Imperial College London

Department of Chemical Engineering and Chemical Technology

Undergraduate Syllabuses_2005–06

This publication refers to the session 2005–06. The information given, including that relating to the availability of courses, is that current at the time of going to press, October 2005, and is subject to alteration.

For details of **postgraduate** opportunities go to www.imperial.ac.uk/pgprospectus.

Chemical Engineering and Chemical Technology

A wide range of sciences and engineering relevant to the technology of the process industries are covered by chemical engineering and chemical technology at Imperial College. Research areas range from technological studies of the behaviour of processes and equipment, and fundamental scientific study of the underlying physical and chemical phenomena, to the development of techniques for planning, design and control of processes.

The teaching and research laboratories are exceptionally well equipped and backed with comprehensive technical services. Facilities available include high pressure engineering laboratories for studies up to 80,000 bar, a clean laboratory for work on surfaces, a pilot plant laboratory with four computer-controlled plants, a high pressure multi-phase flow facility, tissue engineering, mammalian cell culture and biochemical engineering facilities, and a wide range of analytical facilities. There is also a cluster of DEC workstations, together with over 100 networked microcomputers and a number of dedicated high performance workstations for systems engineering.

Details of postgraduate opportunities can be found in the online *Postgraduate Prospectus* at www.imperial.ac.uk/pgprospectus.

Undergraduate courses

At undergraduate level two four-year Honours degree courses in Chemical Engineering and in Chemical Engineering with a Year Abroad, with a range of electives are offered, providing for some specialisation in the last two years of the course.

Chemical Engineering

The four-year Honours degree course in Chemical Engineering leads to the MEng degree of the University of London and to the Associateship of the City and Guilds of London Institute (ACGI), and gives complete exemption from the academic requirements for full professional membership of the Institution of Chemical Engineers. Students entering the first year must normally have satisfied the general University entrance requirements and the individual course requirements in terms of passes at A level in the GCE examination, as indicated in the section on Conditions of Admission in the *Undergraduate Prospectus* and online at www.imperial.ac.uk/p2729.htm#4.

The course provides a firm foundation of fundamental science, closely integrated with practical application to engineering and carried to an advanced level. It involves projects carried out in industry and also includes economics, industrial sociology, management and business studies, supported by case studies and project work.

Electives enable the student to specialise in design and development or the technology of a particular sector of the process industries. In addition to the selection of technological electives, there are a number of electives covering a wide range of social studies and humanities subjects, which include the possibility of study of a foreign language. Electives are taken in the third and fourth years.

Also offered is a new stream called Chemical engineering with fine chemicals processing, run jointly with the Department of Chemistry. This stream was introduced to meet the need identified in the fine chemicals and pharmaceutical industries for chemical engineering graduates with formal training in synthetic chemistry and process development. It combines the core of the main chemical engineering MEng programme with special courses aimed at developing skills and knowledge in the chemical, engineering and socio-economic aspects of drug and speciality chemical synthesis and production.

Each of the individual courses described in later sections comprise of lectures supported by seminars and tutorials, together with project work as appropriate. The projects may involve theoretical or computing work, design studies, case studies or practical work in the chemical engineering laboratories, including work on the computer-controlled pilot plants. Formal lectures and tutorial work are mostly timetabled in the morning, leaving the afternoons free for project work, which forms an important part of the course.

In addition, students are encouraged to carry out an industrial project, which involves work carried out in industry during the summer vacation preceding the fourth year of the course and which continues into the first term of that year. Students may alternatively elect to carry out a research project in the fourth year. The spring term of the final year contains a major process design study.

MEng course

FIRST YEAR

ChE.101	Chemical engineering I (Mastery)	
ChE.102	Process analysis	
ChE.103	Coursework 1	
	ChE.103.1	Design project
	ChE.103.2	Laboratory course
	ChE.103.3	Pilot plant project
	ChE.103.4	Computing– Introduction to Maple
	ChE.103.5	Mastery–Test
ChE.104	Transfer Processes I	
	ChE.104.1	Fluid mechanics
	ChE.104.2	Heat and mass transfer
ChE.105	Thermodynamics I	
ChE.106	Chemistry	
	ChE.106.1	Chemistry
	ChE.106.2	Biochemistry
	ChE.106.3	Properties of matter
ChE.107	Mathematics[1] (MEng.1.2)	

SECOND YEAR

ChE.201	Chemical engineering II (Mastery)	
ChE.202	Transfer Processes II	
	ChE.202.1	Heat transfer
	ChE.202.2	Separation processes I
ChE.203	Coursework 2	
	ChE.203.1	Control project
	ChE.203.2	Computing
	ChE.203.3	Laboratory theme
	ChE.203.4	Pilot plant project
	ChE.203.5	Reactor design
ChE.204	Reaction Engineering I	
	ChE.204.1	Industrial chemistry
	ChE.204.2	Reaction engineering I
ChE.205	Thermodynamics II	
ChE.206	Process dynamics and control	
ChE.207	Mathematics[1] (MEng.2.2)	
ChE.208	Fine chemicals stream courses	
ChE.209	Managerial Economics(BS0804)[2]	

THIRD YEAR

ChE.301	Chemical engineering III (Mastery)	
ChE.302	Reaction engineering II	
ChE.303	Transfer processes III	
	ChE.303.1	Separation processes II
	ChE.303.2	Fluid mechanics
	ChE.303.3	Particle engineering
ChE.304	Strategy of process design	
ChE.305	Safety and loss prevention	

[1] Taught by the Department of Mathematics
[2] Taught by Tanaka Business School

ChE.306	Environmental engineering	
ChE.307	Coursework 3	
	ChE.307.1	Techno-socio-economic project
	ChE.307.2	Flowsheeting project
	ChE.307.3	Mechanical design
	ChE.307.4	Environmental engineering project
ChE.308	Behaviour in industrial organisations[2]	
ChE.309	Fine chemicals stream courses	

Together with two electives chosen from the following list (the list may vary from year to year):

ChE.410	Electrochemical engineering
ChE.412	Fluids engineering
ChE.413	Formulation engineering and technology
ChE.414	Introduction to nuclear technology
ChE.415	Membrane science and membrane separation processes
ChE.416	Process heat transfer
ChE.418	Introduction to modelling the phase equilibria of fluids
ChE.419	Fundamentals of biotechnology
ChE.424	Environmental biotechnology: principles and applications
BS0806	Entrepreneurship[2]
BS0808	Finance and financial management[2]
BS0820/BS088	Innovation management[2]

Or any course from the Humanities Programme.

