Textos docentes | 180

Chemical and Biotechnological Process Engineering: Labs and Seminars in Action

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edual

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texto:
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Textos Docentes n.º 180

edición:
Editorial Universidad de Almería, 2024
editorial@ual.es
www.ual.es/editorial
Telf/Fax: 950 015459
¤
ISBN: 978-84-1351-349-2

edual editorial UNIVERSIDAD DE ALMERÍA

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COURSE INTRODUCTION

In this course, the organization of the working groups of the subject involves various collaborative activities designed to enhance students' understanding and application of chemical engineering principles. The organization of small groups is necessary for certain dynamics, including problem-solving exercises, but there are also times in the general teaching group when students may be asked to collaboratively tackle parts of the problem list, as deemed essential by the teacher for a better acquisition of related knowledge, particularly when the number of students allows for such an approach. Students should avoid linking teaching lessons solely with theory and working groups only with practical applications, as working groups can also be utilized for the acquisition of theoretical knowledge when the dynamic of small group collaboration is required.

The structure of the course includes the following key components:

Collaborative Exercises

Students will work in reduced groups to tackle lists of exercises that align with the course material. These exercises will reinforce theoretical concepts and provide practical applications of the knowledge gained in lectures, enhancing students' critical thinking and analytical skills. Please notice that

Practical Work in the Lab

Each group will also engage in hands-on practical work in the laboratory. These sessions will allow students to apply theoretical concepts in a controlled environment, encouraging experimentation and exploration of chemical processes and reactions.

Collaborative Presentations

Students will come together to collaboratively present their final presentations. This process will require them to synthesize their findings, analyses, and insights from both their practical work and theoretical studies. By preparing and delivering presentations as a team, students will learn to convey complex information clearly and effectively.

Integration of Industry Visits

The course includes visits to various industries, which are directly linked, among other skills, to the theoretical concepts developed in the teaching group (so, part of the time of the visits is related to teaching group organization). During these visits, students will observe real-world applications of what they have learned in class, allowing them to connect theory with practice. This hands-on exposure will deepen their understanding and appreciation of the field.

Through these activities, students will not only gain theoretical knowledge but also develop practical skills and teamwork abilities essential for their future careers in chemical engineering. The combination of exercises, lab work, presentations, and industry visits creates a comprehensive learning experience that prepares students for the challenges they will face in the professional world.

Industry Visits Linked to Course Program

As mentioned above, the industry visits will include a dedicated section in which key insights will be discussed and explained in detail, as it is a challenge for all of us. Visiting industries is a vital component of education for chemical engineering students for several reasons:

1. Real-World Application of Theoretical Knowledge
    - Bridging Theory and Practice: Students can see firsthand how the concepts and theories learned in the classroom are applied in real-world settings. This helps solidify their understanding and makes the learning experience more relevant.
    - Process Understanding: Observing actual processes allows students to grasp the complexities and nuances that theoretical studies might overlook, enhancing their comprehension of chemical engineering principles.
2. Exposure to Industrial Equipment and Technology
    - Familiarization with Equipment: Students gain exposure to the equipment and technologies used in the industry, which is crucial for their future careers. Understanding how various machines operate and their roles in processes prepares students for practical challenges.
    - Innovation and Modern Practices: Industry visits often showcase cutting-edge technology and innovative practices, encouraging students to think critically about advancements in the field.
3. Insights into Industry Standards and Regulations
    - Understanding Compliance: Students learn about the regulatory and safety standards that govern chemical processes, which is essential knowledge for working in the industry.

- Quality Assurance and Environmental Concerns: Observing how companies address quality control and environmental sustainability helps students appreciate the importance of these issues in real-world operations.

4. Networking Opportunities

- Building Professional Connections: Industry visits provide students with the chance to meet professionals in the field, fostering networking opportunities that can lead to internships or job placements.
- Mentorship: Interacting with industry experts can offer students guidance, insights, and mentorship, which can be invaluable as they navigate their career paths.

5. Enhanced Problem-Solving Skills

- Exposure to Real Challenges: Students can observe how industries address and solve real-world problems, enhancing their analytical and critical-thinking skills. Understanding how to approach complex issues in a professional setting is crucial for their development.
- Team Collaboration: Industry environments often require teamwork and collaboration. Observing this dynamic helps students develop essential soft skills, such as communication and cooperation.

6. Career Readiness

- Preparation for Employment: Exposure to industry practices and challenges prepares students for the realities of their future jobs. It helps them develop a mindset oriented toward continuous learning and adaptation.
- Understanding Job Roles: Students can better understand various roles and responsibilities within chemical engineering, aiding in their career planning and professional development.

7. Inspiration and Motivation

- Seeing Potential Career Paths: Visiting industries can inspire students by showcasing the diverse career opportunities available in chemical engineering, motivating them to pursue their interests within the field.
- Understanding Industry Impact: Students can appreciate the significant role chemical engineering plays in society, such as in energy production,

pharmaceuticals, and environmental protection, which can deepen their commitment to their chosen profession.

In a few words, industry visits are essential for chemical engineering students as they provide invaluable hands-on experience, insights into the professional environment, and opportunities for personal and professional growth, ultimately enhancing their education and preparing them for successful careers. However, it's important to recognize the logistical challenges associated with organizing these visits. Coordinating with the industry requires teachers to agree on a date that works for them, and they must allocate part of their time to host the group. Additionally, the teaching team need to arrange transportation, which involves renting a bus funded by the Chemical Engineering Department. These visits often extend beyond the time initially planned for teaching, necessitating adjustments to schedules for other courses. As a result, while participation in these visits is highly recommended to enrich your understanding, they are not compulsory if they coincide with other mandatory activities that cannot be rescheduled. Nevertheless, we are truly pleased to note that most students attend all the visits, which motivates us to continue making the effort to organize these valuable experiences.

The Written Report after each visit

The written report submitted after each visit will be invaluable for your group and other students as you prepare for the final presentation. By compiling your observations, analyses, and reflections, you will effectively demonstrate your applied knowledge of process flow conventions in industry, as well as the broader concepts acquired throughout the course.

- Comprehensive Understanding: The report will serve as a foundational resource, helping your group organize thoughts and insights into a cohesive presentation.
- Integration of Course Concepts: You will be able to link real-world observations with the theoretical concepts covered in class, showing a deeper understanding of how these principles apply in industrial contexts. Notice that in the different lists of problems there can be some information about required reports that must be included in your written report of the different visits (i.e. block flow diagram).
- Collaborative Reflection: As you collaborate with your group to finalize the presentation, the report will facilitate discussion and ensure that all relevant information is included, enhancing the overall quality and depth of your presentation.

Additionally, the written report of each of the groups will be marked by the group that prepares the presentation on that topic. This peer review process will not only encourage accountability but also ensure that all aspects of the topic are thoroughly understood and accurately represented. This exercise not only reinforces your learning from the course but also prepares you for practical applications of engineering concepts in the field.

INTRODUCTION TO DIAGRAMS IN CHEMICAL ENGINEERING

Diagrams play a crucial role in engineering as they provide a visual representation of complex concepts, systems, and processes, making them easier to understand and analyse. By translating intricate ideas into clear, graphical formats, diagrams facilitate communication among engineers, stakeholders, and clients, ensuring that everyone has a shared understanding of the project. They can illustrate relationships, workflows, and structural components, enabling engineers to identify potential issues early in the design phase and evaluate the feasibility of solutions. Additionally, diagrams serve as essential tools for documentation, helping to standardize information and ensure compliance with industry regulations. Overall, the use of diagrams enhances problem-solving capabilities, promotes collaboration, and ultimately contributes to the success of engineering projects.

LIST OF PROBLEMS NUMBER 1

TITLE Chemical Process Diagrams

Practical Skills:

- Plotting Block Flow Diagrams (BFD) and utilizing Process Flow Diagram (PFD) information.
- Creating partial PFDs for simple processes based on oral or written descriptions.

Objectives for Problem Set:

1. Develop Competence in Industrial Diagramming: Enable students to create and interpret Block Flow Diagrams (BFDs) and Process Flow Diagrams (PFDs) by analysing process descriptions from real-world applications like milk bottling and orange juice production. Students will practice identifying and representing process flows, utilities, and essential components accurately.
2. Improve Analytical Skills in Process Evaluation: Through diagramming exercises, students will assess the completeness and clarity of their diagrams, ensuring they effectively convey complex process information. Exercises will emphasize critical thinking in the interpretation and simplification of technical information.
3. Strengthen Practical Engineering Problem-Solving: Address practical engineering issues, such as equipment flow and piping system analysis, to identify operational problems and develop actionable recommendations. This hands-on

experience will prepare students for equipment troubleshooting and problem-solving in industrial settings.

4. Promote Understanding of Equality in Industrial Contexts: Foster awareness of gender and diversity issues within industries, particularly in the oil and gas and food sectors, by examining recent trends and statistics on equality in these fields. Students will learn about the impact of inclusive practices on innovation, productivity, and company success, encouraging an inclusive mindset.

5. Engage with Quantitative Process Calculations: Students will practice fundamental quantitative skills by calculating material availability, yield estimations, and other relevant parameters within industrial contexts, developing accuracy and precision in technical assessments.

6. Encourage Inquiry and Engagement with Industry Experts: Through industry visits, students will gain firsthand insight into diversity practices, corporate culture, and technical processes. Observations and inquiries related to minority representation will deepen their understanding of the social and technical dynamics within industrial environments.

Contextualization and activities

Students will begin by plotting Block Flow Diagrams (BFD) and creating Process Flow Diagrams (PFD) based on provided descriptions of industrial processes, such as a milk bottling line and orange juice production. These activities will require students to analyse process descriptions, identify essential utilities, and evaluate the effectiveness of their diagrams in conveying process information. Additionally, students will watch informative videos and complete exercises that involve filling in blanks with specific information, calculating raw material availability, and estimating juice yields. They will also tackle practical problems related to equipment flow issues, requiring them to investigate the condition of piping systems and make recommendations for improvements. Through these activities, students will develop critical skills in process analysis, diagramming, and problem-solving, preparing them for real-world engineering challenges.

In this problem set, we'll focus on using diagrams to effectively communicate crucial information in the oil and gas and food industries. As we explore these sectors, understanding the current state of gender equality provides valuable contextuality:

In the oil and gas sector before 2020, women were still significantly underrepresented, holding only 14% of board seats, 16% of total jobs, and just 1% of CEO positions, with even fewer in technical roles like engineering. However, companies with higher female leadership see substantial benefits, achieving 6% higher net margins and a 34% higher return to shareholders. Recognizing these disparities highlights the value of diversity for innovation and growth, motivating future engineers to support inclusive practices in the industry. The latest Untapped Reserves report by Boston Consulting Group and WPC Energy highlights the slow progress of gender equality in the global oil and gas industry, where women's representation increased only marginally from 22% to 23% since 2021 (Hughes-Plummer et al., 2023; Jodi Shafto, 2019; Katharina Rick, 2017).

The food industry shares similar challenges, with women significantly underrepresented in the food industry's corporate pipeline, particularly at senior levels. While they comprise 49% of entry-level employees, this figure drops to just 23% at the C-suite level. Some differences in opportunities have been correlated to the term "white people". This controversial term generally refers to individuals with lighter skin tones, specifically those whose skin has a high reflectance index according to spectrophotometer measurements, which indicates low melanin levels. Native populations of Europe, more than any other global group, commonly fall within these parameters due to their minimal skin pigmentation). Women usually non considered as fully white, especially Black and Latina women, face even steeper declines in their representation at higher levels of the industry, representing only 3% of C-suite positions. This lack of representation is not due to higher attrition rates but stems largely from barriers in promotion and line-role opportunities, which limit advancement. Furthermore, external hires for VP and senior positions heavily favour men, with no women of colour (i.e. not considered as fully white) selected for top roles in recent years, underscoring persistent inequality in leadership representation.

