The Short Term Effect of Liquids on the Rusting of Nails

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1. Introduction

Our research question asked if different liquids and the amount of time submerged in those liquids had an effect on the rusting of nails. Upon researching the topic we learned that nails tend to take two or more weeks for nails to fully rust in liquid. Given the time frame for our project was slim, we wanted to see if the effect of different liquids rusting nails held true in a shorter time frame. The results of this study could be applicable to professions such as engineering, chemistry, and construction. Many of the objects we use on a daily basis such as cars, bridges, and other machines could be negatively affected by rusting.

Related Articles:
https://rustconverters.net/how-long-does-it-take-metal-to-rust/
https://www.healthline.com/health/stepped-on-a-nail

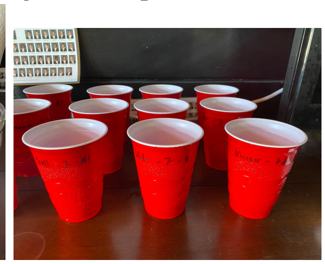
The first article selected is written by a veteran auto body painter, and he speaks on the corrosivity of different types of metal, particularly in the rain and how quickly these materials can rust. He claims that under heavy rain, iron-rich metals can form rust after just four to five days of exposure. This goes hand in hand with our investigation into the short term effects of liquid on causing rust. The second article stems from a common phenomenon that stepping on a rusty nail can plague you with a very threatening illness: Tetanus. While our study is mainly applicable to the usage of nails in construction and machinery, it's important to be wary of a rusty nail when barefoot as well.

While we were interested as to the effects of rusting the nails for 5 days compared to 7 days, we were mainly focused on the difference in rusting between the three liquids; Vinegar, Water, and Salt Water. The latter two with more real world implications such as rainfall and underwater structures. Upon researching the causation of rust, we learned that it stems from oxidation. Knowing this, we expected the most rust from Water and Salt Water submerged for 7 days. We are also very curious as to the effects of vinegar.

2. Materials and Methods

We went to Rite Aid and bought 18 red solo cups, distilled white vinegar, and Morton iodized salt. We then went to Home Depot and got 18 black drywall nails. Note: we also used regular tap water for this experiment. We poured a cup of each liquid into each red solo cup. For the salt water, we put half a tablespoon of salt into the water that was in the red solo cup. This ratio of salt to water nearly mimics the salinity of saltwater in the oceans. Finally, we placed the 18 black drywall nails into each cup. We started the experiment on February 1 2022 at two o'clock pm. On February 6 2022 at two o'clock pm, we took the nails out of the cups that had the treatment for 5 days and weighed them. Two days later, we took the nails that had the treatment for 7 days out and weighed them.

Below are some images of the process:



2.1 Treatment Structure

The treatment structure was a 2 by 3 factorial with 6 treatment combinations. We used 3 replications per treatment. Time was a factor, that being the amount of time each nail was submerged in each liquid. We submerged half of the nails for 5 days and the other half for 7 days. The type of liquid was also a factor. The liquids included salt water, tap water, and vinegar. We did research on liquids that could potentially show rusting of nails and these three continually popped up.

2.2 Response Variable(s)

The response variable is the end weight of the nails after being submerged in the liquids. Our scale measured the nails in ounces and then we converted that to grams. Note that the initial weights of all the nails were the same. We were aiming to have the response variable be high, as then we would be able to show that liquid does truly affect the weight of nails when submerged.

2.3 Experimental Unit

The experimental units were the nails that were placed in each cup. We went to Home Depot and asked for the most standard product of nails they had. All the nails came from the same package.

2.4 Design Structure

We used a completely randomized design structure. To use random assignment, we labeled the nails 1 through 18. We used a random number generator to assign a random nail to each cup so that each cup had a nail. We used three replicates per treatment combination in order to ensure that power was as high as possible. We wanted to detect a significant difference in weights if there was one.

2.5 Dealing with other sources of variation

Some potential sources of variation included the type of cup used, the temperature at which the cups and nails were at, and the location of each cup and nail. To deal with these factors, we aimed to create a uniform procedure so that these sorts of variations would not appear in our data. Like the pictures show, we placed all experimental units in the same location and at the same time, while also using the same exact kind of cup. The cups were also placed in the center of a large room to limit effects of sunlight and changes in temperature. Additionally, which nail went into each cup and the order of doing so were both randomized.

