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Integration of ChatGPT 4o in Teaching Chemical Engineering Process Analysis

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I am an Assistant Professor in Chemical Engineering. I am teaching Chemical Reaction Kinetics, Chemical Engineering Thermodynamics, Process Analysis, Introduction to the Modeling of Engineering Systems, and Chemical Engineering Workshops.

Integration of Free ChatGPT 4o in Teaching Chemical Engineering Process Analysis

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Abstract. The rapid emergence of large language models (LLMs) has introduced new opportunities and challenges for engineering education. This study examines the structured integration of ChatGPT-4o into a junior-level Chemical Engineering Process Analysis course, focusing on how students applied AI tools within mass and energy balance problem solving. Students were instructed to document AI usage, evaluate AI accuracy using disciplinary principles, independently verify outputs, and iteratively refine AI-generated responses. A qualitative analysis of student artifacts and project deliverables was conducted to evaluate learning behaviors across four project groups. Results indicate that students who treated AI as a provisional scaffold—rather than an authoritative solution—demonstrated stronger conceptual reasoning, verification practices, and iterative improvement. The study contributes a pedagogical framework for responsible AI integration emphasizing transparency, engineering judgment, and structured evaluation. Limitations related to sample size, evolving AI models, and qualitative interpretation are discussed, along with implications for future AI-assisted engineering curricula.

1. Background and motivations

Artificial Intelligence (AI) is transforming higher education on teaching and learning methodologies, curriculum design, student engagement, assessment practices, and institutional stratigies[1-6]. Specifically, in Chemical Engineering education, the usage of AI can be clustered into four big use-cases: (1) adaptive and personalized learning (e.g., problem sets, visualization, and self-paced inquiry)[7-10], supporting students' self-paced inquiry and frees instructors for higher-order mentoring (critical thinking, modelling, process design) rather than purely delivering content; (2) enhanced simulation, virtual labs and modelling tools (e.g., flowsheet design and instrumentation diagram correction)[11-13], allowing students to explore process design/optimization, review 'what if' scenarios and engage more deeply with engineering decisions and trade-offs; (3) support for writing, coding, and documentation workflows[10, 12], allowing instructors to shift focus to evaluate critical thinking, interpretation and engineering content rather than grammar/mechanics; (4) data-driven process understanding and problem-solving (e.g., handling large datasets, extracting patterns, building predictive models, and interpretation)[13, 14], preparing students for modern industry/academia where data-analytics, digital twin, smart manufacturing are increasingly important; (5) ethics, safety and interdisciplinary integration (e.g., responsive AI use, interpretability, or risk of over-reliance)[7, 14], emphasizing the importance of embedding reflections on when AI should not replace fundamental engineering reasoning (e.g., scaling issues, safety margins).

Despite the extensive attention on the application of AI in higher education, most published AI-in-education studies focus on general STEM courses[15], introductory programming[16], writing support[17], or conceptual understanding in non-engineering fields. There is very limited empirical work evaluating large language models (LLMs) in core chemical engineering courses, especially those requiring multistep materials and energy balances, thermodynamic property estimation, economic evaluation, and engineering decision-making[9, 18]. Most previously published studies allow unrestricted LLM use, focus on homework rather than final project or analyze student perceptions rather than performance on engineering deliverables. There are limited studies that introduce ChatGPT-4o as a time-limited and freely accessible tool since most faculties and students only have access to free LLM tools. Moreover, there are limited studies that embed AI into a process design mini-project and evaluate how students use it to complete integrative engineering tasks.

Motivated by these, this study provides one of the first discipline-specific evaluations of ChatGPT-4o in a junior-level Chemical Engineering course, offering empirical evidence on how LLMs support and fail within authentic engineering tasks such as process flow diagramming, materials and energy balances, and economic analysis. By systematically differentiating LLM effectiveness across low-order and high-order cognitive tasks, the work fills a documented gap in engineering-education research, which rarely examines AI performance within domain-constrained, multi-step chemical engineering workflows. The integration of ChatGPT-4o as a time-limited tool within a summative design project also represents a novel instructional approach, revealing how direct exposure to AI recalibrates students' professional judgment and reinforces foundational engineering principles. This study therefore contributes a new pedagogical model for responsible AI integration and provides widely generalizable insights applicable to Chemical Engineering programs, especially at resource-limited institutions.

2. Organization of the class

This course, Chemical Engineering Process Analysis, introduces juniors to chemical engineering principles related to mass and energy balances. Students attended this course with basic knowledge in mass and energy balances they acquired from the introduction to the modeling of engineering systems class during the second semester of their sophomore years. They also received systematic training in problem solving skills and how to conduct a 4-week comprehensive project that involves mass and energy balances when they took the introduction to the modeling of engineering systems class during the last semester of their sophomore year.

A total of 13 students participated in the study, organized into four project teams. Prior exposure to ChatGPT varied; approximately 35.7% reported never used ChatGPT, 14.3% reported monthly ChatGPT usage, and 50.0% reported weekly ChatGPT usage. Students were encouraged to iteratively revise submissions over multiple milestones, with an expected minimum of three refinement cycles: initial AI-assisted draft, engineering validation, and final synthesis. AI usage time was documented through required response logs submitted alongside project materials.

Students were asked to integrate ChatGPT 4o during their final project. The final project of process analysis is a four weeklong project during the last month of the semester (Table 1). Prior to the introduction of the project, students have been introduced to the basic principles of chemical engineering materials balance. Before they started their energy balance analysis, the students were introduced to energy balance.

Table 1 Design of the final project and the alignment of the final project milestone with the schedule of the semester

Lecture Schedule		Final Project Milestone	
Week 1	Introduction		
Week 2	Review of Engineering Calculation & Introduction to Processes and Process Variables		
Week 3	Fundamentals of Materials Balance (Materials Balance-Single Unit)		
Week 4	Fundamentals of Materials Balance (Materials Balance-Multiple Unit)		
Week 5	Fundamentals of Materials Balance (Mole Balance-Molecular Balance)		
Week 6	Fundamentals of Materials Balance (Mole Balance-Atomic Balance and Extent of Reaction)		
Week 7	Single Phase-Process Terminology for Phase Transfer		
Week 8	Single Phase-Materials Balance		

Week 9	Multiple Phases-Single Condensable Component		
Week 10	Multiple Phases -Multiple Condensable Components	**Week 0**	Team and Team Leader Assignment
Week 11	Energy Balance Background Review	**Week 1**	Topic Selection, Diagram Development and Labeling
Week 12	Energy Balance-Nonreactive System & Phase transfer	**Week 2**	Identifying the Known variables and Defining Unknown Variable that required for balance analysis
Week 13	Energy Balance-Reactive System	**Week 3**	Materials Balance Analysis
Week 14	Energy Balance-Reactive System & Phase transfer	**Week 4**	Energy Balance & Economic Analysis
Week 15	Final Project Presentation		

3. Team Formation and Leadership Roles

Teams were assigned during Week 0 based on instructor-balanced grouping to distribute academic background and prior performance across teams. Each group consisted of three or four students. A team leader was designated at project initiation to coordinate milestone planning, document AI interactions, and ensure adherence to project objectives. Leadership responsibilities included managing task delegation, facilitating discussion of AI outputs, and overseeing the final integration of modeling results. The leadership structure was implemented to simulate professional engineering collaboration and to enable evaluation of internal participation using structured peer-review rubrics (Supplementary Material I).

4. Rationale of the project

There were three topics that students can choose from:

Topic 1: Cookie Manufacturing with Sugar
Topic 2: Epsom Salt Manufacturing
Topic 3: Removing contaminant (Benzene) from Airplane Fuel (Propane)

These projects were chosen because they were previously proposed by industrial board members while they worked with previous students in this class. The purpose of this project were to evaluate if students can meet the ABET student outcomes[19] 1-3, that includes if students can identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics, apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors, and communicate effectively with a range of audiences.