Now that we've gained some general insight into one of the aspects of the social context of each industry, we can shift our focus to the essential task of technical communication, using precise language and industry-specific terminology.

Problem 1.1: Definitions

A Block Flow Diagram for a process (BFD) serves as an invaluable tool in engineering, particularly during the ----- stages of process design and analysis. As a starting point for developing a ------- --- ------- (PFD), the BFD simplifies complex processes by breaking them down into fundamental ---------- represented by distinct blocks. This visual representation aids engineers in conceptualizing new processes by providing a high-level overview that captures essential components and their interconnections without delving into intricate details. The straightforward nature of BFDs makes them particularly effective for explaining the main features of a process, such as key inputs, -------, and overall ---- direction, which is crucial for stakeholder communication and collaboration.

By focusing on the big picture, engineers can quickly identify potential areas for optimization, assess feasibility, and facilitate discussions with team members and clients. Ultimately, the BFD is a powerful foundational tool that streamlines the design process and enhances clarity in engineering projects.

When constructing a good Block Flow Diagram (BFD), it is essential to follow several general rules to ensure clarity and effectiveness. First, operations should be clearly represented by distinct ------, which allows for easy identification of each process step. Major flow lines should be depicted with ------ that indicate the direction of flow, emphasizing that the flow typically moves from ---- to -----, while any ------- may be illustrated as flowing in the opposite direction. To enhance clarity, lighter streams, such as streams, such as -----, should be positioned toward the top of the diagram, whereas ------ streams, like ------- and ------, should be placed toward the bottom. It is also crucial to include critical information that is unique to the process, along with a simplified -------- ------- to facilitate understanding. Lastly, in cases where lines intersect, the hierarchy must be maintained: the ---------- line remains continuous while the ------- line is represented as broken. By adhering to these guidelines, engineers can create effective BFDs that communicate process information clearly and efficiently. While a process BFD provides a general view of a specific operation, a ----- BFD offers a broader perspective on the entire facility's operations. It helps engineers and stakeholders understand how various processes integrate and interact with one another, including upstream and downstream dependencies. The ------ in a plant BFDs represent a complete process instead of operations.

A **Process Flow Diagram (PFD)** in engineering is a detailed graphical representation of a chemical, biochemical, or industrial process, showing the flow of materials and the ---- ----- involved. It provides a clear visual of how raw materials enter the system, how they are processed through various unit operations, and how products and byproducts exit. PFDs are essential tools in chemical, biochemical, and process engineering. Key components of a PFD include:

1. Main --------- Representation: such as reactors, distillation columns, heat exchangers, pumps, and compressors, are displayed with ------- symbols.
2. Flow Lines: These show the flow of materials (liquids, gases, solids) between equipment. Arrows indicate the direction of ---- .
3. ------ Numbers and Information: Every ------ in the diagram is numbered, and associated data like temperature, pressure, flow rates, and composition are often provided in accompanying tables. This helps to define the ---------- of each material entering and exiting the equipment.

4. Utilities: Utilities like ----- , cooling ----- , and electricity, which are necessary to run the equipment, may also be depicted.

Problem 1.2: Milk Bottling Line in a Dairy Factory

Description:

The following paragraph describes a milk bottling line in a dairy factory: "The factory receives 1500-2000 L of milk daily from a tanker, where it is stored in cool storage at 4ºC until the pasteurizing and bottling line becomes available. The milk is then pasteurized at 72ºC for 15 seconds while being transported to the bottling plant."

Tasks:

a. Develop a block flow diagram (BFD)to illustrate the process of producing and bottling pasteurized milk from raw milk.
b. List the essential utilities required for the milk processing line.
c. Answer the following questions to self-assess the effectiveness of the BFD according to its desirable characteristics:
    i. Is it a suitable starting point for developing a PFD?
    ii. Does it assist in conceptualizing the process?
    iii. Is it effective in explaining the main features of the process without excessive details?
    iv. What do the blocks in the BFD represent?
    v. What do the arrows represent?
    vi. Does flow always move from left to right? Is it correct
    vii. If applicable, are gases, liquids and solids represented at the top or bottom of the diagram according to conventions?
    viii. Is the information general for any process like this but not very much detailed?
    ix. Does the BFD contain main data about the streams? If not, how can this information be calculated?
d. Provide the key additional information necessary to plot the process flow diagram (PFD), excluding equipment details.
e. Create a process flow diagram for the milk bottling process.

Problem 1.3: Orange Juice Production

Description (Ibañez Gonzalez et al., 2024)**:**

In the industrial production of sweet orange juice, the process begins with washing the oranges to ensure they are clean and free of contaminants. After washing, the oranges are fed into an extractor, where the juice is separated from the peels and seeds. In addition to the juice, the extraction process also yields valuable orange oil from the peels, which is collected separately along with water.

Following extraction, the juice passes through a finisher with screens ranging from 0,508 to 0,762 mm, which removes the juice sacs, and the juice ends with an 8-12% of solids. The juice is then heated to 50°C to reduce its viscosity, making it easier to flow through centrifuge and later through resin pores. The resin plays a crucial role in adsorbing *limonin*, a bitter compound present in the juice, which is reduced from 25 ppm to 0 ppm. This debittering process improves the juice's flavour by reducing its bitterness.

After centrifugation, the juice contains between 1% and 3% solids. Once clarified, the pulp is reintroduced into the debittered juice.

The cleaning system uses hot water and a caustic solution to clean the ultrafiltration membranes and the debittering column, with the process taking approximately four hours.

Tasks:

a. Using the description provided for the industrial production of sweet orange juice, create a block flow diagram (BFD) that visually represents the entire process.
b. A plant can receive up to 200 trucks with 120000 oranges daily. Each truck can transport 20000 kg. If 24 oranges are required to fill 1.8 L of juice, calculate the capacity of the plant in oranges/day and kg/day and.
    i. Estimate the average mass of each orange (in grams).
    ii. Calculate the total availability of raw material in oranges per day and kg/day.
    iii. Calculate the juice yield (L/kg) of the oranges
c. In an orange juice plant, 4,000 tons of oranges are processed daily. Oranges contain approximately 43% juice (w/w) and 57% pulp and peel at their optimal ripeness. Smooth juice and juice containing 5% (w/w) pulp and pit are produced in equal quantities. Determine the final quantities and compositions of the streams exiting the juice-solids separator, assuming the oranges were harvested at optimal ripeness.

Problem 1.4: Mass balance issues in MTBE production

Description:

Methyl tert-butyl ether (MTBE) is a chemical compound commonly used as a fuel additive to raise the octane rating of gasoline and improve its combustion efficiency. This helps reduce engine knocking and allows engines to run more smoothly. MTBE is also an oxygenate, meaning it contains oxygen, which enables fuel to burn more completely, thereby reducing carbon monoxide emissions. Since the 2000s, MTBE has been phased out of gasoline in some regions, particularly the U.S., due to groundwater contamination concerns. However, MTBE was still manufactured and exported to other nations that still use it as an oxygenate in fuels. This practice may have been discontinued at the end of 2020 (Atsdr, 2023).

MTBE is synthesized via a catalytic reaction between isobutylene and methanol. In industrial settings, some isobutylene and methanol may remain unreacted due to incomplete conversion, so recycling is often implemented to improve yield.

In an industrial process, **isobutylene (C_4H_8)** and **methanol (CH_3OH)** are combined in a reactor. The fresh feed of isobutylene enters at a rate of 100 kg/h and is mixed with methanol, which is added in a stoichiometric 1:1 molar ratio with respect to isobutylene. In the reactor, isobutylene and methanol undergo a catalytic reaction to form MTBE ($C_5H_{12}O$) with an 80% conversion rate for isobutylene, while 20% of isobutylene remains unreacted. The reactor effluent, containing MTBE, unreacted isobutylene, and any remaining methanol, proceeds to a separation unit where MTBE is extracted as the primary product. The remaining stream, comprising unreacted methanol and isobutylene, is recycled back to the reactor and mixed with the fresh feeds to optimize yield. to maximize the efficiency of MTBE production.

Tasks:

1. Plot the Block Flow Diagram
2. Mass Balance Calculations:
   a. Determine the molar feed of isobutylene and the corresponding stoichiometric amount of methanol.
   b. Calculate the amount of *MTBE* produced based on the 80% conversion rate.
   c. Calculate unreacted reactants in the recycle (kg/h).

Hint:

- Assume complete mixing of fresh and recycled streams before entering the reactor.
- Remember that the conversion of isobutylene is 80%, which affects the amount of isobutylene and methanol in the recycle stream.

Problem 1.5: Process: Ethylene Production Plant

Description:

The ethylene production process is divided into three main zones:

Zone 1: Feed Preparation. This zone is responsible for preparing the raw hydrocarbon feed (e.g., ethane or naphtha) for the cracking process. Here you can find the main feed pump and a backup pump and one Feed Storage Vessel

Zone 2: Cracking and Cooling In this zone, the feed is heated in the Cracking Furnace and cracked in the reactor for hydrocarbon cracking to produce ethylene and other gases. After cracking, the hot gases are cooled in the Primary Cooling Compressors (two identical units in parallel to ensure continuous cooling)

Zone 3: Separation and Compression. The cooled gas mixture from Zone 2 is sent to separation units (a Distillation Column, called Ethylene Separator) to isolate ethylene from other byproducts and then compressed for storage in a Collection Vessel or pipeline transport. There is a Backup compressor in zone unit as well.

Tasks:

Write a summary of the equipment code breakdown for the ethylene production process, presented in both US and EU conventions:

Problem 1.6: Flow Process Diagram Issues

Scenario description: As the production engineer of a chemical plant, you have received multiple reports regarding flow issues in the pipe feeding the equipment labelled P-202 A. Refer to Figure 1.1 and Table 1.1 for details of the PFD.

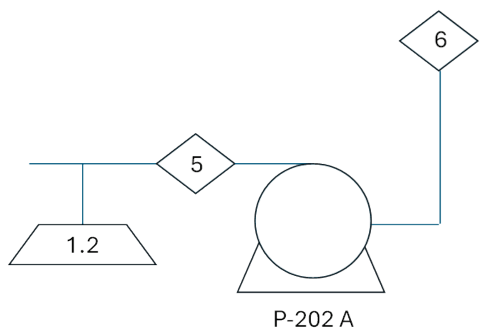

Figure 1.1- Detail of the PFD for P-202 and its connections

Table 1.1- Data accompanying the PFD

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Temperature (°C)	25	25	35	35	30	30	20	15
Pressure (bar)	3	2	1,5	1,2	1,2	5	4,5	4
Vapor fraction	0,0	0,0	0,0	0,0	0,0	0,0	1	0,8
Mass flow (kg/h)	678	678	486	486	486	486	486	486
Mole flow (kmol/h)	13	13	27	27	27	27	27	27
Component flowrates (kmol/h)								
water	10	10	27	27	27	27	27	27
ethanol	3	3	0	0	0	0	0	0

Tasks:

a. Identify where you should go to visually check the condition of the pipe (zone area).

b. Is there any other equipment like P-202A in the vicinity?

c. What is the function of P-202A?

d. Properly include the additional conditions for stream 5 in the plot.

Problem 1.7: Application activity

During your industry visits this semester, you will observe real-world chemical processes and equipment, enhancing your understanding of industrial standards, conventions, and flow diagramming. The findings from this activity will form a key part of your final presentation.

