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Melting Ice: How do Common Household Items – such as Coffee grinds and Sand Compare to Rock Salt and Calcium Chloride as Melting Agents?

Abstract

Snowfall and ice accumulation have been associated with an increased number of roadside accidents. In turn, it is important to find substances that can increase ice melting to combat the dangers of driving in icy conditions. To melt ice, rock salt is most commonly applied, however, it also introduces negative impacts on the environment – including toxicity to fish, plants, and groundwater contamination when excessive amounts dissolve in local water reserves. This study compared four substances: rock salt, sand, coffee grinds and calcium chloride against a negative control to test for the effectiveness of other treatments at melting ice to see whether rock salt is the most effective melting agent. Each ice cube was first measured using a weighing scale, and an initial weight was recorded in grams (g). Succeeding this, the ice cube was placed on a ceramic plate containing the treatment melting agent and allowed to melt for two minutes. The final weight of the ice cube was then recorded on the scale. The difference in the final and initial weight of the ice cube served as a proxy for the amount of ice melted; the values of which were then collected and compared across the five groups (including four treatments and one control) over the span of four trials. It was hypothesized that if rock salt is more effective than the other melting agents at melting ice, then the difference in grams of ice melted for ice cubes treated with rock salt should be higher than ice cubes exposed to other treatments. Results indicated that this response was not the case. Instead, calcium chloride was the most effective at melting ice, with rock salt following second, and finally sand and coffee grinds tying for the last position. Relative to the control, however, all groups led to increased melting. A one-way ANOVA test indicated that the difference in means among these groups was significant. Although less effective than commercial agents (rock salt and calcium chloride), common household items such as sand or coffee grinds may still be a sufficient tool to prevent ice accumulation in one's household and may provide a safer, environmentally friendly alternative to sodium chloride and calcium chloride salts.

Introduction

Increased snowfall has been linked to a sharp increase in the number of roadside accidents according to a study examining traffic data in Montreal, Canada (Andreescu and Frost, 1998). Thus, to warrant road safety, it is important that municipalities and individual house owners are prepared for icy winter conditions and maintain safety during these times. As a result, melting agents are commonly used to ensure roads remain clear. Ionic salts such as NaCl (such as rock salt) lead to a depression in the freezing point of water which can be explained by

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entropic effects (Kim & Yethiraj, 2008; Fernandez, Abascal, &Vega, 2006). Salts lower the chemical potential of the liquid phase relative to the crystal due to an increase in entropy when water molecules undergo mixing with ions (Pruppacher & Klett, 2012). In other words, salt lowers the freezing point of water which can aid in melting.

Currently, rock salt is the most commonly used agent to melt ice which can be attributed to the fact that it is quite inexpensive (Kim & Yethiraj, 2008). However, this may not mean rock salt is actually the most efficient or environmentally friendly melting agent. Unfortunately, considerable amounts of rock salt dissolve and wash into soil and streams (Jackson & Jobbagy, 2005). In the United States, approximately 18 million Mg of NaCl are used on roads each year (Jackson & Jobbagy, 2005). Regrettably, these sources are often forgotten which could not only lead to toxic effects on plants and fish but lead to groundwater contamination (Jackson & Jobbagy, 2005). The accumulation of salts may also lead to human impacts such as increased salt intake from contaminated water, and potential hypertension following over-consumption (Jackson & Jobbagy, 2005). On the flip side, there are various substances that may be able to serve the function of melting ice without the detrimental environmental effects of accumulating NaCl (Jackson & Jobbagy, 2005). Since rock salt is used most commonly in the US, this investigation sought to test whether it is actually the most effective. In this experiment, the effectiveness of other common household agents, and commercial materials will be tested for their ability to melt ice in comparison to rock salt. The research question being investigated throughout this experiment is the following: is rock salt actually more effective at melting ice than other substances such as sand, coffee grinds, and calcium chloride? It is hypothesized that if rock salt is more effective at melting ice, then the difference in grams (g) of ice melted for ice cubes treated with rock salt should be higher than ice cubes exposed to other melting agents.

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Methods

This investigation consisted of four treatment groups and a single negative control. The negative control is essential to establish that the results obtained can be related back to the treatment in question as opposed to other confounding variables that may be presented throughout the procedure. As such, a negative control is a control group that receives no treatment and is not expected to produce results. In this study, the negative control was the group that was not exposed to any melting agents but allowed to melt for two minutes. On the other hand, the treatment groups consisted of ice cubes exposed to one of the following melting agents: rock salt, sand, coffee grinds, or calcium chloride. These treatments are expected to show varying impacts on the melting rate of the ice cube and will in turn be compared to the negative control group to test for differences.