5. Rubrics and expectations

The final evaluation of the project included two major parts, modeling in Microsoft Excel and a 7-minute group presentation. The weight of evaluation was distributed as the following (Table 2):

Table 2. Weight of evaluation

Team leader (Total 100 pts)	Team member (Total 110 pts)
Part I: Modeling in Excel (50 pts)	Part I: Modeling in Excel (50 pts)
Part II: Seven-min Group Presentation (50 pts) • Peer Review (20 pts) • Instructor Review (20 pts) • Internal Participation Review (10 pts)	Part II: Seven-min Group Presentation (50 pts) • Peer Review (20 pts) • Instructor Review (20 pts) • Internal Participation Review (10 pts)
	Extra Points (10 pts) • Leadership Peer Review (5 pts) • Leadership Instructor Review (5 pts)

The instructor used ChatGPT 4o to generate the rubrics for Modeling in Excel and 7-min Group Presentation, as well as the usage of ChatGPT 4o during these activities (Table 3&4). The "Modeling in Excel" component required students to construct a structured mass and energy balance framework using spreadsheet-based calculation workflows. Students developed flow diagrams, defined system boundaries, implemented iterative calculation blocks, and performed consistency checks including unit balance and physical feasibility. Excel served not only as a computational tool but also as a transparency mechanism that allowed both instructor and peers to evaluate how AI-generated suggestions were translated into engineering calculations. Emphasis was placed on documenting assumptions, tracking AI-generated variables, and demonstrating iterative refinement rather than simply presenting final numerical answers.

Students were instructed to use ChatGPT 4o from the beginning of the project and to achieve the following four objectives:

- **Objective 1. Document ChatGPT-4o's responses when AI is used**
  In this course, students were required to explicitly document when and how ChatGPT-4o was used during their work. ChatGPT-4o was selected because, at the time of the final project, it was one of the most advanced large language models freely available to both instructors and students. Artificial intelligence refers to the ability of computer systems to perform tasks that typically require human intelligence, as well as the development of such systems[20]. GPT stands for Generative Pre-trained Transformer, and GPT-based architectures underlie many large language models beyond ChatGPT itself[20].

  By documenting AI-generated responses, students were encouraged to treat AI outputs as external artifacts rather than hidden shortcuts. This practice made AI use transparent, reproducible, and open to evaluation, reinforcing the expectation that AI-generated content must be acknowledged and critically examined rather than implicitly trusted. Students were required to archive selected ChatGPT prompts and responses as part of their deliverables to promote transparency and reproducibility of AI-assisted workflows.

- **Objective 2. Apply Chemical Engineering Process Analysis principles to evaluate AI accuracy**
  Students were instructed to evaluate the accuracy of ChatGPT-4o's responses using the Chemical Engineering Process Analysis principles learned throughout the semester,

including mass, energy, and momentum balances; system boundary definition; assumption validation; unit consistency; and physical feasibility. AI-generated responses were treated as hypotheses, not authoritative answers.

Although modern AI systems such as ChatGPT-4o possess large parameter counts—estimated at 1.76 trillion parameters for GPT-4 compared to 175 billion for GPT-3—greater model complexity does not guarantee correctness. Parameters represent tunable internal variables that allow models to generate nuanced responses, but they do not replace physical laws or engineering judgment. Students were therefore expected to identify incorrect assumptions, missing constraints, or violations of fundamental principles in AI-generated solutions and to revise those outputs accordingly.

- **Objective 3. Use independent methods to verify AI-generated responses**
  Beyond disciplinary reasoning, students were required to independently verify AI-generated outputs using alternative approaches. These included textbook references, lecture notes, hand calculations, numerical checks, dimensional analysis, and comparison with known limiting cases. This mirrors professional engineering practice, where no single tool—AI or otherwise—is considered sufficient validation on its own.

  This objective emphasized that AI-generated work typically reflects competent but incomplete ("C-level") performance. While AI can generate plausible reasoning quickly, professional-quality ("A-level") engineering work requires corroboration, validation, and synthesis across multiple sources of evidence. Students learned to identify hallucinations—confident but incorrect AI outputs—and to understand their causes and potential consequences in engineering contexts.

- **Objective 4. Improve AI-generated responses to A-level work through iteration and engineering judgment**
  The final objective focused on transforming AI-generated outputs into high-quality human work. Students were taught that AI is most effective when used iteratively: refining prompts, incorporating constraints, correcting assumptions, and integrating domain knowledge. Rather than treating AI as a competitor, students learned to establish and fine-tune AI tools as personal assistants that support, but do not replace, expert reasoning.

  This process required students to engage in problem formation, including diagnosis, decomposition, reframing, and constraint design[21, 22]. In chemical engineering, problem solving extends beyond finding numerical answers and involves both divergent thinking (exploring alternative formulations and overlooked variables) and convergent thinking (selecting the most appropriate solution). Through iterative interaction with AI, students practiced these skills by improving question quality, clarifying system boundaries, and progressively enhancing solution rigor.

As the engineering workforce continues to evolve, the ability to ask better questions, connect ideas, evaluate uncertainty, iterate on solutions, and adapt to new information becomes increasingly valuable[21, 23]. By explicitly integrating AI into this problem-solving framework, the course prepared students not only to use AI tools responsibly, but also to demonstrate the critical thinking and adaptability required for long-term professional success.

Together, these four objectives ensure that students do not merely use AI, but learn how to evaluate, verify, and elevate AI-assisted work using Chemical Engineering principles, transforming AI-generated outputs into rigorous, professional-quality solutions.

Table 3. ChatGPT 4o generated rubric for Modeling in Excel.

Criteria	Excellent (Full Points)	Satisfactory (Partial)	Needs Improvement
Materials Balance (10 pts)	Complete, accurate, and clearly shown	Minor errors, mostly accurate	Incomplete or incorrect
Energy Balance (10 pts)	Clearly calculated with assumptions and sources shown	Some gaps or missing details	Inaccurate or missing
Economic Analysis (10 pts)	Justifies feasibility with cost estimations, ROI, or market value	Attempted but lacks depth	Missing or flawed
Use of Excel Tools (5 pts)	Uses formulas, charts, organized layout	Some formulas used but disorganized	Manual entry or unclear
Entrepreneurial Minded Learning - 3Cs (15 pts)	Demonstrates curiosity (innovative idea), connections (link to real-world context), and value creation	Addresses 2 of the 3Cs clearly	Superficial or missing integration
ChatGPT Design Evaluation (Extra credit: 5 pts)	Thoughtful evaluation of ChatGPT's ability and limitations in process design	Brief evaluation without examples	Missing

Table 4. ChatGPT 4o generated rubric for 7-min Group Presentation.

Criteria	Excellent (Full Points)	Satisfactory (Partial)	Needs Improvement
Process Importance / Value Creation (10 pts)	Clearly states societal/industrial value and why it's worth pursuing	General value mentioned	No clear value justification
Materials & Energy Balance in Design (10 pts)	Presented clearly with connection to technical decisions	Somewhat unclear or unconnected	Missing or confusing
Persuasiveness / Why Choose Your Design (10 pts)	Compelling argument, compares to competitors, well-supported	Basic comparison or weak justification	Missing or unclear
Clarity, Organization, and Teamwork (10 pts)	Clear speaking, strong visuals, smooth transitions	Minor issues in clarity or time management	Disorganized or confusing
ChatGPT Evaluation (in slides) (5 pts)	Integrates ChatGPT analysis thoughtfully with examples	Mentions ChatGPT briefly	Missing or irrelevant
Internal Team Evaluation (5 pts)	All members participated equally and reflect on contributions	Slight imbalance	One or more members did not contribute

Although the primary rubric categories were summarized into three qualitative levels (limited, moderate, strong) for cross-case comparison, internal participation evaluation employed a structured 0–5 scoring framework resembling a Likert-style scale (Supplementary Material II). The aggregation into ordinal categories was performed to emphasize interpretive trends rather than statistical inference.

6. Students' submissions and data analysis

6.1 Methods of data analysis

Student submissions were analyzed using a qualitative thematic analysis approach. Artifacts included final project presentation, supporting spreadsheets, and written reflections describing students' use of ChatGPT-4o during the project. A priori coding framework was developed based on the course AI literacy learning objectives, focusing on documentation of AI use, evaluation of AI-generated content using engineering principles, independent verification strategies, and iterative refinement of AI outputs. This framework was iteratively refined through cross-case comparison as codes were applied across multiple submissions.

Coding was conducted by examining both textual reflections and technical artifacts to identify evidence of how students interacted with AI tools and how those interactions influenced problem-solving processes. Codes were applied at the level of meaningful units of analysis, including statements describing AI use, revisions to AI-generated content, and engineering decisions that reflected validation or rejection of AI outputs. Patterns were compared across submissions to identify recurring themes related to the role of AI as an informational scaffold, limitations of AI in constraint-driven engineering tasks, the mediating role of engineering judgment, and the quality of student iteration.

