Improving the Sustainability of Coffee Manufacuture Using Membrane Processes

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Invited Seminar

U.S. Environmental Protection Agency

Building Sustainable Organizations through Professional Development

New York, NY

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Introduction

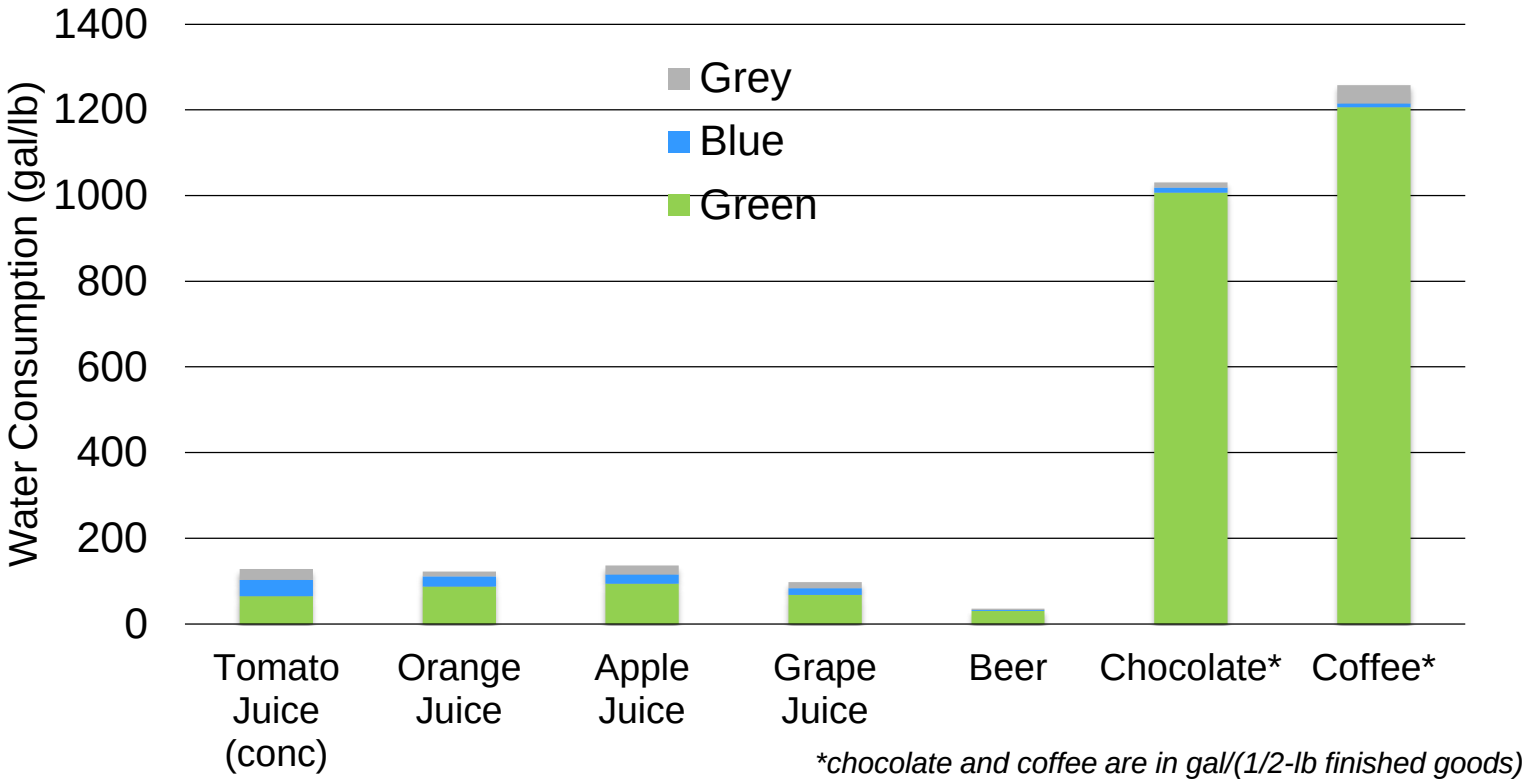
- Investigation of water recovery and sustainable manufacturing in collaboration with Nestlé USA Freehold, NJ coffee plant
  - EPA P2 Program – Region 2
- Engagement of Rowan Engineering Clinic student team
- Opportunities for water reuse from high volume of discharged wastewater
  - Water recovered used for utility generation
- Comparative green design study of water recovery and waste reduction strategies

Rowan Engineering Clinics

- Modeled after medical schools
- Student-faculty problem solving teams
- Applied research, development, design
- Partnership: Industry, Federal/State Agency, Foundation
- Multidisciplinary (Engineering, Sciences, …)
- Year or multi-year projects
- Junior & Seniors and Graduate students



Water Use in Crop-derived Products



**chocolate and coffee are in gal/(1/2-lb finished goods)*

- Water use per product is high in agricultural crops
- Nearly all water is “green” water, from rain; much less is the water for manufacturing (but still significant)

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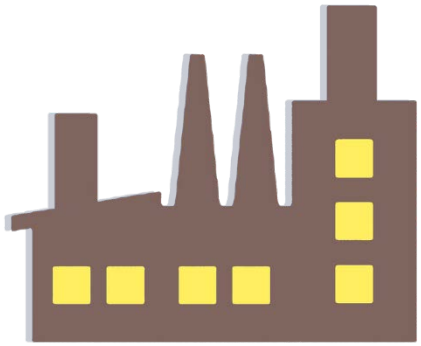
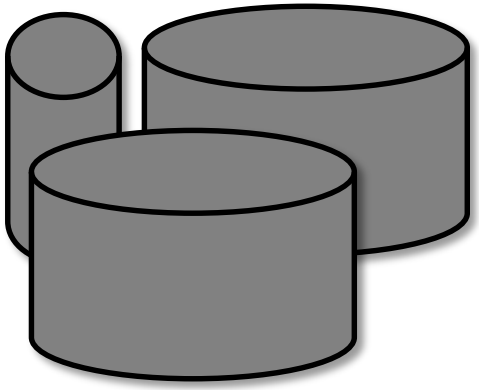
Mekonnen, Hoekstra, *Hydrol Earth Sci.* 15, 1577-1600, 2011

