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The Effect of Different Fluids and Submersion Durations on Nail Corrosion

Chris Chae, Statistics, California Polytechnic State University
Martin Hsu, Statistics, California Polytechnic State University
Sydney Oberg, Statistics, California Polytechnic State University

Abstract

In this study, we looked at what effect lemon juice, tap water, and saltwater had as well as differing liquid submersion time periods of 1, 2, and 3 days had on nail corrosion. We tested this by looking at which liquid over each time caused the greatest corrosion among the nails. The response variable of focus was the change in mass of the nails. Using 54 nails, we separated each nail into a distinct cup filled with one of the three liquids. We randomly assigned each nail to a different cup of liquid and then randomly assigned each nail to a different length of submergent time. After each allotted time, we measured the nails to find corrosion using the change in mass that may have occurred. We found that the interaction effect of Liquid and Time Submerged resulted in significantly different changes in mass of the nails depending on the liquid and time used. Nails submerged in water over 1 and 2 days showed the greatest corrosion. Overall, water had a significantly greater effect on the average corrosion of the nails than other liquids.

1. Introduction

Nails are an important tool in construction and woodworking. As such, it is important to understand the properties of nails, especially how they react to their surroundings. Nails are made of metal or metal alloys, which means they are prone to oxidation in the form of rust. This poses a considerable point of risk to structures and utilities that needs to be fully understood and accounted for. However, not all rust forms at the same rate. Studies have shown that different surroundings and unique conditions can have an effect on the rate of metal rust formation. For instance, a study comparing the corrosion of metals in fresh and saltwater found that the composition of rust was different between the two types of water (Gismelseed). Another study comparing carbon steel corrosion in flowing natural versus synthetic seawater showed that there was a difference in corrosion rates between the two in flowing water but not stagnant water (Xu). Since many studies suggest it is plausible different environmental factors have different effects on rust formation of metals, we wanted to apply this to nails. Our goal for this experiment therefore was to find out if the type of liquid a nail is submerged in and the amount of time it is submerged has an effect on nail rust formation.

2. Materials and Methods

We decided to study these effects by submerging nails in assorted liquids and measuring the change in mass as an indicator of rust levels. To collect our data, we used common 6D 2” bright smooth shank nails from home depot, differing liquids, plastic cups, and a scale. These nails were all purchased in a single package of common 6D 2” bright smooth shank nails that were randomly selected from Home Depot. We collected the data over 3 days in room temperature environments. Each nail was an experimental unit, separated into almost identical plastic cups. Each cup was filled with half a cup of each liquid. The liquids included tap water that we sourced from a kitchen sink, Kroger 100% Lemon Juice, and a saltwater mixture that was composed of 2 tablespoons of salt per one cup of water. All of the data was collected over 24 hour increments beginning and ending at 6:30pm after day one, day two, and day three. Every nail was measured by the same person using the same Taylor Digital Scale at the same location.

2.1 Treatment Structure

Our treatment structure was a 3 by 3 factorial design with 9 treatments total. The first factor was the liquid the nail was submerged in. The three liquids were water, salt water, and lemon juice. The second factor was the time (in days) that the nails would be submerged in the liquid. The nails were either kept in the liquid for 1, 2, or 3 days. We chose the three liquids to simulate different environments, such as salt water or substances with higher acidity. We chose 1, 2, and 3 days as our levels for submersion duration because of their ordinal and equally-spaced nature. We believed that using days as units would provide clearer evidence of effects on rust formation than using hours or minutes.

2.2 Response Variable(s)

The response variable was the change in mass (grams) of the nails. We expected the response variable to be somewhat small. Each initial mass was measured using the same scale that weighed the nails to the nearest decimal hundredths place of a gram. The final mass was measured in a similar manner, with the additional step of letting the nails dry before we put them on the scale. The response variable was measured by subtracting the final and initial mass.

2.3 Experimental Unit

Our experimental unit was each 6D 2” common nail. We used a total of 54 nails in this experiment. All of the nails came from the same package and were purchased at Home Depot.

2.4 Design Structure

The design structure that we came up with was a completely randomized design (CRD). There were 6 replications per treatment. We maximized the number of replicates based on how many nails there were in the package. Additionally, we chose a higher number of replicates to increase our power. There was randomization in run order, so we did not place the nails in liquid following any particular order of liquid treatment or submersion duration treatment.

2.5 Dealing with other sources of variation

To deal with other sources of variation we used randomization of run order and random selection of the materials used. To create randomization of run order we randomly generated numbers in JMP to create an order in which each nail was measured and placed into the differing liquids. We also randomly assigned each nail to a specific treatment. The use of random run order and random assignment of the placement of the nails in the liquids accounted for any variation that may have occurred due to the slight variation of weights and extraneous differences between each nail. We accounted for other sources of confounding variables such as time via direct control such as by using the same brand and type of nails, lemon juice bottle, salt mixture, tap water, location, measuring person and measuring instrument, and starting day of treatment.