To enhance analytic rigor, themes were synthesized across cases rather than interpreted as individual performance outcomes. This cross-case approach allowed for identification of systematic behaviors in student–AI interactions that were consistent across project teams. The qualitative analysis emphasized process-oriented evidence of learning rather than correctness of final numerical results, aligning the study with the goal of understanding how conversational AI influences engineering thinking and decision-making.

6.2 Data analysis results and discussion

The analysis of students' submission is summarized in the table below (Table 5). The comparative analysis presented in Table 5 was derived through structured qualitative coding of four predefined learning objectives. Each group submission was examined for explicit evidence of AI documentation, disciplinary evaluation, independent verification, and iterative refinement. Categories were assigned based on observable artifacts rather than inferred student intention, ensuring that interpretation remained grounded in demonstrable student work.

Table 5: Alignment of Student Submissions with AI Literacy Objectives

Submission	**Obj. 1: Document AI Use**	**Obj. 2: Evaluate AI Accuracy**	**Obj. 3: Verify AI Independently**	**Obj. 4: Iterate to A-Level**
Group A	Moderate	Moderate	Limited	Moderate
Group B	Moderate	Limited– Moderate	Limited	Limited
Group C Supplementary Material II	Limited	Limited	Limited	Limited

Group D Supplementary Material III	Strong	Strong	Strong	Strong

- **Objective 1. Document ChatGPT-4o's responses when AI is used**
  Group A implicitly referenced AI-assisted reasoning but provides less explicit labeling of AI outputs, making documentation present but incomplete. Group B documented ChatGPT's role primarily as a confirmation tool ("Chat GPT was able to confirm that the process modeling was balanced and logical"), indicating explicit but more limited documentation. Group C showed minimal explicit documentation of AI responses, suggesting either limited AI use or incomplete reporting relative to Objective 1. Group D explicitly labeled multiple slides as "ChatGPT – Flow Chart," "ChatGPT – Material Balance," "ChatGPT – Energy Balance," and "ChatGPT – Economic Analysis," clearly separating AI-generated content from student-developed work. This represents the strongest achievement of Objective 1, as AI use is transparent and traceable. Students were more likely to document AI when prompted to label AI-generated artifacts explicitly (e.g., Group D), suggesting that transparency is highly sensitive to assignment structure.

- **Objective 2. Apply Chemical Engineering Process Analysis principles to evaluate AI accuracy**
  Group A demonstrated partial evaluation through selective correction and restructuring of process logic, suggesting the student recognized where AI-style outputs would fail to meet physical or operational constraints. Group B largely accepted AI confirmation at face value, indicating weaker application of evaluative judgment. While balances are presented, there is limited evidence of interrogating AI assumptions or testing physical feasibility beyond surface plausibility. Group C showed limited evidence of evaluating AI accuracy using formal process analysis principles; incomplete balances and system boundary ambiguity suggest that AI outputs, if used, were not rigorously tested. Group D explicitly reflected on AI limitations, stating that ChatGPT "can struggle in aspects that include interpreting numbers, data, and advanced principles" and that CHME 2220 background knowledge was necessary to identify incorrect AI outputs. This demonstrates clear application of process analysis principles to evaluate AI accuracy. Evaluation of AI accuracy strongly correlates with students' conceptual confidence in mass and energy balances.

- **Objective 3. Use independent methods to verify AI-generated responses**
  Group A and C showed little explicit evidence of independent verification beyond basic plausibility, suggesting partial or absent achievement of Objective 3. Group B implied verification by stating that ChatGPT "confirmed" balances, but do not clearly document independent cross-checks (e.g., hand calculations or alternative formulations), making verification present but weakly evidenced. Group D provided the clearest evidence of Objective 3, explicitly contrasting ChatGPT-generated balances and analyses with student-developed calculations and assumptions. This indicates independent verification using course principles rather than reliance on AI alone. Independent verification is the

least consistently achieved objective and appears to require explicit instructional emphasis.

- **Objective 4. Improve AI-generated responses to A-level work through iteration and judgment**
  Group A showed moderate iteration, primarily through organizational and conceptual refinement, though analytical depth remains uneven. Group B relied heavily on AI confirmation rather than iterative refinement, suggesting limited transformation of AI-assisted content into fully human-driven analysis. Group C exhibited mostly superficial iteration, with limited evidence of correcting or substantially improving analytical content. Group D demonstrated substantive iteration: AI-generated drafts are followed by student-modified flow charts, refined assumptions, and reflective critique of AI limitations. This reflects clear movement beyond AI-level (C-level) work toward higher-quality human synthesis. Meaningful iteration occurs only when students both recognize AI limitations and possess sufficient disciplinary grounding to revise outputs.

Comparative analysis across four student group submissions indicates that explicit documentation of AI use and structured reflection are critical enablers of AI literacy. Submissions demonstrating the strongest achievement of the four objectives treated ChatGPT-4o as a provisional scaffold, rigorously evaluated outputs using process analysis principles, independently verified results, and iteratively refined AI-generated content into defensible engineering work. In contrast, submissions with weaker outcomes tended to accept AI confirmation without sufficient validation, underscoring the continued importance of foundational engineering knowledge and explicit instructional scaffolding.

Although formal surveys were not conducted, qualitative student reflections were embedded within project submissions. Several teams explicitly described the need to verify AI outputs using course principles and noted limitations in AI reasoning when handling numerical or advanced thermodynamic concepts. These reflective statements were incorporated into the analysis as indirect indicators of AI literacy development.

7. Limitations

This study should be interpreted within several important limitations. First, the analysis reflects a single junior-level Chemical Engineering Process Analysis course conducted at a primarily undergraduate institution, and therefore may not generalize across institutional types or class sizes. Second, student interactions with ChatGPT-4o were inferred primarily through submitted artifacts and documented responses rather than direct observation of real-time usage, which may underestimate actual AI engagement.

Third, rapid advancements in large language models introduce an evolving technological context. While ChatGPT-4o was selected due to its accessibility at the time of implementation, newer models (e.g., GPT-5-series systems or alternative platforms such as Google Gemini) may demonstrate different reasoning patterns, numerical reliability, or user interaction behaviors. Consequently, the findings should be interpreted as a pedagogical framework rather than a model-specific evaluation.

Fourth, ethical considerations related to AI use and data privacy remain an ongoing concern. Students were instructed to avoid uploading proprietary or sensitive data; however, institutional policies regarding AI data sharing continue to evolve and should be revisited in future implementations.

Finally, ordinal qualitative categories were used to synthesize patterns across student submissions. These categories support interpretive comparison but should not be interpreted as quantitative performance metrics.

8. Discussion

The findings highlight the importance of instructional scaffolding when integrating AI into engineering education. Rather than prohibiting AI use, structured guidance can transform AI into a tool for developing critical thinking, verification practices, and iterative reasoning. The results suggest that AI literacy emerges not from exposure alone but from explicit expectations requiring students to document, critique, and refine AI outputs.

9. Conclusions

This work presents a structured pedagogical approach for integrating generative AI into chemical engineering education. By emphasizing transparency, validation, and iteration, AI can serve as a catalyst for deeper conceptual engagement rather than a shortcut around engineering reasoning. Future research should explore cross-institutional implementations, longitudinal learning outcomes, and comparisons across evolving AI platforms.

10. Acknowledgements

T Students were required to archive selected ChatGPT prompts and responses as part of their deliverables to promote transparency and reproducibility of AI-assisted workflows. This work was conducted under the instructions of IRB #2024-099.

