UNIVERSITY OF CAMBRIDGE
Chemical Engineering and Biotechnology

CHEMICAL ENGINEERING TRIPOS

Part IIA

SYLLABUS 2021-22

Contents ***Page***

General Introduction

Students reading the Chemical Engineering Tripos normally progress as follows:

- 1st year: Part IA Natural Sciences Tripos or Part IA Engineering Tripos
- 2nd year: Part I Chemical Engineering Tripos (CET I)
- 3rd year: Part IIA Chemical Engineering Tripos (CET IIA)
- 4th year: Part IIB Chemical Engineering Tripos (CET IIB)

Progress is dependent on satisfactory performance in the previous year's course – honours standard in CET I is sufficient to do CET IIA. Students are normally required to achieve class II.2 or higher in CET IIA in order to progress to CET IIB.

Please note, this Syllabus document was correct at the time of printing. However, changes may occur during the year due to unforeseen circumstances.

The educational aims of the overall Chemical Engineering Tripos are to:

- give a sound education in the fundamentals of Chemical Engineering;
- develop the skills and confidence necessary for the solution of problems in the chemical, biochemical and allied industries;
- produce graduates of the highest calibre;
- provide an education accredited by the Institution of Chemical Engineers.

Outline of Part I Chemical Engineering Tripos (CET I)

In Part I students gain a broad exposure to the core Chemical Engineering topics.

There are lecture courses on:

- Fundamentals: process calculations; fluid mechanics; biotechnology fundamentals; heat and mass transfer fundamentals
- Process operations: separations; homogeneous reactors; biotechnology operations; heat and mass transfer operations
- Process systems: introductory chemical engineering
- Mathematics: engineering mathematics
- Enabling topics: stress analysis and pressure vessels; mechanical engineering for those who read Natural Sciences in the first year; introductory chemistry for those who read Engineering in the first year

In addition, students are required to undertake classes on:

- Exercises
- Chemical Engineering laboratory
- Engineering drawing: for those who read Natural Sciences in the first year
- Physical chemistry laboratory: for those who read Engineering in the first year

Full details of these courses are provided in the Part I Syllabus Document.

Students for Part I will take four written examination papers. Papers 1-3 will be taken by all students. Paper 4(1) will be taken by students who read Natural Sciences in the first year, and Paper 4(2) will be taken by students who read Engineering in the first year. The format of examinations and weighting of written papers and project work is given in the Form and Conduct Notice published each year by the Chemical Engineering and Biotechnology Syndicate.

Outline of Part IIA Chemical Engineering Tripos (CET IIA)

In Part IIA students continue their study of core chemical engineering topics, both by extending subjects that were introduced in Part I and by being exposed to new topics.

There are lecture courses on:

- Fundamentals: advanced fluid mechanics; equilibrium thermodynamics; radiative heat transfer; corrosion and materials
- Process operations: heterogeneous reactors; separations; bioprocessing; particle processing
- Process systems: process dynamics and control; process synthesis; safety, health and environment
- Mathematical methods: partial differential equations; statistics
- Enabling topics: process design

In addition, students are required to undertake:

- Exercises
- Design project
- Engineering ethics

Full details of these courses are provided in the Part IIA Syllabus Document.

Students for Part IIA will take four written examination papers. These examinations are near the start of Easter term, after which the Design Project takes place. The format of examinations and weighting of written papers and project work is given in the Form and Conduct Notice published each year by the Chemical Engineering and Biotechnology Syndicate.

Rather than staying on for Part IIB, students may graduate with a B.A. degree after successfully completing Part IIA. Students leaving at this stage have not fully completed the academic requirements of the IChemE for becoming a Chartered Engineer.

Outline of Part IIB Chemical Engineering Tripos (CET IIB)

Part IIB is a Master's-level course that gives students a deeper understanding of some fundamental subjects, introduces a range of specialist areas of knowledge, and provides an opportunity for broadening their education.

Topics in Groups A and D are compulsory. Students are required to take a total of six modules from Groups B and C, of which at least two must come from Group B and at least two must come from Group C. Further, at least two of the six modules chosen from Groups B and C should be assessed principally or entirely by written examination.

Group A consists of the following compulsory topics.

- Sustainability in Chemical Engineering
- Energy Technology
- Chemical Product Design

Group B consists of advanced chemical engineering topics.

- Advanced Transport Processes
- Interface Engineering
- Pharmaceutical Engineering
- Adsorption and Advanced Nanoporous Materials
- Fluid Mechanics and the Environment
- Electrochemical Engineering

Group C consists of broadening material topics.

- Optical Microscopy
- Healthcare Biotechnology
- Biophysics
- Biosensors and Bioelectronics
- Foreign Language

The Group D topic is a compulsory project. Each student undertakes a research project, usually in collaboration with another student, supervised by a member of staff.

Full details of these courses are provided in the Part IIB Syllabus Document.

The format of examinations and weighting of written papers and project work is given in the Form and Conduct Notice published each year by the Chemical Engineering and Biotechnology Syndicate.

Students graduate with B.A. and M.Eng. degrees after successfully completing Part IIB. Provided they performed satisfactorily in the design component, they have satisfied the academic requirements of the IChemE for becoming a Chartered Engineer.

Student Workload Statement

It is expected that students will:

- attend and be attentive in all lectures and related classes;
- complete all assignments to a satisfactory standard by the imposed deadlines;
- prepare properly for all College supervisions;
- work in the vacations on consolidation, revision, exam preparation and any coursework.

The normal workload for a typical chemical engineering student is 45 hours each week during term. However, this is not a hard and fast figure. Some students work intensely and can achieve a great deal in an hour. Other students work less efficiently. In an ideal world, students would work on a particular task (problem sheet, lab write-up, exercise report) until the desired learning outcomes have been achieved. That said, students are advised not to spend significantly more time on work than the typical workload on a frequent basis. For supervision work, while it can be useful educationally for a student to battle through a problem to reach a solution (even if it takes a long time), it is perfectly acceptable for a student to "give up" after a decent effort and go on to the next question. One of the roles of supervisions is for students to ask for help on questions that they cannot answer. Question & Answer sessions and demonstrator assistance are also provided for much of the coursework to assist students.

Student Feedback

The Department of Chemical Engineering and Biotechnology has a strong tradition of good relations between staff and students and takes student feedback seriously.

You will be asked to complete a questionnaire on each lecture unit when it finishes. You will also be asked to complete an end-of-year questionnaire on the overall course. Please take time to fill these in. Staff very much value receiving constructive comments.

If there are any problems with teaching in the Department, please tell the lecturer or course organiser. It is a good idea to tell the organiser before the end of the course because it may be possible to rectify the problem. However, if the problem persists, please contact either Rachael Tuley, rlt23@cam.ac.uk or Helen Stevens Smith, hcs24@cam.ac.uk. If you would like to remain anonymous, your name can be removed before passing on to the relevant academic staff.

If there are any problems with College supervisions, then please tell your Director of Studies or Senior Tutor.

A further feedback mechanism within the Department is provided by the Staff-Student Consultative Committee (SSCC). This is the formal forum in which students comment on issues concerning life in the Department. Two student representatives will be elected from each undergraduate year group early in Michaelmas term to serve on this Committee. Meetings are held at least twice a year.

There is also an undergraduate representative on the Chemical Engineering and Biotechnology Syndicate. This is the University body that is responsible for overseeing the running of the Department – it is the equivalent of a Faculty Board. The election of the undergraduate representative to the Syndicate takes place late in Michaelmas term.

Chemical Engineering Tripos: information on plagiarism

The University's website on plagiarism makes the following statement:

> "Plagiarism is defined as submitting as one's own work, irrespective of intent to deceive, that which derives in part or in its entirety from the work of others without due acknowledgement. It is both poor scholarship and a breach of academic integrity."

The open literature, including web-based literature, is available for you to consult. Discussions about continually assessed work with other students, or with demonstrators or supervisors, can be beneficial, and we wish to encourage such discussions. However, any work that you submit for assessment must represent your own knowledge and understanding and not that of someone else. When you draw on the work of others, e.g. words, facts, data, ideas, diagrams, and software, you must acknowledge the source with an appropriate citation.

Any attempt to pass off the work of others as your own is a serious offence. If plagiarism (which includes unauthorised collusion) is detected, the Examiners will award a mark which reflects the underlying academic merit and extent of a candidate's own work. Further, the case may be referred to the Senior Proctor, the University Advocate, or taken to the University's Court of Discipline, depending on the nature of the offence.

Moreover, as well as not copying the work of others, you should not allow another person to copy your work. If you allow another person to copy your work, you may be found guilty of assisting an attempt to use unfair means.

