



Loughborough
University

IDRIST – Temporal pinch-point analysis for energy demand reduction in batch production

Content

- Introduction to IDRIST project
- Importance of pinch-methodology for energy demand reduction
- Challenges of thermal integration in batch processes
- Summary of approach taken
- Outlook

IDRIST Project Phases

Poster presented at 2015 UKES Conference

Industrial Demand Reduction through Innovative Storage Technologies

1. Market Potential Assessment
 1. Identify industry needs and market potential
2. Investigation of Integrated PCM thermal storage systems
 1. Identify and characterise candidate PCMs
 2. Design laboratory tests and simulation
 3. Experimental evaluation & model validation
 4. System modelling for industrial applications
3. Investigation of Thermo-chemical heat storage and transformation
 1. Short list salt-refrigerant working pairs using ideal thermodynamics
4. Whole systems modelling
 1. Business models, techno-economic assessments
 2. Whole system performance modelling

Industrial Demand Reduction through Innovative Storage Technologies (EPSRC EP/M030581)
Centre for Renewable Energy Systems Technology

Opportunities for industrial heat storage in the UK using Phase Change Materials 

Thorsten Spillmann, Philip Eames

1) Introduction
The reduction of the industrial energy demand is of significant importance for meeting the government's 2020 emission targets. In heat intensive industries significant cost and emission savings can be achieved by the effective management of site-specific thermal loads. Thermal energy storage is envisioned to play an important part in this context, because it provides the possibility to extend process integration approaches to batch operation plants allowing for the design of more efficient yet flexible production systems.

2) Site and process characteristics for determining the suitability of thermal storage applications
A list of process and site specific attributes is compiled to help assess the suitability of thermal storage applications to individual production systems.

Characteristic	Description
Heat intensity	The heat intensity of a process is a measure of the relative importance of thermal energy in running costs and revenues of production. It is therefore directly related to the impact heat integration can have on the reduction of those figures.
Batch production	Many possibilities for thermal storage integration due to the discontinuous nature of the production process.
Low production	Thermal storage enables continuous production processes for rotating plant sizes and start-up times to be maintained and transport of heat, e.g. for distillate heating.
High added value product	High relative cost-of-production make thermal integration an effective tool for production efficiency enhancement in heat intensive industries.
Space limitation	Apart from operation in a tight temperature range, latent heat storage systems provide energy storage densities far superior to sensible heat storage systems, enabling the design of smaller stores. For use with limited availability of space, this can be an important advantage.
Process temperature	The multiple of process streams with heating and cooling demands at different temperature levels can be integrated into a series of time-dependent heat exchangers. While traditional heat integration schemes (based on continuous production processes) only focus on heat integration within individual cascades (direct heat transfer), the integration of a thermal storage system furthermore allows the integration of heat from different cascades, in different parts in time (heat integration between the releases or between releases), i.e. to more extensively use the heat available, are the target the possibilities for heat recovery during production.

3) Assessment of heat intensity of UK industry
An assessment based on the fuel consumption of industry sectors¹ revealed the Chemical industry and the Food Sector to be the major industrial thermal energy consumers in the UK.



4) Detailed look at the food & beverage sector
The UK National Allocation Plan² calculates a site specific "relative CO₂ emissions" value, that is used as a basis for the participation in the European Union Emissions Trading Scheme for the period 2008 to 2012 (Phase II). A comparison of the site specific emissions relative to the sector's overall emissions indicates, that the brewery, distillery, dairy, and fruit & vegetable sub-sectors, where batch-production is common, create a significant portion of the sector's overall heat demand. Temperature ranges of unit-processes common for those sub-sectors are determined from industry specific best-practice documents³.



5) Detailed look at the chemical sector
The majority of CO₂ emissions in the Chemical sector is attributed to bulk chemicals, that are mainly produced in continuous processes. The diverse nature of the sub-sectors of Pharmaceutical, Fine Organic and Specialty Inorganic Chemicals, where batch production is common, make the identification of representative processes difficult. Based on sub-sector specific best-practice reference guides^{4,5} temperature levels of some relevant batch unit-processes could be determined.



