College of Engineering

MEE 4506: Energy Conversion Laboratory

Section 005

Experiment 1

Mass Transfer

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Abstract

This lab covers the topic of mass transfer through convection between water and air. The goal is to find the mass transfer coefficient of the water through experimentation. To do so, a fan blowing air over a plate of water will be placed at various distances to track the change in mass over time. This evaporation rate can then be used in calculations to find the mass transfer coefficient. Our results will be compared to theoretical calculations to determine the accuracy of the tests.

Background

Because an external source is used to provide the airflow over the fluid, this experiment is considered an example of low speed, forced convection with no phase change occurring within the water. Determining the mass transfer coefficient of the water experimentally can be done using a specific function that correlates the evaporation rate to fluid properties, such as surface area, fluid density, and relative humidity.

$$n_A = \overline{h_m} A\rho_{A,sat\,(25°C)}(1 - \varphi_\infty)$$

To find the theoretical mass transfer coefficient, a function relating Sherwood number, diffusion coefficient, and length from airflow source can be used. The following equations are used, in which fluid velocity, distance from fan, diffusion coefficient, kinematic viscosity, and Sc number are either assumed or known values from the experiment.

$$Re_L = \frac{u_\infty L}{\nu}$$

$$Sh_x \equiv 0.037 Re_L^{\frac{4}{5}} Sc^{\frac{1}{3}}$$

$$\overline{h_m} = \overline{Sh_L}\left(\frac{D_{AB}}{L}\right)$$

Known Variables		
Value	Unit	Reference
$D_{AB} = 0.26 \times 10^{-4}$	n/a	Table A-8
$\nu = 15.7 \times 10^{-6}$	$\frac{m^2}{s}$	Table A-4
$Sc \approx 0.60$	n/a	Eq 7.26

Research Hypothesis

We can expect our experimental and theoretical results to be similar based on the experiment's simplicity. We cannot approximate a value for the mass transfer coefficient prior to calculations because there are multiple variables involved, but we can compare our values to ones found in the textbook for reference.

Materials & Procedure

The materials used in this lab are as follows: aluminum plate, fan, hot wire anemometer or pitot tube, electronic balance, thermocouples, and psychrometers.

The following steps were taken to carry out the experiment.

1. Measure the plate dimensions.
2. Measure the air temperature and humidity.
3. Place the fan at some distance from the balance and turn it on.

4. Measure the air velocity.
5. Turn off the fan and place the aluminum plate of the balance.
6. Turn on the balance and zero it.
7. Load the plate with water until the plate is fully covered.
8. Measure the water temperature.
9. Turn on the fan and record mass readings from the balance every minute for up to 15 minutes.
10. Repeat for two more fan positions.

Data Analysis

General data must be collected at the beginning of the lab, prior to experimentation, which is shown in the table below. These values hold true for all data sets, regardless of fan distance.

Plate X (m)	0.17
Plate Y (m)	0.17
Plate Area (m^2)	0.03
Air Temperature (C)	22.7
Air Density (kg/m^3)	1.16

Experimental data collected from each trial is shown in the tables below. Two days of testing at three varying fan distances (3 trials) were conducted, resulting in six sets of data.

Day 1					
Trial 1		Trial 2		Trial 3	
DB Temperature (F)	72	DB Temperature (F)	72	DB Temperature (F)	72
WB Temperature (F)	63	WB Temperature (F)	63	WB Temperature (F)	63
Relative Humidity	0.63	Relative Humidity	0.63	Relative Humidity	0.63
Fan Distance (cm)	30.5	Fan Distance (cm)	40.6	Fan Distance (cm)	55
Air Velocity (m/s)	2.5	Air Velocity (m/s)	2.2	Air Velocity (m/s)	1.95

Minute	Mass (g)	Minute	Mass (g)	Minute	Mass (g)
0	92.5	0	87.94	0	84.13
1	92.3	1	87.9	1	83.7
2	91.9	2	87.4	2	83.7
3	91.3	3	87.4	3	83.2
4	91.2	4	86.8	4	82.8
5	91.1	5	87.1	5	82.6
6	90.7	6	86.9	6	82.3
7	90.4	7	86.6	7	82.3
8	90.2	8	86.2	8	81.9
9	90.1	9	85.7	9	81.6

10	89.4	10	85.9	10	81.4
11	89.6	11	85.3	11	80.7
12	89.2	12	85.1	12	80.9
13	89.0	13	85	13	80.8
14	88.7	14	84.8	14	80.6
15	88.6	15	84.7	15	80.1

