PROCESS UTILITIES AND PIPELINE DESIGN
ENCH 465

Lecture: 3 **Year: IV**
Tutorial: 2 **Part: II**
Practical: 1

Course Objectives:
The objective of this course is to acquire basic understanding of design parameter, complete knowledge of design procedures for piping system and utilities commonly found in process industries. It prepares students to analyze industrial utility demand, execute standard hydraulic sizing, and layout safe piping networks for chemical plants.

1. Introduction to Process Utilities Design (4 hours)
- 1.1. Role of utilities in chemical plants
- 1.2. Overview of major utilities: Steam, Cooling water, Compressed air, Refrigeration
- 1.3. Utility distribution systems
- 1.4. Fluid Flow Fundamentals for Pipelines

2. Pipeline Materials, Valves and Fittings (6 Hours)
- 2.1. Pipe materials: Carbon steel, Stainless steel, PVC, HDPE
- 2.2. Valve types: Gate, globe, ball, check
- 2.3. Flanges and fittings
- 2.4. Piping Support

3. Design of Piping System (6 hours)
- 3.1. Introduction to piping system design basics
- 3.2. Pipe Routing, Pipe diameter selection, Minimization of pressure drop & energy losses
- 3.3. Series and parallel pipe systems, Pipe roughness and material selection
- 3.4. Preparation of Bill of Quantity (BOQ) for piping works

4. Design and Layout Development (10 hours)
- 4.1. Development of piping layout based on P&ID and pipe routing data
- 4.2. Pipe rack design and support systems
- 4.3. 3D layout development of piping system
- 4.4. Stress analysis of designed piping system

5. Pumps and Pumping Systems (4 hours)
- 5.1. Selection criteria and classification
- 5.2. Series and parallel pump operation, speed control, pipeline–pump interaction
- 5.3. cost considerations (capital and operating), maintenance and performance monitoring
- 5.4. energy optimization in pumping systems

6. Cooling Water Systems (4 hours)

6.1. Types and working principles of cooling systems: once-through, recirculating and cooling towers (natural & mechanical draft)
6.2. Heat removal calculations and cooling load estimation in process industries
6.3. Cooling tower performance: range, approach, effectiveness and efficiency
6.4. Water losses (evaporation, drift, blowdown) and water treatment methods (scaling, fouling, corrosion control)

7. Compressed Air Systems (3 Hours)

7.1. Types of compressors: reciprocating, rotary (screw), centrifugal-working principles and applications
7.2. Thermodynamics of air compression (isothermal vs adiabatic compression, multi-staging)
7.3. Air distribution system design: piping layout, pressure drop, receivers and storage
7.4. Air treatment: drying, filtration, moisture removal and industrial uses of compressed air

8. Refrigeration Systems (4 Hours)

8.1. Principles of refrigeration and applications in process industries
8.2. Vapor compression refrigeration cycle: components (compressor, condenser, expansion valve, evaporator)
8.3. Performance parameters: Coefficient of Performance (COP), refrigeration effect and energy analysis
8.4. Refrigerants: types, properties, environmental impact (ODP, GWP) and selection criteria

9. Pipeline Design Codes and Safety (4 Hours)

9.1. Hazard identification (HAZOP basics), Safety distances, relief systems and emergency access
9.2. Pressure ratings and thickness calculation criteria
9.3. Stress analysis basics and Design codes: ASME B31.3
9.4. Safety considerations: Leakage, Corrosion, Thermal expansion

Tutorial (30 hours)

1 Brainstorming operational parameters and performing calculations to formulate Basis of Design (BOD) for the cases of process utilities and piping networks.
2 Preparation of Block Flow Diagrams (BFD), Process Flow Diagrams (PFD), Piping and Instrumentation Diagrams (P&ID), General Arrangement (GA) drawings and piping layouts based on design criteria.
3 Performing thermal load estimation for sizing and selection of cooling tower systems
4 Calculations related to sizing and evaluation refrigeration systems
5 Calculations related to pumping system hydraulics and equipment sizing pump power requirements for series and parallel configurations.
6 Computing compressed air system sizing and network analysis.