Task:

1. During each industry visit, identify and document the following:
   a. Block Flow Diagram (BFD)
      - Observe and identify at least one Block Flow Diagram (BFD) of any process unit within the facility.
      - Record the main components (e.g., feed, product, recycle) and flow paths represented in the BFD.
      - Take notes on the type of convention used to represent the process blocks (e.g., symbols, labels) and flow lines.

b. Equipment Codes

- Document at least two equipment codes found in the facility (e.g., compressor, pump, distillation column).
- Identify the conventions used in the code (e.g., US standard, EU standard, or a customized industry-specific standard).
- Describe the purpose of each piece of equipment and its role in the process.

c. Convention Identification

- Based on your findings, determine whether the US or EU conventions are being used. Look for distinctive aspects, such as letter coding (e.g., "P" for pumps in the US or "PUMP" in the EU) or area designation suffixes.
- Note any unique adaptations the facility may use if it follows an industry-specific or customized code.

d. Industry's approach to equality and inclusion

- During your company visits, take the opportunity to observe and ask experts about the representation and treatment of different minority groups within their organization, including gender, ethnicity, and other diverse backgrounds. This will give you a deeper understanding of the industry's approach to equality and inclusion.

For each visit, submit a brief written report double-spaced in a standard font (e.g., Times New Roman, 12-point), 2 - 3 pages (including commented block flow diagram, other figures and pictures apart).

2. Final Oral Presentation about the visit

At the end of the course each group will deliver a final presentation that includes:

a. Documentation of Observed Diagrams and Codes: Include the Block Flow Diagram and equipment codes you identified, with relevant sketches or photos (where allowed).

b. Analysis of Conventions: Provide a clear analysis comparing the conventions observed in the plant to the standard US or EU conventions. Highlight how these conventions aid in process understanding and efficiency.

c. Reflection on Real-World Application: Briefly discuss how this experience has expanded your understanding of process documentation and equipment identification in industrial settings.

INTRODUCTION TO ECONOMIC FACTORS

A chemical engineer's general knowledge about process economics is crucial to ensuring efficient, safe, and profitable operations. Key concepts include:

Cost Estimation: Chemical engineers must understand the basic categories of costs in a process, such as capital versus operating costs. This knowledge allows them to predict the financial requirements for setting up and running a process, from raw materials to labour, utilities, and equipment depreciation.

Capital Investment and Depreciation: Engineers should grasp the significance of capital investment—initial funds needed for equipment, land, and facilities—and how these costs are recouped over time through depreciation. This affects profitability and long-term budgeting, allowing companies to assess return on investment (ROI) and net present value (NPV).

Operating Expenses (OPEX): Engineers need to be aware of day-to-day expenses, such as utilities, raw materials, labour, and waste management. Understanding OPEX helps identify cost-saving opportunities, as well as evaluate the economic feasibility of different process designs and operating conditions.

Production Cost Analysis and Breakeven: Calculating production costs is essential for pricing, profitability, and competitiveness. Engineers need to understand breakeven analysis to determine the minimum production rate that covers costs, allowing them to optimize production levels and maximize profit.

Profitability Metrics: Engineers commonly use financial metrics like ROI, NPV, internal rate of return (IRR), and payback period to gauge the economic potential of projects. This enables them to make informed decisions about whether to proceed with or modify a process based on its profitability.

Process Optimization and Efficiency: Economic efficiency is often achieved through optimizing yield, energy usage, and raw material efficiency. Engineers use economic analysis to identify process improvements that can reduce costs, minimize waste, and improve output.

Market Analysis and Supply Chain: A chemical engineer should be familiar with the broader market, including trends in supply and demand for materials, price volatility, and supply chain logistics. This knowledge helps engineers anticipate and mitigate potential economic risks in the supply chain.

Understanding these economic principles allows chemical engineers to balance technical performance with cost-effectiveness, making their decisions grounded in both engineering and business considerations. This economic knowledge is especially critical in project feasibility studies, process design, and long-term operational planning.

In this list of problems, you'll focus on key concepts (first through sixth) to gain a solid understanding of cost estimation, capital and operating expenses, and profitability analysis in chemical engineering. These foundational concepts will guide you through economic decision-making processes, helping you analyse production costs, optimize process efficiency, and assess the financial viability of different process designs.

Key last concept, which deals with market analysis and supply chain factors, will be explored during your industry visits. These visits offer you a chance to engage directly with industry professionals, observing how supply, demand, price fluctuations, and logistical challenges influence process economics in real-world applications.

Visit written reports and economic factors

In your visit reports, if possible, reflect on these observations and connect them to the theories covered in class. Your report should include insights on how market forces impact industry operations and profitability, demonstrating your understanding of how external factors shape economic decision-making. Integrating these real-world insights with your classroom learning will enhance your grasp of process economics, better preparing you for the challenges of the field.

LIST OF PROBLEMS NUMBER 2.1

TITLE: Investment

Learning order-of-magnitude estimation is crucial for engineering students, particularly in chemical and biochemical fields, for several key reasons:

Early Project Assessment: Order-of-magnitude estimates allow students to make quick, approximate calculations to assess the feasibility of a process or project before committing to detailed designs. This skill is essential for evaluating the viability of ideas without spending time and resources on complex calculations.

Financial Awareness: Understanding how to approximate costs and resource requirements prepares students to consider the economic impact of engineering decisions. Estimation teaches them to think critically about material, energy, and labour needs, which are fundamental for cost-efficient project planning in industry.

Problem-Solving Skills: Estimation provides a flexible approach to solve real-world problems, especially when complete data isn't available. This approach encourages students to develop intuition around typical values and industry standards, equipping them to make informed assumptions and reason through engineering challenges.

Foundation for Professional Decisions: In industry, engineers often make decisions under time constraints, where precise data is unavailable. By practicing order-of-magnitude estimation, students gain confidence in making educated guesses and learn to evaluate the accuracy of their estimates. This skill can enhance decision-making in fast-paced or resource-constrained situations.

Risk Management: Estimation skills allow students to identify potential risks and limitations early on. For example, estimating raw material needs or production scale gives insights into potential technical challenges or resource bottlenecks, which is essential for planning safe and sustainable processes.

Overall, mastering order-of-magnitude estimation helps students bridge theoretical knowledge with practical engineering applications, providing a valuable tool they'll use frequently in professional settings

Practical Skills:

Through this problem set, you will develop these key practical skills:

- Analytical Skills for Investment Decisions: Ability to analyse different investment options to make informed financial decisions for industrial projects.
- Project Cost Categorization and Estimation: Competence in dividing project costs into ISBL, OSBL, contingency, working capital, and other categories for a more comprehensive investment analysis.
- Scaling and Data Analysis Techniques: Mastery in applying scaling factors and interpreting empirical data to modify cost estimates accurately for varying project scales and technologies.
- Real-World Cost Research and Application: Familiarity with researching current prices, categorizing costs, and breaking down expenses to develop a total investment estimate for specific projects, such as the lighting addition for a bioreactor.

Objectives for Problem Set:

The objectives of this problem set are to equip you with practical skills and a thorough understanding of the methods and considerations involved in investment estimation and cost analysis in chemical engineering. You will learn how to:

1. Perform Investment Analysis: Analyse alternative investment options for a chemical plant, considering both qualitative and quantitative factors to determine the most economically advantageous option.
2. Apply ISBL and OSBL Estimation Techniques: Understand how to categorize costs as ISBL (Inside Battery Limits) and OSBL (Outside Battery Limits) and apply these percentages to estimate the total investment for a variety of industrial projects, ranging from chemical processing to large-scale production.
3. Estimate Investment Costs Using Scaling Factors: Use scaling exponents to adjust capital cost estimates based on the economies of scale for different production levels, guided by industry standards and historical data.
4. Utilize Semi-Empirical Data for Cost Estimation: Apply cost-scaling exponents and capacity data from industry tables to make reasonable estimations for various chemical engineering processes and understand the role of data-driven decision-making.
5. Calculate Capital Costs for Production Plants: Learn to apply economic principles and cost indexes to estimate the capital cost of chemical processing plants based on regional and process-specific factors.

6. Develop Practical Cost Estimation for simple investments related to biotechnology: Conduct a hands-on investment estimation exercise by researching, sourcing prices, and categorizing costs for adding lighting to a microalgae bioreactor, which is essential for practical experience in budget planning, estimating, and applying technical knowledge in investment projects.

Problem 2.1.1: Analysis for Chemical Plant Alternatives

Description:

Two investment alternatives are proposed for a new chemical plant:

- Alternative A: Expected annual revenue of €1500000 from the first year with annual costs of €1430000. Initial capital investment for plant construction and start-up is €6783500.
- Alternative B: Expected annual revenue of €1750000 with annual costs of €1670000. Initial capital investment required is €7916000.

The tax profit rate for both alternatives is 6%, and both options have similar lifespans and performance characteristics over time.

Task:

Determine which investment option is more financially favourable, providing both qualitative and quantitative justifications.

Problem 2.1.2: Project Cost Estimation Based on ISBL Percentage

Description:

Dividing the project investment costs in categories contributes to a more comprehensive and realistic total investment estimate, guiding engineers in budgeting, financial analysis, and project planning for new installations. Each category represents a key component in the total investment estimate, providing essential budgeting guidelines for chemical and industrial projects.

Task:

Link each of the categories with its description

Cost Category	Description
ISBL (Inside Battery Limits)	Additional funds set aside to cover unforeseen expenses, adjusting for unexpected project risks or changes.
OSBL (Outside Battery Limits)	Operating funds required for the initial production phase, including inventory, labour, and maintenance costs.
Contingency	Support facilities outside core production, such as utilities, storage, and necessary infrastructure.
Detailed Design	Core process equipment and facilities essential for production, including reactors and separators.
Working Capital	Costs for in-depth engineering, specifications, and drawings necessary to build the plant accurately.

Problem 2.1.3: Project Cost Estimation Based on ISBL Percentage

Description:

Consider the following project ideas:

a. Small-scale production of fine chemicals using cutting-edge technology.

b. Small-scale fine chemical production using a newly lab-proven process.

c. Large-scale production of pre-washed and cut lettuce for salad processing.

d. Large cement production plant

Task:

Estimate the total investment as a percentage of Inside Battery Limits (ISBL) for each of the projects based on your criteria. Orientate your decisions using data from Table 2.1 and Table 2.2.

Table 2.1- Scaling Factor (n) in Equation 2 for Various Industrial Processes. Adapted from (Towler & Sinnott, 2013)

Scaling factor, n	Process Characteristics
0.9-0.8	Processes requiring extensive mechanical work or gas compression
0.7	Petrochemical processes
0.6	Default factor used when specific process data are unavailable
0.5-0.4	Highly instrumented processes, such as those in specialty chemical or pharmaceutical industries

Table 2.2- Guidelines for estimating total investment costs based on an Inside Battery Limits (ISBL) estimate. Each category explains a different cost component, along with suggested factors or multipliers commonly used for chemical engineering projects.

COST	RANGE FOR ESTIMATE PERCENTAGES		OBSERVATIONS
OSBL	20% of ISBL	50% OF ISBL for chemical plants 90% ISBL for other plants	Decrease if some parts of the plant have already been built.
DETAILED ENGINEERING	10% OF (ISBL + OSBL)	30% OF (ISBL + OSBL)	The percentage is higher for the smaller project
CONTINGENCY	10% OF (ISBL+OSBL)	50% OF (ISBL +OSBL)	10% is usually used. 50% for unproven technologies
Working capital or CIRCULATING	5% OF (ISBL + OSBL)	30% OF (ISBL +OSBL)	15% is usually used. Less sophisticated/fewer number of products require the lowest percentage for estimation.
TOTAL	145% OF ISBL	260%-300% OF ISBL	

Problem 2.1.4: Investment Estimation Based on Economies of Scale

Task:

Estimate the total investment for the following projects by applying economy-of-scale concepts. Justify your estimates.

a) Production of 500000 units of high-tech fine chemicals. Data from a similar plant producing 50,000 units indicates ISBL capital costs of €10000000.

b) Small-scale production of 500000 units of fine chemicals using a newly lab-proven process, with data showing ISBL capital costs of €10000000 for a 50000-unit plant (using a different technology).

c) Large-scale processing of fresh-cut lettuce at 2500 kg/h. A comparable plant processing 400 kg/h has ISBL capital costs of €785000.

d) Cement plant with a daily output of 4000 tons, compared to a plant producing 42000 kg/h with ISBL costs of €155000000.

