UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

Course guide
240052 - 240052 - Thermodynamics

Last modified: 29/05/2023

Unit in charge: Barcelona School of Industrial Engineering
Teaching unit: 724 - MMT - Department of Heat Engines.

Degree: BACHELOR'S DEGREE IN INDUSTRIAL TECHNOLOGY ENGINEERING (Syllabus 2010). (Compulsory subject).

Academic year: 2023 **ECTS Credits:** 6.0 **Languages:** Catalan, Spanish

LECTURER

Coordinating lecturer: XAVIER RAMIS JUAN

Others: Asensio Arjona, Sergio
Fernandez Francos, Xavier
Konuray, Ali Osman
Martin Godoy, Jose Luis
Moradi, Sasan
Morancho Llena, Jose Maria

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
1. Knowledge on applied thermodynamics and heat transfer. Basic principles and their application to solve engineering problems.

TEACHING METHODOLOGY

During theory and problem sessions main theoretical aspects of each topic will be explained and problems with a practical application will be solved. Some of these problems will be solved by students, individually or in small groups, and the necessary data will obtained from charts or graphics. Students will also be proposed to execute design exercises with opened end, out of class time, in which they will have to think how a certain process takes place, raising the application of theoretical knowledge and proceeding to their numerical solution. To solve this type of problems certain computer software, such as EEES or similar, will be allowed to use. Both for exercises done by students in or outside class will be suitable of being part of the subject's continuous evaluation.
Students will execute five practical sessions in the laboratory (two hours each sessions). All laboratory sessions will consist in executing an experimental practice.

LEARNING OBJECTIVES OF THE SUBJECT

The subject's main objective is to apply Thermodynamics principles into processes with an industrial interest, such as energy transformation. Special attention will be placed on thermodynamic cycles of power production, cold and heat production and thermodynamics of combustion reactions and humid air.

At the end of the course the student should be able to:
- Raising and solving energy balances, entropy and exergy of thermodynamic cycles and devices and simple processes related with energy transformation.
- Using charts and graphics of thermodynamic properties and other tools that allow to find these properties.
- Analysing the obtained results, once a problem is solved, are coherent with the studied system.
- Experimentally measuring properties of phenomena related with the subject's contents.

STUDY LOAD

Type	Hours	Percentage
Hours medium group	12,0	8.00
Hours small group	10,0	6.67
Self study	90,0	60.00
Hours large group	38,0	25.33

Total learning time: 150 h

CONTENTS

Topic 1. Properties of pure substances

Description:
PvT surface of a pure substance. Pv, Tv i PT diagrams. Charts and diagrams of properties. Analytical ways to relate PvT properties. Calculation of thermodynamic properties by means of the discrepancy functions method.

Specific objectives:
Acquiring a methodology to estimate thermodynamic properties of pure substances.
Applying the energy balance for closed systems to solve problems.

Related activities:
Activity 1. Practice 1. PvT properties of a pure substance.
Activity 8. Resolution of problems outside the classroom and/or Activity 7. Group test.

Related competencies :
CE7. Knowledge on applied thermodynamics and heat transfer. Basic principles and their application to solve engineering problems.

Full-or-part-time: 34h
Theory classes: 5h
Practical classes: 6h
Laboratory classes: 2h
Self study : 21h

Topic 2. Energy analysis of opened systems

Description:
Mass and energy balance in opened systems. Continuity equation. Analysis in a control volume for stationary and transitory systems. Application of the energy balance in systems with an engineering interest: filling and emptying tanks, cauldrons, valves, exchangers, nozzles, diffuser, compressors and turbines.

Specific objectives:
Applying mass and energy balances in opened systems to solve problems.

Related activities:
Activity 2. Practice 2. Compression of gases at low pressures.
Activity 6. Individual test of continuous evaluation in the classroom
Activity 8. Resolution of problems outside the classroom and/or Activity 7. Group test.

Related competencies :
CE7. Knowledge on applied thermodynamics and heat transfer. Basic principles and their application to solve engineering problems.

Full-or-part-time: 21h 30m
Theory classes: 3h 30m
Practical classes: 3h
Laboratory classes: 2h
Self study : 13h

Topic 3. Entropy and exergy balances in opened systems

Description:
Entropy balance in opened systems. Analysis in a control volume. Isentropic performance. T-s and h-s diagrams. Exergy. Lost work. Exergy balance in stationary opened systems. Exergetic performance.

Specific objectives:
Using entropy data to calculate isentropic performances.
Applying the entropy and applying the entropy and exergy balance in the different formulations to solve the problems.

