Recovery of sodium sulphate from a reverse osmosis concentrate of silica-industry wastewater by eutectic freeze crystallisation technology

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Thesis Report

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ABSTRACT

Resources recovery from wastewater is pursued as it facilitates a circular economy, which a society runs with a minimal environmental impact. Eutectic freeze crystallisation (EFC) has been identified as a potential technology that can assist to achieve such goal. High quality of salt and ice can be retrieved with this treatment with a note of high energy efficiency. In this paper, based on an actual case of a Spanish silica production company, freeze and eutectic freeze crystallisation are found to be applicable to a complex RO concentrate, which involved Na, Mg, Ca, Sr, Ba, SiO_2. Quality ice and mirabilite products were also produced, which the impurities attached can be further washed away easily. The influence of the impurities on the eutectic point of sodium sulphate solution is investigated. A conservative recovery rate of 42wt% and 55wt% are obtained respectively for mirabilite and ice. Heat transfer characteristics of the equipment are also conducted, the boundary layers in the working solution and in the coolant have a clear influence on the overall heat transfer. A heat transfer of 404W/K-m^2 is obtained for the EFC cooling, which is found to be comparable to past study. Energy consumption for a complete EFC process on the RO concentrate is estimated to be 0.1437 kWh/kg-solution, which is only 22% of the energy consumed in heat crystallisation. Column crystalliser is suggested to be a possible method to resolve impurities accumulation issue. Torque was also identified to indicate nucleation and crystallisation during the process. A crystal size distribution model is developed and can be used to evaluate or predict the performance of an EFC system. During the thesis study, a successful demonstration and training was provided to the staff from Fundació CTM Centre Tecnològic, which is the respondent for the Spanish case and will later perform a EFC experiment in the treatment plant.

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NOMENCLATURE

List of symbols	
Symbol	Description
[-]	unit less
/	per
°C	degree Celsius
cm	centimetre
g	gram
h	hour
K	Kelvin
kg	kilogram
kWh	kilowatt-hour
L	litre
m	mass
mg	milligram
min	minute
ml	millilitre
mm	millimetre
ppb	parts per billion
ppm	parts per million
Q	heat flux
R	R-value (for statistic)
rpm	revolutions per minute
s	second
W	Watt
wt%	weight percentage
µm	micrometre

List of abbreviations	
Abbreviation	Description
Al	Aluminium
Ba	Barium
Ca	Calcium
Cl	Chloride
EC	electrolytic conductivity
EFC	eutectic freeze crystallisation
Fe	Iron
H2O	water
HEX	heat exchanger
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
NO3-	Nitrate
RO	reverse osmosis
SiO2	Silica
SO42-	sulphate
Sr	Strontium
TIC	total inorganic carbon
ZLD	zero liquid discharge

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1 BACKGROUND

Zero liquid discharge is an idea of converting industrial process wastewater into useful resources. By eliminating wastewater discharge, environmental impact from industries can be reduced; business can also be improved in a circular economy.

ZERO BRINE project in 2017 is proposed to achieve such goal to facilitate the implementation of circular economy scheme in precipitated silica industry to recover resources. Eutectic freeze crystallization (EFC) is considered to be a promising candidate to retrieve sodium sulphate and water from concentrated effluents in the silica industry. The concentrated effluent is a reverse osmosis concentrate of process wastewater; study on such has already been done by Casadellà & Meca (2018) and this study will succeed to analyse if EFC can be used to recover sodium sulphate and ice from the concentrate.

1.1 Brief discussion on EFC

Crystallisation is a unit operation for solid-liquid separation by utilising the solubility of a compound. Solutions are forced to reach supersaturation by evaporating or cooling or other methods resulting solute transformation from aqueous phase to crystalline phase. Noted, as cooling is more thermodynamically favourable than evaporating, less energy is required for cooling which should be preferred in industry process. A discussion on crystallisation is inevitably to understand and employ a solid-liquid phase diagram.

A solid-liquid phase diagram is a diagram shows a system condition in given temperature and concentration. Presented in Fig 1 (Fernández-Torres, et al., 2012, after Hougen, et al., 1954) a binary phase diagram of sodium sulphate and water indicates the system condition of sodium sulphate solution with different concentration under different temperature conditions. For example, an 8wt% solution is undersaturated at 20°C, yet, at 10°C, the concentration exceeds its solubility in water and results in crystal forms in the solution; cooling crystallisation can be achieved by lowering the temperature of a certain concentration. As shown in the figure, having a solution with 4.19% weight fraction at eutectic temperature (-1.27°C), eutectic freeze crystallisation can be achieved, which sodium sulphate decahydrate, aka mirabilite, and ice are crystallised and obtained instantaneously. Similar concept applies to a ternary or even more complex phase diagram for a more complicated solution.

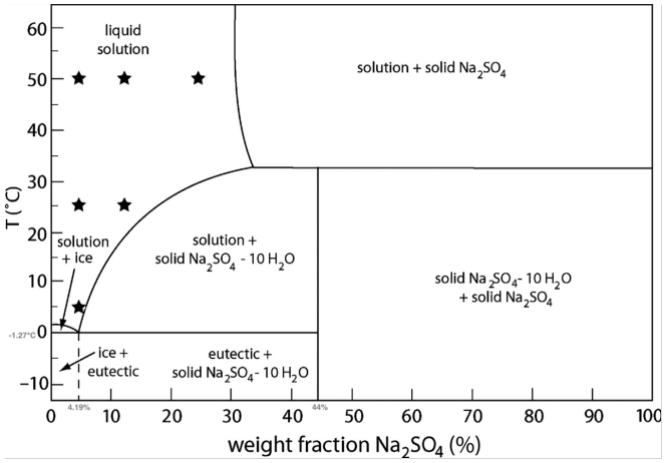

Figure 1. Binary phase diagram for sodium sulphate-water system.

Eutectic freeze crystallization is a recent technology on treating brines and concentrates (van der Ham, et al., 1999; Vaessen, 2003; Rodrigues Pascual, 2009; Fernández-Torres, et al., 2012; Lu, et al., 2017). Crystallisation at eutectic point, unlike regular crystallization, produces two compounds simultaneously, both the solute and water will be crystallised and retrieved. A theoretical zero liquid discharge can then

be achieved in addition of a production of high quality of ice and salt product. The technology is also proven to have a lower energy consumption than conventional evaporation processes with its applicability of different aqueous streams with various concentrations. It has been mostly studied and applied in wastewater treatment for water and salt recovery. Various organic and inorganic compounds are researched to be separable from aqueous solutions.

In terms of operation, when reaching eutectic point, a three-phase situation will occur; ice, salt and saturated solution will coexist in a crystalliser. Based on the different density of the components, ice crystals will float and salt crystals will sink and the saturated solution will stay in between simultaneously. Ice can then be retrieved from the top of the solution and salt can be recovered from an exit at the bottom of the reactor after filtration.

Recovering sodium sulphate from a mining wastewater was recently researched (Reddy, et al., 2010), EFC of a RO concentrate, which had a similar concentration as eutectic composition, was succeed and a recovery of over 90% of pure sodium sulphate crystals was obtained from concentrated streams.

1.2 Wastewater from silica industry

In this thesis, wastewater from a silica-production company, Industrias Químicas del Ebro S.A. (IQE), from Spain is studied for the possibility of recovering sodium sulphate. Amorphous silica (REACH number: 01-2119379499-16-0058) is produced through a production process which is schemed in the following:

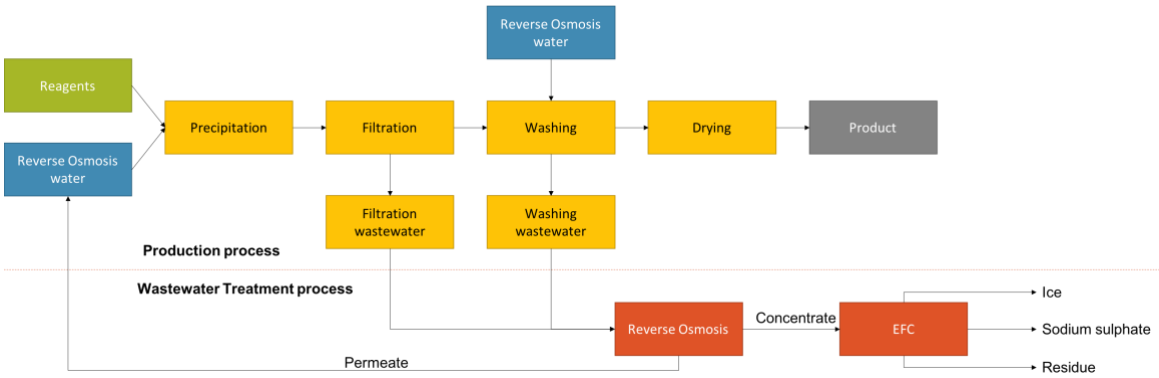

Figure 2. Production and proposed wastewater treatment process at IQE.

The filtration wastewater and washing wastewater from the production line are combined and treated in a wastewater treatment plant. The water stream quantities and qualities are presented in the Appendix 8.1.

1.3 Feed of EFC

From the Appendix 8.1, it is noted the concentration of the combined stream is undersaturated for direct eutectic freeze crystallisation, concentrating the stream is necessary. A study on concentrating the wastewater via reverse osmosis was done by Casadellà & Meca (2018) and provided a perspective of recovering sodium sulphate from silica industry wastewater. Though anti-scalent was suspected to be used in RO for preventing silica polarisation, it is not mentioned of its existence and concentration, this study assumes no anti-scalent appears in the concentrate. The concentration of the mentioned ions/compounds in theRO concentrate is as shown in Table 1.

Table 1. Composition of the RO concentrate of combined wastewater

Ion		MW	Concentration		Weight %		Charge
		[g/mol]	[mg/L]	[mmol/L]	Wet mass	Dry mass	
Sulphate	SO_4^{2-}	96.060	54663.000	569.051	5.13	61.216	-2
Sodium	Na^+	22.990	27930.300	1214.889	2.62	31.278	1
Chloride	Cl^-	35.453	5370.700	151.488	0.49	6.015	-1
Magnesium	Mg^{2+}	24.305	817.000	33.614	0.08	0.915	2
Silica	SiO_2	60.080	269.200	4.481	0.03	0.301	0
Potassium	K^+	39.098	142.200	3.637	0.014	0.159	1
Calcium	Ca^{2+}	40.078	60.200	1.502	0.006	0.067	2
Nitrate	NO_3^-	62.000	36.700	0.592	0.004	0.041	-1
Bicarbonate	HCO_3^-	61.017	3.400	0.056	0.000	0.004	-1
Strontium	Sr^{2+}	87.620	1.100	0.013	0.000	0.001	2
Manganese	Mn^{2+}	24.305	0.980	0.040	0.000	0.001	2
Carbonate	CO_3^{2-}	60.010	0.800	0.013	0.000	0.001	-2
Barium	Ba^{2+}	137.330	0.130	0.001	0.000	0.000	2
Iron III	Fe^{3+}	55.845	0.030	0.001	0.000	0.000	3
Aluminium	Al^{3+}	26.982	0.030	0.001	0.000	0.000	3
Fluoride	F^-	18.998	0.000	0.000	0.000	0.000	-1

Sulphate and sodium ions combined are the most dominating in the concentrate, which is about 92.49 wt% among all the ions. In addition to chloride and magnesium, 99.42 wt% of the ions are considered. The research is therefore narrowed to these four ions, which will be included in the synthetic wastewater.

Eutectic freeze crystallisation occurs when a solution with sufficient concentration reaches eutectic point. The salt combinations of the EFC outcome are as followed in the descending order of the eutectic point under their water binary situation:

Table 2. Eutectic condition of the possible compounds in the synthetic wastewater

Compound		Eutectic point	Eutectic concentration	Reference
		[°C]	[wt%]	
Sodium sulphate	Na_2SO_4	-1.27	4.19	Hougen et al., 1954
Magnesium sulphate	$MgSO_4$	-3.7	17.4	Pillay et al., 2005
Sodium chloride	NaCl	-21.1	23.3	Verbeek, 2011
Magnesium chloride	$MgCl_2$	-33	21.6	FHWA, 2012

Among the possible compounds, sodium sulphate is the only possible compound that reaches its eutectic concentration and is meanwhile with a highest eutectic point. Sodium sulphate is expected to be eutectic freeze crystallised and retrieved from the RO concentrate.

Some impurities, such as barium, strontium, calcium, and silica, in the concentrate can form insoluble crystal before the sodium sulphate crystallised, the purity of crystals in this multi-compound situation maybe affected. Except calcium, the other three compounds are not studied in previous research (Reddy, et al., 2010). Moreover, the eutectic temperature of sodium sulphate may also be affected by the impurities due to common ion effect. Therefore, these ions are worth to be investigated and included as addition in experiments.

1.4 Stirring in EFC

Stirrer has two purposes: increasing hydrodynamics and scale scraping. The increased hydrodynamics ensures an even temperature distribution throughout the solution and reduce the localised boundary layer between the cooling plate and working solution for preventing scaling.

Scaling is a critical issue in EFC technology that affects the whole treatment process, as it reduces the heat transfer and further affect the temperature in the crystalliser (Vaessen, 2003; Verbeek, 2011). Also, ice scaling enhances the difficultness of harvesting the formed ice and may additionally trapped part of the salt crystals onto the scaling and further reduce the gain in salt product. Therefore, ice scaling should be avoided. Stirring torque is often used for signalling the ice scaling happened on the heat exchange (HEX) surface. In this study, stirring torque was also used to monitor the EFC process in case of scaling occurs.

1.5 Heat transfer in EFC

Heat transfer of a crystalliser is a critical factor on its performance and capacity. The indication and calculation of the overall heat transfer is therefore necessary to be made. Heat fluxes from heat exchange plate, crystallisation, system leakage, and dissipation are identified as the major contributors in the overall heat transfer (Verbeek, 2011; Alexopoulos, 2018), which can be expressed in following equation:

$$Q_{overall} = -Q_{plate} + Q_{crystallisation} + Q_{environment} + Q_{dissipation}$$

Noted heat gain by the system is set as positive and therefore heat flux from the cooling plate is stated as negative and the others as positive. From Appendix 8.4, factors of the individual heat transfers were further stated and identified, they are: bubbling rate, stirrer speed, operation temperature, and coolant pump rate. Influences from these factors on the overall heat transfer were investigated in this study.

1.6 Crystals recovery

High-purity salt and ice are aimed to recover during EFC process, the amount of such can be calculated via the phase diagram. At eutectic conditions, sodium sulphate decahydrate and ice from a perfect solid-liquid separation in a binary system are produced simultaneously in the following ratio (Fernández-Torres, et al., 2012):

$$m_{ice} \cdot (0.0419 - 0) = m_{Na_2SO_4 \cdot H_2O} \cdot (0.44 - 0.0419)$$

$$\frac{m_{ice}}{m_{Na_2SO_4 \cdot H_2O}} = 9.5012$$

With a known amount of sodium sulphate decahydrate in target solution, the amount of ice produced can be estimated. In this case, for (eutectic concentration) 4.19wt% sodium sulphate in 9L Na_2SO_4-H_2O solution, 390g of sodium sulphate anhydrous are involved, which corresponds to 884g of sodium sulphate decahydrates. By using the above formula, 8401g of ice is expected to be recovered. Noted, the ice production in undersaturation or the salt production in supersaturation condition during cooling are different from that formed once at eutectic condition.

Past research investigated the practical recovery of sodium sulphate decahydrate from a mix system with sodium chloride (Reddy, et al., 2010). Over 90% recovery of the hydrated salt was achieved, yet the ice recovery was not mentioned.

1.7 Development of the 15L EFC crystalliser

Development and improvement of the 15L EFC crystalliser were involved in the thesis work before it was used for experiments. The design and production were conducted by DEMO department in TU Delft, while the testing of its performance was part of the thesis work. Several trials are conducted for each improvement to validate if the equipment can perform EFC process smoothly without any ice scaling issue. The stirrer design was currently settled with four vertical blades pressing on the heat exchange plate, the equipment design drawing was shown in Appendix 8.2 and the picture was shown in Figure 3.

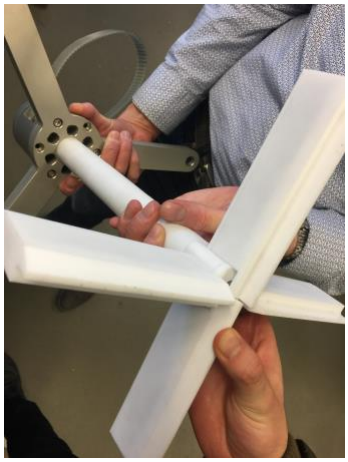

Figure 3. Picture of the current stirrer, which was used in this study .

Months of efforts were required to alter and improve the crystalliser for a proper running. The following is a brief description on the main design stages and the corresponding issues during the time:

1. The EFC crystalliser was designed based on the images from Vaessen (2003). As the original detail drawings were not available, DEMO designed and built it in addition to their expertise. The first version was with a stirrer, which its blades were inclined and with reinforcing springs installed, fixated at the centre of the heat exchange plate due to stability. The inclined feature was not Vaessen's design but was applied to improve the hydrodynamic resistance. Figure 4 is a picture of the original stirrer. Ice scaling was observed during the trial test, it was suspected to occur due to the exposing metal components of the stirrer. Therefore, plastic coating on the stirrer was suggested. Moreover, small area near the plate centre was not scraped by the blade, a small scrapping piece was suggested to be installed for handling that area.

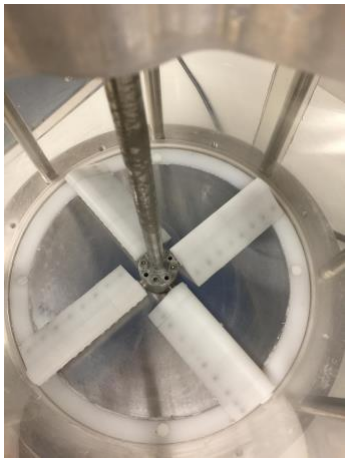

Figure 4. Top view of the original stirrer in the EFC crystalliser.

2. With the plastic coating, ice scaling was still occurred. It was noticed that part of the blades were uplifted and misaligned after the EFC process, the pressing of the blades were suspected to be insufficient. Hence, stronger reinforced springs inside the blades are installed. Figure 5 shows the stirrer at this stage and the issue of uplifted blade.

Figure 5. Top view of the stirrer with plastic-coating (Left) and ice scaling with uplifted blade (Right).

3. Ice scaling was still observed after the alternation. The inclined blades were concluded not having sufficient pressing force to handle scaling even with stronger springs. Therefore, the blades were redesigned to vertical ones and were added with features that the pressing was adjustable. Moreover, it was always suspected that the fixation joint of the stirrer on the heat exchange plate was one of the reasons causing ice scaling, as small fraction of metal component was still exposed to the solution even with the plastic coating. The stirrer was redesigned to be unfixed on the plate, the fixation hole on the plate was filled with a plastic block. Figure 6 shows both the stirrer with inclined blades and the stirrer with vertical blades.

Figure 6. Inclined-blade stirrer (Left) and Vertical-blade stirrer (Right) sat on a table .

4. The new design was tested with different stirrer pressing settings and the equipment performed EFC smoothly with 1.5mm pressing, which the pressing force for each blade was 11.2N/mm. As the stirrer was with four blades, the pressing force acting from the stirrer was estimated to be 67.2N. Such setting and design was used for the experiments in this study.

2 RESEARCH SCOPE

Brine discharge from industrial plant may soon be banned in Europe in the coming future, eutectic freeze crystallisation (EFC) has been identified as a potential technology, which is energy efficient, that can assist to achieve such goal. At the same time, sodium sulphate is dominating in silica-industry wastewater and is a very common chemical that is used in different industries. EFC is a possible method on achieving zero liquid discharge and at the same time retrieve promising crystal products. The performance of EFC on such is worth to be investigated. The issue can be expressed in the following question:

Is eutectic freeze crystallization technology possible to be used to recover sodium sulphate and water from RO concentrate of treated silica-industry wastewater?

In order to answer this question, the following aspects are further addressed:

- How the impurities in the RO concentrate influence the eutectic crystallisation of sodium sulphate?
- What is the quality and yield of the mirabilite and ice product from RO concentrate by EFC?
- If there are impurities in the product, can they be easily removed via washing?
- Which are the key factors influence the overall heat transfer, which influences EFC process?
- What is the energy consumption of the EFC working with the RO concentrate?
- Is there any issue that should be addressed for a full scale implementation of EFC?

3 METHODS AND MATERIAL

3.1 Solution preparation

High precision scale is used to prepare synthetic RO concentrate solution as the feed of EFC, the concentration will be based on the research by CTM. Solutions with the calculated concentration are prepared for study, as shown in Table 3. Experiment 1 solution is a simple case which has only one type of pollutant; sodium bicarbonate was chosen as it is harmless and it can prevent scaling comparing with a pure binary system. Solution 2 is a solution without any suspected insoluble compounds (Ca^{2+}, Sr^{2+}, Ba^{2+}, SiO_2). Solution 3 is the synthetic RO concentrate based on the Spanish case. Solution 4 is a solution simulates a situation during a continuous EFC process with accumulation of impurities. As it is a simulation of an ongoing EFC processes, the sodium sulphate concentration in the solution was assumed to be the same as the eutectic concentration and lower than the concentration in solution 3; the other concentrations were assumed doubled.

Table 3. Compositions of the synthetic experimental solutions

Ion	Solution 1: 8wt% sodium sulphate solution with 1% sodium bicarbonate		2: Na_2SO_4 – NaCl – $MgCl_2$ system		3: Synthetic RO concentrate		4: 4.5wt% sodium sulphate with doubled RO concentrate impurities	
	[mg/L]	wt%	[mg/L]	wt%	[mg/L]	wt%	[mg/L]	wt%
Sulphate	54103.07	5.41	54663.00	5.47	54663.00	5.47	29320.00	2.82
Sodium	28633.61	2.86	27930.30	2.79	27930.30	2.79	17769.20	1.71
Chloride			5105.83	0.51	5213.29	0.52	10741.49	1.03
Magnesium			817.00	0.08	817.00	0.08	1634.00	0.16
Silica					269.20	0.03	538.40	0.05
Calcium					60.20	0.01	120.40	0.01
Bicarbonate	7263.32	0.73						
Strontium					1.10	0.00	2.20	0.00
Barium					0.13	0.00	0.26	0.00

9L synthetic solution is prepared for each experiment. Based on the concentration required, salts are added according, the amount are stated as in Table 4. The water amount was considered with the solution density, which is assumed be the same as that of a binary solution with the same concentration of sodium sulphate. The calculation is forecast based on the linear regression of the known density of different sodium sulphate solution (Haynes, 1999). As calcium, barium, and strontium chloride are easily formed insoluble salts when they encountered sulphates, 100ml from the required water was used separately for dissolving them before combining the whole solution. Moreover, as silica is known to be less soluble, complete dissolution of silica into the water is ensured before adding the other soluble compounds. Measuring cylinder is used to measure the water amount and a precise scale is used for weighting the salts. Stir bar is used when dissolving compounds.

Table 4. Mass of chemicals used for experimental solutions

Compound	Unit	Solution 1	2	3	4
Na_2SO_4	g	745.00	727.45	727.45	390.19
$NaHCO_3$	g	93.12	/	/	/
NaCl	g	/	40.39	40.39	85.45
$MgCl_2$ $6H_2O$	g	/	6.83	6.83	13.66
$CaCl_2$ $2H_2O$	g	/	/	0.22	0.44
$BaCl_2$ $2H_2O$	mg	/	/	0.23	0.46
$SrCl_2$ $6H_2O$	mg	/	/	3.35	6.69
SiO_2	g	/	/	0.27	0.54
H_2O	ml	8474.34	8816.89	8857.14	8857.14

3.2 Eutectic freeze crystallisation

A 15L cooled disk column crystalliser, which was constructed by DEMO TU Delft, is used for crystallisation experiments. The design drawing of the crystalliser is in Appendix 8.2. The crystalliser is connected to LAUDA Proline Kryomat RP 4090 CW thermostat, which is for thermostating the cooling plate and measuring internal temperature of the crystalliser. Heat transfer liquid Kryo 90 is used for the thermostating. Heidolph Hei-TORQUE 400 motor is installed above the crystalliser for stirring during the experiment. The thermostat and the motor are connected to a computer, which controls, monitors and logs measurements via their official software. As an amplifier was included in the setup, the actual torque encountered in the system is doubled and the stirring speed is halved comparing to the value obtained, the torque and stirring speed mentioned in this report is already adjusted to the actual encounter of the system

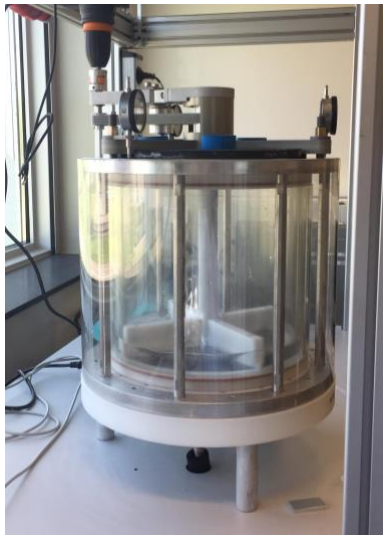

Figure 7. 15L EFC crystalliser by DEMO TU Delft .

The crystalliser is also linked to a flow cell and two vacuum filtrations, circulation of the slurry or filtered solution is achieved in the system. The pressing of the stirrer is being done by the built-in gear on the crystalliser. Pressing of 1.5mm and rotating speed of 75rpm are set as reference in this study. A schematic diagram of the equipment and connections are shown in Appendix 8.3.

For start, with solution 3 and 4, as potential precipitating compounds were involved, the bigger volume solution (with sodium sulphate) was added to the reactor and the small volume solution (with calcium, barium, and strontium) was added later. Direct pouring of one mix solution was conducted for solution 1 and 2.

As to prevent ice scaling on the cooling plate, 50g of smashed ice are added to the solution at -0.9 °C in every EFC experiments.

3.3 Crystals recovery

A recovery of sodium sulphate decahydrates and ice was performed from a 4wt% Na_2SO_4-15wt% $MgSO_4$ system. Magnesium sulphate was chosen as it has the second highest concentration in the target industrial wastewater. Though its eutectic temperature is close to that of sodium sulphate, comparing with sodium chloride used by Reddy et al. (2010), the effect on sodium sulphate formation should be insignificant with the change of the side compound.

The solution was cooled with a set coolant temperature of -4°C throughout the experiment. Regular domestic sieve was manually used to retrieve the ice from the top of the slurry. Salts were collected via a bottom outlet of the crystallizer and pumped to a vacuum glass filter, made by Prism Research Glass. 50g ice seeds were added to the system at -0.9°C for preventing scaling.

15g of mirabilite product was incubated under 105 °C for a rough estimation on the hydrate water mass. ice product was incubated under 105 °C for verifying its amount of impurities.

3.4 Overall heat transfer characteristics

The 15L cooled disk column crystalliser is used for verifying the overall heat transfer characteristics of the operation. A detailed explanation of the heat transfer was attached in Appendix 8.4. From that, the following parameters are identified that can affect the heat transfer during the EFC process:

Table 5. Parameters and baseline that are set as dependent variable for analysing the overall heat transfer of the EFC process.

Parameter	Measurable Quality	Unit	Baseline	Contribution
Reactor temperature	3.5, 15	°C	15	Q_{plate}
Coolant pumping level	6, 7, 8	-	7	Q_{plate}
Rotating Speed	35, 50, 75	rpm	150	$Q_{dissipation}$
Bubbling rate	0, 2.47, 3.30	cm^3/s	0	$Q_{environment}$
PET film on cooling plate	With, Without	-	Without	Q_{plate}

A 9L solution of 4.5wt% sodium sulphate and 0.5wt% sodium bicarbonate was used as the testing solution in the heat transfer experiments. The coolant flow rate was controlled by the pump level of the LAUDA thermostat, which its maximum pump level is 8 and corresponds to 19L/min. Rotational speed of the stirrer was controlled by the Heidolph motor with an indication of rpm. Air pumping rate was controlled by Watson-Marlow Sci-Q with an indication of rpm; the bubbling rate was calculated from the known rotational speed of the peristaltic pump and the known dimensions of the tube. The solution temperature was measured by the external temperature probe from LAUDA thermostat.

3.5 Crystal sampling

Two double-walled vacuum glass filtrations, made by Prism Research Glass, are individually installed for filtering salt crystals and ice crystals. The filters' porosity was 10-26 µm. Salt crystals were collected as slurry from the bottom valve of the crystalliser and pumped by a peristaltic pump to the top of the filtration. Ice crystals are scooped via a domestic plastic sieve and transported manually to the top of the filtration; the transportation time is around 1 second. Noted all tubing were insulated by insulating foam as to minimise heat transfer with the environment.

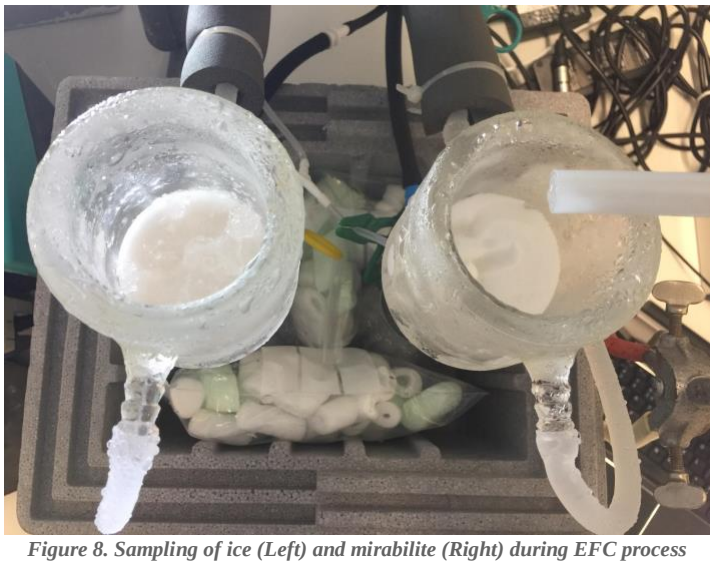

Figure 8. Sampling of ice (Left) and mirabilite (Right) during EFC process

3.6 Crystal washing

The amount of impurities on the crystal surface are investigated via direct washing on a thermostating vacuum filtration. The filtered crystals from the crystalliser are the unwashed crystal products. Washing will be conducted with 20ml, 40ml, and 60ml washing solution on about 2g crystal products. For mirabilite product, the samples are washed at room temperature; the washing solution used in each wash

is saturated sodium sulphate. Similarly, for ice product, the samples are washed at 0°C; the washing solution used in each wash is 0°C Milli-Q water. Noted the washing was conducted without stirring the crystal products.

3.7 Crystal purity measurements

Purities of ice product and salt product were analysed to understand the quality of the raw products and the impact from washing. The experimental solutions were also analysed for verification. Originally the Ion chromatography was planned to use for a complete understanding with both cations and anions. Yet, the values are inconsistent from the ion chromatography; it is suggested to conduct a less ideal elemental analysis with Inductively Coupled Plasma Mass Spectrometry (ICP-MS). By then, only the cationic elements (Na, Mg, Ca, Sr, Ba) were verified, but at least some observation could be done. HACH Silicomolybdate method (Method 8185) was used to analyse silica content in the samples. Dilution were conducted in advance due to the concentration and testing requirement; the test samples were prepared as following:

Table 6. Preparation procedures for different samples before conducting ICP-MS.

Sample	Target element/ compound	Preparation step
Salt product	Na, Mg	1. Dissolve 100mg sample into 100ml Milli-Q water. 2. Add 200μl Step 1 solution to 9.8ml nitric acid.
	Ca, Sr, Ba	1. Dissolve 100mg sample into 100ml Milli-Q water. 2. Add 5ml Step 1 solution to 5ml nitric acid.
	SiO_2	1. Dissolve 500mg sample into 10ml Milli-Q water.
Ice product	Na, Mg, Ca, Sr, Ba, SiO_2	1. Add 100μl melted sample to 9.9ml nitric acid.
Solution	Na, Mg, Ca	1. Dilute 1ml sample with 99ml Milli-Q water. 2. Add 200μl Step 1 solution to 9.8ml nitric acid.
	Sr, Ba	1. Dilute 1ml sample with 99ml nitric acid.
	SiO_2	1. Dilute 1ml sample with 9ml Milli-Q water

Noted the dilution was conducted with both pipette and scale for a precision.

