

SPIRIT Summer school

Industrial high-temperature heat pumps for decarbonization of industrial process heating

General information

Dates: June 15th – June 27th (last class will end at 14:00 on the 27th)

Location: Technical University of Denmark, Copenhagen (Lyngby)

Scope & Form: The class is taught all weekdays from 8-17. The Teaching will be a combination of lectures, Q&A sessions and supervised project work. An industrial case will be chosen on the first day. There will be time each day to implement the tools and methods taught to the industrial case.

Evaluation: The final assessment is based on a submission consisting of one abstract and one poster on the industrial case study (submission date 1/9-2025)

Workload: 5 ECTS

Confirmed speakers

Benjamin Zühlsdorf	Danish Technological Institute	
Carlo De Servi	VITO	
Gabriele Fregonese	SINLOC	
Jonas Kjær Jensen	Technical University of Denmark	
Jonas Lundsted Poulsen	Danish Technological Institute	
Jozefien Vanbecelaere	European Heat Pump Association	
Laura Alonso Ojanguren	Tecnalia	
Manuel Gräber	TLK Energy	
Maximilian Kriese	The German Aerospace Center (DLR)	
Nitish Anand	VITO	
Panagiotis Stathopoulos	The German Aerospace Center (DLR)	
Wiebke Meesenburg	Technical University of Denmark	
Xabier Peña Anton	Tecnalia	

Social events

Sunday June 15 th	Welcome reception and opening ceremony
Thursday June 26 th	Dinner in Copenhagen



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Agenda and curriculum

Day 1: Decarbonization of Industrial Process Heat	
Monday June 16 th	 Session 1: Introduction to industrial process heat & decarbonization Overview of current process heat technologies in different industrial sectors (Food & Beverage, Paper & Pulp, Chemical, Pharmaceutical) Economic and environment impact of industrial process heat Decarbonization strategies: indirect electrification, direct electrification, integration of renewable energy Cost savings and emissions reduction potential for decarbonization of industrial process heat Technical, non-technical and economic barriers for decarbonizing industrial process heat Session 2: Introduction to industrial heat pumps Heat pump working principles, work driven and heat driven cycles Heat pump performance measures Thermodynamic limits for infinite & finite Reservoirs Second Law and exergy-based performance measures Student case introduction Presentation of industrial cases Peer discussion session, case selection & group formation Project work
Day 2: Process	integration and techno-economic analysis of HTHP
Tuesday June 17 th	 Session 1: Process Integration and Pinch Analysis Introduction to Process Integration and Pinch Analysis: composite curves, pinch point, pinch based guidelines for HTHP integration Step-by-step guide on conducting Pinch Analysis including examples from industry Energy Savings Potential via pinch analysis and energy demand management Introduction and Step-by-Step Guide to TLK Pinch Analysis Tool Emerging trends and methods in Process Integration and Pinch Analysis Session 2: Techno-economic analysis of HTHP integration Estimation of CAPEX & OPEX for HTHPs Break-even COP Economic analysis and viability of HTHPs Levelized cost of heat for industrial process heat



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Day 3: HTHP Technologies – Cycles & Working Fluids		
	 Session 1: Thermodynamic cycles and working fluids for HTHP Overview of HTHP working fluids: Classification of working fluids synthetic vs. natural Environmental impact of working fluids Safety and technical constraints Overview of HTHP cycles: 	
	 Vapour Compression Cycles (Rankine), Gas Cycle (Brayton) Transcritical Cycles Zeotropic Mixture Cycles 	
Wednesday June 18 th	Session 2: Industrial HTHP in practice • Advanced cycle layouts for HTHP • Two-stage compression cycles • Cascade cycles • Open-cycles • Design and operation of real-life heat pumps including auxiliary components and control.	
	 Session 3: Modelling and Simulation of HTHP Overview of modelling tools and resources for: EoS and thermodynamic properties Component libraries Equations solvers for systems non-linear equation Model development methods Control Volume equations Constitutive equations Auxiliary and closure equations Degree of Freedom 	
Day 4: HTHP Technologies – Compressors for HTHP		
Thursday June 19 th	 Session 1: Compressor technology overview Working principles of HTHP compressors Volumetric compressors – reciprocating and screw Dynamic compressors – centrifugal and axial Application range of the above HTHP compressors in terms of capacity, pressure and temperature 	