Firstly, two ice cube trays consisting of twelve ice cubes spots each were filled with tap water and allowed to freeze overnight. On the day of data collection, five stations were set up consisting of five ceramic plates containing either one tablespoon of JanSan rock salt, Procom Silica sand, Starbucks house blend coffee grinds, Snow Joe calcium chloride, or no melting agent (negative control). Next, a single ice cube was carefully removed from the ice-cube tray in the freezer using tongs to minimize contact with hands (and thus body heat). The initial weight was measured and recorded using an AccuChef weighing scale as shown below in figure 1. Following this, the ice cube was immediately placed on the plate containing rock salt to minimize melting in between the time it takes to move the ice cube from the scale to the station. A timer was started for two minutes to allow for detectable melting. The ice cube was then removed from the treatment and weighed again on the scale. The initial and final weights of the ice cube were recorded. This step was repeated for each of the other groups (sand, coffee grinds, calcium chloride and the control) resulting in five measurements. In order to obtain four trials, and a larger number of replicates, (for more ecological validity) this experiment was repeated over an additional three trials for a period of four days. To keep temperature relatively constant, all trials were conducted in the same location (home kitchen) while the ambient temperature of each room was measured using a thermometer and recorded for each trial. This room temperature was kept constant (at 21 degrees Celsius) across all trials. To analyze the data, a one-way ANOVA test was employed to compare the differences among the five groups. A histogram of the data was compiled to confirm that the data was normally distributed such that the requirements of the one-way ANOVA analysis were met (see appendix B).

Figure 1. *Displays the weighing scale as part of the experimental set-up. The AccuChef weighing scale was used to measure the initial and final weights of the ice cubes. This instrument provides readings in grams (g) to whole number digits. A ceramic plate was placed on the scale and tared to allow for a reading of the ice cube prior to and following exposure to a melting agent.*

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Results

As depicted in figure 2 below, all melting agents (rock salt, sand, coffee grinds, and calcium chloride) resulted in a non-zero amount of ice melted. Relative to the control, the treatments resulted in a larger amount of ice melted. Across all treatment groups, calcium chloride resulted in the highest amount of ice melted, with rock salt following second. Sand and coffee grinds melted the least and an approximately equal amount of ice. Over the span of the four trials, the trends for each group stayed relatively constant. An average of 4.25g of ice was melted by calcium chloride, 3.25g by rock salt and 2.25g for both sand and coffee grinds as described in table one below. Qualitatively, the rock salt and calcium chloride were observed to be the most coarse in texture, and white in color. The coffee grinds were dark brown and dissolved into a brown solution when ice was melted. Finally, the silica sand was fine in texture and tan in color. There was noticeable melting across all melting agents, with very little distinguishable melting in the control sample. This was noted as a puddle of water forming in the ceramic plate sample.