3.8 Crystal size distribution modelling

For estimating EFC performance of a solution system, a crystal size distribution model was written based on a former made program. Python programming language was used due to its open-source nature. This process simulation includes heat balance, mass balances, and population of crystals, based on crystal nucleation, growth and dissolution, literatures were used for the formulas and parameters as explained in detail in Appendix 8.8. The model describes a Na_2SO_4-H_2O binary system with few impurities being cooled at a constant rate. The model can be used to evaluate and estimate an EFC process on a sodium sulphate solution in different operating conditions, including different volume, different cooling rate, and different concentration.

The model was written in a way which target compound and its properties can be easily changed from one another. Such code was already altered for evaluating EFC process on urea (Alexopoulos, 2018). Further alternation and prediction for different solutions with this code should be handy and promising.

The model was structured as shown in Figure 9, the program runs when the calculated time interval is equal or less than 50000 seconds and if the solid content of the slurry is less than the set maximum limit, which is adjustable. The brief explanations for each calculation section are listed as following chronologically:

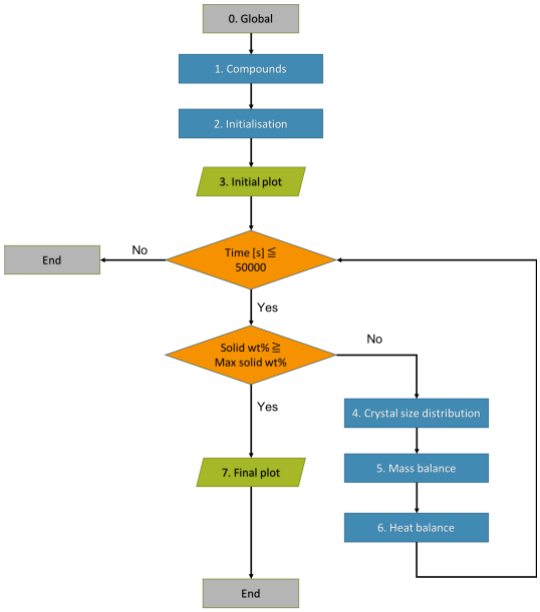

Figure 9. Process flow of the crystal size distribution model

0. Global
   The compounds physical properties, such as crystallisation rate, specific heat capacity, density, and solubility line, are stated as a global variable. The reactor size, the assumed class size arrangement, cooling rate, and maximum solid content are also included in this section.

1. Compounds
   This section is to select the properties parameters and input the concentrations of the salt compounds, which are sodium sulphate (compound 1) and sodium chloride (compound 2). The solubility line and ice line of sodium sulphate is also loaded in this section.

2. Initialisation
   With an input initial reactor temperature, the masses of water, compound 1, compound 2, ice, crystal form of compound 1, and overall system are calculated in this section. By then, the volumes of these components are calculated. Finally, the number of compound 1 crystal and ice are also assumed to have a standard distribution based on the previous model.

3. Initial Plot
   Initial size distributions with crystal number and volume are stored to be plotted in this section.

4. Crystal size distribution
   For each time interval, a new temperature is reached. The compound 1 equilibrium concentration are calculated according to the solubility curve. If the current concentration is higher than that of equilibrium, supersaturation is reached, which the number of crystals for each length class are calculated based on the crystal growth, nucleation, and dissolution rate. Noted the time and length interval are set to be minimal which the differences of each crystal class size are minimal. The new mass and volume of the compound 1 crystal is then calculated accordingly.

   Similarly, the number, mass, and volume of ice in each length class are calculated.

5. Mass balance
   Due to the mass change of the compound 1 crystal and ice, the new mass of water, dissolved compound 1, and dissolved compound 2 have to be recalculated. The new concentration of compound 1 and new solid content of the slurry are also calculated.

6. Heat balance
   With the known amount of crystal formations compound 1 crystals and ice, heat transfer due to the crystallisations are calculated. In addition to the heat transfer from cooling, the new reactor temperature is then calculated with a known specific heat capacity. This new temperature is then used for the next calculation on the equilibrium concentration of the next loop.

7. Final Plot
   The following 9 graphs are plotted when the program finishes:
   - Initial and final crystal size distribution with the number of compound 1 crystals
   - Initial and final crystal size distribution with the number of ice crystals
   - Initial and final crystal size distribution with the ice volume
   - Initial and final crystal size distribution with the compound 1 crystal volume
   - Supersaturation profile with time
   - Ice undercooling profile with time
   - Mass profile of compound 1 crystal with time
   - Mass profile of ice with time
   - Temperature profile with time

3.9 Energy consumption for EFC process

Cooling and stirring are two critical components for the EFC process. Based on the experiments, the temperature of the working solution and the coolant were recorded, which the overall heat transfer can then be calculated from the equation in Appendix 8.4. The energy consumption for cooling can then be calculated. The energy use in stirring can also be calculated from the recorded torque and the know rotational speed. Noted, the other side equipment, such as pumps and filter setup, are not included in this study

4 RESULTS AND DISCUSSION

4.1 Depression of eutectic temperature in different solutions

Depressions of the eutectic freeze point due to impurities are observed in different solutions, as shown in Table 7. A more impure solution is observed to encounter a deeper depression.

Table 7. Recorded eutectic freeze point of different solutions

Eutectic freeze point recorded [°C]				
Na_2SO_4 system (Hougen, et al., 1954)	Na_2SO_4 – $NaHCO_3$ system	Na_2SO_4 – NaCl – $MgCl_2$ system	Synthetic RO concentrate	Synthetic concentrated RO concentrate
-1.27	-1.34	-1.36	-1.36	-1.49

Noted the doubled impurities solution simulates a doubled impurities accumulation in the RO concentrate during a continuous EFC process, the recorded freeze points are a good indication which the depression is minor in terms of industrial application.

4.2 Conservative recovery of 42% mirabilite and 55% ice with the 15L EFC equipment

Attempt was made on evaluating the recovery of sodium sulphate decahydrate and ice with the batch crystalliser. Due to the avoidance of the stirrer blades during the manual harvesting, only part of the mirabilites and ice from the solution are recovered, the obtained value does not reflect the optimal recovery of the mirabilite and ice; the value can be seen as the conservative estimation of the recovery via the EFC equipment.

371.5g of salt product and 5044.2g of ice product were collected from the process, excluding the 50g of seeding ice; the remaining slurry was 3918g. Considering the ice product contains some salt on the surface, the actual amount of ice within the ice product needs to be verified. 15.23g of the ice product was put into a 105°C oven, 0.52g residue is remained. Assuming the residue was all sodium sulphate anhydrite, it corresponds to 1.18g of sodium sulphate decahydrate, which contributes 7.7% of the ice product mass. Hence, ice composes 92.3% of the ice product, which is 4655.8g. Noted the similar heating procedure was also done with the salt product, the amount of water lost was as same as the water mass expected in hydrates, the salt product was vastly sodium sulphate decahydrate.

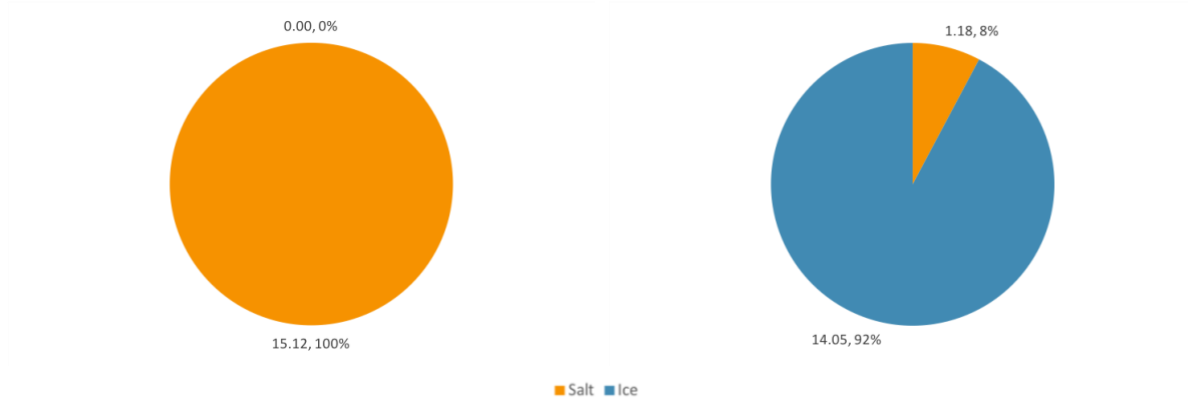

Figure 10. Composition of the recovered salt product (Left) and ice product (Right)

Comparing with the theoretical recovery, which is 884g mirabilite and 8401g ice, 42.0% of mirabilite and 55.4% of ice were already recovered from the solution with this simple harvest method. A higher recovery rate is expected with an advance harvesting equipment or a secondary treatment, such as a secondary EFC or evaporator, on the crystal product. Still, an almost pure mirabilite were obtained and a quality ice product were produced. As the mirabilite quality found in the market is mostly higher than 99%, the salt retrieved can already be used or sold directly without any further purification.

4.3 Quality crystal products obtained in different slurries and crystallisation stages

Mirabilite and ice crystal products are obtained with low impurities despite the impurities in target solution and the phase of the crystallisation. Taking the obtained products from eutectic point as an example, the concentration of impurities (Mg, Ca, Sr, Ba, SiO_2) in salt product are consistently negligible from different target solutions/ slurries, as shown in Table 8; impurities (Na, Mg, Ca, Sr, Ba, SiO_2) in ice product are observed to be low, as shown in Table 9. It indicates that the technology is robust with different impure solutions/ slurry conditions. Noted that sodium was found to be the dominant in ice product, which is expected as some mirabilite are attached on the ice surface during the process.

Table 8. Impurities in salt product from different slurry

Solution	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	SiO_2
	[mg/ 100mg-salt product; wt%]				
Na_2SO_4 – $NaHCO_3$ system	0.000	0.000	0.000	0.000	0.000
Na_2SO_4 – NaCl – $MgCl_2$ system	0.032	0.000	0.000	0.000	0.000
Synthetic RO concentrate	0.029	0.003	0.000	0.000	0.003
Synthetic concentrated RO concentrate	0.038	0.013	0.000	0.000	0.000
S.D.	0.005	0.007	0.000	0.000	0.002

Table 9. Impurities in ice product from different slurry

Solution	Na^{+}	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	SiO_2
	[mg/ 100mg-ice product; wt%]					
Na_2SO_4 – $NaHCO_3$ system	2.181	0.000	0.000	0.000	0.000	0.000
Na_2SO_4 – NaCl – $MgCl_2$ system	2.431	0.023	0.000	0.000	0.000	0.000
Synthetic RO concentrate	2.017	0.038	0.032	0.000	0.000	0.000
Synthetic concentrated RO concentrate	2.335	0.003	0.032	0.000	0.000	0.000
S.D.	0.181	0.017	0.018	0.000	0.000	0.000

Similar observation is found in different crystallisation stage, which crystals were taken at 3°C (during freeze crystallisation), eutectic point (during eutectic freeze crystallisation), and 30 min after reaching eutectic point (during eutectic freeze crystallisation). For synthetic RO concentration, Table 10 and 11 shows the impurities concentration of salt and ice products respectively in different sampling stage. Noted there is no ice produced at freeze crystallisation.

Table 10. Impurities in salt product in different sampling stage

Sampling stage	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	SiO_2
	[mg/ 100mg-salt product; wt%]				
Freeze crystallisation (3°C)	0.020	0.084	0.002	0.001	0.000
Eutectic freeze crystallisation (eutectic point)	0.029	0.028	0.000	0.000	0.031
Eutectic freeze crystallisation (eutectic point for 30min)	0.010	0.018	0.000	0.000	0.000
S.D.	0.164	0.036	0.001	0.000	0.018

Table 11. Impurities in salt product in different sampling stage

Sampling stage	Na^+	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	SiO_2
	[mg/ 100mg-salt product; wt%]					
Eutectic freeze crystallisation (eutectic point)	2.017	0.038	0.032	0.000	0.000	0.000
Eutectic freeze crystallisation (eutectic point for 30min)	1.904	0.068	0.030	0.000	0.000	0.000
S.D.	0.080	0.022	0.001	0.000	0.000	0.000

It is obvious that the technology is also robust to produce quality crystals with different crystallisation stages. In other words, steady quality mirabilite and ice products are promised throughout the EFC process.

In the world market, mirabilite is mostly sold with a purity more than 99%, it is important that the mirabilite product recovered from the RO concentrate by EFC is competitive. Viewing the highest concentration of dominant impurities (magnesium and calcium) obtained from the analysis, which is 0.068 wt% and 0.037 wt% respectively, if these cations are sulphate salt, the concentration of magnesium sulphate and calcium sulphate would be 0.336 wt% and 0.126 wt%. The calculation is based on the cationic element weight percentage divided by its molar mass and multiply by the molar mass of its sulphate. Similarly, if these cations are sulphate salt, the concentration of magnesium chloride and calcium chloride would be 0.267 wt% and 0.103 wt%. In both cases, the concentration of impurities is less than 1 wt%, it shows the mirabilite product obtained can be sold directly to the market without any treatment.

For raw ice product, as there were few but attentional amount of impurities. Washing should be conducted to obtain a purer product before using.

4.4 Impurities not embedded in the crystal product

The obtained crystal products are with high quality, yet few impurities are still detected. As to identify if the impurities are embedded in the crystals' structure, washing step is required. If the impurities are not embedded, impurities can be easily washed out and the product quality will be enhanced. The following is the washing effect on the produced crystals from synthetic RO concentrate.

For mirabilite product, as seen in Figure 11, the impurities (Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, SiO_2) are reduced along with the washing step. It indicates that the impurities are not fixed inside the mirabilite salt structure, washing can enhance the salt product quality. Con

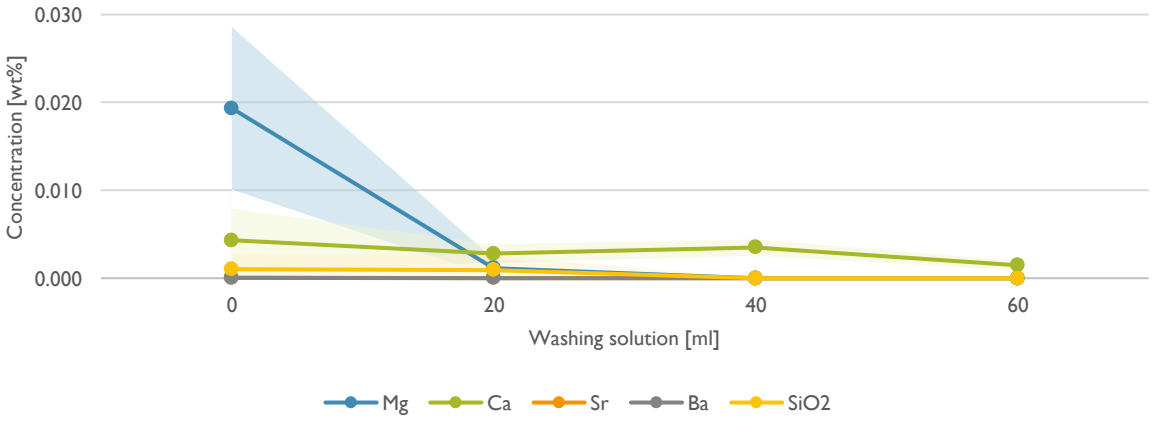

Figure 11. Concentration of Na^+, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, SiO_2 in mirabilite product for different washing step

For ice product, as seen in Figure 12, the dominant impurities (Na) are reduced via washing. Similar effect is also observed for other impurities (Na, Mg, Ca, Sr, Ba, SiO_2), as shown in Figure 13. The

results indicate the impurities are not embedded to the ice crystal structure, washing can enhance the ice product quality.

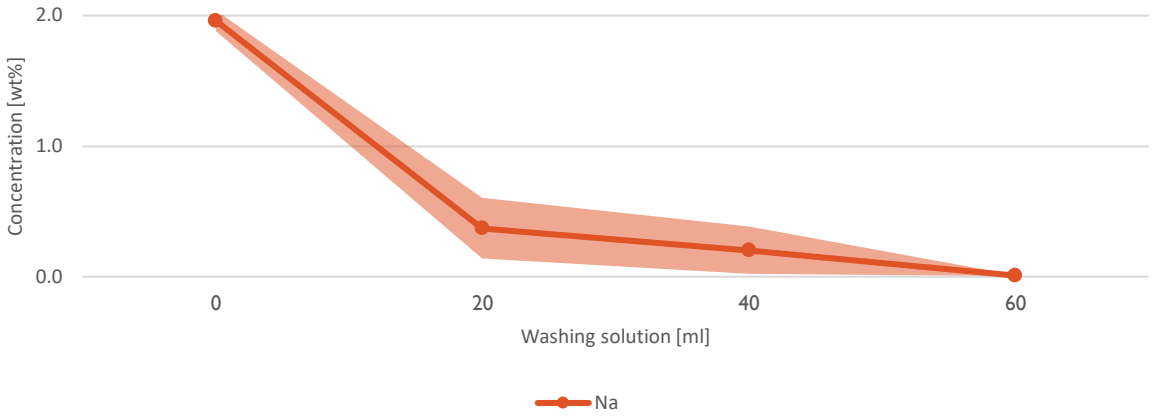

Figure 12. Concentration of Na in ice product for different washing step

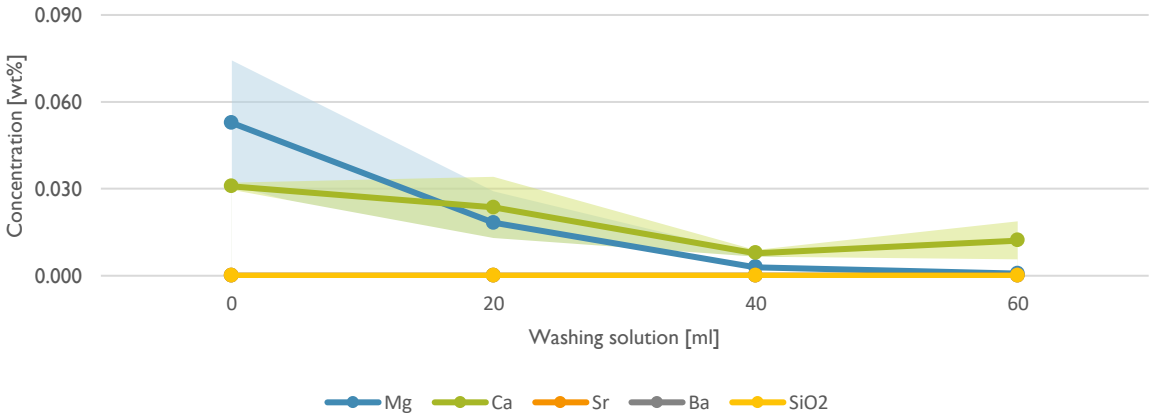

Figure 13. Concentration of Mg, Ca, Sr, Ba, SiO_2 in ice product for different washing step

4.5 Heat transfer characterisation on the 15L EFC equipment

Heat transfer characteristics of the 15L EFC was analysed in terms of the impact of the boundary layers between the target solution and the coolant, the heat gain from bubbling, work done by different stirring speed, heat transfer through an additional PET film, and heat transfer in different working temperature. Table 12 shows the specific heat flux experienced by the solution in different operational conditions.

Table 12. Specific heat flux from the cooling plate to the solution in different parameter changes

Experiment	Cooling pump level	Stirrer speed	Bubbling rate	PET film	Solution temperature	Specific heat flux	S.D.
	[-]	[rpm]	[cm^3/s]	[-]	[°C]	[$W/K\text{-}m^2$]	[$W/K\text{-}m^2$]
1 (baseline)	7	75	0	Without	15.5	-724.33	9.12
2	7	75	0	Without	3.5	-407.29	9.17
3	6	75	0	Without	15.5	-682.09	40.27
4	8	75	0	Without	15.5	-769.84	41.09
5	7	35	0	Without	15.5	-665.28	68.39
6	7	50	0	Without	15.5	-680.31	41.14

7	7	75	2.47	Without	15.5	-749.69	22.04
8	7	75	3.30	Without	15.5	-722.82	11.39
9	7	75	2.47	Without	3.5	-400.59	12.75
10	7	75	3.30	Without	3.5	-392.37	7.05
11	7	75	0	With	15.5	-403.73	9.05

The impact from different parameters can be seen from the following experiment groups:

a. *Working temperature: Experiment 1, 2*

In terms of working temperature, as to obtain the similar driving force range in lower temperature operation, it requires longer time to reach close to equilibrium. In other words, the specific heat flux obtained is much closer to equilibrium, which means the heat transfer from the solution to the plate is lower. The working temperature comparison is a background for the comparison of the bubbling rate.

b. *Cooling pump level: Experiment 1, 3, 4*

As shown in Figure 14, the overall heat transfer decreases with the cooling pump level linearly. As cooling pump level influences the boundary layer in the cooling liquid, a correlation between the coolant boundary layers and the heat transfer through the plate is concluded. Higher coolant pumping level can improve the heat loss from the working solution.

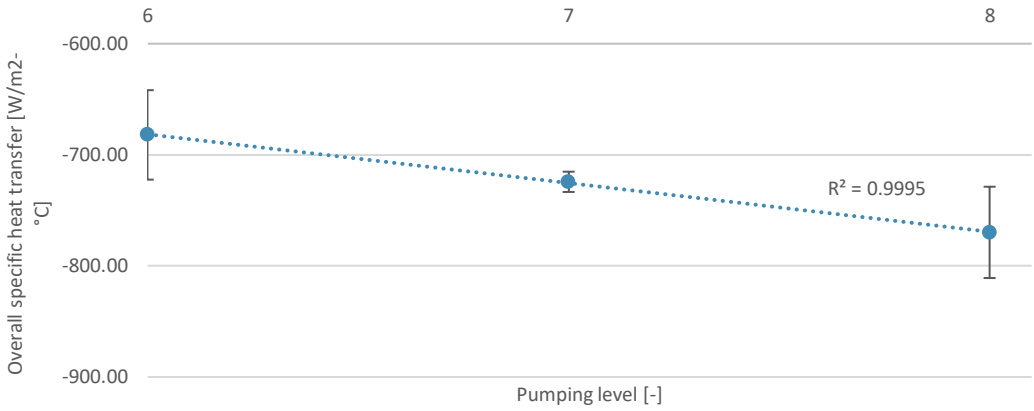

Figure 14. Overall specific heat transfer in different coolant pumping level

c. *Stirring speed: Experiment 1, 5, 6*

As shown in Figure 15, the overall heat transfer decreases with the stirring rate linearly. As stirring rate influences the boundary layer in the working solution, a correlation between the solution
boundary layers and the heat transfer through the plate is concluded. Faster stirring can improve the heat loss from the working solution.

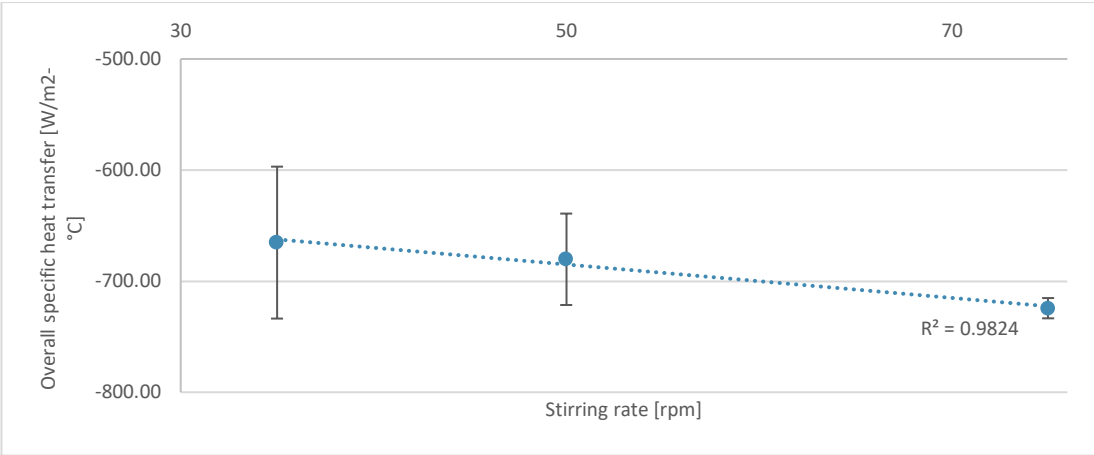

Figure 15. Overall specific heat transfer in different stirring rate

d. Bubbling rate: Experiment 1, 2, 7, 8, 9, 10

The extra heat flux due to air bubbling is listed in Table 13, higher bubbling rate results in a greater heat flux to the solution. It can also be seen, from Figure 10, bubbling at a lower temperature has a greater heat flux gain than that in higher temperature. Yet, the heat flux due to the air bubbles are minimal, the extra cooling power required for compensation is expected to be negligible.

Table 13. Heat flux from air bubble in different bubbling rate at 3.5°C and 15.5°C working temperature

Bubbling rate	Heat flux [W]	
[cm³/s]	15.5°C	3.5°C
2.47	0.69	0.97
3.30	1.14	2.43

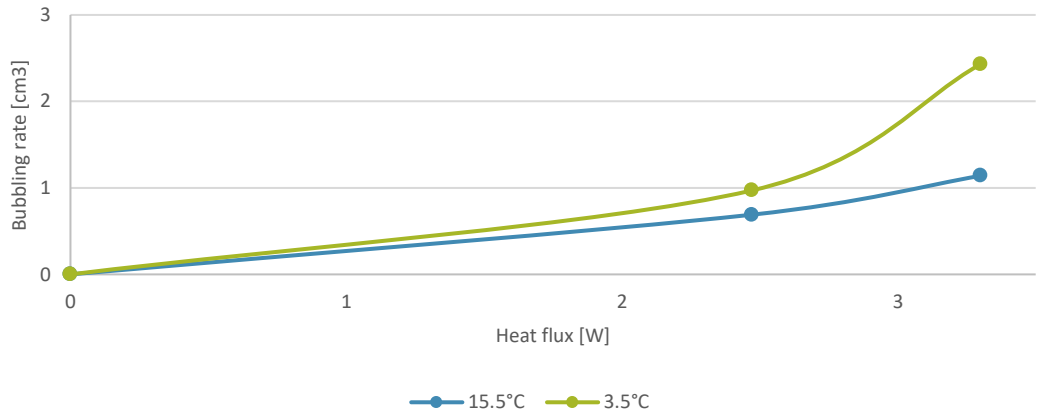

Figure 16. Overall specific heat transfer in different stirring rate

e. Additional PET film: Experiment 1, 11

A thin PET film applying on top of the cooling plate is observed to reduce the overall heat transfer significantly. It is expected due to the heat resistance of the PET material. Such application though reduced the heat transfer, it also indicates the driving force is reduced, which ice scaling is less likely to happen under the same operation.

4.6 Stirring torque as a parameter on crystallisation process

Stirring torque is a common parameter in EFC studies to identify if ice scaling occurs during the process. Adding on that, the stirring torque can also identify the initiation of nucleation, which is when the solution turns into slurry.

Taking the Na_2SO_4 – $NaHCO_3$ solution as an example, Figure 11 gives the temperature profile of the solution and the torque profile of the stirrer of the above solution system. A hump is found started from about 19 minutes, which is also the time which the temperature profile becoming less steep. The temperature at that moment is 9.39°C, it is the point where the first mirabilite crystallised; solution is also observed to turn milky from colourless. The recorded temperature is higher than that of a pure binary system (8.71°C), as the 1wt% sodium bicarbonate decreases the solubility of sodium sulphate, which is known as common ion effect. Similar temperature shift was reported before with a Na_2SO_4 – brine solution (Reddy, et al., 2010). Such phenomenon is also reported in different solution experiments, as shown in Appendix 8.5.

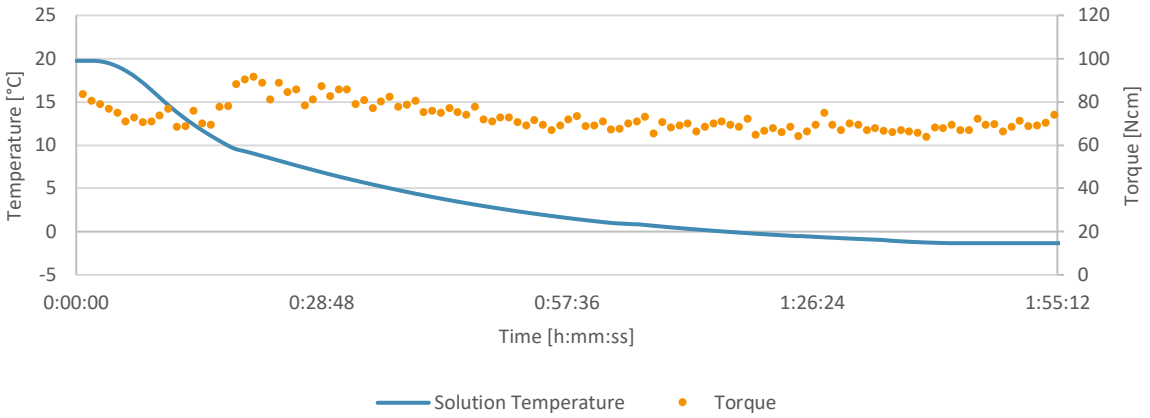

Figure 17. Graph showing the temperature profile for a 8wt% Na_2SO_4 – 1wt% $NaHCO_3$ solution cooled from ambient to eutectic temperature and the corresponding torque profile of the stirrer.

The torque change can be explained by the momentum of the bulk solution/slurry. When nucleation occurs, the mirabilite crystal is produced immediately. With the conserved angular momentum, the heavier mirabilite is expected to move slower than the lighter aqueous compound. As to maintain a same rotational speed, the stirrer applied a higher power for stirring and results in a torque jump. Then, the crystals orbit back to the expected speed, no extra power is needed for angular acceleration, which results in a torque drop. Therefore, a torque hump is observed during nucleation.

After reaching the eutectic point, the torque is also observed increasing gradually. It is the same principle due to the mass increase of the mirabilite and this time also the ice crystals. The mass gain from the formed crystals is less than that from an aqueous compound during nucleation, the torque increase is therefore milder. Noted ice seeds were introduced before the eutectic point, the slight temperature increase due to ice nucleation is absent. Yet, a similar torque jump is expected.

4.7 EFC of synthetic RO concentrate requires 0.144 kWh/kg-solution

The energy required for the EFC process on the synthetic RO concentrate were estimated based on the experimental data. Cooling and stirring were identified as the major energy-consuming operations, the values obtained reflected the actual energy consumption during the cooling process. The energy use from pumps and filters were excluded in this calculation. An average overall heat flux of 404W/m^2-K was observed during the experiments, which is slightly lower but similar to 585 W/°C-m^2 from the previous finding (Vaessen, 2003). The variation can be due to the difference on the crystalliser design and the stirring operation.

The energy required, as expressed in kWh/kg-solution, for a complete EFC on the solution was estimated with the following parameters:

Table 14. Calculation on the energy consumption for complete EFC process

Process stage	Parameter	Unit	Value
Temperature change (cooling)	Solution mass	kg	9.594
	Process time	h	1.58
	Average power for cooling	W	137.3
	Energy required for cooling	kWh/kg-solution	0.21743
	Average power for stirring	W	4.68
	Energy required for stirring	kWh/kg-solution	0.00077
Phase change	Specific latent heat of formation	kJ/kg-ice	-333.55
	ice mass percentage	%	87.565
	Energy required for ice formation	kWh/kg-slurry	-0.081
	MW of mirabilite	g/mol	322.04
	Heat of crystallisation from solution	kJ/mol-mirabilite	78.40816
		kJ/kg-mirabilite	243.4734
	mirabilite mass percentage	%	9.21
	Energy required for mirabilite formation	kWh/kg-slurry	0.0062
	Process time	h	0.73
	Average power for stirring	W	4.68
	Energy required for stirring	kWh/kg-solution	0.00036
	Total energy required	kWh/kg-solution	0.14366

Energy in EFC process is mostly used for temperature change or phase change. During temperature change, the energy encountered from cooling and stirring was obtained by experiment, is calculated by multiplying the average power with the process time and then divided by the solution mass. Noted as the density of such sodium sulphate solution is 1.066 kg/L, 9L solution is expected to be 9.594 kg.

For phase change, the solution is assumed to be ideal which will all converted into ice and mirabilite, which the calculation was stated in section 1.6. The energy required for ice formation from this slurry is the product of the specific latent heat of formation of water and the ice weight percentage in the slurry. The energy for mirabilite formation is also the product of the heat of crystallisation from solution and the mirabilite weight percentage in the slurry. The heat of mirabilite crystallisation is assumed to be the reverse of the heat of mirabilite dissolution, which the value was obtained by Perry & Green (2008; table 2-182). Noted that stirring is also required during the phase changing. Based on the model developed in this study, in ideal situation, the process requires extra 0.73 hours (43.8 min). Assuming the stirring power is the same as that required during cooling, the energy for stirring during the phase change is the product of the process time and stirring power.

