Module Handbook Solar Thermal Perpignan

Fakultät 5: Mathematik und Naturwissenschaften Institut für Physik *Subject:* European Master in Renewable Energy Summer Term 2017	*Category:* - Master Module *Degree award:* - Master
Emphases: -	*Sections:* -
Module reference number/Title: **pre364 - Thermal Storage**	
Duration: 1 semester *Cycle:* once a year *Type of module:* mandatory *Level:* MM (master module) *This module should be taken in* 2nd semester	*Type of program:* - Lecture, Tutorial *Language:* English *Attainable credit points:* 4,00 CP *Workload:* 100 hours *Required attendance:* 30 hours
Person responsible for the programme: Prof. Pierre Neveu	*Person responsible for this module:* Prof. Xavier Py
Alternative person(s) responsible for this module: -	*Examiner(s):* All listed persons

Objective of the module / skills:

After the completion of the module the student will

- be familiar with main storage materials and technologies and will be able to choose which one is the most adapted to a specific solar application.
- have an understanding of the basic physical phenomena relevant to the principles of operation and design of thermal energy storages.
- have an understanding of the principles of operation and design of thermal energy storages.
- have an understanding of the need to define properly the functionalities of the TES.
- acquire the knowledge of the main technologies and materials used in TES.
- acquire the awareness of the importance of considering the relevant integration of TES in the whole process of application.
- acquire the awareness of the importance of strategy and management in the use of TES.
- acquire the knowledge of the main companies involved in the various aspects of TES (material, envelopes, fluids).
- have a critical understanding of the physical principles used in TES.
- be able to compare the design, operation and performances of the main types of TES.
- be able to choose the relevant TES for a particular application.
- be able to highlight the main limitations of a TES.

- be able to avoid the usual mistakes encountered in TES.
- be able to propose companies providing the various components of TES.

Content of the module:

1. Overview on Thermal Energy Storage (TES)
- TES definitions
- TES functionalities
- TES basic principles
- TES technologies
- ES hybridations
- ES bottlenecks and current research areas

2. Needs of TES in solar applications
- Resource/demand shift management
- Thermal protection
- Thermal regulation
- Production optimisation
- Process design optimisation
- Process management

3. Available technologies (sensible, latent heat, thermochemical)
- Sensible heat based TES, direct mode.
- Sensible heat based TES, indirect mode.
- Latent heat based TES (organic, inorganic)
- Thermochemical based TES

4. Related materials
- Low temperature TES materials (sensible heat, latent heat, thermochemical, classifications and properties, characterizations)
- High temperature TES materials (sensible heat, latent heat, thermochemical, classifications and properties, characterizations)

5. Heat transfer interfaces and fluids
- Envelops for TES units
- Insulating materials for TES units
- Heat transfer fluids for TES

6. Implementation of TS
- TES integration
- TES instrumentation
- TES charge/discharge assessments

7. Management and strategy of TS
- TES management
- TES strategy
- LTA of TES in Solar Applications

8. Related companies and products
- Companies and products for sensible heat based TES
- Companies and products for latent heat based TES
- Companies and products for thermochemical TES
- Companies and products for envelopes and connections

Suggested reading:

F. P. Incropera, D.P. DeWitt (ed.): Fundamentals of Heat and Mass Transfer, ISBN 0471304603.

A. V. Da Rosa, Elsevier (ed.): Fundamentals of renewable Energy Processes, 2005, ISBN 0120885107.

I. Dincer, M.A. Rosen, Wiley (ed.):Thermal Energy Storage, 2002, ISBN 0471495735.

J.A. Duffie, W.A. Beckman: Solar Engineering of Thermal Processes, Wiley ed., 2006, ISBN 100471698679.

B. Sorensen: Renewable Energy, Elsevier, 2004, ISBN 0126561532.

Gil, A., Medrano, M., Martorell, I., Lazaro, A., Dolado, P., Zalba, B., and Cabeza, L.F.: State of the art on high temperature thermal energy storage for power generation. Part 1-Concepts, materials and modelization, Renew. and Sust. Energy Reviews, 2010, 14, pp. 31-55.