2.6 Statistical model and data analysis

Given that this experiment was a completely randomized design with a factorial treatment structure, the effects mode we constructed for this study is:

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

where y_{ijk} represents the k^{th} response change in mass for the i^{th} liquid and j^{th} day. μ represents the overall mean response change in mass. α_i represents the effect of the i^{th} liquid on the response change in mass. βj represents the effect of the j^{th} day on the response change in mass. $(\alpha\beta)_{ij}$ represents the interaction effect of the i^{th} liquid crossed with the j^{th} day on the response change in mass.

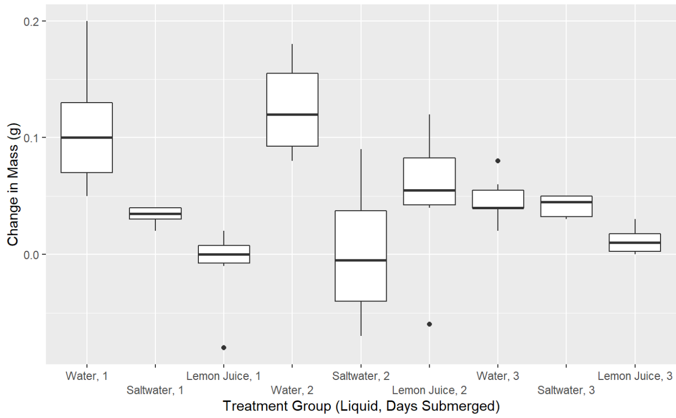
To analyze our data, we used the JMP® Pro 16.0.0 release for Windows, developed by the SAS Institute. Graphs (based on JMP statistical analyses) present in this report were developed using R version 4.1.2 “Bird Hippie” in the RStudio IDE, version 2021.09.1+372 "Ghost Orchid" release for Windows.

3. Analysis and Results

3.1 Descriptive statistics

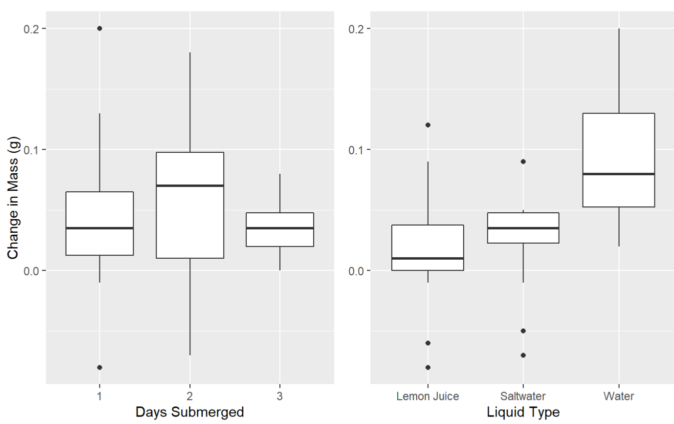
Based on a preliminary visualization of the data in Figure 3.1, it is plausible that there is a difference between the treatment groups. There are groups whose ranges do not overlap. Overall, it appears that the groups submerged in Water have the highest changes in mass while Lemon Juice and Saltwater have the lowest changes in mass.

Figure 3.1: Side-by-side boxplot showing how mass change differed based on treatment group



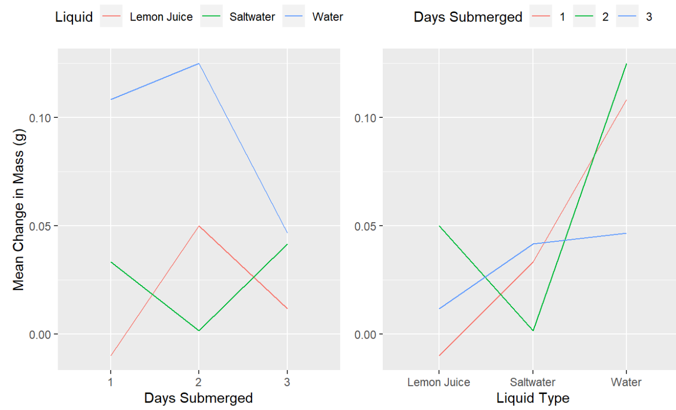
This observation is further confirmed by the boxplot in Figure 3.2. While there does not appear to be much effect of submersion time, in liquid type the groups treated with water appear to have greater changes in mass on average than Lemon Juice or Saltwater.

Figure 3.2: Side-by-side boxplots showing how mass change differed based on Liquid Type and based on Submersion Time



Furthermore, upon inspection of the interaction plot in Figure 3.3, there appears to be evidence of an interaction. While Lemon Juice and Water appear to behave similarly across the three days, Saltwater behaves differently. This can be seen by the relatively parallel behavior of Lemon Juice and Water versus the non-parallel behavior of Saltwater in the left plot of Figure 3.3. This implies that submersion time has an effect on nail oxidation that depends on liquid type.

Figure 3.3: Interaction plot of Liquid Type and Submersion Time



As a result, when performing an analysis on the data, we expected to find significant interaction and Liquid Type main effects.

3.2 Inferential findings

We looked for a significant effect by using a standard ANOVA F-test.