The total energy required for the complete EFC process is the sum of all energy and is estimated to be 0.1437kWh/kg-solution.

As to determine whether EFC process is energy efficient, a comparison with heat crystallisation is conducted. Noted, heat crystallisation is a conventional method to separate water from salt compound via evaporation. The energy required, as expressed in kWh/kg-solution, for a complete heat crystallisation on the solution was estimated with the following parameters:

Table 15. Calculation on the energy consumption for complete evaporation process

Process stage	Parameter	Unit	Value
Temperature change (heating)	Initial temperature	°C	20
	Final temperature	°C	100
	Specific heat capacity	J/kg-°C	3935.93
	Energy required for heating	J/kg-solution	314874
		kWh/kg-solution	0.0875
Phase change	Specific latent heat of vaporisation	kJ/kg-vapor	2260
	water mass percentage	%	92.5
	Energy required for vaporisation	kWh/kg-solution	0.581
	MW of thenardite	g/mol	142.04
	Specific latent heat of formation	kJ/mol-thenardite	-1.17152
		kJ/kg-thenardite	-8.2478
	thenardite-solution mass percentage	%	7.5
	Energy required for thenardite crystalisation	kWh/kg-solution	-0.0002
	Total energy required	kWh/kg-solution	0.6680

Similarly, energy for heat crystallisation is mostly used by the system for temperature change or phase change. The specific energy for heating the solution is the product of the specific heat capacity and the temperature raised. The specific heat capacity is estimated with a pure sodium sulphate solution with the same concentration as that in the RO concentrate, the estimation is based on the regression of the known value in different concentration from Clara et al. (2002). The final temperature (boiling temperature) is assumed to be 100°C, boiling-point elevation should yet be expected with a salted solution, the boiling point in reality should be higher; the energy consumption for heating is underestimated.

For phase change, the solution was assumed to be ideal and all the water will be evaporated, sodium sulphate anhydrous (thenardite) is assumed to be formed. The energy for vaporisation is the product of the specific latent heat of vaporisation and the mass percent of water in the solution. The energy for thenardite formation was also the product of the heat of crystallisation from solution and the its weight percentage in the solution. The heat of thenardite crystallisation was assumed to be the reverse of the heat of thenardite dissolution, which the value was obtained by Perry & Green (2008; table 2-182). Stirring is neglected in this calculation.

The total energy required for the complete evaporation process is the sum of all energy and is estimated to be 0.6680kWh/kg-solution.

By comparison, the total energy required for EFC is only 22% of the energy consumed in heat crystallisation. Noted that the latent heat of ice formation is almost 7 times less than the latent heat of vaporisation and the temperature change for EFC is less than that for evaporation, such result is reasonable. EFC is more energy efficient than heat crystallisation.

4.8 Crystal size distribution model

A crystal size distribution model is successfully made for simulating an ideal sodium sulphate binary system with minor impurities, crystal quality in terms of crystal number, volume, and mass can be forecast. The model is used for three different simulations as examples, the mass, number, and volume of mirabilite and ice are estimated, which the plots are as in Figure 18.

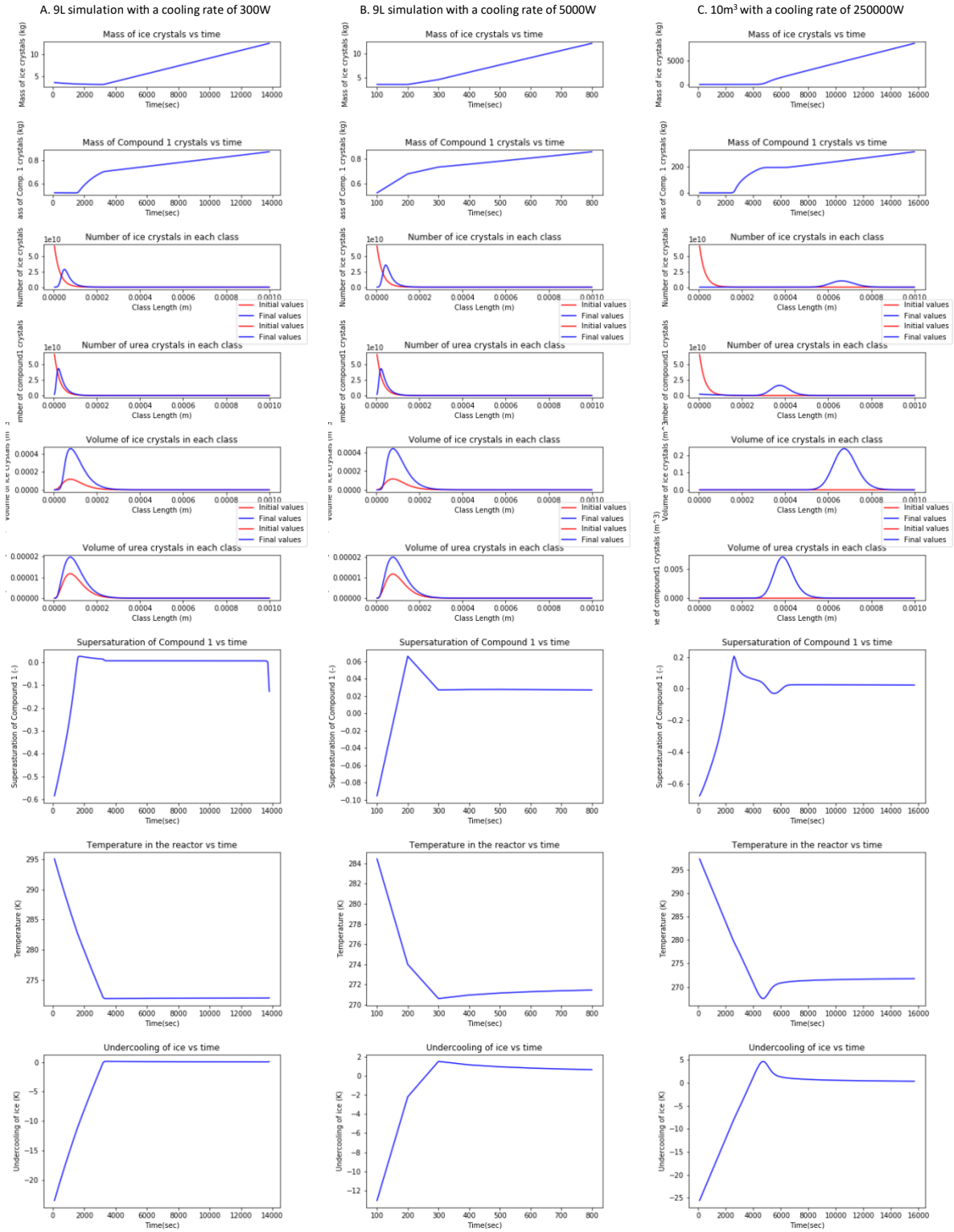

Figure 18. Graph showing the temperature profile for a 8wt% Na_2SO_4 – 1wt% $NaHCO_3$ solution cooled from ambient to eutectic temperature and the corresponding torque profile of the stirrer.

Simulation A mimics the operation condition similar to the actual experiment. Simulation B imitates the experiment condition but with a higher cooling rate. Simulation C estimates a $10m^3$ EFC operation, a high cooling rate was chosen for faster running. Noted the simulation was set to end when the solid content reaches 100%. Noted the initial values stated should all be zero in reality, yet the assumptions are given for the initial hypothetical distribution and occurrence of crystals for easy simulation.

The simulation shows that the mass and size of crystals are depending on the solution volume. Higher cooling rate only would not affect the mass and size and volume of the crystals. In this stage, though the code can successfully simulate the outcome of different EFC conditions, the temperature profiles indicates the code performance is not ideal with a low cooling rate and low volume. It is suspected to be related to the temperature storage and printing method, which improvements can be made.

4.9 Column crystalliser for resolving impurity-accumulation during the EFC process

During the EFC process, sodium sulphate and water were extracted from the slurry. Experiments shows that the impurities were not escaping from the system via the retrieved products, accumulation is expected inside the solution. No matter the running is in batch or continuous, it is inevitable. Regular bleed stream can remove the impurities directly, but it will result in an additional evaporator if zero liquid discharge is aimed. Extra evaporator means extra operation and extra energy, which is not ideal. A column crystalliser can be an alternative, it can simply be a tank filled with crystals of the impurities in the slurry. Before the filtered slurry going back to the EFC crystalliser, the slurry goes through a column crystalliser, where the impurities will be crystallised on the crystal seeds in the column; the slurry can then be purified. It is therefore suggested to be implement for the EFC process and the operation and effectiveness on different compounds should be investigated in the future. Figure 18 is an addition of column crystalliser on a schematic continuous EFC process scheme based on Van der Ham (1999).

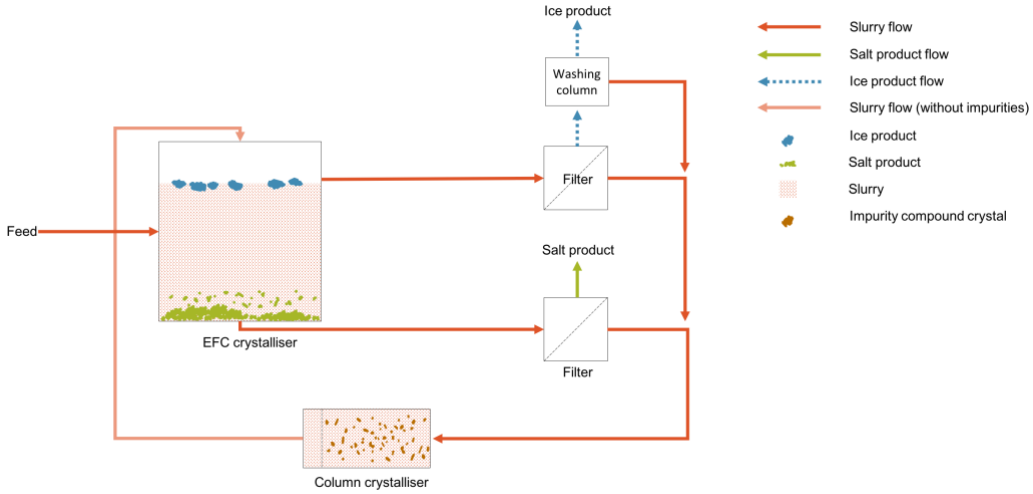

Figure 19. Schematic diagram of the implementation of column crystalliser in the EFC process.

5 CONCLUSION

The aim of this research is to understand if eutectic freeze crystallisation is possible to be used for recovering sodium sulphate and water recovery from a reverse osmosis concentrate of silica-industry wastewater. For this purpose, a 15L EFC crystalliser and synthetic RO concentrate was used for experimentation and it is confirmed that EFC can be used to recover sodium sulphate and water from the concentrate.

- How the impurities in the RO concentrate influence the eutectic crystallisation of sodium sulphate?
- What is the quality and yield of the mirabilite and ice product from RO concentrate by EFC?
- If there are impurities in the product, can they be easily removed via washing?
- Which are the key factors influence the overall heat transfer, which influences EFC process?
- What is the energy consumption of the EFC working with the RO concentrate?
- Is there any issue that may face during full scale operation with EFC?

This study also leads to answering of the issues raised in the research scope with the following conclusion:

- Impurities affects the eutectic temperature. A slight depression of eutectic temperature is observed due to the occurrence of impurities. The depression is recorded greater when more impurities are involved. A eutectic temperature of -1.36°C is observed for the synthesised RO concentrate.
- With a simple manual retrieving method, conservative recovery of 42% mirabilite and 55% ice is obtained. For the raw unwashed products, mirabilite product is almost pure which can be sold directly to the market. Ice product contains 7.7wt% of mirabilite impurities, which washing should be required.
- Analysis shows the impurities are not embedded inside both the mirabilite and ice product, washing can effectively increases the products' purity. Quality mirabilite and ice products are consistently obtained from different polluted working solution.
- The factors on overall heat transfer during EFC process is identified. Reducing the boundary layer in working solution and that in coolant is shown to improve the specific heat flux through the cooling plate linearly, faster stirring and coolant pumping rate are preferred. Air bubbling is shown to enhance the magnitude of the specific heat flux. The impact is greater with more bubbling and in colder operation. Still, the studied bubbling rate is shown to be minimally affecting the overall heat transfer.
- Energy consumption for a complete EFC process on the RO concentrate is estimated to be 0.1437 kWh/kg-solution, which is only 22% of the energy consumed in heat crystallisation.
- Impurities accumulation is expected and may adversely affect the EFC process and the product quality. Column crystalliser is suggested to be a possible method to resolve the accumulation issue. Moreover, stirring torque is recognised to be a possible parameter for indicating different crystallisation stage during the process. A crystal size distribution model is successfully developed and can be used to estimate the performance and design of an eutectic system in different operating conditions.

6 RECOMMENDATIONS

Some interesting conclusions are made in this study regarding the EFC issue, still few questions are raised and recommended for further research:

- Evaluate the overall heat transfer coefficient of the EFC equipment with a comprehensive coolant temperature monitoring.
- Evaluate the anion impurities on the crystal products for a complete overview on the quality.
- Investigate if silica polarisation occurs on the heat exchange plate and its consequences on the EFC performance. Viewing that the crystal products were observed with a minimal amount of silica, silica is expected to accumulate during the process. The removal of the silica should also be investigated.
- Investigate how anti-scalent will affect the EFC performance with the RO concentrate, which should have some amount of anti-scalent.
- Investigate the optimum recovery of mirabilite and salt with an advance retrieving method.
- Investigate the relationship between the torque change and the solid content in a slurry, which can be used as an operational indicator.
- Investigate a scale-up EFC operation for treating the RO concentrate and further compare with a conventional evaporator. Find out which method is more feasible.
- Investigate the continuous operation with EFC for silica industrial plant achieving zero liquid discharge.
- Improve the crystal size distribution model to estimate a continuous system and a multi-effect condition.

Like bigger crystals require more time to grow, an optimised EFC operation for full-scale use requires decades of investigation, every knowledge matters for the success of the technology.

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8 APPENDIX

8.1 Wastewater effluent characteristic of a silica industry

Flow rate of the water streams in production line.

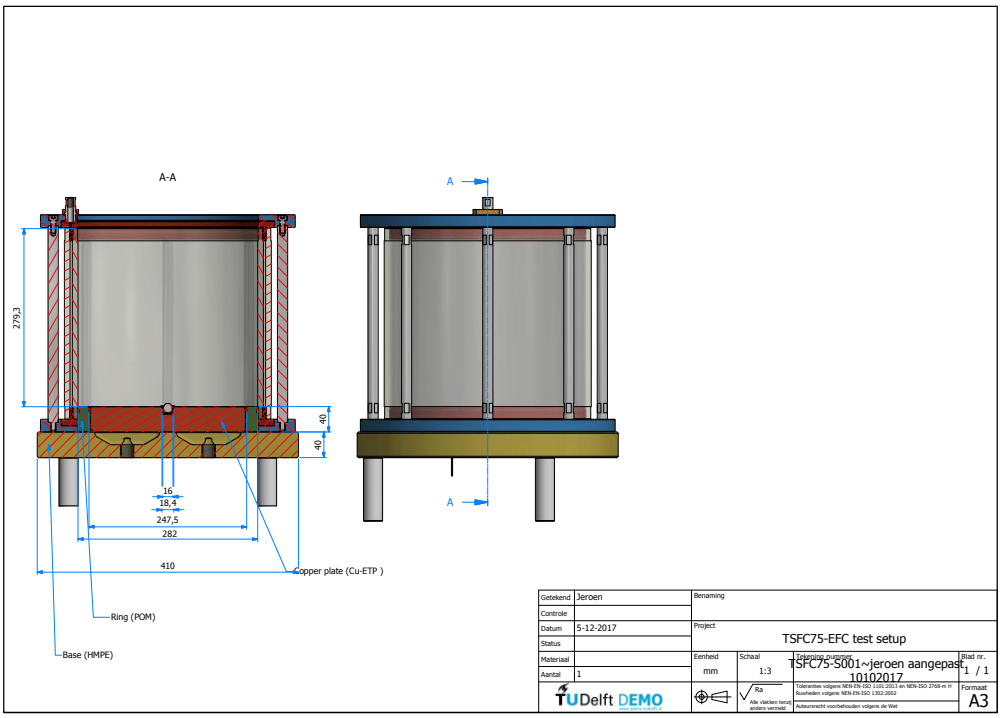
	Units	Value
Reverse Osmotic water for reaction	m^3/day	919
Filtration wastewater	m^3/day	840
Washing wastewater = Reverse Osmotic water	m^3/day	1,506

Characteristic of the wastewater stream from production line (n/a = not applicable; SD = standard deviation; n = number of samples).

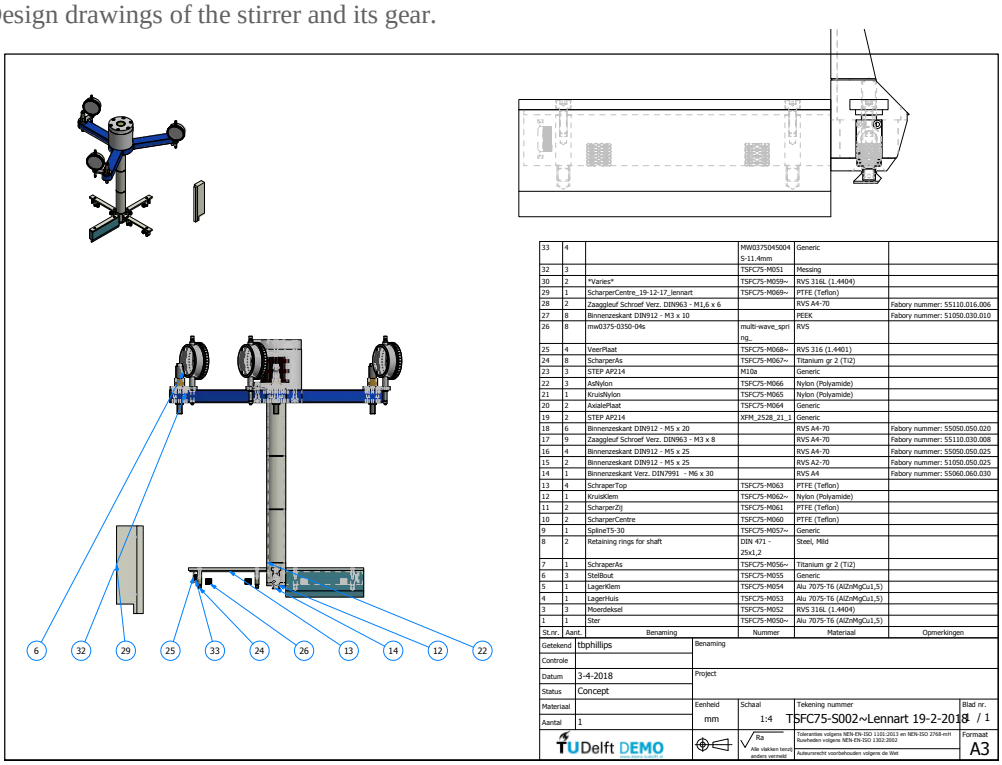
		Filtration wastewater (n=4)		*Washing wastewater (n=4)*		*Filtration + Washing wastewater (n=6)*	
Parameter	Units	Value	SD	Value	SD	Value	SD
pH	upH	6.1	0.6	6.4	1.1	4.8	1.3
EC	mS/cm	38.3	10.4	15.5	10.7	27.3	5.9
Turbidity	NTU	313	347	207	337	67.4	133
Cl	mg/L	1,655	1,028	523	449	1,759	498
NO_3	mg/L	14.4	3.1	11.3	3.66	11.8	0.61
SO_4	mg/L	23,612	6,598	8,511	7,114	16,468	4,451
K	mg/L	52	5.5	14	11	434	11
Na	mg/L	12,340	4,199	4,603	3,924	7,325	2,061
Ca	mg/L	16.2	9.2	<5.0	n/a	38.5	35.3
Mg	mg/L	<12.5	n/a	<5.0	n/a	213	235
TIC	mg/L	<10	n/a	49.9	92.1	<5	n/a
Al	µg/L	468	510	173	189	2,272	2,876
Si total	mg/L	74.2	57.8	26.4	26.0	80.5	22.8
Si reactive	mg/L	64.3	50.2	24.1	24.0	77.1	23.0
Mn	µg/L	112.5	18.9	34.75	37.11	278	182
Fe	µg/L	215.0	343.8	215	390.26	855	712
Sr	µg/L	532.5	213.3	195.5	208.61	495	431
Ba	µg/L	160.8	179.7	79.2	127.4	49.2	16.4

8.2 Drawings of the 15L EFC crystalliser

Design drawings of the crystalliser vessel.



Design drawings of the stirrer and its gear.



St.nr.	Aant.	Benaming	Nummer	Materiaal	Opmerkingen
33	4		MW0375045004 S-11.4mm	Generic	
32	3		TSFC75-M051	Messing	
30	2	*Varies*	TSFC75-M059~	RVS 316L (1.4404)	
29	1	ScharperCentre_19-12-17_lennart	TSFC75-M069~	PTFE (Teflon)	
28	2	Zaaggleuf Schroef Verz. DIN963 - M1,6 x 6		RVS A4-70	Fabory nummer: 55110.016.006
27	8	Binnenzeskant DIN912 - M3 x 10		PEEK	Fabory nummer: 51050.030.010
26	8	mw0375-0350-04s	multi-wave_spring_	RVS	
25	4	VeerPlaat	TSFC75-M068~	RVS 316 (1.4401)	
24	8	ScharperAs	TSFC75-M067~	Titanium gr 2 (Ti2)	
23	3	STEP AP214	M10a	Generic	
22	3	AsNylon	TSFC75-M066	Nylon (Polyamide)	
21	1	KruisNylon	TSFC75-M065	Nylon (Polyamide)	
20	2	AxialePlaat	TSFC75-M064	Generic	
19	2	STEP AP214	XFM_2528_21_1	Generic	
18	6	Binnenzeskant DIN912 - M5 x 20		RVS A4-70	Fabory nummer: 55050.050.020
17	9	Zaaggleuf Schroef Verz. DIN963 - M3 x 8		RVS A4-70	Fabory nummer: 55110.030.008
16	4	Binnenzeskant DIN912 - M5 x 25		RVS A4-70	Fabory nummer: 55050.050.025
15	2	Binnenzeskant DIN912 - M5 x 25		RVS A2-70	Fabory nummer: 51050.050.025
14	1	Binnenzeskant Verz. DIN7991 - M6 x 30		RVS A4	Fabory nummer: 55060.060.030
13	4	ScraperTop	TSFC75-M063	PTFE (Teflon)	
12	1	KruisKlem	TSFC75-M062~	Nylon (Polyamide)	
11	2	ScharperZij	TSFC75-M061	PTFE (Teflon)	
10	2	ScharperCentre	TSFC75-M060	PTFE (Teflon)	
9	1	SplineTS-30	TSFC75-M057~	Generic	
8	2	Retaining rings for shaft	DIN 471 - 25x1,2	Steel, Mild	
7	1	ScraperAs	TSFC75-M056~	Titanium gr 2 (Ti2)	
6	3	Stellbout	TSFC75-M055	Generic	
5	1	LagerKlem	TSFC75-M054	Alu 7075-T6 (AlZnMgCu1,5)	
4	1	LagerHuis	TSFC75-M053	Alu 7075-T6 (AlZnMgCu1,5)	
3	3	Moerdeksel	TSFC75-M052	RVS 316L (1.4404)	
1	1	Ster	TSFC75-M050~	Alu 7075-T6 (AlZnMgCu1,5)	

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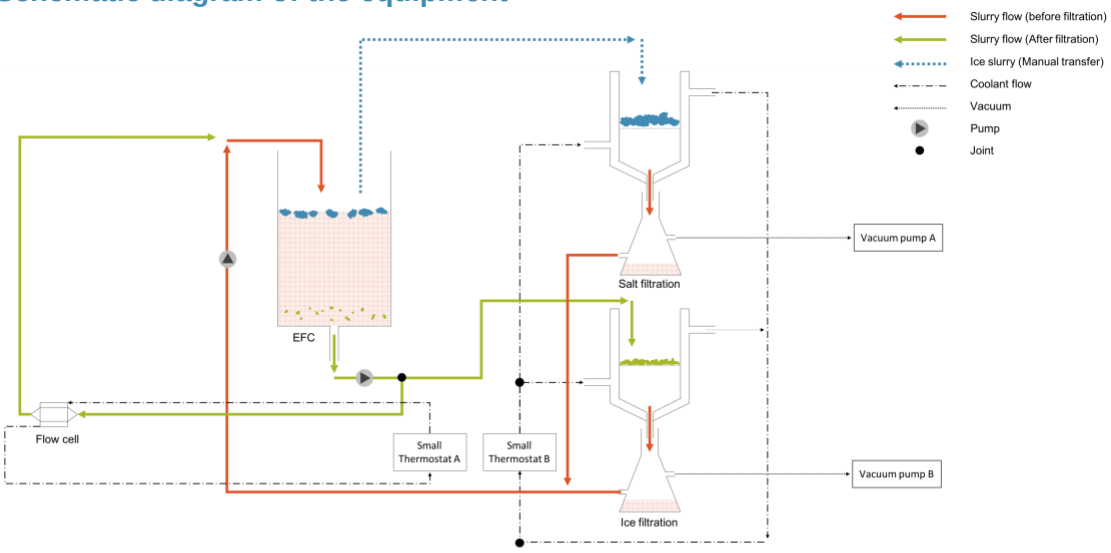
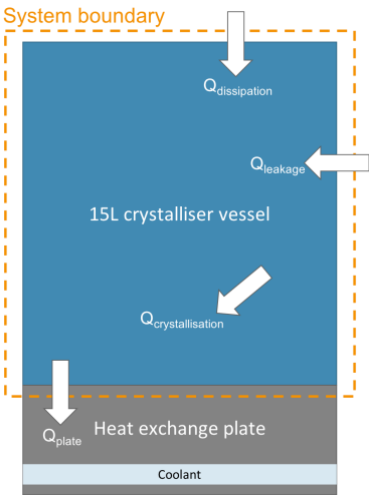
8.3 Schematic diagram of the equipment



8.4 Heat transfer of the 15L crystallizer

Heat transfer is the main drive in eutectic freeze crystallisation. Analysis on the heat transfer performance of a crystalliser is crucial to determine the design and capacity of the crystalliser.

The system boundary of the heat transfer in this study is limited to the volume inside the crystalliser vessel, where the solution is freezing at. Four major heat fluxes are identified, which are from heat exchange plate, crystallisation, system leakage, and dissipation by stirring.



Noted that heat gain by the system is set as positive and heat loss is negative. Therefore, heat flux from the cooling plate is stated as negative and the others as positive. The total heat transfer, in W, can be then written as in following equation:

$$Q_{overall} = -Q_{plate} + Q_{crystallisation} + Q_{environment} + Q_{dissipation}$$

Where:

$Q_{overall}$:	Overall heat flux encountered in the system [W]
Q_{plate}:	Heat flux from the cooling plate [W]
$Q_{crystallisation}$:	Heat flux due to crystallisation [W]
$Q_{environemtn}$:	Heat flux due to the surrounding environment [W]
$Q_{dissipation}$:	Heat flux due to the dissipation of the stirrer [W]

Heat transfer rate in the cooling plate (Q_{plate}) between the solution and coolant is defined as following:

$$Q_{plate} = A_{plate} \cdot \alpha_{overall} \cdot \Delta T_{LM}$$

Where:

Q_{plate}:	Heat flux from the cooling plate [W]
A_{plate}:	Contact area between the plate and solution [m^2]
$\alpha_{overall}$:	Overall heat transfer resistance coefficient from coolant to solution [$W/m^2/K$]
ΔT_{LM}:	Logarithmic mean temperature difference between solution and coolant [K]

The overall heat transfer resistance coefficient is composed of the resistance coefficient of the coolant, plate, and the solution. An equation can then be formed as following:

$$\frac{1}{\alpha_{overall}} = \frac{1}{\alpha_{coolant}} + \frac{1}{\alpha_{plate}} + \frac{1}{\alpha_{solution}}$$

Where:

$\alpha_{overall}$:	Overall heat transfer resistance coefficient from coolant to solution

$\alpha_{coolant}$: Heat transfer resistance coefficient of the boundary layer near the plate in coolant
α_{plate}: Heat transfer resistance coefficient of heat exchanging plate
$\alpha_{solution}$: Heat transfer resistance coefficient of the boundary layer near the plate in solution

Due to the current equipment with limited temperature measurement points, the logarithmic mean temperature cannot be calculated. Yet, considering the coefficients of coolant and solution are highly depending on the thickness of the boundary layer, effects on different thickness due to different parameters can be measured and verify its influence on heat transfer. Noted the heat resistance of the plate is constant and cannot be changed by different operation conditions.

Heat transfer resistance of the solution boundary layer ($\alpha_{coolant}$) is influenced by the coolant flow rate, which is the coolant pumping rate of the thermostat. A test on such can understand how the flow rate influences the overall heat transfer performance of the process.

Heat transfer resistance of the solution boundary layer ($\alpha_{solution}$) is influenced by the rotational speed and the viscosity of the solution based on the penetration theory. As rapid rotating stirrer is contacted to the cooling plate in this case, laminar boundary layer of the solution near the plate is expected to be removed and a complete mix is expected in the solution/slurry. Change on viscosity is minimal in a small temperature range; the heat transfer experiments are performed in a small temperature span, it is assumed constant. A test on stirring speed can provide a better understanding on the overall heat transfer performance of the process.

Heat flux from crystallisation ($Q_{crystallisation}$) is related to the enthalpy change of the crystal, which can be found in literatures. As this value is irrelevant to the verification of the crystalliser design, it is excluded in these heat transfer experiments. The exclusion is simply arranged by running the system at a higher temperature than the regular EFC operation, crystallisation is then absent from the process.

Heat transfer rate to the environment ($Q_{environment}$) is related to the crystalliser design and influence the process performance. Different environmental conditions will also affect this heat flux. Bubbling from the bottom sampling tube is often required as to prevent clogging. However, it will result in extra heat gain from the environment (bubbles), a study on such should be conducted. A heat transfer in different temperature is also conducted.

Heat flux of heat dissipation ($Q_{dissipation}$) from the stirrer, which can be calculated with the following equation:

$$Q_{dissipation} = \frac{\tau \cdot 2\pi \cdot \omega}{6000}$$

Where:

Q_{plate}: Heat flux due to the heat dissipation [W]
τ: Torque experienced by the stirrer [Ncm]
ω: Angular velocity of the stirrer [rpm]

Different rotational speed of the stirrer are set to evaluate its influence on the heat transfer; the torque can be obtained by the motor.

The overall heat transfer rate ($Q_{overall}$) of the system can be calculated from the following equation:

$$Q_{overall} = m \cdot C_p \cdot \frac{\Delta T}{dt}$$

Where:

$Q_{overall}$: Overall heat flux encountered in the system [W]
m: Solution mass [g]
C_p: Specific heat capacity of the solution [J/g/K]
$\frac{\Delta T}{dt}$: Temperature change of the solution per time [K/s]

This equation is used to estimate the overall heat transfer in different operations. Measurements are obtained every 60 seconds.

