Eutectic freeze crystallization: application, process design and future potential

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Abstract. This paper aims to analyze the process of eutectic freeze crystallization, as well as its current use and future potential. The fundamental concepts of this process and the equipment required are studied to ascertain its advantages compared to conventional separation methods such as evaporative crystallization and reverse osmosis. Various equipment or combinations of equipment are also evaluated in terms of energy requirement and cost in order to optimize eutectic freeze crystallization based on situational conditions. By looking at current industrial applications of eutectic freeze crystallization, the future of this process and its feasibility in larger scale productions can be determined. Lastly, an in-depth analysis is carried out on the use of eutectic freeze crystallization in Kemira Chemical Plant and DWP Botlek of Evides Industriewater to improve the understanding of this process in a real industrial setting.

1. Introduction

Increasing solution concentration is necessary in terms of transportation, conservation and manufacturing in food industry, desalination and wastewater treatment. There are several methods in concentration and water removal process such as evaporation, reverse osmosis (RO) and freeze concentration (FC). Many efforts have been committed to develop improved methods for concentration and water removal process. In evaporation, higher level of concentration can be obtained compared to FC and RO. However, there are impairment of sensory (colour, taste and aroma) and nutritional value of the finished product such as vitamin because of the heat induced [1].

In RO, water is removed as a permeate through the membrane without the phase change and heat is not supplied for separation of water. Thus, energy requirement is low and thermal damage to the product is low, thus resulting in better flavor and colour retention compared to evaporation. The performance of RO depend on the types of membrane [2] and the cost of membrane, which is quite high [3]. A single stage of RO system cannot achieve a concentration higher than 25° - 30° Brix, which is much lower than 45°- 65° Brix for products obtained from evaporation [4]. In addition, a major problem of RO is fouling, which can affect the quality of the water produced.

Water may also be removed by freezing out water as ice crystals. FC is the process of concentrating a solution by freezing out the water content into ice crystals [5]. The aim of FC is to form very pure ice crystals in which there is only water without any solid retained in the ice crystals [6]. The resulting solid and liquid phase are then subsequently separated as ice and concentrated solutions [7]. During ice crystal formation, solutes are rejected by the nature of ice crystal lattice formation that is formed by pure water.
Water solidification process forming the small dimension ice crystal lattice make the inclusion of any impurities impossible except for fluorohydric acid and ammonia, thus there is no solute contaminants in ice [8].

2. Freeze Concentration

By comparing all concentration processes (evaporation, RO and FC), FC is the most capable method to remove water from solution with smallest changes in product quality [10,11]. FC is a method of increasing the concentration of the liquid solution by preferentially freezing water from the solution [11]. The remaining liquid solution has a higher concentration of solutes as the ice formed consist mainly of water, meaning that water has been removed from the liquid solution by freezing. Complete separation of these ice crystal results in specific removal of water at very low processing temperatures.

FC does not have any pre-treatment methods for separation of chemicals. Therefore, it does not release toxic chemicals to the environment [12]. FC has been applied to concentrate fruit juices [14–19], management of wastewater [20–24], desalination process [25–28] and removal of pharmaceutically active compounds from water [28]. Various types of FC processes have been discovered and explored such as suspension freeze concentration (SFC) [29], progressive freeze concentration (PFC) [31–33] and block freeze concentration (BFC) [34–36]. These methods could surely still operate at eutectic conditions which can be named as eutectic freeze crystallization (EFC) [37,38].

SFC process produces a lot of small-sized of ice particles in the mother liquor and the process consists of three stages: crystallization, growth and separation of ice crystal particles [5]. PFC only forms a large single layer of ice crystals on the cooled surface; therefore, the separation of the ice layer from the concentrated solution becomes easier as it only contains one layer of ice crystals [30]. According to Moreno et al. [33], BFC is recognized as freeze-thaw concentration, in which the solution is frozen and partially thawed. This process also comprises three stages, which are freezing, thawing and separation. For EFC, the process operates at the eutectic temperature as both ice and salt should form crystals [38].

2.1 Eutectic Freeze Crystallization

EFC is a newer process derived from several core concepts of freeze crystallization. The process consists of simultaneous crystallization for recovery of pure water and salt at eutectic conditions [39]. The principle of the process is that when a solution is slowly cooled down to its eutectic point, ice begins to form and rise to the surface, whereas salt begins to crystallize in the remaining solution. The separation of ice and salt is very easy due to their density difference [20].