Some continually assessed work is designed to be carried out individually, and some in collaboration with other students. The specifications regarding the manner of working and reporting are shown in the Student Collaboration Table below.

Information about the University's policy and procedures on plagiarism can be found at http://www.admin.cam.ac.uk/univ/plagiarism/

The University Library provides a Guide on Good Academic Practice and Avoiding Plagiarism here: https://libguides.cam.ac.uk/plagiarism

Plagiarism Quiz
At the start of the academic year, you will be asked to complete the Plagiarism Quiz on Moodle. Links will be provided to all cohorts at the start of term. All students must take the quiz. Successful completion of the quiz confirms that you have read and understood the policies and procedures of the Department and the University on plagiarism.

Student Collaboration Table 2021/2022

Level	Course	Instructions
CET I	Exercises	You must work as an individual.
CET I	Chemical Engineering Laboratory	You normally work in a group of two. You may collaborate with the other member or members of your group in conducting experiments and theoretical investigations, but your reports must be written independently.
CET I	Engineering Drawing	You must work as an individual.
CET I	Physical Chemistry Laboratory	You normally work in a group of two. You may collaborate with the other members of your group in conducting experiments and theoretical investigations, but your reports must be written independently.
CET IIA	Engineering Ethics	You must work as an individual.
CET IIA	Exercises	You must work as an individual.
CET IIA	Design Project	Because the projects are carried out in groups, cooperation between members of each group is essential. However, collaboration between different groups, and exchange of information, drawings, text, calculations and computer files, other than that which takes place at office hours and seminars, is prohibited. The report and associated calculations must represent the work only of the members of the group.
CET IIB	Chemical Product Design	Because some of the work is carried out in groups, cooperation between members of each group is essential. However, collaboration between different groups, and exchange of information, drawings, text, calculations and computer files, other than that which takes place during and following workshops and seminars, is prohibited. All individual reports must be written individually.
CET IIB	Research Project	You normally work in pairs, in which case you may collaborate with your partner in conducting experiments and theoretical investigations, but your reports must be written independently. If you work with a research group, you may collaborate with members of the group on experimental and theoretical investigations. However, your report must be written independently, and you should clearly state the assistance provided by other members of the research group.
CET IIB	Foreign Language	You must work as an individual.
CET IIB	Biosensors and Bioectronics	You must work as an individual when specified. When it is specified that you should work in a group, you may collaborate with the other members of your group in conducting experiments, theoretical investigations, and design exercises but your reports must be written independently.

Unit

Fluid Mechanics 2

Level	*Term*	*Duration*
CET IIA	LT 2022	24 lectures

Background

This course covers laminar incompressible flow, turbulent flow in a pipe, compressible flow, and two-phase flows, all of which are encountered in chemical engineering.

Aims

The aim is to cover the fundamental fluid mechanics principles, as well as mass and energy conservation, to enable the solution of general problems involving laminar flow, simple turbulent flow, and two-phase (gas-liquid, solid-liquid) flows.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- use the Navier-Stokes equations to analyse and solve laminar flow problems.
- examine the nature of turbulent flow and quantify velocity field fluctuations.
- analyse and solve problems concerning compressible flow through ducts of varying cross-section and through long pipelines.
- analyse and solve problems concerning the motion of single bubbles or particles.
- analyse and solve problems concerning two-phase gas-liquid flows in a pipe.

Assumed Knowledge

Material	*Source*
Basic fluid mechanics	CET I Fluid Mechanics
Averages, variances, correlation coefficients	CET I Laboratory / CET IIA Statistics
Solution of ODEs and PDEs	CET I Engineering Maths

Connections To Other Units

Several CET IIB units will build on the concepts introduced in this unit.

Self Assessment

Three problem sheets will be issued during lectures. The following examination questions indicate the level of achievement expected:
CET IIA: 2014-18 Paper 1, questions 1-4 ; 2019 Paper 1, questions 1-3; 2020 Paper A, question 1; 2021 Paper 1, questions 1-3

Assessment

The material from this unit is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
SSSC 6/9/2021	AJS	Fundamentals

Unit	Staff
Fluid Mechanics	Professor S.S.S. Cardoso

Synopsis

I Equations of Motion

1. Basic building blocks of fluid mechanics. Notation: scalars, vectors, tensors. Coordinates and frames of reference. The continuum hypothesis. Conservation equations and control volumes.
2. The equations of motion. Continuity equation in cartesian coordinates: mass conservation. The convective derivative. Energy equation. Species conservation. Momentum equation (Navier-Stokes) in cartesian coordinates. Stresses and rates of strain in a Newtonian incompressible fluid. Non-dimensionalising the Navier-Stokes equations: special cases – Euler's equation; Stokes' equation.
3. Application of the Navier-Stokes equations. Closed equation set for laminar flow; boundary conditions. Examples: uniform falling film; radial flow between parallel discs. Flow around a sphere. Computational fluid dynamics.
4. Turbulent Flow. Experimental observations of turbulent flow; Reynolds experiment. Averaging processes: time averages, spatial averages, ensemble means, cup means, averaging rules. Time-averaging of the equations of motion: Reynolds stresses; turbulent fluxes. Turbulent heat and mass fluxes.
5. Turbulence Models. Eddy viscosity and mixing length. Turbulent boundary layers: viscous sublayer, buffer layer and turbulent core. Other approaches for turbulent flow calculations: one-equation model and two-equation K-ε model.

II Compressible Flow

1. Isentropic flow. The velocity of sound. The Mach number, subsonic and supersonic flow. Flow through a constriction. Stagnation state. Area-velocity relation. Example: use of isentropic flow chart. Flow in a convergent nozzle. Mass flow rate. Choking. Area-ratio as a function of the Mach number. The impulse function. Example: use of isentropic flow chart. Flow in a convergent-divergent nozzle. Limiting velocity.
2. Non-isentropic flow. The normal shock wave. Application: force on a rocket.
3. Flow in a constant-area duct with friction. Adiabatic flow. Isothermal flow.

III Two-Phase Flow

1. Introduction to two-phase flow. Gas-liquid flow. Flow pattern maps. Lockhart-Martinelli correlation. Flooding correlations.
2. Solid particles. Stokes velocity; drag coefficients; non-spherical particles, concentration effects.
3. Drops and bubbles. Internal circulation and its effect on drag. Eötvös plot. Bubbles and slugs in free motion. Wallis' generalized correlation.
4. Drift flux analysis of bubbly flow.

Teaching Materials

The following books cover the majority of the unit:

- W. Deen, "Analysis of Transport Phenomena", Oxford University Press.
- R. Bird, W.E. Stewart and E.N. Lightfoot, "Transport Phenomena", Wiley, 2nd ed. 2007.
- J.M. Coulson and J.F. Richardson, "Chemical Engineering Vol. 1", Butterworth-Heinemann, 6th ed. 1999.
- J.M. Kay and R.M. Nedderman, "Fluid Mechanics and Transfer Processes", CUP, 1985.
- P.B. Whalley, "Two-phase flow and heat transfer", OUP Chemistry Primers, 1996.
- P.B. Whalley, "Boiling, Condensation and Gas-Liquid Flow", Oxford Science Publications, 1990.

Unit

Equilibrium Thermodynamics

Level	*Term*	*Duration*
CET IIA	MT 2021	16 lectures

Background

Thermodynamics underpins many chemical engineering processes because systems move towards equilibrium. Some unit operations (reactors; separators) are designed so that equilibrium is approached and so predicting equilibrium thermodynamics is important. This unit extends CET I Process Calculations to cover multi-component multi-phase equilibria.

Aims

The aim is to give students an understanding of the factors affecting physical and chemical equilibria for mixtures of real substances, and to enable them to perform calculations of equilibrium conditions.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- define fugacity and calculate it in simple cases
- describe and understand activity coefficient models
- perform solid-liquid equilibrium calculations for mixtures using an activity coefficient model
- perform osmotic equilibrium calculations
- perform vapour-liquid equilibrium calculations for mixtures using an activity coefficient model (phase diagrams; azeotropes; gas solubility)
- describe vapour-liquid equilibrium at high pressure (near critical points)
- perform liquid-liquid and vapour-liquid-liquid equilibrium calculations for mixtures using anactivity coefficient model
- describe the behaviour of diffusion coefficients in liquid mixtures that can show immiscibility

Assumed Knowledge

Material	*Source*
Laws of thermodynamics	CET I Process Calculations
Properties of pure fluids	CET I Process Calculations
Properties of ideal mixtures	CET I Process Calculations
Phase equilibria for simple case	CET I Process Calculations

Connections To Other Units

This unit builds on CET I Process Calculations. Many chemical engineering courses require some knowledge of thermodynamics. In particular, knowledge of this course may be needed in a CET IIA Exercise and in the CET IIA Design Project.