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List of Supplementary Materials

Criteria	Evaluation (0 = not at all and 5= strongly agree)	Team leader name	Team leader name
Leadership skillset	Maximum score, 20. Your team leader has: 1) Setup efficient communication with the team members through email, text message, or group chat. (0-5) 2) Managed the progress of the project by communicating between the team members and instructor. (0-5) 3) Been inclusive during the project; for example, listening to suggestions and making sure that team members contributed their strength and improved their weakness. (0-5) 4) Clearly assigned tasks to each team member. (0-5)		
	Total		

Criteria	Evaluation (0 = not at all and 5= strongly agree)	Team member name	Team member name	Team member name
Level of participation	Maximum score, 25. Your team member has actively participated in: 1) Helping plan the milestones of the project. (0-5) 2) Helping manage the progress of the project. (0-5) 3) Being inclusive and active in group meetings. (0-5) 4) Being inclusive and active in group discussions. (0-5) 5) Actively contributing to the progress of the project (0-5)			
	Total			

AIRPLANE FUEL PRODUCTION

[redacted]

PROJECT GOAL

- Develop a comprehensive, economically viable process for effectively removing solid contaminants from airplane fuel

PROCESS IMPORTANCE

- The process is crucial to ensure rider safety and environmental protection
  - Solid contaminants can lead to clogs in aerospace pipelines, preventing fuel flow

- Process needs to be cost effective to be widely adopted within the aviation industry

- Can offer potential benefits such as reduced emissions and improved engine performance

CHAT GPT ANALYSIS

- The program was used to determine which form of aviation fuel should be focused on and gave a list of the pros and cons in addition to which derivation of aviation fuel is used for specific processes
    - Jet A-1 fuel was the selected version of aviation fuel

- Used to determine specific properties such as boiling point, freezing point, Cp values, pressure values, and ideal temperatures used in the filtration process

- Chat GPT was asked to create a general filtration process for Jet A-1 fuel, from the diagram the final filtration process were derived and modeled

- A preliminary design was made based off the design Chat GPT provided

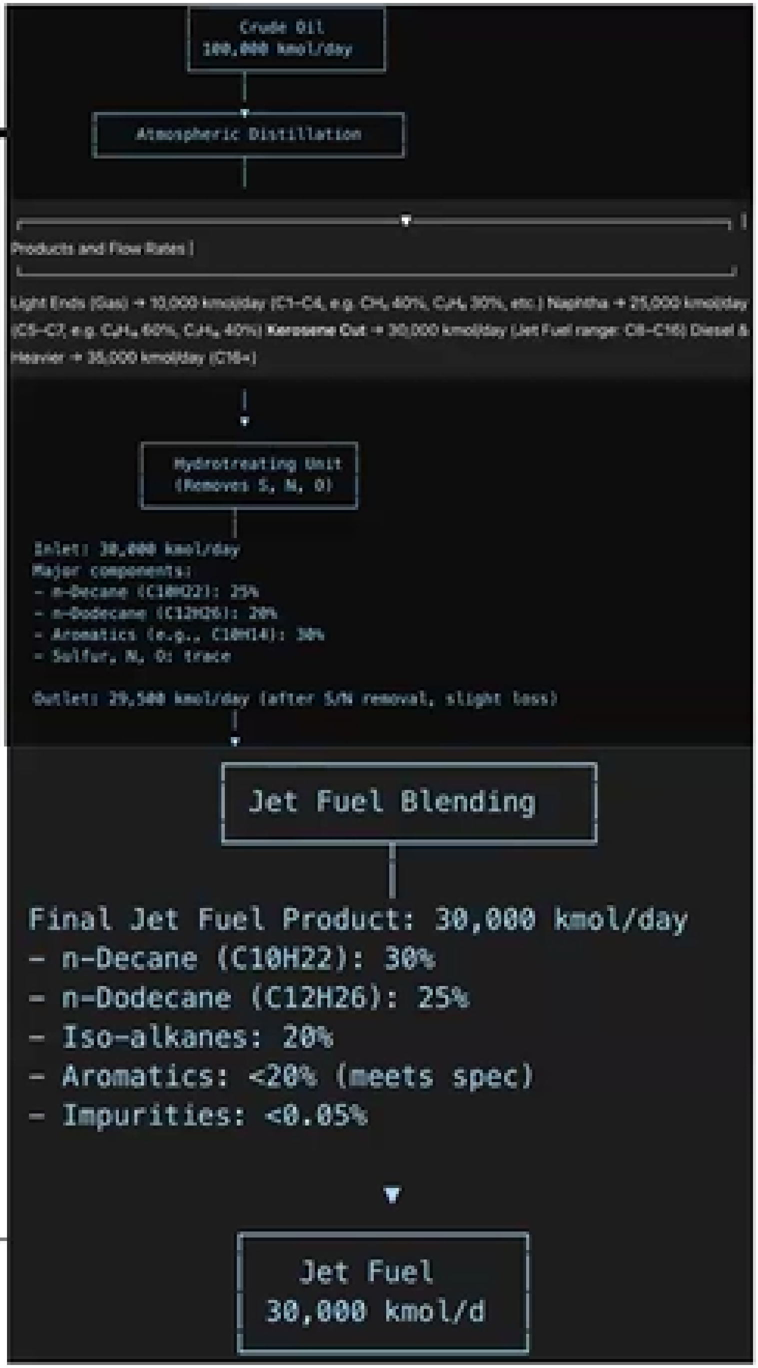
CHAT GPT ANALYSIS CONT.

- The figure to the right displays the diagram Chat GPT provided of a general production process of Jet A-1 fuel

- Provides general numerical values and stream inputs and outputs to how the system functions

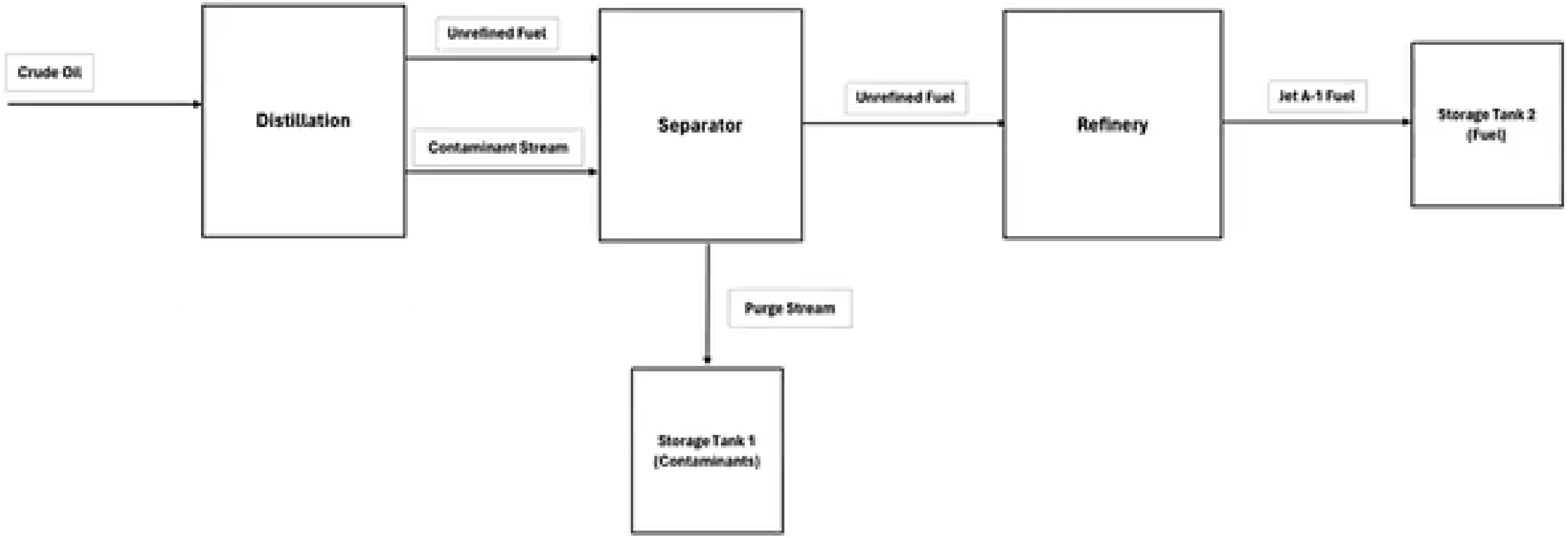
- Initial values were pulled from this diagram