6) Temperature levels of target applications and candidate materials
Based on the information obtained from the above specific production processes, three temperature bands are identified, in which the application of latent heat storage systems from the typical perspective. This allows for the prescription of a number of suitable candidate materials^{6,7} for industrial heat storage.



REFERENCES (only UK cases) (Data Source)
1. Department of Energy and Climate Change (2011) 'Energy Efficiency in Industry', London: Department of Energy and Climate Change.
2. Department of Energy and Climate Change (2011) 'Energy Efficiency in Industry', London: Department of Energy and Climate Change.
3. Department of Energy and Climate Change (2011) 'Energy Efficiency in Industry', London: Department of Energy and Climate Change.
4. Department of Energy and Climate Change (2011) 'Energy Efficiency in Industry', London: Department of Energy and Climate Change.
5. Department of Energy and Climate Change (2011) 'Energy Efficiency in Industry', London: Department of Energy and Climate Change.
6. Department of Energy and Climate Change (2011) 'Energy Efficiency in Industry', London: Department of Energy and Climate Change.
7. Department of Energy and Climate Change (2011) 'Energy Efficiency in Industry', London: Department of Energy and Climate Change.

online at: <http://i-stute.org/>

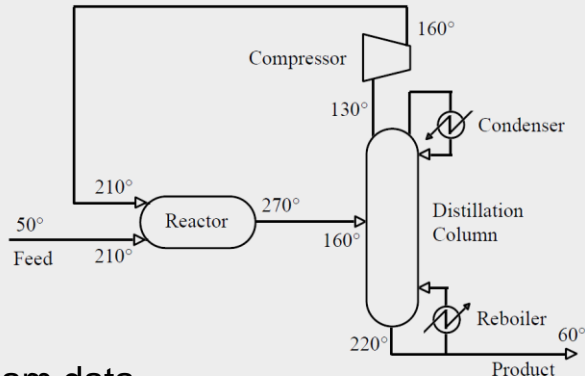
Pinch methodology for energy demand reduction (1)

- Pinch Analysis is a discipline of Process Integration, which emphasises on the “*efficient use of energy and reducing environmental effects*” (IEA).
- Developed for heat recovery in continuous production processes, but also used in other areas (e.g. waste water minimisation, hydrogen distribution in oil refineries)
- Central Aspect is the identification of the point of smallest driving force for network integration
- Pinch Concept: Establishment of performance targets before design
- 4-Phase Approach:



Pinch methodology for energy demand reduction (2)

Block diagram



- Necessary stream data from energy audit:
 - Mass flow rate
 - Specific heat capacity
 - Supply & Target temperatures
 - Start and stop times
 - Heat of vaporisation
- Decision if heat integration of certain units is not desired
 - Costly piping
 - Safety, product purity
 - operability

Stream data

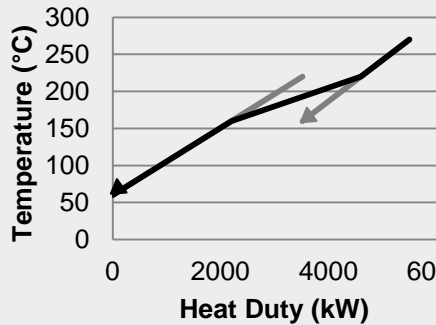
Stream	ID	T_s (°C)	T_t (°C)	T_s^* (°C)	T_t^* (°C)	MCp(kW/°C)	ΔQ (kW)	ΔT_{min} (°C)
Reactor Outlet	H1	270	160	280	170	18	1980	20
Product	H2	220	60	230	70	22	3520	
Feed	C1	50	210	40	200	20	3200	
Recycle	C2	160	210	150	200	50	2500	

- 4-Phase Approach:

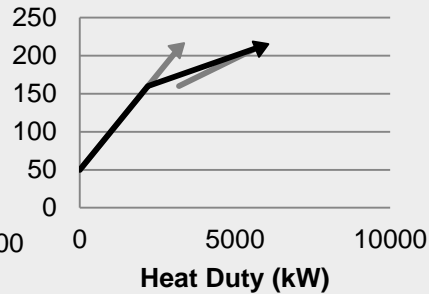


Pinch methodology for energy demand reduction (3)

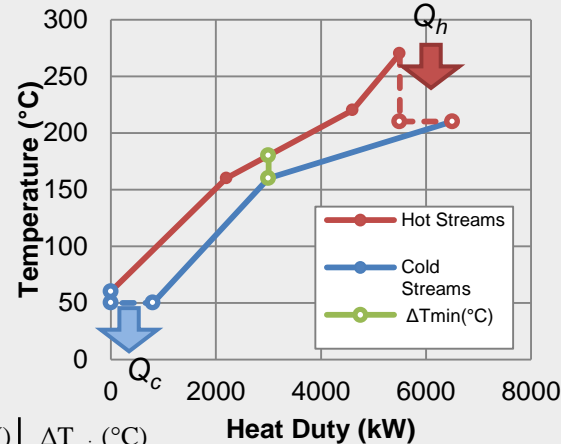
hot streams



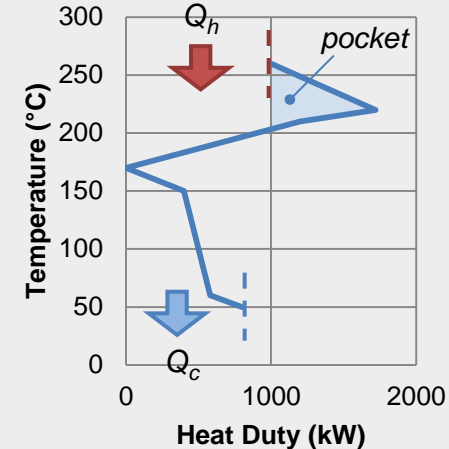
cold streams



Composite Streams



Grand Composite Curve



Stream data

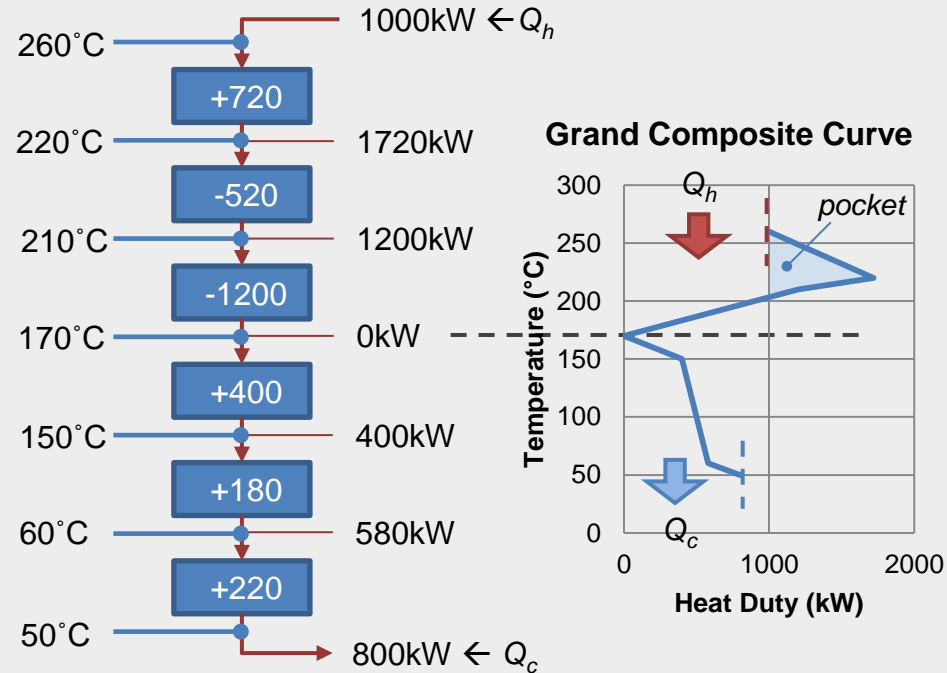
Stream	ID	T_c (°C)	T_h (°C)	T_c^* (°C)	T_h^* (°C)	MCp(kW/°C)	ΔQ (kW)	ΔT_{min} (°C)
Reactor Outlet	H1	270	160	250	140	18	1980	20
Product	H2	220	60	210	40	22	3520	
Feed	C1	50	210	70	230	20	3200	
Recycle	C2	160	210	180	230	50	2500	