Water Use in Coffee Manufacture

Green coffee crop irrigation and processing



Soluble (Instant) coffee manufacturing steps

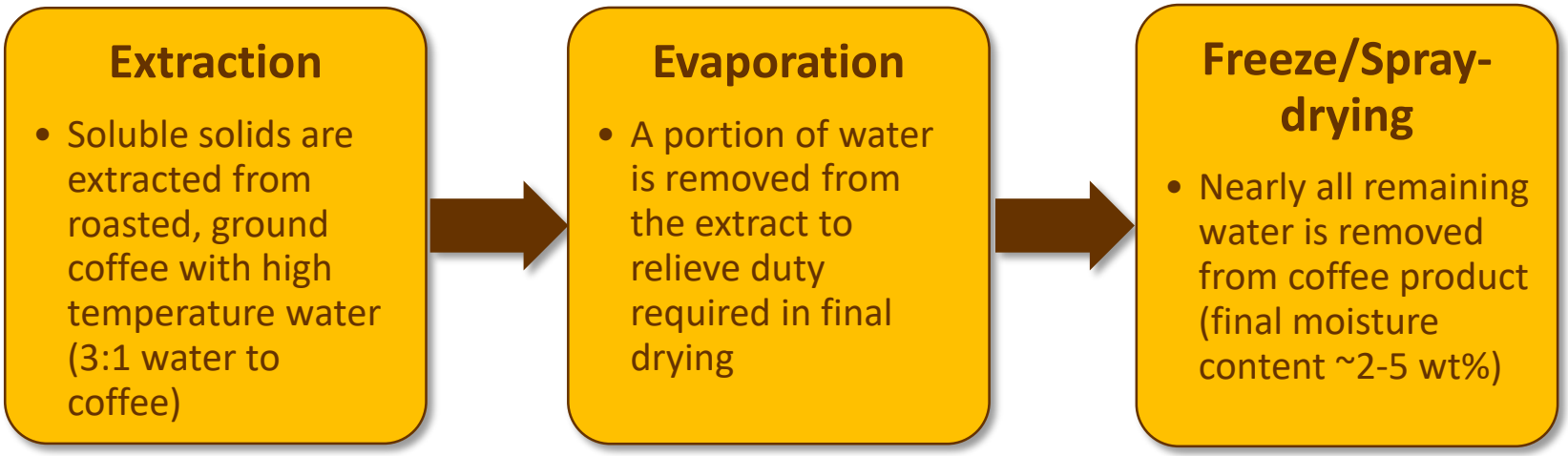


Wastewater discharge and treatment

Clarke and Macrae, *Coffee Vol 2: Technology*, New York: Elsevier, 1987.

Soluble Coffee Manufacture Water Use

- Highly water intensive processes required; essentially no water in finished product
- Water used in processing of coffee; process heating/ cooling; plant utility generation; plant maintenance
- High amount of wastewater generated
- As much as 4 gal of water per pound soluble coffee



Humbert, Loerincik, Rossi, Margni, Jolliet, *J. Cleaner Production,* 17, 1351-1358, 2009

Water Recovery from Wastewater

- Coffee wastewater has a complex nature
  - Aroma and flavor constituents
  - Constituents from other processes at factory
  - Suspended and dissolved solids
  - Inorganic and organic constituents
  - Light to dark brown color
  - Variable concentrations depending on daily production

Representative Waste Stream		
COD (mg/L)	Turbidity (NTU)	Conductivity (µS/cm)
1,140	22	940

Wisniewski, Savelski, Slater, *Water Env Technol, 30, 56-58,* 2018

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Approach for Case Study

- Evaluate current process
  - Water use and wastewater generation
- Provide estimates based on a projected plant operation
- Scale-up from laboratory study
- Assess proposed recovery process(es)
  - Environmental and economic
- Recovered water for utility generation in cooling tower operation or for other ancillary uses at factory