2.6 Statistical model and data analysis

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

Y_{ijk} represents the kth response of the ith level of time and jth level of liquid.

μ represents the overall mean response.

α_i represents the ith level of amount of time submerged on the response.

B_j represents the jth level of type of liquid on the response.

$(\alpha\beta)_{ij}$ represents the "effect" of the ith level of Time submerged crossed with the jth level of type of liquid on the response.

ϵ_{ijk} represents the error on the kth response of the ith level of time submerged and jth level of type of liquid.

We assume ϵ_{ijk} - $iidN(0,\sigma2)$

$i = 1, 2;\quad j = 1, 2, 3;\quad k = 1, 2, 3$

To analyze the data, we used JMP version 15. Both time submerged and type of liquid are fixed effects. The statistical method that we used was ANOVA.

3. Analysis and Results

Note: all graphs are in the appendix to comply with the rubric and keep it under 4 pages

3.1 Descriptive Statistics

Since our study had two factors (type of liquid and time nail spent in liquid), we have two main effects plots as well as an interaction effect. First off, boxplots can be a good way to get a sense of the distribution of a quantitative variable. As seen in figure 3.1, the distribution of the six replicates in salt water, tap water, and vinegar is shown. The number of dots on a liquid type represent the number of unique end weights for that particular treatment group. The red box plots give information on the distribution of the end weights for each of the three liquids. The larger the boxplot, the more within group variation there is for that specific liquid type. The green diamond gives information on the estimate for the population mean. The center of the diamond is the sample mean, or the estimate for the population mean for that specific liquid type. The top and bottom of the diamond represent a 95% confidence interval for the population mean. As seen in figure 3.1, there is very little overlap between the vinegar green diamond and the other liquid's green diamonds. This means that there is very little or no overlap between the confidence intervals for the population mean of end weight for each liquid type, so there could potentially be a significant difference between these groups.

In figure 3.2, the distribution of the six replicates is shown. Since there are only two levels to this factor (five days and seven days), we have two distributions shown. Notice that there is lots of overlap between the two confidence intervals, meaning we are unlikely to find a significant difference between the mean end weight between the five day group and the seven day group.

Before interpreting the p-values for the main effects, we need to analyze our data to determine if there is an interaction. If there is an interaction effect between liquid type and the amount of time the nail spends in the cup, then we don't test for main effects. When interpreting an interaction plot, if the slopes are the same then there is not an interaction between the two factors. Figures 3.6 and 3.7 give us reason to believe that there is no interaction between liquid type and duration of time the nail spent in the cup. Because vinegar has a constant value of end weight, its slope is a flat line as seen in figure 3.7. For the most part, the lines seem to be roughly parallel giving reason to believe there is no interaction effect.

If the interaction effect is not significant, then the plots of our main effects can give us clues on whether or not liquid type and the amount of time the nail is left in the cup has a statistically significant effect on the amount a nail rusts. In figure 3.3, a plot is shown comparing the distribution of nails left in the cup for five days and nails left in the cup for seven days. The red upward sloping line indicates that the nails left in the cups for seven days have a higher mean end weight than the nails left in the cups for five days. However, we don't know if the sample mean is statistically significant until we unpack the ANOVA table. In figure 3.4, the main effect of liquid is shown. From left to right, the distributions of vinegar, salt water, and tap water are shown. Once again, the upward sloping red line indicates that the different liquid types have a different mean end weight. We can't prove that this difference is significant until we interpret the ANOVA table.

3.2 Inferential Findings

Before interpreting any of the ANOVA tables, a good place to start is to verify the ANOVA assumptions. Firstly, the nails are completely independent of each other. How much one nail rusts has no effect on the rusting of another nail. Secondly, we have to check if the random errors are normally distributed. As seen in figure 3.8, random errors do seem to lie along the diagonal line generally well, but we can check for sure if the normality assumption is violated by running a Shapiro-Wilk test. In figure 3.9, Shapiro Wilk's test gives us a p-value of 0.0016, meaning that random errors are not normally distributed. Finally, we need to test for equal variance among the different levels for each factor(liquid type and duration of time the nail was left in the cup). Running Welch's test for equal variance, we can obtain a p-value that tells us if the variations between each level of a factor are statistically different. According to figure 3.11, we have evidence that at least one of the variances between liquid types is significantly different (Prob > F = 0.0008). Because vinegar had no within group variation, this is most likely why JMP tells us we have unequal variances. Vinegar could have a special property that prevents rusting, so the fact that we have unequal variances does not necessarily invalidate the results of our study. For the variance between the five day group and the seven day group, the p-value in figure 3.12 (Prob>F = 0.2108) shows us that the variances between each level of time are not statistically different.