Problem 2.1.5: Analysis of Scaling Exponents and Capacity Ranges from Towler and Sinnott Data

Description:

In this exercise, you will explore some tools for costs estimate based on semi empirical data of Table 7.1 from(Towler & Sinnott, 2013).

Task:

a. Identify the most common scaling exponent n in the table
b. For the final entry in the table:

- Identify the process it refers to.
- Specify the units for the S parameter (production capacity).
- Record the values of a and n.
- Note the minimum and maximum production capacities for scaling this process.
- State the units for the estimated cost.

Problem 2.1.6: Capital Cost Estimation for Glucose Production

Task:

Estimate the capital costs for a U.S. Gulf Coast plant producing 21325 tons of 40% glucose solution monthly using basic wet corn milling.

Problem 2.1.7: Cost Estimation for Microalgae Biomass Processing

Description:

The production and separation of internal metabolites from microalgae biomass typically account for approximately 30% of ISBL costs for target biomolecule production, being the rest used for purification.

Task:

Consider a process to produce arachidonic acid from microalgae biomass, which includes microalgae culture, fatty acid esterification, and purification. Given that an esterification plant for fish-derived arachidonic acid reported ISBL costs of €1,5 million, estimate the capital costs for a similar plant using microalgae.

Problem 2.1.8: Cost Estimation for Spray Dryer Equipment

Description:

A spray dryer is a device used to convert liquid solutions or suspensions into dry powder form by spraying the liquid into a hot drying chamber. The liquid feed is atomized into fine droplets, which quickly lose moisture as they come into contact with hot air, leaving behind dry particles that fall to the bottom of the chamber. Spray drying is widely used in the food, pharmaceutical, and chemical industries for its ability to produce consistent, fine powders while preserving heat-sensitive compounds

Task:

Estimate the cost of a spray dryer (275 g/sec evaporation rate) for the following locations, using the inflation index (607,5 for 2019) and location factors:

a) Almería (2019)

b) Las Palmas de Gran Canaria (2018)

Problem 2.1.9: Capital Cost Estimation for Microalgae Bioreactor Lighting

Description:

In this exercise, you'll apply your engineering and economic knowledge to perform a real investment estimation for a simple yet practical project: adding LED lighting to a microalgae bioreactor. This process will require you to research and source prices, identify the relevant categories of costs, and use this information to develop an accurate estimate for the total investment required. This hands-on approach will help you solidify your understanding of investment estimation and resource allocation in a practical engineering context.

Task:

Estimate the investment needed to add lighting to a microalgae bioreactor The lighting kit includes 20 LED strips, each 50 cm in length, mounted on individual supports along a 70 cm PVC tube (Figure 2.1). Provide a cost breakdown and estimate total investment.

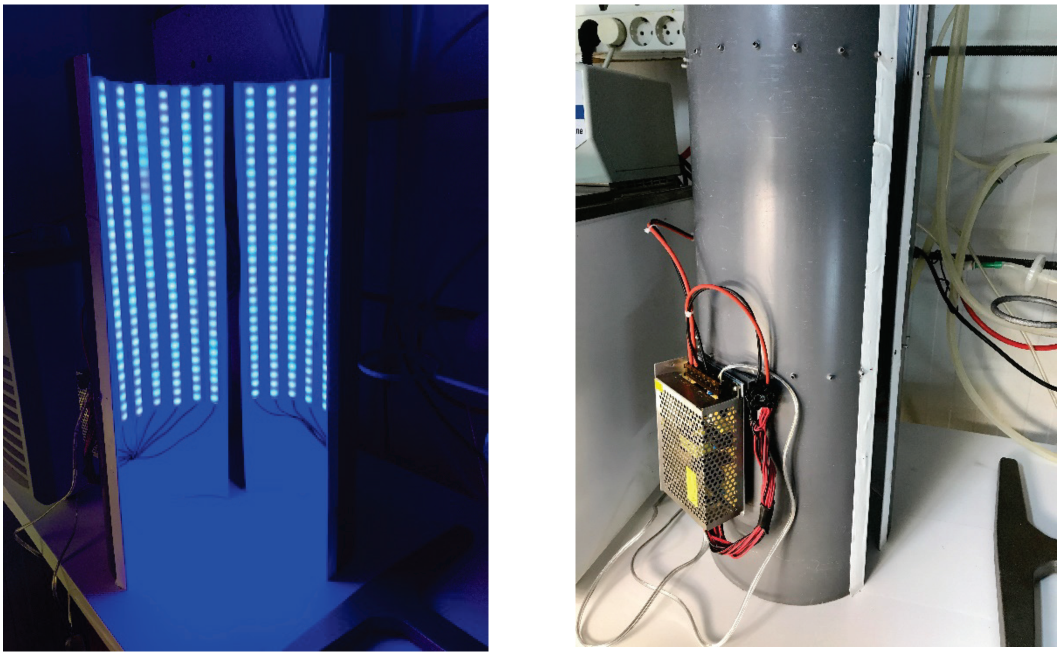

Figure 2.1 Blue LEDs facility built at the University of Almeria for lighting microalgae cultures.

LIST OF PROBLEMS NUMBER 2.2

TITLE: Production costs

Production costs in chemical engineering refer to the total expenses incurred in the manufacturing of chemical products or biotechnological processes. These costs encompass a wide range of expenses, including raw materials, labour, utilities, maintenance, and overhead associated with plant operations.

Knowledge of how to estimate production costs is fundamental, as it influences decision-making across various aspects of project management, financial planning, process optimization, and compliance with industry regulations.

Chemical engineers must have a thorough understanding of these production costs to optimize processes, enhance efficiency, and contribute to effective budgeting and financial planning. Their expertise allows them to:

- Optimize Process Design: By analysing cost components, engineers can design processes that minimize expenses while maximizing output.
- Conduct Economic Evaluations: Accurate cost estimates are crucial for feasibility studies and project evaluations, enabling informed decision-making.
- Implement Cost Control Measures: Understanding cost drivers allows engineers to identify areas for cost reduction and improve overall profitability.

This expertise ultimately supports the successful implementation of projects within the chemical and biotechnology sectors.

In a production setting, costs generally fall into several main categories that contribute to the total expense of manufacturing products or delivering services. Here are the primary types of production costs:

- The production costs for a chemical or biotechnology plant generally encompass a range of categories, reflecting both the fixed and variable expenses needed to produce and maintain output. Key cost categories include:
    1. Raw Materials and Feedstocks
        - Raw Material Costs: The cost of raw materials often represents the largest proportion of variable costs, especially in chemical plants. In biotechnology, this includes substrates and growth media for microorganisms or cells. Pricing can fluctuate based on global supply and demand.

- Utilities and Energy Costs: Energy for heating, cooling, powering machinery, and water for processes (steam, deionized water) can constitute a significant portion, especially for processes with high energy demands (e.g., distillation or drying).

2. Labor and Personnel

- Direct Labor Costs: These cover salaries and wages for operators and technicians directly involved in production. Biotechnology plants often have higher labour costs due to the specialized knowledge required.
- Indirect Labor Costs: Support roles, such as maintenance, quality control, and administrative personnel, are crucial, particularly in facilities that require stringent compliance with regulatory standards (like cGMP for biotech).

3. Maintenance and Repairs

- Routine Maintenance: The cost to keep equipment operational, replace worn parts, and conduct regular inspections.
- Downtime Costs: If equipment needs to be shut down for repairs, lost production time is a cost factor.
- Predictive Maintenance Programs: These are more common in large or highly automated plants and can add upfront costs, although they may reduce long-term expenses.

4. Operating Supplies

Includes smaller items like lubricants, filters, and cleaning chemicals, which are necessary for day-to-day operations but are not part of the final product.

5. Quality Control and Assurance

- Lab Testing Costs: Regular testing of materials, intermediates, and products to meet quality standards.
- Compliance Costs: Ensuring regulatory standards are met, especially in biotechnology where validation and compliance with FDA or EMA regulations are extensive.

6. Waste Treatment and Environmental Management

- Waste Disposal: Costs for treating and disposing of hazardous and non-hazardous waste. This is more substantial in chemical plants with byproducts requiring special disposal.

- Environmental Compliance: Costs associated with meeting environmental regulations, such as emissions or wastewater treatment.

7. Research and Development (R&D)

   For biotechnology plants, R&D is a significant investment, often recurring to improve processes or develop new products. Chemical plants may also invest in process optimization, though the cost burden is generally less.

8. Depreciation and Amortization

   Spread over the lifespan of equipment and facilities, these represent the gradual loss in value of capital assets. Depreciation is a fixed cost and affects cash flow calculations and tax deductions.

9. General and Administrative (G&A) Expenses

   - Insurance, Taxes, and Licenses: For property, liability, and regulatory compliance.
   - Overhead Costs: Include accounting, legal, and management salaries not directly tied to production.

Practical Skills:

Analytical Thinking: Students will learn to break down complex processes into manageable steps, identifying key components such as raw materials, energy requirements, and labour costs.

Mathematical Proficiency: They will enhance their mathematical skills through calculations involving mass and energy balances, cost estimations, and efficiency assessments.

Technical Knowledge: Students will gain a deeper understanding of biochemical processes such as fermentation, distillation, and evaporation, as well as their operational requirements in a chemical plant.

Cost Estimation Techniques: They will develop proficiency in estimating production costs by considering various factors including raw materials, labour, energy consumption, and overhead costs.

Problem-Solving: The exercises will improve their ability to tackle real-world engineering problems, applying theoretical knowledge to practical situations.

Interdisciplinary Approach: Students will learn to integrate concepts from different areas such as thermodynamics, fluid dynamics, and process design to optimize production processes.

Research and Resource Management: They will develop skills to assess the availability and cost of raw materials and auxiliary resources, considering practical constraints faced in industrial settings.

Objectives of the problem set:

1. Understanding Process Design: Students will understand the intricacies of designing a fermentation process, including the selection of raw materials and the design of key equipment like fermenters and evaporators.
2. Energy and Material Balances: They will learn to perform energy and mass balance calculations necessary for evaluating the efficiency of chemical processes.
3. Cost Analysis: Students will be able to perform a comprehensive cost analysis for a chemical or fermentation plant, identifying major cost drivers and their implications for profitability.
4. Critical Evaluation: They will cultivate the ability to critically evaluate the feasibility of a process, considering economic, environmental, and logistical factors in their decision-making.
5. Practical Application: By applying their knowledge to hypothetical yet realistic scenarios, students will be better prepared for challenges in the field of chemical engineering and biotechnology.
6. Communication Skills: Presenting their findings will improve their ability to communicate technical information clearly and effectively to different stakeholders.

Problem 2.2.1: Production of Ethanol from Corn Fermentation

Description: In this problem, you will analyse a simple ethanol production process using corn as the raw material. The process involves the fermentation of corn starch into ethanol, which can be used as a biofuel.

Problem Details:

1. Process Overview: The production of ethanol from corn involves several steps:
   - Milling: Corn kernels are milled to produce corn meal.

