Corn to Ethanol Plant

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Project Objectives: Assess current line performance and design a plant for the production of ethanol from a corn feed based glucose solution with an annual design capacity of 30 Million gallons ethanol per year. Consider the effect of feedstock, reactor sensitivity to yield, and design choices on plant economics and environmental impact.

Ethanol from Corn Production Process: The current plant located in the “corn belt” of the US has been producing a corn based fermentation feed (as a glucose solution) that it then shipped via rail tanker to customers across the US that they then take and produce ethanol. Site management has decided to consider vertically integrating by adding on to the existing plant capabilities by producing the ethanol on site for shipment to ethanol/gasoline mixing points across the US to produce E85 gasoline.

Plant management has asked your team to assess two key aspects: 1) is the current process that takes corn through to the fermentation feed stream (Pre-Ferm process) optimized and 2) what will be the total cost to install process capability allowing the plant to produce, on-site, the fermentation based ethanol (Ferm. Process) at an annual capacity of 30M gals./yr.

Standard Fermentation Reaction Assumption:

$$\text{Glucose} \xrightarrow{Yeast} \text{2Ethanol} + \text{2Carbon Dioxide} \qquad (1)$$

<u>Pre-Ferm. Process Description/Information:</u>

The pre-ferm process is the current capability of the site. It consists of 6 parallel process trains all designed exactly the same but, as with any process, don’t have the same performance per process train. Your team has been asked to evaluate line # 4. The line is scheduled/runs 24X7 except for the annual 4 week maintenance shutdown.

Step 1 is to clean the raw corn, that has been de-husked prior to arrival at the plant, of various impurities (dirt, stalks, insects, etc.). The incoming raw corn has been dried and is stored in a silo. Your team has not had time to observe the cleaning step process equipment performance but you have been given summary data indicating that the cleaning step has a yield of 95% and the equipment has unplanned downtime of 25%. The feed rate of the bulk corn to the cleaning step is 104 kgs/min. The cleaned corn is stored in a small silo prior to use in the next step.

Step 2 is to take the clean corn and mill it to the desired particle size spec. required for subsequent processing. The milling of the corn is completed using a large hammer mill. The hammer mill also has a cyclone dust collector that collects any fines (dust collector material is discarded) from the process before exhausting air flow to the atmosphere. The yield of the milling step is 80%. Your team observed the milling operation for a 24 hour period starting at 8AM. The scheduled run (actual milling) time for the mill was 22hrs. Your team’s observation of the mill operation has yielded the following data:

8A-2P	Mill Running
2P-3P	Cyclone plugged/cleaned
3P-6P	Mill Running
6P-7:30P	Mill motor stopped/fixed
7:30P-3A	Mill Running
3A-5A	Screens need to be cleaning
5A-6A	Mill Running
6A-8A	Batch Change-Over

You have been told from the folks running the mill that this is typical run performance except that the change-over is typically 2-4 hrs since sometimes the hammers or screens in the mill need to be replaced/repaired. When running, the mill is feed 84 kgs/min cleaned corn.

Step 3 consists of two heated/agitated vessels that run together in a semi-continuous manner that convert the starches in the milled corn to glucose through a two step enzymatic reaction. The first agitated vessel (liquefaction) is charged with water, corn, ammonia, lime, and Alpha-Amylase then aged at temp. The liquefied solution is then fed to the second vessel (saccharification) were it is further converted to glucose completion using Glucoamlyase with acid addition to adjust pH. The output of the step is a 20 wt% glucose solution that is then fed to an agitated holding tank prior to shipping to the customer via tanker cars. It takes 1 kg. of corn feed into the step to produce 1.1 kgs of glucose in solution.

Your team observed the process for Step 3 and collected the following line performance data:

Data Collection Sheet
22-Jun-16
Pre-Ferm. Process - Line #4

Batch #	Process Cycle Time (min)	Set-up Time (min)	Change-over Time (min)
1	320	80	120
2	240	60	118
3	360	63	119
4	236	58	123
5	239	59	180
6	242	78	123
7	241	59	300
8	242	60	120
9	390	61	118
10	240	85	122

Each batch produced on average 28,800 kgs glucose

The output demand (accounting for the 4 week annual shutdown) for the Pre-Ferm process is 495 gpm (assumes all six lines producing equally to meet demand) of the 20 wt% glucose solution that is produced from Step 3. Assume a density of 1.1kgs/liter for the 20 wt% glucose solution.