After checking the ANOVA assumptions, we can look at our ANOVA table to determine if liquid type, time, and the interaction had a significant effect on the mean amount of rust accumulated by a nail. Before we can interpret our main effects, we need to check if we had a statistically significant interaction effect. Because we are making three comparisons of means, we used an individual significance level of 0.017 (0.05/3) since our family-wise error rate was 0.05. According to the interaction p-value in figure 3.13(0.30), we do not have evidence that the interaction effect is significant, allowing us to interpret the p-values of our main effects. Looking at the p-value for liquid in figure 3.13, we have strong evidence(p-value = 0.0003) that the type of liquid does have an effect on the mean end weight for nails that are similar to the ones used in the study. However, we do not have strong enough evidence(p-value = 0.0395) to conclude that the duration of time (5 days or 7 days) has an effect on the mean end weight for nails that are similar to the ones used in the study.

Now that we know that at least one of the liquid types has a significant effect on the mean end weight for submerged nails, we can use Tukey's output in JMP to determine which liquid was significantly different. According to figure 3.14, vinegar has a significantly different effect on the mean end weight for nails when compared to tap water and salt water. Levels in Tukey's output that do not share a letter are significantly different. Vinegar is the only liquid that does not have the letter A, so we know that it is significantly different from tap water and salt water.

4. Conclusion

The first conclusion that we were able to draw is that there is no significant interaction between type of liquid and duration submerged on the effect of nail weight (grams) due to rust.

We found there to be a significant effect of the type of liquid on the weight of the nails (grams). However, we did not find enough evidence to conclude a significant effect of duration submerged on the weight of the nails (grams).

We did not find any significant evidence of a liquid type with the highest average nail weight (grams) as Water and Salt Water were neck and neck. However, we found significant evidence that Vinegar had the lowest average nail weight (grams).

We did not have enough evidence to conclude that any one specific treatment had the largest or smallest effect. The treatments with Water and Salt water tended to be greater while the treatments with Vinegar tended to be smaller.

Note that these results were concluded at a 95% confidence level and these results can be applied to similar nails with the same testing conditions.

5. Next Steps

If we were to conduct this experiment again there are a few things we would change. Firstly, we would replace vinegar with a different liquid as across both durations, the nails did not rust at all. Perhaps the timeline needed to be longer to see rusting from vinegar. Secondly, we would've gotten a more precise scale. The scale used only provided increments of 0.1 oz, which is equivalent to almost 3 grams. This severely hampered the accuracy of our study.

Finally, one of the black marks on our study is that it did not satisfy the Normality Assumption. If given a second chance we would either expand the breadth of our study, or the time frame in order to achieve Normality.

References

Kurt Gorman (2021), "How Long Does It Take Metal to Rust?"
Valencia Higuera (2019), "How to Prevent Complications from Stepping on a Nail"

