

FREEZING DESALINATION PROCESS

Z. Lu and L. Xu

Department of Environmental Engineering, East China University of Science and Technology, China

Keywords: Counterwasher, Desublime, Desublimate, Indirect freezing, Supertriple point, Vacuum freezing

Contents

1. Introduction
 2. Desalination Freezing Process
 - 2.1. Basic Components in the Freezing Processes
 - 2.2. Indirect Freezing Process
 - 2.3. Direct Freezing Processes
 3. Comments on Freezing Processes
 4. Future Prospects
- Acknowledgements
Glossary
Bibliography and Suggestions for further study

Summary

Desalination by freezing processes is based on the fact of that ice crystals are made up of essentially pure water. It consists of three discrete steps: ice formation, ice cleaning, and ice melting. Because it has a number of advantages, e.g. low energy requirements, immunity of fouling and corrosion or scaling as well as almost no pre-treatment etc., the freezing process has been developed rapidly during the past 50 years. Although more efforts have been undertaken, desalination by freezing is still in the form of studies and pilot plant units; attempts at its commercial application have not been successful until now. This chapter presents a retrospect to the historical development of the freezing process and describes the basic flow diagram of each freezing process. The principles of the process and functions of the major process components are discussed in detail. The advantages and disadvantages of each process are commented on. The freezing process will be used widely in the field of industrial waste water treatment and food industry in the future. The combination of freezing processes and other desalination processes can reduce the rejected brine from desalination and produce various salts from seawater.

1. Introduction

Desalination by freezing processes is based on the fact that, in physical chemistry, ice crystals formed are made up of essentially pure water when the temperature of saline water is lowered to its freezing point and further heat is removed. In fact it is the nature of all crystals that impurities are excluded from the crystals' structures as they grow. In contrast to distillation, the freezing method utilizes the phase change of water from liquid to solid. It requires the separation of the ice crystals from the brine, cleaning of the ice crystals to remove the adhering salts on the crystals surface, and melting of the

ice to produce fresh water.

Compared to other desalination processes, particularly the distillation process, the freezing process offers a number of advantages. It requires the transfer of less energy, needs almost no pretreatment, and has minimal corrosion and metallurgical problems. Theoretically, to freeze 1 kg of water requires the heat removal of only approximately 80 kcal; the evaporation of 1 kg of water requires the addition of approximately 600 kcal. The energy required to carry out the process is thus potentially reduced. Because the freezing process is operated at low temperature (about -3°C), it greatly reduces the problems of scale formation and corrosion, which are very troublesome in all forms of distillation. This permits a wider selection of materials and construction methods. Another advantage of the freezing process is that it is relatively insensitive to changes in the concentration or type of substances in the feedwater. It is suitable for difficult brackish water with a high salt content and even industrial or wastewater, which cannot be desalted by membrane processes. These attractive features of the process have stimulated considerable investigation since the 1950s.

Colt Industries first began development of the vacuum-freezing vapor compression (VFVC) desalting process in 1960 and the capacity of its pilot was increased from 60 000 to 120 000 gal day⁻¹ (227 to 554 m³ day⁻¹). In 1969, Colt Industries demonstrated reliable performance of units with 100 000 gpd (379 m³ d⁻¹) capacity and had proposed units with 500 000 gal day⁻¹ (1893 m³ day⁻¹) capacity. On the base of the VFVC process, other vacuum-freezing processes were further developed rapidly and the pilot units were operated successfully, e.g. the vacuum-freezing vapor absorption (VFVA) process, vacuum-freezing ejector absorption (VFEA) process, vacuum-freezing high pressure ice-melting (VFPIM) process, and vacuum-freezing multiple phase transformation (VFMP) process. During the same period, another interesting variation of the direct freezing process, the secondary refrigerant freezing (SRF) process, was developed too. Karnofsky and Steinhoff (1960) and Weigandt (1960) first proposed the saline water conversion by direct freezing process with butane as the secondary refrigerant in 1960. AVCO Corporation designed and manufactured the 75 000 gal day⁻¹ (284 m³ day⁻¹) secondary refrigerant freezing (SRF) pilot plant in which R-114 (dichlorotetrafluoroethane) was used as the refrigerant and demonstrated the SRF process at a capacity of up to 100 000 gal day⁻¹ (379 m³ day⁻¹). Although more efforts had been undertaken, desalination by freezing was still in the form of studies and pilot plant units; attempts at commercial application have not been successful till now. The principle problems in freezing process may be the separation of the ice crystals from the concentrated brine and the unsuitability of conventional refrigerant compressors. The recent invention and development of the hydraulic refrigerant compressor may provide a solution to the compressor problems. Rice and Chau (1997) described such a compressor and the characteristics of the resulting freeze desalination system.

