Optimizing a Beer Brewing Process with Custom Compounds and Recycle Streams in ASPEN Plus

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- OUR GOAL -

Establish and optimize a beer brewing process that utilizes recycling streams to reduce CO_2 emissions and conserve energy

BACKGROUND

- Beer brewing is an extensive process, requiring many steps to turn barley, hops, yeast, water, and other inputs into malt, wort, and eventually, beer.
- This project focuses on designing a continuous beer brewing process that models key steps such as barley drying, mashing, fermentation, and packaging in Aspen Plus. Emphasis is placed on energy integration, resource recovery, and economic feasibility to develop a scalable and environmentally conscious solution.
- Throughout this project, two major proposed alternatives to the standard brewing process were evaluated and modified for implementation: the use of a recycle stream for CO_2 capture and reuse, and the use of a recycle stream for thermal energy in the form of water vapor for the conservation of energy and reduction of heat utility.

PROCESS OVERVIEW

Soaking Tank: Soak barley in water → Germination Chamber: Allows barley to sprout → Dryer: Stop germination and dry malted barley

Mill: Crush malted barley into grist → Mash: Mix grist with hot water, starches converts to sugars → Lauter: Seperate wort from spent grains

Boiler: boil wort for flavor and sterilization → Separator: Filters solids from boiled wort → Fermenter: yeast mixed with wort, sugar converts to alcohol

Cold Crashing: Quickly cooling beer to enchance clarity and feel → Conditioning/Aging: Allow beer to rest to enhance flavor → Filtration: Remove suspended yeast and leftover particles

Carbonation: Add CO_2 to add to taste and mouthfeel → Bottling: prepare beer for preservation, transportation, and sale

