ADVANCING CHEMICAL ENGINEERING WORLDWIDE

Checklist for Design Portfolios in Chemical Engineering Programmes

1.0 Introduction

Design is the creation of a plan or convention for the construction of an object, system or measurable human interaction, often necessitating consideration of the aesthetic, functional, economic, and socio-political dimensions of both the design object and design process. The design process may involve considerable research, thought, modelling, interactive adjustment, and re-design.

In the context of Design Portfolios and Chemical Engineering Design Projects appropriate to all areas of Chemical Engineering application (Chemical Engineering Process Design) within undergraduate teaching, we may consider design to encompass:

- translation of development work into designs
- translation of designs into operating plants
- design for construction and commissioning.

In each case SHE, Ethical and Sustainability considerations should be fully integrated into design.

The process of design involves the application of knowledge, synthesis of information, project management skills (including adherence to time, cost and quality), business & commercial skills and a number of interpersonal skills such as interdisciplinary & team working, communication (written & oral), information retrieval & record keeping.

2.0 Design Objectives

The objective of Chemical Engineering Process Design in a professional setting is generally to provide the necessary inputs to a multidiscipline Project Team at the earliest possible stage without prejudice to process integrity.

A series of key documents are completed in a progressive and logical pre-determined order.

Process design is required to be flexible and to be compatible with a wide variety of starting points and sources of technology. For any project the starting point will be defined and from this information the key documents referred to above are developed at the correct time and sequence in accordance with the appropriate standard of quality assurance. The required key documents, tailored to project needs, will be identified at the start of a project.

2.1 Progression of Design

Process design may generally be considered to progress in a number of key Project stages and identified Key Documents produced to the quality level appropriate to the Project Stage:

- Feasibility Studies
- Front End (or Basic) Design
- Detailed Design
- Construction
- Commissioning
- Operation

And for a full life cycle will include: Optimisation, Maintenance and Decommissioning

2.2 Key Process Design Activities

In outline, the key process skills applied to a particular project may cover the following main activities, developed through the course of a project for completion at the correct project stage:

- Conceptual design (development, feasibility studies)
- Basis of design
- Overall balances (mass, flow, energy, inventory)
- Flowsheeting (process flow diagrams, piping & instrumentation diagrams)
- Control (philosophy, descriptions)
- SHE (HAZOP, HAZAN)
- Equipment (specification, selection)
- Plant operation (commissioning, operating instructions, operator training, operation)

A key feature of Process Design is that it should encompass requirements for commissioning and plant operation. Safety and ease of operation should be considered on a continuous basis throughout the design process, and a staged series of reviews used to ensure safe and trouble free commissioning and operation, for example:

- Environmental / safety audits
- Environmental / safety management systems
- Legislative guidance
- SHE reviews (including HAZOP)
- Planning and permitting
- Environmental assessment / statement
- Availability, reliability, maintainability assessments
- Risk assessments
- Safety assessments (hazard identification / analysis, risk determination)
- Specialised safety assessments (fire, chemical, etc.)

Other staged reviews may take place throughout a project to ensure that development, business and project objectives are being met.

2.3 Design Portfolio Checklist

A checklist is appended (Design Portfolio Checklist) that identifies those key documents and activities that are entailed in a full commercial design. The checklist is provided for guidance, to assist those involved in the design and accreditation of Chemical Engineering courses with understanding the key elements of design that a Chemical Engineer may be expected to be familiar.

It should be noted that the checklist is not intended to be exhaustive or cover every eventuality. Some industries for example, require specific deliverables to satisfy regulatory and other bodies (eg Pharmaceuticals, Food, Nuclear, amongst others), whilst some end users require specific suites of documentation or deliverables developed to suit their ways of working.

3.0 Chemical Engineering Design Practice & Design Projects

3.1 Design Practice

The IChemE guidelines identify the desirability of learning outcomes for design being achieved throughout programmes. This approach allows students to accumulate a portfolio of design work and has many benefits, allowing students to progressively and simultaneously develop design skills and experience across a wide range of process, product and plant design problems.