Then, for each test, the specific heat transfer rate of the system can be obtained by the following:

$$q_{overall} = \frac{Q_{overall}}{A \cdot |DF|}$$

Where:

$q_{overall}$: Overall specific heat flux encountered in the system [W/m^2/K]
$Q_{overall}$: Overall heat flux encountered in the system [W]
A: Solution mass [g]
DF: Driving force that the solution experienced [K]

Noted the driving force is the average temperature difference between the solution and the thermostat coolant in a time interval. These values are obtained from the thermometers and the driving force can be calculated as following:

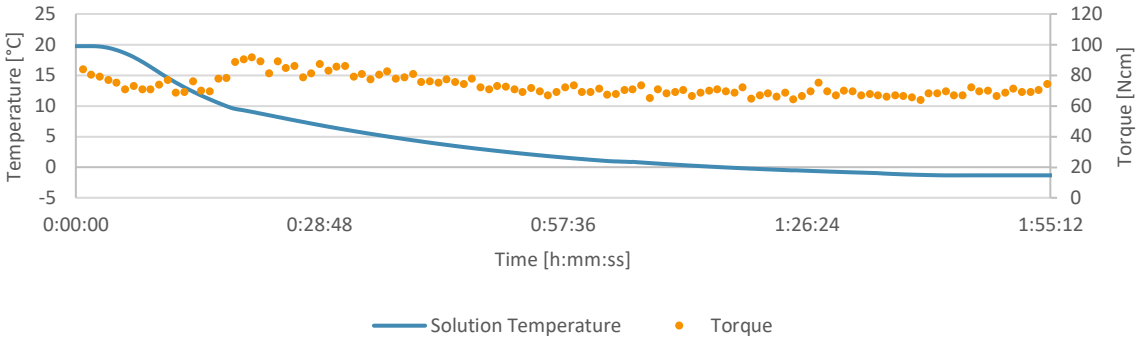
$$DF = \overline{T_{solution}} - \overline{T_{coolant}}$$

Where:

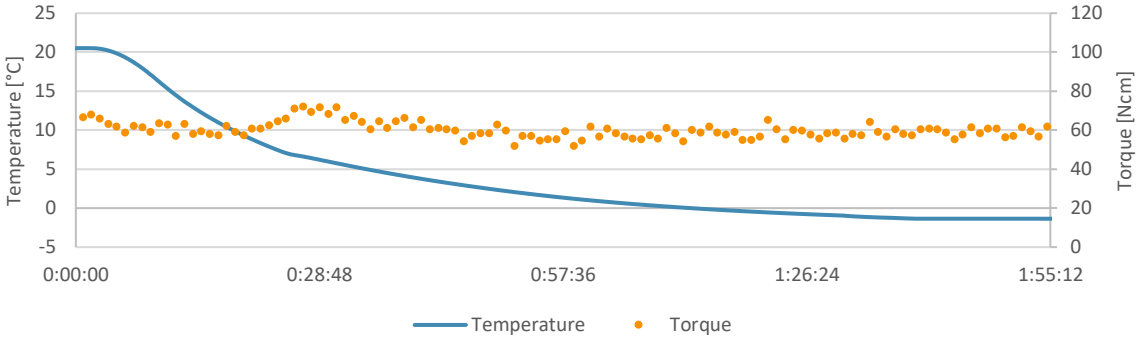
DF: Driving force that the solution experienced [K]
$T_{solution}$: Average solution temperature in a time interval [K]
$T_{coolant}$: Average coolant temperature in a time [K]

8.5 Temperature and torque profile of the EFC experiments

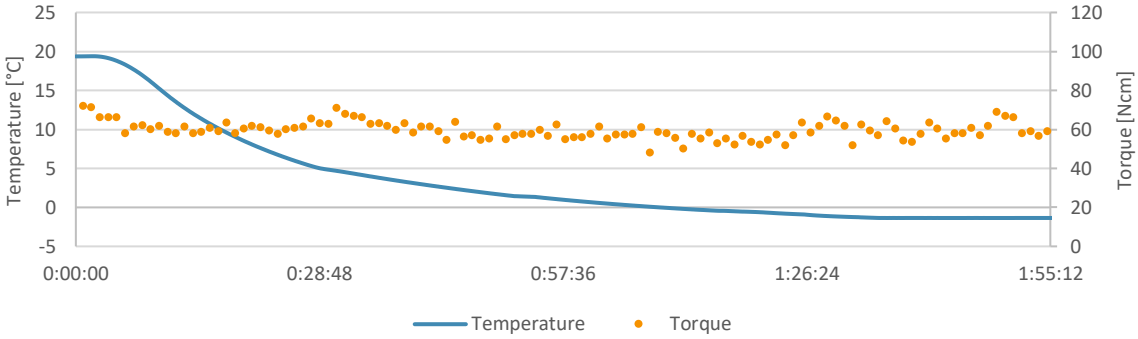
Na_2SO_4 – $NaHCO_3$ system



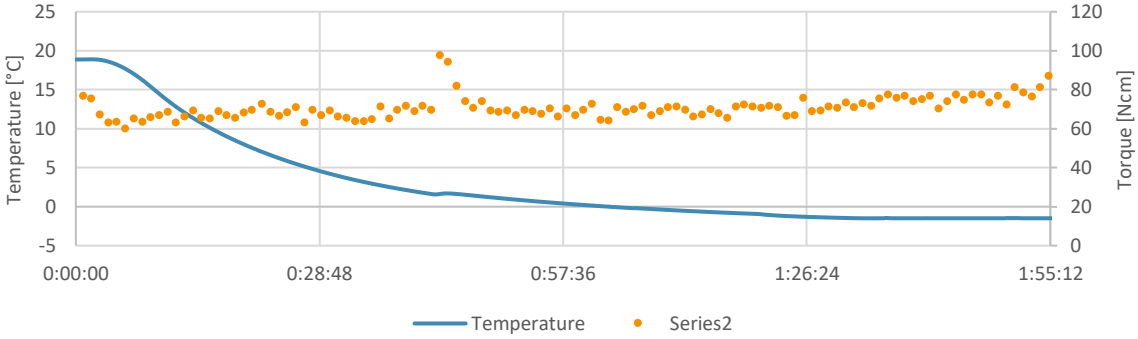
Na_2SO_4 – $NaCl$ – $MgCl_2$ system



Synthetic RO concentrate



Synthetic concentrated RO concentrate



8.6 Code of the Crystal Size Distribution (CSD) model

'''Crystal Size Distribution in a Eutectic System'''

#Model for estimating the distribution of crystal sizes during the cooling and eutectic freeze crystallization of an
#aqueous solution of Compound 1 , that includes traces of Compound 2, as impurity, in a batch reactor.

"""
INSTRUCTION

To select the compunds in the solution, please input in Compounds()
Please change the desired parameters which are indicated with 'CHANGE:'
"""

#%%

#Import the libraries that will be used
import math
pi=math.pi
exp=math.exp
log=math.log

import matplotlib.pyplot as plt
fig1=plt.figure(1)
fig2=plt.figure(2)
fig3=plt.figure(3)
fig4=plt.figure(4)
fig5=plt.figure(5)
fig6=plt.figure(6)

import time

import numpy as np

from scipy import interpolate

from sklearn.linear_model import LinearRegression
lm = LinearRegression()

from collections import namedtuple

#Set initial time to calculate the elapsed time of the calculations
time0=time.time()
#%%

#Declaration of constant process parameters - Part 1: Process Parameters
#Volume of the reactor : m^3

#Influx
Fin_water=0 #Influx of water (in mother liquor) in the reactor : kg/s

```
Fin_compound1=0                                    #Influx of Compound
1 (in mother liquor) in the reactor : kg/s
Fin_compound2=0                                    #Influx of Compound
2 (in mother liquor) in the reactor : kg/s
Fin_mother_liquor=Fin_water+Fin_compound1+Fin_compound2                    #Influx
of mother liquor in the reactor : kg/s
Fin_liquid_tot=Fin_mother_liquor                   #Total influx of
liquid in the reactor : kg/s

Fin_ice=0                                          #Influx of ice crystals in
the reactor : kg/s
Fin_compound1_cr=0                                 #Influx of Compound
1 crystals in the reactor : kg/s
Fin_solids_tot=Fin_ice+Fin_compound1_cr                                    #Total
influx of solid crystals in the reactor : kg/s

#Outflux
Fout_water=0                                       #Outflux of water (in
mother liquor) from the reactor : kg/s
Fout_compound1=0                                   #Outflux of Compound
1 (in mother liquor) from the reactor : kg/s
Fout_compound2=0                                   #Outflux of Compound
2 (in mother liquor) from the reactor : kg/s
Fout_mother_liquor=Fin_water+Fin_compound1+Fin_compound2
#Outflux of mother liquor from the reactor : kg/s
Fout_liquid_tot=Fout_mother_liquor                 #Total outflux
of liquid from the reactor : kg/s

Fout_ice=0                                         #Outflux of ice crystals
from the reactor : kg/s
Fout_compound1_cr=0                                #Outflux of
Compound 1 crystals from the reactor : kg/s
Fout_solids_tot=Fout_ice+Fout_compound1_cr                                 #Total
outflux of solid crystals from the reactor : kg/s

Fout_top=0                                         #Outflux from the top
(ice and mother liquor) : kg/s
Fout_bottom=0                                      #Outflux from the
bottom (Compound 1 and mother liquor) : kg/s

#General Parameters
classes=300                                        #Number of crystal size
classes
maxl=1e-3                                          #Maximum crystal length :
m
deltal=maxl/classes                                #Length interval per
class : m
deltat=2                                           #Time interval : sec

class_length=np.array([])                          #Array of the lengths
for the crystal size classes used for plotting
for i in range(0,classes):
    class_length=np.append(class_length,((i*deltal)+deltal))

#Storage lists for different values
```

```
t_store=np.array([])
sigma_compound1_store=np.array([])
DT_ice_store=np.array([])
M_ice_store=np.array([])
M_compound1_cr_store=np.array([])
Treactor_store=np.array([])
#V_ice_distr_store=np.array([])
#V_urea_cr_distr_store=np.array([])

#%%
#Declaration of constant process parameters - Part 2: WATER Properties library

#Physical properties
d_water=1*1000                                  #Density of water
(25oC) : kg/m^3 (source:Wikipedia)
Cp_water=4.1813*1000                            #Heat capacity of
water (25 oC) : J/(kg * K) (source:Wikipedia)
#%%
#Declaration of constant process parameters - Part 3: ICE Properties

#Kinetic and Shape Parameters

#Ice
kg_ice=5e-8                                     #Growth rate constant
for ice crystals : m/(K*s) (source: Characterization and Population....)
kb_ice=5e4                                      #Nucleation rate constant
for ice crystals : 1/(m^2*s*K^2) (source: Characterization and Population....)
kd_ice=1e-10                                    #ASSUMED Dissolution
rate constant for ice crystals : m/(K*s)

r_ice=10                                        #L/h aspect ratio of ice
crystals, assuming a disk shape where length=10*height : -
kv_ice=pi/(4*r_ice)                             #Shape factor of ice
crystals, where V=kv*l^3 (assuming disk shape and l=longest side) : -
ka_ice=pi*(1/r_ice+1)                           #Surface factor of ice
crystals, where A=ka*l^2 (assuming disk shape and l=longest side) : -

#Physical Properties
d_ice=0.917*1000                                #Density of ice (25oC) :
kg/m^3 (source:https://hypertextbook.com/facts/2000/AlexDallas.shtml)
Cp_ice=2.05*1000                                #Heat capacity of ice
(0 oC) : J/(kg * K) (source:https://www.engineeringtoolbox.com/ice-thermal-properties-d_576.html)

#Thermodynamic Properties
DHfus_ice=333.55*1000                           #Enthalpy of fusion
of ice : J/kg (source:Wikipedia)


#%%
#Declaration of constant process parameters - Part 5: Sodium Sulfate Properties
#CHANGE:Parameters of Compound 1

#Physical Properties
MW_Na2SO4=142.04                                #Molecular weight
of sodium sulfate : g/mol
```

```
d_Na2SO4=2.66*1000                                                    #Density of sodium
sulfate (25oC) : kg/m^3 (source:???)
Cp_Na2SO4=128.2*MW_Na2SO4*1000                                        #Heat
capacity of sodium sulfate (25 oC) : J/(kg * K) (source:source:
https://en.wikipedia.org/wiki/Sodium_sulfate_(data_page))

#Kinetic and Shape Parameters
kg_Na2SO4=(43960*exp(-24600/((8.314)*298)))/(1000*3600)               #Growth
rate constant for sodium sulfate crystals : m/s : Mirabilite at 25oC(source: crystallization kinetics of
sodium sulfate... #UBC TBC)
kb_Na2SO4=(0.064*exp(70900/((8.314)*298)))*1000/(3600*d_Na2SO4)
#Nucleation rate constant for sodium sulfate crystals : 1/(kg*s) : Mirabilite (source: crystallization
kinetics of sodium sulfate... #UBC TBC)
kd_Na2SO4=1e-10                                                       #ASSUMED
Dissolution rate constant for sodium sulfate crystals : m/s

r_Na2SO4=1                                                            #L/h aspect
ratio of sodium sulfate crystals, assuming a cylindrical shape where length=height/10 : -
kv_Na2SO4=(pi*r_Na2SO4**2)/4                                          #Shape factor
of sodium sulfate crystals, where V=kv*h^3 (assuming cylindrical shape and h=longest side) : -
ka_Na2SO4=(pi*r_Na2SO4)*(1+r_Na2SO4/2)                                #Surface
factor of sodium sulfate crystals, where A=ka*h^2 (assuming cylindrical shape and h=longest side) : -

#Thermodynamic Properties
DHfus_Na2SO4=252*1000                                                 #Enthalpy of
fusion of sodium sulfate : J/kg (source:Solubility of Urea...)

#Create the library with the constant parameters for sodium sulfate
Na2SO4Parameters = namedtuple('Na2SO4Parameters', ['MW','d','Cp',
                                    'DHfus','kg','kb','kd','r',
                                    'kv','ka'])

Na2SO4Par = Na2SO4Parameters(MW=MW_Na2SO4,
                    d=d_Na2SO4,
                    Cp=Cp_Na2SO4,
                    DHfus=DHfus_Na2SO4,
                    kg=kg_Na2SO4,
                    kb=kb_Na2SO4,
                    kd=kd_Na2SO4,
                    r=r_Na2SO4,
                    kv=kv_Na2SO4,
                    ka=ka_Na2SO4)


#%%

#Declaration of constant process parameters - Part 4: UREA Properties

#Kinetic and Shape Parameters
kg_urea=1e-5                                                          #Growth rate constant
for urea crystals : m/s (source: Characterization and Population....)
kb_urea=2e7                                                           #Nucleation rate constant
for urea crystals : 1/(kg*s) (source: Characterization and Population....)
kd_urea=1e-10                                                         #ASSUMED Dissolution
rate constant for urea crystals : m/s
```

```
r_urea=1/10                                                    #L/h aspect ratio of urea
crystals, assuming a cylindrical shape where length=height/10 : -
kv_urea=(pi*r_urea**2)/4                                       #Shape factor of
urea crystals, where V=kv*h^3 (assuming cylindrical shape and h=longest side) : -
ka_urea=(pi*r_urea)*(1+r_urea/2)                               #Surface factor
of urea crystals, where A=ka*h^2 (assuming cylindrical shape and h=longest side) : -


#Physical Properties
MW_urea=60.06                                                  #Molecular weight of
urea : g/mol
d_urea=1.323*1000                                              #Density of urea
(25oC) : kg/m^3 (source:https://pubchem.ncbi.nlm.nih.gov/compound/urea#section=Solubility)
Cp_urea=1.4342*1000                                            #Heat capacity of
urea (25 oC) : J/(kg * K) (source:Low temperature heat capacity of urea)

#Thermodynamic Properties
DHfus_urea=((3470*4.184)/MW_urea)*1000                         #Enthalpy
of fusion of urea : J/kg (source:Solubility of Urea...)

#Create the library with the constant parameters for urea
UreaParameters = namedtuple('UreaParameters', ['MW','d','Cp',
                                'DHfus','kg','kb','kd','r',
                                'kv','ka'])

UreaPar = UreaParameters(MW=MW_urea,
                d=d_urea,
                Cp=Cp_urea,
                DHfus=DHfus_urea,
                kg=kg_urea,
                kb=kb_urea,
                kd=kd_urea,
                r=r_urea,
                kv=kv_urea,
                ka=ka_urea)
#%%

#CHANGE:Solubility line of Compound 1
#Na2SO4
#Interpolation/Extrapolation of the Na2SO4 solubility line with a cubic spline
#Sodium sulfate Solubility Line, Data from source: The solution ref on dropbox (1100-1200; P.1120)
T_Na2SO4_sol_line=[273.15,278.15,283.15,288.15,293.15,298.15,300.65,303.15,305.15,305.55]
#Units : K
C_Na2SO4_sol_line=np.array([4.5,6.2,9.0,13.2,19.0,28.0,33.6,41.2,48.0,49.7])
#Units : g Na2SO4/ 100g of water (neglecting impurities)
C_Na2SO4_sol_line_mol=(10/MW_Na2SO4)*C_Na2SO4_sol_line
#Transform the solubility line in mols Na2SO4/ kg water = molals
tck_Na2SO4 = interpolate.splrep(T_Na2SO4_sol_line, C_Na2SO4_sol_line_mol, s=0)

#Interpolation/Extrapolation of the ice line using linear regression

#Ice line in the Na2SO4-Water phase diagram : Source : CONCENTRATIVE PROPERTIES OF
AQUEOUS SOLUTIONS:DENSITY, REFRACTIVE INDEX, FREEZING POINT DEPRESSION,
AND VISCOSITY
```

```
C_Na2SO4_ice_line=[0,0.035,0.071,0.144,0.218,0.293,0.371,0.449]
Freeze_point_depr_Na2SO4=np.array([0,0.17,0.32,0.61,0.87,1.13,1.36,1.56])
#mol Na2SO4/kg water = molals
T_freeze_point_ice_line_Na2SO4=273-Freeze_point_depr_Na2SO4
#Freezing point of the solutions with the above mentioned molalities of Na2SO4 : K
lm = LinearRegression()
Linear_regr_Na2SO4=lm.fit(np.array(C_Na2SO4_ice_line).reshape(-1, 1),
T_freeze_point_ice_line_Na2SO4)



#%%
#UREA
#Interpolation/Extrapolation of the urea solubility line with a cubic spline
#Urea Solubility Line, Data from source: 'The solubility of urea in water 2/Precise urea-water eutectic...'
T_urea_sol_line=[261.6,273.15,283.15,293.15,303.15,312.85,323.15,323.75,333.15,341.65,343.15]
#Units : K
C_urea_sol_line=np.array([48.81,67,84,104.7,136,165.4,205,206.4,246,295,314.6])
#Units : g urea/ 100g of water (neglecting impurities)
C_urea_sol_line=(10/MW_urea)*C_urea_sol_line #Transform
the solubility line concentrations in : mols urea/ kg water = molals
tck_Urea= interpolate.splrep(T_urea_sol_line, C_urea_sol_line, s=0)
#Interpolation/Extrapolation of the ice line using linear regression
#Ice line in the Urea-Water phase diagram : Source : 'The freezing points of concentrated aqueous
solutions of urea...'
C_urea_ice_line=[0.324,0.432,0.646,1.521,3.36,3.37,4.545,5.285,6.013,8.083,8.127]
#Units : mol urea/kg water = molals
Freeze_point_depr_urea=np.array([0.595,0.789,1.17,2.673,5.49,5.594,7.151,8.023,8.966,11.398,11.4])
#Freezing point depression for the above molalities for urea: oC
T_freeze_point_ice_line_urea=273-Freeze_point_depr_urea #Freezing
point of the solutions with the above mentioned molalities of urea : K
#lm_Urea = LinearRegression()
Linear_regr_Urea=lm.fit(np.array(C_urea_ice_line).reshape(-1, 1), T_freeze_point_ice_line_urea)



#%%
#Declaration of constant process parameters - Part 7: Sodium Chloride Properties
"""CHANGE:Parameters of Compound 2"""

#Physical Properties
MW_NaCl=58.4 #Molecular weight
of NaCl : g/mol
d_NaCl=2.16*1000 #Density of NaCl
(25oC) : kg/m^3
(source:https://pubchem.ncbi.nlm.nih.gov/compound/sodium_chloride#section=Solubility)
Cp_NaCl=(50.5*MW_NaCl)*1000 #Heat
capacity of NaCl (25 oC) : J/(kg * K)
(source:http://webbook.nist.gov/cgi/cbook.cgi?ID=C7647145&Type=JANAFS&Table=on)

#Create the library with the constant parameters for sodium chloride
NaClParameters = namedtuple('NaClParameters', ['MW','d','Cp'])
```

```
NaClPar = NaClParameters(MW=MW_NaCl,
                d=d_NaCl,
                Cp=Cp_NaCl)
#%%
#Assign all the used (non-constant) variables to a class

class Variables:
   def
__init__(self,t,N_ice,N_compound1_cr,V_ice,V_compound1_cr,V_solids_tot,M_ice,M_compound1_
cr,M_solids_tot,Ntot_ice,Ntot_compound1_cr,Ntot,C_compound1,C_compound2,Treactor,V_liquid_
tot,V_mother_liquor,V_water,V_compound1,V_compound2,M_water,M_compound1,M_compound2
,M_mother_liquor,M_liquid_tot,Vtot,Mtot,solids_weight_percentage,V_ice_distr,V_compound1_cr_
distr,V_ice_previous_loop,V_compound1_cr_previous_loop):
      self.t=t
      self.N_ice=N_ice
      self.N_compound1_cr=N_compound1_cr
      self.V_ice=V_ice
      self.V_compound1_cr=V_compound1_cr
      self.V_solids_tot=V_solids_tot
      self.M_ice=M_ice
      self.M_compound1_cr=M_compound1_cr
      self.M_solids_tot=M_solids_tot
      self.Ntot_ice=Ntot_ice
      self.Ntot_compound1_cr=Ntot_compound1_cr
      self.Ntot=Ntot
      self.C_compound1=C_compound1
      self.C_compound2=C_compound2
      self.Treactor=Treactor
      self.V_liquid_tot=V_liquid_tot
      self.V_mother_liquor=V_mother_liquor
      self.V_water=V_water
      self.V_compound1=V_compound1
      self.V_compound2=V_compound2
      self.M_water=M_water
      self.M_liquid_tot=M_liquid_tot
      self.M_mother_liquor=M_mother_liquor
      self.M_compound1=M_compound1
      self.M_compound2=M_compound2
      self.Mtot=Mtot
      self.Vtot=Vtot
      self.solids_weight_percentage=solids_weight_percentage
      self.V_ice_distr=V_ice_distr
      self.V_compound1_cr_distr=V_compound1_cr_distr
      self.V_ice_previous_loop=V_ice_previous_loop
      self.V_compound1_cr_previous_loop=V_compound1_cr_previous_loop

Var=Variables

#%%
"""CHANGE: the desired compounds in the simulation"""

def Compounds():
   global Compound1,Compound2,tck,lm,Linear_regr,C_compound1_initial,C_compound2_initial

   "There are 3 parts needed to be input"
```

```
    "1. Set Desired compounds (Urea,Na2SO4,NaCl,Eps)"
    #e.g.: If desire Urea, please input "UreaPar"
    Compound1=UreaPar#Na2SO4Par#UreaPar
    Compound2=NaClPar #EpsPar

    "2. Set initial concentration [mol/kg-water;molals]"
    #For testing: Urea(12.57),Na2SO4(0.598),NaCl(0.001),Eps(0.001)
    C_compound1_initial=0.598
    C_compound2_initial=0.001

    "3.Input the corresponding solubility line and ice line"
    tck = tck_Na2SO4#tck_Na2SO4#tck_Urea
    Linear_regr = Linear_regr_Na2SO4#Linear_regr_Na2SO4 #Linear_regr_Urea

#%%
#Function for the initialization of all the (non-constant) variables, that are assigned to the Variables
class

def Initialize(Var):
    global Compound1,Compound2,C_compound1_initial,C_compound2_initial
    #Initial values

    Var.t=0                                                    #Time : sec

    Var.N_ice=np.array([])                                     #Number of ice
crystals in each class in the reactor : absolute number of ice crystals
    Var.N_compound1_cr=np.array([])                            #Number of
compound 1 crystals in each class in the reactor : absolute number of urea crystals

    Var.V_ice=0                                                #Total volume of ice
crystals in the reactor: m^3
    Var.V_compound1_cr=0                                       #Total volume
of compound 1 crystals in the reactor: m^3
    Var.V_solids_tot=Var.V_ice+Var.V_compound1_cr              #Total
volume of solids in the reactor : m^3

    Var.V_ice_distr=np.zeros(classes)                          #Volume
distribution of ice crystals in each class : m^3
    Var.V_compound1_cr_distr=np.zeros(classes)                 #Volume
distribution of compound 1 crystals in each class : m^3

    Var.M_ice=0                                                #Total mass of ice in
the reactor : kg
    Var.M_compound1_cr=0                                       #Total mass of
compound 1 crystals in the reactor : kg
    Var.M_solids_tot=Var.M_ice+Var.M_compound1_cr              #Total
mass of solids in the reactor : kg

    Var.Ntot_ice=0                                             #Total number of ice
crystals in the reactor
    Var.Ntot_compound1_cr=0                                    #Total number
of compound 1 crystals in the reactor
    Var.Ntot=Var.Ntot_ice+Var.Ntot_compound1_cr                #Total
number of crystals in the reactor
```

```
    Var.C_compound1=C_compound1_initial                                    #Initial
compound 1 concentration in the mother liquor in the reactor : molal = mol compound 1/kg water
    Var.C_compound2=C_compound2_initial                                    #Initial
compound 2 concentration in the mother liquor in the reactor : molal = mol compound 2/kg water

    Var.Treactor=298                                                       #Initial temperature
of the bulk liquid in the crystallizer : K

    Var.V_liquid_tot=0.9*Vreactor                                          #Total volume
of liquid in the reactor : m^3 (ASSSUMED to be 70 % of the reactor volume)
    Var.V_mother_liquor=Var.V_liquid_tot                                   #Volume
of the mother liquor in the reactor = Vwater+V_compound1+V_compound2: m^3

Var.V_water=Var.V_mother_liquor/(1+Var.C_compound1*Compound1.MW*d_water/(1000*Comp
ound1.d)+Var.C_compound2*Compound2.MW*d_water/(1000*Compound2.d))     #Volume of water
in the reactor : m^3

Var.V_compound1=(Var.C_compound1*Compound1.MW*Var.V_water*d_water)/(1000*Compoun
d1.d)                                                  #Volume of compound 1 in the reactor : m^3
    Var.V_compound2=Var.V_mother_liquor-Var.V_water-Var.V_compound1
#Volume of compound 2 in the reactor : m^3

    Var.M_water=Var.V_water*d_water                                        #Mass of
water in the reactor : kg
    Var.M_compound1=Var.V_compound1*Compound1.d                            #Mass
of compound 1 in the reactor : kg
    Var.M_compound2=Var.V_compound2*Compound2.d                            #Mass
of compound 2 in the reactor : kg
    Var.M_mother_liquor=Var.M_water+Var.M_compound1+Var.M_compound2
#Mass of the mother liquor in the reactor :kg
    Var.M_liquid_tot=Var.M_mother_liquor                                   #Total
mass of liquid in the reactor :kg

    Var.Vtot=Var.V_solids_tot+Var.V_liquid_tot                             #Total
volume of solids and liquid in the reactor : m^3
    Var.Mtot=Var.M_solids_tot+Var.M_liquid_tot                             #Total
mass of solids and liquid in the reactor : kg

    Var.V_ice_previous_loop=Var.V_ice                                      #Total
volume of ice crystals stored from the previous time interval : m^3
    Var.V_compound1_cr_previous_loop=Var.V_compound1_cr                    #Total
volume of compound 1 crystals stored from the previous time interval : m^3

    Var.solids_weight_percentage=(Var.M_solids_tot/Var.Mtot)*100           #Solids
weight percentage in the reactor : solids wt % = (total mass of solids in the reactor / total mass in the
reactor)*100 % (neglecting the potential solid impurities)

    for i in range(0,classes):                                             #Loop over the
number of (classes-1) to initialize all the values (The range of the loop is from 0 to classes due to python
syntax, the loop actually runs from 0 to classes-1=299 )
        Init_size_distr=2e16*deltal*(exp((-i*deltal)/2.5e-5))              #Initialize
the number of crystals in each with this standard distribution (source:???)

        Var.N_ice=np.append(Var.N_ice,Init_size_distr)
```

```
        Var.N_compound1_cr=np.append(Var.N_compound1_cr,Init_size_distr)

        Var.V_ice=Var.V_ice+Var.N_ice[i]*kv_ice*exp(3*log(deltal*(i+1)))

Var.V_compound1_cr=Var.V_compound1_cr+Var.N_compound1_cr[i]*Compound1.kv*exp(3*log(
deltal*(i+1)))

    Var.V_ice_distr[0]=Var.N_ice[0]*kv_ice*0.25*(deltal**4)/deltal
    Var.V_compound1_cr_distr[0]=Var.N_compound1_cr[0]*Compound1.kv*0.25*(deltal**4)/deltal

    for i in range (1,classes-1):

        Var.V_ice_distr[i]=Var.N_ice[i]*kv_ice*0.25*((((i+1)*deltal)**4)-((i*deltal)**4))/deltal

Var.V_compound1_cr_distr[i]=Var.N_compound1_cr[i]*Compound1.kv*0.25*((((i+1)*deltal)**4)-
((i*deltal)**4))/deltal

    Var.V_ice_distr[classes-1]=Var.N_ice[classes-1]*kv_ice*0.25*(((classes*deltal)**4)-(((classes-
1)*deltal)**4))/deltal
    Var.V_compound1_cr_distr[classes-1]=Var.N_compound1_cr[classes-
1]*Compound1.kv*0.25*(((classes*deltal)**4)-(((classes-1)*deltal)**4))/deltal

    Var.V_solids_tot=Var.V_ice+Var.V_compound1_cr

    Var.M_ice=Var.M_ice+Var.V_ice*d_ice
    Var.M_compound1_cr=Var.M_compound1_cr+Var.V_compound1_cr*Compound1.d
    Var.M_solids_tot=Var.M_ice+Var.M_compound1_cr

    Var.Ntot_ice=Var.Ntot_ice+sum(Var.N_ice)
    Var.Ntot_compound1_cr=Var.Ntot_compound1_cr+sum(Var.N_compound1_cr)
    Var.Ntot=Var.Ntot_ice+Var.Ntot_compound1_cr

    Var.Vtot=Var.V_solids_tot+Var.V_liquid_tot
    Var.Mtot=Var.M_solids_tot+Var.M_liquid_tot

    Var.V_ice_previous_loop=Var.V_ice
    Var.V_compound1_cr_previous_loop=Var.V_compound1_cr

    Var.solids_weight_percentage=(Var.M_solids_tot/Var.Mtot)*100

    return (Var)
#%%

#Function for the estimation of crystal size distribution - Part 1 : Initialization of the local parameters
and time interval

def CrystalSizeDistribution():
    global
sigma_compound1,DT_ice,V_ice_diff,V_compound1_cr_diff,M_ice_diff,M_compound1_cr_diff,M_
ice_reactions,M_compound1_cr_reactions,Compound1,Compound2,tck,lm,Linear_regr

    #Time interval
    Var.t=Var.t+deltat
```

```
    atot_ice=0                                                    #Total surface area of ice
crystals in the reactor in every loop: m^2
    atot_compound1_cr=0                                           #Total surface area
of compound 1 crystals in the reactor in every loop: m^2

    #Volume and mass difference(increase/decrease) of crystals in every time interval
    V_ice_diff=0                                                  #Volume difference of
ice crystals in every time interval : m^3
    V_compound1_cr_diff=0                                         #Volume difference
of compound 1 crystals in every time interval : m^3

    M_ice_diff=0                                                  #Mass difference of ice
crystals in every time interval : kg
    M_compound1_cr_diff=0                                         #Mass difference
of compound 1 crystals in every time interval : kg

    #Mass of crystals produced/consumed via reacting : growth and/or nucleation and/or dissolution in
every time interval
    M_ice_reactions=0                                             #Mass of ice crystals
produced/consumed via reacting : growth and/or nucleation and/or dissolution in every time interval :
kg
    M_compound1_cr_reactions=0                                    #Mass of
compound 1 crystals produced/consumed via reacting : growth and/or nucleation and/or dissolution in
every time interval : kg

    #Number of crystals produced by nucleation in every time interval
    Nb_ice=0
    Nb_compound1_cr=0

    #Number of crystals that  grow in OR out of every class size in every time interval (ASSUMED
POSITIVE for growth INTO a class and NEGATIVE for growth OUT of a class)
    Ng_ice=0
    Ng_compound1_cr=0

    #Number of crystals dissolved in OR out of every class size in every time interval (ASSUMED
POSITIVE for dissolution INTO a class and NEGATIVE for dissolution OUT of a class)
    Nd_ice=0
    Nd_compound1_cr=0

    #Calculation of the equilibrium values using interpolation/extrapolation of the solubility and ice lines
    C_compound1_eq=interpolate.splev(Var.Treactor, tck, der=0)
    C_compound1_eq=float(C_compound1_eq)

    T_ice_eq_array=lm.predict(Var.C_compound1)
    T_ice_eq=T_ice_eq_array[0]

    #Supersaturation
    sigma_compound1=(Var.C_compound1/C_compound1_eq)-1

    #Ice undercooling
    DT_ice=T_ice_eq-Var.Treactor
    #%%

    #Function for the estimation of crystal size distribution - Part 2 : Compound 1 crystal size distribution
/ Mass balance
```

```
   if sigma_compound1<0:                                                    #If there is no supersaturation,the system is undersaturated and there is only dissolution of compound 1 crystals
      #Compound 1 crystals growth rate : m/s
      G_compound1_cr=0

      #Compound 1 crystals nucleation rate : crystals/s
      B_compound1_cr=0

      #Compound 1 crystals dissolution rate : m/s
      D_compound1_cr=Compound1.kd*(-sigma_compound1)

   else:

      G_compound1_cr=Compound1.kg*(sigma_compound1**2)
      B_compound1_cr=Compound1.kb*Var.M_compound1_cr*(sigma_compound1**2)
      D_compound1_cr=0

   #0 compound 1 crystal class size due to secondary nucleation (neglecting primary nucleation : ASSUMPTION)
   Nb_compound1_cr=B_compound1_cr*deltat
   Ng_compound1_cr=-(G_compound1_cr*Var.N_compound1_cr[0]*deltat)/deltal
   Nd_compound1_cr=-(D_compound1_cr*Var.N_compound1_cr[0]*deltat)/deltal


Var.N_compound1_cr[0]=Var.N_compound1_cr[0]+Nb_compound1_cr+Ng_compound1_cr+Nd_compound1_cr-(Fout_compound1_cr*deltat*Var.N_compound1_cr[0])/Var.M_compound1_cr
   Var.V_compound1_cr_distr[0]=Var.N_compound1_cr[0]*Compound1.kv*0.25*(deltal**4)/deltal

atot_compound1_cr=atot_compound1_cr+Var.N_compound1_cr[0]*Compound1.ka*(deltal**2)*(0**2)

   #1-298 crystal class size                                                #The range of the loop is from 1 to classes-1=299 due to python syntax, the loop actually runs from 1 to 298
   for i in range(1,(classes-1)):
      Ng_compound1_cr=(G_compound1_cr*deltat*(Var.N_compound1_cr[i-1]-Var.N_compound1_cr[i]))/deltal
      Nd_compound1_cr=(D_compound1_cr*deltat*(Var.N_compound1_cr[i+1]-Var.N_compound1_cr[i]))/deltal

      Var.N_compound1_cr[i]=Var.N_compound1_cr[i]+Ng_compound1_cr+Nd_compound1_cr-(Var.N_compound1_cr[i]*Fout_compound1_cr*deltat)/Var.M_compound1_cr

Var.V_compound1_cr_distr[i]=Var.N_compound1_cr[i]*Compound1.kv*0.25*((((i+1)*deltal)**4)-((i*deltal)**4))/deltal

atot_compound1_cr=atot_compound1_cr+Var.N_compound1_cr[i]*Compound1.ka*(deltal**2)*(i**2)

   #299 crystal class size
   Ng_compound1_cr=(G_compound1_cr*deltat*Var.N_compound1_cr[classes-2])/deltal
   Nd_compound1_cr=-(D_compound1_cr*deltat*Var.N_compound1_cr[classes-1])/deltal

   Var.N_compound1_cr[classes-1]=Var.N_compound1_cr[classes-1]+Ng_compound1_cr+Nd_compound1_cr-(Var.N_compound1_cr[classes-1]*deltat*Fout_compound1_cr)/Var.M_compound1_cr
```

```
    Var.V_compound1_cr_distr[classes-1]=Var.N_compound1_cr[classes-
1]*Compound1.kv*0.25*(((classes*deltal)**4)-(((classes-1)*deltal)**4))/deltal
    atot_compound1_cr=atot_compound1_cr+Var.N_compound1_cr[classes-
1]*Compound1.ka*(deltal**2)*((classes-1)**2)

    #Volume difference(increase/decrease) of compound 1 crystals in this interval
    V_compound1_cr_diff=sum(Var.V_compound1_cr_distr)-Var.V_compound1_cr_previous_loop

    #Mass difference(increase/decrease) of compound 1 crystals in this interval
    M_compound1_cr_diff=V_compound1_cr_diff*Compound1.d

    #Mass of compound 1 crystals produced/consumed via reacting : growth and/or nucleation and/or
dissolution in this time interval
    M_compound1_cr_reactions=M_compound1_cr_diff-
Fin_compound1_cr*deltat+Fout_compound1_cr*deltat
    #%%

    #Function for the estimation of crystal size distribution - Part 3 :Ice crystal size distribution / Mass
balance
    if DT_ice<0:                                                    #If there is no ice
undercooling, there is only dissolution of ice crystals
        #Ice crystals growth rate : m/s
        G_ice=0

        #Ice crystals nucleation rate : crystals/s
        B_ice=0

        #Ice crystals dissolution rate : m/s
        D_ice=kd_ice*(-DT_ice)

    else:

        G_ice=kg_ice*DT_ice
        B_ice=kb_ice*atot_ice*(DT_ice**2)
        D_ice=0

    #0 ice crystal class size due to secondary nucleation (neglecting primary nucleation : ASSUMPTION)
    Nb_ice=B_ice*deltat
    Ng_ice=-(G_ice*Var.N_ice[0]*deltat)/deltal
    Nd_ice=-(D_ice*Var.N_ice[0]*deltat)/deltal

    Var.N_ice[0]=Var.N_ice[0]+Nb_ice+Ng_ice+Nd_ice-(Fout_ice*deltat*Var.N_ice[0])/Var.M_ice
    Var.V_ice_distr[0]=Var.N_ice[0]*kv_ice*0.25*(deltal**4)/deltal
    atot_ice=atot_ice+Var.N_ice[0]*ka_ice*(deltal**2)*(0**2)

    #1-298 crystal class size                                       #The range of the loop
is from 1 to classes-1=299 due to python syntax, the loop actually runs from 1 to 298
    for i in range(1,(classes-1)):
        Ng_ice=(G_ice*deltat*(Var.N_ice[i-1]-Var.N_ice[i]))/deltal
        Nd_ice=(D_ice*deltat*(Var.N_ice[i+1]-Var.N_ice[i]))/deltal

        Var.N_ice[i]=Var.N_ice[i]+Ng_ice+Nd_ice-(Var.N_ice[i]*Fout_ice*deltat)/Var.M_ice
        Var.V_ice_distr[i]=Var.N_ice[i]*kv_ice*0.25*((((i+1)*deltal)**4)-((i*deltal)**4))/deltal
        atot_ice=atot_ice+Var.N_ice[i]*ka_ice*(deltal**2)*(i**2)
```

```
    #299 crystal class size
    Ng_ice=(G_ice*deltat*Var.N_ice[classes-2])/deltal
    Nd_ice=-(D_ice*deltat*Var.N_ice[classes-1])/deltal

    Var.N_ice[classes-1]=Var.N_ice[classes-1]+Ng_ice+Nd_ice-(Var.N_ice[classes-
1]*deltat*Fout_ice)/Var.M_ice
    Var.V_ice_distr[classes-1]=Var.N_ice[classes-1]*kv_ice*0.25*(((classes*deltal)**4)-(((classes-
1)*deltal)**4))/deltal
    atot_ice=atot_ice+Var.N_ice[classes-1]*ka_ice*(deltal**2)*((classes-1)**2)

    #Volume difference(increase/decrease) of ice crystals in this interval
    V_ice_diff=sum(Var.V_ice_distr)-Var.V_ice_previous_loop

    #Mass difference(increase/decrease) of ice crystals in this interval
    M_ice_diff=V_ice_diff*d_ice

    #Mass of ice crystals produced/consumed via reacting : growth and/or nucleation and/or dissolution
in this time interval
    M_ice_reactions=M_ice_diff-Fin_ice*deltat+Fout_ice*deltat

    return (Var)
#%%

#Function for the calculation of the mass balances for the different compounds

def MassBalances():

    global
V_ice_diff,V_compound1_cr_diff,M_ice_diff,M_compound1_cr_diff,M_ice_reactions,M_compound
1_cr_reactions

    #Calculation of new values based on mass balances

    #Calculation of the new mass for every compound in the reactor
    Var.M_ice=Var.M_ice+M_ice_diff
    Var.M_compound1_cr=Var.M_compound1_cr+M_compound1_cr_diff
    Var.M_solids_tot=Var.M_ice+Var.M_compound1_cr

    Var.M_water=Var.M_water+Fin_water*deltat-Fout_water*deltat-M_ice_reactions
    Var.M_compound1=Var.M_compound1+Fin_compound1*deltat-Fout_compound1*deltat-
M_compound1_cr_reactions
    Var.M_compound2=Var.M_compound2+Fin_compound2*deltat-Fout_compound2*deltat
    Var.M_mother_liquor=Var.M_water+Var.M_compound1+Var.M_compound2
    Var.M_liquid_tot=Var.M_mother_liquor

    Var.Mtot=Var.M_solids_tot+Var.M_liquid_tot

    #Calculation of the new volume for every compound in the reactor
    Var.V_ice=Var.V_ice+V_ice_diff
    Var.V_compound1_cr=Var.V_compound1_cr+V_compound1_cr_diff
    Var.V_solids_tot=Var.V_ice+Var.V_compound1_cr

    Var.V_water=Var.M_water/d_water
    Var.V_compound1=Var.M_compound1/Compound1.d
    Var.V_compound2=Var.M_compound2/Compound2.d
```

```
    Var.V_mother_liquor=Var.V_water+Var.V_compound1+Var.V_compound2
    Var.V_liquid_tot=Var.V_mother_liquor

    Var.Vtot=Var.V_solids_tot+Var.V_liquid_tot

    #New concentration of compound 1 in the bulk liquid in the reactor
    Var.C_compound1=(Var.M_compound1*1000)/(Compound1.MW*Var.M_water)
# Units : molals = mol compound 1/kg water

    #Store the new volumes of ice and compound 1 crystals for the calculation of V_diff in the next time interval
    Var.V_ice_previous_loop=Var.V_ice
    Var.V_compound1_cr_previous_loop=Var.V_compound1_cr

    #Calculation of the new solids contents in the reactor
    Var.solids_weight_percentage=(Var.M_solids_tot/Var.Mtot)*100

    return (Var)
#%%

#Function for the calculation of the heat balance
def HeatBalances():
    global M_ice_reactions,M_compound1_cr_reactions

    #Heat balance - New temperature in the reactor (!!!Assumed heat flux into the system is POSITIVE)
    Qcryst_ice=(M_ice_reactions*DHfus_ice)/deltat                                    #Heat flux to the system due to ice crystallization : J/s
    Qcryst_compound1_cr=(M_compound1_cr_reactions*Compound1.DHfus)/deltat
#Heat flux to the system due to compound 1 crystallization : J/s

    Qtot=Qcryst_ice+Qcryst_compound1_cr-Cooling_rate                                  #Total heat flux to the system : J/s

    '''Specific heat capacity of Na2SO4'''
    Na2SO4_weight_percentage=(Var.M_compound1/Var.M_liquid_tot)*100
#Urea weight percentage in the liquid in the reactor for the estimation of the heat capacity of the solution : urea wt % = (total mass of urea in the liquid in the reactor / total mass of liquid in the reactor)*100 %
    Cp_solution=1000*(0.1299*((Na2SO4_weight_percentage*10/Compound1.MW)**2)-0.6017*(Na2SO4_weight_percentage*10/Compound1.MW)+4.1725)    #Heat capacity of the solution (Calculated for 25 oC, Neglecting the impurities and assuming no change of heat capacity due to temperature) (source:Heat of solution, heat capacity...) :   J/(kg*K)


    """
    '''CHANGE THE HEAT CAPACITY of SOLUTION FOR SODIUM SULFATE''' #Heat Capacities of Concentrated Aqueous Solutions of Sodium Sulfate, Sodium Carbonate, and Sodium Hydroxide at 25 °C
    Urea_weight_percentage=(Var.M_compound1/Var.M_liquid_tot)*100
#Urea weight percentage in the liquid in the reactor for the estimation of the heat capacity of the solution : urea wt % = (total mass of urea in the liquid in the reactor / total mass of liquid in the reactor)*100 %
    Cp_solution=(0.9988-0.006494*Urea_weight_percentage+0.00003025*(Urea_weight_percentage**2)-0.0000001286*(Urea_weight_percentage**3))*4.184*1000          #Heat capacity of the solution
```

```
(Calculated for 25 oC, Neglecting the impurities and assuming no change of heat capacity due to temperature) (source:Heat of solution, heat capacity...) :   J/(kg*K)

   #dsol=0.9974+0.002625*Urea_weight_percentage+0.00000401*Urea_weight_percentage**2
#Density of the solution (Calculated for 25 oC, Neglecting the impurities and assuming no change of density due to temperature) (source:Heat of solution, heat capacity...) : g/ml
   """

Var.Treactor=(Qtot*deltat)/(Var.M_liquid_tot*Cp_solution+Var.M_compound1_cr*Compound1.Cp
+Var.M_ice*Cp_ice)+Var.Treactor

   return (Var)
#%%

#Function for storing several values
def Store():
   global
t_store,sigma_compound1_store,DT_ice_store,M_ice_store,M_compound1_cr_store,Treactor_store
#,V_ice_distr_store,V_urea_cr_distr_store

   t_store=np.append(t_store,Var.t)
   sigma_compound1_store=np.append(sigma_compound1_store,sigma_compound1)
   DT_ice_store=np.append(DT_ice_store,DT_ice)
   M_ice_store=np.append(M_ice_store,Var.M_ice)
   M_compound1_cr_store=np.append(M_compound1_cr_store,Var.M_compound1_cr)
   Treactor_store=np.append(Treactor_store,Var.Treactor)

#%%

#Function for plotting the initial values of several variables
def InitialPlot():
   global graph1,graph2,graph3,graph4

   graph1=fig1.add_subplot(311)
   graph1.set_title('Number of ice crystals in each class')
   graph1.set_xlabel('Class Length (m)')
   graph1.set_ylabel('Number of ice crystals')
   graph1.plot(class_length, Var.N_ice, 'r-',label='Initial values')

   graph2=fig1.add_subplot(313)
   graph2.set_title('Number of urea crystals in each class')
   graph2.set_xlabel('Class Length (m)')
   graph2.set_ylabel('Number of urea crystals')
   graph2.plot(class_length, Var.N_compound1_cr, 'r-',label='Initial values')

   graph3=fig2.add_subplot(311)
   graph3.set_title('Volume of ice crystals in each class')
   graph3.set_xlabel('Class Length (m)')
   graph3.set_ylabel('Volume of ice crystals (m^3)')
   graph3.plot(class_length, Var.V_ice_distr, 'r-',label='Initial values')

   graph4=fig2.add_subplot(313)
   graph4.set_title('Volume of urea crystals in each class')
   graph4.set_xlabel('Class Length (m)')
   graph4.set_ylabel('Volume of urea crystals (m^3)')
```

```
    graph4.plot(class_length, Var.V_compound1_cr_distr, 'r-',label='Initial values')
#%%

#Function for plotting final results

def Plot():
    global
t_store,sigma_compound1_store,DT_ice_Store,M_ice_store,M_compound1_cr_store,Treactor_store,
graph1,graph2,graph3,graph4 #,V_ice_distr_store,V_urea_cr_distr_store,

    graph1.plot(class_length,Var.N_ice,'b-',label='Final values')

    graph2.plot(class_length,Var.N_compound1_cr,'b-',label='Final values')
    fig1.legend(loc='right')
    fig1.show

    graph3.plot(class_length,Var.V_ice_distr,'b-',label='Final values')

    graph4.plot(class_length,Var.V_compound1_cr_distr,'b-',label='Final values')
    fig2.legend(loc='right')
    fig2.show

    graph5=fig3.add_subplot(111)
    graph5.plot(t_store,sigma_compound1_store,'b-')
    graph5.set_title('Supersaturation of Compound 1 vs time')
    graph5.set_xlabel('Time(sec)')
    graph5.set_ylabel('Superasturation of Compound 1 (-)')
    fig3.show

    graph6=fig4.add_subplot(111)
    graph6.plot(t_store,DT_ice_store,'b-')
    graph6.set_title('Undercooling of ice vs time')
    graph6.set_xlabel('Time(sec)')
    graph6.set_ylabel('Undercooling of ice (K)')
    fig4.show

    graph7=fig5.add_subplot(311)
    graph7.set_title('Mass of ice crystals vs time')
    graph7.set_xlabel('Time(sec)')
    graph7.set_ylabel('Mass of ice crystals (kg)')
    graph7.plot(t_store,M_ice_store,'b-')


    graph8=fig5.add_subplot(313)
    graph8.set_title('Mass of Compound 1 crystals vs time')
    graph8.set_xlabel('Time(sec)')
    graph8.set_ylabel('Mass of Comp. 1 crystals (kg)')
    graph8.plot(t_store,M_compound1_cr_store,'b-')
    fig5.show


    graph9=fig6.add_subplot(111)
    graph9.set_title('Temperature in the reactor vs time')
    graph9.set_xlabel('Time(sec)')
    graph9.set_ylabel('Temperature (K)')
```

```
    graph9.plot(t_store,Treactor_store,'b-')
    fig6.show

#%%
"MAIN"
#Main Procedure

"CHANGE:Reactor volume (Vreactor)"
Vreactor=10

#Net Heat flux
"CHANGE: cooling rate"
Cooling_rate=500000#250000                                                    #Assumed NET
cooling rate to cool down : W = J/s :Assumption !!! Includes the heat removed by the heat exchanger
and the heat provided by the environment and the system


Compounds()
Var=Initialize(Var)
InitialPlot()
"Input the eutectic concentration od compound 1 below"
Max_solid_conc=40  #Desired max solid wt% in the reactor

while Var.t<=18000:
    if Var.solids_weight_percentage >=Max_solid_conc:                         #Set
a maximum limit based on the solids weight percentage (wt%)
        print('Reactor Size:',Vreactor,'m3.')
        #print('Reaction Time:',Var.t,'sec (',round(Var.t/60,2),'min ).',)
        print('Reaction Time:',Var.t,'sec (',Var.t/60,'min ).',)
        print('Max solid wt% in the reactor reached :', Max_solid_conc ,'wt% solids.')
        break
    else:
        Var=CrystalSizeDistribution()
        Var=MassBalances()
        Var=HeatBalances()
        if ((Var.t)%100)==0:
            Store()
        else:
            pass


Plot()

#Plot save
fig1.savefig('CSD with crystal number.png')
fig2.savefig('CSD with crystal volume.png')
fig3.savefig('Supersaturation vs time.png')
fig4.savefig('Undercooling ice vs time.png')
fig5.savefig('CSD with crystal mass.png')
fig6.savefig('Temperature profile.png')

#Calculate and print the elapsed time after the calculations
elapsed=time.time()-time0
print('Time elapsed : ',round(elapsed,2))
```

