Academic Year 2026/2027

Course Guide:

APPLIED THERMODYNAMICS

FACULTY OF CHEMICAL SCIENCES

1. IDENTIFICATION

Degree Programme	Bachelor's Degree in Chemical Engineering			Code	801541
Course	Applied Thermodynamics			ECTS	6
Subject Area	Thermodynamics and Thermal Engineering				
Module	Industrial Engineering				
Course Type	Compulsory	Year	Second	Semester	Second
Responsible Department	Chemical Engineering and Materials Science				

Teaching Staff

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Group A

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2. OBJECTIVES

General Objective

The aim of this course is to study different applications of thermodynamic principles to various separation operations, heat engines, and processes in the chemical industry.

The general objective is to provide the student with extensive and in-depth knowledge of the main methods for estimating and calculating thermodynamic properties related to phase equilibrium and chemical equilibrium, and to study thermodynamic (energy and exergy) analysis methods for the design of more efficient thermal systems.

Specific Objectives

- Solve problems involving real fluids using volumetric equations of state.
- Identify equilibrium criteria in systems subject to different constraints.
- Identify the conditions for phase equilibrium.
- Calculate the fugacity of a pure compound.
- Use fugacity in the calculation of vapour–liquid equilibrium.
- Obtain the criteria for phase equilibrium in multicomponent systems.
- Distinguish between ideal and non-ideal mixtures.
- Understand the concepts of excess properties and activity coefficients.
- Calculate the fugacity of a compound in a multicomponent mixture.
- Use activity coefficient models, both when experimental data are available and when predictions must be made in the absence of experimental data.
- Know how to select the most appropriate thermodynamic model for the system under study.
- Calculate the bubble point, dew point, and partial vaporisation of ideal and non-ideal systems.
- Understand the importance of vapour–liquid equilibrium in the distillation separation operation.
- Calculate the solubility of a gas in a liquid.
- Calculate equilibrium compositions when two partially miscible liquids are mixed.
- Calculate equilibrium compositions when two partially miscible liquids and their vapour are mixed.
- Calculate the solubility of a solute in a fluid phase.
- Calculate the chemical equilibrium of a single-phase system with one chemical reaction.
- Calculate the chemical equilibrium of a multiphase system with several chemical reactions.
- Calculate the enthalpy of a pure compound in a single-phase system and in a two-phase system at equilibrium.
- Calculate the enthalpy of multicomponent mixtures in a multiphase system under equilibrium conditions.
- Calculate exergy in closed and open systems.
- Calculate exergy efficiency in different systems.
- Perform exergy analysis of thermal systems for power production.
- Understand the behaviour of steam and obtain its properties from tables, diagrams, and correlations.
- Understand the fundamentals of heat engines used in power cycles.
- Thermodynamically model the devices used for power generation.
- Calculate the thermal efficiency of steam and gas turbines and understand the modifications to improve their efficiency.
- Calculate the coefficient of performance (COP) of refrigeration systems and understand the modifications to improve their efficiency.

3. PRIOR KNOWLEDGE AND RECOMMENDATIONS

Prior Knowledge

Following this course satisfactorily requires the student to have previously acquired the knowledge and competences corresponding to the following courses: “*Applied Computing*”, “*Fundamentals of Chemical Engineering*”, and “*Thermodynamics and Chemical Kinetics*”. Although enrolment is not formally conditioned on these knowledge, effective mastery of this knowledge is essential to this course with a reasonable prospect of success.

Recommendations

It is recommended that students should have a basic level of English that enables them to use English-language bibliography, conduct information searches, and communicate in writing and orally in that language. Furthermore, to make better use of the course, students are advised to be familiar with computer tools and software for solving complex problems, e.g., Microsoft Excel, as well as applications for drafting, editing, and presenting technical reports.

4. CONTENTS

Brief Description

Thermodynamic properties of real fluids. Thermodynamics of phase equilibrium. Chemical equilibrium. Exergy analysis of systems. Steam and gas turbines. Refrigeration systems.