2. Desalination Freezing Processes

2.1. Basic Components in the Freezing Processes

Freezing of salt water can be carried out in many ways. Any process involves three discrete steps in obtaining fresh water from a saline source: ice formation by the heat

removal of saline water, separation of ice from the brine, and melting of the ice. Therefore, almost all freezing processes utilize functional components because they utilize similar mechanisms for forming ice and separation from the brine. There are four basic components in all freezing desalination processes: Freezer, washer, melter, and heat removal systems. The freezer consists of a vessel in which ice crystals and vapor are formed simultaneously. The various freezing processes generally differ in the apparatus which removes heat from the brine in order to produce ice crystals which can be easily transferred, removed, separated, washed, and then melted. The heat removed in the freezing process is usually transferred to the melter where it is utilized for melting the ice. The design and operation of the freezer are two keys to producing a high proportion of discrete ice crystals rather than clumps of ice so that the amount of brine trapped between the crystals formed is minimized. The size of the crystals formed is very important because fine crystals are difficult to wash. The nucleation and growth rate of ice crystals is always of interest in the desalination of seawater by freezing which has been discussed elsewhere (see below). Ice crystals formed in the freezer are pumped as slurry to the washer where the ice crystals are separated from the brine. The counter current wash column is usually utilized as the washer, in which a small part of the product water, flowing in a direction counter to that of the ice motion, is used to wash the ice to remove the brine adhering to the crystal surfaces. Two variations of the wash separation column called the "gravity" and "pressurized" wash separation columns have proven to be technically feasible and the choice between the two must be made from an economic standpoint based on a specific process application. In the melter the ice from the washer is usually melted by transferring the heat of crystallization removed from the brine in the freezer to the melter. This is usually done by discharging the refrigerant into the melter, where the ice picks up heat and melts. Because all freezing processes operate at temperatures below ambient, the heat must be removed from the system continuously. Heat removal can be accomplished by evaporating refrigerant, compression vapor, and heat exchanging from product fresh water or concentrated brine, etc. Different methods of heat removal will result in different desalination freezing processes. There are other conventional ancillary components in freezing processes including heat exchangers and deaerators etc. Heat exchangers are usually used between the brine and feedwater streams as well as between the product and feedwater streams in order to reduce the temperature of the feedwater and conserve energy. The aim of the deaerator is to remove the dissolved gases in the feedwater which would otherwise be liberated in the process. These non-condensable gases would affect the operational efficiency of the systems.

Freezing processes can be classified into two groups: indirect freezing and direct freezing processes. The latter includes secondary refrigerant freezing and vacuum-freezing processes. The following paragraphs outline the key points of these processes.

2.2. Indirect Freezing Process

In indirect freezing process, saline water does not come into contact with refrigerant directly. Ice is formed on a surface by mechanical refrigeration or other methods. A schematic diagram of the indirect freezing process is shown in Figure 1. The feed seawater is first pumped through a heat exchanger to reduce its temperature, then entered into the freezing chamber, where it is cooled further to the temperature at which

the ice crystals are formed. The ice and brine slurry is pumped to a wash column where the ice and brine is separated. The ice is transported to the melter, where ice is melted by the heat released from condensation of the compressed refrigerant. A small part of the product freshwater is bypassed to the wash column and is used to wash the ice crystals and the major part is passed through the heat exchanger to cool the feed seawater and is then discharged for storage. The brine from the wash column is returned to the heat exchanger to cool the feed seawater and discarded.