EFC is as process that separates components at the eutectic point [40]. At this point, the two solid phases are actually the two pure components [41]. This method offers several advantages over other separation methods. The major advantages are EFC has much lower energy requirement compared to evaporative processes [44,45] and the rate of corrosion is low due to the low operating temperatures.

EFC concept can be shown using a typical phase diagram of a binary aqueous solution [44]. As shown in Figure 1, a water-salt mixture at a given temperature $T_A$ and composition $C_A$ (point A) is cooled to point B, where the water begins to solidify and form ice. Cooling is continued and the temperature drops whereas salt concentration in the remaining liquid mixture increases along the line BC until it reaches the eutectic point at D with temperature $T_{\text{EUTEC}}$ and composition $C_{\text{EUTEC}}$. The same situation applies if the initial composition of water-salt mixture is greater than the eutectic point, in which salt will solidify first and the concentration of salt in the liquid mixture decrease with temperature until it also reaches the eutectic point. At this point, both water and salt solidify into two separate solids that can be separated using the difference in density between the two solids [45]. Figure 2 explains the flow of EFC process as it can relate to Figure 1. Initially, the salt solution is immersed in the crystallizer and after the temperature achieved the eutectic temperature, two layers of ice crystals (i.e., pure ice crystals and salt crystals) are formed at that time. Theoretically, pure ice crystals float to the surface due to lower density compared to salt crystals [46]. Thus, both ice and salt crystals can be separated by using gravitational force.

Both ice and salt crystallize simultaneously if the initial concentration of the water-salt mixture is exactly the same as eutectic concentration [47]. For mixtures with more than one type of salt, separation
is still possible because the eutectic point of each water-salt solution is different [48]. This means that salts can be separated from the water sequentially at each respective eutectic temperature, in which eutectic temperature is the lowest melting temperature of a water-salt mixture [49].

![Binary phase diagram of water-salt mixture](image1)

**Figure 1.** Binary phase diagram of water-salt mixture

![Eutectic freeze crystallization process](image2)

**Figure 2.** Eutectic freeze crystallization process

### 3. The Need for Eutectic Freeze Crystallization

Separation is a key part in many industries such as mining, medical, food and biotechnological industries as most processes are 100% selective. However, energy consumption and equipment cost are high, and as the world population and demands continue to rise, these costs will also increase. Therefore, there is pressure on researchers and industry developers to create innovative and sustainable separation processes. With more efficient separation, not only energy consumption be reduced dramatically, waste streams previously thought unfeasible to treat or recycle can be separated into its raw materials and reused. Energy consumption and cost for evaporation, RO, and FC are shown in Table 1.
Table 1. Energy consumption and cost for desalination technology

| Desalination Technology | Energy Consumption | Cost | Remarks |
|-------------------------|--------------------|------|---------|
| Evaporation [50]        | High energy requirement | (Not mentioned) | Estimation for nanofiltration composition recovery is 85%. |
| Evaporation [51]        | Saves energy about 15% (blend feed – seawater and brine) | • It is profitable and economical for desalination plants<br>• Operating cost reduced by 20% | Can operate and recover 50% of salt for desalination plants. |
| Reverse Osmosis [52]    | • Supply by back pressure turbine<br>• Energy consumption for brine discharge is 80% of using seawater | Using brine as a raw material is not approved due to economic difficulties. | The optimum current density is 3 A/dm² for electrodialyses of brine discharge. |
| Reverse Osmosis [53]    | Using alternative energy sources | Cost operation with renewable energy is higher compared to typical plants | RO membranes for seawater have good salt rejections (i.e., greater than 99%). |
| Reverse Osmosis [54]    | Requires low energy compared to evaporation | (Not mentioned) | Separation of substances depends on size and osmotic pressure |
| Freeze Concentration [9] | Requires low energy compared to evaporation | Cost for energy is low because latent heat of fusion of ice is one-seventh of the latent heat of vaporization | FC is not only for dairy and food processing but can also be applied in desalination process. |
| Freeze Concentration [54] | Requires low energy as latent heat of fusion is lower than latent heat of evaporation | (Not mentioned) | Effective partition constant is used to determine the effectiveness of FC (separation process). |
| Freeze Concentration [44] | Requires less energy per kg of product | (Not mentioned) | Conversion into water and salt (100%) |

Conventional methods such as evaporation and RO have drawbacks that can be overcome with EFC. Evaporative crystallization has extremely high energy requirement [50], which translates into high monetary cost to generate the energy needed. This method can reduce brine volume but fails to produce pure salt [55]. Meanwhile, in the case of RO, the rate of RO is limited by blockage of the pores of membrane surface [56]. In order to prolong membrane life, the waste stream must first be treated before separation can be carried out, which further increases the cost of RO processes [57].