- 4-Phase Approach:



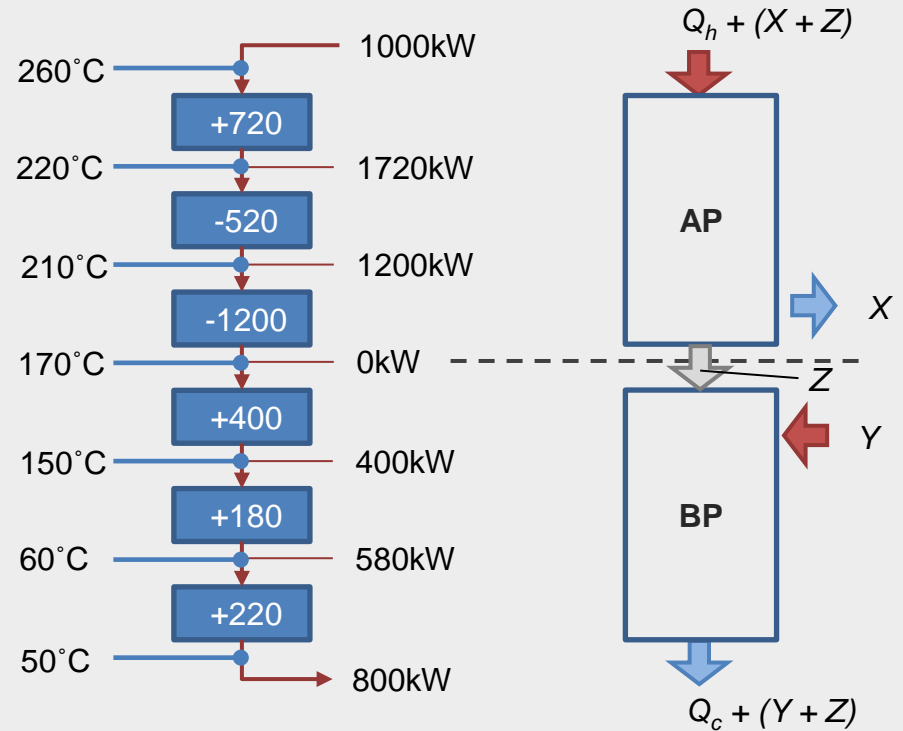
Pinch methodology for energy demand reduction (3)

- Streams are grouped together into subnetworks based on their temperatures
- A minimum ΔT_{\min} for heat exchange is defined that represents the physical constraint to heat transfer and is related to heat exchanger surface area and costs.
- The pinch point represents the location in the network, where the driving force for heat transfer is minimal
- 4-Phase Approach:

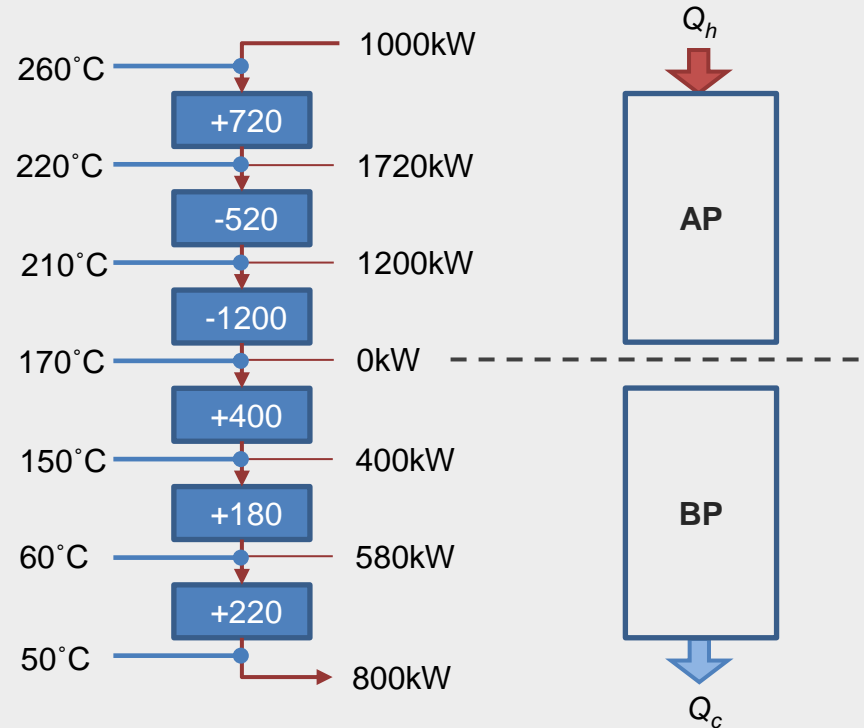
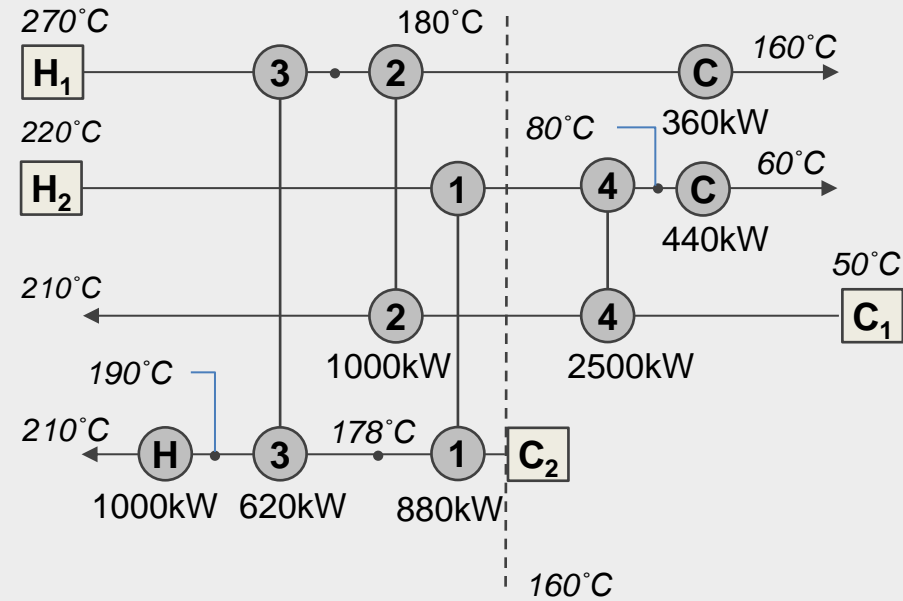


Pinch methodology for energy demand reduction (3)

- The pinch divides the network into a high temperature region, that only requires hot utility supply, and a low temperature region, that only requires cold utility.
- Heat transfer between the two regions results in increased utility demands.
- This means that subnetworks for the two regions can be designed independently from one another
- Pockets of the Grand Composite Curve represent internal heat transfer between subnetworks
 - 4-Phase Approach:



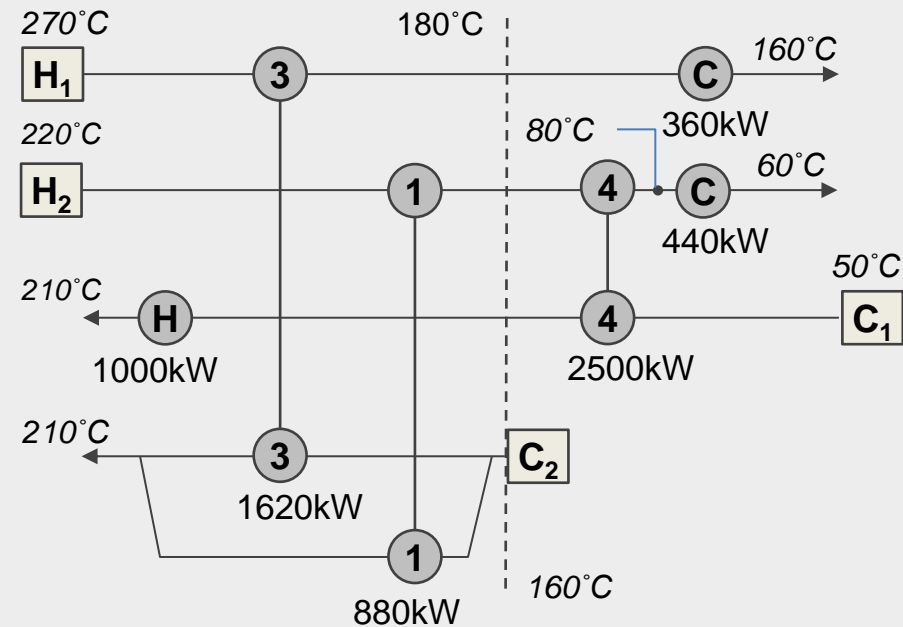
Pinch methodology for energy demand reduction (4)



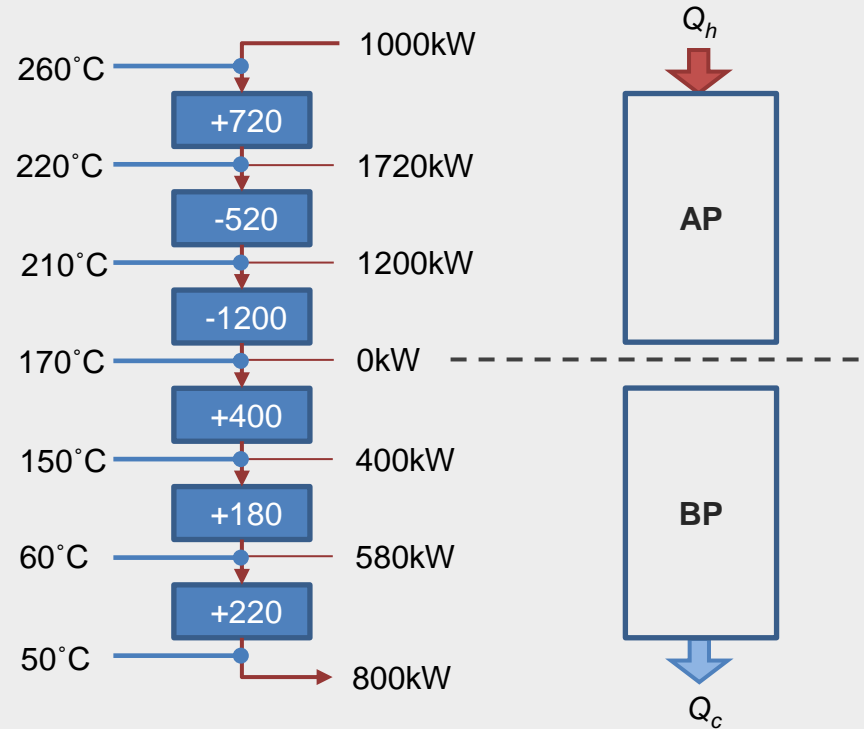
- 4-Phase Approach:



Pinch methodology for energy demand reduction (5)

