THE HYBRIDICE HIF FILTER IN FREEZE DESALINATION OF MINE WATERS: AN OVERVIEW OF OPERATION, PROCESS ANALYSIS AND RESEARCH NEEDS

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Abstract: Mine waste water is a serious pollution problem globally in which its treatment and disposal are being researched on. The HybridICE freeze crystallization process is a viable solution to freeze desalination of mine waters. The paper thus presented an overview of the hybridICE HIF filter which is a significant unit operation in the HybridICE Freeze Crystallization process. The filter separates the ice from the slurry. The performance of the filter directly impacts the yield of the whole process and the purity of the recovered ice. The ice faction in the liquid ice slurry feed into the filter must be high for a high yield of ice in the filter. The purity of the ice recovered from the filter must be high. Major process parameters that affect ice fraction will be investigated for optimum ice fraction. The performance of the filter will be evaluated and process parameters will be optimized to improve its performance. The possible optimum dimension of the filter and the filter medium will be specified.

Keywords: HybridICE HIF filter, mine water, operation, process analysis, research needs

INTRODUCTION

Freeze desalination which works on the principle that solutes are rejected by the growing ice crystals during freezing of a solution, has many advantages over other methods of desalination. These advantages include minimization of inevitable thermodynamic losses in heat exchange.

In mine waters, desalination may be required for the following reasons (Shone, 1987): (a) To reduce the scaling and corrosion of pipes, heat exchangers, and other equipment; (b) To reduce the salinity of service water and make it suitable for operating water-powered hydraulic machinery; (c) To conserve water by recycling; (d) To make all the water piped into a mine safe to drink, and (e) To reduce the pollution of land and water courses caused by highly saline effluent water.

Apart from these, in some deep mines it is advantageous to send ice underground in place of cold water, due to the high cooling effect of the latent heat of melting ice.

The HybridICE Freeze Crystallization Technology is a freeze desalination process the commercial prototype of which has been built. This technology has taken care of issues raised in past work on the continuous freeze crystallization process. These issues include (Conlon, 1992) complexity of heat exchanger surface scraper, separation of the ice from the liquid ice and the melt chamber. Advantages and feasibility of the technology include: (a) Unlike other processes, no pre-treatment chemicals are added to the feed water. (b) It is not affected if feed water contains metals/mud or other impurities. (c) The process removes both organic and inorganic compounds. (d) Freezing-out the water part is possible with any chemical composition. (e) Low sludge production if compared to chemical treatment. (f) An existing refrigeration system can be retrofitted to become a HybridICE system. (g) Waste heat from refrigeration cycle can be utilized to further reduce the operating and investment costs for evaporation. (h) The thermo-physical properties of the contaminated fluid, as secondary refrigerant, make it an ideal medium for storage, transport and transfer of cold energy. (i) Cheap off-peak electric power can be utilised. (j) There is no need to wash the ice produced with water

Typical components for the HybridICE Freeze Crystallization Technology include the following: HybridICE Freeze Crystallization Generators, HybridICE HIF Filter Modules, HybridICE Heat Pump, and Optional HybridICE Vacuum Evaporator. Previous work on the HybridICE Freeze Crystallization Technology on brine treatment (Mtombeni et al, 2011) showed the cost effectiveness in terms of low energy demand, low pollution from by-products, process flexibility, simplicity and the possibility to further utilize the cold energy as process by-product. In the case of deep mining operations this technology is particularly interesting as this technology could be integrated and implemented for both cooling and water treatment as an integral part of any cooling system. This process is particularly efficient due to the latent energy (333 kJ/kg) resulting from the phase change of ice to water. This allows the transport of significantly reduced fluid volumes due to the high cooling density which effectively reduces the amount of pumping power required. In deep mines this process will assist in the provision of a healthy and well acclimatized working environment by reducing the high humidity.

HybridICE HIF Filter Module

The HybridICE HIF Filter is a key unit operation for the HybridICE® Freeze Crystallization Process. It separates the ice from the slurry.

Unlike conventional filters, the HybridICE HIF filter achieves mechanical separation by buoyancy. The ice fraction in the slurry, being less dense than the brine, float in the filter and the concentrated brine is pumped out through a filter medium which hinders the ice. The ice continuously builds up until it reaches the height where it can be scrapped out of the filter.