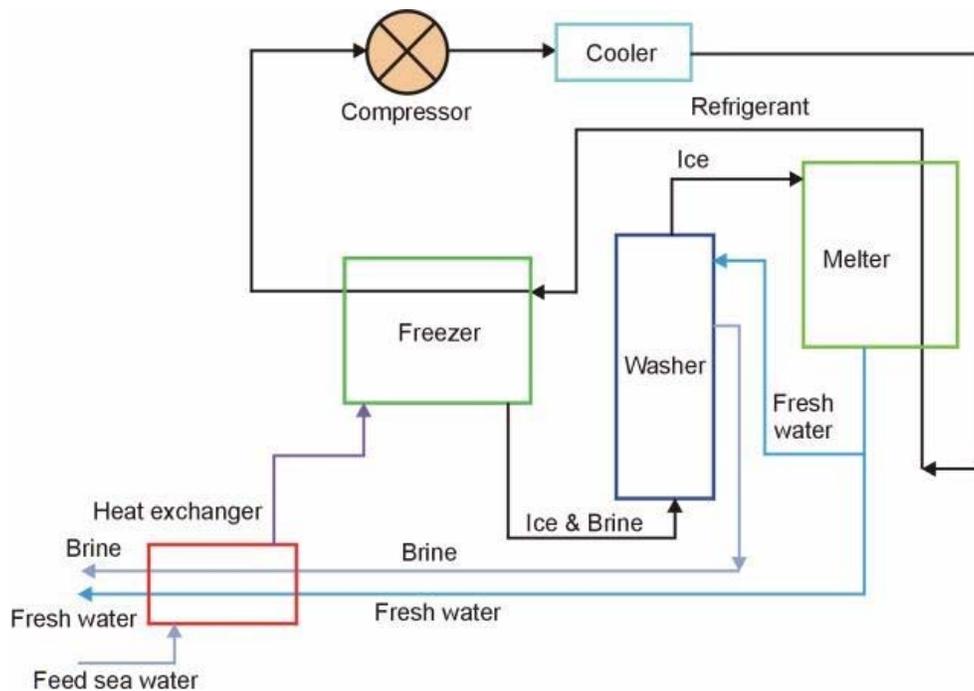


Figure 1. An indirect freezing process.

While the indirect freezing process is straightforward and would appear simple, it has a number of disadvantages (Weiss 1973). The energy requirements tend to be relatively high due to the resistance of the surface between the saline water and refrigerant. Large metallic heat transfer surfaces are required for both the freezing and melting steps. The equipment is complex, expensive, and difficult to operate and maintain. Therefore, this process is seldom utilized practically in desalination. Instead, the direct exchange of heat between the feed seawater and refrigerant is desirable. This is the direct freezing technique.

-
-
-

TO ACCESS ALL THE 16 PAGES OF THIS CHAPTER,
Visit: <http://www.desware.net/DESWARE-SampleAllChapter.aspx>