7 Application of Pipeline Safety Standards and Design Codes.

Practical **(15 hours)**

1. Estimation of Refrigeration Loading
2. Determination of compressor efficiency and power consumption
3. Determination of air leakage losses in system
4. Evaluation of storage capacity of air receiver
5. Evaluation of Coefficient of Performance (COP) of refrigeration system
6. Evaluation of cooling tower effectiveness

Final Exam

The questions will cover all the chapters in the syllabus. The evaluation scheme will be as indicated in the table below:

Chapter	Hours	Marks
1	4	6
2	6	7
3	6	7
4	10	11
5	4	6
6	4	6
7	3	5
8	4	6
9	4	6
Total	**45**	**60**

*There may be minor deviation in mark distribution.

References:

1. Broughton, J. (Ed.). (1994). Process utility systems: Introduction to design, operation, and maintenance. Institution of Chemical Engineers.
2. McKetta, J. J. (Ed.). (1992). Piping design handbook. Marcel Dekker.
3. Smith, P., & Botermans, R. W. (2004). Advanced piping design. Gulf Professional Publishing.
4. Thakore, S. B., & Bhatt, B. I. (2015). Introduction to process engineering and design (Latest ed.). McGraw-Hill Education.
5. Toghraei, M. (2019). Piping and instrumentation diagram development. John Wiley & Sons.

LIFE CYCLE ASSESSMENT

ENCH 466

Lecture : 3 **Year : IV**

Tutorial : 2 **Part : II**

Practical: 1

Course Objectives:

This course introduces students to the principles, methodology and practical application of Life Cycle Assessment (LCA) for evaluating the environmental performance of chemical products, processes and technologies.

1. Fundamentals of Life Cycle Assessment (5 hours)

1.1 Environmental burdens of chemical and process industries and the need for life cycle thinking
1.2 Life-cycle stages and environmental burden shifting between raw materials, production, use and end-of-life
1.3 Historical development of LCA and standardisation under ISO 14040 and ISO 14044
1.4 Four phases of LCA: goal and scope definition, inventory analysis, impact assessment and interpretation
1.5 Attributional and consequential LCA; screening, streamlined, detailed and prospective studies
1.6 LCA and related tools: material flow analysis, environmental input-output analysis, risk assessment, carbon footprint and water footprint
1.7 Applications of LCA in process selection, product development, environmental reporting, procurement and environmental declarations

2. Goal, Scope and System Definition (4 hours)

2.1 Defining the goal of an LCA study: intended application, decision context and intended audience
2.2 Functional unit and reference flow: purpose and formulation for chemicals, fuels, fertilizers, solvents and polymers
2.3 System boundaries: gate-to-gate, cradle-to-gate, cradle-to-grave and cradle-to-cradle
2.4 Product-system flow diagrams: identifying processes, raw materials, energy inputs, products, emissions and waste
2.5 Foreground and background systems; cut-off criteria based on mass, energy and environmental significance
2.6 Temporal, geographical and technological coverage; assumptions, data representativeness and study limitations

3. Life Cycle Inventory Analysis (9 hours)

3.1 Unit processes and life cycle flows: product, intermediate and elementary flows; inputs and outputs
3.2 Inventory from material and energy balances: mass balance, carbon balance, energy use and process losses
3.3 Treatment of emissions and losses: vents, flares, fugitive emissions, wastewater and solid waste