- The preliminary design would also be inspired off the system

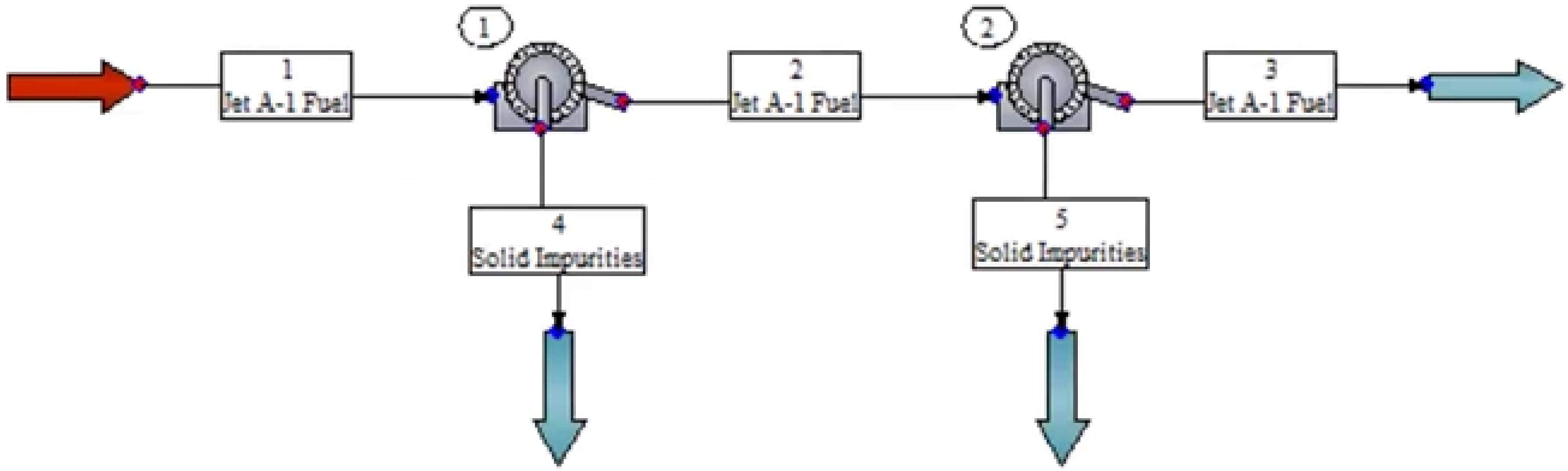


PRELIMINARY MODEL

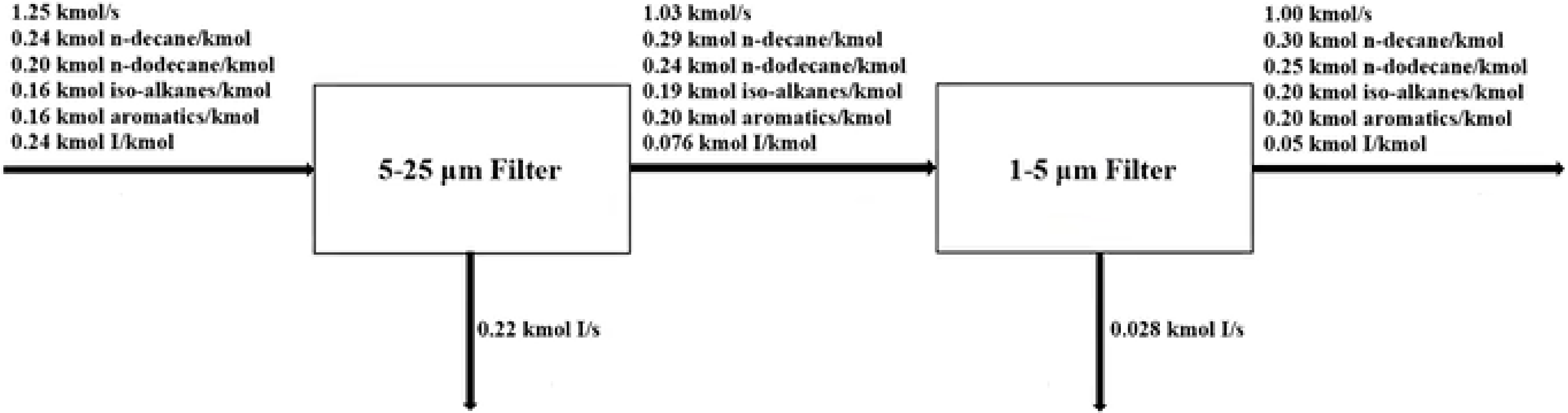
Below is the preliminary modeling design of the process which included production, not just filtration based off the Chat GPT figure.



MODEL FOR MATERIAL BALANCE



MATERIAL BALANCE



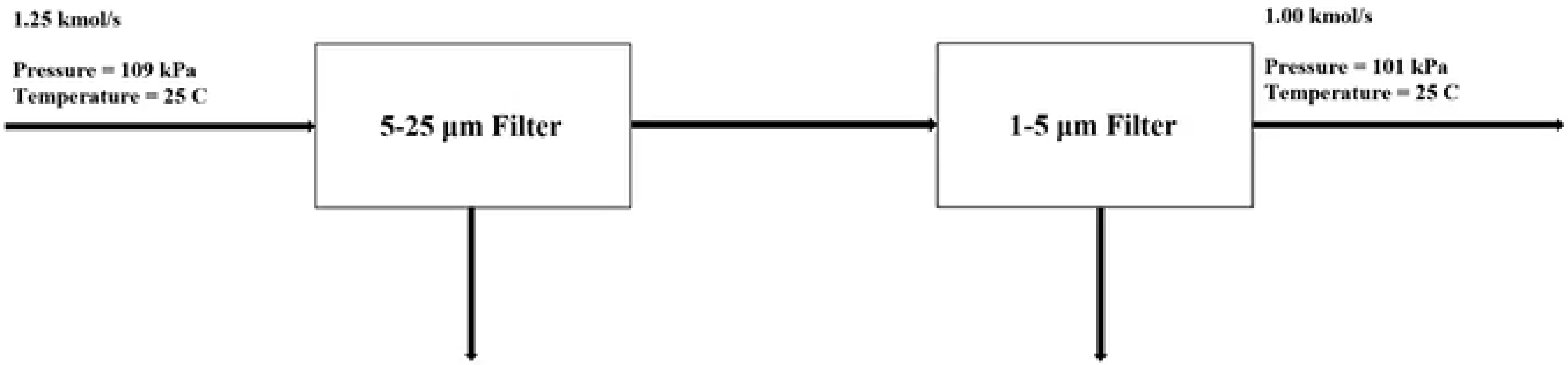
- The 5-25 micron filter was estimated to remove an average of 74% of fed contaminants
- The 1-5 micron filter was estimated to remove 99% of fed contaminants

ENERGY BALANCE BACKGROUND

- Temperatures Analyzed: 25 C, 27 C, 127 C, 227 C, 250 C
- Three Different Scenarios:
  - New Filter's: feed pressure of 109 kPa
  - Partially Loaded Filters: feed pressure of 136 kPa
  - Fully Loaded Filters: feed pressure of 201 kPa
- Each scenario has an atmospheric output pressure (101 kPa)

SAMPLE ENERGY BALANCE MODEL

New Filters, Operating Temperature of 25 C



SAMPLE ENERGY BALANCE CALCULATION

$$\Delta E_k + \Delta E_p + \Delta H = Q - W_s$$

$$\Delta H = Q$$

$$h_{output} n_{output} - h_{feed} n_{feed} = Q$$

$$0.00 \frac{kJ}{mol} * 1000 \frac{mol}{s} - 0.009 \frac{kJ}{mol} * 1250 \frac{mol}{s} = \mathrm{Q}$$