FOURTH YEAR

In the fourth year all students carry out an industrial link project or a research project (ChE.401.1) and the plant design project (ChE.401.2). In addition, they are required to take six electives selected from the other courses listed below:

ChE.401	Coursework 4	
	ChE.401.1	Link/research project
	ChE.401.2	Plant design project
ChE.404A	Advanced process control A	
ChE.405	Advanced process operations	
ChE.406A	Advanced process synthesis and optimisation I	
ChE.406B	Advanced process synthesis and optimisation II	
ChE.407	Polymers and polymerisation processes	
ChE.408	Dynamic behaviour of process systems	
ChE.410	Electrochemical engineering	
ChE.411	Flexible plant operation	
ChE.412	Fluids engineering	
ChE.413	Formulation engineering and technology	
ChE.414	Introduction to nuclear technology	
ChE.415	Membrane science and membrane separation processes	
ChE.416	Process heat transfer	
ChE.417	Introduction to colloid and interface science	
ChE.418	Introduction to modelling the phase equilibria of fluids	
ChE.419	Fundamentals of biotechnology	
ChE.421	Biological systems: fundamentals and modelling	
ChE.422	Downstream separation in biotechnology	
ChE.423	Product characterisation	
ChE.424	Environmental biotechnology: principles and applications	
BS0806	Entrepreneurship[2]	

[2] Taught by Tanaka Business School

BS0808 Finance and financial management[2]
BS0820/BS0828 Innovation management[2]
BS0821 Project management[2]
PT.3.3 Dynamical systems and chaos[1]
Or any course from the Humanities Programme.
Fine chemicals stream students also take courses offered by the Department of Chemistry.

Chemical Engineering with a Year Abroad

The MEng course in Chemical Engineering with a Year Abroad is accepted by the College and the Institution of Chemical Engineers as fully equivalent to the MEng in Chemical Engineering. While they are in London, students take the same courses, with some exceptions, as the Chemical Engineering students. They then spend either their penultimate year in Spain, Switzerland, Germany, the USA, Singapore or Australia or their final year in France or the Netherlands. Students wishing to go to Spain, Switzerland, France or Germany take an intensive language course in the two or three preceding years, in order to achieve the necessary level of fluency and technical knowledge that will enable a year to be spent in a European institution. Students will follow the lecture courses and project work of the host institution. At present the European institutes taking part in the scheme are the Ecole Nationale Supérieure des Industries Chimiques, Nancy, the Ecole Nationale Supérieure des Ingénieurs en Arts Chimiques et Technologiques, Toulouse, the Ecole Nationale Supérieure en Génie des Technologies Industrielles, Pau, the Universidad de Zaragoza, the Universidad de Valladolid, Ecole Polytechnique Fédérale de Lausanne and the Rheinisch-Westfälische Technische Hochschule, Aachen. In the future it is hoped to increase the choice of institutions to include other European countries.

Students wishing to go to Spain, Switzerland, France or Germany must show demonstrable skill in Spanish, French or German or aptitude for learning either language; a qualification at AS level or the upper grades in GCSE would be appropriate.

The Department of Chemical Engineering and Chemical Technology reserves the right to refuse to allow any student to take a year abroad who has not, on aggregate, performed to an upper second or first class standard in the years spent at Imperial preceding the year abroad.

Syllabuses

PART I

ChE.101 Chemical engineering I (Mastery)

DR O.K. MATAR, DR C.S. ADJIMAN, PROFESSOR D.R. DUGWELL, PROFESSOR J.P.M. TRUSLER, DR C.D. IMMANUEL, DR E.A. MÜLLER
A course in mastery of chemical engineering principles, drawing together fundamental concepts from Part I courses.

ChE.102 Process analysis

DR C.S. ADJIMAN
40 lectures.
The process industries: an introduction to the production of chemicals, foods and pharmaceuticals on the industrial scale. Examples of continuous processes and batch processes; biochemical processes. Comparison of alternative routes available for production of some major products of the chemical industry and factors—technical, economic and environmental—which affect their choice.
Material balances: development of flowsheets; comparison of alternative processes; economic potential; conservation of mass. Mass balances in chemical and biochemical reacting systems, stoichiometry, extents of reaction, conversion, yield and selectivity. Complex flowsheets: multi-stage processes, recycles, bypasses and purges. Calculation procedures: choice of basis. Typical process examples.
Energy balances: conservation of energy and applications to chemical and biochemical processes, phase changes; ideal and non-ideal mixtures. Enthalpies of reaction; simple reaction equilibria; effects of

[1] Taught by the Department of Mathematics
[2] Taught by Tanaka Business School

temperature. Isothermal, adiabatic and non-adiabatic processes. Combustion systems. Use of thermodynamic tables.
Separation processes: physical basis for common separation processes; equilibrium properties. Analysis of representative vapour/liquid equilibrium processes, material and energy balances, elementary calculations and design procedures.
Environmental issues in chemical engineering: (i) Global environment. Biological cycles of carbon, nitrogen and sulphur. Greenhouse effect, global warming. Toxicity and bioaccumulation. Magnitude of the pollution problem. Fates and pathways of gaseous, liquid and solid pollutants in the ecosystem.
(ii) Applications to chemical engineering. Waste minimisation. Clean technology and process alternatives. Environmental audits and life cycle analysis.
Project: application of all the above in a group design exercise: the project requires carrying out calculations and making decisions in the context of the preliminary design of a chemical plant.

ChE.104 Coursework

ChE.103.1 Design project
PROFESSOR S.M. RICHARDSON, DR A. BISMARCK
A two-week course on problem solving in which students are taught conventions for the statement of problems, how to write design briefs, how to devise large numbers of solutions to problems, how to evaluate those solutions and how to present them. Students are also taught to become effective members of teams.

ChE.103.2 Laboratory course
PROFESSOR P.F. LUCKHAM
The objectives of the first-year laboratory course are: (i) to become familiar with experimental apparatus; (ii) to reinforce in a practical way theoretical concepts taught in lectures; and (iii) to gain experience in communication of experimental findings in oral and written form. The course comprises a sequence of six experiments associated with the various first-year mastery topics. Assessment is based on five short written reports, one longer written report and an oral presentation.

ChE.103.3 Pilot plant project
DR. A. BISMARCK
Students use one of the four computer-controlled pilot plants in operation in the Chemical Engineering laboratory, an evaporator, to concentrate a solution of potassium nitrate. The plant is started up, run to obtain experimental data and shut down by the students themselves, with the aid of a computer controlled system. The entire installation of process equipment plus instrumentation is as similar to an industrial environment as is feasible in a university laboratory.

ChE.103.4 Computing—Introduction to Maple
DR C.D. IMMANUEL, MEMBERS OF THE MATHEMATICS DEPARTMENT
The course allows students to perform analytic mathematical operations on a PC. Maple's capabilities can also be exploited to draw graphs of functions and data. In addition, students can perform analytic intergration and differentiation operations, and solve linear, non-linear and ordinary differentials analytically. Numerical solutions of these equations can also be carried out using Maple.