8.8 Explanation and assumption of crystal size distribution model

Literatures are reviewed and assumptions were made when building this CSD model.

The reactor volume is default to be 10L, and the initial volume of the liquid is 90% of the reactor volume.

The model simulates a batch reactor. No influx and outflux is involved during the process. Yet the model can be altered to simulate a continuous system by introducing the flux components in the crystal size distribution calculation and the mass balance calculation.

The model net cooling rate is default to set as 500W, which is similar to that of the observed experimental value. The net cooling rate involved the heat transfer via the cooling and the environment and the heat dissipation from the stirrer.

The length interval is calculated via the set number of classes and assumed maximum crystal length. The length interval is required to be minimal which allows only a slight change between classes. The maximum crystal length is the length which no crystals can reach during the process.

All the densities, specific heat capacities and enthalpies of fusion of the compounds are assumed to be constant, which the changes due to temperature difference are neglected.

The growth kinetics of sodium sulphate were obtained from literature (Shi & Rousseau, 2001) The dissolution rate of ice and mirabilite are assumed to be the same as that on previous study on magnesium sulphate (Himawan, 2005). A sensitivity analysis was performed previously on similar model simulating urea, which is with the same dissolution rate (Alexopoulos, 2018). It is found to be acceptable for the simulation.

The solubility line was plotted via linear regression from the known solubility point with the known concentration (Marion & Farren, 1999). Ice line was plotted via linear regression from the known depressed freeze point with the known concentration (Haynes, 1999).

Shape and surface area factors are assumed constant. The crystal shape is a product of the cube of the longest side length and the shape factor. The surface area of crystals is a product of the square of the longest side length and the surface area factor.

Both the ice and mirabilite are assumed to have a disk shape with a length/height ratio of 10.

The initial temperature in the reactor is assumed to be 298K.

The initial concentration of sodium sulphate is set as 0.598mol/kg-water, which is 8wt%. The initial concentration of sodium chloride is set as 0.001mol/kg

The initial size distribution of crystals is based on the previous version and is assumed to have a standard crystal size distribution.

The total surface area and volume calculation is also based on the previous version.

The maximum solid content allowed in the reactor is assumed to be 40wt%.

This code also includes the option to simulate the EFC process of a urea solution with few EPS.

8.9 Concentration data of crystal products and solutions

ICP-MS was conducted to analyse the concentration. The following is the concentration data obtained and the conversion to the actual concentation.For the "Period" column, A is the working solution; B is the salt sample at 3°C; C is the salt sample at eutectic temperature; D is the ice sample at the eutectic temperature; E is is the salt sample at eutectic temperature for 30min; F is the ice sample at the eutectic temperature for 30min.

					Test trial 1						Test trial 2											
					[ppm]		[ppb]			[ppm]	[ppm]		[ppb]			[ppm]	[wt%]					
No.	Solution	Period	Washing	Name	Na	Mg	Ca	Sr	Ba	Si	Na	Mg	Ca	Sr	Ba	Si	Na	Mg	Ca	Sr	Ba	Si
1	1	B	0	1B0	1.402	0.000	0.000	0.000	0.000		1.484	0.000	0.000	0.000	0.000		14.430	0.000	0.000	0.000	0.000	
2	1	B	1	1B1	1.660	0.000	0.000	0.000	0.000		1.552	0.000	0.000	0.000	0.000		16.060	0.002	0.000	0.000	0.000	
3	1	B	2	1B2	1.467	0.000	0.000	0.000	0.000		1.531	0.000	0.000	0.000	0.000		14.990	0.000	0.000	0.000	0.000	
4	1	B	3	1B3	1.527	0.000	0.000	0.000	0.000		1.573	0.000	0.000	0.000	0.000		15.501	0.000	0.000	0.000	0.000	
5	1	C	0	1C0	1.460	0.000	0.000	0.000	0.000		1.437	0.000	0.000	0.000	0.000		14.483	0.000	0.000	0.000	0.000	
6	1	C	1	1C1	1.277	0.000	0.000	0.000	0.000		1.651	0.000	0.000	0.000	0.000		14.640	0.002	0.000	0.000	0.000	
7	1	C	2	1C2	1.457	0.000	0.000	0.000	0.000		1.655	0.000	0.000	0.000	0.000		15.562	0.000	0.000	0.000	0.000	
8	1	C	3	1C3	1.397	0.000	0.000	0.000	0.000		1.549	0.000	0.000	0.000	0.000		14.731	0.000	0.000	0.000	0.000	
9	1	D	0	1D0	2.134	0.000	0.000	0.000	0.000		2.228	0.000	0.000	0.000	0.000		2.181	0.000	0.000	0.000	0.000	
10	1	D	1	1D1	1.447	0.000	0.000	0.000	0.000		2.151	0.000	0.000	0.000	0.000		1.799	0.000	0.000	0.000	0.000	
11	1	D	2	1D2	0.547	0.000	0.000	0.000	0.000		0.107	0.000	0.000	0.000	0.000		0.327	0.000	0.000	0.000	0.000	
12	1	D	3	1D3	0.330	0.000	0.000	0.000	0.000		0.133	0.000	0.000	0.000	0.000		0.232	0.000	0.000	0.000	0.000	
13	1	E	0	1E0	1.389	0.000	0.000	0.000	0.000		1.303	0.000	0.000	0.000	0.000		13.461	0.000	0.000	0.000	0.000	
14	1	E	1	1E1	1.439	0.000	0.000	0.000	0.000		1.361	0.000	0.000	0.000	0.000		13.997	0.000	0.000	0.000	0.000	
15	1	E	2	1E2	1.543	0.000	0.000	0.000	0.000		1.455	0.000	0.000	0.000	0.000		14.989	0.000	0.000	0.000	0.000	
16	1	E	3	1E3	1.355	0.000	0.000	0.000	0.000		1.397	0.000	0.000	0.000	0.000		13.761	0.000	0.000	0.000	0.000	
17	1	F	0	1F0	2.833	0.000	0.000	0.000	0.000		2.076	0.000	0.000	0.000	0.000		2.455	0.000	0.000	0.000	0.000	
18	1	F	1	1F1	0.215	0.000	0.000	0.000	0.000		0.321	0.000	0.000	0.000	0.000		0.268	0.000	0.000	0.000	0.000	
19	1	F	2	1F2	0.107	0.000	0.000	0.000	0.000		0.133	0.000	0.000	0.000	0.000		0.120	0.000	0.000	0.000	0.000	
20	1	F	3	1F3	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	
21	2	B	0	2B0	1.487	0.002	0.000	0.000	0.000		1.484	0.001	0.000	0.000	0.000		14.857	0.017	0.000	0.000	0.000	
22	2	B	1	2B1	1.641	0.000	0.000	0.000	0.000		1.552	0.000	0.000	0.000	0.000		15.964	0.000	0.000	0.000	0.000	
23	2	B	2	2B2	1.568	0.000	0.000	0.000	0.000		1.531	0.000	0.000	0.000	0.000		15.494	0.000	0.000	0.000	0.000	
24	2	B	3	2B3	1.429	0.000	0.000	0.000	0.000		1.437	0.000	0.000	0.000	0.000		14.329	0.000	0.000	0.000	0.000	
25	2	C	0	2C0	1.643	0.003	0.000	0.000	0.000		1.573	0.003	0.000	0.000	0.000		16.082	0.032	0.000	0.000	0.000	
26	2	C	1	2C1	1.686	0.000	0.000	0.000	0.000		1.651	0.000	0.000	0.000	0.000		16.683	0.004	0.000	0.000	0.000	

27	2	C	2	2C2	1.697	0.000	0.000	0.000	0.000		1.655	0.000	0.000	0.000	0.000		16.760	0.000	0.000	0.000	0.000	
28	2	C	3	2C3	1.546	0.000	0.000	0.000	0.000		1.474	0.000	0.000	0.000	0.000		15.103	0.000	0.000	0.000	0.000	
29	2	D	0	2D0	2.409	0.003	0.000	0.000	0.000		2.453	0.042	0.000	0.000	0.000		2.431	0.023	0.000	0.000	0.000	
30	2	D	1	2D1	0.993	0.061	0.000	0.000	0.000		0.143	0.030	0.000	0.000	0.000		0.568	0.046	0.000	0.000	0.000	
31	2	D	2	2D2	0.917	0.030	0.000	0.000	0.000		0.946	0.030	0.000	0.000	0.000		0.932	0.030	0.000	0.000	0.000	
32	2	D	3	2D3	0.001	0.000	0.000	0.000	0.000		0.001	0.000	0.000	0.000	0.000		0.001	0.000	0.000	0.000	0.000	
33	2	E	0	2E0	1.568	0.002	0.000	0.000	0.000		1.549	0.002	0.000	0.000	0.000		15.584	0.018	0.000	0.000	0.000	
34	2	E	1	2E1	1.634	0.002	0.000	0.000	0.000		1.608	0.000	0.000	0.000	0.000		16.209	0.013	0.000	0.000	0.000	
35	2	E	2	2E2	1.574	0.002	0.000	0.000	0.000		1.481	0.001	0.000	0.000	0.000		15.276	0.012	0.000	0.000	0.000	
36	2	E	3	2E3	1.490	0.000	0.000	0.000	0.000		1.462	0.000	0.000	0.000	0.000		14.763	0.000	0.000	0.000	0.000	
37	2	F	0	2F0	2.464	0.043	0.000	0.000	0.000		2.460	0.057	0.000	0.000	0.000		2.462	0.050	0.000	0.000	0.000	
38	2	F	1	2F1	0.448	0.000	0.000	0.000	0.000		0.402	0.000	0.000	0.000	0.000		0.425	0.000	0.000	0.000	0.000	
39	2	F	2	2F2	0.154	0.000	0.000	0.000	0.000		0.159	0.002	0.000	0.000	0.000		0.157	0.001	0.000	0.000	0.000	
40	2	F	3	2F3	0.016	0.000	0.000	0.000	0.000		0.019	0.000	0.000	0.000	0.000		0.017	0.000	0.000	0.000	0.000	
41	3	B	0	3B0	1.424	0.002	0.042	0.088	0.093	0.000	1.391	0.002	0.042	0.090	0.000	0.000	14.074	0.020	0.008	0.000	0.000	0.000
42	3	B	1	3B1	1.435	0.000	0.004	0.000	0.000	0.000	1.449	0.000	0.031	0.000	0.000	0.000	14.418	0.002	0.003	0.000	0.000	0.000
43	3	B	2	3B2	1.571	0.000	0.012	0.000	0.000	0.000	1.540	0.000	0.020	0.000	0.000	0.000	15.558	0.000	0.003	0.000	0.000	0.000
44	3	B	3	3B3	1.403	0.000	0.000	0.000	0.000	0.000	1.355	0.000	0.020	0.000	0.000	0.000	13.790	0.000	0.002	0.000	0.000	0.000
45	3	C	0	3C0	1.393	0.003	0.019	0.094	0.089	1.500	1.303	0.002	0.009	0.000	0.000	1.600	13.480	0.029	0.003	0.000	0.000	0.003
46	3	C	1	3C1	1.440	0.000	0.027	0.097	0.097	1.400	1.361	0.000	0.006	0.000	0.000	1.400	14.002	0.002	0.003	0.000	0.000	0.003
47	3	C	2	3C2	1.482	0.000	0.015	0.000	0.000	0.000	1.455	0.000	0.012	0.000	0.000	0.000	14.682	0.000	0.003	0.000	0.000	0.000
48	3	C	3	3C3	1.400	0.000	0.012	0.000	0.000	0.000	1.397	0.000	0.002	0.000	0.000	0.000	13.988	0.000	0.001	0.000	0.000	0.000
49	3	D	0	3D0	2.037	0.035	0.031	0.000	0.000	0.000	1.997	0.040	0.032	0.000	0.000	0.000	2.017	0.038	0.032	0.000	0.000	0.000
50	3	D	1	3D1	0.512	0.021	0.015	0.000	0.000	0.000	0.557	0.000	0.017	0.000	0.000	0.000	0.535	0.011	0.016	0.000	0.000	0.000
51	3	D	2	3D2	0.067	0.012	0.004	0.000	0.000	0.000	0.083	0.000	0.010	0.000	0.000	0.000	0.075	0.006	0.007	0.000	0.000	0.000
52	3	D	3	3D3	0.007	0.003	0.013	0.000	0.000	0.000	0.016	0.000	0.021	0.000	0.000	0.000	0.012	0.002	0.017	0.000	0.000	0.000
53	3	E	0	3E0	1.348	0.001	0.018	0.110	0.094	0.000	1.313	0.001	0.000	0.108	0.086	0.000	13.306	0.010	0.002	0.000	0.000	0.000
54	3	E	1	3E1	1.328	0.000	0.016	0.084	0.091	0.000	1.363	0.000	0.000	0.091	0.088	0.000	13.453	0.000	0.002	0.000	0.000	0.000
55	3	E	2	3E2	1.450	0.000	0.021	0.000	0.000	0.000	1.398	0.000	0.024	0.000	0.000	0.000	14.241	0.000	0.005	0.000	0.000	0.000
56	3	E	3	3E3	1.514	0.000	0.000	0.000	0.000	0.000	1.385	0.000	0.009	0.000	0.000	0.000	14.495	0.000	0.001	0.000	0.000	0.000
57	3	F	0	3F0	1.975	0.075	0.029	0.000	0.000	0.000	1.833	0.061	0.031	0.000	0.000	0.000	1.904	0.068	0.030	0.000	0.000	0.000
58	3	F	1	3F1	0.188	0.052	0.025	0.000	0.000	0.000	0.225	0.000	0.037	0.000	0.000	0.000	0.207	0.026	0.031	0.000	0.000	0.000
59	3	F	2	3F2	0.012	0.000	0.003	0.000	0.000	0.000	0.648	0.000	0.014	0.000	0.000	0.000	0.330	0.000	0.009	0.000	0.000	0.000
60	3	F	3	3F3	0.003	0.000	0.011	0.000	0.000	0.000	0.008	0.000	0.004	0.000	0.000	0.000	0.006	0.000	0.008	0.000	0.000	0.000