Day 2					
Trial 1		Trial 2		Trial 3	
DB Temperature (F)	73	DB Temperature (F)	73	DB Temperature (F)	73
WB Temperature (F)	61	WB Temperature (F)	61	WB Temperature (F)	61
Relative Humidity	0.58	Relative Humidity	0.58	Relative Humidity	0.58
Fan Distance (cm)	30.5	Fan Distance (cm)	40.6	Fan Distance (cm)	55
Air Velocity (m/s)	2.26	Air Velocity (m/s)	1.9	Air Velocity (m/s)	2.05

Minute	Mass (g)	Minute	Mass (g)	Minute	Mass (g)
0	76.5	0	81.4	0	72.9
1	76.2	1	81.3	1	73.4
2	75.8	2	80.5	2	73.1
3	75.7	3	80.2	3	72.2
4	75.4	4	79.9	4	71.6
5	75.3	5	79.4	5	71.9
6	75.2	6	79.2	6	71.4
7	74.9	7	78.7	7	71.2
8	74.6	8	78.7	8	70.8
9	74.5	9	78.6	9	70.5
10	74.1	10	78.1	10	69.9
11	73.9	11	77.9	11	69.6
12	73.6	12	77.6	12	69.2
13	73.4	13	77.3	13	68.6
14	73.2	14	77.4	14	69
15	72.8	15	76.8	15	68.4

From the raw data collected in the tables above, we can move forward with the equations described in the background section of the report. Calculated values of all necessary variables are found using the equations listed in the above sections. These values are shown in the respective tables below for all distances in both trials. The highlighted cells indicate the mass transfer coefficients of the water at each distance.

Day 1				
Variable	Units	Trial 1	Trial 2	Trial 3

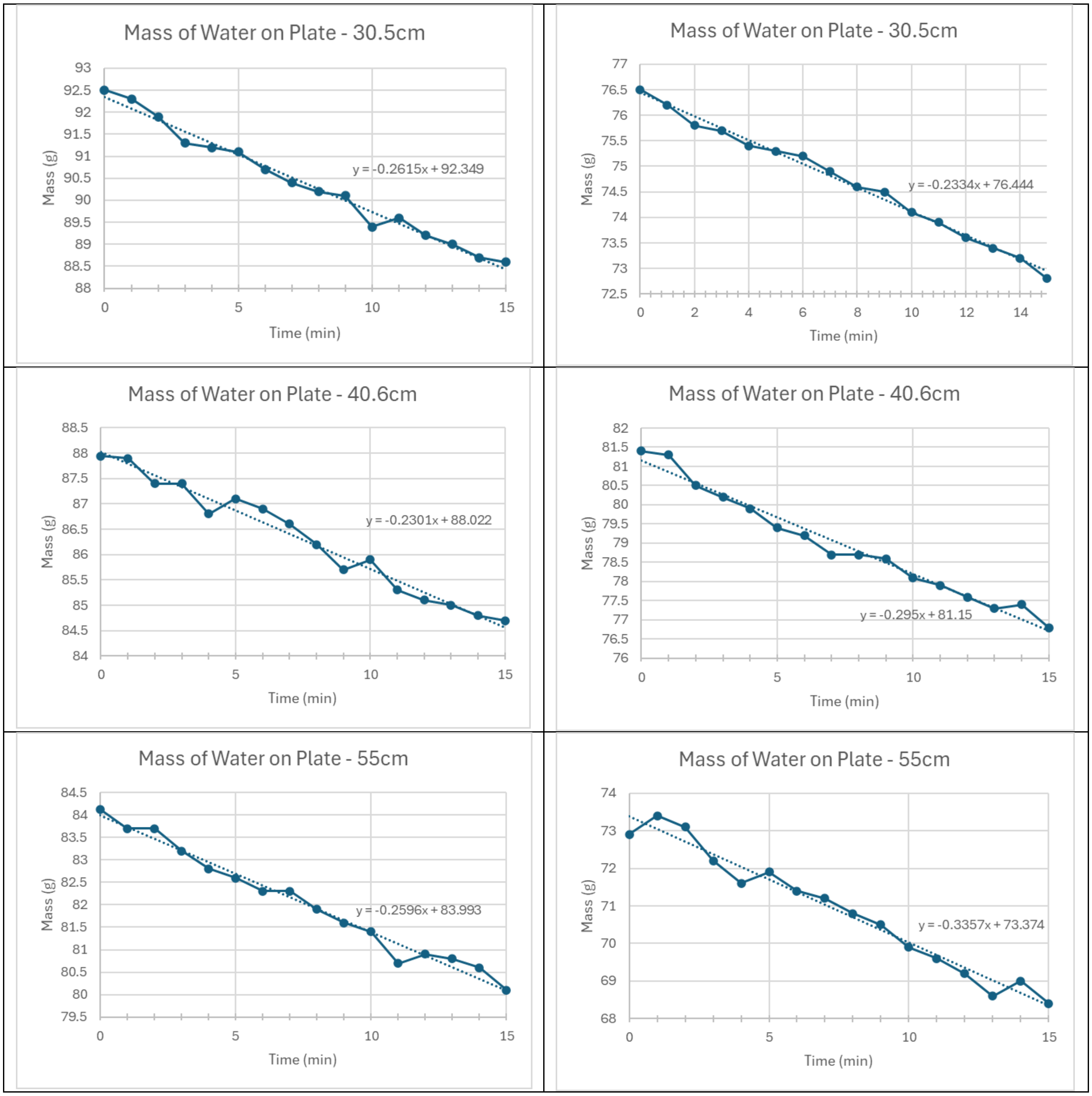
	Fan Distance (cm)	cm	30.5	40.6	55
	Air Velocity (m/s)	m/s	2.5	2.2	1.95
Theoretical Calculations	Reynold's Number	unitless	48566.88	56891.72	68312.10
	Sherwood Number	unitless	175.12	198.74	230.06
	Mass Transfer Coefficient, hm	m/s	0.01493	0.01273	0.01088
Experimental Calculations	Evaporation Rate, n	kg/s	0.00026	0.00023	0.00026
	Mass Transfer Coefficient, hm	m/s	0.02057	0.01811	0.02043

