KVM013

INDUSTRIAL ENERGY SYSTEMS

Course Syllabus and Schedule

Industrial Energy Systems 2021

KVM013, 7,5 hec (higher education credit units)

Examiner and course coordinator:
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Division of Energy Technology
Department of Space, Earth and Environment
Chalmers University of Technology
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Course Prerequisites

Engineering thermodynamics, heat transfer, energy technology (incl. heat exchanger theory).

Aim

The aim of the course is to train students to use process integration methods and tools necessary for identifying and designing efficient energy system solutions for the process industry that contribute to sustainable development. Technical systems encountered in the course include steam networks, heat exchanger networks, boilers, heat pumps, and combined heat and power systems. Besides technical issues and economic assessment, the course also covers the role of industrial process energy systems for meeting greenhouse gas emissions reduction targets. The course also introduces a method to identify the cost-optimal mix of different process heating technologies for a given heat demand curve and analyse how future energy policy scenarios will influence this optimal solution.

Learning outcomes

After completion of this course, the student should be able to:

- identify the major equipment units in an industrial steam network, perform mass balance calculations at steam headers, and calculate relevant energy performance indicators
- calculate energy conversion performance characteristics for process utility boilers, heat pumps, and combined heat and power (CHP) units based on steam turbine or gas turbine cycles, for given energy conversion process parameters
- determine the pinch temperature and the minimum heating and cooling requirements for a given industrial process and a given value of minimum acceptable temperature difference for heat exchanging
- determine target values for the number of heat exchanger units, the heat exchanger network surface area, and the investment cost for a heat exchanger network that meets the above energy targets, and analyse the impact of choice of minimum temperature difference for heat exchanging on these energy and cost targets (supertargeting)
- design a heat exchanger network for maximum heat recovery for a given new (greenfield) process and improve this design by relaxation of the requirement for maximum heat recovery
- identify and quantify inefficiencies (pinch violations) in the heat exchanger network of an existing process and suggest design modifications to reduce the heating and cooling demands of the existing network (retrofit)
- identify opportunities and quantify the potential for integration of high-efficiency energy conversion technologies and advanced utility systems (heat pumps, combined

heat and power units, district heating) at an industrial process site

- evaluate designs of new heat exchanger networks, retrofit modifications of existing heat exchanger networks and the integration of heat pumps and combined heat and power unit with respect to energy efficiency, greenhouse gas emissions and economic performance
- identify the cost-optimal mix of technologies for satisfying an industrial process heat demand with given load characteristics, accounting for current and possible future energy market conditions, including costs associated with emissions of greenhouse gases

Contents

The course contains the following parts:

Introduction to industrial process energy systems: Basic concepts, description of industrial steam networks.

Process integration: Basics of process integration methodologies with emphasis on pinch analysis (Pinch temperature, minimum process heating and cooling requirements, composite curves and grand composite curve, utility targeting, targeting for minimum number of heat exchanger units, and heat exchanger surface area costs). Design of heat exchanger networks for maximum heat recovery and network relaxation. Process integration principles for high-efficiency energy conversion technologies and advanced utility systems (heat pumps, combined heat and power units, district heating). Process integration methodologies for retrofit applications in existing industrial energy systems. Energy efficiency and economic performance evaluation of process integration measures.

Energy conversion technologies in industrial energy systems: Overview of utility boilers, steam networks, heat pumps, steam turbine combined heat and power (CHP) and gas turbine CHP. Characteristics of heat pumps and CHP units (performance, investment costs). Optimization of size and various design parameters based on process integration principles. Methodology for identifying the cost-optimal mix of technologies for satisfying a process heat demand, accounting for heat load variation over the course of the year.

Greenhouse gas emissions consequences of energy efficiency measures in industry: Greenhouse gas emissions from industrial energy systems. Optimisation of industrial energy systems considering future costs associated with greenhouse gas emissions.