Medrano, M., Gil, A., Martorell, I., Potau, X., and Cabeza, L.F.: State of the art on high temperature thermal energy storage for power generation. Part 2- Case studies, Renew. and Sust. Energy Reviews, 14, pp. 56-72.

Comments:

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Prerequisites for admission:

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Helpful previous knowledge:

Basic Understanding in
- thermodynamics
- thermal and energy science and engineering
- materials
- chemistry

Associated with the module(s):

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Maximum number of students / selection criteria:

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Types of examinations:

Written exam: 2 hours

Examination periods:

End of the Semester

Registration procedure:

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Fakultät 5: Mathematik und Naturwissenschaften Institut für Physik *Subject:* European Master in Renewable Energy Summer Term 2017	*Category:* - Master Module *Degree award:* - Master
Emphases: -	*Sections:* -

Module reference number/Title:

pre365 - Fundamentals

Duration: 1 semester *Cycle:* once a year *Type of module:* mandatory *Level:* MM (master module) *This module should be taken in* 2nd semester	*Type of program:* - Lecture, Tutorial, Laboratory *Language:* English *Attainable credit points:* 7,00 CP *Workload:* 200 hours *Required attendance:* 60 hours
Person responsible for the programme: Prof. Pierre Neveu	*Person responsible for this module:* Dr. Cyril Caliot
Alternative person(s) responsible for this module: -	*Examiner(s):* All listed persons

Objective of the module / skills:

After the completion of the module the student will

- understand the theoretical basis of radiation models to be used in solar engineering processes.
- understand the principles and the modelling approaches of combined heat and mass transfer in solar processes.
- understand the effect of radiation in a solar process.
- understand the radiative heat transfer methods of resolution to be used in solar applications.
- understand the various assumptions and computing efficiency of radiation models.
- understand the models' limitations to practical uses.
- acquire the knowledge of the main radiative properties of materials used in solar processes.
- be aware of the important development in radiation measurement.
- acquire knowledge of the optical measurement issues.
- have a critical understanding of the effect of radiation on fluid flows.
- have a critical understanding of radiation modelling in solar processes.
- have a critical understanding of the methodology that should be used in a practical situation where radiative heat transfer is to be solved, and coupled with other transfer modes.
- be able to compare and evaluate radiation simulation results from different models.
- have a critical understanding of optical properties and their influences on radiation heat transfer.
- will have a critical understanding of optical measurements.

Content of the module:

1. Radiative heat transfer

- Fundamentals of Thermal Radiation
- Radiative Exchange between Surfaces
- Radiative properties of opaque surfaces
- View factors
- Radiative exchange between grey and diffuse surfaces
- Equation of Radiative Transfer in Participating Media
- Equation of radiative transfer
- Formal solutions
- Boundary conditions
- Radiative Properties of Participating Media
- Radiative properties of molecular gases
- Radiative properties of particulate media
- Radiative Transfer through Participating Media
- Collimated irradiation
- The Two-Flux method
- The method of Discrete Ordinates
- The Monte Carlo method
- The Rosseland approximation
- The Diffusion approximation
- High temperature measurements
- Pyrometry
- Infrared thermography

2. Combined heat and mass

- Conduction
- Fundamental Equations
- Balance equations
- Examples
- Convection
- Fundamental Equations
- Forced Convection (resolution of the Couette flow with temperature)
- Natural Convection (approximation of Boussinesq)
- Adimensionnal equations
- CFD softwares

Suggested reading:

Modest M. F.: Radiative Heat Transfer. 2003.

Siegel R., Howell J.R.: Thermal Radiation Heat Transfer. 2002.

Lesieur: Turbulence in Fluids, Kluwer Academic Publisher, 1997.

James, Smith and Wolford: Applied numerical methods for digital computation, Harper & Row, New-York.