Course Syllabus

BLOCK 1. PHASE EQUILIBRIUM AND CHEMICAL EQUILIBRIUM

Topic 1: Thermodynamics of Phase Equilibrium

Equilibrium state. Equilibrium criteria. Chemical potential. Equilibrium in a closed multiphase system. Gibbs-Duhem equation. The phase rule. Fugacity and fugacity coefficient. Ideal systems. Activity and activity coefficient.

Topic 2: Fugacity and Fugacity Coefficient

Basic relations. Equations of state. Calculation formulae.

Topic 3: Activity Coefficients in Liquid Mixtures

Activity coefficients from excess properties. Wilson, NRTL, and UNIQUAC equations. Estimation of activity coefficients by group contribution methods: UNIFAC. Activity coefficients from experimental equilibrium measurements.

Topic 4: Vapour-Liquid Equilibrium

Vapour–liquid equilibrium diagrams. Vapour–liquid equilibrium ratio. Composition-independent equilibrium ratios. Composition-dependent equilibrium ratios. Solubility of gases in liquids. Henry’s Law. Thermodynamic consistency of equilibrium data. Equilibrium diagrams.

Topic 5: Liquid-Liquid Equilibrium

Miscibility and thermodynamic stability in liquid-liquid equilibrium. Binary mixtures. Ternary and multicomponent mixtures.

Topic 6: Liquid-Solid Equilibrium

Solubility of solids in liquids. Solubility of solids and liquids in supercritical fluids.

Topic 7: Enthalpies of Mixing

Molar enthalpies of pure compounds. Partial molar enthalpies of mixing. Enthalpy diagrams of binary mixtures. Enthalpies of reaction.

Topic 8: Chemical Equilibrium

Chemical equilibrium in a single-phase system. The equilibrium constant. Equilibrium compositions. Chemical equilibrium with multiple reactions in a single phase. Combination of chemical equilibrium and phase equilibrium.

BLOCK 2. THERMAL ENGINEERING

Topic 9: Thermodynamics of Water and Steam

Introduction. Water in the liquid state. Saturated steam. Superheated steam. Tables, correlations, CoolProp library, and diagrams for steam.

Topic 10: Exergy Analysis of Systems

Concept of exergy. Exergy balances in closed systems. Exergy balances in open systems. Exergetic efficiency of equipment. Sankey and Grassmann diagrams.

Topic 11: Steam Turbines

Introduction. Operation of a thermal power plant. The Rankine cycle. The Rankine cycle with steam reheat. Regenerative Rankine cycle. Organic Rankine cycles. Cogeneration systems.

Topic 12: Gas Turbines

Introduction. Applications of gas turbines. Brayton cycle. Modified Brayton cycles. Combined gas-steam cycles.

Topic 13: Refrigeration Systems

Introduction. Vapour-compression refrigeration. Types of refrigerants. Cascade compression systems. Multistage compression systems. Absorption refrigeration. The heat pump. Gas refrigeration: reversed Brayton cycle.

5. COMPETENCES

General

CG1-MII1	Apply concepts of applied thermodynamics.

Specific

CE7-T1	Apply the principles of thermodynamics to different types of systems.
CE7-T2	Formulate the equilibrium and stability criteria of systems and apply them to phase equilibria and chemical equilibrium.
CE7-T3	Calculate the parameters and variables that define phase equilibrium and chemical equilibrium.
CE7-T9	Apply the principles of thermodynamics to different types of industrial and technological systems.
CE7-T11	Design selected heat and refrigeration installations and devices: steam and gas turbines and refrigeration machines.

Cross-cutting

CT2-II1	Demonstrate problem-solving ability.
CT5-II1	Consult, use and analyse bibliographic sources.
CT5-II2	Use bibliography, specialised databases and resources accessible through the Internet.
CT6-III	Use computer tools and software.