The Design Portfolio Checklist indicates the major areas and detailed elements in which all students should be able to demonstrate learning outcomes:

Major Areas	Learning
Key Process Design Documents & Activities	- all areas
Safety, Health and Environmental Activities	- general SHE, some specialist
Mechanical Engineering Design	- equipment specification
Management & Control of Project Activities	- general appreciation
Commercial & Business Activities	- costs, viability
Reflective	- appreciation of learning

3.2 Design Projects

The IChemE guidelines require that the design portfolio includes a major design exercise (design project) which addresses the complexity issues arising from the interaction and integration of the different parts of a process or system.

The exercise is likely to take the form of a project involving teamwork and may well include a wider range of design and design related activities. An academic design project should simulate so far as is reasonably possible the real world, whilst acknowledging the constraints of the educational setting, course aims and students stage of development. It is reasonable to expect that the design project should be a pinnacle of a student's learning and development, that brings together those aspects of Chemical Engineering which have been included in the course alongside other specialised topics and combines these to provide a solution of a typical process industry problem. The project should allow the student to demonstrate creative and critical powers by requiring choices and decisions to be made in areas of uncertainty.

The major design exercise should therefore take elements from the Design Portfolio Checklist that build into a cohesive piece of work, following the progression of design and build up of key activities.

It should be noted that a full commercial design would encompass all elements of the Design Portfolio Checklist and this is not expected for an academic programme. It is considered that an academic programme would normally include most of those elements from the first three columns of the table (i.e. Feasibility, Front End (or Basic) and, Detailed Design); some programmes may also include elements from the remaining columns (Construct, Commission, Operate), though these more practical items are usually outside the scope of what can be accomplished in a university environment.

A typical project may, therefore, include some or all of the following, together with more university specific in-depth topics (from the outset full consideration to SHE, sustainability and ethical considerations is expected):

- Statement of individual project, including legislative drivers
- Key Business drivers, including an investigation to determine whether the product serves its functional purpose
- Project viability and financial key metrics
- Review of alternative processes
- Literature survey
- Review of available physical and chemical data
- Overall material and thermal balances
- Creation and synthesis of the final flow sheet
- Process design documentation
- Chemical engineering design of one or more units
- Outline mechanical engineering outline design or specification of one or more units
- Equipment selection
- Optimisation of process design
- Outline control system design and operability study including start-up and shut-down, general SHE activities, HAZOP and some specialist activities

- Summary or conclusion
- Reflective

4.0 Learning Outcomes

The Accreditation Guidelines identify the Learning Outcomes expected for programmes at each level. Students graduating from an accredited programme should expect the following outcomes.

4.1 Common Learning Outcomes

LEVEL	COMMON LEARNING OUTCOMES
ALL	**Deploy chemical engineering knowledge** using rigorous calculation and results analysis to arrive at and verify the realism of the chosen design. **Take a systems approach** to design appreciating: Complexity, Interaction, and Integration. **Work in a team** and understand and manage the processes of: peer challenge, planning, prioritising and organising team activity, and the discipline of mutual dependency. **Communicate** effectively to: acquire input information, present the outcomes of the design clearly, concisely and with the appropriate amount of detail, including flowsheets and stream data, and explain and defend chosen design options and decisions taken.

4.2 Specific Learning Outcomes

LEVEL	SPECIFIC LEARNING OUTCOMES
D	**Be aware** of the importance of identifying the objectives and context of the design in terms of: the business requirements: • the technical requirements • sustainable development • safety, health and environmental issues • appreciation of public perception and concerns. **Appreciate** that design is an open-ended process, lacking a pre-determined solution, which requires: • synthesis, innovation and creativity • choices on the basis of incomplete and contradictory information • decision making • working with constraints and multiple objectives • justification of the choices and decisions taken.
B	**Understand** the importance of identifying the objectives and context of the design in terms of: the business requirements: • the technical requirements • sustainable development • safety, health and environmental issues • appreciation of public perception and concerns. **Understand** that design is an open-ended process, lacking a pre-determined solution, which requires: • synthesis, innovation and creativity • choices on the basis of incomplete and contradictory information • decision making • working with constraints and multiple objectives • justification of the choices and decisions taken.