61	4	B	0	4B0																
62	4	B	1	4B1																
63	4	B	2	4B2																
64	4	B	3	4B3																
65	4	C	0	4C0	1.493	0.004	0.067	0.088	0.120	0.000	1.489	0.004	0.063	0.086	0.099	0.000	14.911	0.038	0.013	0.000	0.000	0.000
66	4	C	1	4C1	1.561	0.000	0.049	0.000	0.000	0.000	1.562	0.000	0.047	0.000	0.000	0.000	15.613	0.000	0.010	0.000	0.000	0.000
67	4	C	2	4C2	1.547	0.000	0.052	0.000	0.000	0.000	1.552	0.000	0.050	0.000	0.000	0.000	15.495	0.000	0.010	0.000	0.000	0.000
68	4	C	3	4C3	1.497	0.000	0.012	0.000	0.000	0.000	1.501	0.000	0.010	0.000	0.000	0.000	14.991	0.000	0.002	0.000	0.000	0.000
69	4	D	0	4D0	2.334	0.004	0.032	0.000	0.000	0.000	2.335	0.002	0.032	0.000	0.000	0.000	2.335	0.003	0.032	0.000	0.000	0.000
70	4	D	1	4D1	0.744	0.000	0.017	0.000	0.000	0.000	0.805	0.000	0.017	0.000	0.000	0.000	0.775	0.000	0.017	0.000	0.000	0.000
71	4	D	2	4D2	0.015	0.000	0.010	0.000	0.000	0.000	0.012	0.000	0.010	0.000	0.000	0.000	0.014	0.000	0.010	0.000	0.000	0.000
72	4	D	3	4D3	0.003	0.000	0.021	0.000	0.000	0.000	0.010	0.000	0.021	0.000	0.000	0.000	0.007	0.000	0.021	0.000	0.000	0.000
73	4	E	0	4E0	1.433	0.000	0.086	0.105	0.098	1.200	1.439	0.000	0.073	0.107	0.105	1.200	14.360	0.000	0.016	0.000	0.000	0.002
74	4	E	1	4E1	1.625	0.000	0.053	0.092	0.091	1.300	1.627	0.000	0.065	0.091	0.089	1.200	16.260	0.000	0.012	0.000	0.000	0.003
75	4	E	2	4E2	1.481	0.000	0.000	0.000	0.000	0.000	1.477	0.000	0.021	0.000	0.000	0.000	14.790	0.000	0.002	0.000	0.000	0.000
76	4	E	3	4E3	1.488	0.000	0.042	0.010	0.000	0.000	1.492	0.000	0.039	0.000	0.000	0.000	14.900	0.000	0.008	0.000	0.000	0.000
77	4	F	0	4F0	2.783	0.006	0.031	0.000	0.000	0.000	2.742	0.001	0.031	0.000	0.000	0.000	2.763	0.004	0.031	0.000	0.000	0.000
78	4	F	1	4F1	1.255	0.000	0.037	0.000	0.000	0.000	1.283	0.000	0.037	0.000	0.000	0.000	1.269	0.000	0.037	0.000	0.000	0.000
79	4	F	2	4F2	0.689	0.000	0.014	0.000	0.000	0.000	0.650	0.000	0.014	0.000	0.000	0.000	0.670	0.000	0.014	0.000	0.000	0.000
80	4	F	3	4F3	0.001	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.001	0.000	0.004	0.000	0.000	0.000
81	1	A			5.6442	0	0	0	0		5.7135	0	0	0	0		2.8394	0.0000	0.0000	0.0000	0.0000	
82	2	A			5.2419	0.1513	0	0	0		5.2415	0.1646	0.000	0.000	0.000		2.6209	0.0790	0.0000	0.0000	0.0000	
83	3	A			5.2404	0.1513	0.016	9.964	1.337	21	5.1792	0.1422	0.0096	10.188	1.195	23	2.6049	0.0734	0.0064	0.0001	0.0000	0.0220
84	4	A			3.3298	0.3155	0.0221	20.7943	2.312	43	3.3353	0.3122	0.0218	20.515	2.3768	43.2	1.6663	0.1569	0.0110	0.0002	0.0000	0.0431

8.10 Temperature and torque data during the EFC experiments

Solution																				
Time	1					2					3					4				
	8wt% sodium sulphate solution with 1% sodium bicarbonate					Na_2SO_4 – NaCl – $MgCl_2$ system					Synthetic RO concentrate					4.5wt% sodium sulphate with doubled RO concentrate impurities				
	Set temp.	Bath temp	Working solution temp.	Pump level	Torque	Set temp.	Bath temp	Working solution temp.	Pump level	Torque	Set temp.	Bath temp	Working solution temp.	Pump level	Torque	Set temp.	Bath temp	Working solution temp.	Pump level	Torque
[h:mm:ss]	[°C]	[°C]	[°C]	[-]	[Ncm]	[°C]	[°C]	[°C]	[-]	[Ncm]	[°C]	[°C]	[°C]	[-]	[Ncm]	[°C]	[°C]	[°C]	[-]	[Ncm]
0:00:00	20	19.373	19.743	7	98.8	20	19.931	20.507	7	67.4	20	19.169	19.368	7	73.2	20.00	18.83	18.87	7.00	78.40
0:00:10	-4	19.373	19.744	7	72	-4	19.926	20.512	7	66.2	-4	19.522	19.368	7	71	-4.00	18.83	18.87	7.00	87.80
0:00:20	-4	19.373	19.744	7	87.2	-4	19.817	20.517	7	73.2	-4	19.581	19.369	7	69.8	-4.00	18.75	18.88	7.00	68.00
0:00:30	-4	19.373	19.744	7	83.8	-4	19.827	20.521	7	62.8	-4	19.359	19.369	7	68.6	-4.00	18.75	18.88	7.00	86.60
0:00:40	-4	19.256	19.744	7	77.8	-4	19.833	20.522	7	65	-4	19.329	19.37	7	80.2	-4.00	18.74	18.88	7.00	78.40
0:00:50	-4	19.262	19.745	7	82.6	-4	19.842	20.522	7	65	-4	19.319	19.372	7	71	-4.00	18.75	18.88	7.00	62.20
0:01:00	-4	19.255	19.746	7	86	-4	19.85	20.522	7	71	-4	19.32	19.374	7	87.2	-4.00	18.75	18.88	7.00	84.40
0:01:10	-4	19.261	19.746	7	75.6	-4	19.859	20.521	7	68.6	-4	19.324	19.376	7	59.2	-4.00	18.76	18.89	7.00	56.40
0:01:20	-4	19.268	19.746	7	79	-4	19.862	20.52	7	61.6	-4	19.328	19.379	7	65	-4.00	18.76	18.89	7.00	80.80
0:01:30	-4	19.271	19.745	7	91.8	-4	19.586	20.519	7	61.6	-4	19.33	19.381	7	79	-4.00	18.59	18.89	7.00	82.00
0:01:40	-4	19.13	19.745	7	75.6	-4	19.202	20.517	7	67.4	-4	19.009	19.384	7	60.4	-4.00	18.12	18.89	7.00	69.20
0:01:50	-4	18.362	19.744	7	74.4	-4	18.672	20.516	7	77.8	-4	18.537	19.386	7	79	-4.00	17.34	18.89	7.00	80.80
0:02:00	-4	17.452	19.743	7	88.4	-4	17.927	20.511	7	65	-4	17.705	19.387	7	59.2	-4.00	16.57	18.89	7.00	64.60
0:02:10	-4	16.796	19.74	7	77.8	-4	17.171	20.505	7	55.8	-4	17.064	19.387	7	61.6	-4.00	16.01	18.89	7.00	69.20
0:02:20	-4	16.122	19.732	7	74.4	-4	16.606	20.495	7	86	-4	16.382	19.383	7	68.6	-4.00	15.35	18.88	7.00	58.60
0:02:30	-4	15.495	19.719	7	81.4	-4	15.945	20.481	7	54.6	-4	15.847	19.374	7	62.8	-4.00	14.75	18.87	7.00	66.80
0:02:40	-4	14.897	19.703	7	76.8	-4	15.349	20.462	7	74.4	-4	15.191	19.361	7	73.2	-4.00	14.11	18.85	7.00	79.60
0:02:50	-4	14.279	19.682	7	74.4	-4	14.765	20.439	7	59.2	-4	14.619	19.343	7	72	-4.00	13.56	18.83	7.00	66.80
0:03:00	-4	13.645	19.657	7	69.8	-4	14.155	20.411	7	61.6	-4	14.031	19.322	7	72	-4.00	13.01	18.80	7.00	58.60
0:03:10	-4	13.035	19.627	7	80.2	-4	13.586	20.381	7	69.8	-4	13.438	19.294	7	74.4	-4.00	12.38	18.77	7.00	64.60
0:03:20	-4	12.404	19.594	7	86	-4	12.982	20.346	7	65	-4	12.867	19.264	7	55.8	-4.00	11.83	18.74	7.00	56.40
0:03:30	-4	11.813	19.555	7	76.8	-4	12.434	20.306	7	58.2	-4	12.332	19.228	7	80.2	-4.00	11.10	18.70	7.00	77.40
0:03:40	-4	11.217	19.511	7	67.4	-4	11.824	20.26	7	64	-4	11.711	19.19	7	55.8	-4.00	10.59	18.65	7.00	52.80
0:03:50	-4	10.643	19.467	7	80.2	-4	11.348	20.214	7	61.6	-4	11.105	19.145	7	59.2	-4.00	9.98	18.60	7.00	69.20
0:04:00	-4	10.027	19.412	7	80.2	-4	10.72	20.159	7	81.4	-4	10.556	19.097	7	83.8	-4.00	9.50	18.55	7.00	68.00
0:04:10	-4	9.502	19.359	7	75.6	-4	10.211	20.106	7	47.6	-4	9.997	19.046	7	58.2	-4.00	8.93	18.49	7.00	63.40
0:04:20	-4	8.98	19.297	7	71	-4	9.567	20.043	7	59.2	-4	9.458	18.989	7	73.2	-4.00	8.33	18.43	7.00	62.20
0:04:30	-4	8.4	19.232	7	75.6	-4	9.005	19.981	7	74.4	-4	8.882	18.93	7	60.4	-4.00	7.81	18.36	7.00	55.20
0:04:40	-4	7.742	19.164	7	73.2	-4	8.534	19.915	7	48.8	-4	8.305	18.862	7	62.8	-4.00	7.27	18.29	7.00	64.60
0:04:50	-4	7.256	19.095	7	74.4	-4	7.902	19.846	7	59.2	-4	7.884	18.797	7	59.2	-4.00	6.66	18.22	7.00	69.20
0:05:00	-4	6.693	19.021	7	73.2	-4	7.309	19.767	7	59.2	-4	7.251	18.721	7	54.6	-4.00	6.07	18.14	7.00	49.40
0:05:10	-4	6.068	18.938	7	64	-4	6.744	19.688	7	72	-4	6.679	18.646	7	68.6	-4.00	5.47	18.06	7.00	75.00
0:05:20	-4	5.472	18.861	7	80.2	-4	6.194	19.606	7	57	-4	6.123	18.568	7	58.2	-4.00	4.95	17.97	7.00	70.40
0:05:30	-4	4.986	18.772	7	64	-4	5.693	19.519	7	52.2	-4	5.558	18.484	7	53.4	-4.00	4.32	17.88	7.00	52.80
0:05:40	-4	4.448	18.679	7	73.2	-4	5.136	19.43	7	65	-4	5.017	18.4	7	64	-4.00	3.87	17.79	7.00	61.00
0:05:50	-4	3.811	18.588	7	71	-4	4.562	19.334	7	47.6	-4	4.503	18.309	7	50	-4.00	3.36	17.69	7.00	52.80

0:06:00	-4	3.276	18.49	7	71	-4	4.054	19.241	7	58.2	-4	3.986	18.214	7	57	-4.00	2.72	17.59	7.00	78.40
0:06:10	-4	2.721	18.392	7	91.8	-4	3.519	19.144	7	62.8	-4	3.407	18.115	7	73.2	-4.00	2.19	17.48	7.00	51.80
0:06:20	-4	2.177	18.292	7	64	-4	2.977	19.034	7	55.8	-4	2.878	18.016	7	57	-4.00	1.60	17.38	7.00	62.20
0:06:30	-4	1.675	18.188	7	67.4	-4	2.472	18.931	7	77.8	-4	2.382	17.911	7	69.8	-4.00	1.15	17.27	7.00	73.80
0:06:40	-4	1.154	18.078	7	72	-4	1.924	18.818	7	58.2	-4	1.878	17.8	7	55.8	-4.00	0.72	17.16	7.00	61.00
0:06:50	-4	0.683	17.96	7	71	-4	1.44	18.709	7	60.4	-4	1.341	17.691	7	55.8	-4.00	0.15	17.04	7.00	64.60
0:07:00	-4	0.109	17.836	7	62.8	-4	0.98	18.59	7	57	-4	0.881	17.581	7	65	-4.00	-0.33	16.92	7.00	65.60
0:07:10	-4	-0.398	17.711	7	76.8	-4	0.418	18.472	7	53.4	-4	0.336	17.465	7	53.4	-4.00	-0.88	16.79	7.00	52.80
0:07:20	-4	-0.933	17.594	7	73.2	-4	-0.17	18.346	7	74.4	-4	-0.23	17.342	7	66.2	-4.00	-1.42	16.66	7.00	70.40
0:07:30	-4	-1.419	17.458	7	72	-4	-0.537	18.223	7	55.8	-4	-0.682	17.227	7	51.2	-4.00	-1.90	16.53	7.00	66.80
0:07:40	-4	-1.87	17.331	7	62.8	-4	-1.105	18.101	7	52.2	-4	-1.24	17.097	7	66.2	-4.00	-2.41	16.40	7.00	66.80
0:07:50	-4	-2.41	17.201	7	75.6	-4	-1.61	17.965	7	75.6	-4	-1.636	16.967	7	72	-4.00	-2.84	16.27	7.00	59.80
0:08:00	-4	-2.858	17.071	7	64	-4	-2.018	17.836	7	48.8	-4	-2.145	16.834	7	50	-4.00	-3.37	16.13	7.00	68.00
0:08:10	-4	-3.381	16.931	7	64	-4	-2.554	17.691	7	69.8	-4	-2.623	16.699	7	68.6	-4.00	-3.67	15.99	7.00	73.80
0:08:20	-4	-3.666	16.783	7	71	-4	-2.976	17.556	7	52.2	-4	-3.016	16.566	7	51.2	-4.00	-3.99	15.85	7.00	57.60
0:08:30	-4	-4.013	16.646	7	73.2	-4	-3.397	17.408	7	60.4	-4	-3.516	16.426	7	55.8	-4.00	-4.31	15.69	7.00	64.60
0:08:40	-4	-4.288	16.496	7	77.8	-4	-3.704	17.262	7	79	-4	-3.799	16.292	7	81.4	-4.00	-4.50	15.55	7.00	63.40
0:08:50	-4	-4.486	16.357	7	75.6	-4	-4	17.12	7	44.2	-4	-4.11	16.139	7	54.6	-4.00	-4.78	15.39	7.00	68.00
0:09:00	-4	-4.749	16.206	7	67.4	-4	-4.28	16.982	7	75.6	-4	-4.398	15.992	7	72	-4.00	-4.88	15.25	7.00	65.60
0:09:10	-4	-4.841	16.06	7	81.4	-4	-4.563	16.836	7	52.2	-4	-4.607	15.852	7	58.2	-4.00	-4.93	15.09	7.00	65.60
0:09:20	-4	-4.905	15.916	7	68.6	-4	-4.711	16.68	7	58.2	-4	-4.834	15.698	7	51.2	-4.00	-4.97	14.95	7.00	69.20
0:09:30	-4	-4.946	15.764	7	77.8	-4	-4.831	16.528	7	67.4	-4	-4.956	15.552	7	69.8	-4.00	-4.97	14.80	7.00	70.40
0:09:40	-4	-4.971	15.618	7	80.2	-4	-4.889	16.373	7	58.2	-4	-4.991	15.398	7	51.2	-4.00	-4.97	14.65	7.00	54.00
0:09:50	-4	-4.992	15.467	7	67.4	-4	-4.906	16.229	7	69.8	-4	-5.038	15.25	7	69.8	-4.00	-4.93	14.50	7.00	77.40
0:10:00	-4	-4.933	15.324	7	94.2	-4	-4.947	16.076	7	57	-4	-5.042	15.109	7	58.2	-4.00	-4.86	14.35	7.00	69.20
0:10:10	-4	-4.875	15.171	7	60.4	-4	-4.939	15.915	7	53.4	-4	-5.007	14.953	7	51.2	-4.00	-4.85	14.20	7.00	71.40
0:10:20	-4	-4.856	15.032	7	79	-4	-4.876	15.772	7	80.2	-4	-4.964	14.81	7	62.8	-4.00	-4.84	14.06	7.00	65.60
0:10:30	-4	-4.824	14.886	7	68.6	-4	-4.822	15.624	7	47.6	-4	-4.895	14.662	7	65	-4.00	-4.87	13.91	7.00	62.20
0:10:40	-4	-4.795	14.743	7	69.8	-4	-4.791	15.485	7	67.4	-4	-4.843	14.518	7	57	-4.00	-4.89	13.77	7.00	79.60
0:10:50	-4	-4.823	14.609	7	89.6	-4	-4.803	15.332	7	71	-4	-4.848	14.371	7	58.2	-4.00	-4.87	13.63	7.00	64.60
0:11:00	-4	-4.844	14.465	7	64	-4	-4.791	15.192	7	53.4	-4	-4.824	14.23	7	57	-4.00	-4.86	13.50	7.00	62.20
0:11:10	-4	-4.806	14.329	7	69.8	-4	-4.808	15.045	7	68.6	-4	-4.846	14.082	7	69.8	-4.00	-4.82	13.35	7.00	64.60
0:11:20	-4	-4.779	14.19	7	75.6	-4	-4.84	14.893	7	55.8	-4	-4.863	13.946	7	54.6	-4.00	-4.79	13.23	7.00	63.40
0:11:30	-4	-4.771	14.063	7	64	-4	-4.828	14.758	7	59.2	-4	-4.812	13.815	7	52.2	-4.00	-4.72	13.08	7.00	63.40
0:11:40	-4	-4.709	13.922	7	61.6	-4	-4.8	14.616	7	57	-4	-4.8	13.674	7	65	-4.00	-4.67	12.95	7.00	66.80
0:11:50	-4	-4.67	13.791	7	76.8	-4	-4.768	14.481	7	47.6	-4	-4.764	13.544	7	51.2	-4.00	-4.61	12.82	7.00	58.60
0:12:00	-4	-4.609	13.661	7	71	-4	-4.725	14.347	7	72	-4	-4.718	13.4	7	66.2	-4.00	-4.55	12.69	7.00	75.00
0:12:10	-4	-4.563	13.537	7	68.6	-4	-4.681	14.21	7	55.8	-4	-4.664	13.276	7	47.6	-4.00	-4.49	12.56	7.00	63.40
0:12:20	-4	-4.508	13.411	7	66.2	-4	-4.621	14.076	7	58.2	-4	-4.617	13.14	7	68.6	-4.00	-4.44	12.44	7.00	69.20
0:12:30	-4	-4.476	13.285	7	73.2	-4	-4.568	13.942	7	74.4	-4	-4.545	13.013	7	71	-4.00	-4.38	12.32	7.00	65.60
0:12:40	-4	-4.408	13.16	7	61.6	-4	-4.519	13.811	7	48.8	-4	-4.489	12.884	7	46.4	-4.00	-4.33	12.19	7.00	65.60
0:12:50	-4	-4.344	13.032	7	72	-4	-4.451	13.677	7	71	-4	-4.429	12.76	7	69.8	-4.00	-4.30	12.07	7.00	59.80
0:13:00	-4	-4.295	12.914	7	90.6	-4	-4.414	13.554	7	51.2	-4	-4.392	12.642	7	58.2	-4.00	-4.24	11.95	7.00	61.00
0:13:10	-4	-4.255	12.798	7	64	-4	-4.337	13.433	7	60.4	-4	-4.333	12.514	7	57	-4.00	-4.20	11.83	7.00	80.80
0:13:20	-4	-4.219	12.674	7	79	-4	-4.308	13.32	7	52.2	-4	-4.297	12.394	7	60.4	-4.00	-4.18	11.72	7.00	70.40
0:13:30	-4	-4.189	12.565	7	74.4	-4	-4.242	13.201	7	54.6	-4	-4.226	12.269	7	57	-4.00	-4.14	11.60	7.00	63.40
0:13:40	-4	-4.127	12.45	7	67.4	-4	-4.203	13.075	7	74.4	-4	-4.186	12.154	7	54.6	-4.00	-4.08	11.49	7.00	79.60
0:13:50	-4	-4.117	12.338	7	80.2	-4	-4.151	12.96	7	55.8	-4	-4.174	12.039	7	61.6	-4.00	-4.07	11.38	7.00	62.20
0:14:00	-4	-4.08	12.226	7	59.2	-4	-4.121	12.837	7	59.2	-4	-4.113	11.919	7	74.4	-4.00	-4.05	11.27	7.00	66.80
0:14:10	-4	-4.067	12.109	7	76.8	-4	-4.103	12.721	7	67.4	-4	-4.096	11.808	7	52.2	-4.00	-4.03	11.15	7.00	61.00

0:14:20	-4	-4.043	12.004	7	62.8	-4	-4.102	12.604	7	58.2	-4	-4.066	11.7	7	50	-4.00	-4.02	11.05	7.00	62.20
0:14:30	-4	-4.036	11.888	7	67.4	-4	-4.033	12.488	7	69.8	-4	-4.055	11.59	7	72	-4.00	-4.01	10.94	7.00	59.80
0:14:40	-4	-4.022	11.785	7	94.2	-4	-4.036	12.371	7	51.2	-4	-4.038	11.476	7	55.8	-4.00	-4.01	10.83	7.00	75.00
0:14:50	-4	-4.018	11.678	7	59.2	-4	-4.03	12.26	7	51.2	-4	-4.035	11.371	7	48.8	-4.00	-3.97	10.73	7.00	69.20
0:15:00	-4	-4.009	11.577	7	75.6	-4	-3.99	12.151	7	55.8	-4	-4.005	11.261	7	62.8	-4.00	-3.97	10.62	7.00	62.20
0:15:10	-4	-3.998	11.472	7	66.2	-4	-3.993	12.039	7	57	-4	-3.987	11.151	7	62.8	-4.00	-3.98	10.53	7.00	70.40
0:15:20	-4	-3.997	11.373	7	72	-4	-3.969	11.93	7	58.2	-4	-3.995	11.048	7	58.2	-4.00	-4.00	10.42	7.00	63.40
0:15:30	-4	-3.983	11.27	7	67.4	-4	-3.987	11.819	7	55.8	-4	-4.009	10.942	7	53.4	-4.00	-3.98	10.33	7.00	75.00
0:15:40	-4	-3.991	11.166	7	64	-4	-3.973	11.716	7	53.4	-4	-3.964	10.839	7	59.2	-4.00	-3.97	10.22	7.00	62.20
0:15:50	-4	-3.986	11.071	7	72	-4	-3.99	11.607	7	68.6	-4	-3.987	10.74	7	69.8	-4.00	-4.00	10.12	7.00	59.80
0:16:00	-4	-3.983	10.967	7	75.6	-4	-3.971	11.504	7	58.2	-4	-3.996	10.645	7	52.2	-4.00	-3.99	10.03	7.00	73.80
0:16:10	-4	-3.982	10.874	7	64	-4	-4.009	11.396	7	68.6	-4	-3.993	10.54	7	58.2	-4.00	-3.99	9.93	7.00	59.80
0:16:20	-4	-3.987	10.771	7	91.8	-4	-3.981	11.298	7	55.8	-4	-3.999	10.436	7	66.2	-4.00	-3.99	9.83	7.00	71.40
0:16:30	-4	-3.982	10.678	7	76.8	-4	-3.985	11.199	7	48.8	-4	-3.977	10.343	7	52.2	-4.00	-3.99	9.74	7.00	68.00
0:16:40	-4	-3.974	10.582	7	72	-4	-3.98	11.091	7	66.2	-4	-3.983	10.242	7	75.6	-4.00	-3.99	9.65	7.00	77.40
0:16:50	-4	-3.993	10.488	7	86	-4	-3.989	10.992	7	46.4	-4	-3.979	10.147	7	51.2	-4.00	-3.99	9.55	7.00	64.60
0:17:00	-4	-3.979	10.399	7	66.2	-4	-3.99	10.887	7	59.2	-4	-4.003	10.048	7	69.8	-4.00	-3.98	9.46	7.00	75.00
0:17:10	-4	-3.983	10.299	7	89.6	-4	-3.97	10.795	7	74.4	-4	-4.001	9.953	7	69.8	-4.00	-4.00	9.37	7.00	57.60
0:17:20	-4	-3.979	10.213	7	71	-4	-3.999	10.691	7	62.8	-4	-3.981	9.862	7	47.6	-4.00	-3.99	9.27	7.00	65.60
0:17:30	-4	-3.995	10.12	7	73.2	-4	-4.002	10.592	7	69.8	-4	-3.984	9.766	7	74.4	-4.00	-4.00	9.18	7.00	79.60
0:17:40	-4	-4.001	10.032	7	91.8	-4	-3.998	10.5	7	48.8	-4	-4	9.677	7	57	-4.00	-4.00	9.09	7.00	59.80
0:17:50	-4	-4.014	9.942	7	76.8	-4	-4.006	10.412	7	58.2	-4	-4.009	9.581	7	64	-4.00	-4.01	9.01	7.00	64.60
0:18:00	-4	-4.003	9.856	7	94.2	-4	-4.012	10.318	7	50	-4	-3.999	9.494	7	60.4	-4.00	-4.01	8.92	7.00	62.20
0:18:10	-4	-4.005	9.777	7	77.8	-4	-4.002	10.225	7	52.2	-4	-4.018	9.401	7	59.2	-4.00	-4.02	8.83	7.00	64.60
0:18:20	-4	-4.024	9.695	7	97.6	-4	-4.003	10.129	7	69.8	-4	-4.011	9.315	7	55.8	-4.00	-4.01	8.75	7.00	66.80
0:18:30	-4	-4.026	9.626	7	96.6	-4	-4.005	10.039	7	47.6	-4	-4.025	9.226	7	62.8	-4.00	-4.02	8.66	7.00	64.60
0:18:40	-4	-4.005	9.562	7	67.4	-4	-4.023	9.942	7	67.4	-4	-4.013	9.138	7	58.2	-4.00	-4.01	8.58	7.00	68.00
0:18:50	-4	-4.008	9.511	7	96.6	-4	-4.021	9.857	7	68.6	-4	-4.021	9.053	7	53.4	-4.00	-4.02	8.49	7.00	68.00
0:19:00	-4	-4.021	9.469	7	74.4	-4	-4.025	9.764	7	45.2	-4	-4.033	8.965	7	58.2	-4.00	-4.01	8.41	7.00	75.00
0:19:10	-4	-4.013	9.426	7	94.2	-4	-4.034	9.674	7	73.2	-4	-4.016	8.882	7	72	-4.00	-4.02	8.33	7.00	57.60
0:19:20	-4	-4.017	9.391	7	107	-4	-4.04	9.593	7	48.8	-4	-4.002	8.795	7	55.8	-4.00	-4.03	8.24	7.00	70.40
0:19:30	-4	-4.007	9.356	7	80.2	-4	-4.042	9.506	7	65	-4	-4.03	8.712	7	50	-4.00	-4.02	8.16	7.00	65.60
0:19:40	-4	-4.028	9.319	7	104.6	-4	-4.031	9.416	7	57	-4	-4.015	8.623	7	66.2	-4.00	-4.02	8.09	7.00	69.20
0:19:50	-4	-4.012	9.278	7	81.4	-4	-4.036	9.327	7	55.8	-4	-4.013	8.546	7	61.6	-4.00	-4.01	8.01	7.00	73.80
0:20:00	-4	-4.01	9.238	7	93	-4	-4.026	9.243	7	64	-4	-4.012	8.46	7	58.2	-4.00	-4.01	7.93	7.00	64.60
0:20:10	-4	-4.021	9.195	7	97.6	-4	-4.027	9.155	7	64	-4	-4.018	8.382	7	57	-4.00	-4.01	7.85	7.00	77.40
0:20:20	-4	-4.016	9.153	7	83.8	-4	-4.025	9.073	7	51.2	-4	-4.014	8.305	7	59.2	-4.00	-4.01	7.77	7.00	62.20
0:20:30	-4	-4.027	9.109	7	94.2	-4	-4.022	8.987	7	66.2	-4	-4.025	8.224	7	69.8	-4.00	-4.01	7.69	7.00	82.00
0:20:40	-4	-4.017	9.064	7	76.8	-4	-4.018	8.907	7	51.2	-4	-4.006	8.148	7	53.4	-4.00	-4.01	7.62	7.00	69.20
0:20:50	-4	-4.015	9.021	7	104.6	-4	-4.016	8.827	7	67.4	-4	-4.028	8.064	7	73.2	-4.00	-4.01	7.54	7.00	63.40
0:21:00	-4	-3.999	8.978	7	101.2	-4	-4.01	8.743	7	54.6	-4	-4.023	7.989	7	66.2	-4.00	-4.00	7.47	7.00	77.40
0:21:10	-4	-4.012	8.932	7	84.8	-4	-4.008	8.663	7	66.2	-4	-4.034	7.91	7	54.6	-4.00	-4.01	7.40	7.00	78.40
0:21:20	-4	-4.009	8.887	7	91.8	-4	-4.018	8.585	7	60.4	-4	-4.013	7.834	7	67.4	-4.00	-4.00	7.33	7.00	70.40
0:21:30	-4	-4.006	8.838	7	69.8	-4	-4.022	8.506	7	57	-4	-4.024	7.76	7	58.2	-4.00	-4.01	7.25	7.00	70.40
0:21:40	-4	-4.013	8.792	7	83.8	-4	-4.013	8.421	7	81.4	-4	-4.039	7.685	7	60.4	-4.00	-4.02	7.17	7.00	75.00
0:21:50	-4	-4.018	8.746	7	102.4	-4	-3.999	8.35	7	45.2	-4	-4.029	7.614	7	60.4	-4.00	-4.02	7.03	7.00	65.60
0:22:00	-4	-4.01	8.701	7	75.6	-4	-4.012	8.267	7	64	-4	-4.028	7.537	7	75.6	-4.00	-4.02	6.96	7.00	58.60
0:22:10	-4	-4.029	8.654	7	81.4	-4	-4.022	8.192	7	68.6	-4	-4.029	7.466	7	51.2	-4.00	-4.02	6.89	7.00	78.40
0:22:20	-4	-4.013	8.61	7	94.2	-4	-4.01	8.118	7	50	-4	-4.032	7.392	7	58.2	-4.00	-4.01	6.83	7.00	63.40
0:22:30	-4	-4.013	8.565	7	72	-4	-4.013	8.041	7	69.8	-4	-4.015	7.319	7	54.6	-4.00	-4.01	6.76	7.00	77.40

