



DIDACTIC

The phenomenon of brine rejection: a practical proposal for prospective primary teacher training



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Abstract The fact that sea ice may be a suitable source for fresh water is nothing new; in fact, sailors were aware of this long ago. Nevertheless, the issue that ice does reject the ions of a saline solution is not a well known topic by both novice learners and prospective teachers. This paper describes a practical activity carried out in the regular chemistry training course aimed at teachers-to-be with the objectives of, on the one hand, getting to know the phenomenon of brine rejection and, on the other hand, taking advantage of the utilized experimental design to gain insight into the colligative properties of solutions. This activity might also be adequate for secondary and high school levels.

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El fenómeno de la exclusión de la salmuera: una propuesta práctica para la formación de maestros de primaria

Resumen El hielo proveniente de la congelación del agua de mar es una fuente de agua potable. Este es un hecho bien conocido por pescadores y gentes de la mar desde antaño. Sin embargo, el fenómeno de la exclusión de la salmuera durante la congelación de disolución de agua salada es un tema poco conocido entre el profesorado en formación. Este artículo presenta una actividad práctica diseñada para ser llevada a cabo en un curso de formación básica en química para el alumnado de magisterio, con el objetivo de, por un lado, conocer más de cerca el fenómeno de la exclusión de la salmuera, y por otro, ayudar a lograr una mejor comprensión de las propiedades coligativas de las disoluciones. La actividad que se presenta también puede ser adecuada para el aula de secundaria.

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Introduction

The brine rejection phenomenon has for long been known as an effective way for freshwater production (Nebbia and Menozzi, 1968). Proof of this is the testimony written by the navigator James Cook during his second voyage, who accounted for the fact that water resulting from melting of sea ice is perfectly sweet and fresh (Herdman, 1959).

This phenomenon is explained by the differences that ice and liquid water present in terms of their capacity to dissolve inorganic salts. Thus, whereas liquid water dissolves molar values of inorganic salts, ice barely accepts small amount of salt, on the order of micromoles (Vrbka and Jungwirth, 2007). As a result of this difference, while freezing saltwater, the ordered molecular structures that make up ice tend to exclude the dissociated ions of the saline solution (Vrbka and Jungwirth, 2005); meaning that, for instance, the salinity of samples of ice collected in a natural environment, usually ranges between 0.3-0.8%, which represents a salinity level significantly lower than that of seawater, around 3.5% (Xie, Ma, Cheng, Li, Liu, Chen, Wang, 2009).

This paper describes the procedure designed during the 2014-2015 academic year to be undertaken with students enrolled in the 3rd course of the Bachelor of Primary Education at the University College of Teacher Training in Bilbao (University of The Basque Country, Spain) with the objective of gaining insight into the phenomena of brine rejection and one particular colligative property of solutions: the freezing-point depression. The topic of brine rejection paves the way to the introduction of the phenomenon of freezing-point depression, a well-known observable fact that provides a significant opportunity to introduce the topic of colligative properties of solutions at all levels of the educational system (Chang & Overby, 2011).

In view of this, the ultimate purpose of this paper is nothing but to contribute to the development of easy to implement laboratory activities which may support prospective primary teachers in their process of grasping essential concepts related to the colligative properties.

What follows is, first, a description of the procedure carried out with students; then, the results drawn from this activity and, finally, the educational opportunities that the detailed procedure provides to the formation of teachers-to-be.

Material and methods

Concerning the procedure proposed, priority was given to a design that would ensure that the activity may be carried out at a regular school laboratory; that is to say, employing household utensils and avoiding hazardous or expensive material. This choice is in line with the idea that the chemistry training for trainee teachers necessarily has to involve the use of teaching resources with appropriate activities to be developed in a school context.

Material

The material requirements of the activity are as follows: one 500-ml plastic container, one 50-ml metal stainless steel cup, a dessert spoon, a hand crank portable ice-crusher,

two thermometers, suitable for a range of working temperatures varying from -40°C to 40°C, a refractometer to measure salinity levels and scales. The products used are, sodium chloride (common salt for cooking), tap-water and ice made from tap-water.

Procedure

First, 3.5 g of sodium chloride is dissolved in 100 ml of tap water to obtain a solution that may resemble sea water and replicate in the classroom what really occurs in a natural context when seawater freezes.

Notwithstanding the foregoing, pointing out the fact that the content of salt ions in seawater is not limit to Cl^- and Na^+ and that other ions appear in lower but significant levels (SO_4^{2-} , Mg^{2+} , Ca^{2+} , K^+) is a complementary but worthy aspect to be highlighted in the course of the learning activity.

Then, a cooling bath should be prepared. To this purpose, 300 g of ice are crushed with the help of the ice-crusher. Then, the plastic container is filled with alternating layers of 300 g of NaCl together with the crushed ice (see Image 1).

Subsequently, a hollow-like cavity is made in the centre of this ice-salt mixture made by a dessert spoon. This cavity should be wide enough to put the metal stainless steel cup inside.

Afterwards, a 50 ml of a sodium chloride solution (3.5%) is poured into the metal stainless steel cup and the cup is placed inside the cooling bath contained, in the previously prepared cavity.