Independence of errors, normality of errors, and equal variance of errors are all necessary assumptions that we checked for to use an ANOVA test. We assumed independence of error due to the randomization involved in the experiment. Next, we assumed normality of error based on an inspection of the normal quantile plot of residuals and the large p-value (0.0492) of a Shapiro-Wilk test performed on the residuals at a significance level of 0.01. Finally, we assumed equal variance by inspecting the residual versus predicted values plot for patterns of fanning, which we did not find.

The ANOVA was performed at a global Type I error rate of 0.05, split into an error rate of 0.017 for each effect test for the individual significance level. Based on the effect tests, it is safe to say that the interaction effect between submerging time and liquid type appeared to be significant. The interaction effect had a p-value of 0.0023. Since there was found to be an interaction effect, it is not reliable to test any main effect of the liquid type nor the submerging time.

To find out the significant differences within the interaction effects, we used a Tukey comparison at a global Type I error rate of 0.05. Through this post-hoc analysis, we found that the Liquid-Submersion Time combination with the greatest change in mass was Water at 2 days and 1 day, as evidenced by Table 3.2.

Table 3.2: Connecting Letters Report, with mean (± SE) change in mass (grams) for Liquid Type * Submersion Time combinations

Liquid Type	Days Submerged	Mean	SE	Letter
Water	2	0.1250	0.0162	A
Water	1	0.1083	0.0162	A, B
Lemon Juice	2	0.0500	0.0162	B, C
Water	3	0.0467	0.0162	B, C
Saltwater	3	0.0417	0.0162	B, C
Saltwater	1	0.0333	0.0162	C
Lemon Juice	3	0.0117	0.0162	C
Saltwater	2	0.0017	0.0162	C
Lemon Juice	1	-0.001	0.0162	C

Note: *Levels that share a letter have means that are not statistically significantly different.*

We additionally decided to test a contrast at a 0.05 significance level to see if there was a significant difference between the mean of water-treated groups and the mean of saltwater and lemon juice treated groups:

$$\mu_{water} - \frac{\mu_{salt\ water} + \mu_{lemon\ juice}}{2}$$

The contrasts between water and the average of salt water and lemon juice shows that there is a significant difference between water and the other liquids. There is enough evidence to say that there is a difference between water and the other liquids because the p-value was <.0001. We are 95% confident that the average change in mass of water will be between 0.0489 and 0.095 grams greater than the change of mass when the nail is submerged in lemon juice or salt water.

4. Conclusion

We found strong evidence that the different liquids (salt water, water, lemon juice) had an effect on corrosion of similar nails (measured through average change in mass) that depended on submergent time (1 day, 2 days, 3 days). We also found that water causes the greatest corrosion compared to lemon juice and salt water. The treatment combination that caused the greatest amount of rust build up on the nails was the combination of 1 and 2 days submerged in water. The treatment that caused the smallest change in mass in our experiment were nails left in saltwater for 1 or 2 days and in lemon juice for 1 or 3 days. It is very clear that regular tap water will cause a greater buildup of rust in similar nails in comparison to lemon juice and saltwater.

5. Next steps

The largest issue that we would address if this study were run again would be the method by which we measured the rust on the nails. We measured rust by the simple change in mass of the nail itself; however, as the nail oxidizes, it gains weight, and as the rust falls off, it loses weight. This property may have introduced complications or inconsistencies when measuring change in mass for the nails. A more refined strategy that may be more time consuming might involve scraping off the rust before measuring the final nail mass.

There are many directions this experiment could be taken a step further, through either liquid types, submersion duration, or nail type. In terms of liquid type, it would be interesting to expand the types of liquids used or to focus on and compare different properties of the same liquid (such as concentration or temperature). In terms of submersion time, one could test to see if these results extend to longer terms (ie. weeks, months, years). Finally, this experiment could be repeated as a randomized complete block experiment with a random sample of nail brands or types as blocks to see if these conclusions can be generalized to all/more nail types or brands.

References

- Xu, Yunze and Qipiao Zhou, Liang Liu, Qiliang Zhang, Shide Song, Yi Huang (2020), "Exploring the corrosion performances of carbon steel in flowing natural sea water and synthetic sea waters." *Corrosion Engineering, Science & Technology,* vol. 55 issue 7, p579-588, Accessed Feb 21 2022. https://doi.org/10.1080/1478422X.2020.1765476
- Gismelseed, A. and M. Elzain, A. Yousif, A. Al Rawas, I. A. Al-Omari, H. Widatallah, A. Rais (2004). "Identification of corrosion products due to seawater and fresh water." *ICAME 2003*, 487–492. Accessed Feb 23 2022. https://doi.org/10.1007/978-1-4020-2852-6_72

