Summary:

- final project report for *BEE 4630: Digital Food Engineering*, taken Spring of 2023
- investigated optimal conditions for vacuum drying a grape to a raisin in COMSOL software
- supervised by and presented to Professor Ashim Datta
- collaborated with Rachel Bocian (B.Sc. Biological Engineering, Cornell University ‘24) and Wangqi Ma (M.Eng. Biological and Environmental Engineering, Cornell University ‘24)

**NOTE - this presentation includes GIFs that cannot be viewed in the PDF version, link below for full presentation:*
https://docs.google.com/presentation/d/1aFcjsTkbpbMSwrhOd3ZKJIdhf47yQJ_HwD1SeDemN9I/edit?usp=sharing

Optimization of vacuum drying a grape to a raisin

BEE 4630/6630 Group 2

Rachel Bocian, Isaiah Guenther, Wangqi Ma

Intro

- Vacuum drying creates a low pressure and low moisture environment which speeds up the drying process
- Grape skin diffusivity is low… can increase with pretreatment
    - Alkali
        - Potassium carbonate creates microfissures on skin
        - Ethyl oleate creates cracks on surface leading to nonuniform skin removal
    - Physical
        - Physical abrasion leads to uniform skin removal

Goals

- Investigate vacuum drying at different skin diffusivities
- Construct model of the shrinkage of the grape drying process

Problem formulation

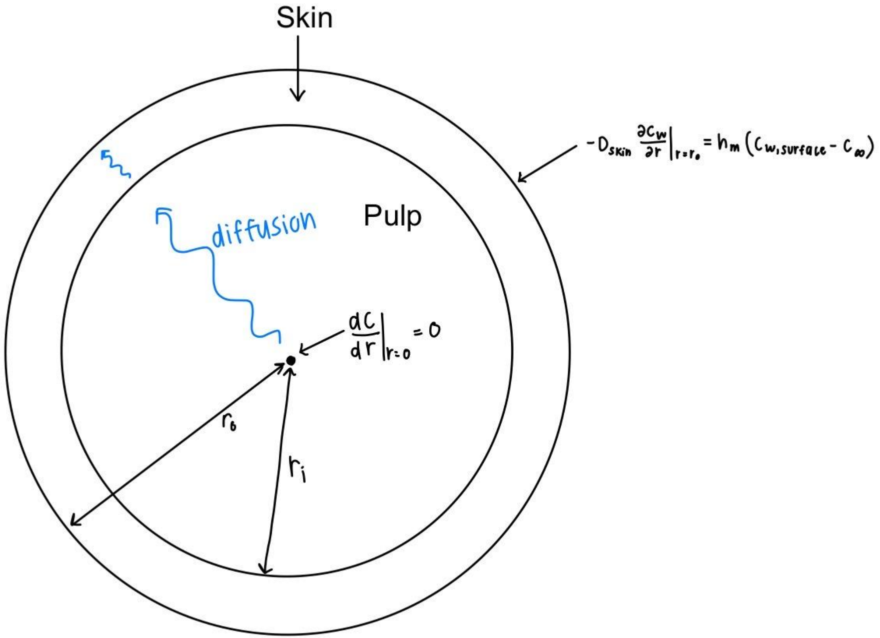
- Governing equation:

$$\frac{\partial c_A}{\partial t} = D_{AB} \frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial c_A}{\partial r}\right)$$

- Boundary conditions:

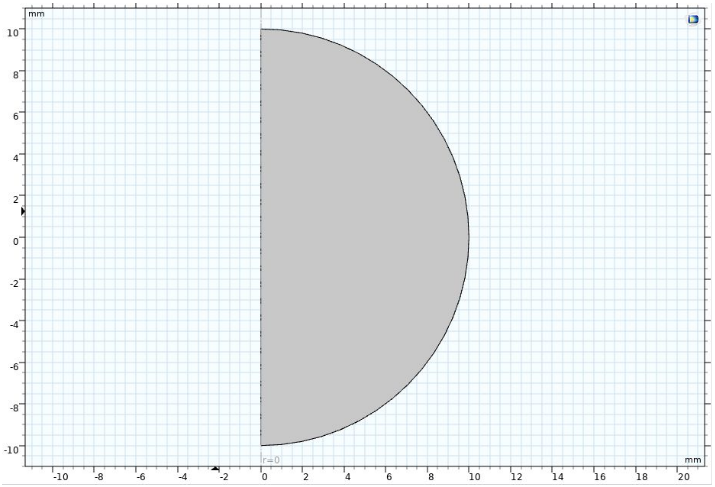
1. $\frac{dC}{dr}\Big|_{r=0} = 0$

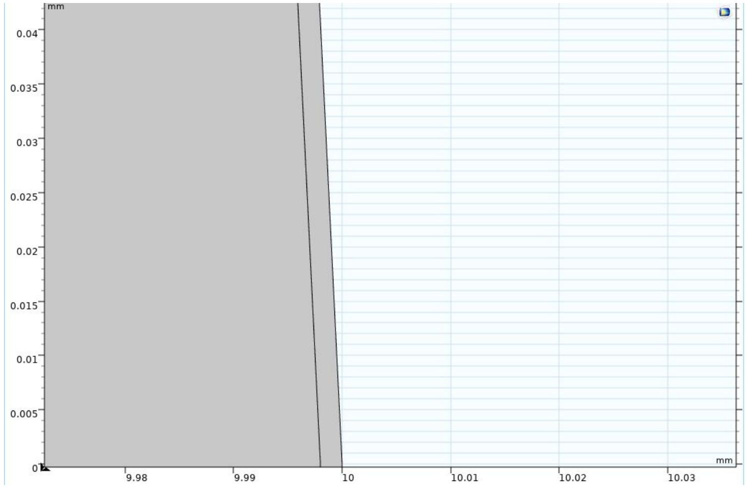
2. $-D_{skin} \frac{\partial c_A}{\partial r}\Big|_{r=r_o} = h_m(c_{A,surface} - c_\infty) = h_m\left(\frac{P_v a_w}{RT} - c_\infty\right)$



Geometry & initial values

- Sphere in 2D-Axisymmetric
- Pulp and skin separate, a large circle with r = 10 mm and a small circle with r = 9.998 mm, and using Difference to represent skin
- 5g grape, 81.3% moisture content = 54000 mol/m^3 moisture





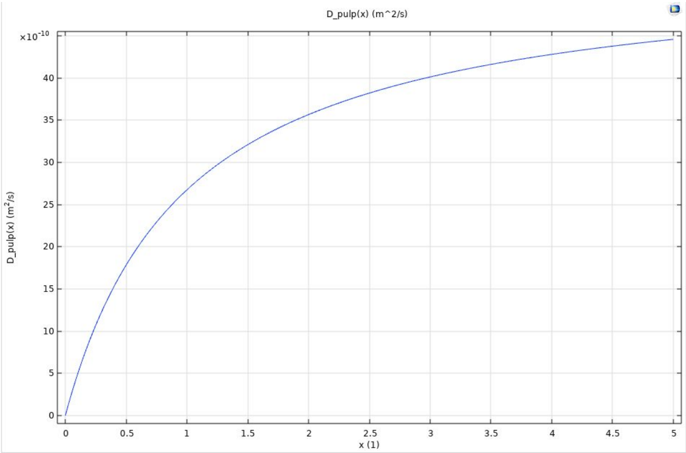
Different diffusivities

- Pulp diffusivity:

$$D = \frac{1}{1+X} D_o \exp\left[-\frac{E_o}{R}\left(\frac{1}{T}-\frac{1}{T_r}\right)\right] + \frac{X}{1+X} D_i \exp\left[-\frac{E_i}{R}\left(\frac{1}{T}-\frac{1}{T_r}\right)\right]$$

- Skin diffusivity varied for investigation
  - $10^{-18} - 10^{-22}\ [m^2/s]$ for **untreated** skin
  - $10^{-10} - 10^{-17}\ [m^2/s]$ for **pretreated** skin