Bibliography and Suggestions for further study

- Allo V F, Carbery T R, Cutler D C, Engdahi G E and Nail J A (1979) *Process Design of a 100 000 Gallon per Day Vacuum Freezing Ejector Absorption Pilot Plant*, Rep. PB 80-144017, 111 pp. Washington DC: National Technical Information Service.
- Ammerlaan A C F and Ko A (1984) *Investigation of Methods for the Improvement of the Absorption Freeze Pilot Plant Operation*, Rep. PB 85-128759, 102 pp. Washington DC: National Technical Information Service.
- Avco Systems Div. Wilmington (1977) *Test and Evaluation of 75 000 Gallon Per Day Crystal Pilot Plant*, Rep. PB 84-128602, 55 pp. Washington DC: National Technical Information Service.
- Barduhn A J (1975) The status of freeze-desalination. *Chemical Engineering Progress* 71(11), 82-87.
- Brian P L T (1968) Engineering for pure water part 2: freezing. *Mechanical Engineering* 2, 42-50.
- Buros O K (1980) Freezing. *The U.S.A.I.D. Desalination Manual*, pp. 4-1-4-23. International Desalination and Environmental Association, New Jersey.
- Cheng C Y (1981) *A Study of the Vacuum-Freezing High Pressure Ice-Melting Process*, Rep. PB 82-200734, 72 pp. Washington DC: National Technical Information Service.
- Cheng C Y and Cheng W C (1986) *Final Report on the Vacuum Freezing Multiple Phase Transformation Process Investigation*, Rep. PB 87-198560, 83 pp. Washington DC: National Technical Information Service.
- Cheng C Y and Cheng W C (1988) *Water Purification and Waste Concentration by the Vacuum Freezing Multiple Phase Transformation Process and its Eutectic Extension*, Rep. PB 89-220891, 87 pp. Washington DC: National Technical Information Service.
- Cheng C Y and Hopkins D N (1982) Desalination by the improved vacuum freezing high pressure ice melting process. *Desalination* 42(2), 141-151.
- Cheng C Y, Cheng S W and Yang M D (1987) The vacuum freezing multiple phase transformation. *Desalination* 67, 139-153.
- Consie R (1969) *Vacuum Freezing Vapor Compression Process: One and Five Million Gallon Per Day Desalination Plants*, Rep. 451, 67 pp. Washington DC: National Technical Information Service.
- Dickey L C (1996) Evaporation of water from agitated freezing slurries at low pressure. *Desalination* 104(3), 155-163.
- Dickey L C, Dallmer M F, Radewonuk E R and McAloon A (1996) Horizontal cross flow filtration and rinsing of ice from saline slurries. *Canadian Journal of Chemical Engineering* 74(6), 905-910.
- El-Nashar A M (1984) Solar desalination using the vacuum freezing ejector absorption (VFEA) process. *Desalination* 49(3), 293-319.
- Fleming L (1982) *Final Report on the Testing of the Adsorption Freezing Vapor Compression Pilot Plant at the Wrightsville Beach Test Facility*, Rep. PB 84-110741, 110 pp. Washington DC: National Technical Information Service.
- Fraser J H (1980) Absorption freezing vapor compression-process selection, pilot plant design, process economics. *Desalination* 33(1), 85-98.
- Fraser J H and Emmermann D K (1970) *Vacuum Freezing Vapor-Compression Process: 60 000 GPD Pilot Plant Evaluation*, Rep. 573, 108 pp. Washington DC: National Technical Information Service.
- Hahn W J (1986) Measurement and control in freeze-desalination plants. *Desalination* 59, 321-341.
- Hale R (1980) Concentration of impurities by progressive freezing. *Water Research* 14(6), 575-580.
- Hanafi A (1994) Desalination using renewable energy sources. *Desalination and Water Treatment in Harmony with the Environment* (Proceedings of the IDA and WRPC World Conference on Desalination and Water Treatment, Yokohama, Japan, 1993) International Desalination Association pp. 339-352.
- Heavener C M and Nowak T J (1983) *The Start-up and Testing of a 6000 GPD Indirect Freeze*

Desalination Pilot Plant, Rep. PB 83-226886, 59 pp. Washington DC: National Technical Information Service.

Jhawar M M and Fraser J H (1970) *Vacuum-freezing Vapor-compression Process: Evaluation on Brackish Water*, Rep. 541, 46 pp. Washington DC: National Technical Information Service.

Johnson W E, Fraser J H, Gibson W E, Modica A P and Grossman G (1972) *Spray Freezing, Decanting, and Hydrolysis as Related to Secondary Refrigerant Freezing*, Rep. 786, 137 pp. Washington DC: National Technical Information Service.

Karnofsky G and Steinhoff P F (1960) *Saline Water Conversion by Direct Freezing with Butane*, Rep. 40, 67 pp. Washington DC: National Technical Information Service.

Koretchko J and Hajela G (1971) *Bench Scale Study of the Vacuum Freezing Ejector Absorption Process*, Rep. 744, 257 pp. Washington DC: National Technical Information Service.

Leinroth J P J, White W P, Sherwood T K and Brain P L T (1965) *Washington of Brine from Ice Crystals*, Rep. 128, 82 pp. Washington DC: National Technical Information Service.