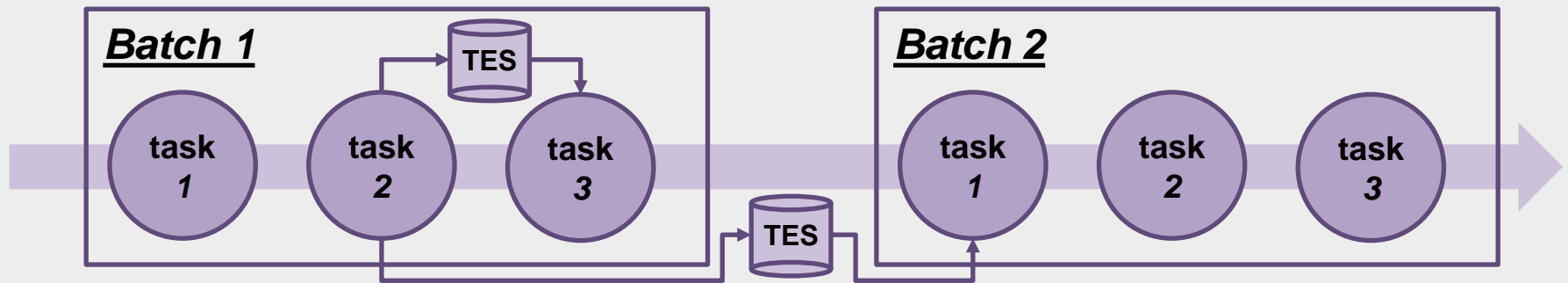


- 4-Phase Approach:



Thermal integration in batch processes

- Process Integration becomes more complex with the time-dependence of process streams, i.e. heat transfer possibilities are now constrained not only by temperature, but also by time
- Heat exchange can occur direct, when processes occur at the same time, or indirect when heat is exchanged with a storage medium to be used at a later point in time
- Limited implementation due to lack of established methods and design tools. Approaches suggested in literature differ according to simplifying assumption made and degree of complexity
- Two types of thermal integration: within batches, between batches

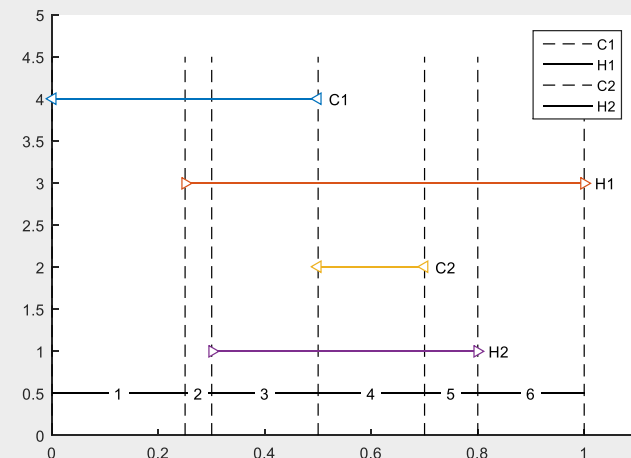


Approach taken (1)

- Division of time horizon into intervals with pseudo-continuous streams
- Composition of interval specific heat cascades identifying utility demand reduction through direct heat integration (within individual intervals).
- Composition of modified heat cascades identifying further reductions in utility requirements due to indirect heat integration (between intervals).
- Initial Heat Exchange Network Design based on Pinch Design Method

Literature Example: Chaturvedi (2014)

Name	T_{supply}	T_{target}	MCp	t_{start}	t_{stop}	ΔT_{min}
C1	80	140	8	0	0.5	10
H1	170	60	4	0.25	1	10
C2	20	135	10	0.5	0.7	10
H2	150	30	3	0.3	0.8	10



Approach taken (2)

Direct Heat Transfer

Indirect Heat Transfer

Divide streams into time slices

Modify GCC to determine thermal energy available for integration with subsequent intervals