Potential New Ferm. Process information:

Aqueous/Glucose Feed Stream Specifications:

1. 28 C, 1 atmospheric pressure
2. 20wt% glucose
3. 15wt% solids (inert cells and corn mass)

Yeast Feed Stream Specifications:

1. 28 C, 1 atmospheric pressure
2. 0.01 wt% of the glucose feed stream
3. Comprised of 30wt% yeast in water (assume yeast has no active role in ASPEN simulation)

Product Specifications:

Ethanol: >99.5 wt%

Utilities:

1. Steam: saturated at 8 bar and at 28 bar
2. Cooling water: 293 K
3. Process water: 293 K

Database: ASPEN PLUS has the base components within its database.

You should use the Wilson property method for this simulation.

General Project Guidelines:

It is expected that your design will follow the general, best-practice process design guidelines that have been presented in this class. You will need to use the library as a resource for finding relevant information regarding chemistry, thermodynamics, pricing, etc. The content of your overall analysis of Line #4 and design for the new facility should include but is not limited to:

Pre-ferm. Process

- A performance analysis of Line #4 including takt time, step run rates, process constraints etc. Does the process meet demand and if it does not then define where and what are the constraints along with recommendations to improve in order to meet demand. Are there any additional improvements that would be recommended for the process? **Do not simulate this part of the process in ASPEN.**
- Providing a clear, complete, and labeled Block Diagram for both the Current Condition and Target Condition with all relevant data for the process steps.

For the Ferm. Process only

- Formulating an optimized preliminary design of a plant to make fermentation based ethanol from a glucose feed solution. The plant is considered to be part of the existing manufacturing facility so you do not need to estimate costs associated with land, site preparation, etc. State all assumptions needed for design capacity, unit operation selection, etc. ASPEN simulation is the basis for this part of the project assessment.
- Providing a detailed overview of relevant safety and environmental information and concerns which will impact the manufacturing process and operations.
- Providing a clear, complete, and labeled Block Diagram and Process Flow Diagram of the optimized process with all required conventions employed and information presented. For the applicable diagram, you must include all equipment and the location of major control loops.
- Providing complete material and energy balance calculations for the process. Display all computed values in a clear stream flow table that includes T, P, total flow rate in kg/hr and kmol/hr, component flow rate in kmol/hr, and phase for each process stream
- Sizing and costing of all major items of the process including storage vessels, reactors, separation systems, mixers, as well as important pumps, compressors, and heat exchangers. Also include details on the internal construction of the major equipment. Do not explicitly treat piping, valves, instrumentation, etc. in your design (these are accounted for in the major equipment). Create a detailed list of new equipment to be purchased including size, costs, and materials of construction.
- Identifying complete design specifications for at least one major process operation step using ASPEN PLUS (ex. Distillation, reactor, compressor, condenser) As an attachment, you must provide supporting documentation to detail what was simulated, etc.
- Recommending at least one process modification for improved production based on simulation results
- Computing the Total Capital Investment
- Computing and estimate of the annual Cost of Manufacture (i.e. the annual operating cost) not including depreciation.
- Performing an economic evaluation of the optimized process including ROI, PBP, and a 12-year NPV (includes construction period). Use the following
    - After-tax annual internal hurdle rate (interest rate) = 9%
    - Depreciation = straight-line depreciation at 10%/yr
    - Marginal taxation rate = 37%
    - Construction period = 2 years
    - Project plant life = 10 years after start-up
- Performing a sensitivity analysis for various pricing scenarios – typical, unfavorable, and favorable – for key cost and revenue items (e.g. raw materials, utilities, usable by-products, etc.)
- Providing a business plan on the plant viability and determining under what conditions it will be viable.
- Determining the environmental impacts associated with different design alternatives.

Calculations may be performed by hand and/or spreadsheet and must be provided as attachments to you report; simulation results are treated separately, as noted above. Also utility systems are not to be explicitly design. You may assume that steam, cooling fluids, electricity, etc. are available for use and that they have the “present-day” costs associated with them.

The format of the report should follow the structure provided on the “Report Guide” slides provided during class. You must also include a detailed list of references used in formulating your process, you r assumptions, actually market data, etc. Attachments are allowed and must be listed as part of the Table of Contents.

Note: This is NOT a collaborative effort between groups. The work performed and presented by your group MUST be unique. You may ask the instructor specific questions as they relate to the process and project expectations. It will be at the instructor’s discretion to provide additional guidance/direction to the class.

The process steps are intentionally left vague. Each group is expected to create a base case model with the information. For example use of DSTWU versus RADFRAC based system. Further research should be conducted to further flush out at least one unit operation. Further process details will enhance the quality of the final project.