Related activities:
Activity 8. Resolution of problems outside the classroom and/or Activity 7. Group test.

Related competencies :
CE7. Knowledge on applied thermodynamics and heat transfer. Basic principles and their application to solve engineering problems.

Full-or-part-time: 15h
Theory classes: 3h
Practical classes: 3h
Self study : 9h

Topic 4. Power cycles of a vapour turbine

Description:
Analysis method of thermodynamic cycles. Rankine cycle. Improvements: overheating, intermediate heating, regeneration. Cogeneration. Exergetic analysis of a vapour turbine power plant.

Specific objectives:
Making schematic T-s diagrams and representations of vapour power cycles.
Analysing energetically and exergetically Rankine's power cycles.

Related activities:
Activity 6. Individual test of continuous evaluation (in the classroom)
Activity 8. Solving problems outside the classroom and/or Activity 7. Group test.

Related competencies :
CE7. Knowledge on applied thermodynamics and heat transfer. Basic principles and their application to solve engineering problems.

Full-or-part-time: 18h 30m
Theory classes: 3h 30m
Practical classes: 4h
Self study : 11h

Topic 5. Gas power cycles

Description:
Alternative internal combustion engines. Indicator diagram. Otto's cycle with standard air. Diesel cycle with standard air. Dual cycle with standard air. Ericsson's and Stirling's cycles. Opened and closed gas turbine. Brayton's cycle with standard air. Regenerative Brayton's cycle. Gas turbine with intermediate overheating and intermediate overcooling. Combined cycle of gas an vapour.

Specific objectives:
Analysing Otto, Diesel and Dual cycles.
Analysing energetically and exergetically a gas turbine's cycles.

Related activities:
Activity 3. Practice 3. Stirling's engine
Activity 8. Solving problems outside the classroom and/or Activity 7. Group test.

Related competencies :
CE7. Knowledge on applied thermodynamics and heat transfer. Basic principles and their application to solve engineering problems.

Full-or-part-time: 19h
Theory classes: 3h 30m
Practical classes: 2h 30m
Laboratory classes: 2h
Self study : 11h

Topic 6. Cooling cycles and heat pumps

Description:
Cooling cycle by means of compressing vapour. Heat pump. Coefficient of performance. Properties of refrigerants. Multiple stages and cascade cooling cycles. Refrigerating systems by means of gas.

Specific objectives:
Analysing refrigerating cycles by means of compressing vapour and by means of gas refrigeration.

Related activities:
Activity 4. Practice 4. Refrigerating cycle by means of compressing vapour with R-134a.
Activity 6. Individual test of continuous evaluation (in the classroom)
Activity 8. Solving problems outside the classroom and/or Activity 7. Group test.

Related competencies :
CE7. Knowledge on applied thermodynamics and heat transfer. Basic principles and their application to solve engineering problems.

Full-or-part-time: 15h
Theory classes: 2h
Practical classes: 2h
Laboratory classes: 2h
Self study : 9h

Topic 7. Non-reactive mixtures of ideal gases. Humid air

Description:
Description of ideal gases mixtures. Basic concepts of psychometry. Humid air. Maas and energy balances in systems with humid air. Temperature of adiabatic saturation and of humid bulb. Psychometric diagram. Air conditioning processes.

Specific objectives:
Applying principles of mass and energy conservation to analyse different processes of air conditioning.
Using the psychometric diagram to analyse air conditioning processes.

Related activities:
Activity 5. Practice 5. Humid air. Air conditioning processes.
Activity 8. Solving problems outside the classroom and/or Activity 7. Group test.

Related competencies :
CE7. Knowledge on applied thermodynamics and heat transfer. Basic principles and their application to solve engineering problems.

Full-or-part-time: 15h 30m
Theory classes: 2h 30m
Practical classes: 2h
Laboratory classes: 2h
Self study : 9h

Topic 8. Reactive mixtures. Combustion

Description:
Thermodynamics of reactive systems. Combustion. Stoichiometric air and excess of air. Mass and energy balances in reactive mixtures. Absolute entropies. Standard combustion and formation enthalpies. Superior and inferior calorific power. Flame's adiabatic temperature. Entropy balance in reactive systems. Exergetic analysis.

Specific objectives:
Applying mass and energy balances in reactive mixtures.

Related activities:
Activity 8. Solving problems outside the classroom and/or Activity 7. Group test.

Related competencies :
CE7. Knowledge on applied thermodynamics and heat transfer. Basic principles and their application to solve engineering problems.