PROCESS FLOW DIAGRAM

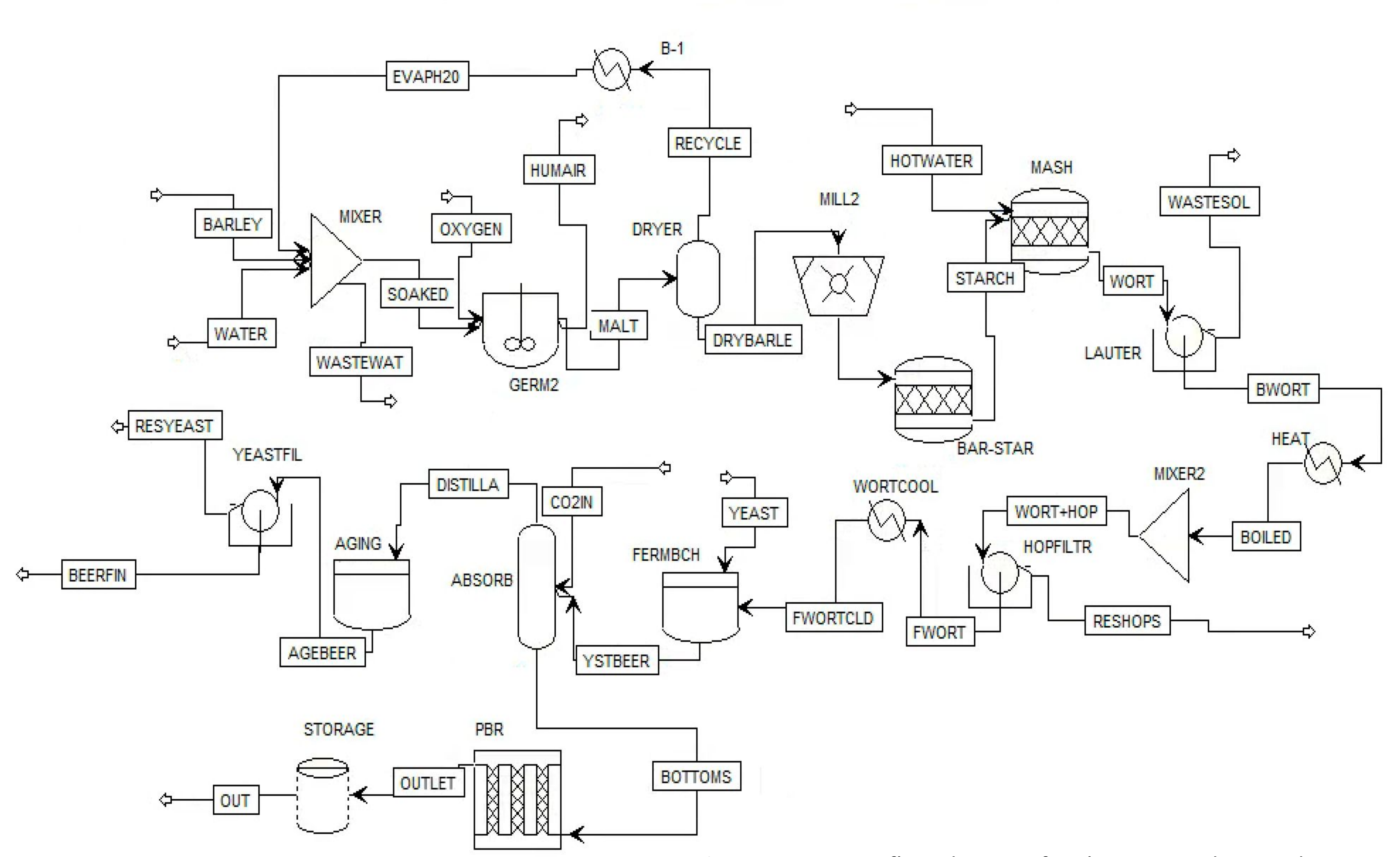

Figure 1: Process flow diagram for the system designed in Aspen

ALTERNATIVES & SENSITIVITY ANALYSIS

- We implemented two recycle streams into the typical beer brewing process, one for carbon capture and recycling and one for heat utility and water reduction.
  - **Carbon Capture**: Allows for the storage and reuse of CO_2 by collecting CO_2 from fermenter output, and cycling it through an adsorber column and packed bed reactor.
  - **Heat Utility/Water Input:** Captures and cools waste water vapor from the dryer, cycles through a heat exchanger and use it to preheat the incoming water used in the soaking stage. Reduces the need for freshwater and conserves energy by utilizing the latent heat of the water vapor.