Although it is true that evaporation and RO have become much more efficient as newer approaches to these processes means that the processes cannot be scaled up to an extreme degree as the heat required would render the process unsustainable or inefficient [58]. These limitations can be overcome by applying EFC, which on the other hand, offers a more sustainable method of separation that can be...
scaled up to meet industry demands. Pure water and salt can be recovered by EFC [59]. This new process can also be combined with existing processes to enable new operations to be designed [60].

4. Current Applications of Eutectic Freeze Crystallization

4.1 Sodium Chloride Production
Refined salt contains about 97% to 99% of sodium chloride (NaCl) that can be commercialized in many manufacturing processes, such as the production of pulp and paper, setting dyes in textiles and fabrics and the making of soaps and detergents. Pure salt and pure water are separated by cooling to the eutectic temperature. A cooled disk column crystallizer (CDCC) was used to perform experiments and further experiments were performed using a large-scale setup built in a skid. 70 kg of filtered ice and 18 kg of the anhydrate of NaCl were produced during 5 h of continuous operation of the skid [61].

Barduhn and Manudhane [62] used a simple eutectic freezing system for desalination process. Heat was removed so that the operating temperature could reach -21 °C, which was higher than the usual eutectic point (-25 °C). Salt slurry was filtered to produce wet solid salt product whereas ice slurry was washed to remove salt by using a wash column. An ice-salt separator and a salt filter are apparatus that differentiate between EFC and other crystallization processes. Besides, another difference between EFC and other crystallization processes for desalination is EFC operates at -21 °C to -25 °C whereas other crystallization processes operate at -5 °C.

4.2 Treatment of Potassium Nitrate
A waste stream containing 16 wt. % of potassium nitrate (KNO₃), 1.1 wt. % of nitric acid (HNO₃) and 3,345 ppm of organic material are formed during the production of starch from potatoes. It is important to separate this stream into KNO₃ and pure water in order to recycle KNO₃ and reduce the negative environmental impact of starch production. Commonly, the conventional method of evaporative crystallization is applied [63]. Thus, a comparison is made between using EFC and conventional evaporative crystallization to separate the KNO₃ stream [58].

In the case of conventional evaporative crystallization, the maximum yield is 90% [58]. Additional chemicals are also needed to neutralize the stream before separation. There is also a higher safety risk associated with this method as toxic fumes are generated and there is a risk of explosion due to high temperatures needed for this method. From an economic viewpoint, high temperature also increases rate of corrosion, which will increase maintenance costs of equipment. On the other hand, EFC is able to have a yield up to 99% without the need to add any additional chemical before separation. There are no toxic fumes produces and no risk of explosion. EFC is also more economic as low temperature inhibit rate of corrosion [58].

4.3 Treatment of Magnesium Sulphate
Various toxic gases are generated during the combustion of fossil fuels. Among those is sulfur dioxide (SO₂) [64]. In the process of desulphurization, SO₂ is absorbed into aqueous magnesium hydroxide solution. However this processes produces a stream of magnesium sulfate (MgSO₄) solution [58]. Although this stream is harmless, MgSO₄ has many uses, such as being used as a fertilizer. Therefore, it would be desirable to separate and recover MgSO₄. EFC offers many advantages in separating the MgSO₄ stream. First, approximately 19 GWh of electricity can be saved per year by using EFC compared to conventional evaporative crystallization. Recycling MgSO₄ can also be used to boost production of various industries, such as fertilizers.

5. Design of Eutectic Freeze Crystallization Equipment

5.1 Cooled Disk Column Crystallizer
One of the designs of EFC is a cooled-disk column crystallizer (CDCC) where salt is separated from water. In a CDCC, crystallization and gravitational separation occurs within one system. Figure 3 shows that the feed enters the crystallizer and ice and salt crystals are formed at the eutectic temperature. The
ice leaves the crystallizer from the top due to its lower density whereas salt leaves through the bottom [65]. Then, the ice and salt are washed and filtered respectively to produce a higher purity product whereas the recycled salt solution flows back to the crystallizer. Part of the melted ice is used as the wash fluid in the washing column.