Appendix

Figure 3.1

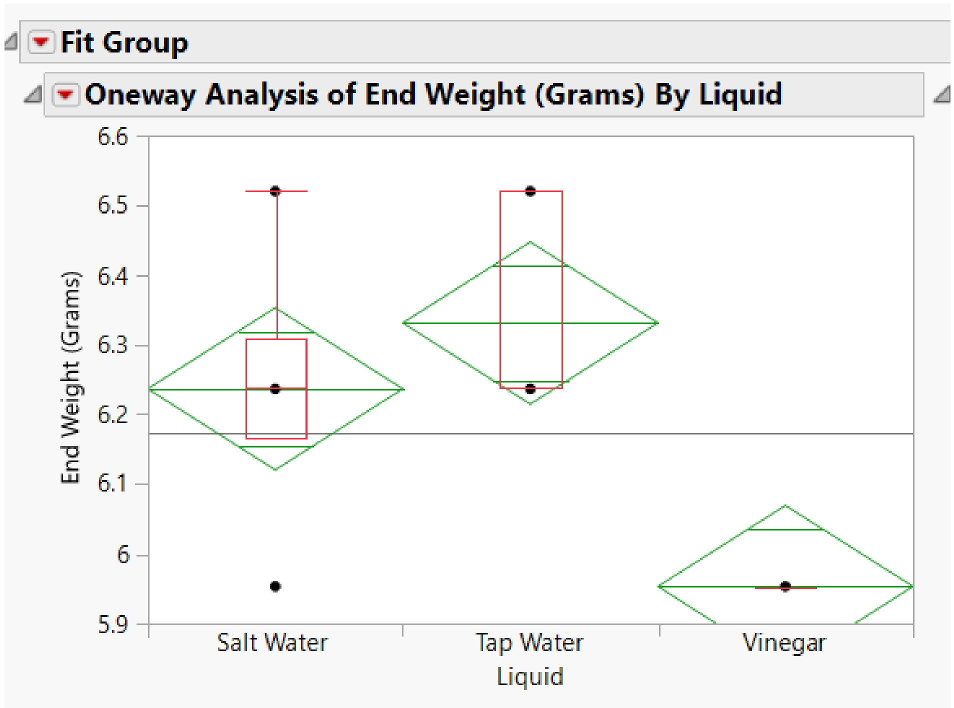
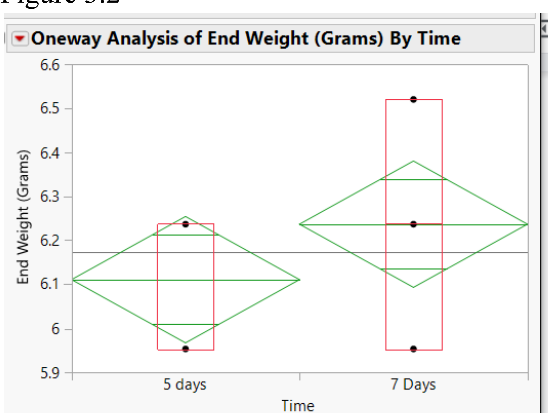


Figure 3.2



Oneway Anova

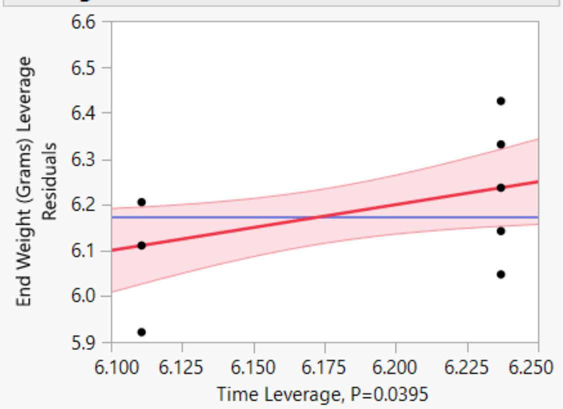
Summary of Fit

Rsquare	0.097559
Adj Rsquare	0.041156
Root Mean Square Error	0.203227
Mean of Response	6.173898
Observations (or Sum Wgts)	18

Figure 3.3

Time

Leverage Plot



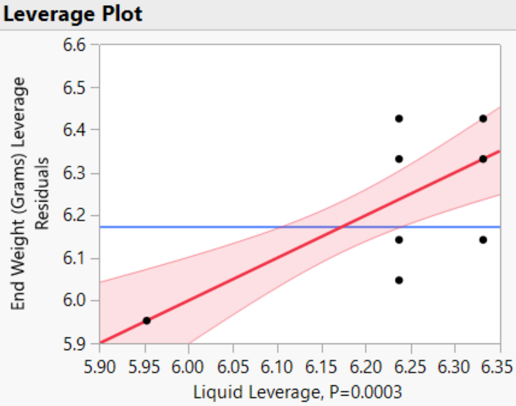
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
5 days	6.1109000	0.03857856	6.11090
7 Days	6.2368967	0.03857856	6.23690

Figure 3.4

Liquid

Leverage Plot



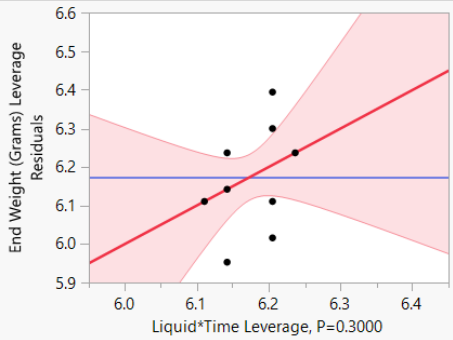
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
Salt Water	6.2368983	0.04724889	6.23690
Tap Water	6.3313967	0.04724889	6.33140
Vinegar	5.9534000	0.04724889	5.95340