- Liquefaction: Corn meal is mixed with water and heated to convert starches to sugars using enzymes (alpha-amylase).
- Fermentation: Yeast is added to the liquefied corn mixture, where it converts sugars into ethanol and carbon dioxide.
- Distillation: The fermented mixture is distilled to separate ethanol from the byproducts.

Assumptions:

- Corn conversion efficiency: Approximately 2,5 litres of ethanol per kilogram of corn.
- Water requirement: 1 litre of water per litres of ethanol produced.
- Enzyme requirement: 0,1 kg of alpha-amylase per ton of corn.
- Yeast requirement: 0,01 kg of yeast per litres of fermentation broth (assuming an average density for the broth).
- Nutrients for yeast: Estimate based on a percentage of the weight of corn (1%).

Tasks:

1. List all the raw materials needed for the ethanol production process in a table.
2. Determine the quantities of each raw material required to produce 10000 litres of ethanol. Show all calculations.
3. Discuss any additional considerations or potential issues related to sourcing these raw materials in an industrial setting.
4. Estimate the costs of the raw materials to produce 10000 litres of ethanol

Problem 2.2.2: Cost of Electrical Heating in Chemical Process

Description:

In chemical processes, heating is a critical operation that often determines the efficiency and effectiveness of production. Estimating the energy required for heating materials is essential for cost analysis, process design, and operational planning.

You designed a continuous stirred-tank reactor for heating the aqueous solution of sodium hydroxide (NaOH). The reactor operates with a feed rate of 2000 kg/hr, starting at an initial temperature of 25°C and requiring a final temperature of 85°C.

Hints:

The specific heat capacity of the NaOH solution is 4.18 kJ/(kg·°C)

Task:

Calculate the energy requirement to achieve the desired temperature increase. in kWh, expressing the energy consumption in terms of electricity costs (1 kWh = 3600 kJ).

Once you have determined the energy requirements, you should further assess the cost implications by considering the energy prices applicable to the heating process. This exercise will help you understand the economic aspects of thermal energy requirements in chemical processes.

Problem 2.2.3: Energy Calculation for Water Evaporation in an Evaporator

Description:

An evaporator system receives a feed stream F of 100 kg/h of a solution containing 4% salts (4 kg salt and 96 kg water) at an initial temperature of 20°C. The process goal is to concentrate this solution to a brine stream P with a 60% salt concentration. To reach this concentration, water V must be removed through evaporation.

Task:

1. Calculate the mass of water V that must be evaporated from F to produce a 60% salt solution in P.
2. Calculate the energy required to evaporate the necessary amount of water V, considering that the stream F has water -like properties.
3. Calculate the energy required to evaporate the necessary amount of water V, when there is a 5% energy loss due to heat dissipation in the evaporator.
4. In the evaporator system where water must be removed, consider the energy required to vaporize the necessary water. What might be a practical and efficient method to supply this heat energy? Could you identify any external utility or equipment that could assist in generating the heat required for this phase change?
5. Identify and Estimate Auxiliary Water Needs for the Boiler

Problem 2.2.4: Production costs associated with a Compressor

Description:

To estimate the power required for a compressor, several factors must be considered, including the type of compressor, the gas being compressed, the inlet and discharge pressures, and the efficiency of the compressor. The general formula for calculating the power needed for compression can vary based on the compressor type but often follows these principles:

Key Considerations

- Gas Properties: The specific gas characteristics, such as molecular weight and temperature, significantly impact the power requirement. For ideal gases, calculations can use the ideal gas law.
- Efficiency: It's essential to account for the efficiency of the compressor. Real-world efficiencies range from 70% to over 90%, depending on the compressor design and operating conditions.
- Thermodynamic Principles: Calculations ca use the ideal gas law as a rough approximation. For more complex applications, thermodynamic principles can be applied, which may involve calculations of enthalpy changes and the adiabatic or isothermal process equations.
- Efficiency: It's essential to account for the efficiency of the compressor. Real-world efficiencies range from 70% to over 90%, depending on the compressor design and operating conditions.
- Thermodynamic Principles: For more complex applications, thermodynamic principles can be applied, which may involve calculations of enthalpy changes and the adiabatic or isothermal process equations.

Task:

1. Calculate the theoretical minimum power of a compressor. Consider the totally reversible and isothermal process, when 50 kg / h of air is compressed from 1 atm to 150 atm at 17°C.
2. Estimate the production costs associated with the compression.

Problem 2.2.5: Cost Estimation for a Yeast Fermentation Plant

Description:

A yeast fermentation plant to produce 100 tons of dry yeast annually is to be designed. The plant will utilize fermentation tanks and will include necessary auxiliary systems for growth, harvesting, and processing. Here is a list of needs for the production process.

1. Raw Materials:
    - Sugar Source: The yeast will require a sugar source for fermentation. Assume the primary sugar source is molasses, costing €0,30 per kg.
    - Nutrients: Nutrients such as nitrogen, vitamins, and minerals are necessary for yeast growth. Assume a nutrient cost of €2,00 per kg and that producing 100 tons of dry yeast will require 5 tons of nutrients.
    - Water: Each kilogram of dry yeast produced requires approximately 1000 litres of water. The cost of water is €0,005 per litre.
2. Labor Costs:
    - You will need to hire three technicians who will work full-time at an annual salary of €32000 each.
3. Energy Costs:
    - The facility will require energy for heating, stirring, and cooling. Assume an average electricity cost of €0,15 per kWh. The estimated energy consumption is 30000 kWh per year for the entire plant.
4. Equipment and Maintenance:
    - The initial capital investment for the fermentation tanks and related systems is €250000. It is estimated that annual maintenance costs amount to 10% of the initial investment.
5. Overhead Costs:
    - Include overhead costs such as rent, insurance, and miscellaneous expenses, estimated at €30000 per year.

Tasks:

You are tasked with estimating the production costs of a yeast fermentation plant designed to produce 100 tons of dry yeast annually.

1. Calculate the total cost of raw materials, including the sugar source, nutrients, and water.

- Molasses: For this exercise, assume you need 80 tons of molasses to produce 100 tons of dry yeast.

2. Estimate the total labour costs for the year.
3. Calculate the total energy costs for the year.
4. Determine the annual maintenance costs for the equipment.
5. Estimate the total production cost for the yeast.
6. Calculate the cost per kilogram of dry yeast produced.

LIST OF PROBLEMS NUMBER 2.3

Practical Skills:

1. Financial Analysis: Develop the ability to perform financial calculations such as Net Present Value (NPV) and Internal Rate of Return (IRR) to evaluate investment projects. This includes understanding and applying depreciation methods and tax implications.
2. Critical Thinking: Enhance analytical skills by interpreting financial data, assessing the viability of a project, and making informed decisions based on quantitative metrics.
3. Sensitivity Analysis: Learn how to conduct sensitivity analyses by examining how changes in discount rates affect NPV, fostering an understanding of how financial metrics can change with varying market conditions.
4. Excel Proficiency: Gain experience in using spreadsheet software (e.g., Microsoft Excel) for financial modelling, which includes creating formulas to automate calculations for NPV and IRR.
5. Industry Understanding: Understand the significance of different discount rates and how they relate to the risk profile of various industries, equipping students with the knowledge to tailor financial assessments appropriately.

Objectives:

1. Calculate NPV: Students will learn to calculate the NPV of a project using given data, which helps in evaluating the profitability of investment projects. This will reinforce the understanding of time value of money concepts.
2. Determine IRR: The objective is to enable students to compute the IRR of the project, providing insights into the expected return on investment and helping them compare it with industry benchmarks and cost of capital.
3. Conduct Sensitivity Analysis: Students will analyse how variations in discount rates impact NPV, facilitating a deeper understanding of the financial landscape of investment projects and their sensitivity to economic factors.
4. Interpret Results: The final objective is to interpret the results of the NPV and IRR calculations to make informed decisions about the viability and strategic direction of the project, thus enhancing their capacity for project assessment in real-world scenarios.

TITLE: Project viability

Problem 2.3: Investment and Financial Analysis

Description:

A project has an initial investment of €850000, which can be depreciated linearly over a period of 10 years with no residual value at the end of its life. The total production costs amount to €15010, and the project produces and sells 22000 items at a price of €9 each. A tax rate of 30% is applied to profits after accounting for depreciation.

Tasks:

Using Excell:

1. Calculate the Net Present Value (NPV) of the project. Discount rates for diverse industries usually range from 8% to 12%. According to factors such as the cost of capital, risk profile, current market conditions, and industry standards you can use a discount rate of 8%.
2. Determine the Internal Rate of Return (IRR) for the project.
3. Analyse the change of the VAN with different discount rates.
4. Report your results explaining your findings.

Introduction to the use of Simulation Software: Epsom Salt Production Plant

Practical Skills:

Process Simulation:

- Learn to use SuperPro Designer software to create and simulate chemical production processes.
- Develop skills in creating process flow diagrams (PFDs) that accurately represent the production of Epsom salt.

Cost Analysis and Budgeting:

- Gain experience in performing a detailed cost breakdown for raw materials, utilities, and operational expenses by using a simulation software.

Environmental Considerations:

- Explore the implications of using magnesium hydroxide sourced from industrial wastewater, including environmental benefits and potential challenges.

Reporting and Reflection:

- Develop skills in compiling simulation results and cost analysis into a cohesive report.
- Reflect on the potential for sustainability in chemical production through the use of alternative raw materials.

Objectives:

1. Design Understanding:

   Understand the complete process of Epsom salt production, from raw materials to the chemical reactions involved.

2. Technical Proficiency:

   Achieve proficiency in using chemical engineering simulation tools, enhancing the ability to model and optimize chemical processes.

3. Cost Estimation:

   Develop an understanding of the financial aspects of plant design, enabling the estimation of production costs and feasibility analysis.

4. Sustainability Awareness:

   Encourage critical thinking about resource utilization in chemical processes, particularly regarding waste management and environmental sustainability.

5. Collaboration and Communication:

   Foster teamwork skills by collaborating on simulations and discussions regarding the use of industrial waste in the production process, preparing students for real-world engineering challenges.

Description:

Epsom salt, which is used in agriculture, pharmaceuticals, and as a dietary supplement. The production process involves reacting magnesium hydroxide with sulfuric acid.

1. Given Data:
   - Reaction: $MgCO_3 + H_sSO_4 \rightarrow MgSO_4 + H_2O + CO_2$
2. Raw Materials and utilities costs:
   - Magnesium Carbonate ($MgCO_3$) aqueous solution at 15%
     - Cost: €250/MT
   - Sulfuric Acid (H_2SO_4) aqueous solution at 20%
     - Cost: €70/MT
   - Utilities:
     - Electricity: at €0.15/kWh.
     - Water: at €0.01/litre.
3. Basic Process Parameters and costs:
   - Production Capacity: 2000 kg of Epsom salt per day.
   - Operating Hours: 300 days/year.

Tasks:

You are tasked with designing a production plant for Epsom salt. The production process involves reacting magnesium hydroxide with sulfuric acid.

1. **Simulation in SuperPro Designer:**
   - Create a process flow diagram (PFD) for the Epsom salt production process.
   - Model the reaction between magnesium hydroxide and sulfuric acid, considering reaction kinetics and yield.
   - Consider you will sell the solution, so, don't include any downstream processes for purification and crystallization.
   - Magnesium hydroxide (Mg $(OH)_2$) can also be obtained through the treatment of magnesium-containing industrial wastes. This process typically involves precipitating magnesium hydroxide from aqueous solutions containing magnesium ions. Industrial waste sources can include byproducts from various industries such as magnesium mining, paper production, or wastewater treatment. The precipitation process generally requires adjusting the pH of the solution, which causes magnesium ions to react with hydroxide ions, forming magnesium hydroxide as a solid precipitate. Would you consider the use of wastewater to produce the base? Why?