Self Assessment

Problem sheets will be issued during lectures.

The following examination questions indicate the level of achievement expected:
CET IIA: 2019 Paper 1, questions 4 and 5; 2014-18 Paper 1, questions 5-7; 2010-2013 Paper 3, questions 1-3

Assessment

The material from this unit is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
JAZ 9/2021	AJS	Fundamentals

Unit Thermodynamics	**_Staff_** Professor A. Zeitler

Synopsis

1. Revision
   Criteria for equilibrium. Chemical potential.

2. Example system : VLE with an inert insoluble gas present
   Calculation of chemical potential. Poynting correction. Fugacity.

3. Activity coefficient models
   Definition of activity coefficient. Excess properties. Gibbs-Duhem equation. Examples of activity coefficient models.

4. Solid-liquid equilibrium (SLE)
   Freezing point of liquid mixtures. Pressure dependence of freezing point.

5. Osmotic equilibrium
   Equilibrium across a semi-permeable membrane.

6. Multicomponent vapour-liquid equilibrium (VLE)
   Bubbles and droplets. Binary mixture phase diagrams. Bubble point and dew point calculations, particularly using an activity coefficient model. Azeotropes. Solubility of gases in liquids. High pressure VLE (near critical point) - retrograde condensation.

7. Liquid-liquid (LLE) and vapour-liquid-liquid (VLLE) equilibrium
   Criteria for immiscibility. Phase diagrams. Calculations using activity coefficient models. Distillation of immiscible liquids. Diffusion coefficients in non-ideal liquid mixtures, particularly close to immiscibility. Phase diagrams when 3 phases are present (VLLE).

Teaching Materials

The recommended textbook is:
S.I. Sandler, “Chemical, Biochemical and Engineering Thermodynamics”, Wiley, 4th ed. 2007.

Unit		
Separations 2		
Level CET IIA	***Term*** MT 2021	***Duration*** 16 lectures

Background

Separations technology is important in almost every chemical engineering process. This unit builds on material taught in CET I to cover multi-component systems and it introduces additional unit operations.

Aims

The aim is to give students an ability to calculate the performance of items of separation equipment. The first half of the course covers multi-component separations processes using equilibrium stages. The second half of the course covers some unit operations in which mass transfer rates are important.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- explain how the principles for binary separations can be extended to multi-component systems
- analyse the properties of simple flash systems operating isothermally and adiabatically
- perform approximate calculations on multi-component multi-stage separations such as distillation
- understand the principles behind computer-based methods for predicting distillation column performance
- use humidity charts showing equilibrium data for gas-liquid mixtures
- understand the design of dryers
- describe membrane separation processes and perform calculations on the rates of flux using underlying principles
- describe adsorption in a packed bed and perform calculations using underlying principles

Assumed Knowledge

Material	*Source*
Equilibrium staged processes	CET I Separations
Thermodynamics	CET I Process Calculations
Countercurrent contacting processes	CET I Heat and Mass Transfer Operations
Transport processes	CET I Heat and Mass Transfer Fundamentals

Connections To Other Units

The course builds on CET I Separations and CET I Heat and Mass Transfer Operations. This unit assumes some knowledge of equilibrium thermodynamics (taught in CET I and CET IIA).
The material is likely to be used in a CET IIA Exercise and in the CET IIA Design Project.

Self Assessment

Problem sheets will be issued during lectures.

The following examination questions indicate the level of achievement expected:
CET IIA: 2019, Paper 2, questions 1 and 2; 2014-17 Paper 2, questions 1-3 ; 2010-2013 Paper 3, questions 4-6

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
LTM 09/2021	AJS	Process Operations

Unit	*Staff*
Separations	Dr Laura Torrente Murciano

Synopsis

Multi-component Separations Processes

1. Introduction
2. Multi-component vapour/liquid equilibrium
    - Definition of *K*-values
    - Finding values of K_i
3. Bubble points and dew points
    - Determination for single and multiple components
    - Bubble and dew points for >1 liquid phase
4. Multi-component flashes
    - Isothermal and non-isothermal flashes
    - Flash calculations for immiscible liquid phases
5. Designer's degrees of freedom
    - Procedure for finding the number of degrees of freedom
6. Multi-component distillation: short-cut methods
    - Estimation of minimum number of plates. Example using Fenske's equation
    - Estimation of minimum reflux ratio. Example of use of Underwood's equation
    - Selecting the operating values of *R* and *N*. Example of the use of Gilliland's correlation
    - Feed stage location
    - Refining estimates of x_{iD} and x_{iB} for non-keys
7. "Rigorous" simulation methods for multi-component multi-stage separations
    - The "MESH" equations and solution strategies
    - Column concentration and temperature profiles
8. Isothermal multi-component absorption
    - The key component
    - Design calculations
9. Enhanced procedures
    - Extractive distillation, salt distillation, reactive distillation etc.

Advanced Continuous Contacting Processes

1. Introduction and revision
2. Equilibrium data for gas-vapour mixtures
    - Humidity, dew point temperature, wet bulb temperature
    - Enthalpy of gas/vapour mixture and humid heat
    - Relationship between the slopes of the adiabatic saturation line and the wet-bulb line
3. Drying of solids by thermal vaporisation
    - Types of dryer
    - Adiabatic drying in a cross-circulation dryer
4. Membrane separations
    - Introduction to membranes and their structure
    - Transport processes in membranes. Transport equations
    - Membrane separation of binary gas mixtures
    - Concentration polarisation
    - Osmotic pressure and reverse osmosis
    - Hyperfiltration
    - Membrane fouling
    - Comparison with direct filtration (liquid-solid systems)

5 Adsorption
- Introduction to adsorption
- Equilibrium characteristics
- Mass transfer resistances
- Operating protocols

Teaching Materials

Suitable text-books covering the material in this course include:

- E.J. Henley, J.D. Seader and D.K. Roper, "Separation Process Principles", Wiley, 3rd ed. 2011.
- P.C. Wankat, "Separation Process Engineering", Pearson, 4th ed. 2016 (or earlier edition).
- W.L. McCabe, J.C. Smith and P. Harriott, "Unit Operations of Chemical Engineering", McGraw-Hill, 7th ed. 2005.
- J.M. Coulson and J.F. Richardson, "Chemical Engineering Volume 2", Butterworth-Heinemann, 5th ed. 2002.

Unit

Heterogeneous Reactors

Level	*Term*	*Duration*
CET IIA	LT 2022	16 lectures

Background

Reactors lie at the heart of almost all chemical processes. This unit builds on the CET I Reactors course which considered only homogeneous reactions in reactors with idealised flow patterns. This course focuses on heterogeneous reactors (which may or may not involve a solid catalyst) and also considers non-ideal mixing.

Aims

The aim is to give students a good understanding of chemical reaction engineering and reactor design, particularly of heterogeneous reactors, using the fundamental principles of mass and energy balances, reaction kinetics, mixing characteristics and mass transfer rates.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- use appropriate equations to calculate reactor sizes for a specified conversion
- calculate conversion when one of the reagents is a solid and different rate limiting steps control the process
- describe common types of heterogeneous catalyst, deactivation mechanisms, and reactor types
- understand and use adsorption isotherms for chemical and physical adsorption
- understand and use the Kelvin equation to predict capillary condensation and adsorption hysteresis
- predict reaction kinetics on solid surfaces using the Langmuir-Hinshelwood and Eley-Ridel mechanisms
- describe diffusion in porous solids
- predict reaction kinetics in catalysts when intraparticle diffusion affects the rate
- understand how to use residence time distributions to describe non-ideal flow patterns in reactors
- calculate conversion in reactors (or perform a design calculation) for differing degrees of fluid mixing within a reactor (e.g. using maximum mixedness and complete segregation models)

Assumed Knowledge

Material	*Source*
Chemical kinetics	NST IA Chemistry or CET I Chemistry
Analysis of ideal CSTR and PFR	CET I Reactors
Laplace transforms	CET I Engineering Maths
Mass and energy balances	CET I Process Calculations

Connections To Other Units

This course builds on CET I Homogeneous Reactors. The material may be used in the CET IIA Design Project.

Self Assessment

Problem sheets will be issued during lectures.