Organisation

The course includes 14 lectures, 4 compulsory projects (P1-P4), one of which (P3) is a 2-weeks duration project with a full report and presentation, and 5 non-compulsory exercises (E1-E5), one of which (E5) is combined with a non-compulsory (but highly recommended) industrial study visit.

Literature

Compendium produced at the Division of Energy Technology, available in Canvas website of the course.

For further reading, the book "Pinch Analysis and Process Integration: A User Guide on Process Integration for the Efficient Use of Energy" by I.C. Kemp is recommended. The book is available as an e-book from Chalmers library.

Handouts and Task descriptions

All lecture slides will be available at the latest 24 hours before the respective lecture session. Course participants are encouraged to study the lecture material and corresponding sections of the course compendium ahead of the lecture.

The description of the tasks for all projects and exercises, except P3, will be posted in Canvas from the beginning of the course. P3 will be introduced during the first day of the 2-weeks project session. Please be aware that the teaching staff will prioritize questions regarding the project or exercise topic of the particular session rather than questions related to future projects or exercises.

Examination

The written 4-hour examination includes theory and problem solving (with non-comprehensive calculations). The examination will be conducted in English. The standard Chalmers grade scale is used (Fail, 3, 4, 5).

The **regular examination** is scheduled on January 12th, 2022, from 14:00-18:00. The **first re-sit examination** is scheduled on April 12th, 2022, from 14:00-18:00. The **second re-sit examination** is scheduled on August 22nd, 2021, from 8:30-12:30.

Completed and approved reports for the compulsory projects (P1-P4) are a course requirement. For submission deadlines, see the information provided in the "Exercise and project sessions" section.

Staff

Simon Harvey (SH) – Examiner and coordinator	simon.harvey@chalmers.se
Lia Detterfelt (LD) - guest lecturer (Renova)	
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Elin Svensson (ES) – lecturer and project assistant	elin.svensson@chalmersindustriteknik.se

Course schedule (calendar week within brackets)

Week	Day	Time	Room	Activity	Book Chapter	Staff
1 (44)	Tuesday Nov 02	8-10	SB-H2	**L1** Introduction to industrial energy systems **L2** Industrial process steam networks	PM Ch1	SH
		10-12	SB-D309 / SB-D409	**E1** Steam system networks	Ch1	MF,CL VP,TK
	Wednesday Nov 03	8-10	HC1	**L3** Fundamentals of pinch analysis: Energy targeting	Ch 2	SH
	Friday Nov 05	8-10	KA	**L4** Stream data extraction. Targeting for optimal utility distribution, minimum heat exchanger network area and number of units	Ch 2	SH
	Friday Nov 05	10-12	KD1 / KD2	**E2** Energy targeting	Ch 2	MF,CL VP,TK
2 (45)	Tuesday Nov 9	8-10	HC3	**L5** Heat exchanger network design	Ch 3	ES
		10-12	KD1/KD2	**P1** Pinch analysis with energy and cost targeting and MER network design	Ch 2 & 3	CL,VP, ES, SH
	Wednesday Nov 10	8-10	HC1	**L6** a) Basic economics of process integration b) Targeting for minimum network total cost - Supertargeting	App A Ch 2	SH
	Friday Nov 12	8-8:30	HB1	**Common introduction to P1 part 2**		
		8:30-12	HB 105/110	**P1** cont'd	Ch 2 & 3	CL,VP, ES, SH
3 (46)	Tuesday Nov 16	8-10	HC3	**L7** Integration of Combined Heat and Power (CHP) units	Ch 4, App B	SH
		10-12	KD1/KD2	**E3** Supertargeting	Ch 2	MF,CL VP,TK
	Wednesday Nov 17	8-10	KD1/KD2	**E4** Utility targeting of CHP units	Ch 4	MF, CL VP,TK
	Friday Nov 19	8-12	HA3	**L8** Process integration of industrial heat pumps **(including in-class exercises related to basic concepts)**	Ch 4, App B	SH + 2 TAs

Course schedule cont'd (calendar week within brackets)