$$-11.6\, kW = Q$$

Requires external heat input to remain steady-state

ENERGY OPTIMIZATION

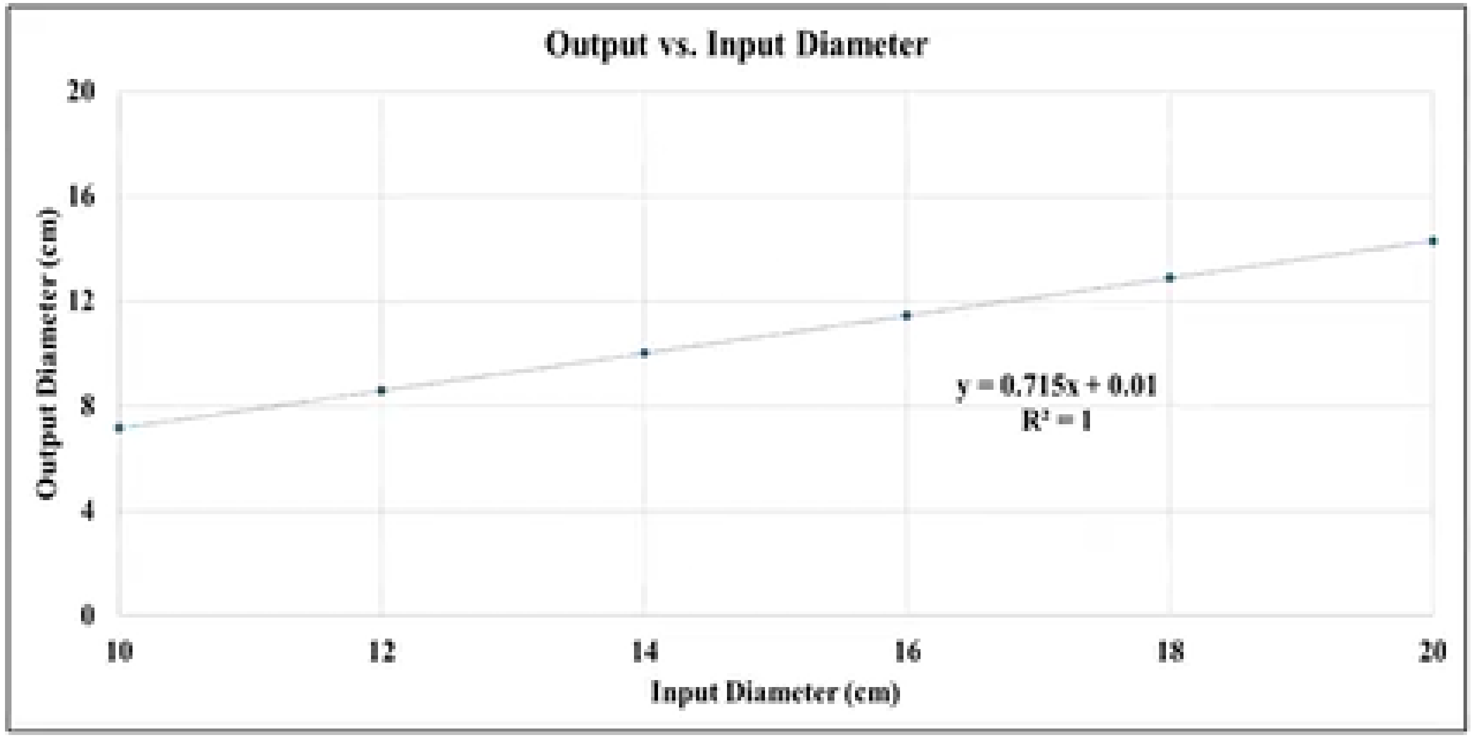
- To design a self-sustaining process, energy input must equal zero; however, the energy must be compensated another way:
  - Differences in kinetic energy can be used
  - Equation derivation used to calculate an output pipe diameter to satisfy the energy balance equation

$$\Delta E_k + \Delta E_p + \Delta H = Q - W_s$$
$$\Delta E_k + \Delta H = 0$$
$$\Delta E_k = -\Delta H$$

$$\sqrt{\frac{n_{out}^3}{\frac{n_{feed}^3}{D_{feed}^2} - \frac{2\Delta H\pi^2}{16M^3v^2}}} = D_{out}$$

ENERGY OPTIMIZATION

- Standard pipe sizes for Jet A-1 production processes include sizes from 10-20 cm
- Output pipe diameter depends on feed pipe diameter alone, independent of pressure and temperature



ANNUAL COST ANALYSIS

- 1-5 micron Filter: -$2412/yr
- 5-25 micron Filter: -$2308/yr
- Estimated Fuel Sales: $3.5 billion/yr
- Total Profit: approximately $3.5 billion/yr

WHY THIS DESIGN

1. Designed to be a self-sustaining system, eliminating operating cost
2. Can reasonably remain self-sufficient under all temperatures and pressures
3. Increase in pressure from each filter naturally ensure fluid remains liquid

QUESTIONS?

PROJECT 3

CHME 2220 – 01

Process Analysis Project 3

[redacted]

Pure Epsom Salt Manufacturing

BACKGROUND

Topic : Epsom Salt Manufacturing

Uses: Human and Medical Uses

Parameters: Raw Materials, Chemical Reactions, Units, Flow Chart, Label

Amount: 10,000 / month, based on Dr. Teal's Epsom Salt

99 % Pure Crystals

Epsom Salt Process

Raw Materials
↓
Reactor
↓
Filter Press
↓
Crystallizer
↓
Dryer
↓
Packaging

PARAMETERS

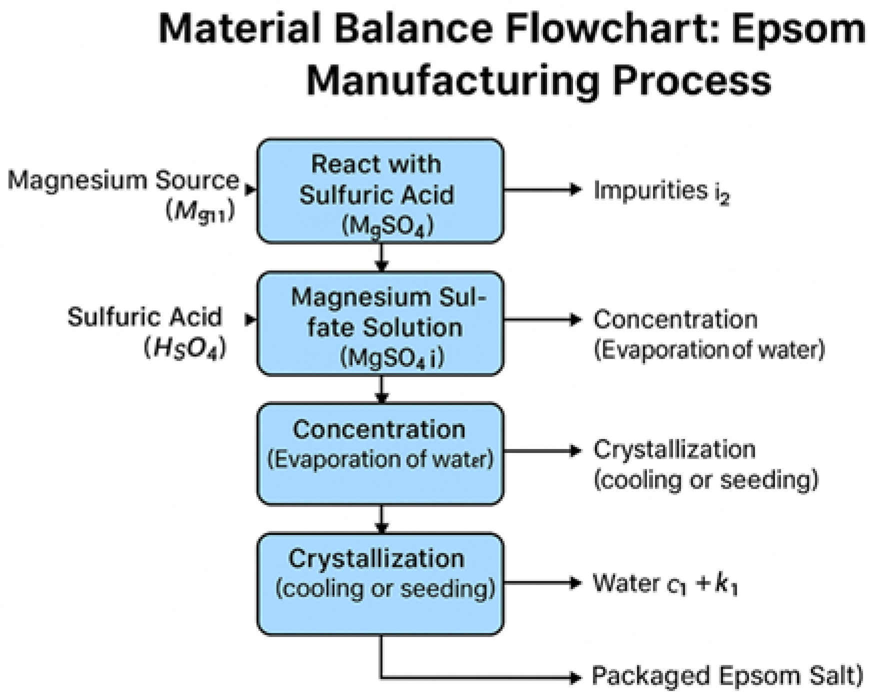
- Raw Materials - Minimal Reaction: Magnesium carbonate ($MgCO_3$) or **Magnesium oxide (MgO)** reacts with sulfuric acid (H_2SO_4)
- Chemical Reactions - $MgSO_4 \cdot 7H_2O$ (s) → Mg^{2+} (aq) + SO_4^{2-} (aq) + $7H_2O$ (l)
- Units – Reactor, Filter, Crystallize, Dryer, Mixing point (5)
- Flow Chart
- Labeling