Deliverables:

- A completed process flow diagram in SuperPro Designer.
- A detailed cost breakdown report including all calculations.
- Your Reflection about the potential improvement of using wastewater to produce the base.

INTRODUCTION TO SAFETY ASSESSMENT METHODS

HAZOP (Hazard and Operability Study) and the "What If" method are two widely used risk assessment tools in chemical engineering that help ensure safety in complex industrial processes. Both methods focus on systematically identifying potential hazards, evaluating possible risks, and developing effective safeguards to prevent accidents. HAZOP, a structured and detailed approach, involves analysing process deviations by reviewing each step of the process to identify where failures might occur and what their consequences could be. The "What If" method, by contrast, is a brainstorming approach where team members propose "What if...?" scenarios to uncover potential risks and operational issues. Together, these techniques play a central role in hazard identification and risk mitigation, equipping engineers with the insights needed to design safer processes, reduce the chance of incidents, and protect both personnel and the environment.

In a HAZOP meeting, each participant plays a distinct and essential role, contributing unique expertise and perspectives to ensure a thorough risk assessment. Here's a breakdown of typical roles and responsibilities:

1. **Process Engineer(s)**: Process engineers bring deep knowledge of the design, function, and operational details of the system under review. They clarify how each part of the process works; help identify realistic deviations and provide insights into how failures might affect operations.

2. **Operations and Maintenance Personnel**: These individuals offer practical insights into the day-to-day running and upkeep of the process. They can identify practical hazards, operational challenges, and historical issues, and suggest realistic safeguards based on their experience with the equipment and processes.

3. **Instrumentation and Control Engineer(s)**: These specialists contribute knowledge of control systems, alarms, and automated safeguards. They assess whether controls are sufficient to detect and manage deviations, advising on potential upgrades or additional layers of protection if needed.

4. **Safety or Environmental Engineer**: This participant focuses on safety, health, and environmental impacts. They provide expertise on regulatory compliance, potential environmental impacts, toxicology, and emergency response, helping to evaluate the broader safety implications of identified hazards.

5. **Project Manager or Design Leader**: Representing the project's overall goals, this person ensures that the HAZOP aligns with project objectives and schedules.

They track findings and help prioritize which recommendations should be implemented.

6. **Scribe or Recorder**: Often overlooked but essential, the scribe documents the meeting's findings, including identified deviations, potential hazards, consequences, and recommendations. Accurate documentation is critical for follow-up and ensuring that actionable insights are captured.

Together, these roles form a multi-disciplinary team that comprehensively evaluates hazards, shares unique perspectives, and ensures that the HAZOP process is both thorough and applicable to real-world operations.

In a HAZOP meeting, participants are expected to maintain a collaborative, respectful, and open-minded approach to ensure productive and comprehensive discussions. Here's how team members are generally expected to conduct themselves:

1. **Stay Focused and Engaged**: Each participant should actively follow the discussion and stay focused on the task at hand. HAZOP sessions are detail-oriented and can be lengthy, so staying engaged helps ensure that all potential hazards are thoroughly evaluated.

2. **Contribute Constructively**: Team members should share their expertise openly and contribute relevant insights, while avoiding overly technical jargon that may alienate non-experts. Contributions should aim to clarify and enhance the discussion rather than dominate or sidetrack it.

3. **Respect All Perspectives**: A HAZOP team includes individuals from diverse backgrounds—process engineering, operations, safety, and management. Each perspective is valuable, so members are encouraged to listen actively and respect differing viewpoints, understanding that a diverse team ensures more comprehensive risk identification.

4. **Communicate Clearly and Concisely**: Each participant should express their thoughts in a clear and concise manner to keep discussions efficient and ensure all points are understood by the group. Avoiding long, convoluted explanations help maintain the meeting's momentum.

5. **Practice Objectivity and Open-Mindedness**: Members should remain objective and avoid dismissing ideas prematurely. The purpose of HAZOP is to anticipate unlikely, "what if" scenarios that might otherwise be overlooked, so openness to exploring all possible risks is essential.

6. **Avoid Assigning Blame**: HAZOP meetings are focused on systems and processes, not on individuals or specific roles. Discussions should avoid attributing past incidents or potential hazards to specific team members or departments, which promotes a more positive and solution-oriented atmosphere.

7. **Maintain Confidentiality and Professionalism**: Sensitive information about process weaknesses or past incidents may be discussed. Team members are expected to treat all information as confidential and maintain professionalism throughout.

These behaviours help create a constructive environment where the team can thoroughly assess risks, identify effective safeguards, and foster a culture of safety.

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5. **Practice Objectivity and Open-Mindedness**: Members should remain objective and avoid dismissing ideas prematurely. The purpose of HAZOP is to anticipate

unlikely, "what if" scenarios that might otherwise be overlooked, so openness to exploring all possible risks is essential.

6. **Avoid Assigning Blame**: HAZOP meetings are focused on systems and processes, not on individuals or specific roles. Discussions should avoid attributing past incidents or potential hazards to specific team members or departments, which promotes a more positive and solution-oriented atmosphere.
7. **Maintain Confidentiality and Professionalism**: Sensitive information about process weaknesses or past incidents may be discussed. Team members are expected to treat all information as confidential and maintain professionalism throughout.

These behaviours help create a constructive environment where the team can thoroughly assess risks, identify effective safeguards, and foster a culture of safety

Practical Skills:

Team Collaboration: Students will enhance their ability to work effectively in teams, taking on different roles within the HAZOP meeting. This fosters collaboration and communication skills essential for future engineering projects.

Risk Assessment: Students will learn to identify and evaluate potential hazards and operability issues within a chemical engineering process, developing critical thinking and analytical skills.

Meeting Facilitation: Students will practice facilitating a structured meeting, ensuring all relevant topics are covered and maintaining a focused discussion.

Technical Communication: Recording and presenting the HAZOP meeting will enhance students' ability to communicate complex technical information clearly and effectively to various stakeholders.

Video Production: Participating in video-based oral presentations offers students a valuable opportunity to develop and refine their presentation skills. This format requires them to articulate ideas clearly and confidently, practice speaking at a steady pace, and engage their audience, even through a camera lens. Preparing for and recording a video presentation helps students focus on key aspects of effective communication, such as tone, clarity, and body language, while also giving them a chance to review and improve their performance. Video presentations mimic real-world scenarios where engineers, scientists, and professionals are often called to present their work remotely or in recorded formats. As such, this practice not only builds students' confidence in public speaking but also prepares them for future situations where they will need to present information clearly and persuasively in professional settings.

Objectives:

1. Understanding HAZOP Methodology: Students will understand the principles and methodologies of conducting a HAZOP study, including the significance of using guide words to identify deviations from design intent.
2. Application of Safety Management Principles: By engaging in the simulation, students will apply theoretical knowledge of safety management in practical scenarios, learning how to propose effective safeguards and mitigation strategies.
3. Industry-Specific Insights: Students will gain insights into the specific hazards and operational challenges associated with their chosen industry, which will enhance their overall comprehension of the field of chemical engineering.
4. Reflection on Learning Outcomes: Students will reflect on their learning experiences, assessing both their performance and that of their peers, leading to improved skills in self-evaluation and constructive feedback.

LIST OF PROBLEMS NUMBER 3

SAFETY IN CHEMICAL AND BIOTECHNOLOGICAL PROCESS

Problem 3.1: To identify potential hazards within a specific node of an industrial plant

Description:

Students will simulate a HAZOP (Hazard and Operability Study) meeting for a specified target industry, with the added task of recording the meeting. This exercise aims to enhance students' understanding of risk assessment and safety management in chemical engineering processes while developing their presentation skills.

Tasks:

1. Group Formation: Form groups of 4-5 students. Each group will represent different roles in the HAZOP meeting (i.e.: Facilitator, Process Engineer, Production Manager, etc…)
2. Target Industry Selection: Choose one of the following target industries for your HAZOP simulation:
   - Pharmaceutical Manufacturing
   - Petrochemical Processing
   - Food and Beverage Processing
   - Wastewater Treatment
3. Process Description: Each group should select a specific process within their chosen industry. For example, a pharmaceutical group might focus on the synthesis of an active pharmaceutical ingredient (API).
4. Simulation Meeting: Conduct the simulated HAZOP meeting and discuss potential hazards and operability issues associated with the selected process. Consider the following important characteristics:
   - The facilitator should conduct the meeting according to the desirable characteristics of the HAZOP meetings, that should be outlined at the beginning of the meeting.
   - Identify potential deviations from the design intent using guide words.
   - Discuss the possible causes and consequences of these deviations.

  - Suggest safeguards and mitigations to address identified hazards.
  - Design responsible for the different tasks

5. Video Recording: Record the simulated meeting using a video camera or smartphone. Ensure that all group members are visible, and that the discussion is clear. The video should capture the entire meeting process, including:
   - Introduction of the process being analysed and the method to be applied.
   - Discussion of identified hazards and operability issues.
   - Recommended actions and safeguards and responsibilities.

Deliverables:

- A recorded video of the simulated meeting for presentation.

Assessment Criteria:

- Clarity and organization of the report.
- Depth of analysis and identification of hazards.
- Effectiveness of communication during the video presentation.
- Collaboration and engagement within the group.

This rubric will assess students based on various criteria, focusing on the simulation of the HAZOP meeting, their report, and video presentation. Each criterion will be rated on a scale of 1 to 5, where 1 represents poor performance and 5 represents excellent performance.

Criteria	Poor: 11-15	Fair: 16-20	Good: 21-25	Very Good: 26-30	Excellent: 31-35	Score
Understanding of HAZOP	Lacks understanding of HAZOP principles and process.	Basic understanding but lacks depth in analysis.	Demonstrates a good understanding of HAZOP principles.	Very good understanding with some insights.	Excellent understanding with clear insights and application of HAZOP principles.	
Identification of Hazards	Fails to identify significant hazards; misses key issues.	Identifies some hazards, but many are overlooked.	Identifies most key hazards and operability issues.	Identifies all significant hazards with detailed discussion.	Thoroughly identifies all potential hazards with comprehensive analysis.	
Quality of Discussion	Discussion is disorganized and lacks coherence.	Some organization but lacks depth in discussion.	Well-organized discussion with relevant points.	Clear, organized, and insightful discussion with relevant details.	Exceptionally organized discussion that engages all participants effectively.	
Recommendations and Safeguards	Provides no recommendations or ineffective suggestions.	Offers vague or impractical recommendations.	Provides relevant recommendations and safeguards.	Offers well-thought-out recommendations and practical safeguards.	Provides comprehensive, innovative recommendations with strong justification.	
Report Quality	Report is incomplete or poorly written; lacks clarity.	Report is written but lacks organization and detail.	Report is well-structured with clear points.	Comprehensive report with strong analysis and clarity.	Exceptionally well-written report that is thorough and insightful.	
Video Presentation	Presentation is unclear, difficult to follow, and lacks engagement.	Presentation has some clarity but lacks engagement.	Clear presentation with relevant information.	Engaging and clear presentation with strong teamwork.	Highly engaging presentation that is clear, well-organized, and shows excellent teamwork.	
Reflection and Analysis	No reflection provided; lacks insight.	Minimal reflection with little analysis of potential improvements.	Good reflection on the process and some analysis.	Thoughtful reflection with detailed analysis of potential improvements.	Deep, insightful reflection with strong analysis of potential improvements.	