4 (47)	Tuesday Nov 23	8-10	HC3	**L9** Renova Waste-to-Energy Plant. Overview of waste management strategies & plant description. Introduction to Study Visit and E5	Handouts	LD (+AD) SH
		10-12	KD1/KD2	**P2** Process Integration and Economic Performance of Industrial Heat Pumps	Ch 4, App B	MF, CL VP,TK
		13.30-16	RENOVA	**STUDY VISIT** Renova WtE plant (Gr 1)		
	Wednesday Nov 24	8-10	HB 105/110	**P2** cont'd	Ch 4, App B	MF, CL VP,TK
		13.30-16	RENOVA	**STUDY VISIT** Renova WtE plant (Gr 2)		
	Thursday Nov 25	9.00-11.30	RENOVA	**STUDY VISIT** Renova WtE plant (Gr 3)		
		13.30-16	RENOVA	**STUDY VISIT** Renova WtE plant (Gr 4)		
	Friday Nov 26	8-12	HB105/HB110	**E5** Performance analysis of low-temperature section of Renova WtE plant	Ch 1 & 4	MF, CL, VP,TK
5 (48)	Tuesday Nov 30	8-10	HC3	**L10** HEN Retrofitting	Ch 5	ES
		10-12	KD1/KD2	**P3** HEN Retrofitting. Introduction	Ch 2, 3 & 5	ES,VP, TK,MF
	Wednesday Dec 01	8-10	HB105/HB110	**P3** cont'd	Ch 2, 3 & 5	ES,VP, TK,MF
	Friday Dec 03	8-12	HB105/HB110	**P3** cont'd	Ch 2, 3 & 5	ES,VP, TK,MF

Course schedule cont'd (calendar week within brackets)

6 (49)	Tuesday Dec 07	8-10	HC3	**L11** Industrial heat integration projects	Handouts	JI, SH, ES
		10-12	KD1/KD2	**P3** cont'd	Ch 2, 3 & 5	ES,VP, TK,MF
	Wednesday Dec 08	8-10	HB105/HB110	**P3** cont'd	Ch 2, 3 & 5	ES,VP, TK,MF
	Friday Dec 10	8-10	HB3	**L12** Characteristics of industrial heat loads and heat production technologies **L13** Optimisation of heat and power production considering CO_2 emissions (Part I)	Ch 6	ES
		10-12	HB105/HB110	**P3** cont'd	Ch 2, 3 & 5	ES,VP, TK,MF
7 (50)	Tuesday Dec 14	8-9	HC3	**L13** Optimisation of heat and power production considering CO_2 emissions (Part II)	Ch 6	ES
		9-10	HC3	**L14** Course wrap-up		SH
		10-12	KD1/KD2	**P4** Optimising heat production with respect to CO2 emissions	Ch 6	SH,VP, CL,MF
	Wednesday Dec 15	8-10	KD1/KD2	**P4** cont'd	Ch 6	SH,VP, CL,MF
	Thursday Dec 16	8-12	ML3/ML4	P3 students' presentation	Ch 2, 3 & 5	ES,MF, VP,TK
		13-17	SB-L300/SB-L308	P3 students' presentation	Ch 2, 3 & 5	ES,MF, VP,TK
	Friday Dec 17	8-12	HB105/HB110	**P4** cont'd	Ch 6	SH,MF, VP,CL
	20 Dec - 7 Jan			**Home study period**		
(2)	7/1, 10/1 and 11/1	9-12	ZOOM	Consultation time		SH

Lectures

L1 Introduction to industrial energy systems
Course contents, concepts and scope.

L2 Industrial process steam networks
Major equipment units in industrial steam networks, mass and energy balances, and energy performance indicators.

L3 Fundamentals of pinch analysis: Energy targeting
Introduction to pinch analysis. Pinch temperature. Targeting for minimum heating and cooling demands. Composite curves, heat cascade and the grand composite curve.

L4 Stream data extraction. Utility, area and number of units targeting
Stream data extraction. Targeting for optimal utility distribution, minimum heat exchanger network area and number of heat exchanger units.