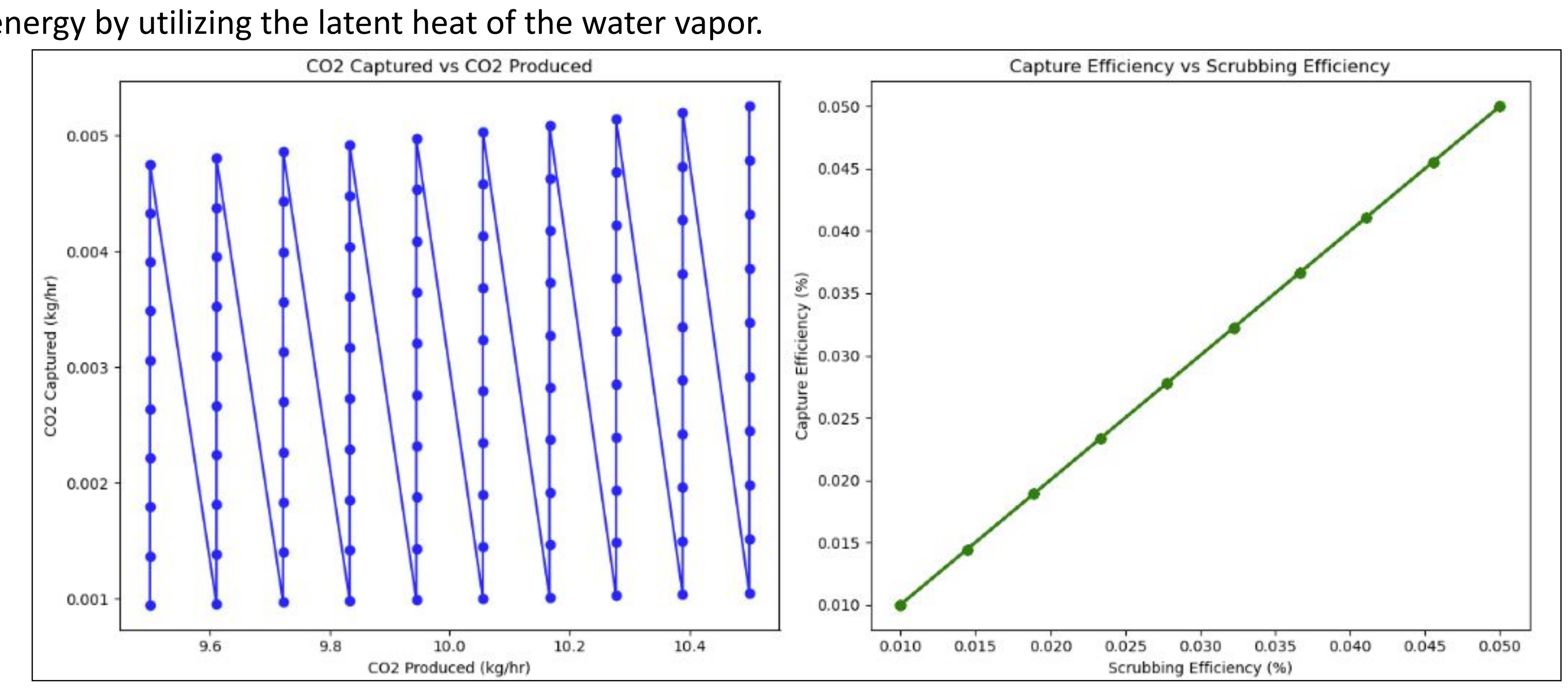

Figure 2: Sensitivity analysis of CO_2 capture performance in the beer brewing process. .

REACTIONS OF INTEREST & KINETICS

- The primary reaction during fermentation is the **conversion of glucose into ethanol and carbon dioxide**: $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$
- **Monod Kinetics Model** (for growth rate of yeast): $r_s = r_{s,max} * S / K_s + S$
- **Ethanol & CO_2 Production** (rate produced during fermentation from glucose): $r_e = Y_e * r_s$, $r_{CO2} = Y_{CO2} * r_s$
- **Biomass Growth** (Yeast): $r_x = \mu_{max} S / K_s + S$
- **Luedeking-Piret model** (for product formation): $r_e = \alpha X + \beta r_x$
- **Starch Hydrolysis** (Mashing): $(C_6H_{10}O_5)n + nH_2O \rightarrow nC_6H_{12}O_6$

DESIGN OUTPUTS

Material Flow Calculations

Stage	Input Flow Rate	Output Flow Rate
Drying (Barley)	3.75677 L/min (dry bar)	149,350 L/min (evap H2O)
Mashing	2.47481 L/min (starch) + 0.347395 L/min (H2O)	11.8266 L/min (wort)
Lautering	11.8258 L/min (out as wastewater)	≈0.00828 L/min (to next step)
Fermentation	0.00205 mol/s (wort)	0.00205 mol/s (beer)
Conditioning Output	0.00205 mol/s (beer)	0.000155 mol/s (aged beer)

CO_2 Capture and Reuse Efficiency

Parameter	Value
CO_2 Produced	9.99995 kg/hr
CO_2 Captured	0.00156 kg/hr
CO_2 Capture Efficiency	0.015%

TEST RESULTS (WHAT-IFS, BELLS AND WHISTLES)

What-If: Water Recycle Stream

Parameter	Before Recycle	After Recycle	Reduction (%)
Water Input (mol/s)	1.07	1.03	3.74%

Observations
- Captured water vapor from dryer.
- Recycled via heat exchanger back to soaking tank.
- Lowered water usage and reduced heating utility.

Bells & Whistles: Innovation Feature 1

CO_2 Scrubber System
- Scrubs CO_2 from fermenter off-gas using a packed-bed absorber.
- Captured gas is compressed and reused for carbonation.
- Reduces greenhouse emissions and external CO_2 purchase.

What-if: Multi-Stage Drying Efficiency

Stage	Temp (C)	Time (min)	Final Moisture (%)	Energy Use (kJ/kg H2O)
High Temp	70	40	7	1700
Low Temp	50	50	5	1250
Total	-	90	5	2950

Observations
- Two-phase drying reduced moisture to 5%, better than single-stage 70°C drying (10%).
- Higher product quality with lower risk of starch damage.
- Slightly higher energy use, but improved performance and enzyme preservation.

Bells & Whistles: Innovation Feature 2

Water Chemistry Control
- Adjusting mineral content (Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}) for:
  - Enzyme optimization in mashing.
  - Flavor tuning of final beer.
- Minerals added directly in Aspen feed stream.

CONCLUSIONS & RECOMMENDATIONS

Key innovations included:
- Enzyme-driven hydrolysis and Monod-based fermentation kinetics
- Recycle streams for water recovery (reducing input by ~3.74%)
- Heat exchanger networks to lower utility demands
- CO_2 capture for reuse in carbonation

Recommendations for future development:
- Improve CO_2 scrubbing efficiency
- Incorporate mineral composition control for flavor consistency
- Explore by-product valorization (e.g., animal feed, biogas)
- Add advanced process controls and predictive analytics
- Consider more specialized brewing simulation software