Figure 4 shows a more detailed look at the crystallizer of the CDCC. The main components of the crystallizer are cooling disk, scrapers, orifice rings, and ice baffles [66]. The cooling disks have flat horizontal cooling surfaces in which a refrigerant flows through a network of paths. This increases the surface area of cooling to facilitate more efficient heat transfer between the mixture and refrigerant. The cooling disks also separate the CDCC into multiple compartments with an equal volume / cooling area ratio, thus allowing a linear scale-up of the CDCC by increasing the number of compartments.

On the other hand, due to the tendency of ice and salt crystals to adhere to the walls of the CDCC, scrapers are used to remove the ice-salt scaling or clean up the wall of the crystallizer [44]. Orifice rings are used to make sure that ice can move freely between the compartments. The design of crystallizer is such that on each cooling disk, there are three rotating blades attached to the center axis of the crystallizer. In order to ensure maximum contact between the scrapers and the wall of crystallizer, springs are used to push the scrapers to the wall with even force [63]. Due to the function of scrapers in removing hard scales from the wall, a tough and high-density material is required for the scrapers. The material used in the crystallizer is high-density polyethylene. Another function of the scrapers is to
facilitate a higher rate of heat transfer between the mixture and refrigerant. The rotational speed of the scrapers is also important. A minimum speed is required to completely prevent scale build-up. Higher speed also facilitates greater heat transfer; however, the enhanced turbulence will interfere with the gravitational separation process that requires a stiller mixture environment [65].

The cooling equipment is attached to poor thermal conducting frames called orifice rings. These rings also create a smooth inner area of the crystallizer, which enable the scrapers to remove scaling more efficiently and reduced the surfaces that the scrapers cannot reach. Lastly, since ice is removed from the top of the crystallizer column by the overflow of the mixture solution, ice baffles are inserted at the top compartment to ensure smooth flow of the ice and prevent the large volume of ice from obstructing the flow.

5.2 Scraped Cooled Wall Crystallizer
A scraped cooled wall crystallizer (SCWC) is another piece of equipment used in EFC processes [65]. An SCWC and CDCC appear quite similar as both crystallizers have a cylindrical structure. However, heat exchangers in a SCWC consist of two cylinders completely immersed in the mixture to prevent heat loss to the environment [67]. This design also allows for unobstructed gravitational separation of ice and salt crystals to take place. Figure 5 shows the top view of an SCWC.

![Figure 5. Top view of scraped cooled wall crystallizer](image_url)

Similar to a CDCC, scrapers are also used to remove crystal scaling from the walls of the heat exchanger in a SCWC. However, in the case of the SCWC, the scrapers are mounted on a special scraper frame that is rotated by a frequency-controlled motor at the top of the crystallizer, as shown in figure 6 [67]. The design of the scraper will determine the turbulence created by the rotational motion of the scraper. This is important as sufficient turbulence must be achieved to properly transfer heat throughout the mixture [66]. There are scrapers on both sides of the cylindrical heat exchangers to remove as much scaling as possible.

The feed enters the crystallizer vertically between the cylindrical heat exchangers. The design of an SCWC is such that the top and bottom portions of the crystallizer are slightly warmer than the middle [67]. This allows ice agglomerates at the top and salt agglomerated at the bottom to melt slightly and break apart so that trapped salt or ice crystals can be separated, further purifying the final products of ice and salt. The conical shape at the top also prevents a vortex being formed by the centrifugal force of the scrapers’ rotation, thereby allowing ice to move toward the outlets.
6. **Case Study**

6.1 **Kemira Chemical Plant**

6.1.1. **Introduction.** Kemira is a chemical company located in Rozenburg, Netherlands that produces ammonium nitrate, nitric acid and urea at an industrial scale. However, in the production of ammonium nitrate, which is a key component of fertilizers, a large wastewater stream (130,000 ton/year) containing low concentrations of ammonium nitrate is produced [68]. Initially, the wastewater is simply dumped into the local environment through the sewer. However, many benefits can be gained from removing or separating the wastewater stream. The most important benefit is that the environmental impact of the chemical plant can be reduced. This will also be more economical for Kemira as the costs of dumping the wastewater into the sewer will be eliminated. Ammonium nitrate separated from the water stream can also be recycled to increase production efficiency. Ultimately, Kemira’s goal is to separate the wastewater stream into highly concentrated ammonium nitrate (more than 90%) and pure water (less than 50 ppm of ammonium nitrate).