Appendix

Figure A1: Run Order Randomization Scheme

	LiquidType	SubmersionTime (Days)	MassChange(g)	StartMass(g)	EndMass(g)
1	Water	1	•	•	•
2	Saltwater	1	•	•	•
3	Water	1	•	•	•
4	Lemon Juice	3	•	•	•
5	Water	1	•	•	•
6	Lemon Juice	1	•	•	•
7	Saltwater	1	•	•	•
8	Lemon Juice	2	•	•	•
9	Saltwater	3	•	•	•
10	Saltwater	2	•	•	•
11	Water	3	•	•	•
12	Saltwater	1	•	•	•
13	Lemon Juice	1	•	•	•
14	Saltwater	1	•	•	•
15	Lemon Juice	3	•	•	•
16	Lemon Juice	1	•	•	•
17	Lemon Juice	2	•	•	•
18	Saltwater	2	•	•	•
19	Lemon Juice	3	•	•	•
20	Saltwater	1	•	•	•
21	Lemon Juice	2	•	•	•
22	Lemon Juice	2	•	•	•
23	Water	2	•	•	•
24	Lemon Juice	2	•	•	•
25	Lemon Juice	2	•	•	•
26	Water	2	•	•	•
27	Saltwater	3	•	•	•
28	Saltwater	2	•	•	•
29	Lemon Juice	3	•	•	•
30	Water	1	•	•	•
31	Lemon Juice	3	•	•	•
32	Saltwater	3	•	•	•
33	Lemon Juice	1	•	•	•
34	Water	2	•	•	•
35	Water	1	•	•	•
36	Saltwater	1	•	•	•
37	Water	3	•	•	•
38	Lemon Juice	3	•	•	•
39	Saltwater	3	•	•	•
40	Saltwater	2	•	•	•
41	Water	2	•	•	•
42	Saltwater	2	•	•	•
43	Saltwater	3	•	•	•
44	Water	1	•	•	•
45	Water	2	•	•	•
46	Lemon Juice	1	•	•	•
47	Saltwater	2	•	•	•