ChE.104 Transfer processes I

ChE.104.1 Fluid mechanics
DR O.K. MATAR
23 lectures.
Introduction: definition of a fluid, nature of force and pressure, compressible and incompressible fluids, shear stress, Newtonian and non-Newtonian fluids; continuum hypothesis.
Fluid statics: hydrostatic equation, manometers.
General description of fluid motion: steady and non-steady flows, flow visualisation, streamlines and

streamtubes; laminar and turbulent flows, Reynolds number and its interpretation.
Dynamics of fluids in steady motion: continuity equation, momentum principle, Euler equation for steady flow of an ideal fluid along a streamline, Bernoulli equation, steady flow energy equation, forces on a bend, expansion losses.
Flow measurement: pitot and pitot static tubes, orifices, nozzles, venturi meters.
Flow in pipes: laminar flow of Newtonian fluids, Poiseuille equation, turbulent flow of Newtonian fluids, energy considerations, friction factor, minor losses.
Compressible flow: isothermal and adiabatic flows of gases, maximum flow rate, comparison of isothermal and adiabatic flows.

ChE.104.2 Heat and mass transfer
PROFESSOR D.R. DUGWELL
23 lectures.
Kinetics of homogeneous heat and mass transfer: rate equations, heat and mass transfer coefficients; differential formulation of transport equations, conduction and molecular diffusion in planar, cylindrical and spherical configurations; simultaneous conduction or diffusion and flow in direction of transfer. Two-dimensional heat conduction; transient heat conduction. Natural convection, heat losses from lagging. Forced convection; film theory, correlation of transfer coefficients. Boundary layer formation and solutions.
Heat exchangers: exchange diagrams, log-mean temperature difference, effectiveness, NTUs, calculation of exchange surfaces, main type of exchangers and criteria for selection.

ChE.105 Thermodynamics I
PROFESSOR J.P.M. TRUSLER, DR E.A. MÜLLER
33 lectures.
Basic definitions: temperature, heat, work and energy; first law, heat capacities; second law, reversibility and equilibrium, entropy; Maxwell's relations; P-V-T behaviour of pure substances; real gases and equations of state. Free energy, liquid-vapour equilibrium for a pure substance. Application of thermodynamic tables and diagrams for calculation of heat and work for range of machines including multiple stages: compressors, expansion engines, turbines, refrigerators; liquefaction processes; availability and its use: heat exchangers; power generation.

ChE.106 Chemistry

ChE.106.1 Chemistry
DR A. KOGELBAUER
24 lectures.
The course is designed as a revision and an introduction to new concepts. It will build upon A-level chemistry and material developed in the properties of matter course and extend the principles of quantum chemistry to real chemical systems in the inorganic and organic chemistry domain.
Chemical bonding and molecular structure: review of the orbital concept and its implications for periodicity and chemical reactivity, Lewis bonding and the derivation of Lewis structures, octet rule and extensions to the octet rule, VSEPR theory, valence bond theory and hybrid orbitals, MO theory and delocalised orbitals.
Chemical kinetics: rate of reaction and rate laws, elementary reactions, empirical kinetics, first and second order reactions, complex mechanisms (sequential and parallel reactions), reaction intermediates, temperature dependence of rates (Arrhenius law).
Acid-base and solution chemistry: Brønsted and Lewis acids, pH concept and pK values, acidity functions, buffers, solubility and solubility product, simultaneous equilibria.
Organic chemistry: nomenclature, conformations of molecules, chirality, classes of compounds and their most important reactions (alkanes, alkenes, alkynes, alcohols, alkyl halides, aldehydes, ketones, amines, carboxylic acids), mechanistic description of organic reactions such as radical and ionic reactions, addition, substitution and elimination reactions, electrophilic aromatic substitution, substituent effects on regio-selectivity and reactivity.

ChE.106.2 Biochemistry
DR A. MANTALARIS
14 lectures.
The overall aim of this course is to produce a succinct summary of biochemistry and molecular biology and provide engineering students with an introduction to the basic priciples that dictate the molecular processes of the cell. This course serves as an excellent background for students wishing to undertake further training in the areas of biochemical, environmental and biomedical engineering.
Objectives: (i) to understand the thermodynamic laws governing the chemical reactions in the cell; (ii) to become familiar with the different types of living organisms and their structure and function; (iii) to learn the basic structure of amino acids, proteins, DNA and RNA, their function and synthesis mechanisms; (iv) to become familiar with the 'central dogma' of molecular biology; (vii) to understand the main methods utilised in molecular biology and their applications to genetic engineering; and (viii) to learn the major pathways involved in the oxidative catabolism of glucose and fatty acids, the citric acid cycles, electron transport, and the chemiosmotic mechanism for the production of ATP.

ChE.106.3 Properties of matter
DR S.G. KAZARIAN
22 lectures.
The origins of quantum mechanics: photoelectric effect, wave particle duality, introduction to quantum theory.
Quantum mechanics of atoms: Schrödinger equation, wave function and energy, uncertainty principle, hydrogen atom, energy levels and atomic spectra
Quantum mechanics of molecules: molecular structure and bonding, MO theory, intermolecular interactions and hydrogen bonding, molecular spectroscopy: electronic, rotational and vibrational (infrared and Raman) spectra.
Gases and liquids: ideal and real gases, van der Waals equation, critical point and supercritical fluids, Boltzmann relation, formal link between energy levels and thermodynamics, Maxwell-Boltzmann distribution of speeds, viscosity and thermal conductivity of gases.

ChE.107 Mathematics (MEng.1.2)
60 lectures. See Department of Mathematics syllabus for details.

PART II

ChE.201 Chemical engineering II (Mastery)
DR K. LI, PROFESSOR R. KANDIYOTI, DR A. GALINDO
A course of mastery of chemical engineering principles.

ChE.202 Transfer processes II

ChE.202.1 Heat transfer
DR X.Y. XU
26 lectures.
Radiation: radiation from gases, flames, particulate clouds and between multiple surfaces; radiation in furnaces.
Process heat transfer: two-phase flow: flow regimes, flow pattern maps, calculation of frictional pressure drop. Boiling heat transfer: pool boiling, forced-convection boiling, correlations for heat transfer coefficient. Condensation: gravity-controlled filmwise condensation, shear-controlled filmwise condensation, equivalent laminar film model, condensation in the presence of an inert gas, condensation of binary mixtures. Air-water systems: humidity, wet-bulb temperature, adiabatic saturation temperature, psychometric chart, cooling towers, design procedures. Drying of solids: drying curves, drying time.

ChE.202.2 Separation processes I
DR K. LI
20 lectures.
Introduction to mass transfer equipment: distillation, gas absorption, liquid-liquid extraction.
Multi-stage processes: operating relations, limiting operating conditions, determination of number of theoretical plates by graphical and numerical techniques for binary distillation with constant molar overflow; plate efficiency; application of separation theory to liquid-liquid extraction.
Differential contact processes: separating power of packed columns, their performance and calculation of height of packing; absorption and desorption under isothermal and non-isothermal conditions.
Design of separation equipment: mechanical and hydrodynamic factors in packed column and tray design; liquid-liquid equipment.

ChE.203 Coursework 2

ChE.203.1 Control project
DR C.D. IMMANUEL
ChE.206, process dynamics and control, is illustrated by this project involving the control of a simulated plant. The project lasts for two weeks of coursework.

