TEAM M020

Design Of a Small-Scale Biorefinery for Sustainable Valorization of Spent Coffee Grounds in Saudi Arabia

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ME ISE 3 CHE

Introduction/Background

Problem Statement

The increasing consumption of coffee in KSA generates large quantities of spent coffee grounds (SCG), which are typically disposed of in landfills, leading to environmental impact and loss of valuable biomass resources.

Objective

A compact batch pyrolysis reactor that converts SCG into biochar under controlled, oxygen-free conditions, with a scalable design for industrial-level **Key Constraints**

- Maximum temperature ≤ 550 ℃
- Vent pipe always open (5–15 mm, 5 cm length)
- Ceramic band heater, 60 mm × 150 mm, rated ≤ 650 C
- External surface temperature < 150 ℃
- workflow limited to 3 assembly stages (input-prosses-output)

Key Specifications

- Biochar yield = 15–25% with batch size = 0.4-0.7 kg
- Nitrogen purge (0.5–1.0 L/min)
- Reactor OD = 150 mm, with thickness = 4 mm.
- Feed Basket OD = 89 mm, MOC = SS.
- Heating rate: 10–30 ° C/min
- Digital Optimization with accuracy ≥ 85%
- Unit cost ≤ 2.5 SAR/kg, ROI ≥ 15%
- Discrete-event simulation 1 ton/day with resource utilization >75%.

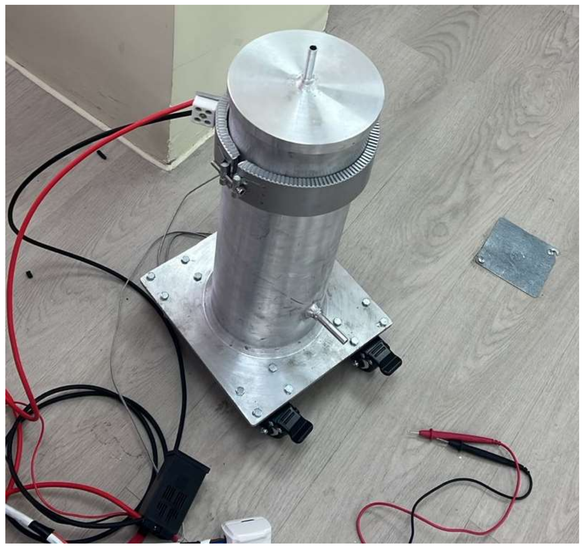
Prototype Design

System Description

- Batch pyrolysis reactor
- Nitrogen inlet (inert operation)
- Vent system (pressure safety)
- Insulation (thermal protection)
- PID controller

Design Highlights

- Safe operation (inert + vented system)
- Ceramic heater bands as a source of heating
- Compact and scalable design



Testing/Validation

CHE discipline:

- Maximum Reactor Temp = 550 ℃ Met using Aspen Plus
- Vent pipe always open 10 mm, L = 5 cm . Met
- Biochar yield = 20.4%. Met using Aspen Plus
- Purge N_2 gas at 0.8 L/min. Met using Aspen Plus

ME discipline:

- External surface temperature < 28.59 ℃. Met using Ansys.
- Ceramic heater bands 60 mm × 150 mm. Met Off-shelf
- Reactor OD = 150 mm, thickness = 4 mm Feed Basket OD = 89 mm, MOC = SS. Met from reactor geometry
- Heating rate 27 C/min. Met using Ansys.

ISE discipline:

- Workflow limited to 3 assembly stages. Met by 6 sigma principle.
- Optimization model accuracy, = 86.7%. Met using Excel Solver.
- Unit cost = 1.368 SAR/kg, ROI = 50.7 %. Met using Excel Solver.
- Discrete-event simulation 1.16 ton/day with resource utilization = 90.4%. Met using ARENA.

Conclusion

- Biochar yield is obtained
- Reactor operates safely under inert and controlled conditions
- System is energy-efficient and economically feasible
- Design is scalable to industrial-level production (≥1 ton/day)
- Supports sustainable waste valorization and circular economy in Saudi Arabia.

Recommendations

- Using Argon instead of Nitrogen to enhance the conversion
- integrate a heat exchanger at outlet to increase thermal efficiency
- Standardize operating procedures to reduce viability between batches

Total cost: 2437 SAR