Figure A2: Interaction Profiles

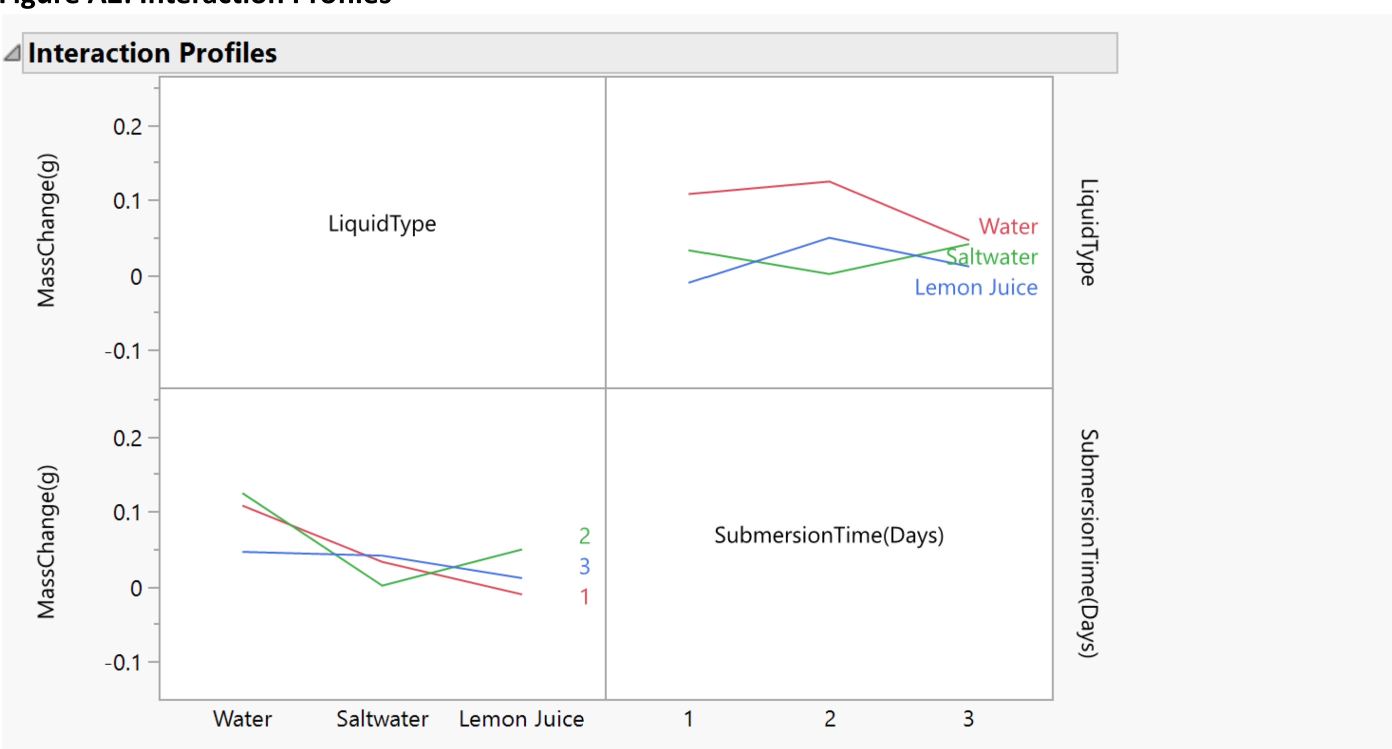


Figure A3: Side-by-Side Boxplots of Each Treatment Group

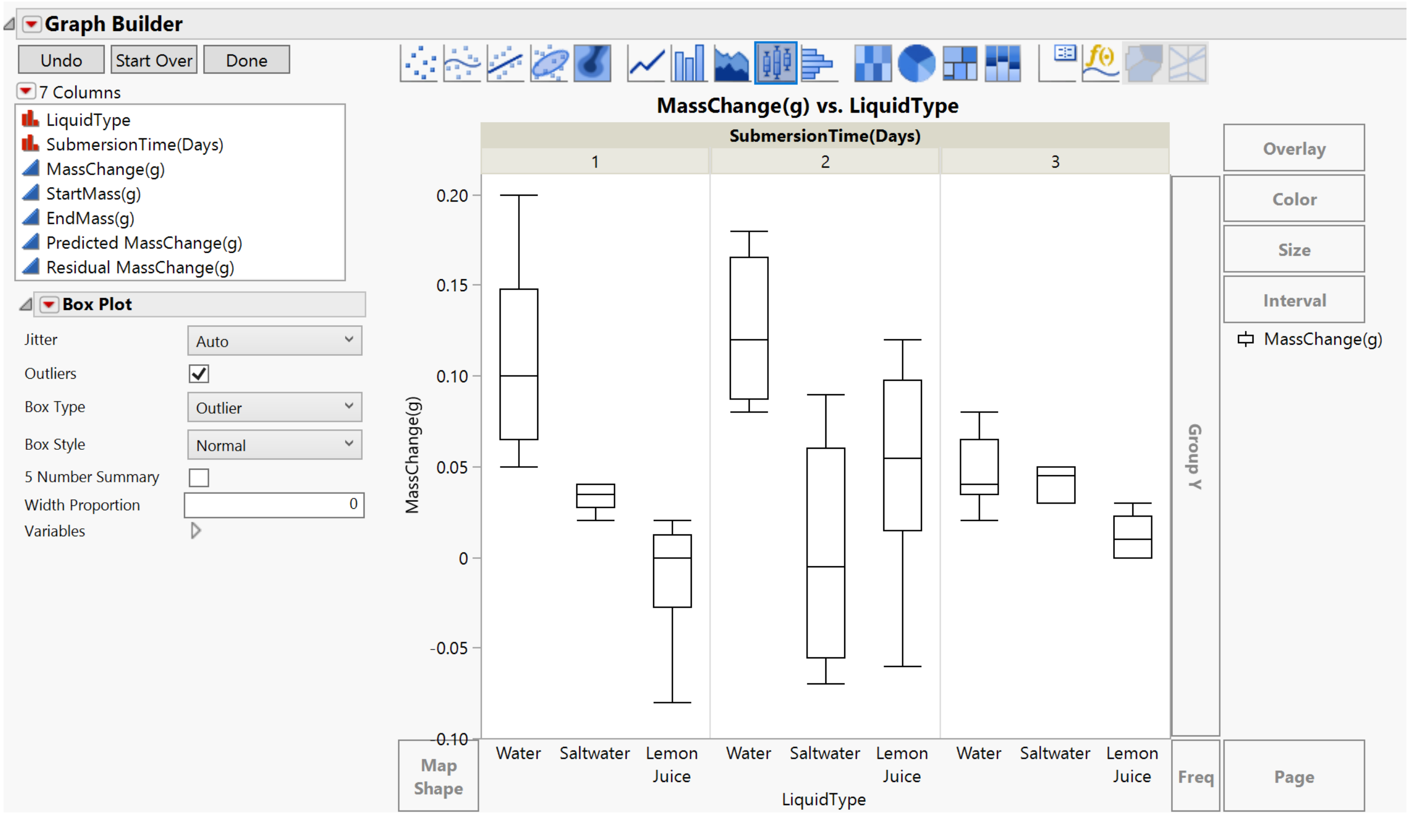


Figure A4: Side-by-Side Boxplots of Each Liquid Group

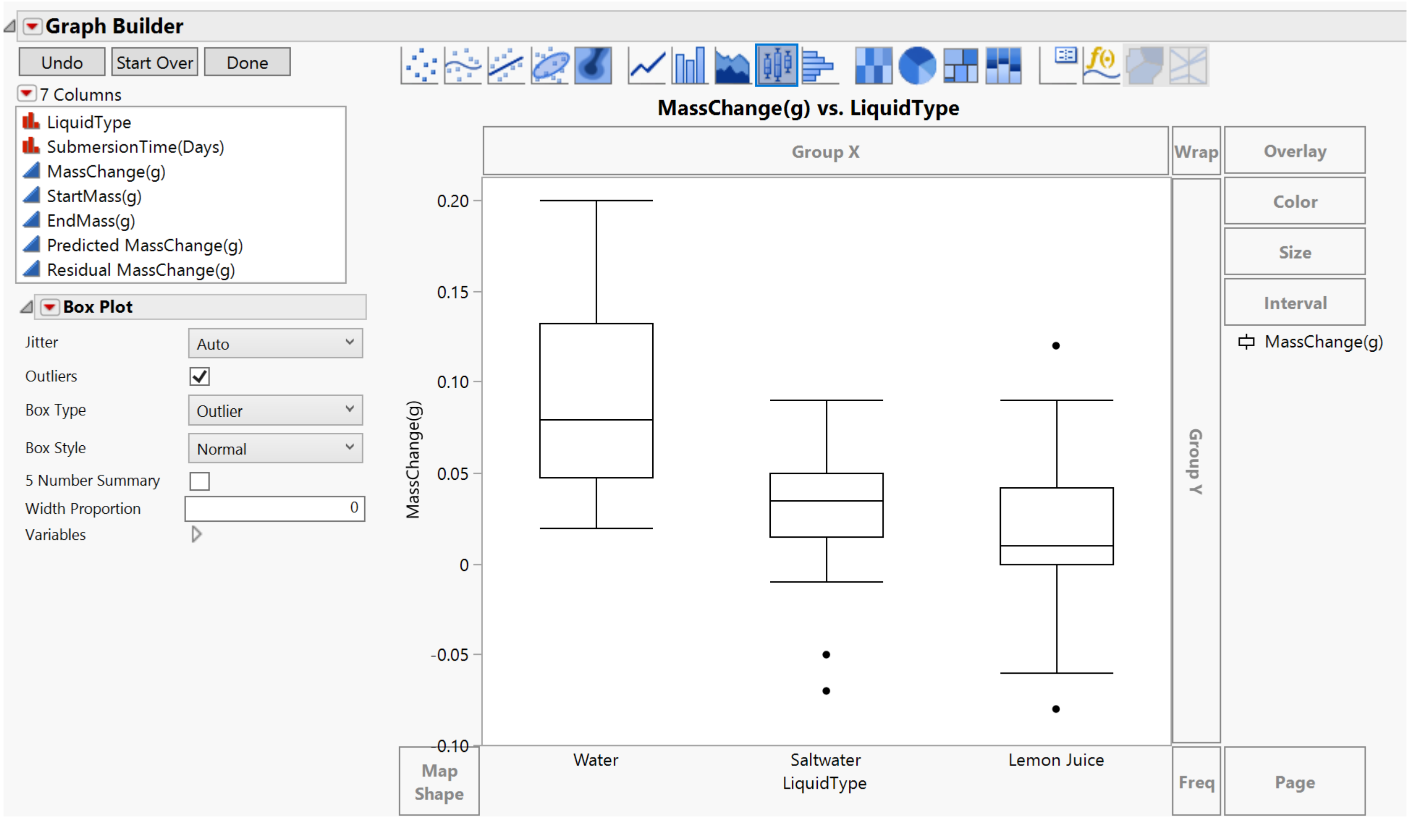


Figure A5: Side-by-Side Boxplots of Each Submersion Time Group

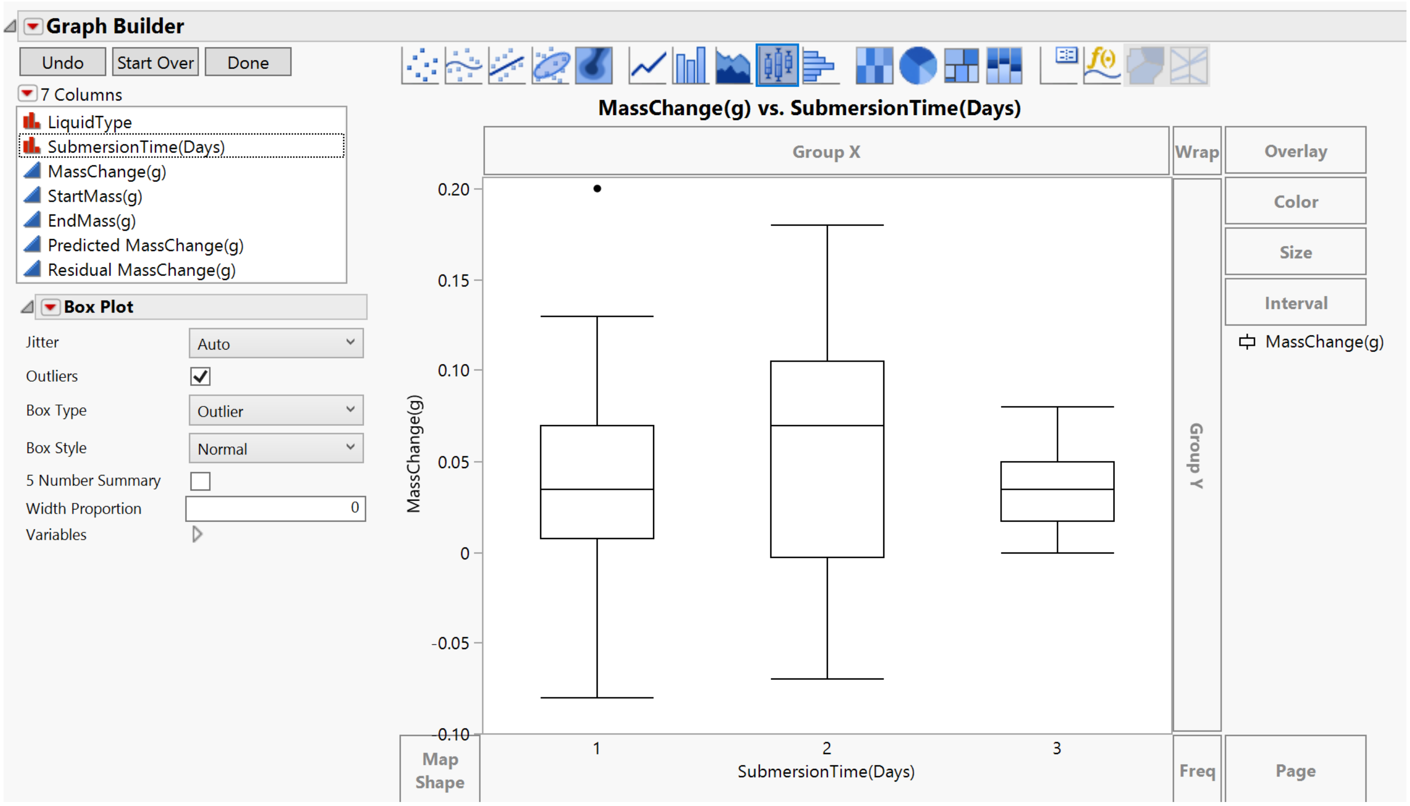


Figure A6: Normal Quantile Plot and Shapiro-Wilk's Goodness of Fit Analysis