ChE.203.2 Computing
PROFESSOR N. SHAH
8 lectures and 40 hours coursework.
Top-down design of computer programs. Code documentation. Introduction to the operation of computers and the MAPLE language. Numerical methods and solution of sets of equations. Process modelling and solution of a problem based on process analysis.

ChE.203.3 Laboratory theme
PROFESSOR D. CHADWICK
Students spend four weeks of coursework working on one undergraduate laboratory theme. Three weeks are spent on experimental work and one week on report writing. The themes cover the following topics; distillation, liquid/liquid extraction, fluid mechanics, heat transfer, reaction engineering, thermodynamics, and biotechnology.
Students on the fine chemicals stream take the Synthesis laboratory course in the Chemistry Department

ChE.203.4 Pilot plant project
PROFESSOR S. MACCHIETTO
In the second year the students run an absorber-desorber plant that separates carbon dioxide from a mixture of carbon dioxide and nitrogen using an amine solution as the absorbent. The students start up the plant, run it to obtain experimental data and shut it down with the aid of a computer controlled system.
Students on the fine chemicals stream do ChE 203.4 in their 3rd year.

ChE.203.5 Reactor design
DR A. KOGELBAUER
Reactor design project: students spend two weeks of coursework designing a chemical reactor. The design involves the numerical solution of the appropriate coupled mass, momentum and energy balances.

ChE.204 Reaction Engineering I

ChE.204.1 Industrial chemistry
PROFESSOR D. CHADWICK
26 hours of lectures and problem classes.
Chemical kinetics: rate equations and integrated rate expressions for single step, autocatalytic, consecutive, parallel and reversible reactions; chain reactions and the steady-state approximation;

apparent activation energy; experimental determination of the rate expression; theory of reaction rates.
Adsorption at solid surfaces: nature of adsorption processes; Langmuir; Freundlich, Temkin and BET isotherms; adsorption isosteres; determination of surface area.
Heterogeneous catalysis: nature of catalysts, structure and manufacture; determination of active area; kinetics of heterogeneous reactions including consecutive, parallel and reversible reactions; apparent reaction order and activation energy.
Industrial processes: basic outline of refinery and petrochemical operations: specific examples of heterogeneous catalysed industrial processes including hydroprocessing, catalytic cracking, ammonia and methanol syntheses.

ChE.204.2 Reaction engineering I

PROFESSOR R. KANDIYOTI
20 lectures.
Batchwise versus continuous reactor operation. Introduction to the steady-state behaviour of continuous stirred tank and tubular reactors.
Elementary mass balances for batch reactors, plug-flow reactors and continuous stirred tank reactors. Implications of the plug-flow and perfect mixing assumptions. Application of isothermal mass balances to the design of reactors. Systems with volume change upon reaction. Comparison of continuous stirred tank and plug-flow reactor performance. Criteria used in the choice of reactors. Sequence of reactors. Plug-flow reactor with recycle. Reactor performance for simultaneous and consecutive reactions.
Thermal effects. Mass and energy balances for batch, continuous stirred tank and plug-flow reactors. Stability and multiplicity of steady states for continuous stirred tank reactors. Temperature profiles in tubular reactors. Limitations of equilibrium in single and multiple reactors. Sequences of reactors with inter-stage and cold shot cooling. Simple reactor design.
Deviations from the plug flow assumption. Residence time distributions.
Reactor design project: see ChE.203.5.

ChE.205 Thermodynamics II

DR A. GALINDO
25 lectures and problem classes
The aim of this course is to present the basic concepts related to the thermodynamics of mixtures in order to understand the factors that affect phase equilibria, chemical equilibria and equilibrium electrochemistry. The following topics will be covered:
Part 1. Review of pure component phase equilibria, and phase stability, the Gibbs phase rule, the chemical potential, and the fugacity, review of equations of state and the intermolecular potential.
Part 2. Mixtures: fundamentals, composition scales, partial molar quantities, the chemical potential of a component in a mixture, the Gibb-Duhem relation. Mixing properties and the perfect gas mixture, mixing properties in real gas mixtures. The ideal solution and Raoult's law, colligative properties, mixing properties in solutions, the infinite dilution case and Henry's law. Real solutions and the activity coefficient, positive and negative deviations. Phase diagrams of mixtures, vapour-liquid coexistence, azeotropy, liquid-liquid coexistence, and vapour-liquid-liquid coexistence.
Part 3. Chemical equilibria and equilibrium electrochemistry. Extent of a reaction and the Gibbs free energy of a reaction. The equilibrium constant, the effect of pressure and le Chatelier's principle, the effect of temperature and van't Hoff's equation, the effect of catalysts, and of pH. The electrochemical cell, standard electrode potentials, the Nerst equation.

ChE.206 Process dynamics and control

DR C.D. IMMANUEL
35 lectures.
Importance of dynamic modelling and control. Inputs, outputs, disturbances, manipulated variables, measured variables, and states. Dynamic modelling of simple unit operations.
Solution methods for non-linear models. Linearisation of single and multi-variable systems. Laplace transforms including final and initial value theorems. Solution of ODE systems using Laplace transforms. Inverse Laplace transforms. Transfer functions for linear systems. Deriving the transfer function matrix

from time-domain models. Poles and zeros of transfer functions. Time delays. Superposition of system inputs. Qualitative analysis of system response. Process identification from simple experiments. Modification of system dynamics, introduction to feedback and feedforward control. P, PI, PID controllers. Measuring devices, control valves and their characteristics. Closed loop transfer functions. Frequency response techniques. Design of feedback control systems, the Bode stability criterion, gain margin. Trial and error tuning. PID tuning rules: Cohen-Coon and Ziegler-Nichols. Cascade, feedforward and ratio control. Estimating achievable performance.
Control structure selection, steady-state disturbance rejection, the relative gain array, speed and strength of response. Plant-wide control, degrees of freedom analysis, identifying control objectives, selecting manipulated and measured variables.
Model predictive control for unconstrained systems; discrete digital control *vis à vis* continuous control
Control project (ChE.203.1).

ChE.207 Mathematics (MEng. 2.2)

60 lectures. See Department of Mathematics syllabus for details.

ChE.208 Fine chemicals courses

Fine chemicals stream students take the following courses given by the Chemistry Department:
1.O3 Haloalkanes, alcohols and amines
1.O4 Chemistry of the Carbonyl and carboxyl groups
See Chemistry Department syllabuses for details

ChE.209 Managerial Economics (BS0804)

20 lectures. (See Tanaka Business School syllabus for details.)

PART III

ChE.301 Chemical engineering III (Mastery)

DR F. STEPANEK, PROFESSOR S.M. RICHARDSON
A course in mastery of chemical engineering principles.