Deliverables:
Project Memo I (due October 3, 2018: 20%)
Project Memo II (due November 4, 2018: 20%)
Final Report and Presentation during Finals week (60%)

Project Memo I Expectations
Overall professionalism (Appropriate formatting: abstract, objectives, references, timeliness, quality, etc (15%)

I. Desired Project Outcome (30%)
    a. State the problem to be solved - what does success for this project look like?
    b. Identify responsibilities, timing, and milestones
        i. Responsibility Matrix
        ii. Gantt Chart
II. Background and Perspective (25%)
    a. What is the context for corn based ethanol production?
    b. What standards or regulations need to be considered in the production of corn based ethanol?
    c. Provide appropriate material safety and environmental information
    d. Describe any environmental, social, and ethical issues, as well as sustainable development goals that must be addressed.
III. Project Scope (25%)
    a. Block flow diagram of the Pre-Ferm. and Ferm processes
    b. Hand calculations for material balances of feed and products
    c. Any relevant process performance indicators for the Pre-Ferm process Line #4
IV. References (5%): provide appropriate references in the text and a bibliography in appropriate format at the end of the memo.

Project Memo II Expectations

Overall professionalism (Appropriate formatting: abstract, objectives, references, timeliness, quality, etc (10%)

I. Project Scope (50%)
   a. Ferm. Process Base case simulation
      i. Process flow diagram
      ii. Stream summaries (in tabular form with analysis)
      iii. Summaries of major unit operations (in tabular form with analysis)

II. Proposal for plant modification (25%)
   a. What anticipated future events may impact the results of this project?
   b. Recommendation and reasoning addressing cost, efficiency, energy, and environmental impacts.
   c. Preliminary block flow diagram

III. Process Analysis of the Pre-Ferm process (15%)
   a. Process flow with perf. indicators
   b. Demand vs process step analysis
   c. Constraint analysis and recommendations

IV. References: provide appropriate references in the text and a bibliography in appropriate format at the end of the report.

Final Report Expectations

I. Title Page

II. Executive Summary (<1 page, 5%)
   a. State project objective and justification
   b. Summarize the proposal

III. Technical Design: Performance analysis of the **Pre-Ferm. Process**
   a. Current Condition (5%)
      i. Takt Time or demand rate required
      ii. Line performance (rates, uptime, yield, etc.) with constraints indicated
   b. Process Discussion (10%)
      i. Present key recommendations for process improvement
      ii. New recommended process (Target Condition) to meet demand
   c. Recommendations beyond Target Condition (5%)
      i. Improvements to the process beyond meeting demand

IV. Technical Design: Details of the proposed design for the **Ferm. Process** to produce ethanol
   a. Design Basis (5%)
      i. List of feed characteristics
      ii. List of product rates and specs
      iii. Parameters governing design of key equipment
      iv. Relevant constraints, design guidelines, process limits, etc
      v. Environmental, social, and ethical issues, as well as sustainable development goals that must be addressed
   b. Process Discussion (10%)
      i. Present key findings from process simulations

ii. Process flow diagrams describing major equipment with important design and operational considerations
iii. Utility balance

c. Stream Data Sheets (5%)
    i. Heat and material balances corresponding to streams on the PFD's
    ii. Calculations for total energy consumed by the plant
    iii. Table of all stream attributes including mole fractions, total molar flow, total mass flow, temperature, pressure, and vapor fraction
d. Economic Assessment and Business Plan: (15%)
    i. Feedstocks costs
    ii. Total capital investment
    iii. Operating costs
    iv. Expected maintenance costs
    v. A discounted cash flow analysis based on a selling price of gasoline grade ethanol product with an after-tax internal rate of return of 10% for 10-yr analysis. Sensitivity analysis may be appropriate.
    vi. Overall project assessment based on multiple financial measures
    vii. Competitive analysis
    viii. Design and development plan
    ix. Operations and management
e. Environmental Assessment (10%)
    i. Qualitative life cycle assessment of corn based ethanol production
f. Summary of proposed recommendations for future application (5%)

V. References

VI. Appendices: Relevant example calculations and PFD alternatives

Written report quality, professionalism, and completeness (5%)
Oral presentation (15-20 minutes) (15%)

You must also provide a detailed listing of the individual contributions of each group member (Gantt chart will suffice). Your team may also receive a team performance feedback survey during the project. You will need to submit both hard and electronic copies of your project materials and presentation. Electronic copies must be e-mailed to the instructor prior to your presentation.