- Single-phase diffusion as liquid



Model construction & study

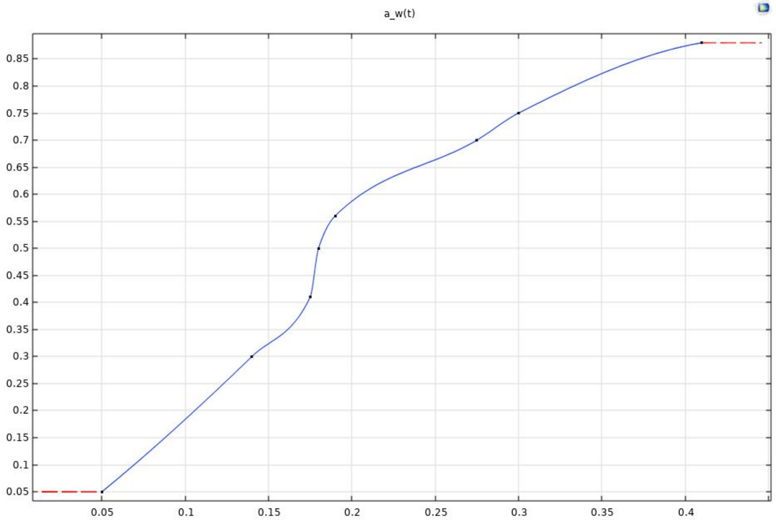
- Using Transport of Diluted Species (tds) as the physics
- Defining boundary conditions and initial values under tds
- Mass transfer rate across the surface boundary applied to outer skin boundary:

$J_{0,c}$ `-h_m*((P_vw*a_w(c*V*M/mass_dry))/(R.*T.)-c_inf)` $\mathrm{mol/(m^2 \cdot s)}$

- Deformed geometry (moving mesh)
- Time dependent study
- Parametric sweep for skin diffusivity (no shrinkage)

Water activity

- Interpolation used from recorded data on grapes
- Constant extrapolation to ensure water activity values stay between 0 and 1
- Used to calculate the mass transfer flux



Shrinkage

- Moisture out = volume change
- Applied as rate to outer skin boundary

$$v_{mesh} = \frac{flux\ [\frac{kg}{m^2 * s}]}{\rho\ [\frac{kg}{m^3}]}$$

Validation for drying time

- Sokac et al. (2022)... dry when 5-8% moisture content

Table 1. Drying conditions for the performed drying processes.

Drying Process	Temperature (°C)	Pressure	Drying Time (h)
Vacuum drying	35	100 mbar	12
Vacuum drying	50	100 mbar	5
Vacuum drying	70	100 mbar	3

- Our data at skin diffusivity of 10^-10 m^2/s

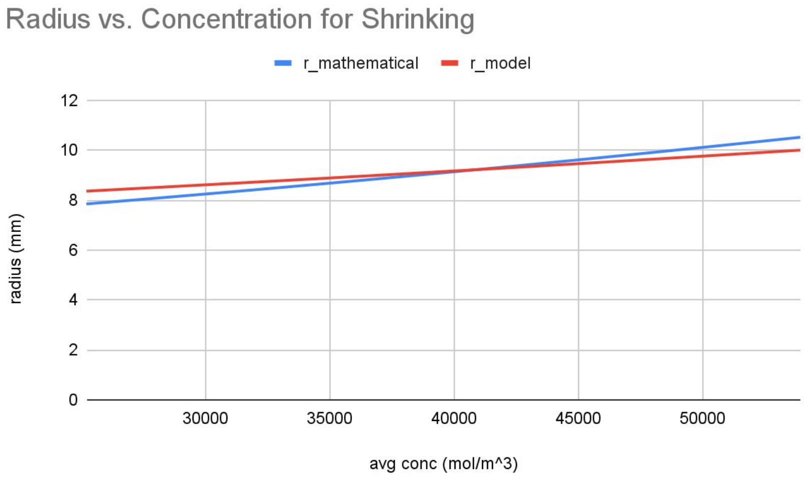
Temperature (C)	Time Run (h)	Moisture Content (%)
35	6.45*	28.9
50	5	57.2
70	3	59.0

Maximum run times for $D_{skin} = 10^{-10}\ m^2/s$

Temperature (C)	Max Time Ran (hr)	Moisture Content (%)
35	6.45	28.9
50	8.11	6.12
70	7.89	3.87

Validation for shrinkage

- Only performing validation when D_skin = 10^-10 m^2/s
- Mathematical models from S. Simal et al. (1996)



$$V/V_o = 0.2276 + 0.2151\ W$$

W	average moisture content	kg water/ kg d.m.