6. WORKLOAD DISTRIBUTION BY ACTIVITY

Activity	In-class (hours)	Self-study (hours)	Credits
Lectures	36	49	3,4
Seminars	20	22,5	1,7
Tutorials / guided work	4	6	0,4
Preparation of assignments and exams	6	6,5	0,5
Total	**66**	**84**	**6**

7. METHODOLOGY

The course teaching time is divided into lectures, seminars, and tutorials.

The lectures will consist mainly of lectures in which the theoretical knowledge necessary to solve the practical examples covered throughout the course will be presented.

The seminars will address both solving previously assigned problems and some complementary and eminently practical topics.

The tutorial sessions will be conducted in two groups, each comprising half of the students enrolled in each group. During the tutorials, student progress will be supervised and questions answered. Some of the tutorials will be carried out using Microsoft Excel.

The UCM Virtual Campus will be used as a tool for making available to students the material to be used in lectures and seminars, and as a means of communication the lecturer and students. Some of the recommended bibliography and support material uploaded to the Virtual Campus for the development of the teaching activities of this course will be in English.

8. BIBLIOGRAPHY

Basic

- PRAUSNITZ, J.M.; LICHTENHALER, R.N. GOMES DE ACEVEDO, E., *Molecular Thermodynamics of Fluid-Phase Equilibria*. Prentice-Hall, Inc.; Upper Saddle River, NJ, 3rd Ed. 1999.
- SMITH, J.M., ABBOTT, M.M., VAN NESS, H.C., *Introduction to Chemical Engineering Thermodynamics*. McGraw-Hill; New York, 7th Ed. 2005.
- MORAN, M. and SHAPIRO, N., Fundamentals of Engineering Thermodynamics. Reverté, Barcelona, 2004.
- MORAN, M. and SHAPIRO, N., Fundamentals of Engineering Thermodynamics. Wiley, 9th Ed. 2018.
- ÇENGEL, Y.A., BOLES, M. A., Thermodynamics. McGraw-Hill, 8th Ed. 2014.
- ÇENGEL, Y.A., BOLES, M. A., Thermodynamics: An Engineering Approach. McGraw-Hill, 9th Ed. 2018.

Complementary

- POLING, B.; PRAUSNITZ, J.M., O'CONNELL, J.O., The Properties of Gases and Liquids. McGraw-Hill Education Co.; New York, 5th Ed. 2000.
- HOUGEN, O.A.; WATSON, K.M. and RAGATZ, R.A., Chemical Process Principles. Vol. II. Thermodynamics. Wiley; New York. 1959.
- WALAS, S.M., *Phase Equilibria in Chemical Engineering*. Butterworth Publishers; Boston, MA. 1985.
- WINTERBONE D., TURAN A., *Advanced Thermodynamics for Engineers*. Butterworth-Heinemann, 2nd Ed. 2015.
- MACCHI, E., ASTOLFI, M. (ed.), *Organic Rankine Cycle (ORC) Power Systems: Technologies and Applications*. Woodhead Publishing, 2016.

9. ASSESSMENT

The student's academic performance, as well as the final grade for the course, will be calculated as a weighted average according to the percentages shown below, which will be maintained in all assessment periods.

The final course grade will be calculated as the weighted average of the different assessable activities. However, to pass the course, students must obtain the minimum grade established for each activity. If this requirement is not met, the final grade will be the weighted average, capped at 4.5 out of 10. This criterion shall apply to both the ordinary and extraordinary assessment periods.

- **WRITTEN EXAMS: 70%**

  The course competences (CG1-MII1, CG4, CE7-T1, CE7-T2, CE7-T9, CE7-T10, CE7-T11, CT1, CT2, CT8) will be assessed through two written partial exams, mainly practical in nature. The first partial exam, scheduled around the middle of the course, will assess Block 1 of the syllabus (phase equilibrium and chemical equilibrium). The second partial exam, at the end of the course, will focus on Block 2 (thermal engineering) and will be carried out in a computer room using MS Excel and the CoolProp add-in, whenever availability allows.