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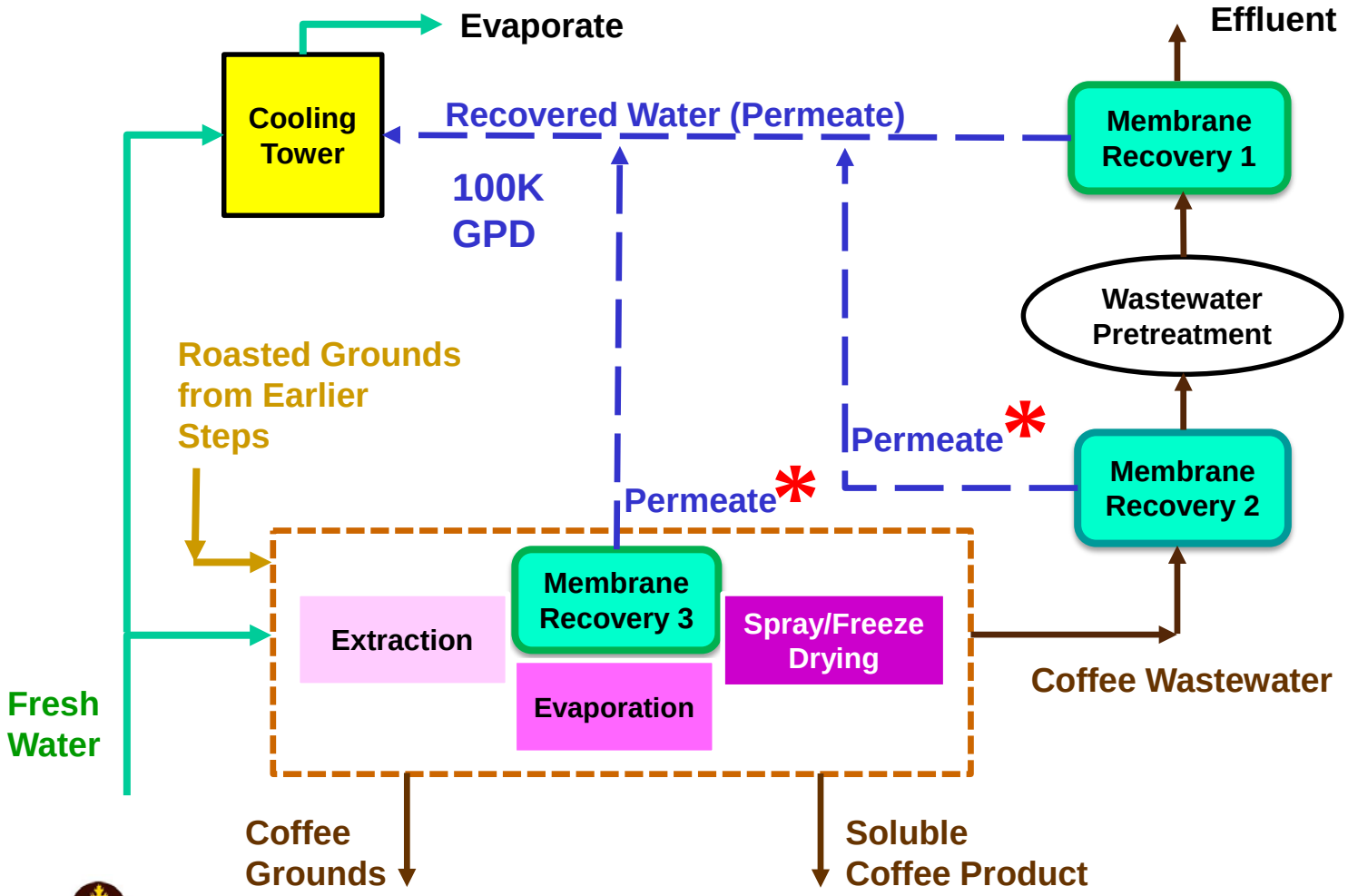
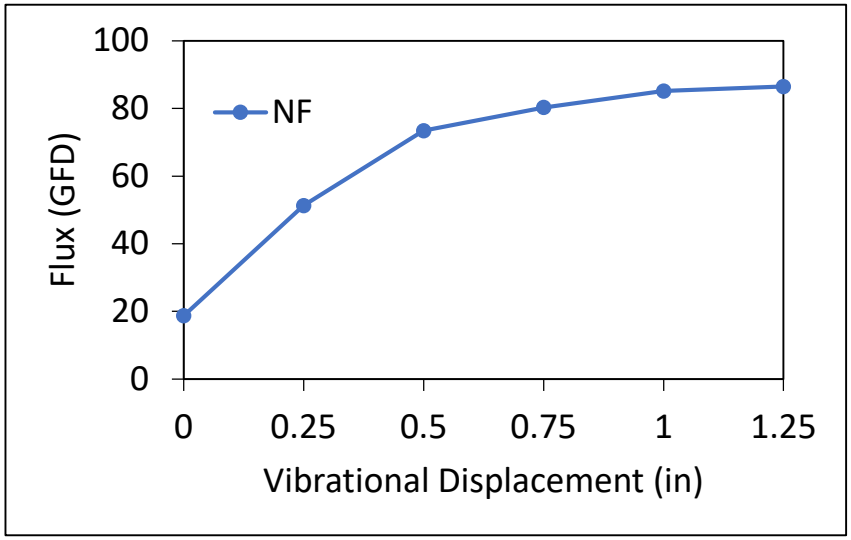
Water Recovery Options



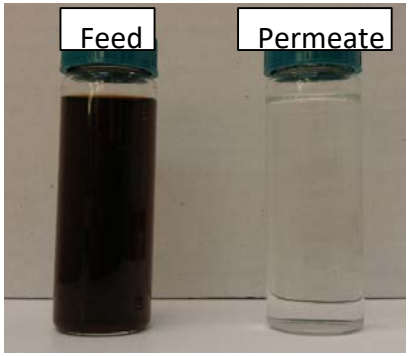
Vibratory Membrane Separation

- Vibratory Shear Enhanced Processing (V-SEP)
- Flux enhancement and stabilization
- Previous screening: RO→MF
- Lab-scale unit; data for scale-up
- Preliminary tests show flux enhancement
  - Nanofiltration: 4x



Nanofiltration, Nanostone NF4, ΔP = 350 psig, T = 25°C, Str A

V-SEP L-101, New Logic Research, Inc

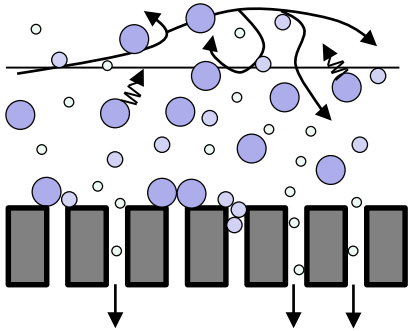


Wisniewski, Slater, Savelski, *Clean Tech Environ Policy, 20, 1791-1803,* 2018

Vibratory Membrane Basics

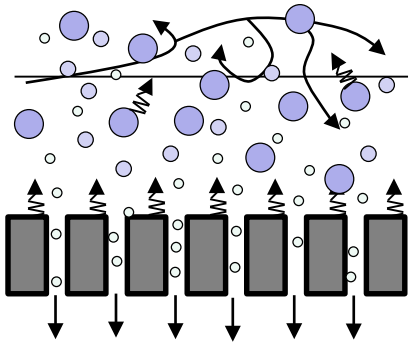
- Useful when processing waste streams with fine suspended matter and colloids
- Vibration at the membrane surface can generate shear rates an order of magnitude greater than crossflow
- 55 Hz and 80,000 sec^{-1}
- Surface fouling and inner pore fouling can be minimized
- Enhanced flux performance is achieved without significant degradation
- Enhanced flux stability