Mass balance around the filter at steady state:

$Q_s = Q_b + Q_i$ ………. (1)

Ice balance gives:

$x_sQ_s = x_bQ_b + x_iQ_i$ …….(2)

Where Q_s is the flow rate of the slurry; Q_b is the flow rate of the concentrated brine; Q_i is the flow rate of ice; x_s is the ice fraction in the slurry; x_b is the ice fraction in the concentrated brine; and x_i is the ice fraction in the ice.

$x_b \longrightarrow 0$; while $x_i \longrightarrow 1$

When $x_b > 0$, there is ice in the brine; and

when $x_i < 1$, there is brine in the ice

The slurry flow rate Q_s and ice fraction x_s are major design parameters for the filter.

The ice faction x_s depends on the concentration of freezing point depressant substances and the respective temperature of the liquid ice feed. There are two main facts which need consideration namely: (a) The equilibrium freezing temperature of a salt solution decreases as its salinity increases. (b) Ice crystals will not nucleate until a temperature lower than the equilibrium is reached. And when undercooling occurs, there is tendency that the liquid ice feed into the filter will contain ice with trapped salts (impurities). Another way to express this is that cooling of the liquid ice to the eutectic temperature will cause formation of solid solution with much salt trapped in the ice.

The two figures below illustrate these two points. Figure 1 shows the effect of concentration on the freezing point depression (FPD) for saline water. This is used because the exact relationship for the mine water is not known.

With increased salt concentration, the freezing point of the solution becomes lower. Saline water would start freezing at a temperature of approximately -2^{o}C although pure water in a liquid state has been recorded at temperatures as low as -30^{0}C.

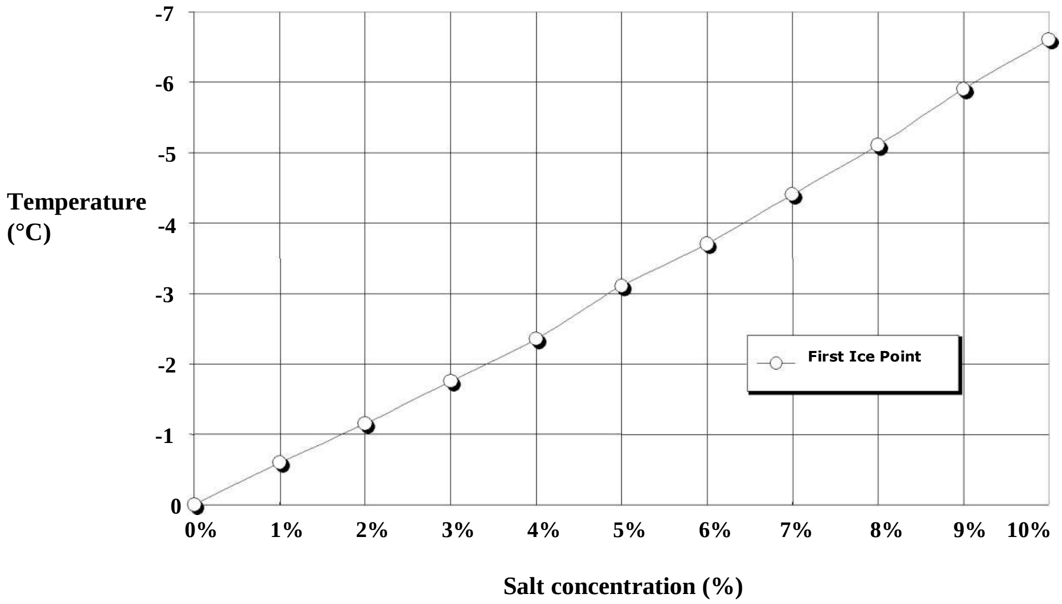

Figure 1: FPD as a function of Salt Concentration.
(source: Mtombeni T et al)

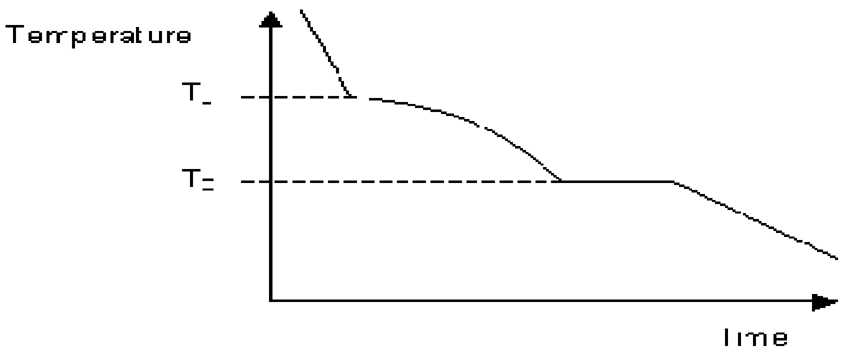

Figure 2: Temperature vs Cooling Time
(source: University of Cambridge, Nov 2011)