Total Score: /35 Grading Scale:

LABORATORY PRACTICE NUMBER 1

Title: Cultivation and Growth Assessment of *Saccharomyces cerevisiae*

Objective:

This lab practice aims to introduce students to the principles of yeast culture preparation and growth assessment. Students will create a starter culture from commercial fresh yeast and evaluate its growth under controlled conditions.

This lab practice spans two consecutive days. On the first day, students will activate yeast from a commercial source using sterile materials and a nutrient medium prepared by the instructor and laboratory technicians. The second day involves inoculating culture vessels and measuring the yeast growth by recording the optical density at regular intervals over a 24-hour period.

VERY IMPORTANT INFORMATION

After the second session, one student from each group will be responsible for coming to the lab every 30 minutes to aseptically sample the yeast culture and measure its absorbance using the spectrophotometer. This sampling frequency is crucial during the initial stages of growth, as it allows for precise monitoring of the yeast's exponential growth phase. Once the growth rate begins to slow and significant changes in absorbance are no longer observed, the frequency of sampling can be adjusted to every 1-2 hours or more. Students must organize themselves according to their availability to ensure consistent sampling during normal working hours. Alternatively, they can arrange for one student from a different group each time to come and take samples for all the groups, ensuring that the data is recorded accurately in the data sheet. The spectrophotometer will remain on, with the blank measurement taken during your experiment, allowing for seamless absorbance readings. The final absorbance measurement should be taken around 24 hours after inoculation, providing a comprehensive view of the growth curve for *Saccharomyces cerevisiae*.

Overview of Factors Affecting Yeast Growth:

To understand the growth dynamics of *Saccharomyces cerevisiae*, several factors need to be considered, including nutrient availability, pH levels, temperature, aeration and inhibitory substances).

(Note: A brief literature review on these factors should be included in your final report, encompassing 100-200 words.)

MATERIALS AND METHODS

Common Equipment:

- Analytical scale
- Spectrophotometer
- Plastic cuvettes
- Temperature-controlled incubator
- Cotton and gauze
- Thermometer
- pH meter

Per Experiment (ideally one experiment per student):

- Saccharomyces cerevisiae: Approximately 5 g
- One 1000 mL volumetric flask for media preparation
- One 1 L flask for autoclaving the media
- One 1000 mL beaker
- 10 mL pipette or volumetric cylinder
- 1 mL sterile pipette tips
- 1 chronometer

Chemical Composition for Media Preparation (per litre):

- Sucrose (commercial sugar): 10 g
- KH_2PO_4: 0,2 g
- $(NH_4)_2SO_4$: 0,3 g
- $MgSO_4 \cdot 7H_2O$: 0,1 g
- Yeast extract: 0,4 g
- Peptone: 0,36 g

Approximately 400 mL of medium per experiment will be required.

Sterile Prepared Material Before Class (per experiment):

- 100 mL of sterile media for *Saccharomyces cerevisiae*
- A 100 mL sterile Erlenmeyer flask with a cotton and gauze cap (permeable to air) and a stirrer inside
- A 1 L Erlenmeyer flask with a cotton and gauze cap (permeable to air)
- Sterile box of 1 mL pipette tips

Calibration Curve for Spectrophotometric Determination of Yeast Concentration:

$$C_b\left[\frac{g}{L}\right] = 1.655 \cdot D.O_{620}$$

PROCEDURE

Inoculum Preparation (Day 1)

1. Under aseptic conditions, scoop a small portion of fresh yeast and place it in a sterile 100 mL Erlenmeyer flask containing a sterile magnetic stirrer bar (fly). Aim for a final yeast concentration of approximately 3% (w/v).
2. Position the Erlenmeyer over a magnetic stirrer in a laminar flow hood or near a Bunsen burner.
3. Slowly add sterile nutrient medium while stirring to suspend the yeast completely.
4. Incubate the culture at a controlled temperature of 30°C with agitation (150 RPM) for 12-24 hours to activate the yeast cells.
5. Prepare the media for the next day's experiment by making ~500 mL of sterile medium and either filter sterilizing or autoclaving it. Prepare and sterilize several 1 mL pipette tips and sterile caps permeable to air.
6. Organize your sampling according to the very important information provided at the beginning of this guide.

Yeast Culture Preparation and Growth Curve Determination (Day 2)

1. Under aseptic conditions, transfer 10 mL of the *Saccharomyces cerevisiae* inoculum into a sterile 1000 mL Erlenmeyer flask.
2. Gradually add sterile medium until reaching a total volume of 350 mL.

3. Aseptically take a 1 mL sample and record the optical density at 620 nm using a spectrophotometer.

4. Place the inoculated Erlenmeyer flask in the incubator, maintaining a temperature between 20°C and 30°C and shaking at 150 RPM.

5. Measure the optical density at 620 nm at regular intervals (ideally every hour) for 24 hours. If the optical density reaches a value above 0.8, dilute the sample and record the absorbance along with the dilution factor. (Appendix 3.1)

6. Verify the calibration curve by preparing dilutions of the yeast culture of known concentration, recording the optical density at 620 nm in a dedicated table.

7. Centrifuge a known volume of the final culture to determine dry weight.

RESULTS

In this section, summarize how the results were obtained, emphasizing the importance of data treatment and presentation. Use graphical representations and tables to effectively convey the findings. Highlight trends, unexpected results, and indicate whether the reported data are single readings or averages.

Identify the different stages in the grow curve of the yeast

CONCLUSION

Students should consolidate their understanding of yeast growth dynamics, the potential effects of different conditions on growth rate, and the practical application of aseptic techniques in microbiology.

Appendix 1-Primary data for plotting the growth curve

Date and time of day (DD/MM/YY) (hh:mm)	**Reaction time elapsed (h)**	**CULTURE NUMBER…**			**CULTURE NUMBER…**			**CULTURE NUMBER…**			**OBSERVATIONS**
		D.O$_{620}$	mL culture	mL water	D.O$_{620}$	mL culture	mL water	D.O$_{620}$	mL culture	mL water	
	0										

LABORATORY PRACTICE NUMBER 2

Title: Determination of Microalgae Extinction Coefficient and Light Availability in Bioreactors

OBJECTIVES:

- Determine the extinction coefficient of various microalgae cultures.
- Discuss factors influencing light availability within bioreactors when microalgae cultures are present.

VERY IMPORTANT INFORMATION

To achieve these goals, students will work with different initial samples of microalgae. In case that the microalgae could be collected directly from various raceways inoculated with distinct species at a pilot plant, students will follow PROCEDURE A. These samples will then be used to prepare dilutions with various concentrations for absorbance measurements. This approach provides practical insight into how initial biomass concentrations affect light penetration and growth dynamics in large-scale cultivation. In the event that fresh microalgae samples are not available from the pilot plant, students can prepare biomass suspensions using dry microalgae powder FOLLOWING THE PROCEDURE B instead of A.

BACKGROUND:

- Briefly describe the specific microalgae species used in this experiment.
- Discuss the biological and physical magnitudes that will be measured, such as absorbance, extinction coefficients, and photosynthetically active radiation.

Maximum length: 700 words

PROCEDURE A: USING FRESH CULTURES OF MICROALGAE

MATERIALS AND METHODS

Common Equipment and Materials

- Analytical scale
- Spectrophotometer
- Plastic cuvettes
- Photosynthetically active scalar irradiance (PAR) meter

- Tubular bioreactor
- Sampling tubes and cuvettes
- Analytical scale
- Spectrophotometer (ideally 5, one at each wavelength)
- Plastic cuvettes
- Sampling tubes and cuvettes
- Desiccator
- Drying oven

Per Experiment (per group)

- Labelling Marker: For marking dilutions clearly
- 3 Glass pre-treated fiber filters (e.g., Whatman GF/C or GF/F), pore size of around 0.7 microns. Smaller pore sizes might be required for very small algal cells, though they could slow down filtration. Pre-treatment: Filters should be pre-washed with distilled water, dried in an oven at 60–70°C, and stored in a desiccator to remove moisture.
- Microalgae samples (from pilot plant raceways). Check that there is enough biomass production in the pilot plant. The volume of the sample of biomass for determining extinction coefficient is around 20 mL. The volume of the sample taken for the dry weight determination should contain at least 100 mg of dry biomass (i.e.: if concentration is around 1 g/L three samples of around 100 mL should be taken).

PROCEDURE A

1. Retrieve around 500 mL of samples of microalgae from various raceways, each inoculated with a different species, and bring them to the lab. These samples will serve as the starting point for dilution series.
2. Starting with an initial concentration, create a series of dilutions by sequentially adding medium to the microalgae samples.
3. For each concentration, measure the absorbance of the microalgae culture at the following wavelengths: 760n nm, 680 nm, 620 nm, 565 nm, and 445 nm and report the primary data in Table….

4. Biomass concentration determination

    4.1. Weight the filters using the analytical balance. Using glass fiber filters with proper pre-treatment ensures reliable and repeatable biomass concentration measurements, a standard in microalgae research and biotechnological applications.

    4.2. Place it over a proper labelled glass plate to clearly identify the filter and its content.

    4.3. Filter an accurate volume of microalgae culture under vacuum assistance. The biomass sample should contain no less than 10 mg of samples.

    4.4. After filtration, place the filter with biomass in an oven set to 105°C.

    4.5. Dry the biomass to a constant weight after 1 hour, which can take approximately 12-24 hours depending on the thickness of the sample layer and oven conditions.

    4.6. After drying, allow the sample to cool in a desiccator to prevent moisture absorption before weighing.

PROCEDURE B: USING DRY POWDER OF MICROALGAE (in Case of Insufficient Production in the Pilot Plant).

in the event that fresh microalgae samples are not available from the pilot plant, students can prepare biomass suspensions using dry microalgae powder. In this case there is no need of filtration equipment, as biomass concentration is determined by direct weighting

MATERIALS

Common materials

Analytical Scale

Spectrophotometer (ideally 5, one at each wavelength)

Wash Bottle

Cuvettes

Per group

- Dry Microalgae Biomass: around 100 mg
- Beaker (100 mL capacity)

- Volumetric flask (no smaller than 10 mL and no bigger than 50 mL
- Magnetic Stirrer and Stir Bar
- Graduated Cylinder and Pipette for accurate measurement and addition of media to reach final volume
- Automatic Pipettes (1 mL, 5 mL- 10 mL)
- Test Tubes or Small Beakers: For holding each dilution (5–10 mL capacity for each dilution)
- Labelling Marker: For marking dilutions clearly
- Lab Notebook: For recording absorbance readings and calculations

Procedure B

1. Use an analytical scale to measure an appropriate amount of dry microalgae biomass and place it in a small baker. Begin with approximately 2 g/L to prepare a concentrated stock solution. No more than 50 mL of stock will be needed.
2. Gradually add the media to the required biomass. Stir the solution well to ensure even dispersion of the biomass. If clumping occurs, a magnetic stirrer can be used for continuous agitation.
3. Accurately bring the volume of the suspension to the final volume (i.e. 50 mL) rinsing the beaker used for suspension to recover any remaining biomass.
4. From the stock solution, prepare a series of dilutions by adding culture medium in calculated proportions. This will simulate different biomass concentrations that approximate those found in typical growth conditions.
5. For each prepared dilution, measure the optical density (absorbance) at the specified wavelengths (760 nm, 680 nm, 620 nm, 565 nm, and 445 nm) using a spectrophotometer

Appendix 3.2- Primary data for analysing light absorbance.