Cross-flow filtration



Permeate

V-SEP

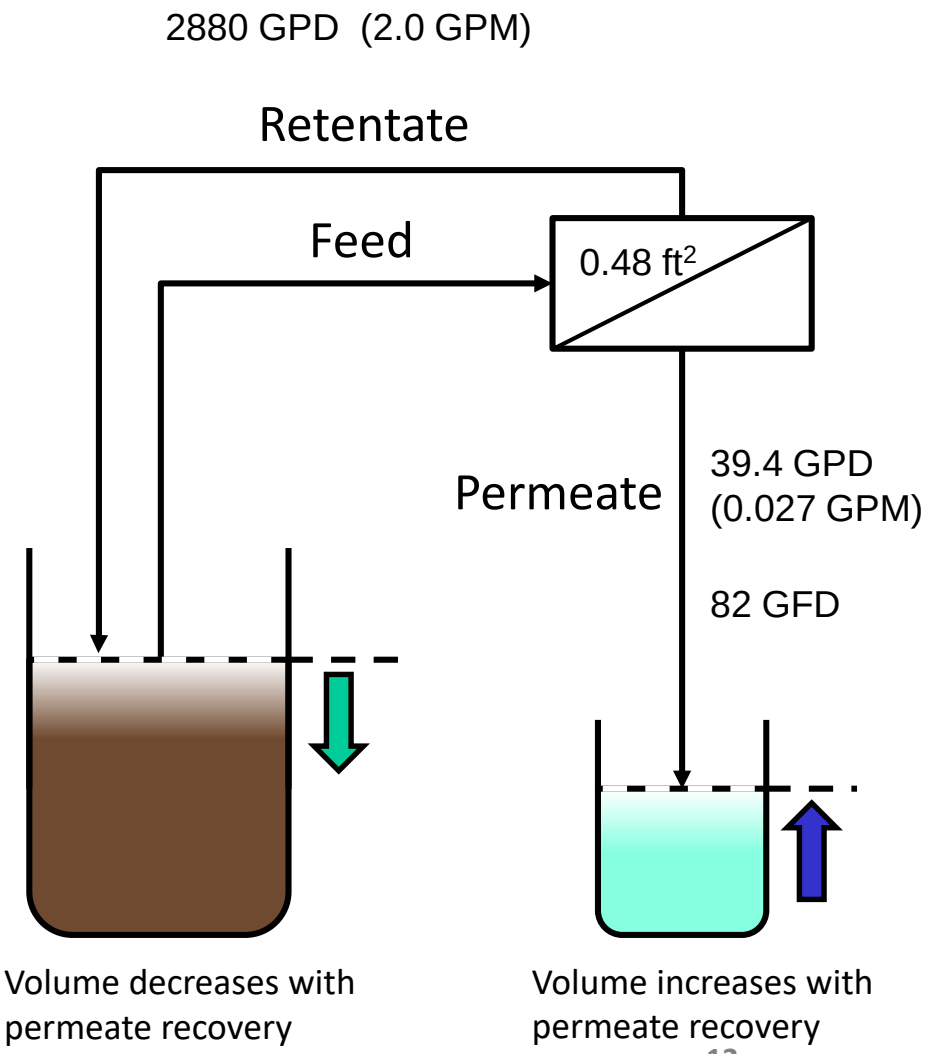


Permeate

New Logic Research Inc., 2016, http://www.vsep.com/technology/index.html

Scale-up Approach – High Recovery

- Recovery of permeate from wastewater in unsteady operation of lab system
- Exposes membrane to higher concentrations
- Simulates high water recovery operation of a commercial-scale unit
  - >80% overall recovery
- Scale-up design protocol for a projected plant operation



High Recovery Study

Permeate Parameter	Recovered Permeate†
Flux @ 80% recovery (gal/ft^{2}day)	108†
COD (mg/L) (Rejection)	524 (54%)†
Turbidity (NTU) (Rejection)	<1 (>99%)†
Conductivity (µS/cm) (Rejection)	241 (74%)†

- Using scale-up "design protocol", lab data at sequentially increasing feed concentration simulates overall commercial-scale operation
- All values are "bulk-average" permeate at 80% overall recovery and average flux
- COD, conductivity, turbidity are in-spec for reuse

† *NF Membrane @ ΔP = 350 psi, T = 25 °C, 1 in vibrational displacement*

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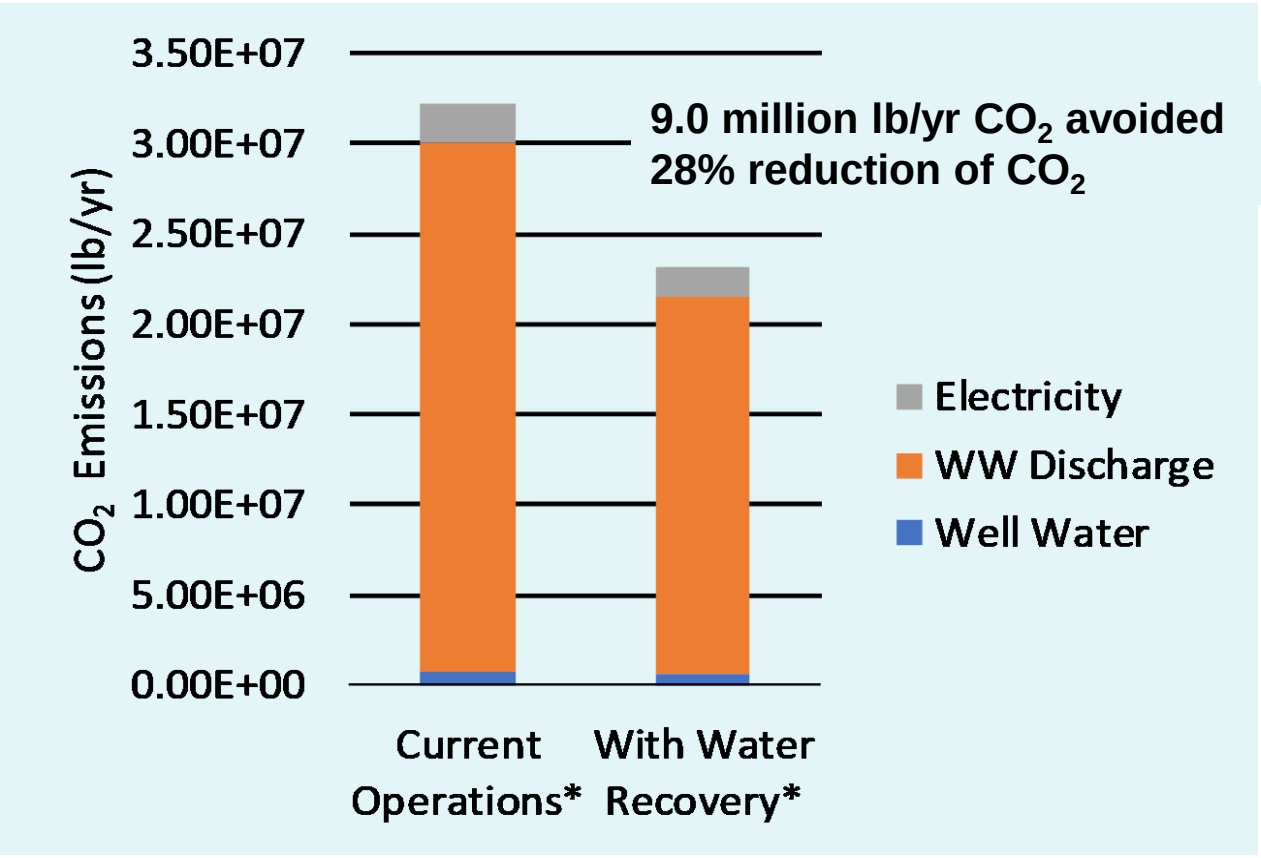
Estimated Life Cycle Emissions Reduction