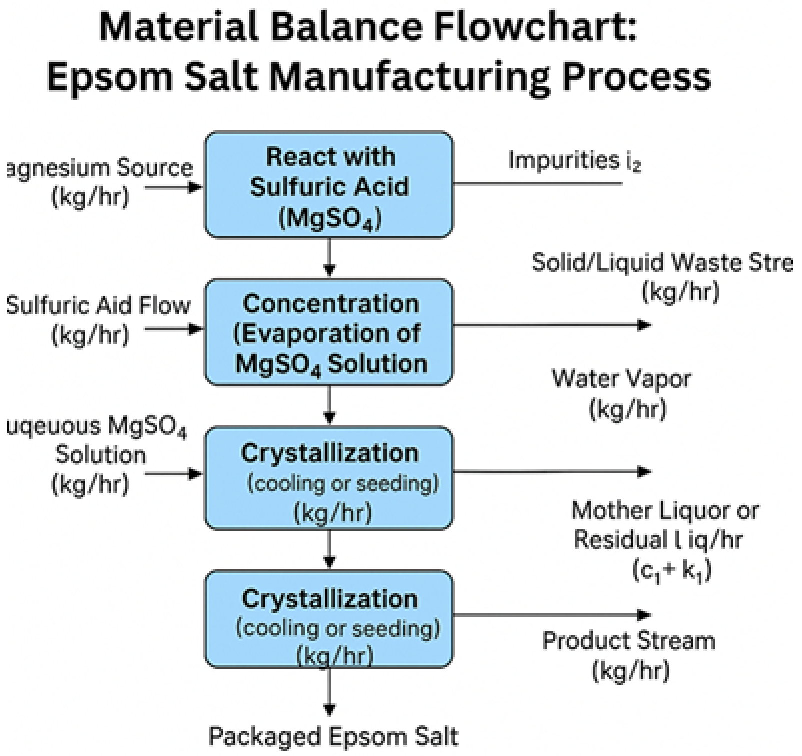
CHAT GPT - BACKGROUND

🧪 Summary Table

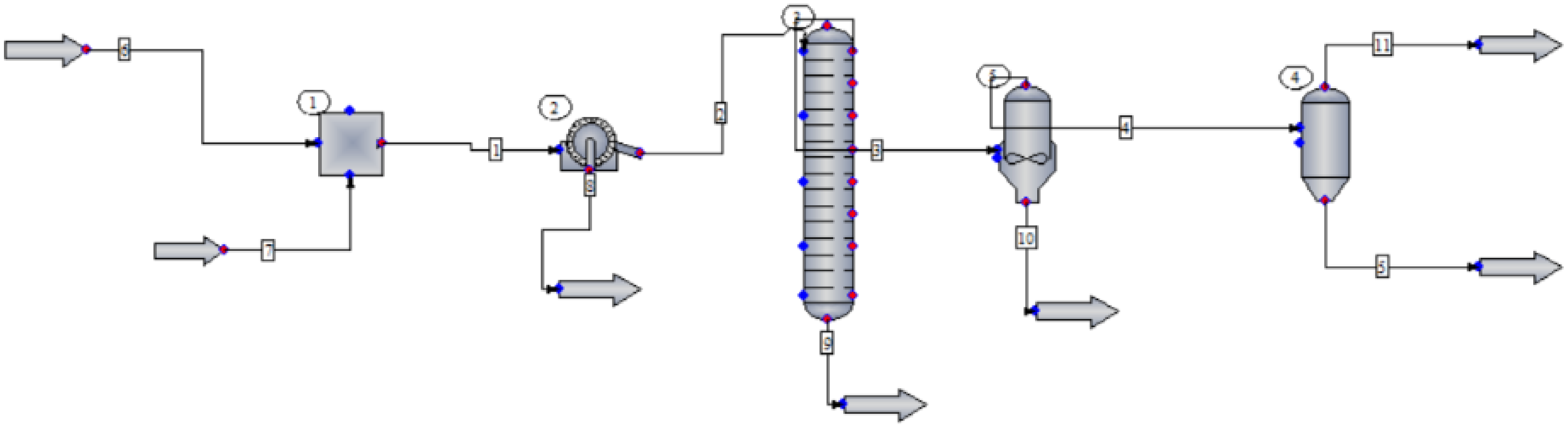
Unit	Main Purpose	Phase In	Phase Out
Reactor	Chemical reaction ($MgO + H_2SO_4$)	Solid + Liquid	Liquid (solution) + minor solids
Filter	Remove insolubles	Liquid + Solids	Clear liquid + waste solids
Evaporator	Concentrate solution	Liquid	Concentrated liquid + vapor
Crystallizer	Form $MgSO_4{\cdot}7H_2O$ crystals	Concentrated liquid	Solid + mother liquor
Dryer	Dry but preserve heptahydrate	Wet solid	Dry crystals (final product)

CHAT GPT – FLOW CHART

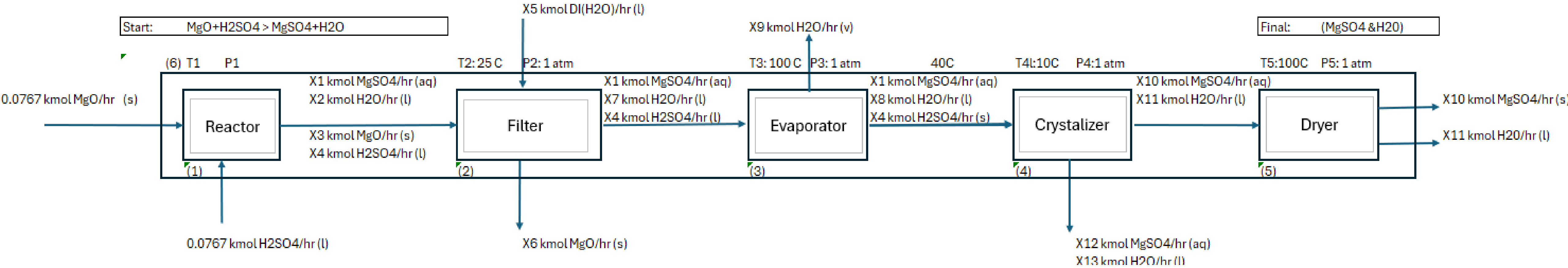




FLOW CHART BY TAYLOR



FLOW CHART


Start: MgO+H2SO4 > MgSO4+H2O
X5 kmol DI(H2O)/hr (l)
X9 kmol H2O/hr (v)
Final: (MgSO4 &H20)
(6) T1 P1
T2: 25 C P2: 1 atm
T3: 100 C P3: 1 atm
40C
T4l:10C P4:1 atm
T5:100C P5: 1 atm
0.0767 kmol MgO/hr (s)
Reactor
X1 kmol MgSO4/hr (aq)
X2 kmol H2O/hr (l)
X3 kmol MgO/hr (s)
X4 kmol H2SO4/hr (l)
Filter
X1 kmol MgSO4/hr (aq)
X7 kmol H2O/hr (l)
X4 kmol H2SO4/hr (l)
Evaporator
X1 kmol MgSO4/hr (aq)
X8 kmol H2O/hr (l)
X4 kmol H2SO4/hr (s)
Crystalizer
X10 kmol MgSO4/hr (aq)
X11 kmol H2O/hr (l)
Dryer
X10 kmol MgSO4/hr (s
X11 kmol H20/hr (l)
(1)
(2)
(3)
(4)
(5)
0.0767 kmol H2SO4/hr (l)
X6 kmol MgO/hr (s)
X12 kmol MgSO4/hr (aq)
X13 kmol H2O/hr (l)

ASSUMPTIONS

Assumptions:
1. reactor has 95% single pass conversion
2. filter has 95% purity when diluted with DI water
4. assuming 1.5 kmol H20 (DI)/h
5.assuming MgO fully dissolved in filter
6. evaporator at 100 Celsius, 30% of output by weight of H20 leaves evaporator
7. crystallizer 99% purity, assume steady state
8. exothermic reaction (reactor)
9. filter: mesh

Summary Table

Unit	Main Purpose	Phase In	Phase Out
Reactor	Chemical reaction (MgO + H_2SO_4)	Solid + Liquid	Liquid (solution) + minor solids
Filter	Remove insolubles	Liquid + Solids	Clear liquid + waste solids
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Crystallizer	Form $MgSO_4 \cdot 7H_2O$ crystals	Concentrated liquid	Solid + mother liquor
Dryer	Dry but preserve heptahydrate	Wet solid	Dry crystals (final product)

DEGREE OF FREEDOM

DOF: Molecular Balance

	Unit 1: Reactor
# unknowns	4(X1,X2,X3,X4)
# indep. Rxn	1
# indep. Species	4(MgO,MgSO4,H2O,H2SO4)
# other	1
DOF	0

DOF: Unit by Unit

	Unit 2: Filter	Unit 3: Evaporator	Unit 4: Crystalizer	Unit 5: Dryer	Unit 6:Overall
# unknowns	3 (X5,X6,X7)	2 (X9,X8)	4 (X12,X13,X10,X11)	2 (X10,X11)	7 (X6,X5,X9,X12,X13,X10,X11)
# indep	4 (MgO,MgSO4,H2O,H2SO4)	3 (MgSO4,H2O,H2SO4)	3 (MgSO4,H2O,H2SO4)	2 (MgSO4,H2O)	4(H2SO4,MgO,H2O,MgSO4)
# other	2	2	2	0	3
DOF	-3	-3	-1	0	0

CHAT GPT – MATERIAL BALANCE

Here's a comprehensive material balance across the major units (reactor, filter, crystallizer, and dryer) for producing **10,000 bags/month of Dr. Teal's Epsom Salt ($MgSO_4 \cdot 7H_2O$)**, assuming each bag weighs **3 kg** (total = 30,000 kg/month). This estimate includes flow rates (mol/h), phases, temperatures, and pressures for each unit, based on the typical process using **MgO and H_2SO_4**.