ChE.302 Reaction engineering II

DR E. ALPAY (GSEPS)
30 lectures.
Transport processes in heterogeneous catalysis: interfacial gradient effects: reaction at a catalyst surface, concentration and temperature differences across the external-film of a catalyst pellet, mass transfer on metallic surfaces; intraparticle gradient effects: catalyst internal structure, pore diffusion, reaction and diffusion within a catalyst pellet, effectiveness factor and generalised effectiveness factor, temperature gradients within a catalyst pellet, Weisz-Prater criteria; combined interfacial and intraparticle resistances.
Fixed bed catalytic reactor design: pseudo-homogeneous PFR and axially dispersed PFR models; heterogeneous models: use of effectiveness factor, use of intraparticle diffusion equations; two-dimensional models.
Fluidised bed reactors: fluidisation principles; key applications; two and three phase models: transport reactor design; catalyst deactivation functions.
Multiphase reactors: two-film theory: Hatta number, general design models; simplifications to design models: instantaneous, fast and slow reactions, solid catalysed reactions, resistances in series approximation; selection of gas-liquid contactors.
Non-catalytic fluid-solid reactions: total particle dissolution; shrinking core model; reactor design.

ChE.303 Transfer processes III

ChE.303.1 Separation processes II

PROFESSOR N. SHAH
18 lectures.
Multicomponent distillation: calculations based on infinite reflux conditions, determination of minimum

reflux conditions. General methods for design of distillation columns and multiple column systems. Distillation with chemical reaction; azeotropic distillation, residue curves.
Solvent extraction: introduction to triangular diagrams, liquid equilibria and tie line construction. Thermodynamic considerations leading to mathematical models of the phase equilibria. Effect of temperature on equilibria, third phase formation. Calculation of stage requirements. Empirical correlations for tie lines and phase equilibria.
Adsorption: design considerations.

ChE.303.2 Fluid mechanics
DR. P.D.M. SPELT
15 lectures.
Conservation of mass: Lagrangian and Eulerian formulations, differentiation following the motion, continuity equation.
Conservation of momentum: body and surface forces, stress, linear momentum, Navier equations, Navier-Stokes equations.
Constitutive equations—rheology: deformation and rate of strain, Newtonian fluids, non-Newtonian fluids.
Exact solutions—self-similarity: vorticity, boundary conditions.
Boundary layers—scaling and dimensional analysis: laminar flow solutions. The boundary layer approximation, wall boundary layers and free thin shear layers, dimensionless parameters.
This course is not taken by fine chemicals stream students.

ChE.303.3 Particle engineering
DR F. STEPANEK
24 hours of mixed lecture and problem solving classes.
Fundamentals: particle characterisation (particle size and shape, particle assemblies, characterisation methods, interpretation of distributions); particle mechanics (particle-particle and fluid-particle forces, friction, electrostatic, Van der Waals forces, powder statics, powder flow); population balances (formulation, kernels, solution methods).
Unit operations: particle formation (physical and chemical routes, crystallisation from melt and solution, aerosol synthesis, emulsions and wet routes); particle-fluid separation (sedimentation, filtration, centrifugation, cyclones, drying); size reduction (crushing, milling); size enlargement (flocculation, dry and wet high- and low-shear granulation, compaction, tabletting, pelletisation); mixing and de-mixing (blending, classification); storage and transport (silos, hoppers, mechanical and pneumatic conveying).

ChE.304 Strategy of process design

PROFESSOR N. SHAH
24 hours of lectures and problems classes.
Synthesis, analysis and optimisation stages of design; the design process. Synthesis of process flowsheets. Top-down approach and economic potential of a process; role of heuristics; consideration and screening of alternatives. Input-output structure of a flowsheet; development of recycle structure; decisions related to and choice of reactor; estimate of reaction heat effects; inclusion of reactor and recycle costs in economic potential. General structure of separation systems; vapour and liquid recovery systems; decisions to be taken and design guidelines; heuristics and short cut calculations and their limitations; inclusion of separation costs in economic potential.
Synthesis of heat exchanger networks.
Composite temperature-enthalpy curves, minimum heating and cooling requirements as a function of minimum approach temperature; minimum number of heat exchange matches; use of loops and split streams; balancing capital and operating costs.
Computer-aided process analysis and simulation.
Synthesis and flowsheeting project: see ChE.307.2.

ChE.305 Safety and loss prevention

PROFESSOR G.H. KELSALL, PROFESSOR S.M. RICHARDSON
45 lectures and seminars.
Introduction: safety engineering, loss control, accident statistics, major hazards.
Combustion: fire and explosion types, pre-mixed reactants, critical, temperature, flame propagation, burning velocity, flammability limits, le Chatelier's principle, flame speed, inhibition, ignition, autoignition, flash-point, quenching, effects of turbulence, pressure piling, deflagration, detonation, overpressure, TNT equivalent, BLEVEs, UVCEs, diffusion flames, pool fires, jet fires, radiation hazards, site layout.
Runaway reactions: reaction engineering, control, relief.
Gas and liquid discharges: discharge systems, vents and flares, relief sizing, dispersion.
Mechanical design: pressure vessels, stress and strain in thin-walled vessels; design using BS5500 drawings.
Systems engineering: hazard identification (F&E indices, HAZOP), consequence analysis (fault and event trees), hazard statistics (fatality rate, fatal accident rate), risk analysis, risk evaluation, risk reduction, laws and regulations (UK and EU), reliability engineering, case study.
Materials degradation and protection: corrosion of metals and materials—degradation caused by reactions with their (chemical and mechanical) environments, in particular circumstances. Metals and alloys in engineering. Costs of corrosion.
Electrochemical thermodynamics: electrode potentials—Nernst equation; electrochemical series; galvanic series; potential-pH diagrams—immunity and passivation; Metal ion activity-pH (solubility) diagrams.
Electrode kinetics: anodic and cathodic processes; Faraday's law; charge transfer controlled electrochemical reactions—Butler-Volmer and Tafel equations; mass transport in electrochemical systems; polarisation curves; oxygen reduction and hydrogen evolution reactions; mixed potential processes; Evans diagrams.
Corrosion of metals in gaseous environments: Ellingham diagrams; predominance diagrams for metal-gas systems; High temperature metal (alloy)/gas oxidation kinetics.
Physical metallurgy: phase diagrams—heterogeneity of alloys; mechanical properties of alloys.
Classification of corrosion failures—principal types of corrosion and design implications: general; galvanic; crevice; pitting; inter-granular; selective leaching; erosion; high temperature; environmentally-induced cracking—stress corrosion, hydrogen-induced cracking, corrosion fatigue; biodegradation.
Corrosion protection—modification of design and/or procedures: materials—alloying; environment—inhibitors; metal/material surface—coatings; cathodic protection—sacrificial anodes and impressed current.
Materials selection for particular service environments.

