MANE 6962: Experimental Mechanics Midterm Presentation

Analysis of Mass Transport Over Wide Volatilities, Pressures, and Ambient Gases

Chris Nkinthorn

October 29, 2018

Rensselaer Polytechnic Institute: Department of MANE

Research Summary

This presentation covers research done at Trinity University by Chris Nkinthorn, under the supervision of Dr. Peter Kelly-Zion, between the dates of 1 Jan 2016 - Aug 2017.

Table of Contents

Vapor Concentration Measurements Using FTIR

Assumptions

Necessary requirements for analysis:

- Sessile Droplet: on horizontal surface with normal opposite gravitational acceleration
- Fixed Radius: satisfied by a pinned edge due to surface tension and radial symmetry.
- Constant Contact Angle Rate: diminishes steadily for steady state assumptions
- Concentration Boundary Conditions: goes to zero infinitely far away

Pressure Vessel

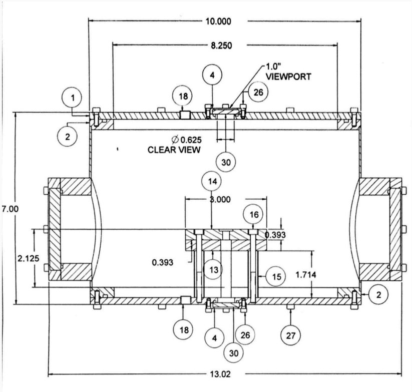

Figure 1: This schematic is a dimensional drawing of the pressure vessel showing the two viewing ports or apertures, which are inline for a FTIR beam to pass through. A single view port allows for viewing from the top. Note that the table is not adjustable which limited the density difference ratio to positive values.

Concentration Measurement

Figure 2: Schlieren Image: Opaque droplet and stand, with pinned surface. Red arrow representing FTIR beam whose drop in intensity can be related to the average concentration by Beer's Law

Diffusion Limited vs Measured Concentration

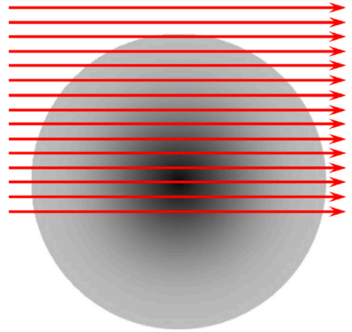

Figure 3: Constant Elevation Beam Paths

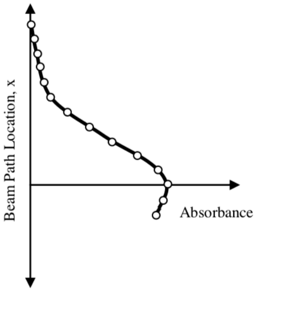

Figure 4: Resulting Distribution of Absorbance

Orthogonal View

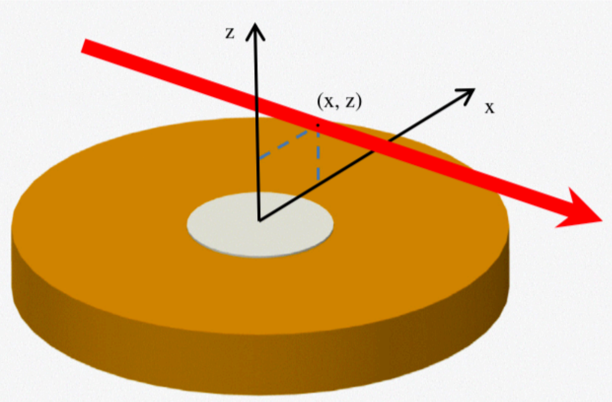

Figure 5: Orthogonal view of the beam, showing an averaged absorbency for a given elevation and radial position, *x*. Must use CT to return a local concentration value.

Mass Transport Mechanisms

Evaporative Mechanisms

Mass Transport Mechanisms of a Sessile Droplet

- Diffusion: Microscopic process, based on a concentration gradient with known analytic solution
- Convection: Macroscopic ”bulk transport”, due to a density difference between two vapors under gravitational acceleration.