SimaPro® v.8 and information provided from industry/utilities sector

- LCEs are dominated by nonhazardous (NH) wastewater disposal
- Reduction in electricity required from on-site aeration blowers offset by V-SEP electricity req'd
- Further reduction of NH wastewater disposal is needed for additional emissions reductions

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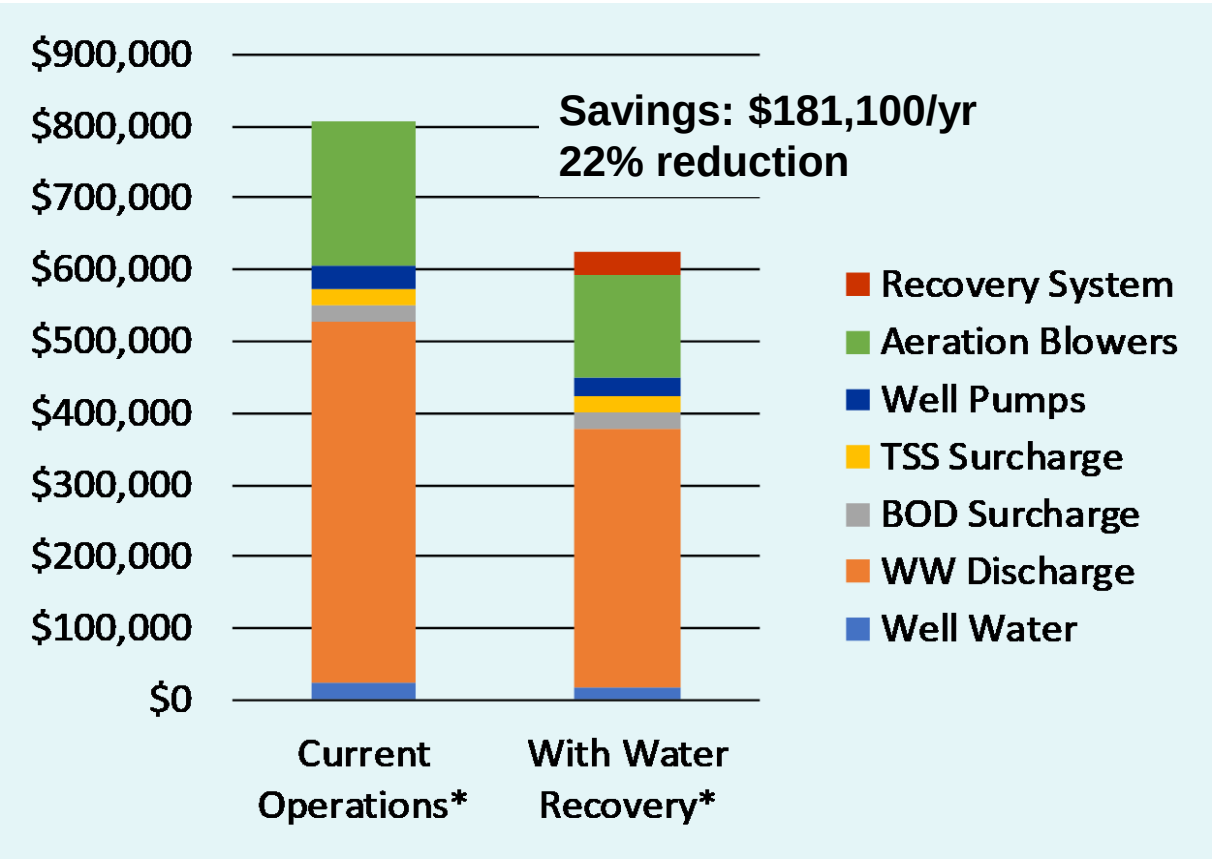
*Based on a projected plant operation

Estimated Annual Operating Savings



- Operating cost savings mainly from nonhazardous (NH) wastewater disposal
- Reduction in electricity required from on-site aeration blowers & well pumps offset by V-SEP electricity req'd
- Greater reductions in freshwater savings in other parts of country

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*Based on a projected plant operation

Summary - Scaled-up Design

1-Module i84 V-SEP System

- 80% Recovery (100K GPD)
- Membrane area: 1,400 ft^2
- Plant footprint (with skid and metering station)
  - 10.1 ft x 17.1 ft (170 ft^2)
- Electricity requirement
  - 185,000 kWh/yr
- LCE reduction 28%
- Payback time 2.7 yr

From New Logic Research, Inc.
http://www.vsep.com/products/i84.html

Coffee Extract Concentration

- Supplemental project focused on extending existing work to other coffee manufacturing areas
  - Coffee extract pre-concentration before spray/freeze-drying (final drying step)
  - Opportunity to save energy in soluble coffee processing and water recovery