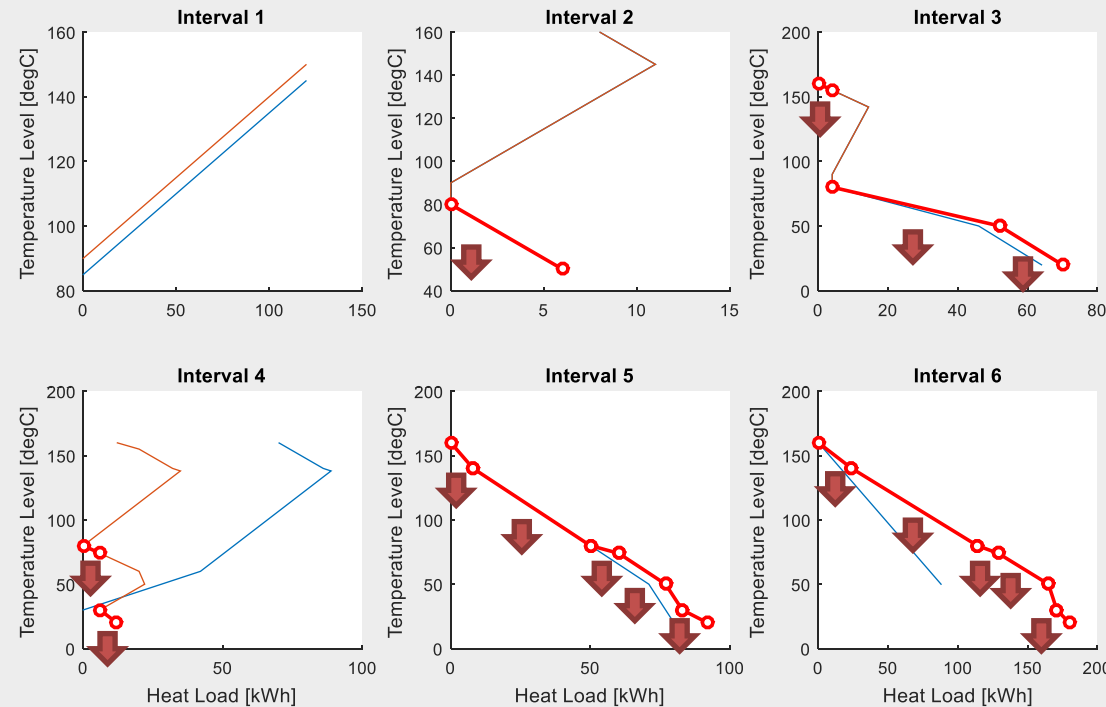


Use conventional pinch methodology (PTA) to calculate utility targets

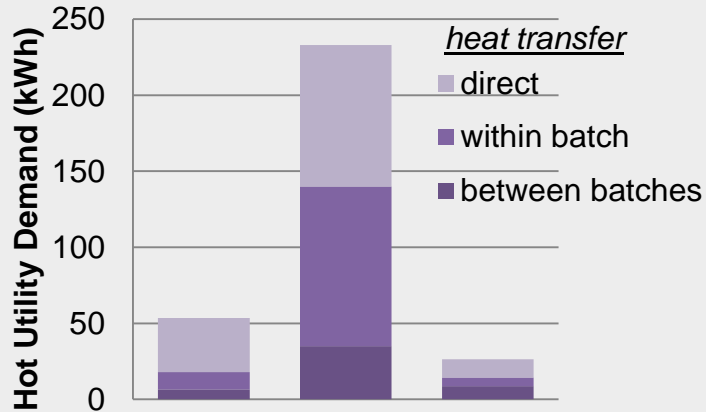
Repeat Integration Procedure for subsequent interval with shifted temperatures including pseudo hot streams

↓ = heat available from subnetworks for integration with subsequent intervals

Grand Composite Curves



Results for 3 example cases



Outlook

- Complete Computerised Initial Network Design Method
- Adapt targeting routine to represent different thermal store/ heat exchanger designs
- Utilise routine on further example cases from literature and industry

THANK YOU!