The temperature of the experiment is registered every five minutes, for half an hour. To that end, one thermometer is placed inside the metal stainless steel cup which contains the sodium chloride solution and a second thermometer is situated inside the mixture of ice and salt. Image 2 presents the final disposition of the elements of the cooling bath.

Once the time is up (30') and the experiment can be considered completed, the liquid fraction which remains inside the steel cup is poured into a graduated test-tube in order to separate it from the frozen fraction. After this, the frozen fraction is left to melt at room temperature.

Finally the refractometer is used to register the salinity level of both samples of water; that which comes for the melting of the ice fraction along with the sample which remained liquid during the experiment.

Results and discussion

In the course of the experiment, the progressive melting of the cooling bath and the freezing of the sodium chloride solution contained inside the steel cup are observed. Image 3 presents details of the changes that the sodium chloride solution has made throughout the experiment.

Moreover, the temperature also undergoes significant changes during the experiment. Figure 1 accounts for these changes over time, in the case of both the cooling bath and the sodium chloride solution placed inside the steel cup.

Regarding the volume of the samples, after the thirty minutes that the experiment lasts, almost all the sample of saltwater ended up frozen and only 0.5 ml of the initial



Image 1 Procedure to prepare the cooling bath.



Image 2 Placement of the thermometers in the cooling bath.

solution remained liquid. Accordingly, 44.5 ml of water was collected following the melting process of the frozen fraction of the sample.

As for the NaCl concentration of the solution, the refractometer indicates relevant changes. Thus, the fraction that remains liquid ends up considerably more concentrated and the reading of the refractometer points out that the salinity level turns out to be increased by 128%, from 3.5% to 8%. On the contrary, the sample of water coming from the melting of the frozen fraction reduces its salinity level by 57%, going from a concentration of 3.5% to 1.5%.

These findings match with the initially presented ideas in the sense that ice formation leads the ejection of the ions

of sodium chloride dissolved in the first saltwater solution, ruling out salt towards the surrounding liquid fraction.

Moreover, it may be worth noting that the reduction in salt concentration achieved in this experiment turns out to be no far from that occurring during sea ice formation in Polar Regions, where the phenomenon of brine rejection is capable of reducing seawater salinity up to 77%. This point may help students consider the potential that brine rejection has as a procedure to desalinate seawater.

Educational implications

The above presented experience brings students closer to the process of ice formation and more specifically, to the fact that the dissociated ions present in saline solution turn out to be excluded from ordered molecular structures that eventually make up ice (Vrbka and Jungwirth, 2005).

Beyond mere curiosity, brine rejection is a significant phenomenon connected with other relevant natural events. Thus, it is believed that this phenomenon triggers massive ocean circulations because of the density differences that it provokes inside the oceanic water bodies of the Earth's Polar Regions (Shcherbina, Talley, & Rudnick, 2004). Furthermore, brine rejection has also been linked to the thundercloud electrification phenomenon (Bauerecker, Ulbig, Buch, Vrbka, and Jungwirth, 2008). In addition, it is worth mentioning that brine rejection is, in essence, a desalination process whose potential for removing salt from liquid water is, even nowadays, under careful consideration (Fujioka, Wang, Dodbiba, Fujita, 2013; Williams, Ahmad, and Connolly, 2013).

The brine rejection phenomenon notwithstanding, the procedure detailed in this paper offers also a unique opportunity to address the topic of colligative properties of solutions and, more specifically, the issue of the freezing point depression. The starting point for this subject is,

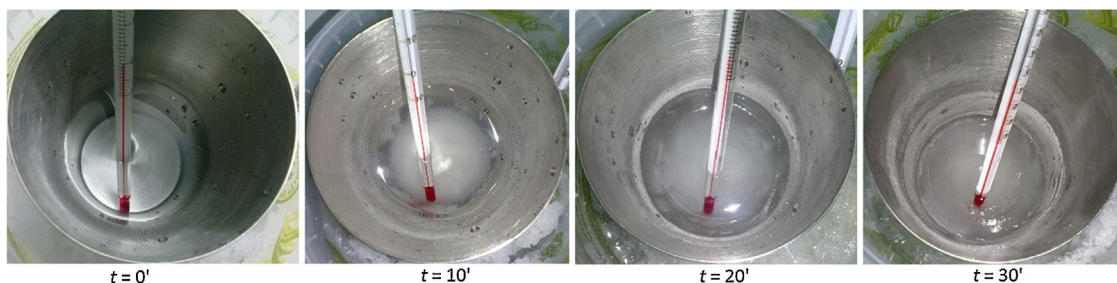


Image 3 Changes in water solution inside the steel cup.