Full-or-part-time: 11h 30m
Theory classes: 2h 30m
Practical classes: 2h
Self study : 7h

ACTIVITIES

PRACTICE 1. PVT PROPERTIES OF A PURE SUBSTANCE

Description:
Executing in groups of two students a laboratory practice about experimental determination of a pure substance's PvT properties.

Specific objectives:
Interpreting the PvT surface of pure substances and their projections.
Identifying different states of a fluid.
Identifying different types of state equations.

Material:
Experimental assembling to determine pressure, volume and temperature of a pure substance confined in a closed system.

Delivery:
The activity will be evaluated by means of the pre-laboratory, the post -laboratory report and the professor's mark on the student's performance in the laboratory.

Full-or-part-time: 7h 30m
Laboratory classes: 2h
Self study: 5h 30m

PRACTICE 2. COMPRESSION OF LOW PRESSURE GASES

Description:
Executing in groups of two students a laboratory practice on compressing low pressure gases.

Specific objectives:
Identifying work and heat as trajectory functions.
Distinguishing the concepts of isothermal, polytrophic and adiabatic processes.
Relating, analytically and graphically, the polytrophic coefficient, work and heat.
Understanding how a heat pump works and how a refrigerating cycle works.

Material:
Experimental assembly consisting in a cylinder-piston with three sensors that allow to measure in, real time, pressure, temperature and volume.

Delivery:
The activity will be evaluated by means of the pre-laboratory, the post -laboratory report and the professor's mark on the student's performance in the laboratory.

Full-or-part-time: 7h 30m
Laboratory classes: 2h
Self study: 5h 30m

PRACTICE 3. STIRLING'S ENGINE

Description:
Executing in groups of two students a laboratory practice on an engine that uses air as a working fluid and alcohol as combustible and that operates according to a Stirling's cycle.

Specific objectives:
Analysing the Stirling's cycle.
Describing the working principle of engines and cycles refrigerated by means of gas.
Determining the performance and the efficiency coefficient of real and ideal Stirling's cycles.

Material:
Experimental assembly consisting in a Stirling's engine with different sensors which allow to measure in real time pressure, volume and temperature of the gas inside the engine and the amount of rotations the engine executes.

Delivery:
The activity will be evaluated by means of the pre-laboratory, the post -laboratory report and the professor's mark on the student's performance in the laboratory.

Full-or-part-time: 7h 30m
Laboratory classes: 2h
Self study: 5h 30m

PRACTICE 4. REFRIGERATION CYCLE BY MEANS OF COMPRESSING VAPOUR WITH R-134ACIÓ POR COMPRESSIÓ DE VAPOR AMB R-134A

Description:
: Executing in groups of two students a laboratory practice on a refrigeration cycle by means of compression which works with R-134as a refrigerant.

Specific objectives:
Analysing refrigeration cycle by means of vapour compression.
Representing a P-h diagram of a refrigeration cycle by means of vapour compression from experimental data.
Applying energy balances to a control volume.

Material:
Experimental assembly consisting in a refrigeration cycle by means of vapour compression with R-134a. Manometers, thermometers, rotametres and wattmeter which allow to measure different experimental parameters.

Delivery:
The activity will be evaluated by means of the pre-laboratory, the post -laboratory report and the professor's mark on the student's performance in the laboratory.

Full-or-part-time: 7h 30m
Laboratory classes: 2h
Self study: 5h 30m

PRACTICE 5. HUMIT AIR

Description:
refrigeration cycle by means of vapour compression on the study of different air-conditioning processes

Specific objectives:
Applying mass and energy balances in reactive mixtures.
Calculating internal combustion energies from combustion enthalpies.
Using concepts such as: oxygen excess, adiabatic temperature, combustion enthalpy.

Learn to measure the properties of the air humidity, using the hygrometer, the psychrometer and the anemometer.
Applying mass and energy balances in air humit
Using some experimental information and the psychrometric chart, calculate heat fluxes of the interior and exterior units.

Material:
Air conditioning unit with R-410.
Hygrometers, psychrometers, thermometers and anemometers.
Wattmeter.

Delivery:
The activity will be evaluated by means of the pre-laboratory, the post -laboratory report and the professor's mark on the student's performance in the laboratory.

Full-or-part-time: 7h 30m
Laboratory classes: 2h
Self study: 5h 30m

INDIVIDUAL TESTS OF CONTINUOUS EVALUATION IN THE CLASSROOMUADA A CLASSE

Description:
Individual test in the classroom consisting in the execution of an exercise to evaluate if the student has achieved the minimal necessary contents of all topics (up to the date of the test).

Specific objectives:
Achieving specific objectives of the topic on which the test is about.