Tube	1	2	3	4	5	6	7	8	9	10
Microalgae concentration [g/L]										
$O.D_{445\ nm}$										
$O.D_{565\ nm}$										
$O.D_{620\ nm}$										
$O.D_{680\ nm}$										
$O.D_{760\ nm}$										
Tube	11	12	13	14	15	16	17	18	19	20
Microalgae concentration [g/L]										
$O.D_{445\ nm}$										
$O.D_{565\ nm}$										
$O.D_{620\ nm}$										
$O.D_{680\ nm}$										
$O.D_{760\ nm}$										

Data Analysis and Discussion

Extinction Coefficient Calculation for Microalgae Cultures

Calculate the extinction coefficient of various microalgae cultures at different wavelengths of incident light, using absorbance readings from spectrophotometric analyses.

Key Equations and Data Processing Fundamentals

For light attenuation through a microalgae culture, the relationship between the irradiance at the point of light incidence $I_{0\lambda}$ and the irradiance at a measured distance I_{λ} can be modeled as follows:

$$I_{\lambda} = I_{0_{\lambda}} \cdot e^{-ka_{\lambda} \cdot d \cdot c_b}$$

where:

- $k_{a\lambda}$ [$L^2 \cdot M^{-1}$] is the extinction coefficient at wavelength λ, specific to each microalgae culture.
- Cb in [$M \cdot L^{-3}$] is the concentration of microalgae.
- D, in [L] is the optical path length (distance from the incident light source to the irradiance measurement point).

Calculation Methods:

Spectrophotometric Absorbance Measurements: For data obtained via spectrophotometry, calculate kaλ based on the absorbance readings. Recall that absorbance at a target wavelength (A_{λ}) is, by definition:

$$A_{\lambda} = -log\frac{I}{I_0}$$

The extinction coefficient can then be derived from the absorbance and path length of the cuvette used in the spectrophotometric setup.

Discussion Points

1. Comparison of Extinction Coefficients: Compare the extinction coefficients obtained spectrophotometric measurements across different microalgae species. Differences in values should be critically examined, considering potential causes such as variations in cell size, shape, and pigment composition that influence light absorption.

2. Impact on Bioreactor and Process Design: Discuss how understanding the extinction coefficient of microalgae affects bioreactor design, specifically in optimizing light penetration and distribution.
3. Application in Bioprocess Optimization: Consider how variations in light attenuation at different wavelengths can inform decisions on light quality and intensity in microalgae cultivation, influencing parameters such as growth rate and productivity, and energy efficiency in industrial settings.

LIST OF PROBLEMS NUMBER 4

TITLE: Growing microorganisms

Problem 4.1: Biomass Concentration via Dry Weight Measurement

Description:

The dry weight method is one of the most common techniques for determining microbial biomass concentration, as it provides an accurate measure of cell mass. You might have done it in the practice of determination of the extinction coefficient of microalgae cultures, when determining the concentration of the culture.

In this method, a known volume of culture is centrifuged or filtered through a fine filter (typically 0.2 µm), isolating the microalgal biomass. After removing the culture medium, the biomass is carefully dried to a constant weight and weighed to determine its concentration.

The following data reflects experiments of dry weight determination using centrifugation instead of filtration, and freeze and dry instead of oven dry.

Volume (mL)	Container Weight (g)	Dry Biomass + Container Weight (g)	Concentration (g/L)
750	12.50	13.46	
1000	12.75	14.11	
500	12.60	13.23	
1250	12.80	14.59	
982	12.45	13.74	

Tasks:

1. Calculate the biomass by subtracting the container weight from the combined weight of dry biomass and container. Divide the biomass by the volume of culture filtered or centrifuged to obtain concentration in g/L.

2. Calculate the average biomass concentration and standard deviation to understand the data's consistency.

Problem 4.2: Monitoring microalgae growth in a bioreactor

Description:

A 100L bubble column containing fertiliser-enriched sea water has been inoculated with a marine microalga. After inoculation, biomass concentration (cb) is followed by indirect absorbance measurement at 680 nm (OD680). The correlation between concentration and absorbance is given by the equation:

$$c_b\left[\frac{g}{L}\right] = OD_{680nm} \cdot k$$

The correlation is valid for DO_{680} values <0,4 otherwise the suspension is diluted and the absorbance reading corrected by the dilution.

Tasks:

For each set of data:

1. Calculate the concentration at each sampling time.
2. Plot the graph of concentration against time of culture.
3. Graphically determine the maximum specific growth rate.
4. Show in the graph the diverse culture growth phases.

a) Data set 1, k=0,572

Time, days	Optical density at 680 nm	mL of culture	ML of medium for dilution
0	0,2797	1	0
1	0,2920	1	0
2	0,3182	1	0
3	0,2597	1	0
4	0,3289	1	0
5	0,3510	1	0
6	0,3298	1	0
7	0,2258	1	1
8	0,2560	1	1
9	0,3832	1	1
10	0,3175	1	2
11	0,2424	1	5
12	0,3352	1	5
13	0,2695	1	9
14	0,3467	1	9

Time, days	Optical density at 680 nm	mL of culture	ML of medium for dilution
15	0,3801	1	9
16	0,3799	1	9
17	0,3884	1	9
18	0,3779	1	9
19	0,3670	1	9
20	0,3568	1	9

b) Data set 2, k=0,67

Time, days	Optical density at 680 nm	mL of culture	ML of medium for dilution
0	0,3791	1	0
1	0,3881	1	0
2	0,3209	1	0
3	0,3841	1	0
4	0,3498	1	0
5	0,3565	1	0
6	0,4673	1	0
7	0,2111	1	1
8	0,2366	1	1
9	0,2631	1	1
10	0,1954	1	2
11	0,1406	1	4
12	0,1732	1	4
13	0,2008	1	4
14	0,2464	1	4
15	0,2494	1	4
16	0,2458	1	4
17	0,2455	1	4
18	0,2523	1	4
19	0,2343	1	4
20	0,2114	1	4

Problem 4.3: Designing a raceway

Description:

You are tasked with establishing a raceway for microalgae cultivation at a chemical plant. Three potential zones have been identified for the raceway setup, each with an additional area allocated for assembly, operator circulation, and equipment:

- **Zone 1:** 15m x 67m
- **Zone 2:** 5m x 200m
- **Zone 3:** 10m x 112m

Based on this information, address the following:

(a) Determine which zone is most suitable for constructing the raceway, considering available space and layout.

(b) Design various raceway configurations for the selected zone, including dimensions and layout. Calculate the stirring power required for each configuration.

(c) During operation, an issue with inefficient CO_2 consumption is identified. What modifications or improvements can be made to optimize CO_2 utilization?

(d) Use the operational data provided below to calculate the amount of bioproduct achievable under different conditions. Assess and recommend ideal operating parameters for maximizing the production of a specific biomolecule A:

Calculate the potential bioproduct yield under each condition, then provide operational recommendations based on the data for optimizing the bioproduct yield.

d, cm	R%	cb, g/L	C prod. g/100g
Maximum	20	1	2
Maximum	30	0,9	2,1
Maximum	40	0,55	2,2
Maximum	50	0,3	2,3
Minimum	20	1,2	2
Minimum	30	1,1	2,1
Minimum	40	1	2,2
Minimum	50	0,5	2,3

Problem 4.4: Designing a tubular bioreactor

Description:

Agitation and aeration are essential for maintaining nutrient dispersion and CO_2 supply in microalgae cultures. However, in sensitive cultures, these processes can also lead to cell damage or death if not properly controlled. At low agitation rates, damage can occur due to vortex formation, bubble entrainment, and bubble breakup, which cause shear stress. As agitation intensity increases (in the absence of vortices and bubbles), damage can instead result from turbulent shear forces in the liquid, which are closely related to the Kolmogorov eddy

The Kolmogorov eddy size (le), which can indicate the potential for cell damage, is given by:

$$le = \left(\frac{\mu}{\rho}\right)^{\frac{3}{4}} \cdot \epsilon^{-\frac{1}{4}}$$

being μ and ρ is the viscosity and density of the culture and $\varepsilon$the specific rate of energy dissipation in the fluid, estimated according to:

$$\frac{2c_f \cdot u_l^3}{\emptyset} = \varepsilon$$

The friction factor (cf) is:

$$c_f = 0.0791 \cdot Re^{-0.25}$$

Being the Reynold number (Re) related as:

$$Re = \frac{\rho \cdot \emptyset \cdot u_l}{\mu}$$

The flow is considered turbulent for Re>3000 and $\emptyset$ is the tube diameter.

Tasks:

1. Calculate the maximum allowable liquid velocity for cells with a 10 μm size in a 6-cm diameter tube and a 5-cm bioreactor tube for cells of 10 μm and 12 μm.
2. Evaluate how elevated medium viscosity (e.g., 10 cp due to polysaccharide excretion) impacts flow and cell damage.
3. Assess if an oxygen generation rate of 0.064 $g \cdot m^{-3} \cdot s^{-1}$ is suitable for an 80 m solar loop with a flow rate of 0.5 m/s in freshwater microalgae cultures, which tolerate up to 27 mg/L dissolved oxygen. Also, consider how variations in environmental temperature and circulation speed might affect operation.

Problem 4.5: CO_2 Remediation at a Power Station

Description:

A thermal power station utilizes microalgae bioreactors to capture CO_2 emissions from coal combustion. Each kg of coal ideally generates 30 MJ, though plant efficiency is 31%. The microalgae's O_2 generation rate ranges between 0.0040 mol·m^{-3}·s^{-1} and 0.0044 mol·m^{-3}·s^{-1} in a 10 m^3 facility under a 16:8 light/dark cycle during summer.

Tasks:

Calculate the CO_2 capture potential under these conditions and translate this to equivalent MJ mitigated at the power station, given that 1 kg of coal (at 100% efficiency) emits 3.66 kg of CO_2.

Problem 4.6: Bioproduct Productivity

Description:

During summer, a bioreactor was operated continuously at dilution rates between 0,01 to 0,088 h^{-1}, with biomass concentrations and external irradiance as listed below. Concentrations of phycobiliproteins (PB) and polyunsaturated fatty acids (PUFAs) are recorded in each case.

Tasks: Calculate maximum productivity of biomass, phycobiliproteins, and PUFAs on sunny days based on the data.

Dilution rate D h^{-1}	Biomass concentration, Cb g·L^{-1}	External irradiance Iw µE·m^{-2}·s^{-1}	Phycobiliproteins PB g/100g of biomass	PUFAs (ARA) g/100g of biomass
0,01	3,07	683	2,835	20,06
0,02	2,01	713	2,291	23,3
0,02	2,40	862	2,465	22,61
0,04	2,98	2157	1,606	20,31
0,043	3,20	2354	1,902	21,84
0,055	0,99	1164	2,612	26,06
0,055	1,30	1474	2,358	27,44
0,052	2,1	1887	2,265	26,5
0,057	2,1	1979	1,792	26,75
0,057	2,5	2444	1,891	25,21
0,074	2,1	3072	2,746	31,95
0,087	0,5	1187	3,188	32,55
0,088	1,45	2457	2,508	33,3

a. Calculate the maximum productivity of biomass, PB, and PUFAs for sunny days.

Contextualization of equality in Biotechnology

Equality in biotechnology is increasingly recognized as essential for fostering innovation, growth, and social responsibility within the industry. While recent findings show gradual improvement in diversity, equity, and inclusion (DEI), especially among general employees, disparities persist at higher levels of leadership. For example, women make up 49% of the total workforce in surveyed organizations, a notable increase from past years. However, representation decreases in executive positions, with women holding 34% of these roles and occupying only 20% of CEO positions, down from 23% previously. These trends reveal that while DEI initiatives are making strides in the industry, there is a significant need for further efforts to close gaps, especially in the top tiers where decision-making power is concentrated. By prioritizing diversity at the executive level, biotechnology firms can better reflect the broader population they serve, drive inclusive innovation, and respond more effectively to societal needs(Bio and Coqual, 2022).

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