Evaporation Rates and Dimensionless Numbers

The purpose of this research is to find a correlation for the total mass transport, or evaporation, E.

$$\begin{aligned} Ra &= Gr \cdot Pr && (1) \\ &= \frac{\rho_m - \rho_a}{\rho_a} \frac{gR^3}{\nu^2} \cdot \frac{\nu}{\alpha} && (2) \\ Sc &= \frac{\nu}{D} && (3) \\ Sh &= c \cdot Sc^{1/3} \cdot Ra^n = \frac{ERT}{\pi R D P_v M} && (4) \end{aligned}$$

1. Rayleigh Number: product of Grashof and Prandtl Numbers, relative convective to viscous effects
2. Schmidt Number: relating viscous and diffusive effects
3. Sherwood Number: a correlation between the Rayleigh and Schmidt numbers, relating to the total mass transport

Diffusion Limited vs Measured Concentration

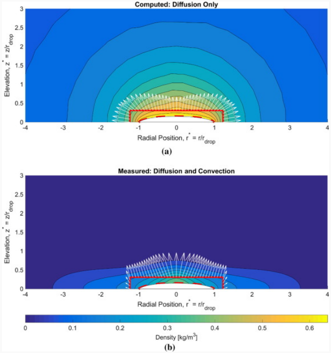

Figure 6: Relating the evaporative rates between diffusion limited and and measured rates. Measured flux through cylindrical control surface differ in magnitude through the circular top.

Correlation Equations

The correlation will be on the Sherwood Number, as it is the dimensionless number representing the total evaporation. As the two mass transport mechanisms are coupled, we will investigate their relation to each other. The symbol K_D is presented for convience.

$$Sh_{cor} = Sh_D^* + Sh_C^* \tag{5}$$

$$= Sh_D(1 + a(\frac{gR^3}{\nu^2})/(\frac{gR_o^3}{\nu_o^2})^b)[(\frac{\rho_m - \rho_a}{\rho_a})Sc]^c \tag{6}$$

$$+ dSc^e(\frac{\rho_m - \rho_a}{\rho_a})^f(\frac{gR_o^3}{\nu^2})^i(\frac{gR^3}{\nu_o^2})^j \tag{7}$$

$$Sh_D^* = Sh_D \cdot K_D \tag{8}$$

$$Sh_C^* = (\frac{\rho_m - \rho_a}{\rho_a})^f(\frac{gR_o^3}{\nu^2})^i(\frac{gR^3}{\nu_o^2})^j \tag{9}$$

Analysis of Data Sets: Pressure/Gas and Radius/Component

Measured Evaporation Rates and Correlation

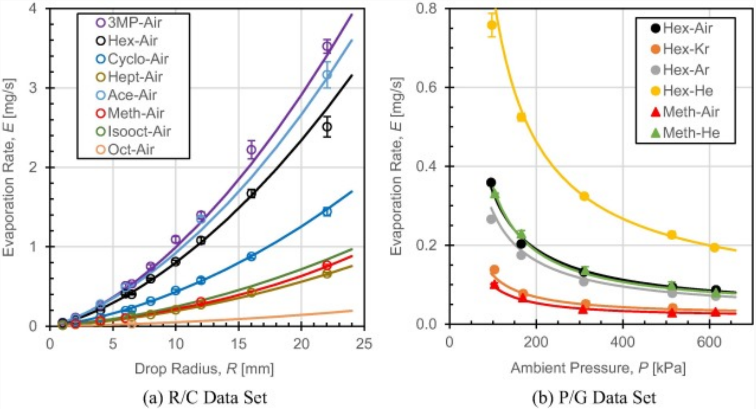

Figure 7: Evaporation data from both sets with correlation in solid. Note the effect are inversely related.