Material:
Test's wording, calculator and thermodynamic charts.

Delivery:
Delivering the solved test with the corresponding teaching staff feedback.

Full-or-part-time: 1h 30m
Practical classes: 0h 30m
Self study: 1h

GROUP TESTS

Description:
Puzzle sessions with base groups of three p students. Numerical problems will be distributed with, a single solution, to the group members this way each problem partially covers the learning objectives which are intended to achieve. After the problems resolution by each member of the group, in the final part of the session the group agrees to a definitive solution and delivers it to the professor.

Specific objectives:
Achieving the topic's specific objectives of the workshop.

Material:
Test's wording, calculator and thermodynamic charts.

Delivery:
Delivering solved problems, with the corresponding teaching staff feedback, in the following session and group thinking on the most remarkable errors if necessary. Alternatively the solution of the problem could be delivered in ATENEA.

Full-or-part-time: 3h 30m
Practical classes: 1h 30m
Self study: 2h

RESOLUTION OF PROBLEMS OUTSIDE THE CLASSROOM

Description:
Solving problems individually outside the classroom. This way the student will progressively achieve the main teaching objectives.

Specific objectives:
Achieving specific objectives of the topic on which the activity is about.

Material:
Test's wording, calculator and thermodynamic charts, books and class notes.

Delivery:
Delivery of solved problems with the corresponding teaching staff feedback.

Full-or-part-time: 1h
Self study: 1h

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PARTIAL EXAM

Description:
Assessment of knowledge.

Delivery:
Solved exam.

FINAL EXAM

Description:
Assessment of knowledge.

Delivery:
Solved exam.

GRADING SYSTEM

Evaluation will consist of four marks:
1) Final exam mark (Nef). Nef is the mark of the test that will take place in a date decided by the School and will consist in a collection of numerical exercises. During the final exam students will be allowed to use a handwritten sheet (DIN A4) with formulas, a book with graphs and charts and the calculator.
2) Partial test mark (Npp). Npp is the mark of the partial test that takes place in mid-semester in a date fixed by the School and will consists in a collection of numerical exercises. During the partial test students will be allowed to use a handwritten sheet (DIN A4) with formulas, a book with graphs and charts and the calculator.
3) Laboratory mark (Nlab). This mark corresponds to the laboratory practices mark and will be obtained from the pre-laboratory work, the post-laboratory report and the professor's evaluation on the student's performance in the laboratory.
4) Continuous evaluation mark (Nac). Nac includes the following three marks:
Nac=0.4*Ncc+0.3*Npac + 0.15*Nqa + 0,15*Ngroupwork
Ncc is the mark of the knowledge tests carried out in class, Npac is the mark of the evaluation tests carried out in Atenea, Nqa is the mark of the self-assessment tests carried out in Atenea and Ngroupwork is the mark of the resolution of problems in group work.

The final mark is calculated as:
Nfinal=0,55*Nef+0,1*Npp+0,1*Nlab+0,25*Nac
Npp and Nac will only be taken into account if they are higher than Nef

The final mark of re-evaluation is calculated with the following formula:
Nfinal,re=0,9*Nef,re+0,1*Nlab
where Nef,re is the re-evaluation exam mark

BIBLIOGRAPHY

Basic:
- Çengel, Yunus A. Termodinámica [on line]. 9a ed. México: McGraw-Hill, 2019 [Consultation: 08/09/2020]. Available on: http://www.ingebook.com/ib/NPcd/IB_BooksVis?cod_primaria=1000187&codigo_libro=8722. ISBN 9781456272081.
- Moran, M. J.; Shapiro, H. N. Fundamentos de termodinámica técnica [on line]. 2a ed. Barcelona: Reverté, 2004 [Consultation: 07/09/2022]. Available on: https://www-ingebook-com.recursos.biblioteca.upc.edu/ib/NPcd/IB_Escritorio_Visualizar?cod_primaria=1000193&libro=7704. ISBN 8429143130.

Complementary:
- Van Wylen, Gordon John. Fundamentos de termodinámica. 2a ed. México: Limusa-Wiley, 1999. ISBN 9681851463.
- Wark, K. Termodinámica. 6a ed. Madrid: McGraw-Hill, 2001. ISBN 844812829X.

RESOURCES

Other resources:

¿ Charts and graphics of thermodynamic properties.

¿ Thermodynamics. Test and problems.

¿ In the ATENEA platform academic material will be uploaded, such as: laboratory practice guidelines, problem wordings and multiple choice sample tests with their resolution. In addition each professor will upload their own audiovisual and software material.