	Day 2				
	Variable	Units	Trial 1	Trial 2	Trial 3
	Fan Distance (cm)	cm	30.5	40.6	55
	Air Velocity (m/s)	m/s	2.5	2.2	1.95
Theoretical Calculations	Reynold's Number	unitless	43904.46	49133.76	71815.29
	Sherwood Number	unitless	161.53	176.75	239.46
	Mass Transfer Coefficient, hm	m/s	0.01377	0.01132	0.01132
Experimental Calculations	Evaporation Rate, n	kg/s	0.00023	0.00030	0.00034
	Mass Transfer Coefficient, hm	m/s	0.01618	0.02045	0.02327

Discussion of Results

From our data collection, we can create a graph of mass versus time to show the mass flow rate of each airflow at varying fan distances. From these graphs, we can plot a line of best fit to view the slope, also known as the evaporation rate of the water. These graphs are shown below to compare all three trials of each day.

Day 1	**Day 2**



From these graphs, the evaporation rate is used to calculate the experimental mass transfer coefficient, hm, for each trail of both days. We can compare our experimental results, green, to the theoretical results, yellow, which are summarized in the table below.

	Day 1				
	Variable	Unit	Trial 1	Trial 2	Trial 3
Theoretical	Mass Transfer Coefficient, hm	m/s	0.01493	0.01273	0.01088
Experimental	Mass Transfer Coefficient, hm	m/s	0.02057	0.01811	0.02043
Percent Error			27.4%	29.7%	46.8%

	Day 2				
	Variable	Unit	Trial 1	Trial 2	Trial 3
Theoretical	Mass Transfer Coefficient, hm	m/s	0.01377	0.01132	0.01132
Experimental	Mass Transfer Coefficient, hm	m/s	0.01618	0.02045	0.02327
Percent Error			14.9%	44.6%	51.4%

Compared to our initial hypothesis, we can conclude that we were correct in the small difference between our theoretical and experimental results. At each trial, the values of mass transfer coefficient are similar, leading us to believe our calculations and experiments were accurate.

Conclusion & Recommendations

Through experimentation and theoretical applications, we were able to find the mass transfer coefficient of water contacted with an airflow provided by an external source. We ran trials at three separate distances from the fan for two days to procure enough data for analysis. Although our comparison of theoretical and experimental results showed some accuracy, there is still probable cause of error. These sources of error include 1) uneven aluminum plate dimensions in calculations 2) faults in experimentation caused by human error 3) assumptions of variables provided by lab manual. All sources of error contribute to the difference in the lab's theoretical and experimental results.

References

1. Bergman, T. L., Lavine, A. S., Incropera, F. P. & DeWitt, D. P. (2019). Fundamentals of Heat and Mass Transfer (8th ed.). Wiley.
2. Mass_transfer_data.xlsx