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Properties of seawater with ice slurry use in focus☆

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ABSTRACT

Seawater is the most common fluid on earth and ice generating machines are increasingly used on fishing vessels to produce ice slurry from seawater with up to 60% ice to be poured over the catch. In this study, a literature search has been made to establish physical property data of seawater as function of salinity and temperature. Ice slurry properties of seawater have been generated and are presented by means of an enthalpy-phase diagram and related tables with ice concentration, enthalpy change and density. This material confirms that an initial salt content of 2–3 % is optimal and it can help determine the potential for long preservation of catch on board and during transport, improving seafood quality. As seawater is known to be corrosive, a brief discussion on corrosion factors and problems, the use of corrosion inhibitors and choice of materials is included in this paper.

Le point sur les propriétés de l'eau de mer dans l'utilisation des coulis de glace

Mots clés : Propriétés de l'eau de mer ; Qualité des fruits de mer ; Propriétés de coulis de glace ; Fraction de masse de glace ; Diagramme de phase d'enthalpie ; Corrosion

1. Introduction

1.1. Background

Seawater can conveniently be used on fishing vessels to produce fine crystalline ice slurry that can be poured over the catch directly or after some processing. This is an excellent method to keep the product fresh and undamaged for several days. Kauffeld et al. (2010) reports on the attention that ice slurry has received as a new technology to maximize the chilling speed of fish, reporting on systematic studies carried out in Canada in the 1980-ies. Research done since then by fishery institutions in several countries has contributed to fish handling guides and regulations. The fish industry has become one of the largest markets for the ice slurry technology and success has been reported for most fish species as

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Nomenclature

c	Mass fraction (kg kg^{-1})
c_p	Specific heat, (J kg^{-1} K^{-1})
h	Enthalpy (kJ kg^{-1})
n	Index of refraction (–)
p	Pressure (decibar)
t	Temperature (°C)
C	Mass per volume (kg m^{-3})
S	Salinity (g kg^{-1})
Δh	Enthalpy change (kJ kg^{-1})
Δh_M	Heat of mixing (kJ kg^{-1})
γ	Surface tension (dyn cm^{-1})
κ	Electric conductance (mS cm^{-1})
ρ	Density (kg m^{-3})

Index

s	solid
w	water
A	additive
B	boiling point
F	freezing point
I	ice
IS	ice slurry
0	value at $c_A = 0$
R	reference
S	solution
X	degrees below freezing point

well as for shrimp and lobster. This application allows for high ice concentration (up to 60%) and an initial salt content of 2–3 % (S = 20–30 g kg^{-1}) ensures maximum preservation results without damage to delicate fish and excessive salt uptake by the fish is avoided. (Kauffeld et al., 2010). Inada (2012) reported on an experiment carried out by Japanese researchers during 2011. The fish, Pacific sauries used in raw fish dishes, was immersed and killed in ice slurry made from seawater on a ship. The following day the fish was put in new ice slurry, sealed in a box, and flown from Hokkaido to Taiwan. The temperature in the box was almost constant (−1.5 to −2.5 °C) during the transport. On the 3rd day the fish was examined and the freshness was seen by the texture and by a blue line on the fish that could not be seen on fish chilled and transported by ordinary procedure. Hence, ice slurry use improved seafood quality. Interest in seawater ice slurry has also been shown in other fishing countries such as Indonesia (Pamitran et al. 2013).

1.2. *Literature search*

A literature search has, in view of these recent developments, been made by collecting data of ocean seawater composition and physical property data as function of salinity and temperature. Thermophysical property values have mainly been obtained from Sharqawy et al. (2010) but also from other sources, such as Weast (1988–89) and Melinder (2010b). The types of chloride salts that can be found in seawater are at times used as brines in cooling applications. It is not common to use seawater as brine, as the salt concentration of seawater is only ≈3.5 wt-% dissolved salts giving a freezing point of −1.93 °C. However, it is possible to remove some of the water to get higher salt content and lower freezing point. As seawater is known to be corrosive, a brief discussion on corrosion factors and problems as well as on choice of machine and transport materials is included in this paper. Ice slurry properties have been generated in a similar way as reported on in Melinder (2010a, 2010b, 2012).

2. Composition and thermophysical properties of single-phase seawater

2.1. *Salinity and composition of seawater in the oceans*

The salinity of near surface ocean seawater varies a little between S = 37.5 (in the Atlantic ocean near the Atlantic central ridge between Florida and the east coast of Africa as well as in the Mediterranean Sea) and 33 (mainly in the polar regions, and along some coast lines such as the east coast of USA). The salinity of deep ocean sea water is just below the standard salinity S = 35 g kg^{-1}or 3.5% by weight. The composition of main components of ocean standard seawater are based on Millero (2006) given in Table 1.

2.2. *Thermophysical property literature search*

Thermophysical property values for seawater have mainly been obtained from Sharqawy et al. (2010) but also from works such as Weast (1988–89) and Melinder (2010b).

Freezing point values, t_F (°C), are here taken from an equation by Fotonoff and Millard (1983), found in an UNESCO marine science paper, where S (g kg^{-1}) is the salinity and p the pressure in decibar:

$$t_F = -0.0575 \cdot S + 1.710523 \cdot S^{3/2} - 2.154996^{-4} \cdot S^2 - 7.53^{-4} \cdot p \quad (1)$$

This equation is valid in the practical salinity range of 4–40 at atmospheric pressure. Freezing point values for S > 40 are for that reason shown in italics in Table 2 (and also in Table 6). One other relation: $t_F = -0.036 - 0.0499 \cdot S - 0.000112 \cdot S^2$ (Fujino et al. 1974) gives for S = 10 – 60 somewhat (≤0.012 °C)

Table 1 – Composition of main components of ocean standard seawater.

Solutes in seawater	% By weight
Sodium, Na^+	1.0784
Magnesium, Mg^{2+}	0.1284
Calcium, Ca^{2+}	0.0412
Potassium, K^+	0.0399
Sulfate, SO_4^{2-}	0.2712
Chlorine, Cl^-	1.9353
Total other solutes	0.0056
Sum total of solutes	3.5000
Water, H_20	96.500

Note: There is no clear eutectic point as with sodium chloride – water and Levy (1982) actually draws diagrams for density and thermal conductivity of seawater even below −50 °C.