Lu Z and Xu L C (1994) The current status and prospect of freezing desalination technology. *Technology of Water Treatment* 20(3), 140-145 (in Chinese).

Madani A A (1990) Economics of desalination for three plant sizes. *Desalination* 78(2), 187-200.

Madani A A (1992) Zero-discharge direct-contact freezing/solar evaporator desalination complex. *Desalination* 85(2), 179-195.

Madani A A and Aly S E (1989) Combined RO/freezing system to reduce inland rejected brine. *Desalination* 75(1-3), 241-258.

Rice W and Chau D S C (1997) Freeze desalination using hydraulic refrigerant compressors. *Desalination* 109(2), 157-164.

Tleimat B W (1980) Freezing methods. *Principles of Desalination, Part B*, 2nd edition (ed. K S Spiegler and A D K Laird), pp. 360-400. New York: Academic Press.

Weiss P A (1973) Desalination by freezing. *Practice of Desalination* (ed. R Bakish), pp. 260-270. New Jersey: Noyes Data Corporation, New Jersey.

Wiegandt H F (1960) *Saline Water Conversion by Freezing: an Integral Processing Unit Using a Secondary Refrigerant*, Rep. 41, 51 pp. Washington DC: National Technical Information Service.

Guide for Further Study

Nucleation and Growth Rate of Ice Crystal in Freezing Desalination Process

Barduhn A J (1987) Why does ice grow faster from salt water than from fresh water. *Desalination* 67, 99-106.

Farrar J and Youel K (1966) *Nucleation and Growth of Ice Crystals*, Rep. 157, 61 pp. Washington DC: National Technical Information Service.

Fernandez R and Barduhn A J (1967) Growth rate of an ice crystal in flowing water and salt solution. *Desalination* 3, 330-342.

Kane S G, Evans T W, Brain P L T and Sarofim A F (1974) Determination of the kinetics of secondary nucleation in batch crystallizers. *AIChE Journal* 20(5), 855-862.

Lu Z and Xu L C (1995) The new technology of desalination by vacuum freezing-vapor condensation (Proceedings of the IDA World Congress on Desalination and Water Sciences, Abu Dhabi, UAE, 1995), Vol. 6, pp. 345-356. Abu Dhabi: IDA/UAE University.

Lu Z, Xu L C and Cai L L (1997) Ice crystal growth rate in seawater under vacuum freezing. *Technology of Water Treatment* 23(5), 280-284 (in Chinese), Proceedings of The IDA World Congress on Desalination and Water Sciences, IDA/UAE University.

Vlahakis J G and Barduhn A J (1974) Growth rate of an ice crystal in flowing water and salt solution. *AIChE Journal* 20(3), 581-591.

Principles of Desalination and Others

Bakish R (1973) *Practice of Desalination*. New Jersey: Noyes Data Corporation, New Jersey.

Chiu, S.Y., L.T. Fan and R.G. Akins,(1969) "Experimental Study of the Ice-Making Operation in the Inversion Desalination Freezing Process," I&EC, Process Design and Development, 8, 347-356

Corrado Sommariva ,(2010),COURSES IN DESALINATION, Thermal Desalination

Heitmann H G (1990) *Saline Water Processing: Desalination and Treatment of Seawater, Brackish Water and Industrial Waste Water*. New York: Winheim.

Howe E D (1974) *Fundamentals of Water Desalination*. New York: Marcel Dekker, Inc.

Lior N (1986) *Measurements and Control in Water Desalination*. New York: Elsevier Science.

M.A. Darwish, N. Al-Najem, N. Lior, (2006), *Towards Sustainable Energy in Seawater Desalting in the Gulf Area*, Tenth International Water Technology Conference, Alexandria, Egypt, pp. 655-684.

Roberton Borsani, Silvio Rebagliati (2005), *Fundamentals and costing of MSF desalination plants and comparison with other technologies*, Desalination **182**, Elsevier, pp. 29-37.

Spiegler K S (1962) *Salt-water Purification*. New York: John Wiley and Sons, Inc.

Spiegler K S and Laird A D K (1980) *Principle of Desalination Part A and B*, 2nd edition. New York: Academic Press.