Figure 3.5

Liquid*Time

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
Salt Water,5 days	6.1424000	0.06682002
Salt Water,7 Days	6.3313967	0.06682002
Tap Water,5 days	6.2369000	0.06682002
Tap Water,7 Days	6.4258933	0.06682002
Vinegar,5 days	5.9534000	0.06682002
Vinegar,7 Days	5.9534000	0.06682002

Figure 3.6

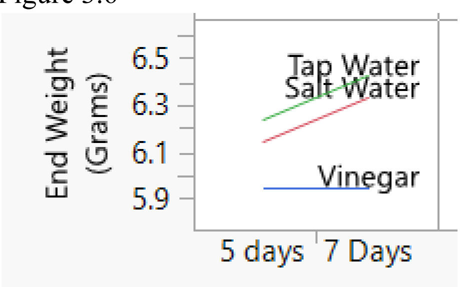


Figure 3.7

Interaction Profiles

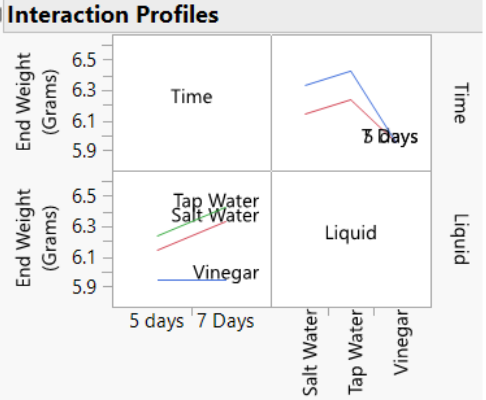


Figure 3.8

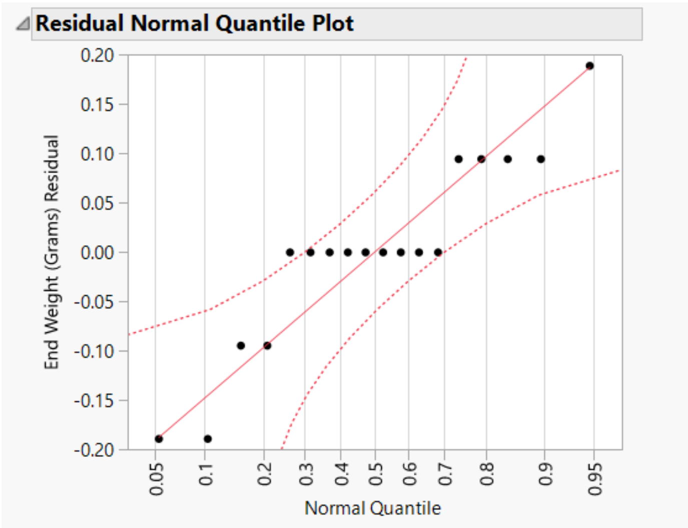


Figure 3.9

AICc	-1.725214
BIC	-0.74447

Goodness-of-Fit Test

	W	Prob<W
Shapiro-Wilk	0.8018117	0.0016*

	A2	Prob > A2
Anderson-Darling	1.5142588	0.0010*

Figure 3.10a

Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Liquid	2	0.46436544	0.232183	13.0004	0.0005*
Error	15	0.26789427	0.017860		
C. Total	17	0.73225971			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Salt Water	6	6.23690	0.05456	6.1206	6.3532
Tap Water	6	6.33140	0.05456	6.2151	6.4477
Vinegar	6	5.95340	0.05456	5.8371	6.0697

Std Error uses a pooled estimate of error variance

Figure 3.10b

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Time	1	0.07143822	0.071438	1.7297	0.2070
Error	16	0.66082149	0.041301		
C. Total	17	0.73225971			

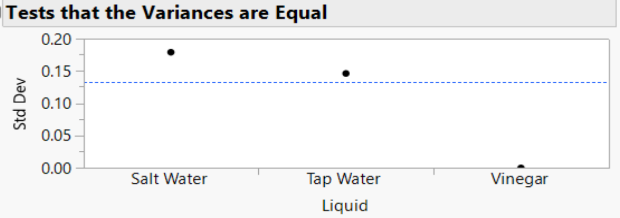
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
5 days	9	6.11090	0.06774	5.9673	6.2545
7 Days	9	6.23690	0.06774	6.0933	6.3805