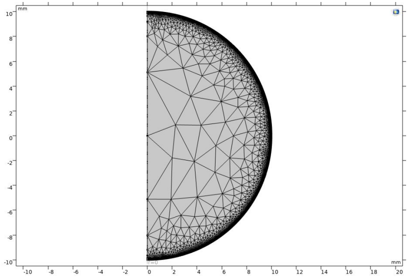
- R_mathematical from linear shrinkage curve based on experimental data

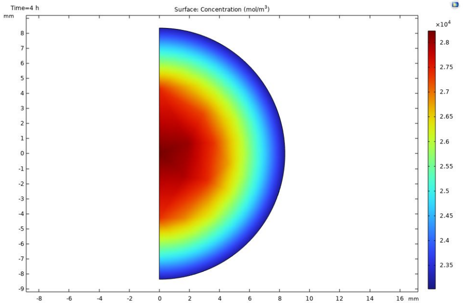
Using Root Mean Square Error to measure similarity, RMSE = 0.399 mm

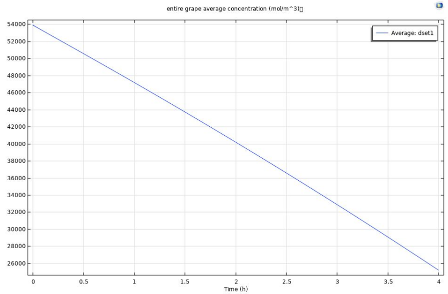
$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} \left(P_i - O_i \right)^2}{n}}$$

Mesh convergence (performed on D_skin = 1e-10 m^2/s)