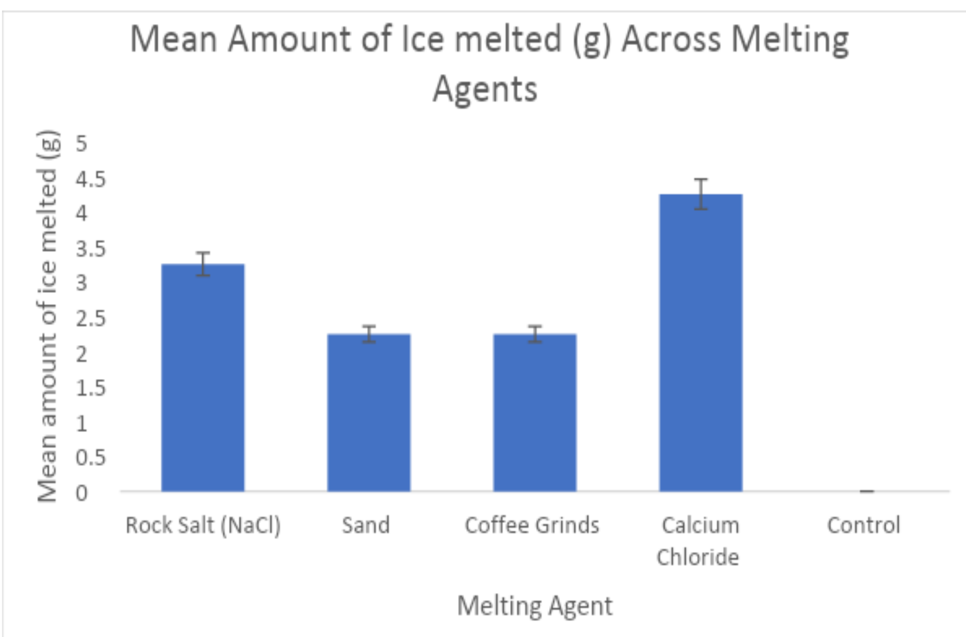

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Figure 2. *Illustrates the mean amount of ice melted (g) as a difference in the final and initial weights of ice cubes (as indicated on the y-axis) after exposure to a melting agent for two minutes. The treatment groups consisted of either JanSan rock salt, Procom Silica sand, Starbucks house-blend coffee grinds, and Snow Joe calcium chloride in addition to the negative control exposed to no melting agent as shown on the x-axis. Each trial was conducted on a separate day and the values were averaged across all trials to obtain a mean value. The ambient temperature was maintained at 21 degrees Celsius across all four trials. Error bars represent a 95% confidence interval. A one-way ANOVA test was conducted to analyze the data and indicated that there is a significant difference in the means of the above groups.*

Melting agent	Rock salt	Sand	Coffee Grinds	Calcium Chloride	Control
Mean amount of ice melted (g)	3.25g	2.25g	2.25g	3.25g	0g

Table 1. *Describes the mean values of ice melted (g) across the four trials for each of the treatments (rock salt, sand, coffee grinds, and calcium chloride) and control groups.*

A one-way ANOVA test provided an analytical tool to evaluate the data for significance. A histogram confirmed that the data followed a normal distribution (see appendix B) thereby fitting the assumptions of the one-way ANOVA. It should be noted that for the purposes of BIOL 342, the assumption of a sufficiently large sample size is ignored for the one-way ANOVA. A P-value of $1.75499\ x\ 10^{-8}$ was obtained through this analysis. It should be noted that an alpha value (or significance level) is the probability of committing a type one error. An alpha of 0.05 is small enough to denote the significance level for the purposes of this investigation and is a value used commonly in the scientific literature (Andreescu & Frost, 1998). As a result, this value was used as the basis for this statistical analysis. This indicates that there is a 5% risk of concluding that there is a difference in the means (if there is no actual difference). Since the P-value obtained ($1.75499\ x\ 10^{-8}$) is smaller than an alpha of 0.05 the means among the five groups (four treatments and one control) are not equal. Consequently, there is a difference in the melting rate across the groups. According to the confidence intervals shown in figure 2, the lack of overlap between the rock salt, and calcium chloride groups with the other treatments also suggest a significant difference in the mean amount of ice melted while following the same trend (with calcium chloride melting the most ice and rock salt following while sand and coffee grinds resulted in a similar amount of ice melting).

Discussion

This experiment sought to compare the effectiveness of various melting agents at melting ice to see if there are other alternatives to rock salt which is used most commonly but at a cost to the environment. To do this, ice cubes were weighed prior to and following exposure to a melting agent for two minutes. The difference in the final and initial weight provided a measure for the amount of ice melted and functioned as a tool to compare the melting efficiency of the treatment groups (rock salt, sand, coffee grinds, calcium chloride, and the control). Since rock salt is used most commonly in the US, this investigation aimed to test whether it is actually the most effective. It was previously hypothesized that if rock salt is more effective as a melting agent, then the difference in grams of ice melted for ice cubes treated with rock salt should be higher than ice cubes exposed to other melting agents. It appears this reaction was not the case.

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Since the obtained P-value of $1.75499 \, x \, 10^{-8}$ is smaller than an alpha of 0.05, there is a statistically significant difference in the means among the following groups: rock salt, sand, coffee grinds, calcium chloride, and the control. Although rock salt was more effective at melting ice than sand or coffee grinds, calcium chloride resulted in the largest amount of melted ice (an average of 4.25g as opposed to 3.25g by rock salt). As a result, the null hypothesis, that there are no differences in the amount of ice melted among the five groups, can be rejected. Since calcium chloride resulted in the largest difference, it is suggested that calcium chloride may be a more effective melting agent than rock salt contrary to the original hypothesis. It should also be noted that relative to the control, all melting agents resulted in a higher amount of ice melting.