3.4 Flow diagrams and data collection: process mapping, primary and secondary data, data sources and assumptions
3.5 From process flowsheet to inventory: translating process streams into LCA flows, scaling data and normalising to the functional unit
3.6 Matrix formulation of LCA: technology matrix, intervention matrix, final demand vector, scaling vector and inventory vector
3.7 Solving a small matrix-based LCA by hand and verifying the result against process balances
3.8 Upstream supply-chain effects: interpretation of the inverse technology matrix and indirect environmental burdens
3.9 Background databases and data quality: dataset selection, geographical and technological matching and pedigree matrix
3.10 Multifunctionality and allocation: subdivision; allocation by mass, energy, economic value and stoichiometry
3.11 System expansion and substitution; comparison with allocation using refinery and chlor-alkali examples
3.12 Recycling and end-of-life modelling: cut-off, avoided burden, shared burden, open-loop and closed-loop recycling; linking process simulation data to LCA

4. Life Cycle Impact Assessment (9 hours)

4.1 From inventory flows to environmental impacts: purpose of impact assessment, classification and characterisation
4.2 Selection of impact categories and linking inventory flows to midpoint and endpoint indicators
4.3 Climate change: greenhouse gas emissions, global warming potential, time horizons, fossil and biogenic carbon
4.4 Ozone depletion, acidification and eutrophication: sources, environmental mechanisms and indicators
4.5 Photochemical ozone formation and particulate matter: precursor emissions and interpretation of indicators
4.6 Human toxicity and ecotoxicity: emission pathways, fate and exposure concepts and uncertainty in toxicity factors
4.7 Water, land and resource impacts: water scarcity, land use, fossil resource and mineral resource depletion
4.8 Impact assessment methods: CML, ReCiPe, Environmental Footprint, TRACI and IMPACT World+
4.9 Effect of impact-assessment method selection on the comparison and ranking of alternatives
4.10 Normalisation and weighting: purpose, single-score indicators and limitations of aggregation

5. Interpretation and Uncertainty (5 hours)

5.1 Identifying environmental hotspots: contribution by process, life-cycle stage and elementary flow
5.2 Completeness and consistency checks: verification of data, assumptions, system boundaries and inventory coverage
5.3 Sensitivity analysis: influence of key parameters, assumptions and modelling choices on LCA results
5.4 Scenario analysis: alternative technologies, electricity mixes, operating conditions and end-of-life assumptions
5.5 Uncertainty in LCA: parameter, scenario and model uncertainty; sources of uncertainty in databases

5.6 Monte Carlo analysis: probability distributions, simulation of LCA results and interpretation of overlapping result distributions
5.7 Conclusions and recommendations: significance of findings, limitations and reporting in accordance with ISO 14044

6. LCA Software, Databases and Reporting (4 hours)

6.1 Structure of an LCA software model: processes, flows, product systems, parameters and calculation engines
6.2 LCA databases: background datasets, dataset matching, geographical and technological representativeness
6.3 Practical softwares: capabilities and typical applications
6.4 Building and analysing an LCA model: creating processes, connecting product systems, entering inventory data and running calculations
6.5 Environmental Product Declarations, Product Category Rules, carbon footprints and water footprints
6.6 Reporting and reproducibility: documentation of data sources, assumptions, database versions and modelling choices

7. Applications in the Chemical and Process Industries (9 hours)

7.1 Green chemistry and LCA: atom economy, E-factor, process mass intensity and energy intensity
7.2 Fossil-based and bio-based chemicals: renewable feedstocks, biomass supply chains, land-use change and biogenic carbon
7.3 Hydrogen production: steam methane reforming, carbon capture and storage, electrolysis and electricity-mix effects
7.4 Ammonia and fertilizer production: feedstock and energy use, nitrous oxide emissions and field emissions
7.5 Plastics and polymer recycling: virgin production, mechanical recycling, chemical recycling and biodegradable alternatives
7.6 Cement, lime and mineral processing: calcination, fuel-related emissions and clinker substitution
7.7 Carbon capture, utilisation and storage: energy penalty, transport and storage and accounting for CO_2 used as feedstock
7.8 Pharmaceutical and fine chemical manufacture: solvent intensity, energy use, waste generation and data scarcity
7.9 Comparative chemical-process case studies: environmental trade-offs, hotspot identification and process-selection decisions