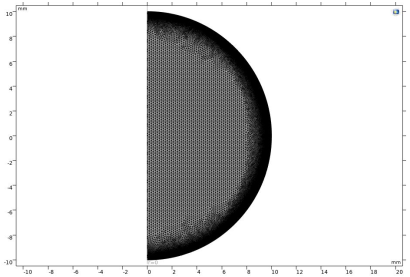
- Extremely coarse: 110 second run time

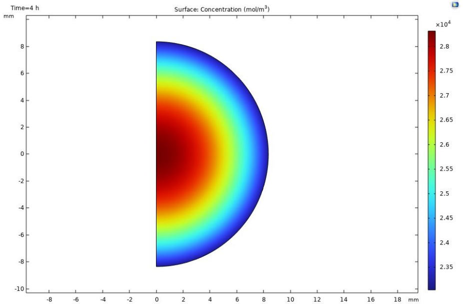


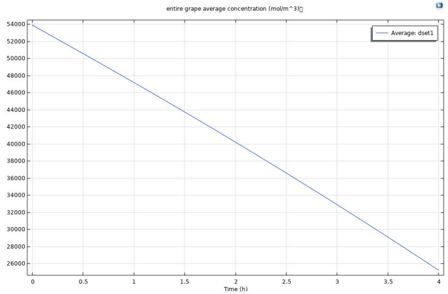




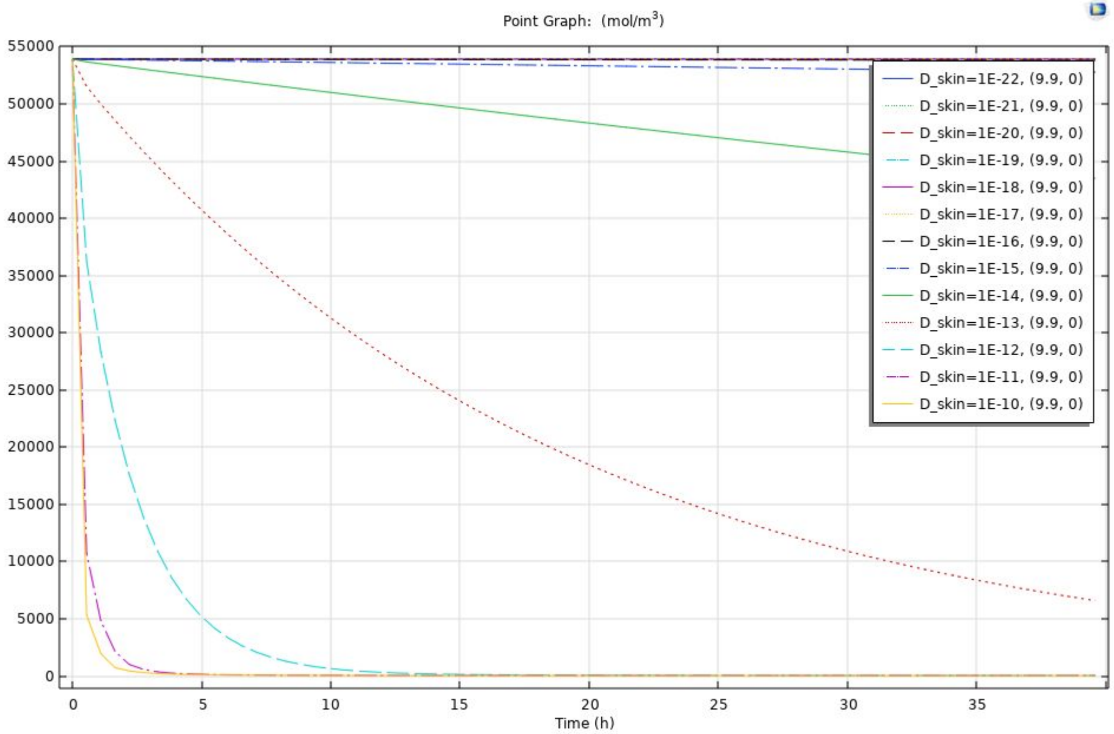
- Extremely fine: 937 second run time



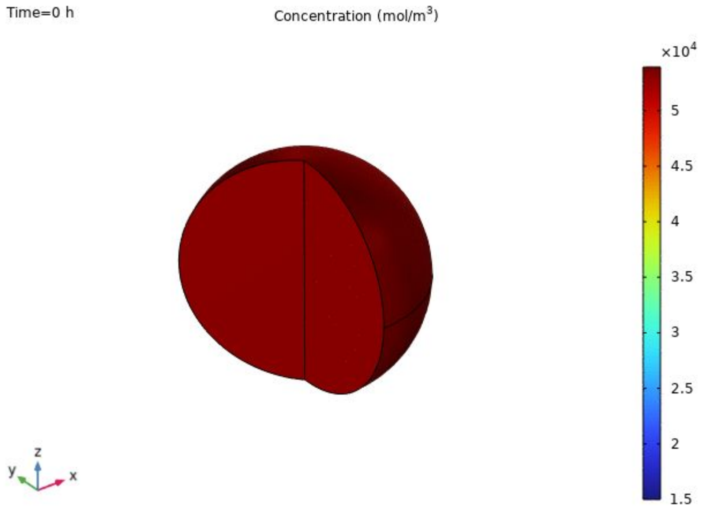


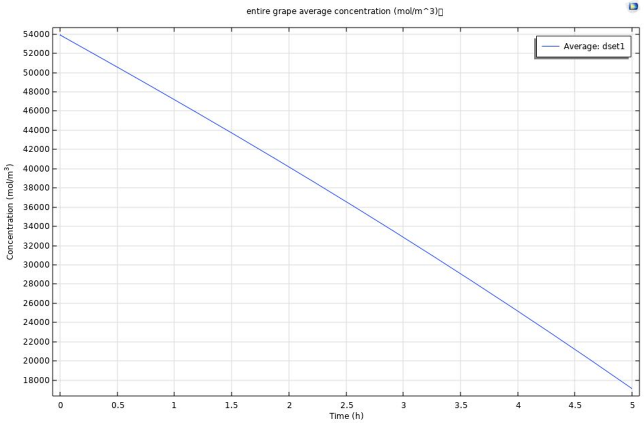


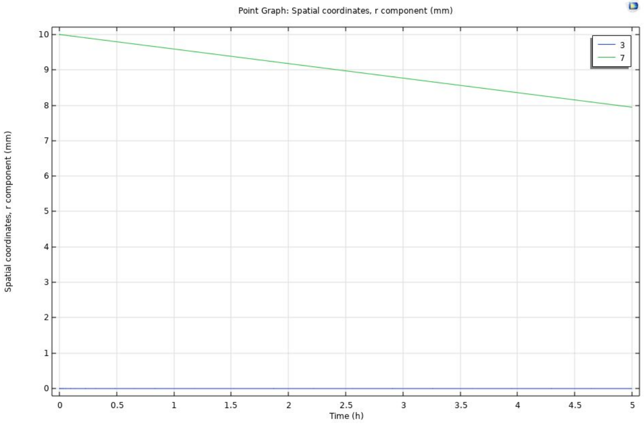
Effect of skin diffusivity on average water concentration



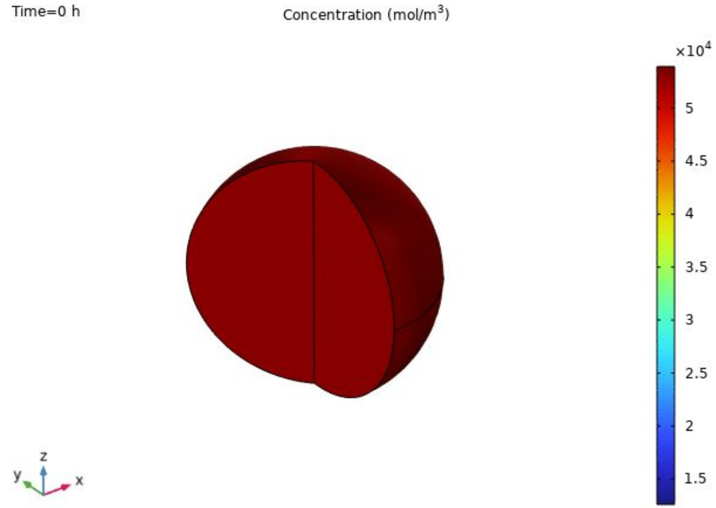
D_skin = 1e-10 m^2/s

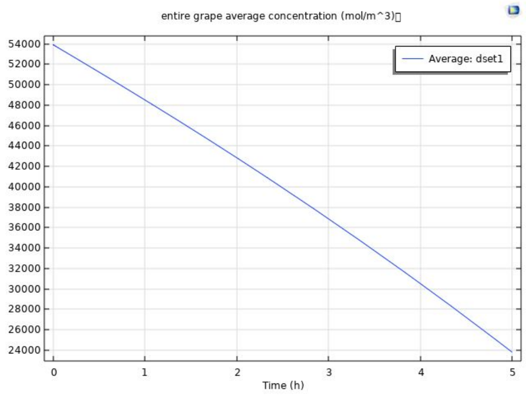