There are also notable limitations to the data obtained in this study. Firstly, across multiple days, there may be variances in outdoor temperature or sun exposure which may influence the melting rate of ice. An elevated temperature may lead to faster melting of ice cubes which may result in an overestimate in the melting agents' effectiveness. On the other hand, a lower temperature may lead to an underestimate of a melting agents' effectiveness. Although the ambient temperatures were recorded and kept constant, the amount of sun exposure may also interfere with the data. Secondly, a small sample size inevitably leads to challenges. A small sample size in an experiment conducted on this scale has low statistical power, as well as low reproducibility. A higher variability may be difficult to replicate. Lastly, it may be difficult to generalize the results of this experiment due to the small sample size.

Substances containing sodium chloride such as rock salt have been used extensively in eliminating ice throughout the past, however, there are negative environmental impacts to groundwater and plant life. Calcium chloride was found to be 80-90% less corrosive than rock salt, and to be more effective at lower temperatures (Minimizing corrosion – calcium chloride, n.d.). Calcium chloride can increase the effectiveness of salt, by releasing heat which activates the melting ability of salt (Murphy, n.d.). However, calcium chloride can also lead to defoliation in plants and trees as well as deplete oxygen levels and kill wildlife in water if the chloride leaches into the waterway (Greener grounds: Searching for environmentally friendly solutions to ice and snow, 2017). Although calcium chloride and rock salt resulted in the highest melting rate, this investigation showed that other, safer alternatives that can be found easily at home are available to melt ice to a noticeable degree. To the average homeowner, these alternatives such as sand may be sufficient and useful in employing more diverse tactics to melt the ice around one's home. This step on a small scale may in turn help to reduce the negative ecological impact on a larger scale.

For future research, the expansion of the set of treatments to other potential melting agents that may also lower the melting point of ice and can be found easily such as rubbing alcohol is suggested. Additionally, magnesium chloride is a more friendly melting agent that poses less harmful side effects on plant life (Greener grounds: Searching for environmentally friendly solutions to ice and snow, 2017). Thus, this may be a promising angle to explore as an alternative to sodium or calcium chloride. Further, the use of more precise instruments that may notice changes in weight over more significant figures to ascertain a higher degree of precision is recommended. The instruments used in this study such as the weighing scale and thermometer did not provide any decimal figures. These small but noticeable changes may have a large impact on the data obtained and its analysis. Overall, the need to find more sustainable, and environmentally friendly sources for melting ice is illuminated and it is suggested that future research explore this field.

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Conclusions

In brief, the means across all five groups varied significantly in their ability to melt ice according to a one-way ANOVA analysis. Thus, the differences in the mean amount of ice melted upon exposure to one of the four melting agents can be attributed to the treatments. Consequently, the null hypothesis, that there are no differences in the mean amount of ice melted among the experimental groups, can be rejected. Contrary to the original hypothesis noted above, calcium chloride resulted in the largest amount of ice melted with rock salt following second, and sand and coffee grinds being the least effective. Notably, all treatment groups had a higher mean amount of ice melted compared to the control. Variations in the temperature and sun exposure may have influenced the melting rates. Additionally, the imprecision of weighing instruments limited how sensitive the obtained data was, and thus for future research, it is recommended that more precise instruments that can detect beyond whole numbers are used to measure weight. Further research exploring the effectiveness of other household agents as well as more environmentally friendly melting agents is recommended to make certain that we are not sacrificing environmental health to maintain road safety but rather addressing both streams through a multifaceted approach.

Acknowledgments

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Appendix A

		Rock salt (NaCl)	Sand	Coffee grinds	Calcium chloride	Control
Amount of ice melted (g) (final - initial weight)	Trial 1 (March 11, 2021, 6:00pm)	3	2	2	4	0
	Trial 2 (March 13, 2021, 6:00pm)	4	2	3	4	0
	Trial 3 (March 29, 2021, 6:00pm)	3	2	2	5	0
	Trial 4 (March 30, 2021, 6:00pm)	3	3	2	4	0

Table 2. *Demonstrates raw data across all four trials. The amount of ice melted was calculated by subtracting the final from the initial weight of the ice cube measured. Ice was allowed to melt for two minutes while exposed to the melting agent.*