Several separation methods can be considered to separate ammonium nitrate and water, such as evaporation, RO and EFC. However, these methods are unable to separate a stream of ammonium nitrate with a concentration of 90%. Therefore, a suitable combination of these methods must be identified based on important factors such as cost and output efficiency. The overall process can be divided into two main steps: the concentrating step, in which a large volume of the water is removed from the wastewater stream and the purification step, in which an ammonia stream of 90% concentration is produced [68].

6.1.2. **Process Design.** Since crystallizing the waste stream directly would be inefficient due to the large volume of water in the diluted stream, the stream must first be concentrated. The primary concentration methods available are evaporation, RO and FC. After concentrating the wastewater stream, purification of the concentrated stream is carried out as shown in figure 7 [68].
From the figure above, it can be seen that the wastewater stream will first be concentrated and then purified through crystallization. The pure water and concentrated ammonium nitrate produced will then be recycled to reduce the overall production costs of the chemical plant. The methods of concentration and purification chosen will be based on costs and energy consumption. Upon further analysis, a suitable combination of methods and technologies can be selected.

6.1.3. Choice of Design. Based on the analysis carried out, a combination of FC for the concentration step and EFC for the purification step has been determined in order to have the lowest combined energy cost, thus is the most suitable and efficient method [68]. This is further aided by the fact that the ammonium nitrate plant of Kemira is located near an ammonia plant. This reduces costs as ammonia, which is used for cooling the wastewater stream, can be easily and cheaply transported. However, in the absence of cooling facilities such as those present at Kemira, a combination of RO and EFC would be the next best option for separating the wastewater stream.

6.1.4. Use of Cooled Disk Column Crystallizer. During EFC, water is solidified into ice whereas ammonium and nitrate ions in the wastewater combine to form solid ammonium nitrate. Both these phase changes can occur simultaneously in the same vessel with the use of a CDCC [65]. The less dense ice crystals float to the top of the column whereas the denser ammonium nitrate salt sink to the bottom. The method of cooling the wastewater to the temperature of 251 K evaporated ammonia in the disks of a CDCC. A problem with a CDCC in this case is the longer time are needed to separate ammonium nitrate and water. This is due to the movement of the scrapers causing turbulent conditions in the CDCC, which is unfavourable for crystal formation. The fact that a CDCC relies on gravity to separate ice and ammonium nitrate crystals also increases the time taken for separation.

6.1.5. Wash Column. After EFC, the resulting ice and solid ammonium nitrate must be washed to remove ammonium nitrate adhering to the ice and also water adhering to the solid ammonium nitrate. Ice and ammonium nitrate are washed in separate washers, with the ice above the CDCC and ammonium nitrate below the CDCC. At the washer above the CDCC, the ice is melted into high purity water and a portion of the water is used as wash water [65]. The washer used in this separation process is a forced transport column. Mechanical and hydraulic columns are the two main types of forced transport wash columns [69]. Due to the fact that hydraulic columns have the ability to handle small crystals better than mechanical columns, thus hydraulic columns are used in the separation process.

The TNO-Thigssen hydraulic wash column is an example of a hydraulic wash column, as depicted in Figure 8 [68]. The feed enters the wash column from the top and travels down. The filters in the column separate crystals from the main stream to form a packed bed of crystals. The bed of crystals moves downward to a scraper where the crystals are scraped off and transported to a melting circuit. However, this wash column functions with crystals that have higher density than the mother liquor. In the case of ice, the wash column is an inverted version of a conventional hydraulic wash column. This means that the feed enters through the bottom of the column and travels up and the scrapers are installed at the top of the column instead. Ice crystals are pushed upward by the pressure of the feed stream entering from the bottom.
Since the filters are a key component of the wash column, a suitable filter must also be chosen. The available filters are gravitational filters, cross-flow filters and rotary disk filters (Figure 9) [68]. Due to the longer filtration time associated with gravity-based filtration, gravitational filters are not considered in the separation process at Kemira Chemical Plant. On the other hand, cross-flow filtration has several advantages such as a higher filtration rate and the ability to function without feed additives, which makes it a better option. However, due to the higher energy supply required and higher operating cost, cross-flow filtration is still not the optimal choice of filters. Rotary disks are chosen to be used in the wash column.