The following examination questions indicate the level of achievement expected: CET IIA: 2021 Paper 1, questions 4 and 5; 2020 Paper A, question 4; 2019 Paper 2, questions 3 and 4; 2014-18 Paper 2, questions 4-6 ; 2010-2013 Paper 2, questions 1-3

Assessment

The material from this unit is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
GDM 10/9/21	AJS	Process Operations

Unit	***Staff***
Reactors	Prof Geoff Moggridge

Synopsis

1) Introduction
- Rate of reaction; ideal CSTR; ideal PF; comparison

2) Reactions of solids
- Reaction of solids by the action of heat
- Shrinking particle model
- Shrinking core model
- Types of reactor
- Plug flow of solids: size distribution
- Mixed flow of solids: fluidized-bed reactor

3) Heterogeneous catalysts
- Types of solid catalyst
- Catalyst loss and deactivation
- Types of reactor for heterogeneous catalysis
- Staged adiabatic packed bed reactors
- Bubbling fluidized beds
- Some examples of industrial interest

4) Adsorption
- Physical adsorption and chemical adsorption
- Langmuir isotherm; dissociative adsorption; competitive adsorption
- BET isotherm
- Capillary condensation
- Obtaining enthalpies of adsorption

5) Reactions on surfaces
- Langmuir-Hinshelwood mechanism; Eley-Rideal mechanism
- Apparent order of reaction and apparent activation energy
- Mechanism for reactions on metal oxides: Mars-van Krevelen mechanism

6) Reactions in porous solids
- Diffusion in porous solids
- Analysis of chemical reaction with internal diffusion: Thiele modulus; effectiveness factor
- Disguised kinetics

7) Residence time distributions
- Definitions; example RTDs; vessels in series
- Predicting conversion in reactors: micromixing and macromixing; models for non-ideal flows (including axial dispersion model)

Teaching Materials

The recommended textbooks are:
- H.S. Fogler, "Elements of Chemical Reaction Engineering", 5th edition, Prentice Hall, 2016 (or earlier edition).
- O. Levenspiel, "Chemical Reaction Engineering", 3rd edition, Wiley, 1999.

Unit

Bioprocessing

Level	*Term*	*Duration*
CET IIA	LT 2022	12 lectures

Background

Biological processes are now in widespread use in providing goods and services for mankind. These range from traditional processes, including alcohol fermentations and cheese making, to recent innovations in biotechnology associated with so called 'biologic' therapeutics (peptide hormones, antibodies, enzymes, gene therapy products). In addition, biological processes occur in the water, environmental and agri-tech and food industries, which collectively encompass important sectors of UK industry. Bioprocessing concerns the scale-up and optimisation of such processes, which requires the application of chemical engineering principles to biological systems.

Aims

The aim of the course is to extend the ideas and concepts encountered in the CET I course on Biotechnology, and to demonstrate how chemical engineering principles can be applied to the design and operation of processes in which biological reactions and/or biological products are present.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- describe the importance of the biotechnology industries and the role to be played therein by the chemical engineer
- design a fermentation vessel engineered to satisfy the critical microbial demand for oxygen while incorporating additional design features that are essential to meet operational criteria such as power requirements and heat transfer considerations
- describe and design techniques for downstream processing in the recovery of biological products, including cell lysis, centrifugation, filtration, precipitation and membrane separation unit operations.
- understand the difficulties associated with scale-up and various practical aspects of operation such as sterilisation.

Assumed Knowledge

Material	*Source*
Biotechnology	CET I Biotechnology
Reactors	CET I Reactors
Heat and mass transfer	CET I Heat and Mass Transfer

Connections To Other Units

This course builds on the CET I unit on Biotechnology. Some aspects of separation technology are associated with CET IIA Separations. Some bioreactors material is connected with CET IIA Heterogeneous Reactors. The biochemical engineering principles taught may be used in some CET IIB options.

Self Assessment

Problem sheets will be issued during lectures.

The following examination questions indicate the level of achievement expected:
CET IIA: 2019 Paper 5, question 5; 2014-18 Paper 2, questions 7-8 ; 2010-2013 Paper 1, questions 1-3

Assessment

The material from this unit is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
GSK 9/21	AJS	Process Operations

Unit	***Staff***
Bioprocessing	Dr G. Kaminski Schierle

Synopsis

Bioprocessing and the chemical engineer

- *Overview to the stages within the development of a biological process*
- *Review of the role that chemical engineers play in the design of biological processes*

Fermentation processes

- *Bioreactor configurations and design*. Stirred-tank reactors, bubble columns and internal air-lift loop reactors.
- *Oxygen transfer and heat transfer demands in fermentation*. Estimation of $k_L a$, scale up issues, power requirements for agitation, heat transfer from stirred fermenters.

Introduction to down-stream processing

- *Introduction*. Design of recovery systems: heuristics and approaches.
- *Cell removal and disruption*: solid/liquid separations; dead-end filtration; micro-filtration; centrifugation (settling of solids, tubular bowl centrifuges, disk-stack centrifuges); direct broth extraction; cell lysis
- *Primary isolation and product enrichment:* aqueous two-phase liquid extraction; precipitation; adsorption; chromatographic techniques
- *Final isolation*: membrane filtration

Practicalities in bioprocessing

- *Sterilisation*
- *Protein refolding*

Teaching Materials

Recommended text-books which include material presented in the course are:

- C. Ratledge and B. Kristiansen, “Basic Biotechnology”, Cambridge University Press, 3rd ed. 2006.
- P.M. Doran, “Bioprocess Engineering Principles” Academic Press, 2nd ed. 2012.
- H.W. Blanch and D.S. Clark, "Biochemical Engineering", Marcel-Dekker, 1997.
- J.E. Bailey and D.F. Ollis, “Biochemical Engineering Fundamentals”, McGraw-Hill, 2nd ed. 1986.

Unit		
Process Dynamics and Control		
Level CET IIA	***Term*** MT 2021	***Duration*** 16 lectures

Background

Chemical processes are dynamic in nature, i.e. their behaviour is time dependent. It is vital for chemical engineers, in both the design and operation of chemical processes, to be able to design and analyse process control systems. These are used both to regulate (e.g. to ensure a stream composition remains at the desired value when the process is subject to disturbances) and to provide servo action (e.g. to allow changes in specification of an outlet temperature).

Aims

The course aims to cover the basics of process dynamics and single-loop feedback control, to give an introduction to some advanced topics in control, and to give an introduction to the control of unit operations. In particular, the course aims to describe mathematically the dynamics and stability of systems, particularly chemical processes, and to apply the knowledge to provide the necessary control actions to ensure that the process operation is stable and the objectives, of providing regulator and servo action, are met.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- design, analyse and evaluate single-loop feedback control systems
- design, analyse and evaluate simple examples of advanced control systems
- design, analyse and evaluate control systems for unit operations

Assumed Knowledge

Material	*Source*
Linear ODEs and differential calculus	ET/NST IA Maths, CET I Engineering Maths
Dynamic mass and energy balances	CET I Engineering Maths
Laplace transforms	CET I Engineering Maths
Transfer functions	CET I Engineering Maths
The laws of thermodynamics	CET I Process Calculations
Residence time distributions	CET I Reactors

Connections To Other Units

This unit uses many of the basic chemical engineering building blocks. Indeed, Process Dynamics itself is one of the chemical engineering building blocks. Process Dynamics is used whenever dynamic mass and energy balances are required, e.g. in fluid mechanics, separation processes, flowsheet synthesis, chemical and biochemical reactor design, and in the Design Project.

Self Assessment

An introductory examples paper, intended for revision, not supervision work, will be issued at the start of the course. Three further examples papers will be issued.

The following examination questions indicate the level of achievement expected:
CET IIA: 2010-2013 Paper 4 questions 1-3; 2014-18 Paper 3, questions 1-3; 2019 Paper 3 questions 1, 2.

Assessment

This course is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
SEA 09/2021	AJS	Process Systems

Unit	**_Staff_**
PD&C	Dr Sebastian Ahnert

Synopsis

The Nature of Process Control

- Objectives. Controlled, measured, manipulated and disturbance variables. Feedback and feed-forward control. Stability.

Dynamics of Linear Systems

- Dynamics of linear systems
- 1st, 2nd and higher order systems. Dead time.
- Stability. Poles.

The Design of a Feedback Process Controller

- Negative feedback. Proportional control. Servo and regulator response. Offset.
- Integral and derivative action.
- Stability. Bode stability criterion. Bode plots.
- Controller tuning. Gain and phase margins. Frequency response analysis. Ultimate sensitivity: Ziegler-Nichols. Optimality criteria: decay ratio, ISE, IAE, ITAE. Process reaction curves: Cohen-Coon.