0:22:40	-4	-4.016	8.517	7	89.6	-4	-4.025	7.966	7	65	-4	-4.022	7.25	7	60.4	-4.00	-4.01	6.69	7.00	63.40
0:22:50	-4	-4.02	8.473	7	74.4	-4	-4.015	7.889	7	58.2	-4	-4.017	7.175	7	57	-4.00	-4.02	6.62	7.00	71.40
0:23:00	-4	-4.018	8.425	7	97.6	-4	-4.021	7.818	7	68.6	-4	-4.023	7.105	7	68.6	-4.00	-4.02	6.55	7.00	70.40
0:23:10	-4	-4.013	8.382	7	98.8	-4	-4.026	7.744	7	51.2	-4	-4.021	7.037	7	62.8	-4.00	-4.02	6.49	7.00	63.40
0:23:20	-4	-4.013	8.335	7	64	-4	-4.024	7.669	7	66.2	-4	-4.014	6.971	7	53.4	-4.00	-4.02	6.42	7.00	75.00
0:23:30	-4	-4.02	8.291	7	102.4	-4	-4.035	7.599	7	61.6	-4	-4.018	6.901	7	52.2	-4.00	-4.02	6.36	7.00	55.20
0:23:40	-4	-4.02	8.24	7	72	-4	-4.021	7.528	7	75.6	-4	-4.014	6.83	7	58.2	-4.00	-4.02	6.29	7.00	70.40
0:23:50	-4	-4.011	8.195	7	98.8	-4	-4.031	7.46	7	65	-4	-4.018	6.764	7	52.2	-4.00	-4.03	6.23	7.00	66.80
0:24:00	-4	-4.018	8.153	7	66.2	-4	-4.01	7.389	7	53.4	-4	-4.009	6.695	7	55.8	-4.00	-4.01	6.16	7.00	70.40
0:24:10	-4	-4.007	8.106	7	80.2	-4	-4.018	7.323	7	76.8	-4	-4.018	6.633	7	66.2	-4.00	-4.02	6.10	7.00	73.80
0:24:20	-4	-4.016	8.061	7	105.8	-4	-4.013	7.253	7	58.2	-4	-4	6.562	7	62.8	-4.00	-4.01	6.04	7.00	66.80
0:24:30	-4	-4.001	8.014	7	71	-4	-4.02	7.186	7	61.6	-4	-4.025	6.498	7	59.2	-4.00	-4.01	5.97	7.00	72.60
0:24:40	-4	-4.004	7.97	7	94.2	-4	-4.016	7.123	7	76.8	-4	-4.014	6.434	7	58.2	-4.00	-4.02	5.91	7.00	62.20
0:24:50	-4	-4.001	7.921	7	90.6	-4	-4.007	7.066	7	69.8	-4	-4.009	6.372	7	58.2	-4.00	-4.01	5.85	7.00	64.60
0:25:00	-4	-4.006	7.875	7	69.8	-4	-4.002	7.012	7	74.4	-4	-4.003	6.307	7	52.2	-4.00	-4.01	5.79	7.00	78.40
0:25:10	-4	-4.01	7.828	7	94.2	-4	-4.016	6.962	7	61.6	-4	-4.01	6.244	7	69.8	-4.00	-4.01	5.73	7.00	55.20
0:25:20	-4	-4.013	7.783	7	90.6	-4	-4.014	6.918	7	79	-4	-4.004	6.18	7	52.4	-4.00	-4.00	5.67	7.00	65.60
0:25:30	-4	-3.998	7.741	7	87.2	-4	-4.012	6.878	7	75.6	-4	-4.015	6.117	7	73.2	-4.00	-3.99	5.61	7.00	83.20
0:25:40	-4	-4.011	7.695	7	96.6	-4	-4.016	6.843	7	52.2	-4	-4.016	6.057	7	66.2	-4.00	-4.01	5.55	7.00	52.80
0:25:50	-4	-3.985	7.652	7	76.8	-4	-4.007	6.81	7	82.6	-4	-4.003	5.995	7	52.2	-4.00	-4.01	5.49	7.00	92.40
0:26:00	-4	-3.995	7.605	7	75.6	-4	-4.01	6.779	7	71	-4	-4.017	5.933	7	50	-4.00	-4.00	5.43	7.00	57.60
0:26:10	-4	-4.032	7.56	7	65	-4	-4.011	6.75	7	67.4	-4	-4.019	5.878	7	72	-4.00	-4.01	5.38	7.00	65.60
0:26:20	-4	-3.996	7.516	7	84.8	-4	-4.011	6.719	7	77.8	-4	-4.019	5.817	7	61.6	-4.00	-4.02	5.32	7.00	56.40
0:26:30	-4	-4.008	7.472	7	79	-4	-4.004	6.689	7	67.4	-4	-4.015	5.76	7	59.2	-4.00	-4.00	5.26	7.00	68.00
0:26:40	-4	-4.004	7.429	7	68.6	-4	-4.004	6.659	7	82.6	-4	-4.013	5.699	7	72	-4.00	-4.02	5.21	7.00	76.20
0:26:50	-4	-4.009	7.382	7	97.6	-4	-4.023	6.628	7	66.2	-4	-4.025	5.643	7	54.6	-4.00	-4.01	5.15	7.00	55.20
0:27:00	-4	-4.004	7.344	7	91.8	-4	-3.997	6.594	7	62.8	-4	-4.014	5.584	7	61.6	-4.00	-4.02	5.10	7.00	78.40
0:27:10	-4	-4.006	7.296	7	69.8	-4	-4.007	6.559	7	83.8	-4	-4.018	5.528	7	54.6	-4.00	-4.00	5.04	7.00	64.60
0:27:20	-4	-4.01	7.25	7	83.8	-4	-4.023	6.526	7	69.8	-4	-4.014	5.47	7	67.6	-4.00	-4.02	4.99	7.00	68.00
0:27:30	-4	-3.999	7.209	7	67.4	-4	-4.014	6.491	7	81.4	-4	-3.999	5.414	7	59.2	-4.00	-4.01	4.93	7.00	55.20
0:27:40	-4	-4.004	7.164	7	110.4	-4	-4.005	6.456	7	61.6	-4	-4.003	5.362	7	72	-4.00	-4.02	4.88	7.00	85.40
0:27:50	-4	-4.004	7.123	7	62.8	-4	-4.027	6.419	7	55.8	-4	-4.017	5.308	7	80	-4.00	-4.02	4.83	7.00	68.00
0:28:00	-4	-4.013	7.077	7	81.4	-4	-4.001	6.382	7	76.8	-4	-4.02	5.255	7	58.2	-4.00	-4.02	4.77	7.00	58.60
0:28:10	-4	-4.012	7.035	7	104.6	-4	-3.999	6.346	7	72	-4	-4.006	5.203	7	62.8	-4.00	-4.01	4.72	7.00	70.40
0:28:20	-4	-3.995	6.988	7	66.2	-4	-4.012	6.31	7	62.8	-4	-4.013	5.153	7	58.2	-4.00	-4.03	4.67	7.00	73.80
0:28:30	-4	-4.007	6.947	7	100	-4	-4.003	6.273	7	71	-4	-4.002	5.107	7	57	-4.00	-4.01	4.62	7.00	62.20
0:28:40	-4	-4.012	6.905	7	65	-4	-3.99	6.237	7	67.4	-4	-3.999	5.063	7	69.8	-4.00	-4.01	4.57	7.00	57.60
0:28:50	-4	-4.019	6.862	7	105.8	-4	-4.012	6.201	7	81.4	-4	-4.008	5.022	7	73.2	-4.00	-4.01	4.52	7.00	80.80
0:29:00	-4	-4.008	6.821	7	81.4	-4	-3.996	6.161	7	59.2	-4	-4.027	4.984	7	68.6	-4.00	-4.01	4.47	7.00	73.80
0:29:10	-4	-4.014	6.777	7	81.4	-4	-4.004	6.123	7	86	-4	-4.007	4.955	7	55.8	-4.00	-4.01	4.42	7.00	73.80
0:29:20	-4	-4.005	6.736	7	81.4	-4	-4.003	6.084	7	71	-4	-4.015	4.923	7	67.4	-4.00	-4.01	4.37	7.00	62.20
0:29:30	-4	-4.004	6.691	7	81.4	-4	-3.999	6.049	7	55.8	-4	-4	4.894	7	64	-4.00	-4.01	4.32	7.00	66.80
0:29:40	-4	-4.01	6.65	7	81.4	-4	-4	6.016	7	75.6	-4	-4.017	4.867	7	54.6	-4.00	-4.02	4.27	7.00	69.20
0:29:50	-4	-4.013	6.611	7	89.6	-4	-4.004	5.976	7	61.6	-4	-4.013	4.841	7	66.2	-4.00	-4.02	4.23	7.00	70.40
0:30:00	-4	-4.016	6.568	7	65	-4	-4.007	5.939	7	81.4	-4	-4.004	4.817	7	83.8	-4.00	-4.02	4.18	7.00	56.40
0:30:10	-4	-4.005	6.529	7	89.6	-4	-4.008	5.901	7	76.8	-4	-4.003	4.79	7	74.6	-4.00	-4.03	4.13	7.00	64.60
0:30:20	-4	-4.02	6.487	7	98.8	-4	-4.015	5.865	7	65	-4	-4.019	4.765	7	65	-4.00	-4.00	4.08	7.00	68.00
0:30:30	-4	-4.006	6.447	7	79	-4	-4.004	5.827	7	79	-4	-4.017	4.738	7	69.8	-4.00	-4.02	4.04	7.00	77.40
0:30:40	-4	-4.01	6.405	7	91.8	-4	-3.998	5.788	7	62.8	-4	-4.015	4.713	7	54.6	-4.00	-4.01	3.99	7.00	61.00
0:30:50	-4	-4.014	6.363	7	89.6	-4	-4.018	5.753	7	66.2	-4	-4	4.684	7	79	-4.00	-4.01	3.94	7.00	71.40

0:31:00	-4	-4.014	6.324	7	108.2	-4	-4.015	5.717	7	71	-4	-4.013	4.657	7	51.2	-4.00	-4.02	3.90	7.00	59.80
0:31:10	-4	-4.004	6.283	7	76.8	-4	-4.002	5.681	7	54.6	-4	-4.011	4.631	7	66.2	-4.00	-4.01	3.85	7.00	64.60
0:31:20	-4	-4.007	6.245	7	72	-4	-4.017	5.644	7	77.8	-4	-3.999	4.601	7	84.4	-4.00	-4.01	3.81	7.00	63.40
0:31:30	-4	-4.021	6.204	7	98.8	-4	-3.997	5.607	7	64	-4	-4.007	4.573	7	64	-4.00	-4.02	3.76	7.00	69.20
0:31:40	-4	-4.017	6.166	7	66.2	-4	-4.01	5.57	7	60.4	-4	-4.001	4.543	7	88.6	-4.00	-4.02	3.72	7.00	75.00
0:31:50	-4	-4.009	6.125	7	93	-4	-4.007	5.533	7	62.8	-4	-4.01	4.516	7	53.4	-4.00	-4.02	3.67	7.00	62.20
0:32:00	-4	-4.012	6.085	7	91.8	-4	-4.001	5.498	7	65	-4	-4.009	4.483	7	76.8	-4.00	-4.00	3.63	7.00	56.40
0:32:10	-4	-4	6.047	7	93	-4	-4.001	5.461	7	60.4	-4	-3.999	4.456	7	59.2	-4.00	-4.03	3.59	7.00	77.40
0:32:20	-4	-4.014	6.007	7	70.8	-4	-3.997	5.423	7	72	-4	-4.002	4.427	7	74.4	-4.00	-4.01	3.54	7.00	58.60
0:32:30	-4	-4.014	5.969	7	66.2	-4	-4.012	5.389	7	69.8	-4	-4.022	4.395	7	54.6	-4.00	-4.01	3.50	7.00	56.40
0:32:40	-4	-4.009	5.928	7	82.6	-4	-4	5.355	7	68.6	-4	-4.008	4.367	7	68.6	-4.00	-4.00	3.46	7.00	72.60
0:32:50	-4	-4.008	5.893	7	69.8	-4	-4.018	5.318	7	67.4	-4	-4.022	4.336	7	68.6	-4.00	-4.01	3.42	7.00	62.20
0:33:00	-4	-4.003	5.852	7	79	-4	-4.003	5.281	7	65	-4	-4.003	4.306	7	57	-4.00	-4.01	3.38	7.00	73.80
0:33:10	-4	-4.008	5.814	7	101.2	-4	-4.018	5.246	7	61.6	-4	-4.003	4.276	7	64	-4.00	-4.01	3.34	7.00	57.60
0:33:20	-4	-3.994	5.776	7	79	-4	-4.009	5.21	7	58.2	-4	-3.995	4.243	7	80.2	-4.00	-4.01	3.30	7.00	68.00
0:33:30	-4	-4.007	5.737	7	77.8	-4	-4.014	5.175	7	67.4	-4	-4.007	4.216	7	53.4	-4.00	-4.02	3.26	7.00	61.00
0:33:40	-4	-4.014	5.702	7	78.8	-4	-4.01	5.139	7	57	-4	-4.008	4.185	7	55.8	-4.00	-4.02	3.22	7.00	58.60
0:33:50	-4	-3.996	5.661	7	68.6	-4	-4.021	5.104	7	76.8	-4	-4.004	4.155	7	88.4	-4.00	-4.02	3.18	7.00	65.60
0:34:00	-4	-4.004	5.626	7	83.8	-4	-4.005	5.072	7	68.6	-4	-4.009	4.124	7	59.2	-4.00	-4.00	3.14	7.00	58.60
0:34:10	-4	-4.002	5.588	7	74.2	-4	-4.014	5.035	7	57	-4	-4.003	4.095	7	81.4	-4.00	-4.00	3.10	7.00	72.60
0:34:20	-4	-4.015	5.552	7	72	-4	-4.009	5.002	7	57	-4	-4	4.065	7	55.8	-4.00	-4.02	3.07	7.00	72.60
0:34:30	-4	-4.007	5.514	7	87.2	-4	-4.013	4.966	7	57	-4	-4.027	4.033	7	52.2	-4.00	-4.02	3.03	7.00	62.20
0:34:40	-4	-4.016	5.476	7	66.2	-4	-4.009	4.933	7	71	-4	-4.011	4.003	7	74.4	-4.00	-4.01	2.99	7.00	65.60
0:34:50	-4	-4.027	5.44	7	80	-4	-4.005	4.898	7	51.2	-4	-4.015	3.973	7	54.6	-4.00	-4.01	2.95	7.00	58.60
0:35:00	-4	-4.01	5.403	7	72	-4	-4.025	4.865	7	64	-4	-4.007	3.947	7	64	-4.00	-4.00	2.91	7.00	80.80
0:35:10	-4	-4.011	5.368	7	82.6	-4	-3.993	4.831	7	75.6	-4	-4.014	3.915	7	55.8	-4.00	-4.01	2.88	7.00	62.20
0:35:20	-4	-4.008	5.329	7	87.2	-4	-4.007	4.795	7	61.6	-4	-4.009	3.887	7	66.2	-4.00	-4.01	2.84	7.00	57.60
0:35:30	-4	-4.018	5.295	7	84.8	-4	-4.03	4.766	7	54.6	-4	-4.025	3.858	7	77.8	-4.00	-4.02	2.81	7.00	91.20
0:35:40	-4	-4.011	5.257	7	84.8	-4	-4.002	4.731	7	64	-4	-4.003	3.828	7	51.2	-4.00	-4.00	2.77	7.00	58.60
0:35:50	-4	-4.017	5.222	7	69.8	-4	-4.002	4.701	7	67.4	-4	-4.018	3.798	7	65	-4.00	-4.00	2.73	7.00	78.40
0:36:00	-4	-4.009	5.186	7	90.6	-4	-4.02	4.667	7	58.2	-4	-3.99	3.769	7	60.4	-4.00	-4.02	2.70	7.00	61.00
0:36:10	-4	-4.017	5.149	7	95.4	-4	-4.006	4.631	7	54.6	-4	-4.017	3.741	7	58.2	-4.00	-4.02	2.66	7.00	79.60
0:36:20	-4	-4.012	5.114	7	71	-4	-4.01	4.599	7	71	-4	-4.01	3.71	7	55.8	-4.00	-4.01	2.63	7.00	62.20
0:36:30	-4	-4.004	5.076	7	89.6	-4	-4.007	4.566	7	58.2	-4	-4.01	3.684	7	61.6	-4.00	-4.01	2.59	7.00	61.00
0:36:40	-4	-4.027	5.042	7	66.2	-4	-4.013	4.534	7	61.6	-4	-3.996	3.655	7	80.2	-4.00	-4.00	2.56	7.00	69.20
0:36:50	-4	-4.005	5.006	7	81.4	-4	-3.993	4.5	7	64	-4	-4.001	3.627	7	54.6	-4.00	-4.02	2.53	7.00	59.80
0:37:00	-4	-4.035	4.968	7	68.6	-4	-4.013	4.471	7	80.2	-4	-4.027	3.597	7	57	-4.00	-4.01	2.49	7.00	71.40
0:37:10	-4	-3.998	4.935	7	81.4	-4	-3.995	4.438	7	55.8	-4	-4.006	3.568	7	59.2	-4.00	-4.01	2.46	7.00	89.00
0:37:20	-4	-4.012	4.901	7	79	-4	-4.008	4.407	7	61.6	-4	-4.007	3.541	7	62.8	-4.00	-4.00	2.43	7.00	54.00
0:37:30	-4	-4.009	4.867	7	89.6	-4	-3.991	4.374	7	67.4	-4	-4.01	3.512	7	52.2	-4.00	-4.03	2.39	7.00	70.40
0:37:40	-4	-4.007	4.831	7	71	-4	-4.02	4.341	7	60.4	-4	-4.016	3.485	7	66.2	-4.00	-4.00	2.36	7.00	61.00
0:37:50	-4	-4.017	4.797	7	76.8	-4	-3.999	4.311	7	61.6	-4	-4.012	3.457	7	61.6	-4.00	-4.01	2.33	7.00	72.60
0:38:00	-4	-4.017	4.76	7	101.2	-4	-3.992	4.276	7	72	-4	-4.016	3.429	7	62.8	-4.00	-4.01	2.30	7.00	80.80
0:38:10	-4	-4.011	4.723	7	69.8	-4	-3.994	4.248	7	64	-4	-4.008	3.403	7	53.4	-4.00	-4.01	2.26	7.00	68.00
0:38:20	-4	-4.007	4.691	7	93	-4	-4.008	4.214	7	59.2	-4	-4.011	3.373	7	64	-4.00	-4.01	2.23	7.00	90.20
0:38:30	-4	-4.01	4.655	7	71	-4	-4.005	4.188	7	73.2	-4	-3.989	3.347	7	54.6	-4.00	-4.01	2.20	7.00	55.20
0:38:40	-4	-4.011	4.624	7	70.2	-4	-4.004	4.155	7	54.6	-4	-4.003	3.319	7	60.4	-4.00	-4.02	2.17	7.00	64.60
0:38:50	-4	-4.002	4.59	7	66.2	-4	-3.978	4.124	7	75.6	-4	-4.018	3.292	7	84.8	-4.00	-4.02	2.14	7.00	72.60
0:39:00	-4	-4.013	4.557	7	80.2	-4	-4.003	4.094	7	57	-4	-4.012	3.265	7	48.8	-4.00	-4.01	2.11	7.00	59.80
0:39:10	-4	-4.009	4.523	7	84.8	-4	-4.007	4.061	7	69.8	-4	-4	3.237	7	71	-4.00	-4.01	2.08	7.00	77.40

0:39:20	-4	-4.016	4.488	7	91.8	-4	-4.002	4.031	7	62.8	-4	-3.998	3.211	7	61.6	-4.00	-4.02	2.05	7.00	76.20
0:39:30	-4	-4.019	4.456	7	75.4	-4	-4.005	4.001	7	64	-4	-4	3.185	7	57	-4.00	-4.01	2.02	7.00	72.60
0:39:40	-4	-4.007	4.42	7	65	-4	-4.007	3.97	7	61.6	-4	-4.019	3.16	7	54.6	-4.00	-4.01	1.99	7.00	64.60
0:39:50	-4	-4.01	4.387	7	86	-4	-4.007	3.941	7	53.4	-4	-4.02	3.132	7	57	-4.00	-4.01	1.96	7.00	64.60
0:40:00	-4	-4.011	4.355	7	77.8	-4	-4.007	3.912	7	55.8	-4	-4.003	3.106	7	69.8	-4.00	-4.00	1.93	7.00	77.40
0:40:10	-4	-4.01	4.325	7	72	-4	-4.02	3.883	7	62.8	-4	-4.005	3.08	7	60.4	-4.00	-4.00	1.91	7.00	51.80
0:40:20	-4	-4.023	4.292	7	80.2	-4	-4.008	3.853	7	72	-4	-4.018	3.053	7	55.8	-4.00	-4.01	1.87	7.00	70.40
0:40:30	-4	-4.013	4.257	7	66.2	-4	-3.997	3.825	7	58.2	-4	-3.996	3.027	7	80.2	-4.00	-4.00	1.85	7.00	87.80
0:40:40	-4	-4.014	4.226	7	90.6	-4	-4.018	3.791	7	57	-4	-4	3	7	50	-4.00	-4.01	1.82	7.00	65.60
0:40:50	-4	-4.007	4.192	7	65	-4	-4.013	3.764	7	84.8	-4	-4.001	2.975	7	52.2	-4.00	-4.03	1.79	7.00	77.40
0:41:00	-4	-3.997	4.159	7	82.6	-4	-4.002	3.734	7	55.8	-4	-4.008	2.949	7	59.2	-4.00	-4.01	1.76	7.00	69.20
0:41:10	-4	-4.007	4.126	7	95.4	-4	-4.014	3.704	7	53.4	-4	-4.007	2.924	7	58.2	-4.00	-4.00	1.73	7.00	65.60
0:41:20	-4	-3.998	4.095	7	62.8	-4	-4.004	3.676	7	67.4	-4	-4.018	2.897	7	73.2	-4.00	-4.01	1.71	7.00	77.40
0:41:30	-4	-4.013	4.065	7	66.2	-4	-4.014	3.646	7	55.8	-4	-3.991	2.87	7	65	-4.00	-4.04	1.68	7.00	47.00
0:41:40	-4	-4.01	4.034	7	71	-4	-4.005	3.618	7	75.6	-4	-4.017	2.845	7	50	-4.00	-4.00	1.65	7.00	79.60
0:41:50	-4	-4.009	4.003	7	76.8	-4	-4.021	3.587	7	54.6	-4	-4.009	2.819	7	64	-4.00	-4.01	1.63	7.00	80.80
0:42:00	-4	-4.013	3.969	7	76.8	-4	-4.014	3.561	7	61.6	-4	-4.011	2.794	7	61.6	-4.00	-4.00	1.60	7.00	77.40
0:42:10	-4	-4.014	3.939	7	81.4	-4	-4.01	3.531	7	65	-4	-4.021	2.767	7	57	-4.00	-4.00	1.58	7.00	114.60
0:42:20	-4	-4.011	3.908	7	71	-4	-4.025	3.501	7	55.8	-4	-4.014	2.744	7	55.8	-4.00	-4.00	1.57	7.00	89.00
0:42:30	-4	-4.004	3.878	7	86	-4	-4.005	3.473	7	58.2	-4	-4.028	2.718	7	57	-4.00	-4.01	1.57	7.00	119.20
0:42:40	-4	-4.02	3.845	7	69.8	-4	-4.01	3.445	7	62.8	-4	-4	2.693	7	74.4	-4.00	-4.01	1.59	7.00	80.80
0:42:50	-4	-4.015	3.815	7	65	-4	-3.998	3.419	7	64	-4	-4.018	2.67	7	48.8	-4.00	-4.00	1.62	7.00	106.40
0:43:00	-4	-4.01	3.784	7	80.2	-4	-4.005	3.391	7	67.4	-4	-4.016	2.642	7	52.2	-4.00	-4.03	1.64	7.00	113.40
0:43:10	-4	-4.017	3.756	7	83.8	-4	-3.991	3.363	7	55.8	-4	-4.005	2.619	7	58.2	-4.00	-4.02	1.67	7.00	101.80
0:43:20	-4	-4.014	3.725	7	80.2	-4	-4.02	3.335	7	68.6	-4	-4.007	2.594	7	59.2	-4.00	-4.00	1.68	7.00	100.60
0:43:30	-4	-4	3.695	7	62.8	-4	-4.005	3.308	7	59.2	-4	-4.013	2.569	7	48.8	-4.00	-4.00	1.69	7.00	72.60
0:43:40	-4	-4.024	3.665	7	79	-4	-4.007	3.279	7	61.6	-4	-4.008	2.545	7	58.2	-4.00	-4.01	1.70	7.00	97.20
0:43:50	-4	-3.999	3.634	7	76.8	-4	-3.996	3.251	7	51.2	-4	-3.997	2.52	7	51.2	-4.00	-4.00	1.69	7.00	82.00
0:44:00	-4	-4.011	3.604	7	73.2	-4	-3.998	3.225	7	54.6	-4	-4.003	2.496	7	75.6	-4.00	-4.00	1.69	7.00	80.80
0:44:10	-4	-4.009	3.574	7	69.8	-4	-4.018	3.197	7	83.8	-4	-4.014	2.471	7	47.6	-4.00	-4.01	1.68	7.00	90.20
0:44:20	-4	-4.013	3.544	7	75.6	-4	-4.012	3.173	7	46.4	-4	-4.011	2.446	7	68.6	-4.00	-4.01	1.67	7.00	92.40
0:44:30	-4	-4.005	3.515	7	83.8	-4	-4.004	3.145	7	58.2	-4	-4.013	2.422	7	51.2	-4.00	-4.02	1.66	7.00	83.20
0:44:40	-4	-4.009	3.486	7	66.2	-4	-4.014	3.118	7	55.8	-4	-4.006	2.398	7	61.6	-4.00	-4.01	1.64	7.00	64.60
0:44:50	-4	-4.009	3.458	7	83.8	-4	-4.009	3.091	7	60.4	-4	-4.006	2.374	7	79	-4.00	-3.99	1.63	7.00	80.80
0:45:00	-4	-4.002	3.43	7	83.8	-4	-4.022	3.064	7	52.2	-4	-4.01	2.348	7	46.4	-4.00	-4.00	1.61	7.00	85.40
0:45:10	-4	-4.007	3.399	7	68.6	-4	-4.018	3.04	7	53.4	-4	-4.002	2.325	7	79	-4.00	-4.00	1.60	7.00	64.60
0:45:20	-4	-4.022	3.371	7	76.8	-4	-4.01	3.011	7	54.6	-4	-4.018	2.302	7	50	-4.00	-4.00	1.58	7.00	76.20
0:45:30	-4	-4.009	3.342	7	64	-4	-4.011	2.986	7	62.8	-4	-4.007	2.279	7	55.8	-4.00	-3.99	1.56	7.00	57.60
0:45:40	-4	-4.017	3.313	7	75.6	-4	-4.009	2.959	7	54.6	-4	-4.025	2.255	7	51.2	-4.00	-4.02	1.55	7.00	80.80
0:45:50	-4	-4.004	3.285	7	75.6	-4	-4.016	2.932	7	47.6	-4	-4.007	2.231	7	55.8	-4.00	-4.00	1.53	7.00	82.00
0:46:00	-4	-4.013	3.258	7	84.8	-4	-4.027	2.908	7	59.2	-4	-4.014	2.207	7	72	-4.00	-3.99	1.51	7.00	61.00
0:46:10	-4	-4.01	3.229	7	67.4	-4	-3.988	2.88	7	62.8	-4	-3.997	2.183	7	50	-4.00	-4.01	1.49	7.00	70.40
0:46:20	-4	-4.004	3.202	7	77.8	-4	-3.991	2.856	7	59.2	-4	-4.017	2.161	7	55.8	-4.00	-4.01	1.48	7.00	76.20
0:46:30	-4	-4.009	3.175	7	94.2	-4	-4.009	2.83	7	48.8	-4	-3.997	2.136	7	69.8	-4.00	-4.00	1.46	7.00	58.60
0:46:40	-4	-3.999	3.146	7	69.8	-4	-4.011	2.805	7	51.2	-4	-4.006	2.115	7	47.6	-4.00	-4.01	1.44	7.00	89.00
0:46:50	-4	-4.001	3.119	7	72	-4	-4.009	2.78	7	60.4	-4	-4.004	2.091	7	47.6	-4.00	-4.00	1.42	7.00	70.40
0:47:00	-4	-4.001	3.091	7	74.4	-4	-4.02	2.755	7	50	-4	-4.017	2.07	7	60.4	-4.00	-4.00	1.40	7.00	71.40

0:47:10	-4	-4.005	3.064	7	81.4	-4	-4.013	2.729	7	67.4	-4	-4.016	2.045	7	55.8	-4.00	-4.01	1.39	7.00	78.40
0:47:20	-4	-4.002	3.037	7	67.4	-4	-4.028	2.703	7	65	-4	-4.008	2.022	7	51.2	-4.00	-4.01	1.37	7.00	77.40
0:47:30	-4	-4.001	3.01	7	74.4	-4	-4.024	2.68	7	51.2	-4	-4.015	2	7	51.2	-4.00	-4.01	1.35	7.00	79.60
0:47:40	-4	-3.998	2.984	7	67.4	-4	-4.011	2.654	7	64	-4	-4.012	1.976	7	57	-4.00	-4.01	1.33	7.00	56.40
0:47:50	-4	-4.01	2.958	7	66.2	-4	-4.011	2.631	7	53.4	-4	-3.991	1.953	7	52.2	-4.00	-4.01	1.31	7.00	83.20
0:48:00	-4	-4.007	2.931	7	58	-4	-4.009	2.605	7	68.6	-4	-4.012	1.931	7	54.6	-4.00	-3.99	1.30	7.00	65.60
0:48:10	-4	-4	2.904	7	81.4	-4	-4.006	2.578	7	53.4	-4	-4.007	1.908	7	57	-4.00	-4.01	1.28	7.00	68.00
0:48:20	-4	-3.994	2.878	7	79	-4	-4.025	2.554	7	69.8	-4	-4.004	1.886	7	45.2	-4.00	-4.00	1.26	7.00	80.80
0:48:30	-4	-4.014	2.851	7	64	-4	-4.01	2.529	7	52.2	-4	-4.014	1.864	7	64	-4.00	-4.00	1.24	7.00	69.20
0:48:40	-4	-4.005	2.824	7	72	-4	-4.012	2.505	7	58.2	-4	-3.994	1.842	7	61.6	-4.00	-4.00	1.22	7.00	58.60
0:48:50	-4	-4.009	2.799	7	71	-4	-4.01	2.481	7	48.8	-4	-4.001	1.819	7	50	-4.00	-4.01	1.21	7.00	73.80
0:49:00	-4	-4.004	2.773	7	67.4	-4	-4.015	2.457	7	58.2	-4	-4.02	1.797	7	68.6	-4.00	-4.00	1.19	7.00	66.80
0:49:10	-4	-4.003	2.748	7	86	-4	-4.004	2.433	7	75.6	-4	-4.003	1.775	7	45.2	-4.00	-4.00	1.17	7.00	85.40
0:49:20	-4	-4.024	2.722	7	62.8	-4	-4.001	2.41	7	60.4	-4	-4.011	1.755	7	74.4	-4.00	-4.01	1.16	7.00	57.60
0:49:30	-4	-4.007	2.697	7	80.2	-4	-4.007	2.383	7	65	-4	-4.006	1.732	7	47.6	-4.00	-3.99	1.14	7.00	68.00
0:49:40	-4	-4.007	2.671	7	71	-4	-3.993	2.358	7	64	-4	-4.005	1.711	7	51.2	-4.00	-4.01	1.12	7.00	77.40
0:49:50	-4	-4.029	2.645	7	69.8	-4	-3.998	2.335	7	54.6	-4	-4.006	1.691	7	81.4	-4.00	-3.99	1.10	7.00	57.60
0:50:00	-4	-4	2.621	7	69.8	-4	-4.005	2.311	7	54.6	-4	-3.994	1.669	7	45.2	-4.00	-4.00	1.09	7.00	70.40
0:50:10	-4	-4.024	2.595	7	82.6	-4	-4	2.288	7	54.6	-4	-4.008	1.648	7	73.2	-4.00	-4.00	1.07	7.00	65.60
0:50:20	-4	-4.009	2.571	7	74.4	-4	-4.005	2.265	7	60.4	-4	-4	1.626	7	52.2	-4.00	-3.99	1.05	7.00	76.20
0:50:30	-4	-4.015	2.546	7	75.6	-4	-4.003	2.243	7	68.6	-4	-4.003	1.606	7	61.6	-4.00	-4.00	1.04	7.00	59.80
0:50:40	-4	-4.027	2.521	7	67.4	-4	-4.008	2.217	7	61.6	-4	-4.01	1.585	7	51.2	-4.00	-4.00	1.02	7.00	64.60
0:50:50	-4	-4.013	2.496	7	66.2	-4	-3.994	2.196	7	58.2	-4	-3.993	1.564	7	47.6	-4.00	-4.00	1.00	7.00	79.60
0:51:00	-4	-4.003	2.47	7	73.2	-4	-4.011	2.173	7	52.2	-4	-4.005	1.543	7	53.4	-4.00	-4.02	0.99	7.00	63.40
0:51:10	-4	-4.012	2.446	7	62.8	-4	-4.011	2.149	7	57	-4	-4.012	1.523	7	55.8	-4.00	-4.00	0.97	7.00	72.60
0:51:20	-4	-4.013	2.421	7	71	-4	-4.002	2.127	7	51.2	-4	-4	1.504	7	58.2	-4.00	-4.00	0.95	7.00	82.00
0:51:30	-4	-4.011	2.397	7	74.4	-4	-4.012	2.103	7	52.2	-4	-4.006	1.483	7	72	-4.00	-4.01	0.94	7.00	55.20
0:51:40	-4	-4.007	2.373	7	72	-4	-4	2.083	7	48.8	-4	-4	1.463	7	47.6	-4.00	-4.00	0.92	7.00	72.60
0:51:50	-4	-4.015	2.349	7	71	-4	-4.009	2.06	7	50	-4	-4.013	1.443	7	55.8	-4.00	-4.02	0.91	7.00	57.60
0:52:00	-4	-4.002	2.326	7	71	-4	-4.012	2.036	7	54.6	-4	-4.008	1.439	7	69.8	-4.00	-4.00	0.89	7.00	66.80
0:52:10	-4	-4.011	2.301	7	73.2	-4	-4.006	2.016	7	59.2	-4	-4.01	1.433	7	58.2	-4.00	-4.02	0.87	7.00	56.40
0:52:20	-4	-4.003	2.278	7	62.8	-4	-4.006	1.993	7	54.6	-4	-4.007	1.426	7	66.2	-4.00	-4.00	0.86	7.00	71.40
0:52:30	-4	-4.001	2.252	7	69.8	-4	-4.014	1.971	7	76.8	-4	-4.013	1.417	7	47.6	-4.00	-4.00	0.84	7.00	89.00
0:52:40	-4	-4.007	2.23	7	60.4	-4	-4.004	1.948	7	41.8	-4	-4.009	1.41	7	55.8	-4.00	-4.01	0.83	7.00	56.40
0:52:50	-4	-4.009	2.207	7	77.8	-4	-4.016	1.928	7	55.8	-4	-4.011	1.402	7	50	-4.00	-4.01	0.81	7.00	78.40
0:53:00	-4	-4.009	2.184	7	79	-4	-4.009	1.905	7	54.6	-4	-4.003	1.396	7	51.2	-4.00	-4.01	0.80	7.00	54.00
0:53:10	-4	-4.005	2.16	7	77.8	-4	-4.021	1.884	7	47.6	-4	-4.008	1.39	7	73.2	-4.00	-4.01	0.78	7.00	65.60
0:53:20	-4	-4.018	2.137	7	67.4	-4	-3.996	1.863	7	60.4	-4	-4	1.383	7	48.8	-4.00	-4.01	0.76	7.00	75.00
0:53:30	-4	-4.002	2.115	7	61.6	-4	-4.011	1.841	7	58.2	-4	-4.01	1.376	7	66.2	-4.00	-4.01	0.75	7.00	73.80
0:53:40	-4	-4.012	2.092	7	73.2	-4	-4.012	1.82	7	72	-4	-4.01	1.37	7	61.6	-4.00	-4.02	0.73	7.00	56.40
0:53:50	-4	-4.017	2.07	7	69.8	-4	-4.013	1.799	7	48.8	-4	-4.003	1.359	7	46.4	-4.00	-4.00	0.72	7.00	90.20
0:54:00	-4	-3.994	2.046	7	66.2	-4	-4.008	1.777	7	54.6	-4	-3.998	1.355	7	69.8	-4.00	-4.02	0.70	7.00	61.00
0:54:10	-4	-3.992	2.025	7	62.8	-4	-4.012	1.755	7	51.2	-4	-4.014	1.349	7	51.2	-4.00	-4.01	0.69	7.00	79.60
0:54:20	-4	-4.014	2.001	7	75.6	-4	-4.016	1.733	7	59.2	-4	-4.013	1.339	7	57	-4.00	-4.00	0.67	7.00	76.20
0:54:30	-4	-4.004	1.977	7	60.4	-4	-4.026	1.713	7	44.2	-4	-4.01	1.318	7	48.8	-4.00	-4.00	0.66	7.00	61.00
0:54:40	-4	-3.992	1.956	7	82.6	-4	-4.001	1.693	7	65	-4	-4.006	1.298	7	55.8	-4.00	-4.00	0.64	7.00	77.40
0:54:50	-4	-4.003	1.934	7	68.6	-4	-4.008	1.673	7	54.6	-4	-4.012	1.281	7	75.6	-4.00	-4.00	0.63	7.00	50.60
0:55:00	-4	-4	1.914	7	61.6	-4	-4.01	1.651	7	64	-4	-4.008	1.261	7	50	-4.00	-4.00	0.61	7.00	79.60
0:55:10	-4	-3.999	1.892	7	62.8	-4	-4.013	1.631	7	50	-4	-4.019	1.242	7	68.6	-4.00	-4.01	0.60	7.00	52.80
0:55:20	-4	-4.006	1.87	7	74.4	-4	-4	1.611	7	44.2	-4	-4.006	1.222	7	60.4	-4.00	-4.01	0.59	7.00	68.00

