LABORATOIRE
PROCÉDÉS, MATÉRIAUX
et ENERGIE SOLAIRE
.UPR 8521 du CNRS.
conventionnée avec
l'université de Perpignan
PROCESSES,MATERIALS
and SOLAR ENERGY
LABORATORY

Syllabus

Specialization Solar Thermal

European Master in Renewable Energy

Site Félix Trombe d'Odeillo :
PROMES-CNRS
7 rue du Four Solaire
66120 Odeillo-Font-Romeu,
France
Tel. 33 (0) 468 307 700
Fax. 33 (0) 468 302 940

Site Tecnosud :
PROMES-CNRS
Tecnosud
Rambla de la
Thermodynamique
66100 Perpignan, France
Tel. 33 (0) 468 682 222
Fax. 33 (0) 468 682 213

Site campus UPVD :
PROMES-CNRS
Université de Perpignan via
Domitia
Bat. B, ELIAUS
52, avenue Paul Alduy
66860 Perpignan Cedex,
France
Tel. 33 (0) 468 662 064
Fax. 33 (0) 468 662 287

Provider:
University of Perpignan Via Domitia
and
PROMES-CNRS

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EU Renewable Energy Masters

SPECIALISATION SYLLABUS
Solar thermal energy

Contents:	TOTAL HOURS
1. Fundamentals	60
2. Solar Low Temperature	60
3. Solar High Temperature	90
4. Thermal Storage	30

TOTAL HOURS	240

Fundamentals			
Syllabus	**Lectures**	**Tutorials**	**Laboratory**
Radiative heat transfer	20	6	4

• 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
	1
	3
	4
	5
	5
	2
		2
		2
		2
			4

Combined heat and mass transfer	20	10	

• 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
• Radiative transferts
  • Fundamental Equations
  • Balance equations
  • Examples
	6
	10
	4
		3
		5
		2	

Learning outcomes			
The student will be familiar with radiative heat transfer and be practised in solving problems including radiation.			
Module total	**40**	**20**	

Solar Low Temperature			
Syllabus	**Lectures**	**Tutorials**	**Laboratory**
Solar Collectors theory and technologies	20	6	4
• Energy collection and heat transfer in solar collectors – characteristics of materials • Design and simulation • Overview of the solar collectors technologies • Implementation	6 6 4 4	2 6	 4
Solar Conversion (solar heating/cooling)	20	6	4

• Solar heating :
  • Solar water heating
  • Solar air heating
  • Combined Solar System
• Solar cooling
  • Liquid Absorption technology
  • Solid sorption technology
	8
	
	12
		2
		
		4
			
			4

Learning outcomes			
The student will be familiar with solar collectors design and technologies and will be able to choose which one is the most adapted to a specific application.			
Module total	**40**	**20**	

Solar High Temperature			
Syllabus	**Lectures**	**Tutorials**	**Laboratory**
Solar concentrating systems and receiver	18	8	4
• The solar resource for concentrating systems	2		
• Introduction to concentration optics	2		
• Linear concentration: trough and linear Fresnel	2	2	
• Point concentration: Dish and Tower (Central receiver systems)	2	2	
• High concentration systems: solar furnace and compound parabolic concentrator (CPC)	2		2
• Selective surfaces for solar receiver	2		
• Solar receivers (absorbers) for linear concentrators	2	2	2
• Solar receivers for point focusing systems	4	2	
Solar power plants	22	8	
• Introduction to Concentrating Solar Power (CSP): various options, plants in operation, industry	4		
• Tools for CSP design and performance evaluation	4	4	
• Techno-economics of CSP	2		
• Case study: Parabolic trough plant	3		
• Case study: Central receiver plant	3		
• Case study: Dish-engine plant	3	4	
• Cogeneration systems: electricity and heat, electricity and water	3		
Solar fuels	20	10	
• H_2 from decarbonization of hydrocarbons o Reforming/Gasification o Cracking o Carbothermal reduction	6	3	
• H_2 from water o Electrolysis/Thermolysis o Thermochemical cycles	6	3	
• Routes towards synthetic liquid fuels	2		
• Solar chemical reactors	6	4	
Learning outcomes			
The student will be familiar with the different routes foreseen to produce solar fuels in the future			
Module total	**60**	**26**	**4**

Thermal Storage			
Syllabus	**Lectures**	**Tutorials**	**Laboratory**
	20	10	
• Overview of thermal storage (TS)	2		
• Needs of TS in solar applications	2		
• Available technologies (sensible, latent heat, thermochemical, ...)	3		
• Related materials	3	3	
• Heat transfer interfaces and fluids	3	3	
• Implementation of TS	3	2	
• Management and strategy of TS	2	2	
• Related companies and products	2		
….			
Learning outcomes			
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			
Module total	**20**	**10**	

Laboratory

The major part of practical training is organised in the PROMES laboratory located in Odeillo. For the low solar energy and storage energy modules, additional practical training will be organised in PROMES –Perpignan.

In Odeillo :
The PROMES laboratory is equipped with large scale concentrating systems, with a high temperature measurement lab and with pilot scale solar receiver testing facilities at low and high temperature.

Concentrating solar facilties:

- 10 very high concentration solar furnaces (1kW – 2 kW)
- One medium concentration solar furnace (5 kW)
- One 50 kW (thermal) dish equipped with a 10 kW *Solo* Stirling engine
- One 1 MW solar furnace
- One 5 MW central receiver concentrating facility (Themis)

High temperature measurement lab

- Black bodies up to 3000K
- Pyrometers and IR camera
- Reflectometer
- Spectroradiometer

Solar receivers

- Mock-ups of pressurized air solar receivers
- Porous ceramic volumetric receivers
- Tube receivers

In Perpignan

Solar collectors
Various technologies of collectors are available for testing (flat plate, vaccum tubes, air heating).
The laboratory is also equipped with an industrial bench for testing of solar collector according to European standard EN12975.

Solar conversion
Solar heating solar water system with stratified storage tank

Two prototypes of solar cooling are in operation (Silicagel/Water, 7,5 kW and $BaCl_2$/ammonia, 5 kW), both including PCM heat and/or cold storage.