L5 Heat exchanger network design
Network design strategies for maximum energy recovery: stream splitting and cyclic matching. Practical design considerations: Network relaxation.

L6 Basic economics of process integration. Cost targeting.
Capital and operating costs of heat exchangers and heat exchanger networks, profitability of energy saving projects. Targeting for minimum total network cost. Supertargeting.

L7 Integration of combined heat and power units
Overview of CHP technologies (gas turbines and steam turbine systems) and their integration in industrial processes.

L8 Integration of industrial heat pumps
Overview of heat pump technologies (closed cycle compression, mechanical vapour recompression and absorption heat pumps) and their integration in industrial processes. This lecture will include in-class exercises related to basic concepts.

L9 Renova waste to energy plant
Guest lecture from Renova. Overview of process technology for waste incineration systems with energy recovery. Presentation of the Sävenäs waste-to-energy plant. Introduction to study visit and E5

L10 Heat exchanger network retrofitting
Basic methods for retrofitting of heat exchanger networks.

L11 Industrial heat integration projects
Guest lecture from Södra. Presentation of heat integration in industrial projects focusing on, but not limited to, applications of pinch analysis method. Presentation of related research projects in the Division of Energy Technology.

L12 Characteristics of industrial heat loads and heat production technologies
Process heat load duration curves. Heat production costs for boilers, heat pumps and CHP units. GHG emissions and associated costs.

L13 Optimisation of heat and power production considering GHG emissions
Methodology to identify best mix of technologies to cover a given heat demand profile considering costs and GHG emissions.

L14 Course wrap-up
Short review of the course contents, principles and methods. Exercises demonstrating selected previous exam topics.

Exercise and project sessions

Exercises and compulsory projects are equally significant in terms of the course learning objectives and are *as likely to be reflected in the final exam.*

Students should join one of the “two-students” groups in Canvas for projects P1, P2, and P4. **Please *sign up* in Canvas in order to be able to submit your reports through Canvas.** Students will be randomly assigned to “four-students” groups in Canvas for project P3.

For exercises E1-E5, it is advised to work in the same groups as for P1, P2 and P4.

Note: the groups will be divided in the rooms indicated in the course schedule table presented above (e.g., for E2 some of the groups will work in the room KD1, some in the room KD2). The distribution of the groups in the rooms will be announced in Canvas. **Please, have a look before the respective exercise and project sessions to know which room your group belongs to**!

Compulsory projects

The projects P1 to P4 are compulsory, which means that completed and approved projects are a course requirement. Projects P1 and P2 should be reported in written format according to the provided report template and P3 with a full written report and presentation. Project P4 can be examined either orally during the last sessions (15/12 or 17/12) or with a written report to be submitted no later than 7/1 2022.

Report requirements. Each “two-students” group should submit one common project report (P1, P2) in electronic format (*.doc*, *.docx* or *.pdf*) via Canvas according to the following rules:

1. The name(s) and group number must appear clearly.
2. All reports must be written in English.
3. The reports should be neat and easy to follow, **according to the corresponding report template** that will be available at the beginning of the respective project.
4. Name your reports according to group number and project number (e.g. “report_P1_group_11”).

Each **“four-students” group should submit one common full report for P3** in electronic format (*.doc*, *.docx* or *.pdf*) via Canvas according to the same rules as for P1, P2 but **no template will be provided**. Each “four-students” group should **present their report and also act as an opponent for another group**. The presentation will be on **Thursday, December 16th**, and the respective time for every group will be announced in Canvas.

Please respect the due date for submitting your reports. The submission possibility in Canvas is automatically closed after the deadline. Deadlines for compulsory project reports:

P1: Monday, November 15th
P2: Thursday, November 25th
P3: Friday, December 10th
P4: Friday, January 7th (if not examined orally)

Results and solutions: Results and feedback for the corrected reports will be provided through Canvas (e.g., approximately 1 week after the report submission deadline).