ChE. 306 Environmental engineering

PROFESSOR G.H. KELSALL, PROFESSOR A.G. LIVINGSTON
48 hours of lectures and tutorials.
Introduction to environmental engineering: biogeochemical cycles and pollution problems (greenhouse effect, ozone depletion, toxicity, bioaccumulation). Effects of toxic materials. Relationship between effect and dosage. Fate modelling and simple 'unit world' concept for pollutant transport and partitioning, lifetimes of pollutants and removal processes. Mobile and stationary sources of air pollutants.
Air pollution control: desulphurisation, pre- and post-combustion; other combustion related pollutants and their abatement.
Industrial wastewater: undesirable characteristics of industrial wastewater. Technology for control of emissions of heavy metals (precipitation, ion exchange), volatile organic compounds (VOCs) and toxic organic compounds (adsorption, steam stripping, solvent extraction, chemical oxidation). Oxidation and oxygen demand. Biological growth and biological oxidation. Characterisation of industrial wastes (COD, BOD, etc.). Waste minimisation. Biological effluent treatment: activated sludge process, trickling filters.
Measuring environmental impacts: atom economy, process mass intensity, green chemistry. Life cycle analysis, definition of system boundaries, pollution metrics/environmental impacts.

Pollution prevention: mass exchange network synthesis for pollution control and minimisation. Optimal degree of abatement. Pollution prevention and clean technology in total impact framework. Legislation controlling discharges. Implications of environmental constraints for process design, policies for regulation of environmental impacts.

ChE.307 Coursework 3

ChE.307.1 Techno-socio-economic project

Dr M.A. MENDES, DR. F. STEPANEK
Project looking at the impact of political, economic and social factors on the application of technology and engineering in both the developed and third world context.

ChE.307.2 Flowsheeting project

PROFESSOR N. SHAH
Synthesis and flowsheeting project: students working in groups develop a conceptual design for a specific process, following the top-down approach outlined in the course. They evolve a basic flowsheet structure, identify key tradeoffs and design variables and their useful range, identify and size key plant items and produce a preliminary economic assessment of the process.

ChE.307.3 Mechanical design

PROFESSOR J.P.M. TRUSLER, PROFESSOR S.M. RICHARDSON
This project is carried out in small groups over a period of two weeks. The objective of the project is to design a pressure vessel suitable for use in a specified process. The design must conform to the requirements of BC5500 and other relevant British Standards. Details of the process are contained in a design specification sheet issued to each group. At the end of the project, each group is required to deliver a report and a set of engineering drawings detailing their design.
Fine chemicals students take ChE.203.4 instead of this project.

ChE.307.4 Environmental engineering project

PROFESSOR G.H. KELSALL, PROFESSOR A.G. LIVINGSTON
The project makes an assessment of the best practicable environmental option (BPEO) for controlling pollution for a chemical process. This involves:
(i) estimating the environmental effects of the pollution from the chemical process (for example, use of fate calculations, plume modelling, calculating atom economy or mass intensity);
(ii) defining the objective of controlling the pollution from the chemical process (one or more objectives);
(iii) generating options to meet the objectives for each chemical process (basic process descriptions including pros and cons for application under consideration);
(iv) assessing two options (more detailed sizing calculations, utility requirements, environmental and economic assessments of two options);
(v) identify the BPEO (justify choice of BPEO from two detailed options and 'do nothing'). This should be shown graphically, for example, cost as a function of environmental impact measured in some relevant way.

ChE.308 Behaviour in industrial organisations (BS0802)

20 lectures plus case studies.
See Tanaka Business School syllabus for details.

ChE.309 Fine chemicals courses

Fine chemical stream students take the following courses given by the Chemistry Department:
2.O1 Organic Synthesis
2.O4 Pericyclic reactions
2.O5 Heteroaromatics
2.O6 Alicyclic and non-aromatic heterocycles
See Chemistry Department syllabus for details
See Part IV for details of the electives.

PART IV

ChE.401 Coursework 4

ChE.401.1 Link/research project
All students carry out either an industry-based link project or a research project. Those students who carry out a link project work in industry for about eight weeks during the vacation following their third year and for a further period back in the College in the autumn term on a project. The College part of the project is assessed as part of their fourth year coursework. Research projects are carried out entirely in the College during the autumn term.

ChE.401.2 Plant design project
Students work together in a team on the design of a complete chemical process. The work includes preliminary economic assessment, choice of process and development of flow sheet, overall process design, design of individual items, plant layout, consideration of the control system, start-up and operating procedures, safety, environmental and statutory requirements.

ChE.404 to ChE.424 plus Tanaka Business School, Humanities and Physics Department courses are the current electives: all are offered to Part IV students and a sub-set is offered to Part III students.

ChE.404A Advanced process control A

DR S.P.K. WALSH (ICI)
20 lectures.
Plant-wide control using conventional controllers: Characteristics of, and motivation for, process control; review of basic control concepts (transfer function, frequency response, bandwidth, poles and zeros); introduction to process modelling; heuristic rules for control structure selection with examples; steady-state disturbance rejection analysis (linear and non-linear); interaction and integrity analysis using the RGA and Niederlinski index; singular value decompostion and effective degrees of freedom; bandwidth and crossover frequency; controller tuning using Ziegler-Nichols, Cohen-Coon, relay tuning, systematic refinement; level control; ‘advanced’ conventional control using feedforward, ratio, cascade, gain-scheduling, input conditioning and decoupling.
A project is carried out to apply these ideas to a plant-wide control problem, based on an industrial example.
Modern methods for multivariable controller design and analysis: Limitation of PIC control; loop shaping with singular values; robust stability; direct Nyquist array; internal model control (IMC); dynamic matrix control (DMC); linear quadratic control (LQ); criteria for selecting advanced control strategies (examples are provided to allow exploration of some of these techinques); feedforward control; illustrative process examples. A plant-wide control project is carried out using the techniques covered in the first part of the course to develop a control scheme for an industrial plant.

ChE.405 Advanced process operations

PROFESSOR S. MACCHIETTO
20 lectures.
Discontinuous processes (batch and semi-continuous) are common in the process industries (chemical, fine chemical, pharmaceutical, biotechnology, food and drink, etc.). The development, control and operational management of such processes requires different techniques than for continuous processes. The course covers two relevant aspects:
Control issues in batch and semi-continuous processes: sequential control, notions of dynamic optimisation, control of batch operation, control of integrated operations.
Mechanistic model building for dynamic systems: statistical validation of models, optimal experiment design for model discrimination and precise parameter estimation.

ChE.406A Advanced process synthesis and optimisation I

PROFESSOR E.N. PISTIKOPOULOS
20 hours of lectures and coursework.
Principles of continuous optimisation. Principles of modelling with integer variables. Principles of mixed-integer linear and non-linear optimisation. Applications to: heat exchanger network synthesis and process planning with environmental objectives.

ChE.406B Advanced process optimisation II

PROFESSOR E.N. PISTIKOPOULOS
20 hours of lectures and coursework.
Prerequisite: ChE.406A.
Principles of optimisation under uncertainty: flexibility analysis, parametric programming, mixed-integer dynamic optimisation. Applications to: interactions of design and control and model based control.

