Essential Oil Recovery from an Entrained Air-Steam Mixture

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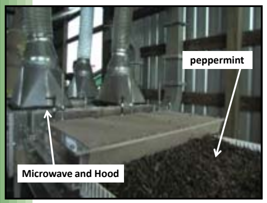
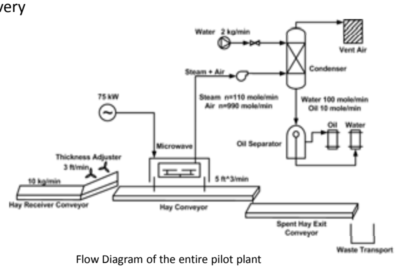
Background

- U.S. mint oil is of the highest quality and comprises 40% of world production
- Current steam distillation is not an energy efficient process
- 100 kW experimental microwave system was created to improve energy efficiency

Problem: The recovered steam/oil is entrained with air which makes the current condenser system incapable of total condensation and recovery



Pilot plant microwave applicator during extraction



Flow Diagram of the entire pilot plant

Engineering Fundamentals

Steam to Air ratio calculations

Energy balance

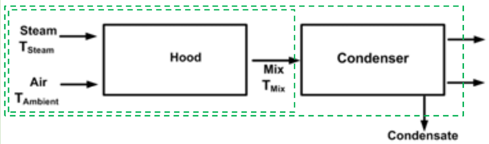
- Assumes adiabatic mixing
- Hood system is the control volume

$$\frac{\dot{m}_{steam}}{\dot{m}_{water}} = \frac{Cp_{water}(T_{mix} - T_{ambient})}{Cp_{steam}(T_{steam} - T_{mix})}$$

Mass Balance

- Assumes ideal solution, ideal gas, Raoult's law applies
- Hood and condenser is the control volume

$$\frac{\dot{m}_{steam}}{\dot{m}_{air}} = \left(\frac{MW_{air}}{MW_{water}} \left(y_{H_2O,2} \left[\frac{P_{H_2O}{}^{sat}(T_1)}{P_{H_2O}{}^{sat}(T_2)} - 1 \right] \right) + \frac{\dot{m}_{condensate}}{\dot{m}_{air}} \right)$$



Yield Optimization

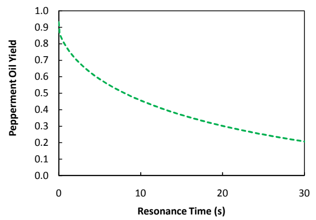
- Navier-Stokes conservation of mass equations

  Assumptions: isothermal, constant density, no convective losses, negligible initial air concentration

- Shows maximum yield of oil taking into account the losses to air as a function of system resonance time.

$$\frac{\partial C_A}{\partial t} = D_{MOH-H2O} \left(\frac{\partial^2 C_A}{\partial r^2} + \frac{2}{r} \frac{\partial C_A}{\partial r} \right)$$

$$Y = 1 + \frac{2R}{\pi r} \sum_{n=1}^{\infty} \frac{(-1)^n}{n} \sin\left(\frac{n \pi r}{R} \right) e^{\frac{-D_{MOH-H2O} n^2 \pi^2 t}{R^2}}$$



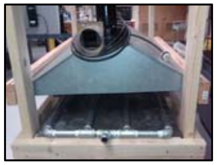
Most of the peppermint oil will be captured with the steam at the resonance time of the pilot plant ~ 2 sec.

- Yield of peppermint oil can be improved by condensing the steam quickly.

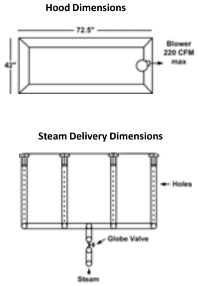
Approach

The pilot plant was simulated at ¼ of its dimensions in order to test the two condenser options. Steam from Oregon State pipelines was used in place of the microwave applicator. Mint oil was delivered with a calibrated sprayer.

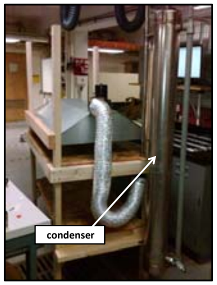
Steam Delivery



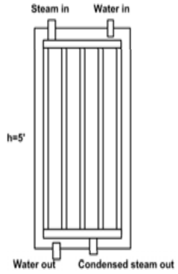
- ¾" steel pipes deliver house steam.
- Hood system captures the steam/air mix and sends it to the condensers.
- Temperature and humidity sensors monitor outlet conditions



Tube and Shell Condenser

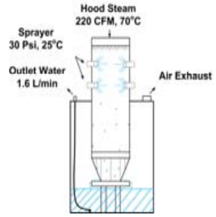


- Operates with a constant cooling water flow of 24 L/min
- Five steam/air compositions were tested.
- Steam velocity out of the hood was 6.2 m/s.



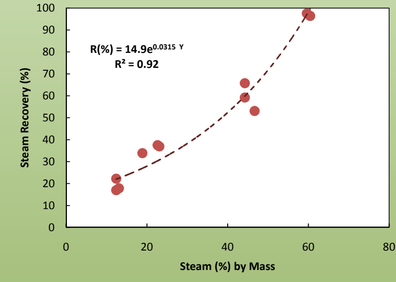
Direct Contact Condenser

- Four sprayers delivered spray to the column
- A bypass valve adjusted pressure to the sprayers from the pump
- Maximum recovery occurred at 55 psi delivered pressure which corresponded to 1.6 L/min of spray.



Results

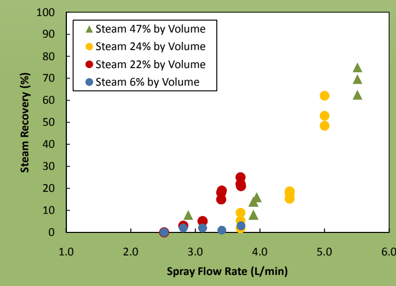
Tube and Shell Condenser



- Similar to the results of Colburn et al, the recovery which is directly proportional to the effective heat transfer coefficient has a power of 0.0315. Colburn et al reported 0.0338.

Conclusions: The low steam to air ratio makes a condenser system unlikely for economic feasibility based on the large size and high water flow rates needed.

Direct Contact Condenser



- A minimum delivery pressure was needed for the sprayers to run
- Additional sprayers would result in higher recovery

Conclusions: With four sprayers and an ordinary agricultural pump, it was possible to recover 22% of the inlet steam mixture. Trials were performed with three replicates.

Conclusion

The direct contact condenser seems promising. Mint was sprayed at 1.5 g/min into the inlet air mixture. A thick viscous layer of mint oil separated in the direct contact condenser basin. The collection system must be optimized in future studies.

Additional benefits to the scrubber system are that minimal water is added to the condensate if the water phase is cooled and re-sprayed. Additionally the oil/water separation techniques currently used can remain in use. This could encourage integration of this condenser into current practices.

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