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Prerequisites for admission:

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Helpful previous knowledge:

Basic Understanding in

- Thermodynamics
- Energy and Thermal Science
- Electromagnetics
- Materials

	- Fluid dynamics *Associated with the module(s):* -
Maximum number of students / selection criteria: - *Types of examinations:* Written exam (50%): 2 hours Written report (50%): extended laboratory report, 10-20 pages *Examination periods:* Written exam : End of the Semester / end of May Written report : during the semester / February to May *Registration procedure:* -	

Fakultät 5: Mathematik und Naturwissenschaften Institut für Physik *Subject:* European Master in Renewable Energy Summer Term 2017	*Category:* - Master Module *Degree award:* - Master
Emphases: -	*Sections:* -

Module reference number/Title:

pre366 - Solar Low Temperature

Duration: 1 semester *Cycle:* once a year *Type of module:* mandatory *Level:* MM (master module) *This module should be taken in* 2nd semester	*Type of program:* - Lectures, Tutorials, Laboratories, Excursions *Language:* English *Attainable credit points:* 7,00 CP *Workload:* 200 hours *Required attendance:* 60 hours
Person responsible for the programme: Prof. Pierre Neveu	*Person responsible for this module:* Prof. Pierre Neveu
Alternative person(s) responsible for this module: Dr. Arnaud Perona, Dr. Driss Stitou	*Examiner(s):* All listed persons

Objective of the module / skills:

At the end of the module the student will
- understand the principles of operation, design and methods of low temperature solar energy use: building heating and cooling, microgeneration systems.
- be aware of the potentialities of solar resource for energy saving in building
- be aware of the solar heating and cooling technologies
- understand the different solar collector technologies
- understand the thermodynamics of energy conversion systems
- be familiar with the utilisation of different numeric tools for heating systems design, performance evaluation and techno-economic viability
- have a critical understanding of the physical principles relating to the operation and design of solar collectors.
- be able to compare the design and operation of solar heating and/or cooling systems in buildings
- will have a critical understanding of the complete system efficiency on the basis of sub-systems efficiency limitation.

Content of the module:

1. Solar Collectors theory and technologies
- The solar resource
- Direct and indirect irradiance
- Mask effects
- Solar collectors theory

- Plate collectors
- Evacuated collectors
- Low concentrated collectors
- Solar collectors technologies and application
- Design software for implantation in buildings.

2. Solar Conversion (solar heating/cooling, microgeneration)

- Thermodynamics optimisation : exergy analysis
- Potentialities of low temperature solar energy for cooling
- Potentialities of low temperature solar energy for electricity production
- Heat driven cooling system theory and technologies
- Liquid absorption system
- Solid sorption systems
- Microgeneration : ORC and Stirling systems

Suggested reading:

B. Sorensen: Renewable Energy. Elsevier, 2004.

Richard E. Sonntag , Gordon J. Van Wylen: Applied thermodynamics. ERPI,2004

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Prerequisites for admission:

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Helpful previous knowledge:

Basic Understanding in

- Heat Transfer
- Thermodynamics
- Energy in buildings

Associated with the module(s):

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Maximum number of students / selection criteria:

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Types of examinations:

Written exam (50 %): 2 hours

Written report (50%): extended laboratory report, 10-20 pages

Examination periods:

Written exam : End of the Semester / end of May

Written report : during the semester / February to May

Registration procedure:

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Fakultät 5: Mathematik und Naturwissenschaften Institut für Physik *Subject:* European Master in Renewable Energy Summer Term 2017	*Category:* - Master Module *Degree award:* - Master
Emphases: -	*Sections:* -
Module reference number/Title: **pre367 - Solar High Temperature**	
Duration: 1 semester *Cycle:* once a year *Type of module:* mandatory *Level:* MM (master module) *This module should be taken in* 2nd semester	*Type of program:* - Lecture, Tutorials, Laboratories, Excursions *Language:* English *Attainable credit points:* 12,00 CP *Workload:* 300 hours *Required attendance:* 90 hours
Person responsible for the programme: Prof. Pierre Neveu	*Person responsible for this module:* Dr. Gilles Flamant
Alternative person(s) responsible for this module: Dr. Alain Ferrière, Dr. Quentin Falcoz	*Examiner(s):* All listed persons
Objective of the module / skills: At the end of the module the student will - understand the principles of operation, design and methods of production of concentrated solar plants and the principles of thermochemistry and process engineering to produce either gaseous or liquid fuels using concentrated solar energy and resource of C, H, O elements. - be aware of the potentialities of concentrated solar resource for energy vectors production (mechanical, electricity, fuels) - will understand the different solar concentrating systems: linear concentration, point concentration, high concentration systems - understand the thermodynamics of chemical reactions that lead to fuels production from solar heat. - be familiar with the utilisation of different numeric tools for CSP design, performance evaluation and techno-economic viability - have a critical understanding of the physical principles relating to the operation and design of concentrating systems, solar receivers and concentrated solar plants. - be able to compare the design and operation of concentrating systems, solar receivers and concentrated solar plants. - have a critical understanding on the influence of the design and performance of concentrating systems on solar receivers. - have a critical understanding of the thermodynamic limitation of solar fuels production - have a critical understanding of the complete system efficiency on the basis of sub-systems efficiency limitation. - be able to compare and evaluate different chemical pathways with respect to solar energy stored in	

the chemicals and to CO_2 mitigation impact.
- have a critical understanding of the principles of solar thermochemical reactor design and modelling.
- be able to compare and evaluate various solar thermochemical and thermodynamic processes.

Content of the module:

1. Solar concentrating systems and receiver
- The solar resource for concentrating systems
- Introduction to concentration optics
- Linear concentration: trough and linear Fresnel
- Point concentration: Dish and Tower (Central receiver systems)
- High concentration systems: solar furnace and compound parabolic concentrator (CPC)
- Selective surfaces for solar receiver
- Solar receivers (absorbers) for linear concentrators

2. Solar concentrating systems and receiver
- Introduction to Concentrating Solar Power (CSP): various options, plants in operation, industry
- Tools for CSP design and performance evaluation
- Techno-economics of CSP
- Case study: Parabolic trough plant
- Case study: Central receiver plant
- Case study: Dish-engine plant
- Cogeneration systems: electricity and heat, electricity and water

3. Solar fuels
- Thermodynamics of chemical reactions
- Chemical pathways to hydrogen, methanol and hydrocarbons from water, carbon dioxide and carbonaceous materials
- Energy and exergy balances
- Energy and material balances when using natural gas, coal and biomass as Carbon resource
- Principle of Redox reaction to split H_2O and CO_2
- Various options for redox reactions
- Material and separation issues of the various options
- Thermodynamics and kinetics of the various redox reactions
- Principles of solar reactors
- Material issues in solar reactors
- Concentrating systems for high temperature solar thermochemistry
- Efficiency of a solar thermochemical process
- Case study as a function of the reaction temperature
- Lab-scale and pilot scale development, state of the art
- Solar thermo-chemistry for industry

Suggested reading:

Journal of Solar Energy Engineering

Proceedings of SolarPACES

Piatkowski N. et al.: Energy and Environmental Science (2011), 4, 73

Abanades S. et al.: Energy (2006) 31, 2469

W. Chueh et al.: Science, (2010) 330, 1797

Schunk L.O. et al.: Chemical Engineering Journal (2009) 150, 502

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<tr><td colspan="2">Maag G. et al.: International Journal of Hydrogen Energy (2010), 35, 13232</td></tr>
<tr><td>Comments:
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Prerequisites for admission:
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Basic Understanding in
- Thermal Transfers
- Optics
- Thermodynamics
- Chemistry
- Chemical Engineering
Associated with the module(s):
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<tr><td colspan="2">Maximum number of students / selection criteria:
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Types of examinations:
Written exam (33%): 2 hours
Written report (33%): extended laboratory report, 10 pages
Written report (33%): project report, 30 pages
Examination periods:
Written exam : End of the semester / end of May
Written report : during the semester / February to May
Registration procedure:
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