Important information about report submission and revisions

If your report is not approved, written guidance will be provided to improve the report. You are expected to resubmit the revised report as soon as possible via Canvas. Please note that the report cannot be re-submitted more than two times. If the revised report is still deemed insufficient or incomplete after three submissions, you will have to re-do, or complete the pending projects in the next fall/autumn semester.

The final course grade will be registered on LADOK on February 12th, 2022. Revised project reports submitted after this date will be put on hold till the next course offering.

Non-compulsory exercises

For the non-compulsory exercises (E1–E5) solutions will be posted in Canvas after the exercise session.

Exercises and project description:

Compulsory projects

P1: Basic pinch analysis and heat exchanger network design
Pinch analysis for energy and cost targeting and design of a heat exchanger network for energy recovery and effluent cooling at a TMP (Thermo Mechanical Pulp) plant.

P2: Process integration of industrial heat pumps
Integration of heat pumps in industrial processes. Simple project investment evaluation. Impact of parameters such as electricity price, COP and temperature lift in the heat pump on economic performance of heat pump projects.

P3: Heat exchanger network retrofitting
Stream data extraction from a given process, identification of possible retrofit measures that improve energy efficiency, and prioritization according to their economic performance.

P4: Optimising process heat production options with respect to costs and CO_2 emissions
Assessing investment options in an industrial process energy system considering possible future increased costs associated with CO_2 emissions.

Non-compulsory exercises

E1: Steam system networks
Enthalpy and mass balance calculations around turbines, steam boilers and heaters of a steam network for combined production of heat and power for an industrial process.

E2: Fundamentals of energy targeting
Pinch analysis for energy targeting using composite curves and heat cascade calculations.

E3: Supertargeting
Choosing ΔT_{min} based on minimum total annualized cost.

E4: Utility targeting for CHP units
Analysis of opportunities for integration of gas turbine CHP units with a background process, based on the background process GCC.

E5: Performance analysis of the low-temperature section of Renova WtE plant
Evaluation of the energy conversion performance of absorption heat pump and district heating system in the Renova plant

Industrial study visit and related exercise (Renova)

- This 3-hours study visit is **non-compulsory, but strongly recommended**. This visit is usually compulsory, but due to the ongoing pandemic situation we have decided to **relax this requirement.** Students who are ill (even with a mild cold) should not participate in the study visit.
- You must **sign up to attend** 1 of the 4 scheduled sessions. The study visit takes place outside of the regular schedule hours, during study week 4 (calendar week 47). Sign up takes place in Canvas for a maximum of 25 students per session. No exceptions will be allowed. You are not allowed to change session without permission from the supervisor.
- Make sure that you **attend Lecture L9** about the energy system at Renova's Waste-to-Energy plant. During this lecture, further information abut the study visit will be provided, as well as an introduction to the related exercise E5.
- You must **arrange your own transportation** to Renova Savenäs. Please allow plenty of time for bus transportation. Latecomers can be forbidden to join an ongoing study visit. The closest bus stop is "Lemmingsgatan" and proper connections (Buses 58 and 519) can be found at www.vasttrafik.se. Be sure to get there at least 10 minutes before the lab starts, as you have to walk a bit from the bus stop. At bus stop Lemmingsgatan just walk back to the roundabout and turn left down Lemmingsgatan to cross the river Säveån and finally get to Renova. Please wait in the reception area.

Extra study material in Canvas

More exercise problems and material for self-studies will be made available in Canvas.

- **Theory and calculation exercises from old exams**
  PDF document with questions arranged according to the course topics. Exam questions from last year(s).
- **Extra reading material**
  Additional literature will be provided as complementary material to lecture notes and compendium chapters.

Course summary and exam preparation in January

A course summary will be discussed in study week 7 (calendar week 51). This occasion is a good opportunity to ask questions and get tips in studying for the exam. The January study week has also time scheduled for consultation (7/1, 10/1 and 11/1 between 9:00-12:00. The consultation will be online and Zoom links will be provided.