ChE.407 Polymers and polymerisation processes

PROFESSOR DAME J.S. HIGGINS, DR A. BISMARCK, DR C.D. IMMANUEL, DR J.H.G. STEINKE (DEPARTMENT OF CHEMISTRY)
15 hours of seminars and associated project work plus structured essay.
The course illustrates the complex interaction from both chemistry and chemical engineering needed to produce a polymer product. The course discusses the challenges of turning a polymer into an industrial product by considering the entire process covering monomer synthesis, polymerisation chemistry, polymer structure and morphology and processability. A further feature of the course is the format in which chemists and chemical engineers will be tackling challenges in groups, working as teams throughout the course, to promote mutual appreciation of each other's discipline through sharing of knowledge and expertise. The course participants will be introduced to a wide range of polymeric materials and their processing ranging from bulk polymers to recent developments in biomedical and electronic materials and the challenges associated with their pilot scale and industrial production. The course consists of a combination of seminars, supervised team exercises, an experimental introduction to polymer characterisation techniques, processing and properties, and includes speakers from industry.

ChE.408 Dynamic behaviour of process systems

PROFESSOR C.C. PANTELIDES
20 hours lectures and project work.
Process modelling: introduction; non-reacting lumped systems involving mass and energy balances, lumped systems with chemical reaction, modelling of lumped separation processes.
Mathematical background: differential-algebraic equation (DAE) systems, high index DAEs, optimisation of transient processes; parameter estimation and design of experiments.
Project work: introduction to *gPROMS*, semi-batch reactor modelling, simulation, parameter estimation, and optimisation.

ChE.410 Electrochemical engineering

PROFESSOR G.H. KELSALL
20 lectures plus tutorials.
Electrochemical thermodynamics—electrode potentials.
Electrochemical kinetics—Butler-Volmer equation.
Transport processes in electrochemical systems.
Experimental techniques for determination of electrochemical kinetics.
Potential, concentration and current density distributions.
Electrode materials, catholyte/anolyte separators and ion-permeable membranes.
Design and modelling of electrochemical reactors.
Fuel cells and batteries.
Electro-inorganic and electro-organic synthesis.
Electrometallurgical processes—*Al, Zn, Cu*.

ChE.411 Flexible plant operation

PROFESSOR N. SHAH
20 hours of lectures and coursework.
Introduction to process operations: overview of operations hierarchy; control of individual equipment and relation to dynamic optimisation; design and validation of operation procedures, interactions between design and operations.
Planning and scheduling: multiproduct and multipurpose plants; the need to represent separately plant, processes, demands, operation data; state-task network representation of processes; modelling more complex operations: changeovers, equipment states, cleaning, etc; campaign operation and campaign planning; simple maintenance issues; industrial examples.
Plant design/retrofit for operation: extension of basic operations models to design. New variables and modified formulations. Choosing/sizing equipment, storage, utilities. Suitable objective functions. Industrial examples. Basic ideas of flexibility, in particular with respect to uncertain demands.
Projects: modelling and solution of simple design scheduling problem.

ChE.412 Fluids engineering

PROFESSOR G.F. HEWITT, DR. X.Y. XU
20 lectures.
The handling of fluids and the prediction of their movement is at the heart of the engineer's job in many sections of industry. This course provides a working knowledge of some of the key industrial areas. It provide a basis from which the engineer in (or about to enter) industry can develop further expertise. Emphasis is given to computational fluid dynamics to reflect the subject's continuing growth in importance.
Two-phase flow: two-phase flow patterns. Conservation equations for two-phase flow. Bubble and stratified flow. Annular flow. Plug and churn flow. Slug flow.
Computational fluid dynamics: introduction, mathematical background, applications, analysis of turbulent and laminar flows and buoyant flows and combustion.

ChE.413 Formulation engineering and technology

DR F. STEPANEK, DR. A. BISMARCK
20 hours of lectures and practicals.
Emulsions and suspensions: microstructure and macroscopic properties, characterisation, processing, applications (inks and paints, cosmetics, food products, etc.).
Creams and pastes.
Granules and particles: structures-property correlations, processing (spray drying, agglomeration, encapsulation), applications (pharmaceuticals, agrochemicals, detergents).
Practical sessions: computer-aided formulation engineering, project characterisation, granulation, drying.

ChE.414 Introduction to nuclear technology

PROFESSOR G.F. HEWITT, PROFESSOR M. STREAT
20 lectures.
Nuclear power is a major UK industry, accounting for around 20 per cent of electrical power in the country, and chemical engineers have traditionally had a major role in it.
This course gives an introduction to nuclear technology with particular emphasis on chemical and thermal engineering aspects. Uranium production technology; uranium hydrometallurgy, uranium purification, uranium enrichment technology. Nuclear fuel processing; waste treatment and storgage. Nuclear power systems: how reactors work. Reactor cooling systems. Two- phase flow and heat transfer. Critical heat flux. Computer codes. LOCA phenomena. Severe accidents. Thermal aspects of reprocessing.

ChE.415 Membrane science and membrane separation processes

DR K. LI
20 lectures, plus problems classes and a project.
This course develops the student's ability to formulate and solve engineering problems involving design of membranes and membrane modules for gas separation, reverse osmosis, filtration, dialysis, pervaporation, and gas absorption/stripping processes.

The course covers membranes for separation processes, membrane preparation, membrane fabrication via phase-inversion, membrane transport—gas permeation, membrane transport—reverse osmosis, polarisation phenomena and membrane fouling, membrane module design, membrane-based gas absorption.

ChE.416 Process heat transfer

PROFESSOR G.F. HEWITT, DR A.W. DEAKIN (BP)
20 lectures.
This course covers the many and varied problems of process heat transfer. It provides an opportunity for direct experience of process heat transfer calculations, enabling students to understand the procedures and to undertake critical assessments of commercial computer codes used in an industrial environment. Topics covered include: selection of heat exchangers, shell-and-tube heat exchangers, compact heat exchangers, plate-and-frame heat exchangers, air-cooled heat exchangers, shell-and-tube condensers, reboilers and evaporators. All topics are complemented by appropriate design studies.

ChE.417 Introduction to colloid and interface science

DR A. BISMARCK, DR O.K. MATAR, PROFESSOR P.F. LUCKHAM
20 hours.
The properties of particles in dilute suspensions. The properties of surfactants. Liquid-liquid and liquid-solid interfaces. Emulsions and foams. Vesicles and liposomes. Characterisation methods for all the above. Molecular dynamic and Monte Carlo simulations.

ChE. 418 Introduction to modelling the phase equilibria of fluids

DR C.S. ADJIMAN, DR A. GALINDO, PROFESSOR G. JACKSON, DR E.A. MÜLLER,
PROFESSOR J.P.M. TRUSLER
20 hours of lectures.
Understanding of phase equilibrium problems and knowing how to solve them is essential for the design of chemical processes and constitutes a significant challenge in the final-year design project. This course is concerned with methods for predicting the phase behaviour of fluids in the context of process design. The aim of the course is to provide the knowledge necessary to understand and discriminate between different modelling techniques and approaches. Some of the theoretical fundamentals (statistical mechanics) and modern computational methods (Monte Carlo and molecular dynamics) will be developed in lectures and applied in a number of case studies to be carried out during the timetabled sessions.