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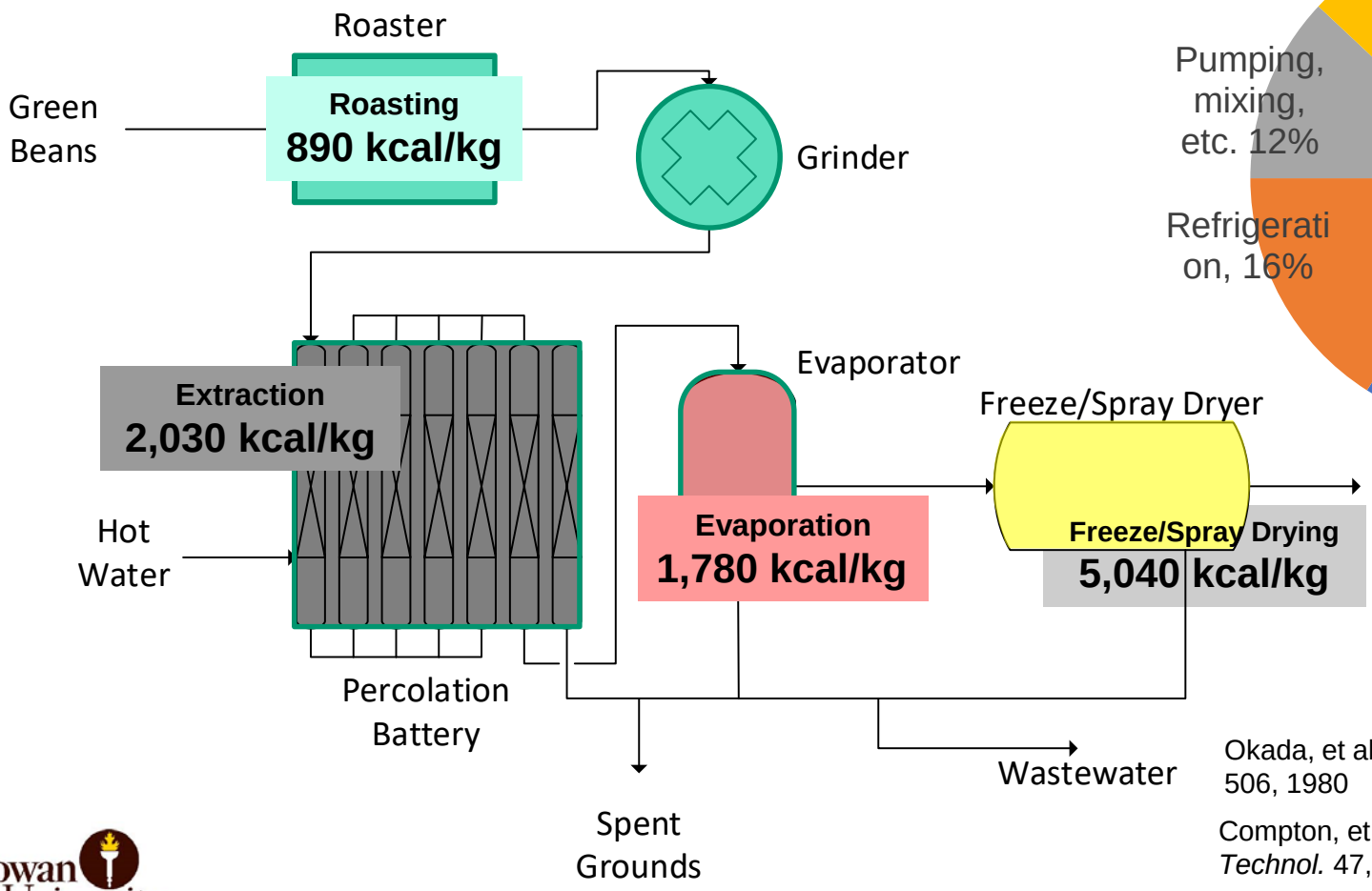
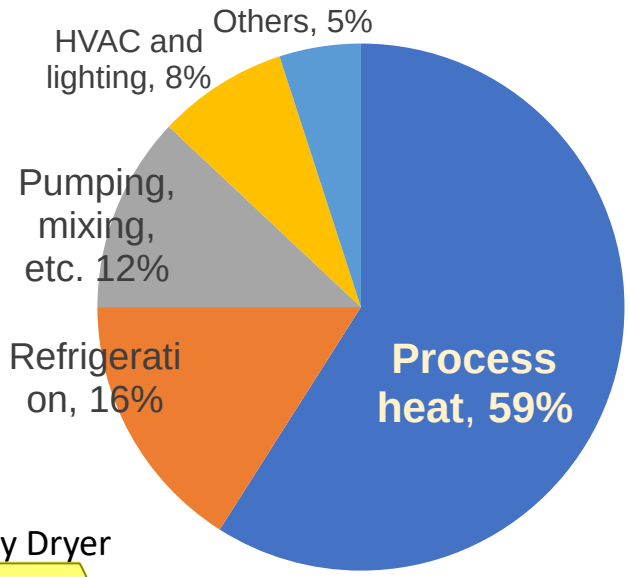
Energy Consumption of Soluble Coffee Production