  Students must achieve a minimum average of 5 in the partial exams to be eligible for the overall grade, and must obtain at least a 4 in partial exam in order to pass the course.

If any partial exam receives a grade below 4, its re-evaluation will be mandatory in the ordinary assessment period in order to pass the course.

Partial exams with a grade above 5 will allow the student, if they so wish, to be exempt from that part in the ordinary assessment period. However, students who choose to take the ordinary examination to improve their grade will be assessed exclusively based on the grade obtained in that session.

In the extraordinary assessment period, students must take examinations for both blocks, regardless of the grades obtained in the partial exams. In both sessions, ordinary and extraordinary, a minimum grade of 4 in each block and a minimum average grade of 5 between both blocks is required in order to pass the course.

❖ INDIVIDUAL WORK AND GUIDED ACTIVITIES: 30%

The assessment of the individual learning work carried out by the student will take into account the student's ~~st~~ability to solve model problems from each part of the course. In tutorials where MS Excel is used, in addition to the corresponding report, the calculation programs/files developed by the student in the preparation of results will be submitted. The personal work completed in each of the two blocks of the course will account for 15% each of the overall assessment.

The assessment will allow the degree of achievement of competences CG4, CE7-T2, CE7-T11, CT1, CT2, CT5, CT8 to be determined. Individual work accounts for 30% of the overall assessment.

❖ ATTENDANCE AND ACTIVE PARTICIPATION:

In order to access the overall assessment of the course, the student must have participated in at least 70% of the in-person teaching activities (lectures, seminars, and tutorials).

The grades for the activities planned for the assessment of the course (examinations, submission of problems, tests, etc.) will be communicated to students with sufficient notice before the final examination, so that they can properly plan their study of this and other courses.

In particular, the grades for the partial exams will be communicated within a maximum period of 20 days, except in the case of the second partial exam, where the period may be shorter in order to adapt to the final examination.

In any case, a minimum period of seven days between the publication of grades and the date of the final examination of the course will be observed.

ACTIVITY PLANNING - SCHEDULE

UNIT	ACTIVITY	HOURS	GROUPS	START	END
1. Phase Equilibrium and Chemical Equilibrium	Lectures	18	1	Week 1	Week 8
	Seminar	10	1		
	Tutorial*	2	2	Weeks 5 and 7	
2. Thermal Engineering	Lectures	18	1	Week 8	Week 15
	Seminar	10	1		
	Tutorial*	2	2	Weeks 12 and 15	

* The scheduled tutorials are subject to possible modifications according to the joint planning of the course.

SUMMARY OF THE ACTIVITIES

ACTIVITY	ASSOCIATED COMPETENCES	TEACHING ACTIVITY	STUDENT ACTIVITY	ASSESSMENT	P	NP	TOTAL	C
Lectures	CG1-MII1, CE7-T1, CE7-T2, CE7-T9, CE7-T11	Verbally present the main lines of each topic in the syllabus.	Attend and actively participate in the development of the class.	Written examinations.	36	49	85	
Seminars	CG1-MII1, CE7-T1, CE7-T2, CE7-T9, CE7-T11, CT2-II1, CT5-II1, CT5-II2	Pose and solve numerical questions and problems.	Discuss and solve the proposed questions and problems.	Written examinations.	20	22,5	42,5	
Tutorials	CG1-MII1, CE7-T1, CE7-T2, CE7-T9, CE7-T11, CT2-II1, CT5-II1, CT5-II2	Supervise the progress of students in their work. Mark written tests	Develop their personal work and complete written tests.	Written tests and submission of solved problems.	4	6	10	**30%**
Examinations	CG1-MII1, CE7-T1, CE7-T2, CE7-T9, CE7-T11, CT2-II1	Design and mark the examinations. Grade students.	Sit the examinations.	Examinations.	6	6,5	12,5	**70%**

P: Contact activities

NP: Non-contact activities (independent study)

C: Grade