Introduction to Advanced Control

- Cascade. Feedforward. Ratio. Level.
- Interacting control loops.

Process Control Strategy

- Design of control systems for unit operations.

Teaching Materials

- T.E. Marlin, "Process Control: Designing Processes and Control Systems for Dynamic Performance", McGraw-Hill, 2000. This book has been made available for study by the author at http://pc-textbook.mcmaster.ca/ (accessed 02/08/2019).
- G. Stephanopoulos, "Chemical Process Control: An Introduction to Theory and Practice", Prentice-Hall, 1984.
- D.E. Seborg, T.F. Edgar, D.A. Mellichamp and F.J. Doyle III, "Process Dynamics and Control", 3rd Edition, Wiley, 2011.

Unit		
Corrosion and Materials		
Level CET IIA	***Term*** MT 2021	***Duration*** 16 lectures

Background

Corrosion is important in industry as it causes huge expenditure due to the costs associated with inspection, maintenance and replacement of materials. Corrosion also has significant safety and environmental implications. A knowledge of corrosion processes is thus essential for any chemical engineer involved in the design and maintenance of process equipment. Knowledge of materials properties, including corrosion aspects, is also needed as materials selection is an important part in the design of a plant. The materials used in a plant have an effect on operation, maintenance and safety; the course will cover metal alloys, glasses, ceramics and polymers.

Aims

This course aims to give students an understanding of the fundamentals of corrosion. It introduces the properties of alloys, ceramics, glasses and polymers with particular emphasis on materials selection.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- discuss the thermodynamic factors that affect corrosion and predict the most stable products
- discuss the kinetic factors that influence average corrosion rates
- calculate average corrosion rates in simple cases
- explain the mechanisms that cause local corrosion to occur
- discuss the methods which can be used to reduce or avoid the effects of corrosion, andperform calculations
- understand high-temperature oxidation and predict its rate
- discuss the range of materials used in process design and the procedure for selecting suitable materials for a process
- predict some properties of ceramics
- derive rate expressions for the kinetics of polymerisation
- understand the effect of microstructure on materials properties in the case of polymermaterials
- understand how polymers and ceramics can be processed

Assumed Knowledge

Material	*Source*
Chemical thermodynamics; reaction kinetics	CET I and chemistry courses
Mechanical properties of materials	ET IA or CET I Mech Prop Mats

Connections To Other Units

Materials selection is an important part of the CET IIA Design Project.

Self Assessment

Problem sheets will be issued during the lectures.
The following examination questions indicate the level of achievement expected:
CET IIA: 2019 Paper 3, questions 3 and 4; 2015-17, Paper 3 questions 4-5 ; 2014, Paper 3 questions 4-6 ; 2010-2013, Paper 1 questions 4-6

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
JAZ 9/2021	AJS	Fundamentals

Unit	***Staff***
Corrosion/Materials	Dr E.J. Rees and Professor J.A. Zeitler

Synopsis

1. *Introduction*

2. *Thermodynamics of aqueous corrosion*
   Electrochemical cells –Faraday equation and Nernst equation
   Pourbaix diagrams

3. *Kinetics of aqueous corrosion*
   Electrode kinetics: activation polarisation – Tafel equation and Evans diagrams
   Mixed potential theory
   Diffusional limitations: concentration polarisation
   Passivation

4. *Local and other corrosion mechanisms*
   Galvanic (or two-metal) corrosion and selective leaching
   Crevice corrosion and pitting
   Intergranular corrosion (including weld decay)
   Erosion corrosion
   Stress corrosion cracking (SCC) and corrosion fatigue
   Hydrogen damage
   Microbially induced corrosion (MIC)
   Corrosive environments: atmospheric corrosion; soil corrosion; seawater corrosion

5. *Corrosion protection*
   Sacrificial anodes and impressed current methods
   Inhibitors
   Barrier methods
   Other control methods
   Detecting corrosion

6. *High-temperature oxidation of metals*
   Models for high-temperature oxidation
   Analysis of parabolic growth rate mechanism

7. *Polymers*
   Properties, molecular mass distribution
   Mechanism and kinetics of stepwise and addition polymerisation
   Polymer microstructure and polymer processing

8. *Ceramics*
   Properties, ceramics processing and applications

9. *Materials selection*
   Factors affecting the choice of materials
   Commonly used materials in chemical plants
   A systematic approach to materials selection; the CES database

Teaching Materials

The following textbooks are useful:

- P.R. Roberge, "Corrosion Engineering: principles and practice", McGraw-Hill, 2008.
- Z. Ahmad, "Principles of Corrosion Engineering and Corrosion Control", Butterworth-Heinemann, 2006.
- D.A. Jones, "Principles and Prevention of Corrosion", Prentice Hall, 2nd ed. 1995.
- M.G. Fontana: "Corrosion Engineering", McGraw-Hill, 1986.
- J.P. Schaffer, A. Saxena, S.D. Antolovich, T.H. Sanders and S.B. Warner, "The Science and Design of Engineering Materials", McGraw-Hill, 2nd ed. 1998.

Unit

Safety, Health and Environment

Level	*Term*	*Duration*
CET IIA	MT 2021	12 lectures

Background

Safety, Health and the Environment (SHE) is of huge importance in industry. All chemical engineers need an awareness of SHE issues. This course is concerned with assessing hazards and quantifying risks. This needs to be done so that informed engineering decisions can be made.

Aims

The aim of this unit is to provide the student with an ability to assess hazards in the process industries and to quantify the risks associated with these. It involves estimating the probability of an incident occurring and predicting the likely consequences.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- demonstrate familiarity with safety terminology
- identify and describe the major hazards associated with a variety of industrial processes
- perform HAZOP analysis of a process
- compare and quantify the risks associated with different processes
- estimate the release rate and dispersion of gases, liquids and two phase mixtures
- estimate the effects of explosions and thermal radiation
- perform cost-benefit analysis to assess the effect of safety measures
- demonstrate an understanding of human operator reliability

Assumed Knowledge

Material	*Source*
Basic principles of risk analysis	CET I Introductory Chemical Engineering
Discounted cash flow	CET I Introductory Chemical Engineering
Radiative heat transfer	CET IIA Radiation
Compressible flow	CETIIA Fluid Mechanics

Connections To Other Units

This unit builds on the safety lectures in CET I Introductory Chemical Engineering. The material covered is likely to be used in the CET IIA Design Project.

Self Assessment

Two problem sheets will be issued.

The following examination questions indicate the level of achievement expected:
CET IIA 2019, Paper 3, question 5; 2015-17, Paper 3, questions 6-7 ; 2014, Paper 3, questions 7-8 ; 2010-2013, Paper 4, questions 6-7.

Assessment

The material in this unit is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
DFJ 9/2021	AJS	Process Systems

Unit	*Staff*
S.H.E.	Dr D. Fairen-Jimenez

Synopsis

Section 1: Safety Principles

The unit will start with a brief review of the material in Introductory Chemical Engineering and include clarification of the definition of the principal terms used in hazard analysis, particularly the concept of ALARP.

Hazard Identification
The techniques of HAZOP will be explained.

Failure Data
The sources of data required for quantitative safety will be provided together with an indication of the various forms the data can take and a discussion on the reliability of such data.

Logic Trees
The principle behind the use of logic trees to determine the sequence of events which lead to (Fault Tree) and arise from (Event Tree) untoward incidents will be explained. The conventions and symbols used will be demonstrated and the methods of quantifying the trees and arriving at the frequency or probability of the 'Top Event' will be discussed. The application of Boolean Algebra and the use of computer packages will be outlined.

Environmental Engineering
Various case studies will be presented where engineering skills have alleviated environmental impact. This section will potentially feature guest industrial lectures.

Protective Systems
The part played by protective systems in safety analysis will be discussed and the concept of fractional dead time explained. The use of redundant and diverse protective systems will be outlined together with the problems associated with common mode failure and ways of allowing for it (β factor).

Section 2: Quantitative Analysis

Consequence Analysis
The importance of being able to predict the consequences as well as the likelihood of incidents will be stressed and an introduction given to the various models available to assist safety analysts in the area. This section will include gas and liquid dispersion models, flame radiation and explosion models and the effects of explosions and thermal radiation on both plant and personnel.

Cost Benefit Analysis/Acceptability
The importance of ensuring a cost effective approach to safety will be reviewed with particular emphasis on the concept of ALARP. The question of diminishing returns with regard to expenditure on safety will be discussed together with public attitudes as to what is acceptable.

Human Operator Reliability
The part played by human operators in safety assurance will be discussed and ways of maximising operator reliability outlined. This section will include an introduction to the basic principles of control room and plant ergonomics.