Error Distribution

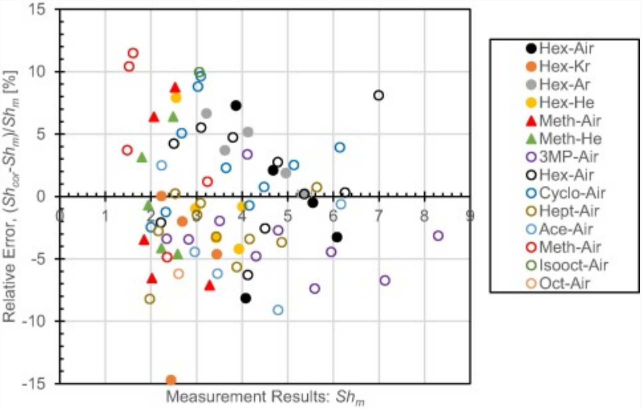

Figure 8: Error for PG and RC Data sets as a function of Evaporation

Convective Contribution

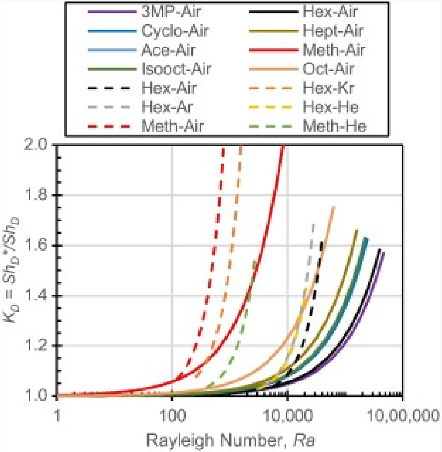

Figure 9: Convection plays a role at a critical Rayleigh Number.

Final Analysis

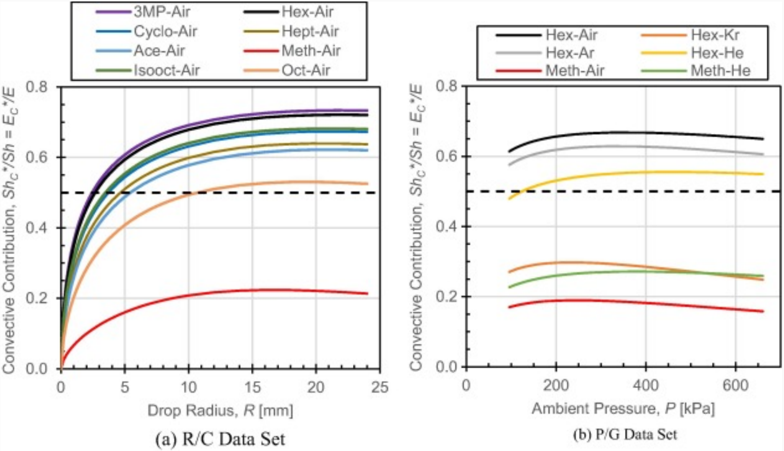

Figure 10: Relating the role of convection to total evaporation across both data sets.

Take Aways

- Radius and therefore, surface area plays a large role in the contribution of convection to overall evaporation, growing at a rate of $R^1.64$.
- In the case where R goes to zero, the distribution returns to the diffusion limited case.
- Ambient gas plays a major influence on the role of convective mass transport.
- Pressure does not affect the relative influence of convection: rather, it reduces both equally.

Questions?

Citations i

- P. L. Kelly-Zion, C. J. Pursell, G .N. Wassom, B. V. Mandelkorn, C. Nkinthorn. Correlation for sessile drop evaporation over a wide range of drop volatilities, ambient gases and pressures. *International Journal of Heat and Mass Transfer*, vol. 118, pp. 355–-367, March 2018.
- P.L. Kelly-Zion, C.J. Pursell, N. Hasbamrer, B. Cardozo, K. Gaughan, K. Nickels. Vapor distribution above an evaporating sessile drop. *International Journal of Heat and Mass Transfer*, vol. 65, pp. 165-172, October 2013.
- F. Carle, B. Sobac and D. Brutin. Experimental evidence of the atmospheric convective transport contribution to sessile droplet evaporation *Applied Physics Letters*, vol. 6102,is. 6, February 2013.