ChE.419 Fundamentals of biotechnology

PROFESSOR D.C. STUCKEY, DR A. MANTALARIS
20 lectures.
Fundamentals of biological systems: from cells to molecules. Microbial and mammalian cell physiology, structure and function. Gene expression and protein synthesis.
Redox reactions as a basis of biological reactions and use of concepts, such as oxidation number to gain insights into these reactions.
How energy is produced in a cell through catabolic pathways. Link through Gibbs' free energy to cell growth and yield coefficients.
Biological reactor design and comparison with chemical engineering.
Selection of key unit operations for separation and recovery of biological products. Sequences of downstream processes for diverse range of biological molecules.
Enabling technologies for animal cell biotechnology, such as monoclonal antibodies. Fundamental principles behind modern molecular biology techniques commonly employed in biotechnology.

ChE.421 Biological systems—fundamentals and modelling

DR A. MANTALARIS, DR X.Y. XU, DR F. STEPANEK
20 hours.
Introduction to the fundamentals of biological systems structure and function: molecules, cells, and tissues. Topics to be discussed include: cellular and molecular mechanisms, cell metabolism and energy production, transport across cell compartment barriers, protein synthesis and secretion, regulation of

gene expression, transduction of signals from the extracellular environment, cell proliferation, cell adhesion and migration, basic mammalian cell physiology (with an emphasis on muscle, cardiovascular, haematopoietic, and immune systems).
Fundamental theories of fluid mechanics in biological systems. The focus is on the anatomy and function of the human circulatory system, namely the heart, arteries, and veins through the application of classical fluid mechanics theories to solve blood flow in simplified models of arteries and veins, the knowledge of modern imaging techniques for in vivo acquisition of anatomical and flow data, and the application of CFD in the modelling of blood flow in the human circulatory system.
Fundamental aspects of microcirculatory flow, transport within blood vessels and towards the surrounding tissue, as well as transport within the tissue. Also, the mechanisms of consumption (nutrient, oxygen, etc.) within tissues will be introduced and modelled. In addition, models of intracellular processes, such as Ca++, which are critical to cell responses, will be developed. A general introduction to strategies for solving such problems, including the use of Maple, will be discussed.

ChE.422 Downstream separation in biotechnology

PROFESSOR D.C. STUCKEY
20 lectures.
Biotechnology products such as proteins, monoclonal antibodies, etc., are often dilute (as low as 100 mg/l), occur in a complex mixture (fermentation broth), are often large (up to 150 KDa), and quite fragile to pH, temperature, and shear extremes. In addition, product purity for injectibles has to be as high as 99.99 per cent. Hence downstream separation flow sheets can constitute up to 20 unit operations, with low overall yields (5-10 per cent), and sometimes the separation and purification costs can amount to 70 per cent of the final product cost. This preliminary course examines basic cell separation techniques such as filtration and centrifugation, cell rupture, and purification techniques such as adsorption (affinity and ligand), chromatography, solvent extraction, precipitation, and crystallisation. Finally, it will examine some aspects of process flowsheeting in downstream separation.
The course gives an overview of many of the techniques used in biotechnology, which in many cases differ markedly from chemical engineering, and to provide students with sufficient information to formulate an initial flowsheet, and carry out a preliminary design.

ChE.423 Product characterisation

DR S.G. KAZARIAN, DR A. BISMARCK, PROFESSOR DAME J.S. HIGGINS, DR D.R. WILLIAMS
30 hours of lectures and laboratory work.
This course provides students with up-to-date knowledge and experience in current experimental techniques for product characterisation. Specifically, the course introduces:
Applied spectroscopy: (Infrared, Raman, UV/Vis, and advanced spectroscopic techniques).
Light scattering (including neutron scattering) methods.
Thermal methods (DSC, TGA, DMTA).
Microscopic and imaging technologies (optical, spectroscopic, atomic force microscopy, STM, surface topography, surface profilometry).
Surface physicochemical techniques (gravimetric, inverse gas chromatography, wetting, etc.).
Surface analytical characterisation (XPS, Auger, SIMS).
Physical characterisation (particle sizing, surface area density—BET).
The above techniques are illustrated by application to the characterisation of ‘real world’ products such as: polymeric materials, pharmaceutical materials, porous materials, foods, health and personal care products, biomedical materials.
Physical characterisation (particle sizing, surface area density—BET).
The above techniques are illustrated by application to the characterisation of ‘real world’ products such as: polymeric materials, pharmaceutical materials, porous materials, foods, health and personal care products, biomedical materials.

ChE.424 Environmental biotechnology: principles and applications

PROFESSOR D.C. STUCKEY
30 hours of lectures and problems classes
Environmental biotechnology utilizes microorganisms to improve environmental quality. These improvements include preventing the discharge of pollutants to the environment, cleaning up contaminated environments, and generating valuable resources for society. This course will develop basic microbial and thermodynamic concepts and quantitative tools in the first part of the course, and then use these principles to describe and design applications in the later part. As such it will cover; stoichiometry and bacterial energetics, microbial kinetics, biofilm kinetics and reactors. It will then use this theory to look at activated sludge and aerobic biofilm processes, nitrification, denitrification, phosphorus removal, anaerobic treatment and detoxification of hazardous chemicals. The course will be based on a textbook by Rittmann and McCarty entitled “Environmental Biotechnology: Principles and Applications”, McGraw-Hill, 2001, and involve some 20-25 hours of lectures and 5-10 hours of problem classes.

BS0806 Entrepreneurship

See Tanaka Business School syllabus for details.

BS0808 Finance and financial management

See Tanaka Business School syllabus for details.

BS0820/BS0828 Innovation management

See Tanaka Business School syllabus for details.

BS0821 Project management

See Tanaka Business School syllabus for details.

PT.3.3 Dynamical systems and chaos

DR F.H. BERKSHIRE (DEPARTMENT OF MATHEMATICS)
28 lectures. (See Physics Department syllabus)

Any course from the Humanities Programme
HUMANITIES PROGRAMME STAFF
Equivalent to 20 hours.

Examinations

	Degree exam for which recognised	Date
PART I		
Process analysis	Final	June
Transfer processes I	"	"
Thermodynamics I	"	"
Chemistry	"	"
Mathematics I	"	"
Mathematics II	"	"
Chemical engineering I (Mastery)	"	May/June
PART II		
Reaction engineering I	Final	June
Transfer processes II	"	"
Thermodynamics II	"	"
Process dynamics and control	"	"
Mathematics III	"	"
Mathematics IV	"	"
Managerial Economics	"	May
Chemical engineering II (Mastery)	"	May/June
PART III		
Transfer processes III	Final	June
Environmental engineering	"	"
Safety and loss prevention	"	"
Strategy of process design	"	"
Reaction engineering II	"	"
Behaviour in industrial organisations	"	April
Electives	"	"
Chemical engineering III (Mastery)	"	May/June
PART IV		
Electives	Final	April/June
Chemical engineeering IV (Mastery)	"	April/June