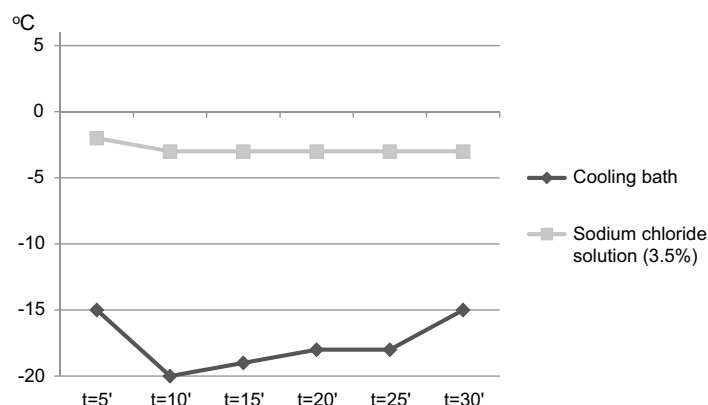


Figure 1 Time-temperature history of both the initial solution and the coolant mixture (Initial temperature 15°C).

undoubtedly, the great interest that students usually show around the question of why the water-salt mixture brings the temperature down to around -20°C.

In this connection, research regarding the understanding of colligative properties reveals that prospective teachers tend to show comprehension deficiencies at a conceptual level (Luoga, Ndunguru, and Mkoma, 2013; Pinarbasi, Sözbilir, and Canpolat, 2009). Thus, prospective teachers are apt to explain changes in the freezing point on the basis of the particular characteristics of the components of the solution; arguing, for instance, that the freezing point may change *due to the fact that firstly [liquid] water freezes and then, salt or because of the impurities in the solution* (Pinarbasi, Sözbilir, and Canpolat, 2009).

In tackling these misconceptions, the experience presented paves the way to discuss in the classroom the essential notion that the colligative properties of solutions depend on no more than the number of solute particles, regardless of the substances involved and their specific features (Chang & Overby, 2011). Moreover, prospective teachers may gain insight into the colligative properties by qualitative explanations that address two more essential notions: (a) the freezing process, as long as it involves a change towards a more ordered state, requiring removing energy from the system and (b) in comparison to a sample of freshwater, salt-water mixture system which starts from a more disordered state implying that more energy is to be removed in order to freeze it.

To sum up, the presented experience is a practical teaching proposal to introduce the themes of brine rejection and the colligative properties of solutions in the designs of chemical training of prospective teachers in a bid to cover these topics from a more concept-based perspective (Azizoglu, Alkan, & Geban, 2006; Yalcin, 2012).

Conflict of interest

The authors declare no conflict of interest.

References

- Azizoglu, N., Alkan, M., & Geban, Ö. (2006). Undergraduate pre-service teachers' understandings and misconceptions of phase equilibrium. *Journal of Chemical Education*, 83(6), 947–953.
- Bauerecker, S., Ulbig, P., Buch, V., Vrbka, L., & Jungwirth, P. (2008). Monitoring ice nucleation in pure and salty water via high-speed imaging and computer simulations. *The Journal of Physical Chemistry C*, 112(20), 7631–7636.
- Chang, R., & Overby, J. (2011). *General chemistry: The essential concepts* (6th edition). New York: Mc Graw Hill.
- Fujioka, R., Wang, L. P., Dodbiba, G., & Fujita, T. (2013). Application of progressive freeze-concentration for desalination. *Desalination*, 319, 33–37.
- Herdman, H. F. (1959). P., Some notes on sea ice observed by captain James Cook, RN, during his circumnavigation of Antarctica, 1772–75. *Journal of Glaciology*, 3, 534–541.
- Luoga, N. E., Ndunguru, P. A., & Mkoma, S. L. (2013). High school students' misconceptions about colligative properties in chemistry. *TaJONAS: Tanzania Journal of Natural and Applied Sciences*, 4(1), 575–581.
- Nebbia, G., & Menozzi, G. N. (1968). Early experiments on water desalination by freezing. *Desalination*, 5(1), 49–54.
- Pinarbasi, T., Sozbilir, M., & Canpolat, N. (2009). Prospective chemistry teachers' misconceptions about colligative properties: Boiling point elevation and freezing point depression. *Chemistry Education Research and Practice*, 10(4), 273–280.
- Shcherbina, A. Y., Talley, L. D., & Rudnick, D. L. (2004). Dense water formation on the northwestern shelf of the Okhotsk sea: 1. direct observations of brine rejection. *Journal of Geophysical Research: Oceans*, 109(C09S08) <http://dx.doi.org/10.1029/2003JC002196>
- Vrbka, L., & Jungwirth, P. (2005). Brine rejection from freezing salt solutions: A molecular dynamics study. *Physical Review Letters*, 95(14), 148501.
- Vrbka, L., & Jungwirth, P. (2007). Molecular dynamics simulations of freezing of water and salt solutions. *Journal of Molecular Liquids*, 134(1), 64–70.
- Williams, P., Ahmad, M., & Connolly, B. (2013). Freeze desalination: An assessment of an ice maker machine for desalting brines. *Desalination*, 308, 219–224.
- Xie, L., Ma, J., Cheng, F., Li, P., Liu, J., Chen, W., & Wang, S. (2009). Study on sea ice desalination technology. *Desalination*, 245(1), 146–154.
- Yalcin, F. A. (2012). Pre-service primary science teachers' understandings of the effect of temperature and pressure on solid-liquid phase transition of water. *Chemistry Education Research and Practice*, 13(3), 369–377.