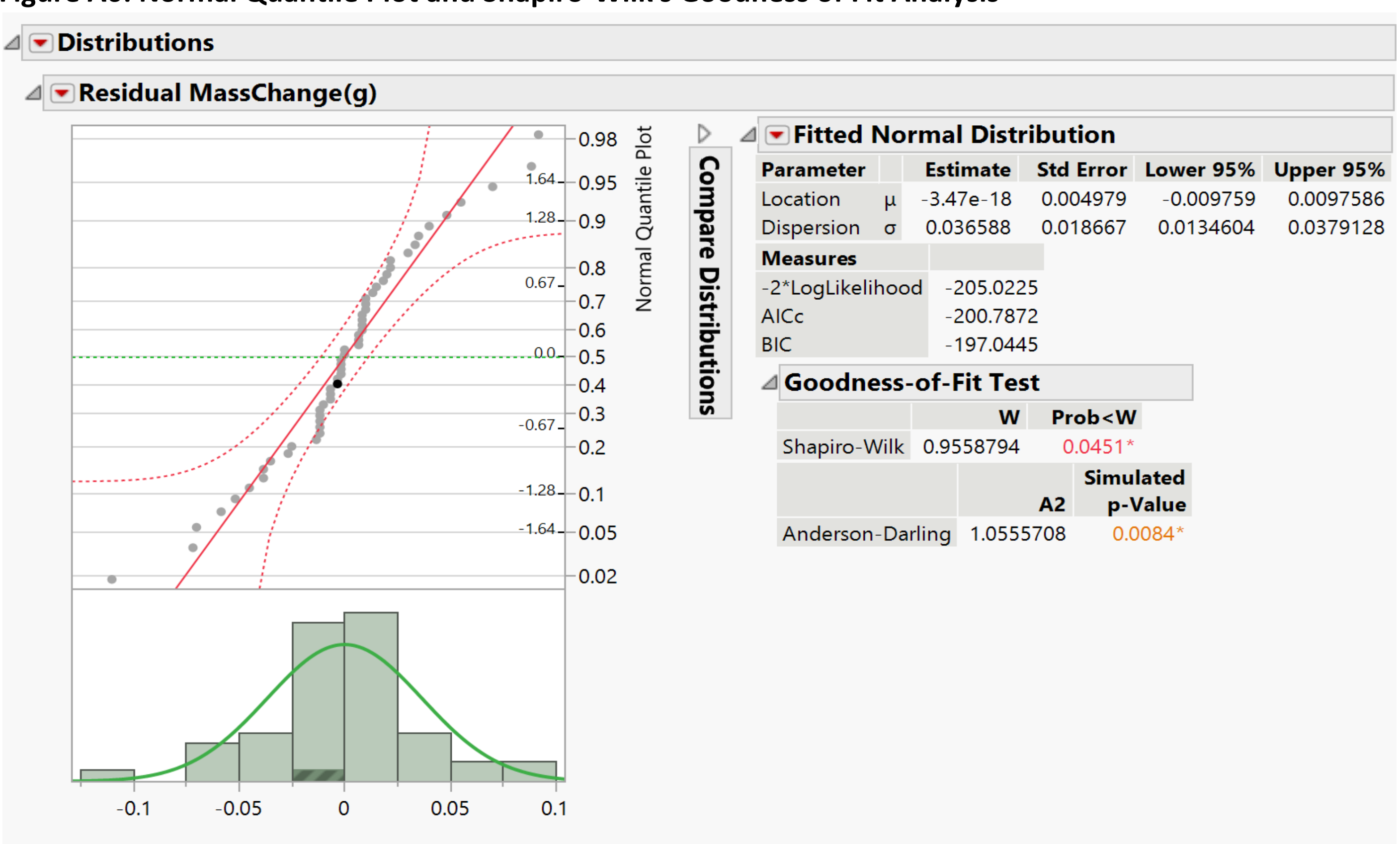


Figure A7: Residual versus Predicted Response Plot

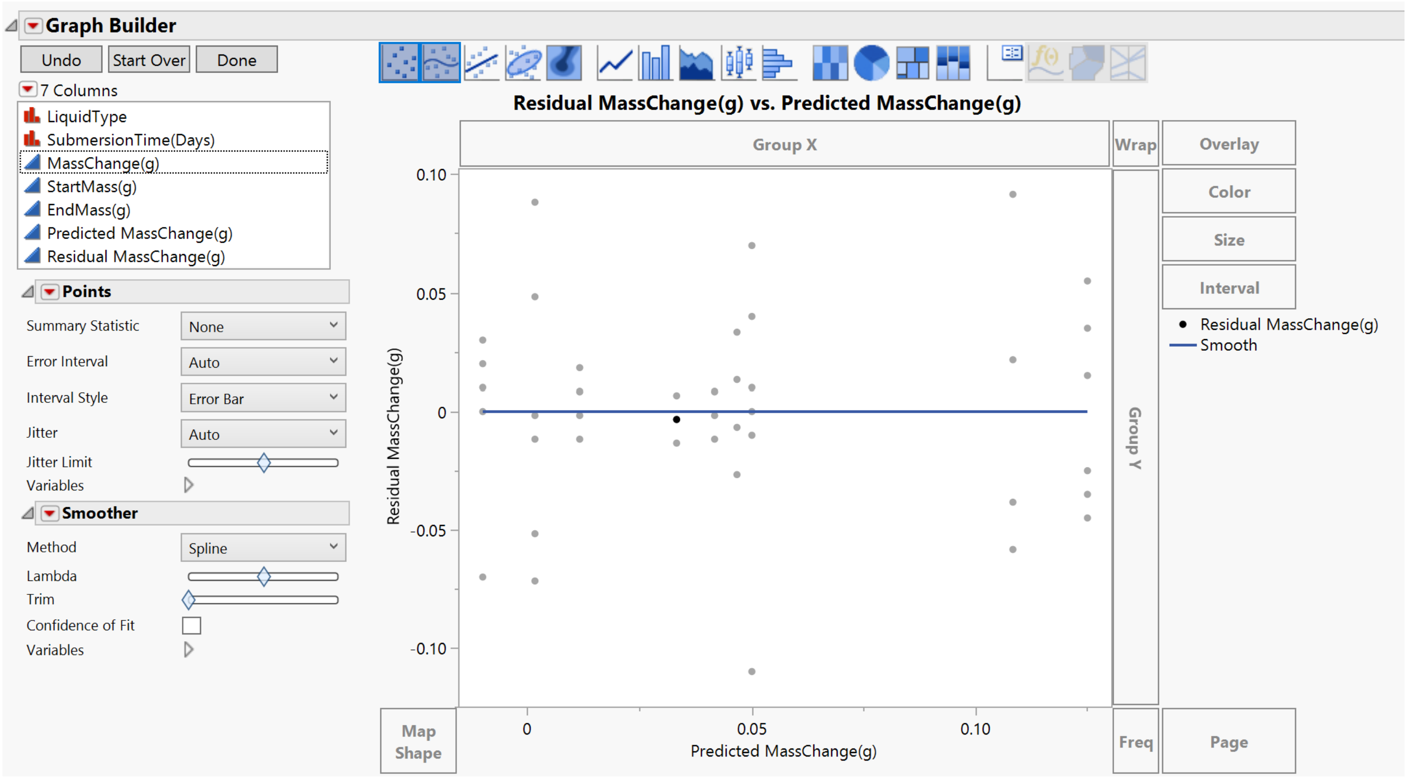


Figure A8: Global F-Test ANOVA and Effects Test Analysis

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	0.09959259	0.012449	7.8958
Error	45	0.07095000	0.001577	**Prob > F**
C. Total	53	0.17054259		<.0001*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LiquidType	2	2	0.06273704	19.8955	<.0001*