Energy Consumption for 1 kg Soluble Coffee Produced



Energy Consumption in Food/Beverage Industries

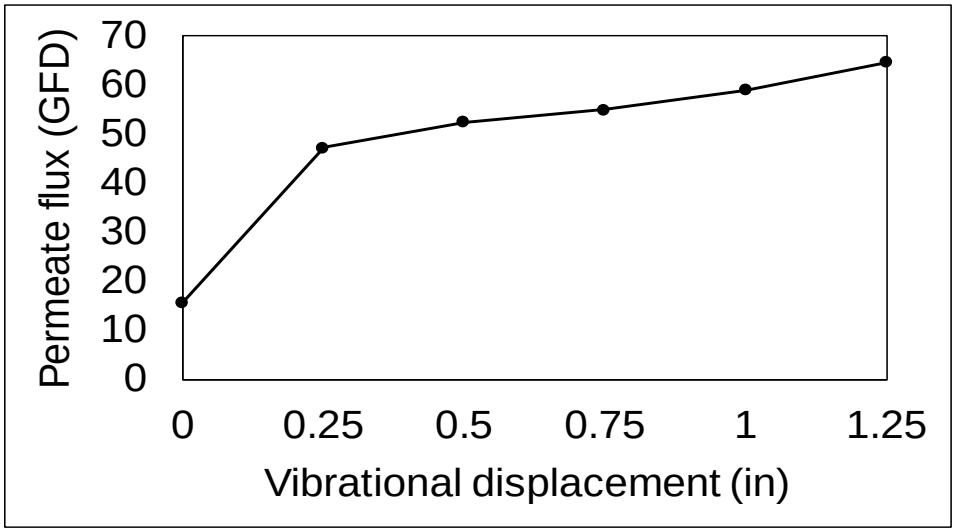


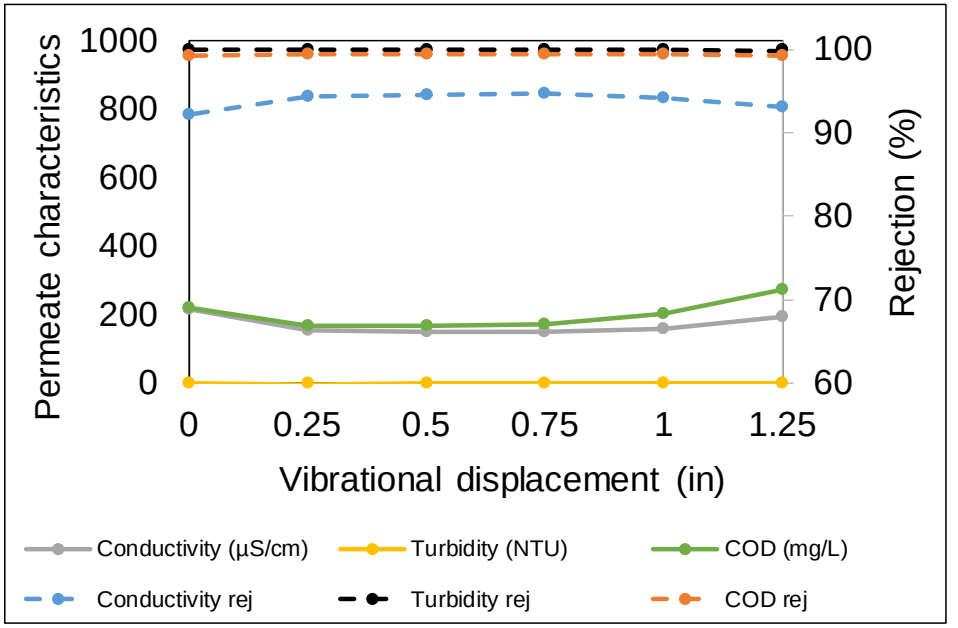
Okada, et al, *Food Chem,* 272, 494–506, 1980

Compton, et al, *Innov. Food Sci. Emerging Technol.* 47, 371–383, 2018

Coffee Extract Concentration Experiments

- Simulated coffee extracts from reconstituted soluble coffee product
- V-SEP NF
- 2 to 3 times flux enhancement
- High rejection (> 90%)





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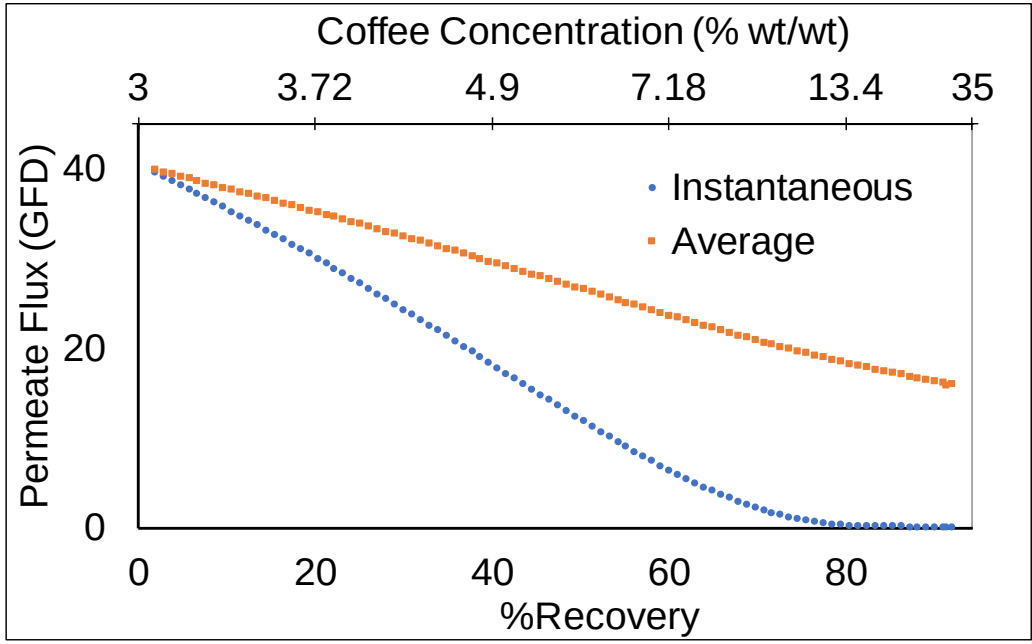
Modified Scale-up Approach

- Modified scale-up approach by relating feed coffee concentrations with water recovery to simulate concentration runs
- All values are “bulk-average” at final coffee concentration of 35%
- COD, conductivity, turbidity are in-spec for reuse (ancillary plant operations)



Permeate Parameter	Recovered Permeate†
Flux @ 94% recovery (gal/ft²/day)	16
COD (mg/L) (Rejection)	450 (98%)
Turbidity (NTU) (Rejection)	< 1 (> 99%)
Conductivity (µS/cm) (Rejection)	490 (86%)

† *NF Membrane @ ΔP = 350 psi, T = 25 °C, 1 in vibrational displacement, 3% feed coffee concentration*