Tutorial (30 hours)

1. Goal, Scope, and Functional Unit: Formulate goal statements, select functional units and reference flows, define system boundaries, and prepare product-system flow diagrams for three chemical products.
2. Inventory from Process Data: Develop a unit-process inventory from material and energy balances, calculate emissions and resource consumption, check mass and carbon balance closure, and normalize data to the functional unit.
3. Matrix-Based LCA Calculation: Construct technology and intervention matrices for a multi-process system, calculate scaling vectors and inventories, and verify matrix results against process balances using a spreadsheet or Python.

4. Multifunctionality and Allocation: Identify co-products using refinery or chlor-alkali examples, apply mass, energy, and economic allocation alongside system expansion, and compare the resulting burden allocations.
5. Life Cycle Impact Assessment: Convert inventories into climate change, acidification, and eutrophication indicators, perform characterization calculations, and compare results across different impact-assessment methods.
6. LCA Software Modelling: Build a cradle-to-gate product system in openLCA, select and adapt background datasets, run calculations, and identify environmental hotspots via contribution analysis.
7. Sensitivity and Uncertainty Analysis: Identify uncertain inventory parameters, assign pedigree scores, define uncertainty distributions, run Monte Carlo simulations, and interpret overlapping result distributions.
8. Comparative LCA Case Study: Conduct a comparative cradle-to-gate LCA of two chemical process routes covering all LCA stages, and critically evaluate a published process-industry LCA study.

Practical **(15 hours)**

1. LCA Software Orientation and Product-System Definition: Explore an LCA software package, create a project, define the goal, functional unit, reference flow, and system boundary, and prepare a product-system flow diagram for a selected chemical product.
2. Life Cycle Inventory from Process Data: Compile a unit-process inventory from material and energy data, calculate resource consumption and emissions, check mass and energy balance closure, and normalize the inventory to the functional unit.
3. Background Database Selection and Data Management: Explore LCA databases, select suitable background datasets, and document geographical, technological, and temporal representativeness along with data-quality considerations.
4. Building and Linking an LCA Model: Create or adapt foreground unit processes, enter product, intermediate, and elementary flows, and assemble a cradle-to-gate product system in openLCA or an equivalent tool.
5. LCA Calculation and Life Cycle Impact Assessment: Run the LCA model, review inventory results, select an impact-assessment method, and calculate key indicators such as climate change, acidification, and eutrophication.
6. Contribution, Hotspot, and Comparative Analysis: Generate contribution charts, identify environmental hotspots, and compare the environmental performance of two alternative chemical products or process routes using consistent parameters.
7. Sensitivity Analysis, Interpretation, and Reporting: Vary selected inventory parameters or modeling assumptions, evaluate their effects on impact results, and prepare a concise LCA report presenting the model, findings, hotspots, limitations, and conclusions.

Final Exam

The questions will cover all the chapters in the syllabus. The evaluation scheme will be as indicated in the table below:

Chapter	Hours	Mark distribution*
1 and 2	9	12
3	9	12
4	9	12
5 and 6	9	12
7	9	12
Total	45	**60**

Reference

1. Baumann, H., & Tillman, A.-M. (2004). The hitch hiker's guide to LCA: An orientation in life cycle assessment methodology and application.
2. Hauschild, M. Z., Rosenbaum, R. K., & Olsen, S. I. (Eds.). (2018). Life cycle assessment: Theory and practice. Springer.
3. Heijungs, R., & Suh, S. (2002). The computational structure of life cycle assessment. Kluwer Academic Publishers.
4. International Organization for Standardization. (2006). Environmental management-Life cycle assessment-Principles and framework (ISO Standard No. 14040:2006).
5. International Organization for Standardization. (2006). Environmental management-Life cycle assessment-Requirements and guidelines (ISO Standard No. 14044:2006).