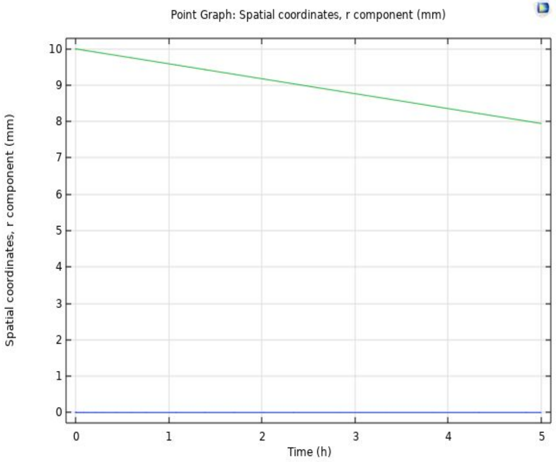




D_skin = 1e-12 m^2/s







Conclusion

- Increase in temperature increases rate of drying
- Increase in skin diffusivity increases rate of drying
    - Pretreatment is necessary to dry grapes in a reasonable amount of time for industry
- Shrinkage is linear
- Rate of drying is nearly linear when shrinkage included

Future Research

- Run model for all diffusivities in range of pre-treated and untreated
- Compare results and optimize rate of drying and drying time