The equilibrium freezing temperature

Figure 2 above shows the relationship between temperature and cooling time. Mine water cools rapidly until temperature T_L, the equilibrium freezing point, is reached where ice formation begins. Thus there are two phases, solid and liquid. The rate of cooling will now become slower until the eutectic point T_E is reached where salts crystals will begin to precipitate with the solid ice. The degree of under-cooling influences the nucleation of crystals, their rate of growth, and their eventual shape and size. Reasonable size and size uniformity of the crystals are desirable for filtering (McCabe et al, 1993). Basically controlling the refrigerator parameters can give a reasonable ice fraction. These parameters include Evaporating temperatures of the refrigerant, flow rate of the feed, temperature of the feed and the feed concentration.

Filter Design/Dimension

Floatation is a result of buoyancy force. At the interface of ice and concentrated brine, buoyancy force is equal to the gravitational force on the ice fraction. The floating rate is a function of the ice fraction. The height of the filter is a main variable. Mass flow through the filter can be considered a flux define in this case as Mass per unit Area per time. The floating flux is sustained with the flux caused by flow of the slurry into the filter balanced with the flux of drawing the brine from the bottom through the filter medium. If the floating flux exceeds the flux of the slurry into the filter, ice will be in the brine. This implies that the buoyancy force will be less than the gravitational force. It follows that the residence time of the ice in the filter must be minimal. The residence time increases with the height of the filter and there is possibility that it impacts the purity of the ice. The cross sectional surface area of the filter is assumed to be okay for allowance of inlet and outlet turbulence. The area of the filter medium is also assumed to be okay for minimal pressure difference due to flow of brine through it. What should be determined is height of the filter, the height of ice buildup in the filter, the height of the filter medium for optimal performance of the filter and the optimum pumping rate of the filtrate (concentrated brine).

RESEARCH DESIGN AND METHOD

The designed method is to investigate the effect of process parameters on the performance of the HybridICE Filter. The following are the materials and methods in use presently.

Materials: The HybridICE freeze crystallization pilot plant, Measuring cylinder, Stop watch, Weighing machines, Ice fraction measuring instrument, microscope, and mine waters samples obtained from mines and also simulated by preparing solutions in the laboratory.

Methods: Batches of mine water are being processed in the HybridICE pilot plant. The lines are run at various flow rates of mine waters having various brine concentrations. Data is being taken on the purity and yield of the ice. Major process parameters that determine the ice fraction in the slurry feed into the filter are investigated to establish the optimum range for these parameters through the estimation of the ice fraction in the slurry. The ice fraction is estimated using the ice fraction measuring instrument. The floating velocity of the ice is measured at various ice fractions and flow rates. This is being done using a measuring cylinder and a stop watch. A measuring cylinder is being be used to take the sample of the slurry. The times taken for the ice to float over specific distance are recorded to calculate the floating velocity. The time taken for the first ice to be harvested from the time of the feeding the slurry into the filter (Ice residence time) is recorded for various feed flow rates. The purity of ice is being taken through conductivity measurement. Recovered ice rate are taken per three minute and weighed at regular intervals to calculate yield. Finally, a metallurgical investigation of micro-structural evolution of the ice will be done through the use of microscope to measure the possible effect of the size of ice crystals and its distribution on the performance of the filter.

CONCLUSION AND RECOMMENDATIONS

The evaluation of operating parameters and process analysis of a typical HybridICE HIF Filter in freeze desalination of mine waters as an ongoing research work in Tshwane University of Technology, Soshaguve site were reviewed and the following research needs are also recommended:

There is need is to establish relationships between process parameters and performance of the HybridICE HIF Filter by investigating the process techniques to optimize the performance of the HybridICE HIF filter. Also there is need to conduct tests with low and high saline brines to evaluate the performance of the HybridICE HIF filter, provide process solution to the treatment of mine waste waters, provide energy and mass balance of available ice for mine cooling, provide possible optimum dimensions for the HybridICE HIF Filter and determine the optimum pumping rate of the filtrate (concentrated brine). All these will help define the following research problem: The need to have a high yield of ice from the process and improvement of the purity of the ice recovered from the filter.

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