Teaching Materials

The following textbooks are useful:

- R.L. Skelton, "Process Safety Analysis", IChemE, 1996.
- D.A. Crowl and J.F. Louvar, "Chemical Process Safety: fundamentals with applications", Pearson, 3rd ed. 2011.

Unit

Radiative Heat Transfer

Level	*Term*	*Duration*
CET IIA	LT 2022	8 lectures

Background

Heat transfer is fundamental to many operations in chemical engineering. This unit builds on the CET I Heat and Mass Transfer course to consider radiative heat transfer, the process by which heat is transferred between bodies by the exchange of electromagnetic radiation, rather than by molecular motion.

Aims

This unit aims to give students an understanding of the fundamental principles of radiative heat transfer and enables radiation calculations to be performed.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- understand the physics of radiative heat transfer
- calculate rates of heat transfer by radiation
- describe the fundamental concepts of the electromagnetic spectrum
- estimate the amount of energy emitted by a blackbody at each wavelength
- calculate the rates of emission and absorption of radiation by gases

Assumed Knowledge

Material	*Source*
Conductive heat transfer	CET I Heat and Mass Transfer
Equation solving; first-order ODEs	First year mathematics
Infrared spectra of gaseous molecules	NST IA Chemistry or CET I Chemistry

Connections To Other Units

The material covered in these lectures builds on material from CET I Heat and Mass Transfer fundamentals. It is required for many design calculations of heat transfer.

Self Assessment

A series of example problems will be provided.

The following are past examination questions:
CET IIA 2019 Paper 4 q.1, 2014-17 Paper 4 either q.1 or q.2 ; 2010-2013 Paper 4 q.5.

Assessment

The material from this unit is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
MDM 09/2021	AJS	Fundamentals

Unit	***Staff***
Radiation	Dr M.D.Mantle

Synopsis

1. Nature of thermal radiation: physics and engineering approximations.

2. Geometry - view factors and their evaluation.

3. Radiative heat transfer (RHT) between black surfaces. Refractory surfaces, total radiationfactor, electrical circuit analogy. RHT between grey surfaces.

4. Emission and absorption by gases, including the greenhouse effect.

5. Notes on flames and measurement of temperature.

Teaching Materials

A handout of lecture notes will be provided. The following book is useful:
H.R.N. Jones, “Radiation Heat Transfer”, OUP Chemistry Primers, 2000.

A table of useful view factors can be found in: J.R. Howell, R. Siegel, M.P. Mengüç, “Thermal Radiation Heat Transfer”, CRC Press, 5th ed. 2010, or at http://www.thermalradiation.net/book.html

Unit

Particle Processing

Level	*Term*	*Duration*
CET IIA	MT 2021	8 lectures

Background

A large number of products manufactured by the chemical and allied industries are in the form of particulate solids. Most chemical engineers will find themselves working with particles at some point in their life. A knowledge of particulate behaviour is therefore essential.

Aims

This course introduces engineering models to describe aspects of particle characterisation, processing and behaviour.

Learning Outcomes

On completing this course, students should be able to describe, evaluate and use the physical principles involved in the:

- Characterisation of particle size and shape;
- Design and operation of gas cyclones;
- Prediction of flowrate of granular material from bunkers and hoppers.

Assumed Knowledge

Material	*Source*
Fluid flows through porous media	CET I Fluid Mechanics
Stress distributions	CET I Stress Analysis and Pressure Vessels
ODEs	CET I Engineering Maths

Connections To Other Units

This unit is a building block for some of the CET IIB modules.

Self Assessment

Problem sheets will be issued as the lectures proceed.
The following examination questions indicate the level of achievement expected:
CET IIA: 2020/B/5(*a*); 2019/4/5; 2018/4/2; 2017/4/1; 2016/4/2; 2015/4/2; 2014/4/1

Assessment

The material from this course is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
SLR 03/09/2021	AJS	Process Operations

Unit	***Staff***
Particle Processing	Dr S.L. Rough

Synopsis

Section 1. *Characterisation of Particles*
Introduction to granular materials
Particle size and shape analysis
Describing particle size distributions
The log-normal distribution

Section 2. *Gas-Solid Separation – Gas Cyclones*
General cyclone description
Analysis of performance
Simple theoretical analysis
Practical design and operation

Section 3. *Flow of Granular Materials from Bunkers and Hoppers*
Empirical correlations for mass flowrate
Theoretical predictions of mass flowrate
Air-augmented flows

Teaching Materials

The following textbooks are useful:

- M. Rhodes, "Introduction to Particle Technology", 2nd edition, Wiley, 2008.
- J.P.K. Seville, U. Tüzün and R. Clift , "Processing of Particulate Solids", Blackie A & P, 1997.
- R.M. Nedderman, "Statics and Kinematics of Granular Materials" CUP, paperback ed., 2005.

Unit

Process Synthesis

Level	***Term***	***Duration***
CET IIA	LT 2022	8 lectures

Background

Process synthesis describes how unit operations are linked together on a plant. Chemical engineers need to be able to synthesise an entire chemical plant flowsheet, selection and linking these unit operations. One particularly important aspect of this is heat integration: how streams that need heating can be matched with streams that need cooling in order to reduce overall energy requirements.

Aims

This unit describes process synthesis and introduces heat integration. It explains the techniques that enable the systematic design of reactor systems, separation systems and heat exchanger networks for minimum energy requirement (or maximum energy recovery).

Learning Outcomes

After completing the course, students should be able to:

- synthesise a chemical plant flowsheet, starting from the feed specification, and using information about plant location and product requirements
- design reactor sequences according to the nature of reactions that occur within them
- design a sequence of distillation columns to achieve a specified separation
- convert simple column sequences into a complex column design
- understand the concept of heat integration
- calculate duty requirements in heaters and coolers and understand the impact of the minimum temperature difference between streams
- use pinch analysis to design energy-efficient heat exchanger networks with minimum energy requirement and maximum energy recovery
- define a common synthesis route used in industry for the manufacture of the 5 top chemicals worldwide by production tonnage

Assumed Knowledge

Material	*Source*
Mass and energy balances	CET I Process Calculations
Process economics	CET I Introductory Chemical Engineering
Safety	CET I Introductory Chemical Engineering
Separations	CET I ESP; CET IIA Separations

Connections To Other Units

Process synthesis is an important part of design and may be useful in the Design Project.

Process synthesis integrates much of the learning about individual unit operations into an overall process.

Self Assessment

A problem sheet will be issued.
CET IIA 2021/Paper4/q.2; 2019/Paper4/q.2; 2014-17/Paper 4/q. 3; 2010-2013/Paper 4/q. 4
Note that there were significant changes to this unit in 2018-19. Some material currently taught did not feature in the former course, Heat Exchanger Networks.

Assessment

The material from this course is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
PJH 8/2021	AJS	Process Systems

Unit	*Staff*
Process Synthesis	Dr P.J. Hodgson

Synopsis

1. Overview of the course

2. Flowsheet Synthesis - how to select the optimal process
   - anatomy of a typical chemical process
   - hierarchical process synthesis method
   - safety in process synthesis, the Kletz six-point framework for assessing inherent safety & quantitative safety metrics
   - choosing between candidate processes
   - alternative synthesis methods
   - choice of reaction(s) and associated raw materials
   - defining recycles and purges
   - choice of purification sequence(s)
   - requirements for heat exchange, pressure change, phase change
   - selection of equipment types for each unit operation required

3. Reactor Network Synthesis
   - manipulation of equilibrium position
   - analysis using instantaneous yield
   - analysis using 'attainable regions'

4. Distillation System Synthesis
   - heuristics for separation sequencing
   - obtaining and using residue curve maps (RCMs)
   - determining column configuration using 'state-task networks' (STNs)

5. Heat exchanger network synthesis
   - basic concepts of heat exchange, heat capacity flow rate
   - temperature / heat load diagrams for HOT and COLD streams/utilities
   - choice of ΔT_{min}, MER (minimum energy requirement / maximum energy recoverable), pinch temperature
   - composite curves – a graphical method
   - problem tables – an analytical method suitable for software implementation
   - shifted temperatures, cascades and optimization thereof
   - grand composite curves (GCCs)
   - heat exchanger network design (HEN) – stream matching heuristics, designing away from the pinch, stream splitting, matched & multiple 'hot' and 'cold' utilities

6. The worldwide chemical industry
   - manufacturing processes for top 5 chemicals worldwide
   - some major disasters in the processing industries and the contribution (or not) of the choice of process synthesis route to causing the disaster

Teaching Materials

The following textbooks are useful:

- J.M. Douglas, "Conceptual Design of Chemical Processes", McGraw-Hill, 1988.
- I.C. Kemp, "Pinch Analysis and Process Integration: a user guide on process integration for the efficient use of energy", Butterworth-Heinemann, 2nd ed. 2007.