Std Error uses a pooled estimate of error variance

Figure 3.11

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Salt Water	6	0.1792980	0.0944994	0.0944983
Tap Water	6	0.1463936	0.1259956	0.0944967
Vinegar	6	9.73e-16	8.882e-16	0.0000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.3827	2	15	0.2811
Brown-Forsythe	1.2500	2	15	0.3147
Levene	3.2500	2	15	0.0672
Bartlett	147.7127	2	.	<.0001*

Welch's Test

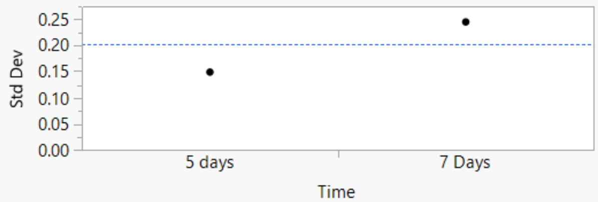
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
25.0011	2	6.6667	0.0008*

Figure 3.12

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
5 days	9	0.1494176	0.1400000	0.1260000
7 Days	9	0.2455139	0.1889978	0.1889967

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	5.4504	1	16	0.0329*
Brown-Forsythe	0.8420	1	16	0.3724
Levene	1.0609	1	16	0.3183
Bartlett	1.7852	1	.	0.1815
F Test 2-sided	2.6999	8	8	0.1816

Welch's Test

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.7297	1	13.211	0.2108

t Test
1.3152

Figure 3.13

5.9 6 6.1 6.2 6.3 6.4 6.5

End Weight (Grams) Predicted

Studentized Residuals

Summary of Fit

RSquare	0.780492
RSquare Adj	0.68903
Root Mean Square Error	0.115736
Mean of Response	6.173898
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	0.57152277	0.114305	8.5335
Error	12	0.16073694	0.013395	Prob > F
C. Total	17	0.73225971		0.0012*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	6.1738983	0.027279	226.32	<.0001*
Time[5 days]	-0.062998	0.027279	-2.31	0.0395*
Liquid[Salt Water]	0.063	0.038579	1.63	0.1284
Liquid[Tap Water]	0.1574983	0.038579	4.08	0.0015*
Liquid[Salt Water]*Time[5 days]	-0.0315	0.038579	-0.82	0.4301
Liquid[Tap Water]*Time[5 days]	-0.031498	0.038579	-0.82	0.4301

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Time	1	1	0.07143822	5.3333	0.0395*
Liquid	2	2	0.46436544	17.3339	0.0003*
Liquid*Time	2	2	0.03571911	1.3333	0.3000

Residual Normal Quantile Plot

Figure 3.14

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level			Mean
Tap Water	A		6.3313967
Salt Water	A		6.2368983
Vinegar		B	5.9534000

Levels not connected by same letter are significantly different.

Figure 3.15

Level			Least Sq Mean
Tap Water,7 Days	A		6.4258933
Salt Water,7 Days	A		6.3313967
Tap Water,5 days	A	B	6.2369000
Salt Water,5 days	A	B	6.1424000
Vinegar,5 days		B	5.9534000
Vinegar,7 Days		B	5.9534000

JMP Randomization

2x3 Factorial
Design 2x3 Factorial
Model
Evaluate Design
DOE Dialog

Columns (4/0)
Pattern
Duration (Days)
Liquid
Weight of Nail

Rows
All rows 18
Selected 0
Excluded 0
Hidden 0
Labeled 0

	Pattern	Duration (Days)	Liquid	Weight of Nail
1	+2	7	Vinegar	•
2	−3	5	Salt Water	•
3	+2	7	Vinegar	•
4	−3	5	Salt Water	•
5	−1	5	Water	•
6	+1	7	Water	•
7	−2	5	Vinegar	•
8	−2	5	Vinegar	•
9	−3	5	Salt Water	•
10	+1	7	Water	•
11	+1	7	Water	•
12	−1	5	Water	•
13	−2	5	Vinegar	•
14	+3	7	Salt Water	•
15	+3	7	Salt Water	•
16	+2	7	Vinegar	•
17	−1	5	Water	•
18	+3	7	Salt Water	•