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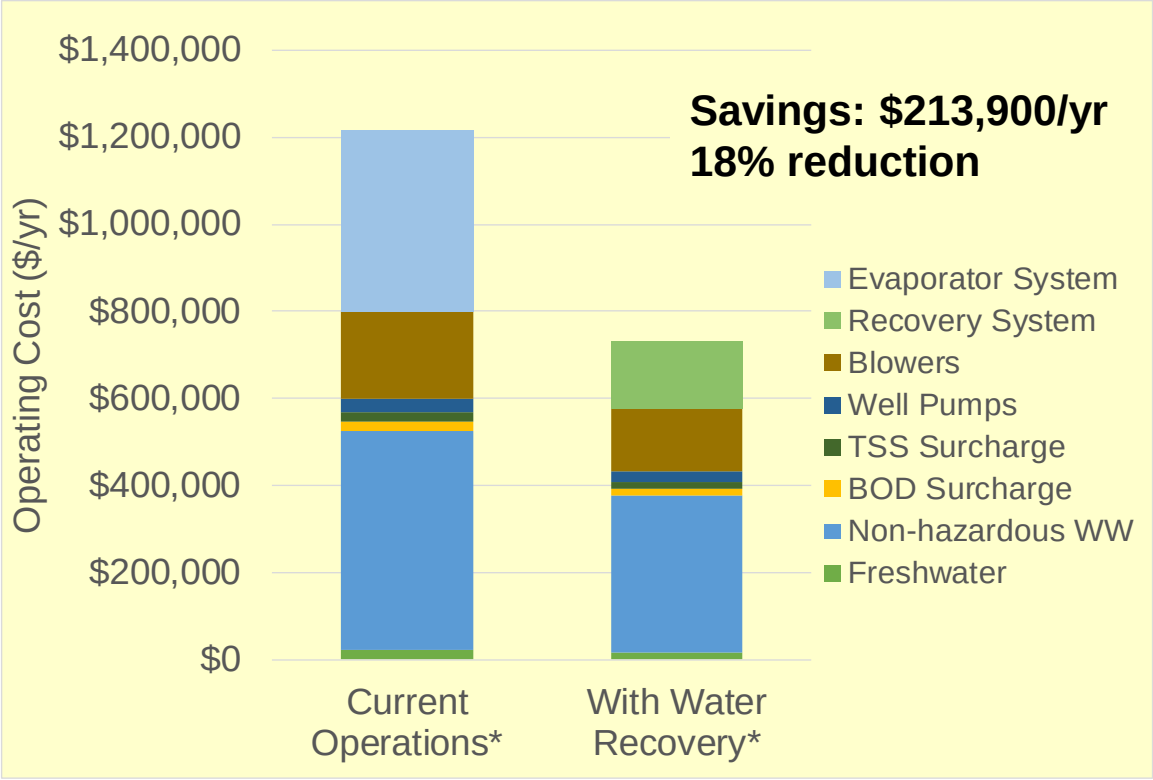
Estimated Annual Operating Savings



*Based on a projected plant operation

- Operating cost savings mainly from coffee extract concentration (evaporator system)
- Reduction in non-hazardous WW generation and electricity used from on-site aeration blowers & well pumps offset by V-SEP electricity req'd
- Greater reductions in freshwater savings in other parts of country

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Summary - Scaled-up Design

7-Module i84 V-SEP System

- 94% Recovery (100K GPD)
- Membrane area per module: 1,400 ft^2
- Plant footprint (with skid and metering station)
  - 16 ft x 34.1 ft (550 ft^2)
- Electricity requirement
  - 546,000 kWh/yr
- LCE reduction 40%
- Payback time 11 yrs

https://www.wateronline.com/doc/niagara-bottling-finalizes-new-logic-research-install-vsep-brine-system-0001

From New Logic Research, Inc.
http://www.vsep.com/products/i84.html

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Potential V-SEP Uses Food Manufacture

Concentrates and powdered beverages (fruit juices, syrups, broths)

Dairy products

Fermented products (alcoholic beverages, sauces)

Cassano & Drioli, *Integrated Membrane Operations,* Walter De Gruyter GmbH, 2014.

Bhattacharjee, et al., *Innov. Food Sci. Emerg. Technol.,* 43, 136-153, 2017

Hu & Dickson, *Membrane Processing for Dairy Ingredient Separation*. John Wiley & Sons, Inc. 2015

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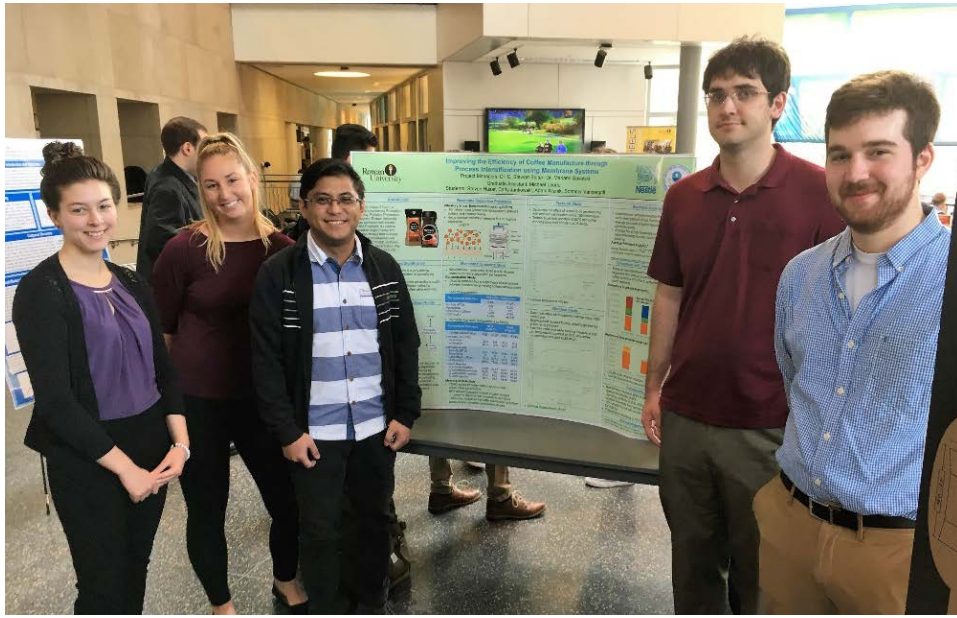

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THANK YOU
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