SubmersionTime(Days)	2	2	0.00593704	1.8828	0.1640
LiquidType*SubmersionTime(Days)	4	4	0.03091852	4.9025	0.0023*

Figure A9: Interaction Effect Connecting Letters Report from Tukey Post-Hoc Analysis

Level				Least Sq Mean
Water,2	A			0.1250000
Water,1	A	B		0.1083333
Lemon Juice,2		B	C	0.0500000
Water,3		B	C	0.0466667
Saltwater,3		B	C	0.0416667
Saltwater,1			C	0.0333333
Lemon Juice,3			C	0.0116667
Saltwater,2			C	0.0016667
Lemon Juice,1			C	-0.0100000

Levels not connected by same letter are significantly different.

Figure A10: Water versus Salt Water and Lemon Juice Contrast Test Report

Contrast

Test Detail

Water,1	0.3333
Water,2	0.3333
Water,3	0.3333
Saltwater,1	-0.167
Saltwater,2	-0.167
Saltwater,3	-0.167
Lemon Juice,1	-0.167
Lemon Juice,2	-0.167
Lemon Juice,3	-0.167
Estimate	0.0719
Std Error	0.0115
t Ratio	6.2765
Prob>|t|	1.2e-7
SS	0.0621
Lower 95%	0.0489
Upper 95%	0.095

SS	NumDF	DenDF	F Ratio	Prob > F
0.062	1	45	39.3945	<.0001*