Unit

Partial Differential Equations

Level	***Term***	***Duration***
CET IIA	LT 2022	8 lectures

Background

Many chemical engineering problems involve solving partial differential equations (PDEs). Solving PDEs is particularly important in core chemical engineering sectors such as reactor technology, transport phenomena, fluid mechanics and complex fluids.

Aims

The aim is to teach the analytical techniques needed to solve partial differential equations (PDEs), particularly those that are encountered in chemical engineering and allied disciplines.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- classify PDEs;
- give a physical interpretation to PDEs and boundary conditions encountered in chemicalengineering;
- identify suitable analytical solution techniques;
- solve PDEs using the methods of separation of variables, combination of variables, characteristics,and Laplace transform.

Assumed Knowledge

Material	*Source*
Linear first order and second order ODEs	CET I Engineering Maths
Equations for transport processes	CET I Heat and Mass Transfer
Laplace transforms	CET I Mathematics

Connections To Other Units

The techniques covered in this unit may subsequently be used in other courses (e.g. on transport processes, reactors and fluid mechanics).

Self Assessment

A problem sheet will be distributed in the lectures.

The following examinations questions indicate the level of achievement expected:
CET IIA: 2014-19 Paper 4 either question 4 or question 5; 2010-2013 Paper 1 question 7.

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
SEA 09/2021	AJS	Mathematical Methods

Unit	***Staff***
PDEs	Dr Sebastian Ahnert

Synopsis

Partial differential equations (PDEs)

1. Basic concepts. Classification of PDEs.
2. Diffusion-type problems: parabolic equations. Physical examples. Boundary conditions. Separation of variables. Non-homogeneous boundary conditions. Non-homogeneous equations. Combination of variables. Error function. Laplace transform. Superposition.
3. Hyperbolic-type problems. Physical examples. The 1-D wave equation. First-order equations: method of characteristics.
4. Elliptic-type problems. Physical example. The Laplacian. Boundary conditions. Laplace's equation inside a circle. Laplace's equation inside a square.
5. Numerical methods. Finite difference method. Analytical and numerical solutions.

Teaching Materials

Suitable textbooks:

- E. Kreyszig, "Advanced Engineering Mathematics", Wiley, 10th ed. 2011 (Chapter 12).
- S.J. Farlow, "Partial differential equations for scientists and engineers", Dover Publications, 1993 (Chapters 1-4).
- G. James, "Advanced modern engineering mathematics", Prentice-Hall, 4th ed. 2010 (Chapter 9).

Unit		
Statistics		
Level CET IIA	***Term*** LT 2022	***Duration*** 12 lectures (or equivalent)

Background

Engineers and scientists are frequently required to analyse experimental data to extract parameters and error estimates of the parameters. They are also required to make predictions based on measurements of a sample (e.g. for quality control purposes). Probability and statistics are the mathematical techniques that underpin this analysis.

Aims

This course aims to explain the statistical methods that are used to analyse and interpret samples of experimental data.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- calculate probabilities involving discrete and continuous random variables
- describe and use common probability distributions
- calculate the properties of combinations of random variables
- analyse a sample of data, perform hypothesis tests on the mean and variance of the population, and calculate appropriate confidence intervals
- perform hypothesis tests to compare the means and variances of two samples of data
- use one-way ANOVA to test if a treatment causes a significant response
- obtain parameters by linear regression and obtain appropriate confidence intervals

Assumed Knowledge

Material	*Source*
▪ A-level maths (or equivalent)	School

Connections To Other Units

The material in this course is often useful in Part IIB research projects. Probability density functions also occur in the courses on reactors (residence time distributions), particle technology (particle size distributions), SHE and Materials (failure rate distributions) and radiative heat transfer (spectral energy distributions).

Self Assessment

Two problem sheets will be issued during lectures.

Past exam questions:
2014-2019: Paper 4, either q. 3, 4 or 5.
The course was substantially revised in 2012-13 and some earlier exam questions are not suitable.

Assessment

The material from this unit is assessed by examination.

Prepared	***Approved***	***Subject Grouping***
PJB 7/9/2021	AJS	Mathematical methods

Unit Statistics	*Staff* Dr P. J. Barrie

Synopsis

1) Introduction: key terminology
- Random variables
- Population vs. sample
- Probability distributions and probability density functions

2) Properties of a random variable
- Expectation; variance; higher order parameters
- Moment generating functions

3) Example probability distributions
- Discrete random variables: binomial distribution, Poisson distribution
- Continuous random variables: uniform, exponential and normal distributions

4) More than one random variable
- Probabilities for more than one event
- Joint probability distributions; marginal and conditional probability distributions
- Parameters obtained from joint probability distributions: covariance, correlation coefficient
- Independent random variables
- The random variable $Z = X + Y$

5) Estimating population parameters from a sample
- Estimators
- Sample mean and sample variance
- Properties of the random variable $\overline{X}$; the central limit theorem
- More on estimating the population variance
- Maximum likelihood estimators

6) Hypothesis tests on the mean of a distribution
- Hypothesis tests and significance levels
- Tests on the mean of a distribution (large sample case)
- Tests on the mean of a normal distribution (small sample case)
- Confidence intervals for the population mean

7) Hypothesis tests using the chi-squared distribution
- Introduction to the chi-squared distribution
- Hypothesis tests on the variance of a normal distribution
- Chi-squared goodness of fit test

8) Hypothesis tests on more than one sample
- Comparing the means of two samples from normal populations
- Comparing the variances of two samples from normal populations
- Single factor analysis of variance (one-way ANOVA)

9) Linear regression
- Method of least squares; quantifying uncertainties in fitted parameters

Teaching Materials

The recommended textbook is:

- S.M. Ross: "Introduction to Probability and Statistics for Engineers and Scientists", 6th ed., Academic Press, 2021 (or earlier edition).

Unit		
Process Design		
Level CET IIA	***Term*** LT 2022	***Duration*** 12 lectures

Background

Process design is a key part of the chemical engineering discipline. It involves putting together knowledge of different chemical engineering topics to come up with a design for a process plant that is realistic and will operate safely.

Aims

This series of lectures is intended to give students a basic understanding of the principles of process design and to cover certain design-related topics and practice not covered elsewhere in the course.

Learning Outcomes

On completing this course students should be able to:

- document a process using PFDs, P&IDs, stream tables and data sheets
- design physically realistic unit operations
- understand basic pressure relief and safety systems
- specify suitable utilities for a process

These outcomes need to be at a level suitable for the design project.

Assumed Knowledge

Material	*Source*
Chemical engineering fundamentals	CET I and CET IIA
Basic physics of electricity	GCSE and A level

Connections To Other Units

These lectures draw on many other CET I and CET IIA units, either in applying the principles covered in those units, or illustrating how that fundamental knowledge is combined with the demands of a process design objective and operating practice. This unit is linked to the Design Project and may be linked to one or more of the CET IIA Exercises.

Self Assessment

Assessment

This course is not formally assessed, but is essential knowledge for the CET IIA Design Project in Easter term.

Prepared	***Approved***	***Subject Grouping***
KY 9/2021	AJS	Enabling Topics

Unit	Staff
Process design	Dr K. Yunus

Synopsis

The design process

- Process objectives
- Concept selection and design hierarchy
- Front end engineering design
- Detailed design

Design documentation

- Process flow diagrams
- Piping and instrumentation diagrams
- Utility flow diagrams
- Data sheets

Process building blocks 1 - reactors

- Reaction path
- Choice of reactor and operating conditions
- Single and multiphase reactions

Process building blocks 2 – liquid / liquid separation

- Distillation system design
- Distillation system optimization

Process building blocks 3 – other separations

- Solid / liquid separations
- Solid / gas separations
- Solute / solvent separations

Connecting together unit operations

- Conveying liquids and gases (pipes, pumps, compressors)
- Conveying slurries (suspension, agitation, special considerations)
- Conveying solids (belts, buckets, screws, pneumatic conveying)

Flow regulation

- Valves and valve control

Vessel specification and pressure relief

- Heuristics for vessel size selection *vs* operating pressure
- Introduction to pressure relief
- Venting and drainage

Utilities

- Steam
- Water
- Process gases

Electricity

- Generation
- Grid systems
- Electrical equipment on plant

Teaching Materials

- G. Towler and R. Sinnott, "Chemical Engineering Design", Butterworth-Heinemann, 2nd ed. 2012 (or its predecessor, volume 6 of Coulson and Richardson's "Chemical Engineering" series).
- M.S. Peters and K.D. Timmerhaus, "Plant Design and Economics for Chemical Engineers", McGraw-Hill, 3rd ed. 2003.