Melting Agent	**Initial Weight of ice cube (g)**	**Final weight of ice cube (g)**	**Difference (g)**	**Observations**
Rock Salt (NaCl)	19	16	3	Rock salt is more coarse than other materials
Sand	18	16	2	Noticed melting in plate
Coffee Grinds	19	17	2	Noticeable melting

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Calcium Chloride	17	13	4	Noticeable melting (puddle forming)
Control	16	16	0	Very little melting

Table 3. *Displays trial 1 data. Collected on March 11, 2021 at 6:00pm. The ambient temperature was 21 degrees Celsius. Illustrates difference in grams (g) which serves as a proxy for the number of grams of ice melted. Refer to methods for procedure on how the data was collected.*

Melting Agent	Initial Weight of ice cube (g)	Final weight of ice cube (g)	Difference (g)	Observations
Rock Salt (NaCl)	17	13	4	Noticed melting immediately; white, coarse
Sand	19	17	2	Fine, tan in colour
Coffee Grinds	19	16	3	Dark brown, less coarse than other items

Calcium Chloride	20	16	4	Fine, white
Control	17	17	0	Very little melting

Table 4. *Displays trial 2 data. Collected on March 13, 2021 at 6:00pm. The ambient temperature was 21 degrees Celsius. Illustrates difference in grams (g) which serves as a proxy for the number of grams of ice melted. Refer to methods for procedure on how the data was collected.*

Melting Agent	**Initial Weight of ice cube (g)**	**Final weight of ice cube (g)**	**Difference (g)**	**Observations**
Rock Salt (NaCl)	16	13	3	Coarse, white
Sand	17	15	2	Fine, tan-colour
Coffee Grinds	16	14	2	Dark brown

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Calcium Chloride	18	13	5	Noticeable melting right away
Control	16	16	0	Very little melting

Table 5. *Displays trial 3 data. Collected on March 29, 2021 at 6:00pm. The ambient temperature was 21 degrees Celsius. Illustrates difference in grams (g) which serves as a proxy for the number of grams of ice melted. Refer to methods for procedure on how the data was collected.*

Melting Agent	**Initial Weight of ice cube (g)**	**Final weight of ice cube (g)**	**Difference (g)**	**Observations**
Rock Salt (NaCl)	19	16	3	Noticeable melting (puddle forming)
Sand	17	14	3	Noticed melting in plate
Coffee Grinds	18	16	2	Noticeable melting

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Calcium Chloride	18	14	4	Noticeable melting
Control	17	17	0	No melting (no puddle forming)

Table 6. *Displays trial 4 data. Collected on March 30, 2021 at 6:00pm. The ambient temperature was 21 degrees Celsius. Illustrates difference in grams (g) which serves as a proxy for the number of grams of ice melted. Refer to methods for procedure on how the data was collected.*

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Appendix B

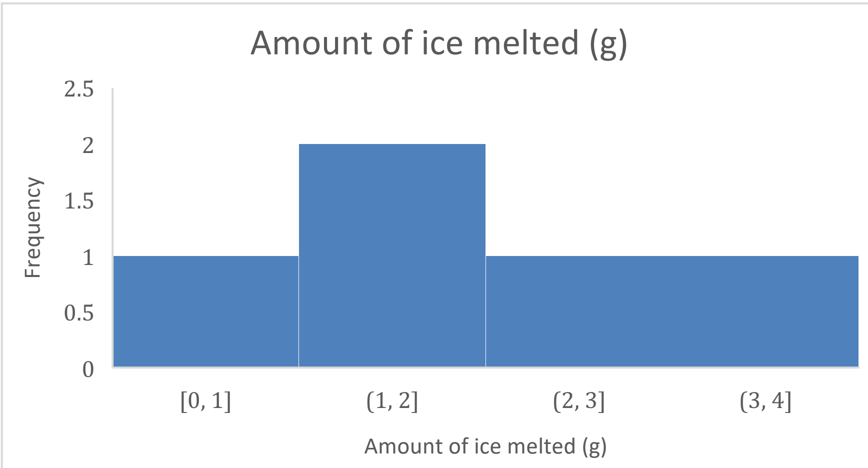

Figure 3*. Illustrates a histogram showing the frequency data for the amount of ice melted (g) across all five experimental groups (four treatments and one control). The histogram provided a measure to ensure the data was normally distributed before a one-way ANOVA analysis was conducted.*