	Session 2:
	Volumetric compressors
	Lubrication of compressors and HTHP lubricants
	 Design and optimization of reciprocating and screw
	compressors
	Technical constraints of reciprocating and screw compressors
	Operational and part-load performance of reciprocating and
	screw compressors
	Session 3:
	Dynamic Compressors
	 Design and optimization of axial and centrifugal compressors
	Technical constraints of axial and centrifugal compressors
	Operational and part-load performance of axial and centrifugal
	compressors
	Session 4:
	Lab tour - DTU Construct refrigeration and Heat Pump Lab
Day 5: HTHP Technologies – Heat exchangers for HTHP	
	Session 1:
	Heat exchanger technology overview
	Working principles of HTHP heat exchangers
	 Plate Heat Exchangers
	 Shell and Tube Heat Exchangers
	 Shell and Plate Heat Exchangers
	Application range of the above HTHP heat exchangers in terms
	of capacity, pressure and temperature
	Session 2:
	Dimensioning of single-phase heat exchangers
Friday June	Estimation of heat transfer coefficients
20 th	Estimation of friction factors and pressure loss
	Session 3:
	Dimensioning of evaporators and condensers heat exchangers
	Estimation of heat transfer coefficients
	Estimation of friction factors and pressure loss
	Session 4:
	Steam generation heat exchangers and steam networks
	Dimensioning of steam generation heat exchangers
	Dimensioning of steam generation heat exchangersDimensioning of steam networks





Day 6: Excursion to Danish Technological Institute (DTI) Århus		
Monday June 23 rd	 Session 1: Annex 58 - Overview of suppliers and market developments Overview of currently available technologies and close-to-market technologies Analysis of overall technology trends and key parameters Achievable temperatures Achievable capacities Expected cost Analysis of available technologies Combinations of technologies to achieve optimal solutions 	
	Session 2: Visit to the HTHP Test Center at DTI and HTHP demonstration	
Day 7: HTHP Integration in practice		
	Session 1: Experience from HTHP Demonstration projects SPIRIT EEETHOS Push2Heat 	
Tuesday June 24 th	 Session 2: Highly integrated heat pump-based processes Pros and cons of integration directly in process units Design approaches for direct heat pump integration 	
	 Session 3: Sector coupling with high temperature HTHP Sector coupling potential for HTHP Practical experience on HTHP used for sector coupling 	
Day 8: Heat sto	prage and flexibility	
	 Session 1: Heat storages for high temperature process heat Heat storage methods and mechanisms Heat storage modelling approaches["] HTHP and heat storage integration 	
Wednesday June 25 th	 Session 2: Flexibility and ancillary services Electric boilers etc. for operational synergy with HTHPs Heat demand flexibility Power consumption flexibility and ancillary services 	
	Session 3: Industrial site visit	





Day 9: Business modes & regulatory frameworks	
Day 9: Busines	s modes & regulatory frameworks Session 1: Business models for HTHPs Introduction to business models Definition and importance The business model canvas Detail of the components of the BM canvas Risk and uncertainty in economic analysis Definitions and types of risks Decision-making under uncertainty The cost/price of risks Business models in the energy sector and servitization "Traditional" manufacturing and sale Leasing EU regulations for heat pumps and HTHP integration Regulatory framework for industrial electrification Current policies such as RED, CID Financial incentives for adoption Waste bert recovery Waste bert recovery
	 Regulatory framework for waste heat recovery
Day 10: Industr	ial case presentations
Friday June 27 th	Session 1: Status presentations and peer-review session All students will present the progress they have made on the industrial cases. Students and instructors will give feedback on the projects and give recommendations for future work. Session 2: Closing ceremony The closing ceremony will end by 14:00