Unit		
Exercises		
Level CET IIA	***Term*** MT 2021 / LT 2022	***Duration*** 6 exercises

Background

The exercises are mini-projects or extended open-ended problems that may need computer modelling to solve them. The exercises take far longer to solve than a single supervision problem or exam question, and are often similar to tasks that chemical engineers undertake in industry.

Aims

The aim of the exercises is to give students experience of performing project work and undertaking extended open-ended problems. Students should improve their time management and report-writing skills by doing them, as well as deepening their knowledge of the topics.

Learning Outcomes

On completing the exercises students should be able to:

- write a literature survey examining the feasibility of a specified chemical process;
- undertake extended modelling work or analysis on chemical engineering problems;
- have gained experience in, and an awareness of, aspects of process design, such as process synthesis, process control;
- draft a piping and instrumentation diagram (P&ID);
- manage their time so that they can meet a deadline for a “long” task;
- write reports.

These exercises satisfy some aspects of the IChemE’s requirements for process design.

Assumed Knowledge

Material	*Source*
Related CET IIA courses	CET IIA

Connections To Other Units

These exercises will deepen students’ understanding of the related CET topics.

Self Assessment

Demonstrator assistance will be available during the exercises. Demonstrators can advise on method, but they will not normally tell you whether your answer is “right” or not.
There will be feedback on each Exercise after marking.

Assessment

The reports submitted are marked and contribute to the overall final mark for the year. The deadlines for submission will be adhered to strictly: material submitted after the deadline will be given zero marks unless a Tutor’s note is received giving a satisfactory reason. However, the Literature Review will be marked as a Pass or Fail. Feedback will be given and students who fail can submit a revised Review.

Prepared	***Approved***	***Subject Grouping***
DIW, PJB, JS 9/2021	AJS	Exercises

Unit	***Staff***
Exercises	Drs L. Torrente-Murcina, J. Stasiak, P.J. Barrie, D. Fairen-Jienez and Professor D.I. Wilson

Synopsis

The provisional topics of the exercises are:

Michaelmas Term
Exercise 1: Literature survey
Exercise 2: Distillation
Exercise 3: Thermodynamics

Lent Term
Exercise 4: PD&C, ABB Rig
Exercise 5: Synthesis
Exercise 6: Plant Dynamics P&IDs

The topic of each exercise is subject to change.

Teaching Materials

Unit

Design Project

Level	*Term*	*Duration*
CET IIA	Easter 2022	5 weeks (full time)

Background

Process design is one of the key parts of the chemical engineering discipline. It involves putting together material covered in many different courses into a single large-scale project. Design also requires a different mindset to other teaching activities as there is rarely one single “right” answer, and estimates have to be made of relevant parameters because desired information is not always available. Dealing with uncertainty and making decisions in an evolving environment is a key skill for engineering practice: communicating how and why decisions were made is another. Students need to pass the Design Project if they wish to satisfy the academic requirements of the IChemE for becoming a Chartered Engineer.

Aims

The Design Project gives students experience of design across different scales – from individual units to plant-wide operations. The project develops team working and communication skills through participation in a small design team to design a chemical plant or a substantial part of a chemical plant. All aspects of the design process are considered. Communication and decision making are key

Learning Outcomes

On completing this course students should be able to

(i) Work as part of a team to design a chemical plant (or part of a chemical plant).

(ii) Communicate and explain design decisions and processes

(iii) Demonstrate proficiency in the topics described in the Synopsis.

Assumed Knowledge

Material	*Source*
▪ Core chemical engineering topics	CET I and CET IIA

Connections To Other Units

The Design Project brings together many Chemical Engineering courses. Particularly relevant ones are Process Design, Engineering Drawing, Safety, Process Economics and Control. There may also be links to Exercises carried out earlier in the year, some of which are associated with the Design Project topic.

Self Assessment

Students work in groups and will be responsible for producing their own project program and monitoring their own progress against that program. Weekly tutorial sessions will be managed by the students with a staff member in attendance.

Assessment

The project is organized into five tasks, with completion dates for each task spaced throughout the duration of the project. Two of the tasks (A and E) are assessed on group performance, comprising *circa* 20% of the total project mark. The remaining three tasks are predominantly individual assessments.

Prepared	*Approved*	*Subject Grouping*
MEW Sep 2021	AJS	Design

Unit Design Project	*Staff* Dr M.E.Williamson

Synopsis

The topic for the Design Project is introduced during Lent Term. The Design project runs over a 5 week period in Easter Term.

Students are formed into groups and each group must first produce an agreed flowsheet of the process based on information given in the Project Brief.

From the agreed flowsheet, the group will carry out the following tasks:

(a) Produce a process flow diagram (PFD) for the process, a piping and instrumentation diagram (P&ID) along with an Overall Control Scheme for each process section (each student will be assigned a section).

(b) Discuss the design methods for a single item of major process equipment, and the basis of any methods of estimating physical or chemical properties.

(c) Complete process data sheets for the main items of process equipment.

(d) Produce a capital cost estimate.

(e) Estimate construction and operating costs.

(f) Discuss how the operation is to be managed and controlled, including any problems or special features arising in normal control of the plant, its start-up or shut-down. This will include identification of appropriate control methods, control loops, measurement of key variables and potentially allocation of set-points.

(g) Identify potential hazards in the plant or its operation and compile a summary of any special procedures which must be implemented to limit the hazard.

(h) Participate in a HAZOP study on a selected plant area.

(i) Produce a basic environmental impact report highlighting possible environmental pollution problems and their alleviation.

(i) Produce a plant layout sketch and brief description of factors influencing the layout.

(j) Produce a utilities schedule and outline ways in which the utilities will be provided.

(k) Communicate a summary of the design and key factors affecting its viability to a board of assessors.

The plant will be divided into process areas with one student responsible for each area. The non-process duties, *e.g*. costing, safety, layout *etc*. are also the responsibility of individual students.

The project is organised in 5 tasks which assesses both team-based and individual problem solving.

Teaching Materials

There will be an introductory Design Brief handout and a number of additional handouts on specific points. The following textbooks will be of general use:

- G. Towler and R. Sinnott, “Chemical Engineering Design”, Butterworth-Heinemann, 2nd ed. 2012 (or its predecessor, volume 6 of Coulson and Richardson’s “Chemical Engineering” series)
- M.S. Peters and K.D. Timmerhaus, “Plant Design and Economics for Chemical Engineers”, McGraw-Hill, 3rd ed. 2003.
- “Guide to Capital Cost Estimation” by IChemE.

Various relevant textbooks will be placed on reserve in the library and as e-books.

Unit

Engineering Ethics

Level	***Term***	***Duration***
CET IIA	MT 2021	3 sessions

Background

Chemical engineers have a wide range of duties with different levels of responsibility, and they need to be able to make informed decisions, address and resolve problems arising from potentially questionable practice, and develop critical thinking skills and professional judgement. In order to deal with issues and overcome the professional challenges, an appreciation of the importance of ethical principles is needed.

Aims

The aim of this course is to prepare students for their professional lives by giving them an appreciation of the importance of professional ethics. The course aims to develop clarity in their understanding and thought about ethical issues and the practice in which they arise. It also helps to develop widely applicable skills in communication, reasoning and reflection, through in-class discussion, and a written assignment.

Learning Outcomes

On completing this course students should be able to:

- identify
- analyse
- answer questions and apply ethical principles
- identify problematic ethical behavior and conduct

Assumed Knowledge

Material	*Source*
None	

Connections To Other Units

There are ethical implications for material in many units of the course.

Self Assessment

Students are encouraged to reflect on ethical professional conduct in general.

Assessment

Students will have an essay assignment, and will participate in live online session

Prepared	***Approved***	***Subject Grouping***
SB 9/2021	AJS	Classes

Unit	***Staff***
Engineering Ethics	Prof S Bahn

Synopsis

1. What are the historical and philosophical principles of ethical conduct?
2. What are possible obstacles to ethical behaviour?
3. Codes of professional ethics. Issues which might affect decision making.
4. Examples of situations in which important ethical questions might arise.
5. How can ethical principles help in personal and professional decision making?

Teaching Materials

References are provided in the lectures.

Companies in the Teaching Consortium supporting undergraduate teaching in Chemical Engineering and Biotechnology 2021-22