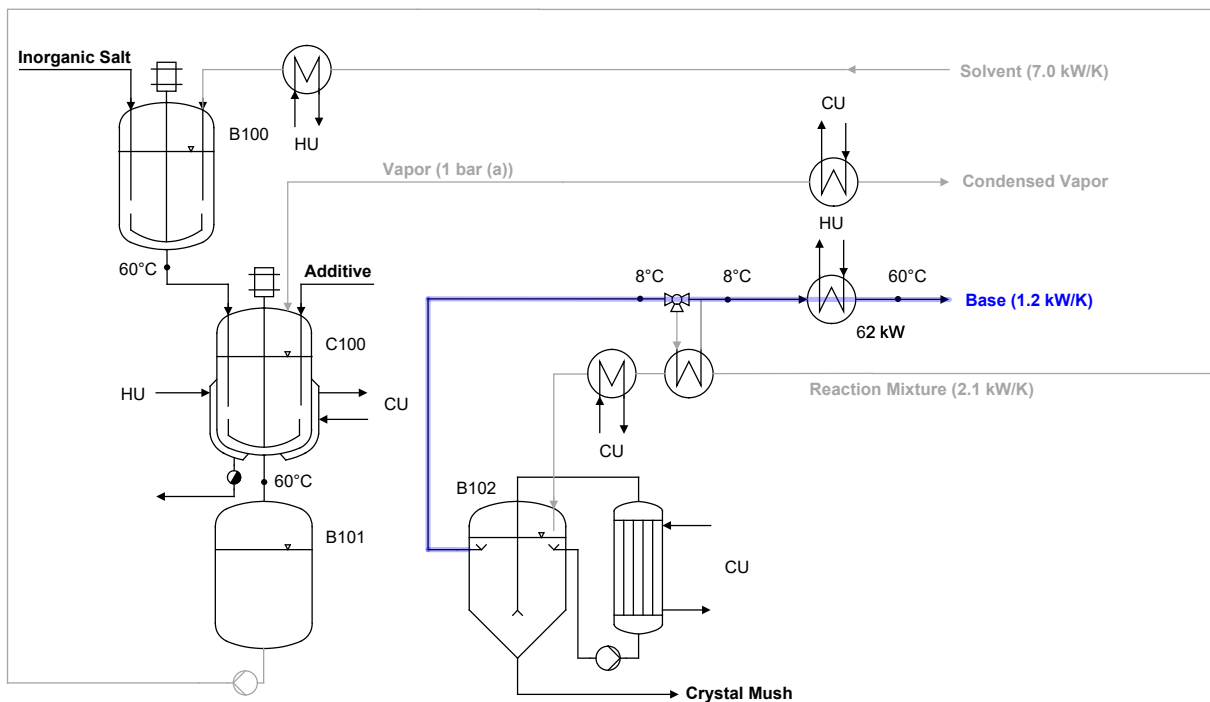

Figure 22: Process flow chart of the optimized production plant in TS4

In Table 6, it is clear that, due to direct HR in TS3, $44\,\text{kW}$ of utilities in TS3 can be saved without reducing flexibility. $76\,\text{MWh}$ of HU and CU can therefore be saved each year. An additional heat exchanger has to be installed for the HR measure, which incurs investment costs of $18'282\,€$. These costs are depreciated

over five years, resulting in annual investment costs of $4'333 \, \text{€/a}$. During the five-year pay-off period, this leads to an annual total costs saving of $4'066 \, \text{€/a}$. This corresponds to a 7.4% reduction in total costs. $8'393 \, \text{€/a}$ can be saved after the five-year pay-off period. This corresponds to a 15.3% reduction in the annual total costs.

Table 6: Comparison of the planned production plant without HR with the optimized production plant

	HU		CU		Operating costs	Annual Inv.	Annual total costs
	[kW]	[MWh/a]	[kW]	[MWh/a]	[€/a]	costs [€/a]	[€/a]
Existing design							
TS1	420	242	-	-	19'354	0	19'354
TS2	-	-	627	722	21'670	0	21'670
TS3	62	107	74	128	12'407	0	12'407
TS4	62	18	-	-	1'427	0	1'427
Total		367		850	54'858	0	**54'858**
Optimized design							
TS1	420	242	-	-	19'354	0	19'354
TS2	-	-	627	722	21'670	0	21'670
TS3	18	31	30	51	4'008	4'333	8'341
TS4	62	18	-	-	1'427	0	1'427
Total		291		773	46'459	4'333	**50'792**
Saving during pay-off period							
TS1	0	0	-	-	0	0	0
TS2	-	-	0	0	0	0	0
TS3	44	76	44	76	8'399	-4'333	4'066
TS4	0	0	-	-	0	0	0
Total		76		76	8'399	-4'333	**4'066**

This tutorial focused on indirect HR. In addition to the direct HR potential, in Step 7 the indirect HR potential was determined with about $320 \, \text{kWh/batch}$. However, indirect HR can only be implemented with thermal energy storage (TES). A more detailed explanation of the process for systematically integrating TES into the case study (making nutrient salt) is provided in Tutorial 4.

Thank you for your time!

You are now familiar with the most elementary steps of using PinCH to perform a pinch analysis on a discontiunous process. Please do not hesitate to contact us if you have any questions. The PinCH team of the Lucerne University of Applied Sciences and Arts and the Centre de Compétence PinCH Francophone of the School of Management and Engineering Vaud are available at your convenience. Please also note the option of coaching to assist with and ensure the quality of your pinch analyses. Learning by doing in this way has already proved to be an excellent experience on multiple occasions. In any case, we hope you have lots of fun and wish you every success with PinCH. Thank you so much for taking the time to join us! For more information, please visit our website www.pinch-analyse.ch. You will find our contact details below.

Kind regards,
the PinCH team of Lucerne University of Applied Sciences and Arts