	Species	Phase	Flowrate (mol/h)	T (°C)	P (atm)
	MgO	Solid	169	25	1
	H_2SO_4 (98%)	Liquid	169	25	1
	Water	Liquid	1183	25	1
Reactor Out	$MgSO_4$ solution	Liquid	~169	80	1
Filter Out	$MgSO_4$ solution	Liquid	~169	80	1
Crystallizer Out	$MgSO_4 \cdot 7H_2O$	Solid	169	15	1
	Water (mother liq)	Liquid	—	15	1
Dryer Out	$MgSO_4 \cdot 7H_2O$	Solid	169	100	1
	Water vapor	Gas	—	100	1

MATERIAL BALANCE

Unit 1: Reactor		Other:	1) 95% single pass conversion			
		Limiting Reactant:	MgO (1:1)			
		Balance:				
	X3	Conversion rate:		0.003835 kmol MgO/hr		
		MgO: (con)=		0.072865		
	X4	H2SO4:		0.003835 kmol H2SO4/hr		
	X1	MgSO4:		0.072865 kmol MgSO4/hr		
	X2	H2O:		0.072865 kmol H2O/hr		

Unit 2: Filter		Other:	1) X5 = 1.5 kmol H2O/hr		(from solubility tables, 45.6g/100g @40C MgSO4 7H2O)	
			2) Filter removed all MgO (100%)		X5 @40C (min)	0.996807657
					^will assume increase of 1.5	
	X6	MgO:		0.003835 kmol MgO/hr		
	X7	H2O:		1.572865 kmol H2O/hr		

MATERIAL BALANCE

Unit 3: Evaporator

	<u>Other:</u>	1) temp @100 C	
		2) temp leaving @ 40 C	
		2) press @1 atm	
X8	H_2O:		1.069672657 kmol H_2O/hr
X9	H_2O:		0.503192343 kmol H_2O/hr

MATERIAL BALANCE

Unit 4: Crystalizer

	other:	1)temp @10 C		
		2) press @1 atm		
		3) concentration of MgSO4 7H2O		0.046246033
		4) assume H20 1%		
X10	MgSO4:		0.023396883 kmol MgSO4/hr	
X11	H2O:		0.010696727 kmol H2O/hr	
X12	MgSO4:		0.049468117 kmol MgSO4/hr	
X13	H2O:		1.05897593 kmol H2O/hr	

Unit 5: Dryer

X10	MgSO4:	0.023396883 kmol MgSO4/hr
X11	H2O:	0.010696727 knol H2O/hr

CHAT GPT – ENERGY BALANCE

Parameter	Value
MgO inlet flow	0.0767 kmol/hr
H_2SO_4 inlet flow (stoichiometric, 1:1)	0.0767 kmol/hr
Reaction conversion	95% (single-pass) → $MgSO_4$ = 0.072865 kmol/hr
H_2O inlet	1.573 kmol/hr
Vaporized in evaporator	0.502 kmol/hr
Water removed in dryer	0.1645 kmol/hr
Crystallized $MgSO_4 \cdot 7H_2O$	0.00176 kmol/hr
Heat of crystallization	-105.02 kJ/mol
Latent heat of water vapor	40.7 kJ/mol @ 100°C
ΔH of reaction ($MgO + H_2SO_4 \rightarrow MgSO_4 + H_2O$)	-57.9 kJ/mol
Output $MgSO_4$ (dry)	0.0235 kmol/hr

Total Energy Balance

Component	kJ/hr	MJ/hr
Reaction (exo)	-4218.9	-4.22
Evaporator (endo)	+20430	+20.43
Crystallizer (exo)	-184.8	-0.185
Dryer (endo)	+6700	+6.70
Net Energy	+22826.3	**+22.83 MJ/hr**

ENERGY BALANCE

Standard Enthalpy of Formation		
Compound	$\Delta H/\Delta t$	units
MgO	-601.6	kJ/mol
H2SO4	-909.3	kJ/mol
MgSO4	-1283	kJ/mol
H2O	-285.8	kJ/mol

Reactor

Single pass conversion 95%

Molar Flow Rate MgO 0.0767 kmol/hr

0.072865 kmol/hr

= -4218.9 kJ/hr

= -4.22 MJ/hr exothermic

Crystallizer

Output MgSO4	=	0.0235 kmol/hr
Liquid H2O Out	=	0.01068 kmol/hr
MgSO4*7H2O	=	0.00176 kmol/hr

From Perrys's Chemical Engineering Handbook

Heat of Solution MgSO4 (s)	=	-91.21 kJ/mol
Heat of Soln MgSO4*7H20	=	13.81 kJ/mol
Heat of Crystallization	=	-105.02 kJ/mol

= -0.185 MJ/hr

Exothermic

Cooling required

ENERGY BALANCE

Evaporator ASSUMPTION

Waters Latent Heat of Vaporization		2260 kJ/kg	@	100 DegC
water evap per hr	=	-1.87 kg/hr		
Total H2O Inlet	=	1.573 kmol/hr		
Water Vap Out	=	0.502 kmol/hr		
Temp ASSUMPTION	=	100 Deg C		
From Perrys's Chemical Engineering Handbook				
	=	40.7 kJ/mol		
	=	20.4314 KJ/hr	Endothermic	

Dryer

Output MgSO4	=	0.0235 kmol/hr		
Water Removed	=	0.1645 kmol/hr		
MgSO4*7H2O	=	0.00176 kmol/hr		

From Perrys's Chemical Engineering Handbook

Latent Heat of Vap H2O	=	40.7 kJ/mol	@	100 DegC
	=	91 kJ/mol		

Total Energy

Q	=	375.9 kJ/mol	
Q	=	8.834 MJ/hr	Endothermic
			energy intense

CHAT GPT – ECONOMIC ANALYSIS

Profitability	Total Revenue	60,480	$/year
	Total Costs	152,902	$/year
	Net Profit	**–92,422**	$/year

1. Epsom Salt - USP (Pharmaceutical Grade) - 50 lb Bag
   - **Price:** $32.50
   - **Price per kg:** Approximately $1.43/kg
   - **Note:** Ideal for those seeking pharmaceutical-grade Epsom salt in bulk quantities.
2. Amazon Brand - Solimo Epsom Salt Soak, Magnesium Sulfate USP
   - **Price:** $52.78 for 24 lbs (three 8 lb bags)
   - **Price per kg:** Approximately $4.85/kg
   - **Note:** Convenient resealable bags suitable for regular personal use.
3. Dr Teal's Unscented Epsom Salt, 19 lbs
   - **Price:** $36.99
   - **Price per kg:** Approximately $4.27/kg
   - **Note:** A popular brand known for quality, suitable for personal and therapeutic use. Mountain Rose Herbs +2

ECONOMIC ANALYSIS

	Item	Value	Units
Production Inputs	Operating Hours per Year	8000	hr/year
	MgO Feed Rate	0.0767	kmol/hour
	H2SO4 Feed Rate	0.0767	kmol/hour
	Salt Production Rate	18.9	kg/hour
	Annual Production	151200	kg/year
Revenue	Selling Price	400	$/ton
	Total Revenue	60480	$/year
Raw Materail Cost	MgO Cost	9888	$/year
	H2SO4 Cost	7219	$/year
	DI Water Cost	39	$/year
	Total Raw Materials	17146	$/year
Utilities and Other Cost	Energy Consumption per Ton	50	kWh/ton
	Electricity Cost	756	$/year
	Labor Cost	50000	$/operator
	Total Labor Cost	100000	$/year
	Maintenance Cost	10000	$/year
	Capital Investment	250000	$
	Amoritized Capital Cost (10 years)	25000	$/year
	Total Annual Operating Cost	402902	$/year
Profitability	Total Revenue	60480	$/year
	Total Costs	402902	$/year
	Net Profit	-342422	$/year

ECONOMIC ANALYSIS

Selling Price		Revenue		Net Profit	
0.4	$/kg	60480	$/year	-342422	$/year
1	$/kg	151200	$/year	-251702	$/year
1.5	$/kg	226800	$/year	-176102	$/year
2.5	$/kg	378000	$/year	-24902	$/year
3.5	$/kg	529200	$/year	126298	$/year
4.5	$/kg	680400	$/year	277498	$/year
5	$/kg	756000	$/year	353098	$/year

CHAT GPT ANALYSIS

- Chat GPT can struggle in aspects that include interpreting numbers, data, and advanced principles.
- Chat GPT is advanced is aspects of explanation and diagrams.
- If Chat GPT is used as more or a search engine, it can be quite successful, while if you have no background to give it, it may be incorrect.
  - An example being for the basis of this project, you would need the background of CHME 2220 to know if Chat GPT was incorrect or not.

THE PITCH

- Curiosity, Connections, and Creating Value
- We have shown you a similar process of Epsom Salt Production to others, but what is different?
  - Cost
  - Purity
  - Production Scale
- As a team we will strive to make sure our production will be done right the first time as well as make it cost effective as possible.

QUESTIONS/ THANK YOU!

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APPENDIX

Compound Name	Chemical Formula	Solubility in g/100 g H_2O at °C						Content of the total solution at 20 °C in %	Density of the total solution at 20 °C in %
		0	20	40	60	80	100		
Magnesium sulfate heptahydrate	$MgSO_4 \cdot 7H_2O$	30.05 (10 °C)	35.6	45.4	–	–	–	26.25	1.31