F	**Have comprehensive understanding** of design processes and methodologies and an ability to apply and adapt them in unfamiliar situations. **Work with information that may be incomplete or uncertain**, quantify the effect of this on the design and, where appropriate, use theory or experimental research to mitigate deficiencies. **Have the ability to generate an innovative design** for processes, systems and products to fulfill new needs. **Have achieved, within the design project(s)** some of the 'Depth' and 'Breadth' Outcomes of Advanced Chemical Engineering at Masters level.
M	**Have comprehensive understanding** of design processes and methodologies and an ability to apply and adapt them in unfamiliar situations. **Work with information that may be incomplete or uncertain**, quantify the effect of this on the design and, where appropriate, use theory or experimental research to mitigate deficiencies. **Have the ability to generate an innovative design** for processes, systems and products to fulfill new needs. **Have achieved, within the design project(s)** some of the 'depth' and 'breadth' outcomes of Advanced Chemical Engineering at Masters level.

Design Portfolio Checklist

DESIGN PROJECT ELEMENTS							
	Project Phase						
Activity	Feasibility	Front End Design	Detailed Design	Construct	Commission	Operate	NOTES
KEY PROCESS DESIGN DOCUMENTS & ACTIVITIES							
Statement of Brief	×						Separate statements for overall project and for individual projects
Project Development	×						Determination of objectives both technical and business, key issues around SHE, Sustainability and Ethics. Review of Literature / alternative processes, available physical and chemical data. **NOTE: For F level, this may involve more in depth study, adaptation, uncertainty or novelty.**
Basis Of Design	×	×					Establish inputs /outputs / performance requirements
Block Diagram	×						
Layout	×	×	×				
Battery Limit/Terminal Point Schedule	×	×					
Heat & Mass Balance	×	×	×				Including energy balance
System List	×	×					
Process Equipment List	×	×	×				
Process Motor List	×	×					
Process Description		×	×				
Feed/Utility/Chemical Requirements	×	×					
Emissions Schedule	×	×	×				
Materials Selection	×	×	×				

Process Flow Diagrams	×	×					
Equipment 4 line (outline) specs	×	×					
P & I.D s		×	×	×	×	×	Identify line size &material, inline fittings, equipment, critical lines, critical levels
Equipment Data Sheets		×	×				Supersede outline specs.
Instrument Data Sheets			×				
Control Philosophy		×	×				Outline control system design Include alarms/trips
Overall Commissioning Philosophy Document			×				
Commissioning Procedures			×	x			
Operability Study			x	x			
Operating Instructions			×	x	x		Outline start-up and shut-down including sampling and analysis requirements, manning, maintenance
Troubleshooting					x	x	
SAFETY, HEALTH AND ENVIROMENTAL ACTIVITIES							
Concept Stage Hazard Review	×						Major Hazards & Identification of specialist SHE requirements
HAZID at Front-End Engineering Design (FEED) or Project Definition Stage		×					Hazard Analysis(HAZAN)
Detailed Design Hazard Study			×				HAZOP, FMEA etc
Construction/Design Verification				×			
Pre-Commissioning Safety Review					×		
Post-Commissioning Safety Review						x	
Relief Valve studies & sizing			×				
LOPA & SIL Reviews			×				
Hazardous Area Classification	x	x	x				
Specialist SHE	x	x	x	x	x	x	Specialist areas include: Planning & permitting, EIA, LCA, Risk Assessments & Analysis, Hazard Assessment & Analysis, Containment, Fire & explosion studies, building siting, SHE plans etc **NOTE: It is not expected that students should have detailed knowledge of every specialism**

MECHANICAL ENGINEERING DESIGN							
Equipment Mechanical Specification			x				Mechanical engineering outline design of one or more units
MANAGEMENT & CONTROL OF PROJECT ACTIVITIES							
Planning	x	x	x	x	x	x	GANTT charts, control of Time
Cost, Estimates	x	x	x	x	x	x	Capital, Operating costs, control of Costs
Quality	x	x	x	x	x	x	Fitness for purpose, key assumptions recorded and limitations understood, Control of Quality
Coordination	x	x	x	x	x	x	Meetings recorded, Team Working
COMMERCIAL & BUSINESS ACTIVITIES							
Business Case & Marketing Plan	x	x	x	x	x	x	Strategic options, risks, financial metrics, Commercial justification & benefits
Financial Plan	x	x	x	x	x	x	Costs, Revenues, NPV, DCF, break even, viability
REFLECTIVE							
Reflective	x	x	x	x	x	x	What has been learnt – continuing professional development