![Figure 8. Diagram of a hydraulic wash column](image)

In a rotary filter, several thin disks are mounted on a shaft. A cloth is stretched on these disks to give a large filtration area per unit area of the filter. A scraper is used to remove crystal cakes above a certain thickness, in this case 10mm, with blowing air flow to aid this process.

![Figure 9. Diagram of a rotary disk filter](image)

6.1.6. Method of Cooling. In order to reach the low temperature required for FC and EFC, liquid ammonia is flash evaporated at low pressure using the indirect cooling method [70]. This is quite economical for Kemira as the chemical plant is located near an ammonia production facility. The pressure in which ammonia is flashed depends on the temperature required for FC and EFC. The FC process is carried out at 270K. Hence, liquid ammonia is flashed to 260 K, which corresponds to the pressure of 2.6 bar. A difference in temperature of 10 K is necessary for effective heat exchange. On the
other hand, the EFC process is carried out at 256 K. Therefore, ammonia is flashed to the temperature of 251 K or 1.7 bar since a temperature difference of 5 K is enough for effective heat exchange [68].

Two separate vessels are required to flash ammonia to the two pressures stated. A knock-out drum is also installed to separate liquid ammonia and ammonia vapor as ammonia is only partially evaporated (80% of the liquid ammonia is evaporated). Ammonia vapor is sent to a compressor to be compressed to the pressure of 4.2 bar, whereas liquid ammonia is recycled in the FC or EFC process.

6.2 DWP Botlek of Evides Industriewater

In this study, EFC process has been applied for treating cation exchange (CIEX) regenerate in order to reduce the volume of waste stream and recover NaCl. CIEX is a resin with a strong acid cation and widely used in water treatment. Removal of calcium (Ca$^{2+}$) and magnesium (Mg$^{2+}$) is carried out by exchanging them with sodium (Na$^+$) available on the surface and pores of CIEX resin beads. Regeneration is done periodically in order to recharge CIEX resin and is performed with regenerant solution (10 wt.% solution of NaCl). The spent regenerant usually contains a mixture of NaCl, calcium chloride (CaCl$_2$) and magnesium chloride (MgCl$_2$) at a total concentration of 2-4 wt.% [71].

Approximately, 1,400 m$^3$/h of demi water is produced using fresh water from Brielse Meer. The raw water has 2-10 NTU of turbidity, 500-850μS/cm of conductivity and 80mg/L calcium of total hardness. Three methods are used for water pre-treatment, which are coagulation/flocculation, dissolved air floatation (DAF), and rapid filtration (anthracite/sand). This pre-treated water is pumped to the softening section of the plant, where CIEX takes place for Ca removal. The softening section consists of eight CIEX vessels regenerated using as overdose regenerant of NaCl. The balance of NaCl is ready for recovery [71].

6.2.1 Eutectic Freeze Crystallization in DWP Botlek. Since EFC is more practical to be used when the concentration of salt is close to eutectic concentration, the spent regenerant needs to be pre-concentrated using FC before feeding to EFC. Figure 10 shows a conceptual model of EFC with the pre-concentration step of FC [71].

![Figure 10. Continuous separation of salt and water by FC followed by EFC](image)

The pilot is divided into two units, namely a crystallizer unit and a separation unit. Ice slurry and salt slurry produced from the crystallizer are pumped into the separation unit where ice and salt are separated from the mother liquor. Both ice and salt are extracted out of the system whereas the mother liquor is reused back for the crystallizer.

7. Conclusion

In conclusion, the process of EFC has many advantages, mainly in terms of energy requirement, cost and yield compared to other separation processes. This allows EFC to be sustainable even in a large industrial scale. The two heat exchangers used in EFC are the scraped surface heat exchanger and the
fluidized bed heat exchanger. Although both types of heat exchangers have their own advantages, the scraped surface heat exchanger is more commonly used. An example of the use of scraped surface heat exchangers in EFC is the CDCC. This crystallizer has been used in the Kemira Chemical Plant in Rozenburg, Netherlands to great success, surpassing the use of conventional separation methods. EFC has also shown promise in other industrial separation processes, such as the treatment of magnesium sulphate and potassium nitrate. A new effective design for EFC setup should be developed in order to increase performance of EFC separation method. With this study, it is hoped that EFC will be seen as a viable option in the industry, with an even better scaling-up potential than conventional separation methods.

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