0:55:30	-4	-4.004	1.849	7	71	-4	-4.006	1.59	7	68.6	-4	-4.011	1.205	7	57	-4.00	-4.01	0.57	7.00	89.00
0:55:40	-4	-4.006	1.825	7	64	-4	-4	1.57	7	50	-4	-4	1.187	7	51.2	-4.00	-4.00	0.56	7.00	49.40
0:55:50	-4	-4.007	1.804	7	67.4	-4	-4.005	1.55	7	55.8	-4	-4.001	1.168	7	53.4	-4.00	-4.01	0.54	7.00	84.40
0:56:00	-4	-4.013	1.783	7	84.8	-4	-4	1.53	7	43	-4	-4.007	1.15	7	66.2	-4.00	-4.02	0.53	7.00	54.00
0:56:10	-4	-4.022	1.762	7	60.4	-4	-4.004	1.511	7	64	-4	-4.011	1.132	7	61.6	-4.00	-4.01	0.51	7.00	70.40
0:56:20	-4	-3.99	1.742	7	60.4	-4	-4.004	1.491	7	62.8	-4	-4.007	1.115	7	50	-4.00	-4.01	0.50	7.00	80.80
0:56:30	-4	-4.019	1.721	7	76.8	-4	-4.009	1.471	7	53.4	-4	-4.015	1.097	7	80.2	-4.00	-4.00	0.48	7.00	70.40
0:56:40	-4	-4.011	1.7	7	67.4	-4	-4	1.451	7	51.2	-4	-4.011	1.08	7	44.2	-4.00	-4.00	0.47	7.00	70.40
0:56:50	-4	-4	1.68	7	65	-4	-4.002	1.432	7	57	-4	-4.016	1.062	7	73.2	-4.00	-4.01	0.46	7.00	52.80
0:57:00	-4	-4.012	1.658	7	74.4	-4	-3.994	1.412	7	64	-4	-4.005	1.044	7	47.6	-4.00	-4.01	0.44	7.00	72.60
0:57:10	-4	-4.003	1.637	7	79	-4	-4.008	1.394	7	61.6	-4	-4.008	1.027	7	48.8	-4.00	-4.02	0.43	7.00	61.00
0:57:20	-4	-4.008	1.618	7	62.8	-4	-3.993	1.374	7	50	-4	-3.989	1.01	7	68.6	-4.00	-4.01	0.42	7.00	64.60
0:57:30	-4	-4.008	1.597	7	73.2	-4	-4.001	1.355	7	81.4	-4	-3.998	0.993	7	57	-4.00	-4.00	0.40	7.00	75.00
0:57:40	-4	-3.998	1.578	7	64	-4	-4.006	1.338	7	43	-4	-4.001	0.976	7	55.8	-4.00	-4.01	0.39	7.00	84.40
0:57:50	-4	-3.993	1.558	7	77.8	-4	-4.013	1.319	7	55.8	-4	-3.995	0.958	7	52.2	-4.00	-4.01	0.37	7.00	65.60
0:58:00	-4	-4.002	1.538	7	69.8	-4	-3.994	1.301	7	55.8	-4	-4.011	0.941	7	60.4	-4.00	-4.01	0.36	7.00	73.80
0:58:10	-4	-4.006	1.517	7	81.4	-4	-4.015	1.281	7	51.2	-4	-4.004	0.925	7	69.8	-4.00	-4.00	0.35	7.00	49.40
0:58:20	-4	-4.002	1.496	7	59.2	-4	-4.011	1.264	7	47.6	-4	-3.994	0.908	7	45.2	-4.00	-4.01	0.34	7.00	91.20
0:58:30	-4	-4.018	1.477	7	91.8	-4	-4.016	1.245	7	51.2	-4	-4.012	0.89	7	58.2	-4.00	-4.02	0.32	7.00	59.80
0:58:40	-4	-4	1.457	7	71	-4	-4.009	1.226	7	55.8	-4	-4.008	0.874	7	45.2	-4.00	-4.00	0.31	7.00	76.20
0:58:50	-4	-3.998	1.439	7	67.4	-4	-3.997	1.208	7	50	-4	-4.01	0.857	7	58.2	-4.00	-4.01	0.30	7.00	52.80
0:59:00	-4	-4.006	1.419	7	65	-4	-4.01	1.189	7	54.6	-4	-4.004	0.842	7	51.2	-4.00	-4.00	0.28	7.00	77.40
0:59:10	-4	-4.015	1.401	7	67.4	-4	-4.009	1.171	7	47.6	-4	-4.006	0.826	7	55.8	-4.00	-4.00	0.27	7.00	76.20
0:59:20	-4	-4.004	1.382	7	88.4	-4	-4.001	1.154	7	62.8	-4	-3.992	0.81	7	72	-4.00	-4.00	0.26	7.00	54.00
0:59:30	-4	-4.015	1.362	7	58	-4	-4.006	1.136	7	51.2	-4	-4.003	0.793	7	46.4	-4.00	-4.01	0.24	7.00	73.80
0:59:40	-4	-4.008	1.344	7	69.8	-4	-3.998	1.117	7	61.6	-4	-4.008	0.777	7	51.2	-4.00	-3.99	0.23	7.00	73.80
0:59:50	-4	-4.016	1.324	7	65	-4	-4.008	1.101	7	50	-4	-4.002	0.762	7	60.4	-4.00	-4.01	0.22	7.00	64.60
1:00:00	-4	-4.006	1.306	7	69.8	-4	-4	1.084	7	60.4	-4	-4.002	0.745	7	46.4	-4.00	-4.00	0.20	7.00	59.80
1:00:10	-4	-4.009	1.287	7	60.4	-4	-4.005	1.067	7	57	-4	-4	0.73	7	68.6	-4.00	-4.01	0.19	7.00	79.60
1:00:20	-4	-3.998	1.269	7	73.2	-4	-4.01	1.049	7	74.4	-4	-4.001	0.714	7	60.4	-4.00	-3.99	0.18	7.00	69.20
1:00:30	-4	-4.004	1.25	7	74.4	-4	-4.009	1.032	7	47.6	-4	-3.997	0.698	7	53.4	-4.00	-4.01	0.17	7.00	71.40
1:00:40	-4	-4.02	1.231	7	71	-4	-4.01	1.015	7	54.6	-4	-3.99	0.684	7	71	-4.00	-3.99	0.16	7.00	75.00
1:00:50	-4	-4.006	1.214	7	66.2	-4	-3.994	0.998	7	77.8	-4	-3.997	0.668	7	46.4	-4.00	-4.02	0.14	7.00	83.20
1:01:00	-4	-4.012	1.196	7	68.6	-4	-4.003	0.981	7	51.2	-4	-4.021	0.652	7	62.8	-4.00	-3.99	0.13	7.00	52.80
1:01:10	-4	-4.021	1.179	7	81.4	-4	-3.994	0.964	7	65	-4	-4.009	0.637	7	53.4	-4.00	-3.99	0.12	7.00	63.40
1:01:20	-4	-3.989	1.16	7	58	-4	-4.007	0.948	7	60.4	-4	-4.01	0.621	7	55.8	-4.00	-4.01	0.10	7.00	70.40
1:01:30	-4	-4.019	1.143	7	76.8	-4	-4.01	0.932	7	57	-4	-4	0.606	7	77.8	-4.00	-3.99	0.09	7.00	68.00
1:01:40	-4	-4.002	1.124	7	72	-4	-4.004	0.915	7	54.6	-4	-4.019	0.591	7	48.8	-4.00	-4.00	0.08	7.00	55.20
1:01:50	-4	-3.997	1.106	7	69.8	-4	-4.003	0.898	7	51.2	-4	-3.993	0.577	7	71	-4.00	-3.99	0.07	7.00	78.40
1:02:00	-4	-4.011	1.088	7	68.6	-4	-3.995	0.883	7	61.6	-4	-4.007	0.561	7	53.4	-4.00	-4.01	0.06	7.00	61.00
1:02:10	-4	-3.998	1.071	7	72	-4	-4.001	0.866	7	50	-4	-3.999	0.547	7	52.2	-4.00	-4.00	0.04	7.00	61.00
1:02:20	-4	-4.004	1.055	7	65	-4	-4.008	0.852	7	55.8	-4	-4.001	0.533	7	65	-4.00	-4.01	0.03	7.00	55.20
1:02:30	-4	-4.005	1.037	7	68.6	-4	-4.015	0.834	7	80.2	-4	-4.024	0.519	7	53.4	-4.00	-4.01	0.02	7.00	71.40
1:02:40	-4	-3.997	1.021	7	68.6	-4	-4.005	0.819	7	54.6	-4	-4.003	0.503	7	62.8	-4.00	-4.01	0.01	7.00	64.60
1:02:50	-4	-4.008	1.004	7	61.6	-4	-4.005	0.803	7	62.8	-4	-4.004	0.489	7	46.4	-4.00	-4.01	0.00	7.00	72.60
1:03:00	-4	-4.009	0.987	7	68.6	-4	-4.006	0.787	7	57	-4	-4.002	0.474	7	52.2	-4.00	-3.99	-0.02	7.00	73.80
1:03:10	-4	-4.008	0.977	7	72	-4	-4.01	0.773	7	57	-4	-4.002	0.46	7	74.4	-4.00	-4.02	-0.03	7.00	90.20
1:03:20	-4	-3.996	0.964	7	62.8	-4	-4.007	0.757	7	48.8	-4	-4.013	0.445	7	46.4	-4.00	-4.00	-0.04	7.00	72.60
1:03:30	-4	-3.997	0.951	7	59.2	-4	-4.01	0.742	7	57	-4	-4.012	0.431	7	76.8	-4.00	-4.01	-0.05	7.00	51.80
1:03:40	-4	-4	0.943	7	74.4	-4	-4.008	0.726	7	68.6	-4	-4.005	0.417	7	43	-4.00	-4.01	-0.06	7.00	78.40

1:03:50	-4	-4.001	0.939	7	68.6	-4	-3.999	0.71	7	62.8	-4	-3.995	0.403	7	51.2	-4.00	-4.01	-0.07	7.00	61.00
1:04:00	-4	-3.998	0.93	7	68.6	-4	-4.009	0.694	7	47.6	-4	-4	0.39	7	68.6	-4.00	-4.02	-0.09	7.00	75.00
1:04:10	-4	-4.006	0.922	7	64	-4	-4.005	0.68	7	79	-4	-3.997	0.376	7	48.8	-4.00	-4.01	-0.10	7.00	55.20
1:04:20	-4	-4.018	0.916	7	72	-4	-4.001	0.665	7	47.6	-4	-4.007	0.362	7	66.2	-4.00	-4.00	-0.11	7.00	80.80
1:04:30	-4	-3.988	0.906	7	68.6	-4	-4	0.65	7	67.4	-4	-4.014	0.348	7	50	-4.00	-4.00	-0.12	7.00	75.00
1:04:40	-4	-4.016	0.899	7	69.8	-4	-4.008	0.636	7	43	-4	-3.995	0.334	7	48.8	-4.00	-4.00	-0.13	7.00	61.00
1:04:50	-4	-3.999	0.888	7	77.8	-4	-4.005	0.62	7	55.8	-4	-4.014	0.319	7	61.6	-4.00	-4.01	-0.14	7.00	66.80
1:05:00	-4	-3.996	0.88	7	76.8	-4	-4.014	0.605	7	53.4	-4	-4.009	0.306	7	46.4	-4.00	-4.01	-0.15	7.00	59.80
1:05:10	-4	-4.002	0.872	7	67.4	-4	-3.992	0.59	7	50	-4	-3.991	0.294	7	64	-4.00	-4.01	-0.16	7.00	79.60
1:05:20	-4	-4.015	0.861	7	69.8	-4	-4.008	0.576	7	59.2	-4	-3.993	0.279	7	60.4	-4.00	-3.99	-0.17	7.00	63.40
1:05:30	-4	-3.999	0.853	7	69.8	-4	-4.015	0.562	7	47.6	-4	-3.999	0.266	7	65	-4.00	-3.99	-0.18	7.00	73.80
1:05:40	-4	-4.008	0.85	7	73.2	-4	-3.998	0.547	7	62.8	-4	-4.007	0.253	7	68.6	-4.00	-4.01	-0.19	7.00	66.80
1:05:50	-4	-4.001	0.866	7	68.6	-4	-4.016	0.533	7	61.6	-4	-4.003	0.239	7	41.8	-4.00	-4.00	-0.20	7.00	77.40
1:06:00	-4	-4.002	0.846	7	67.4	-4	-4.006	0.518	7	48.8	-4	-4.001	0.227	7	66.2	-4.00	-4.01	-0.19	7.00	64.60
1:06:10	-4	-3.998	0.829	7	82.6	-4	-3.994	0.503	7	58.2	-4	-4.006	0.212	7	44.2	-4.00	-4.00	-0.20	7.00	80.80
1:06:20	-4	-3.994	0.812	7	72	-4	-3.999	0.489	7	64	-4	-4.008	0.2	7	52.2	-4.00	-4.00	-0.21	7.00	55.20
1:06:30	-4	-4.005	0.794	7	59.2	-4	-3.996	0.475	7	54.6	-4	-4.01	0.187	7	79	-4.00	-4.01	-0.22	7.00	86.60
1:06:40	-4	-3.995	0.781	7	68.6	-4	-3.997	0.462	7	53.4	-4	-4.004	0.175	7	52.2	-4.00	-4.01	-0.23	7.00	69.20
1:06:50	-4	-3.999	0.764	7	89.6	-4	-4.003	0.447	7	52.2	-4	-3.995	0.162	7	74.4	-4.00	-4.00	-0.24	7.00	75.00
1:07:00	-4	-3.997	0.749	7	55.8	-4	-3.997	0.434	7	76.8	-4	-4.001	0.149	7	46.4	-4.00	-4.01	-0.25	7.00	68.00
1:07:10	-4	-4.01	0.733	7	72	-4	-4.018	0.42	7	47.6	-4	-4.011	0.137	7	47.6	-4.00	-4.01	-0.26	7.00	68.00
1:07:20	-4	-4.007	0.717	7	65	-4	-3.998	0.407	7	52.2	-4	-3.997	0.123	7	47.6	-4.00	-4.00	-0.27	7.00	55.20
1:07:30	-4	-3.998	0.702	7	68.6	-4	-4.013	0.393	7	64	-4	-3.998	0.111	7	47.6	-4.00	-4.01	-0.28	7.00	61.00
1:07:40	-4	-4.003	0.685	7	61.6	-4	-4.007	0.379	7	53.4	-4	-4.012	0.098	7	50	-4.00	-4.01	-0.29	7.00	80.80
1:07:50	-4	-3.998	0.671	7	68.6	-4	-3.994	0.366	7	51.2	-4	-3.997	0.086	7	50	-4.00	-4.00	-0.30	7.00	70.40
1:08:00	-4	-4.011	0.655	7	81.4	-4	-4.009	0.352	7	65	-4	-3.985	0.074	7	60.4	-4.00	-3.99	-0.31	7.00	66.80
1:08:10	-4	-4.001	0.64	7	64	-4	-4.012	0.339	7	62.8	-4	-4.007	0.062	7	59.2	-4.00	-4.00	-0.32	7.00	70.40
1:08:20	-4	-3.993	0.626	7	75.6	-4	-4.009	0.325	7	48.8	-4	-3.991	0.051	7	50	-4.00	-4.01	-0.33	7.00	76.20
1:08:30	-4	-4.014	0.611	7	77.8	-4	-4.012	0.312	7	47.6	-4	-4.009	0.037	7	79	-4.00	-4.00	-0.34	7.00	57.60
1:08:40	-4	-3.988	0.596	7	66.2	-4	-4.009	0.3	7	58.2	-4	-3.995	0.026	7	44.2	-4.00	-4.01	-0.35	7.00	69.20
1:08:50	-4	-4.002	0.581	7	59.2	-4	-3.995	0.287	7	52.2	-4	-3.999	0.014	7	60.4	-4.00	-4.00	-0.36	7.00	75.00
1:09:00	-4	-4	0.565	7	71	-4	-4.016	0.274	7	57	-4	-4.009	0.001	7	69.8	-4.00	-4.00	-0.37	7.00	82.00
1:09:10	-4	-3.996	0.551	7	67.4	-4	-4.001	0.261	7	75.6	-4	-4.017	-0.01	7	47.6	-4.00	-4.01	-0.38	7.00	62.20
1:09:20	-4	-4	0.536	7	62.8	-4	-4.005	0.249	7	54.6	-4	-4.007	-0.022	7	66.2	-4.00	-4.01	-0.39	7.00	71.40
1:09:30	-4	-4.007	0.522	7	62.8	-4	-3.987	0.235	7	77.8	-4	-4.02	-0.033	7	58.2	-4.00	-4.00	-0.40	7.00	84.40
1:09:40	-4	-4.001	0.508	7	68.6	-4	-3.998	0.223	7	45.2	-4	-4.005	-0.045	7	54.6	-4.00	-4.01	-0.41	7.00	57.60
1:09:50	-4	-4.025	0.493	7	76.8	-4	-4.014	0.209	7	55.8	-4	-4.009	-0.057	7	52.2	-4.00	-4.00	-0.42	7.00	70.40
1:10:00	-4	-3.992	0.479	7	61.6	-4	-3.991	0.196	7	48.8	-4	-4.01	-0.067	7	47.6	-4.00	-4.00	-0.43	7.00	78.40
1:10:10	-4	-4	0.466	7	66.2	-4	-4.008	0.185	7	57	-4	-4.001	-0.079	7	71	-4.00	-4.00	-0.44	7.00	66.80
1:10:20	-4	-4.01	0.45	7	68.6	-4	-4.012	0.173	7	73.2	-4	-4	-0.091	7	43	-4.00	-4.00	-0.45	7.00	65.60
1:10:30	-4	-4.003	0.436	7	75.6	-4	-3.999	0.16	7	52.2	-4	-4.007	-0.102	7	58.2	-4.00	-4.01	-0.46	7.00	63.40
1:10:40	-4	-4.001	0.423	7	72	-4	-3.998	0.148	7	52.2	-4	-4.013	-0.114	7	44.2	-4.00	-4.01	-0.47	7.00	79.60
1:10:50	-4	-3.994	0.41	7	69.8	-4	-4.01	0.134	7	66.2	-4	-4.008	-0.125	7	69.8	-4.00	-4.00	-0.48	7.00	76.20
1:11:00	-4	-4.002	0.395	7	62.8	-4	-4.009	0.123	7	53.4	-4	-4.003	-0.136	7	52.2	-4.00	-4.02	-0.49	7.00	62.20
1:11:10	-4	-3.997	0.381	7	66.2	-4	-4.01	0.11	7	44.2	-4	-3.999	-0.147	7	44.2	-4.00	-4.00	-0.50	7.00	83.20
1:11:20	-4	-3.997	0.368	7	79	-4	-3.995	0.098	7	65	-4	-4.005	-0.158	7	65	-4.00	-4.00	-0.50	7.00	64.60
1:11:30	-4	-3.998	0.354	7	59.2	-4	-4	0.086	7	61.6	-4	-4.008	-0.169	7	47.6	-4.00	-3.99	-0.51	7.00	69.20
1:11:40	-4	-4.006	0.341	7	62.8	-4	-4.022	0.075	7	54.6	-4	-4.002	-0.181	7	48.8	-4.00	-4.00	-0.52	7.00	56.40
1:11:50	-4	-4	0.326	7	90.6	-4	-3.99	0.062	7	47.6	-4	-4.006	-0.191	7	44.2	-4.00	-4.00	-0.53	7.00	84.40
1:12:00	-4	-4.003	0.314	7	65	-4	-4.002	0.052	7	61.6	-4	-3.992	-0.203	7	65	-4.00	-4.00	-0.54	7.00	70.40

1:12:10	-4	-4.006	0.3	7	62.8	-4	-3.999	0.039	7	59.2	-4	-4.002	-0.213	7	60.4	-4.00	-4.00	-0.55	7.00	62.20
1:12:20	-4	-4.003	0.287	7	69.8	-4	-4.007	0.026	7	69.8	-4	-4	-0.224	7	50	-4.00	-4.01	-0.56	7.00	85.40
1:12:30	-4	-4.02	0.274	7	75.6	-4	-4.007	0.016	7	52.2	-4	-4.008	-0.235	7	52.2	-4.00	-4.00	-0.57	7.00	61.00
1:12:40	-4	-3.997	0.261	7	62.8	-4	-3.995	0.003	7	52.2	-4	-3.996	-0.244	7	45.2	-4.00	-4.00	-0.58	7.00	58.60
1:12:50	-4	-4.009	0.248	7	61.6	-4	-4	-0.008	7	66.2	-4	-4.004	-0.256	7	74.4	-4.00	-4.01	-0.59	7.00	61.00
1:13:00	-4	-4.014	0.235	7	62.8	-4	-4.001	-0.019	7	45.2	-4	-4.007	-0.265	7	44.2	-4.00	-4.01	-0.60	7.00	77.40
1:13:10	-4	-4.008	0.223	7	74.4	-4	-4.008	-0.03	7	67.4	-4	-4.008	-0.276	7	53.4	-4.00	-4.00	-0.60	7.00	70.40
1:13:20	-4	-4.001	0.21	7	57	-4	-3.997	-0.041	7	68.6	-4	-4.005	-0.287	7	69.8	-4.00	-4.00	-0.61	7.00	77.40
1:13:30	-4	-3.995	0.196	7	80.2	-4	-3.986	-0.053	7	52.2	-4	-4.01	-0.297	7	44.2	-4.00	-4.00	-0.62	7.00	66.80
1:13:40	-4	-4.005	0.184	7	74.4	-4	-4.007	-0.065	7	71	-4	-4.004	-0.307	7	65	-4.00	-4.00	-0.63	7.00	59.80
1:13:50	-4	-4.014	0.172	7	61.6	-4	-4.005	-0.077	7	48.8	-4	-3.998	-0.317	7	55.8	-4.00	-4.01	-0.64	7.00	52.80
1:14:00	-4	-3.998	0.16	7	73.2	-4	-4.003	-0.087	7	60.4	-4	-4.009	-0.324	7	69.8	-4.00	-4.00	-0.65	7.00	70.40
1:14:10	-4	-3.995	0.148	7	65	-4	-4	-0.099	7	46.4	-4	-3.993	-0.333	7	47.6	-4.00	-4.00	-0.66	7.00	75.00
1:14:20	-4	-4.009	0.135	7	68.6	-4	-4.001	-0.109	7	60.4	-4	-4.01	-0.342	7	48.8	-4.00	-4.00	-0.66	7.00	62.20
1:14:30	-4	-4.003	0.122	7	67.4	-4	-4.001	-0.12	7	77.8	-4	-4.007	-0.352	7	73.2	-4.00	-4.00	-0.67	7.00	61.00
1:14:40	-4	-4.014	0.11	7	87.2	-4	-4.006	-0.132	7	59.2	-4	-3.959	-0.362	7	45.2	-4.00	-4.01	-0.68	7.00	68.00
1:14:50	-4	-3.998	0.098	7	58	-4	-4.017	-0.142	7	66.2	-4	-4.06	-0.372	7	66.2	-4.00	-4.00	-0.69	7.00	85.40
1:15:00	-4	-4.023	0.085	7	69.8	-4	-3.992	-0.153	7	48.8	-4	-4.007	-0.383	7	61.6	-4.00	-4.00	-0.70	7.00	57.60
1:15:10	-4	-3.995	0.073	7	59.2	-4	-4.002	-0.164	7	54.6	-4	-3.98	-0.393	7	54.6	-4.00	-4.00	-0.70	7.00	71.40
1:15:20	-4	-4.004	0.06	7	65	-4	-4.016	-0.175	7	54.6	-4	-3.937	-0.402	7	57	-4.00	-3.98	-0.71	7.00	70.40
1:15:30	-4	-3.999	0.05	7	83.8	-4	-3.997	-0.185	7	59.2	-4	-3.901	-0.411	7	45.2	-4.00	-4.00	-0.72	7.00	72.60
1:15:40	-4	-3.993	0.037	7	73.2	-4	-4.018	-0.196	7	61.6	-4	-3.86	-0.421	7	53.4	-4.00	-4.00	-0.73	7.00	62.20
1:15:50	-4	-4.002	0.025	7	74.4	-4	-4.005	-0.207	7	73.2	-4	-3.818	-0.429	7	46.4	-4.00	-4.00	-0.74	7.00	75.00
1:16:00	-4	-4.007	0.014	7	71	-4	-3.989	-0.217	7	64	-4	-3.781	-0.436	7	54.6	-4.00	-4.00	-0.74	7.00	58.60
1:16:10	-4	-4.005	0.002	7	65	-4	-3.993	-0.227	7	66.2	-4	-3.739	-0.438	7	77.8	-4.00	-4.00	-0.75	7.00	62.20
1:16:20	-4	-4.013	-0.009	7	67.4	-4	-4.004	-0.237	7	43	-4	-3.701	-0.438	7	41.8	-4.00	-4.00	-0.76	7.00	62.20
1:16:30	-4	-4.005	-0.022	7	64	-4	-4.005	-0.248	7	68.6	-4	-3.662	-0.439	7	50	-4.00	-4.01	-0.77	7.00	85.40
1:16:40	-4	-4.008	-0.033	7	71	-4	-3.995	-0.258	7	50	-4	-3.626	-0.443	7	44.2	-4.00	-4.01	-0.78	7.00	65.60
1:16:50	-4	-3.99	-0.044	7	77.8	-4	-4.004	-0.268	7	54.6	-5	-3.601	-0.448	7	65	-4.00	-4.00	-0.78	7.00	59.80
1:17:00	-4	-4.014	-0.056	7	72	-4	-3.998	-0.279	7	62.8	-5	-3.585	-0.455	7	66.2	-4.00	-4.00	-0.79	7.00	87.80
1:17:10	-4	-4.019	-0.067	7	69.8	-4	-4.008	-0.289	7	53.4	-5	-3.599	-0.463	7	41.8	-4.00	-3.99	-0.80	7.00	55.20
1:17:20	-4	-4	-0.078	7	65	-4	-3.999	-0.3	7	55.8	-5	-3.575	-0.471	7	65	-4.00	-4.00	-0.81	7.00	73.80
1:17:30	-4	-4.001	-0.09	7	67.4	-4	-3.998	-0.309	7	51.2	-5	-3.788	-0.479	7	44.2	-4.00	-4.00	-0.81	7.00	62.20
1:17:40	-4	-3.996	-0.101	7	64	-4	-4.008	-0.319	7	58.2	-4	-4.038	-0.487	7	52.2	-4.00	-4.00	-0.82	7.00	86.60
1:17:50	-4	-4.004	-0.112	7	73.2	-4	-3.999	-0.329	7	73.2	-4	-3.993	-0.493	7	45.2	-4.00	-4.00	-0.83	7.00	64.60
1:18:00	-4	-3.998	-0.124	7	62.8	-4	-3.997	-0.339	7	44.2	-4	-3.928	-0.502	7	52.2	-4.00	-4.00	-0.84	7.00	70.40
1:18:10	-4	-3.995	-0.135	7	77.8	-4	-3.997	-0.349	7	59.2	-4	-3.902	-0.51	7	72	-4.00	-4.00	-0.84	7.00	64.60
1:18:20	-4	-4.014	-0.145	7	60.4	-4	-4.008	-0.358	7	61.6	-4	-3.867	-0.517	7	40.6	-4.00	-4.01	-0.85	7.00	86.60
1:18:30	-4	-4.002	-0.156	7	76.8	-4	-4.021	-0.368	7	50	-4	-3.842	-0.527	7	64	-4.00	-4.01	-0.86	7.00	78.40
1:18:40	-4	-3.996	-0.167	7	69.8	-4	-4.005	-0.377	7	59.2	-4	-3.798	-0.534	7	58.2	-4.00	-4.00	-0.87	7.00	73.80
1:18:50	-4	-4.007	-0.178	7	84.8	-4	-3.998	-0.387	7	55.8	-4	-3.758	-0.54	7	53.4	-4.00	-3.99	-0.87	7.00	62.20
1:19:00	-4	-4	-0.189	7	57	-4	-3.998	-0.397	7	77.8	-4	-3.718	-0.542	7	47.6	-4.00	-4.01	-0.88	7.00	65.60
1:19:10	-4	-4.007	-0.199	7	68.6	-4	-4.008	-0.406	7	44.2	-4	-3.68	-0.547	7	51.2	-4.00	-4.02	-0.89	7.00	77.40
1:19:20	-4	-3.991	-0.21	7	68.6	-4	-4.013	-0.416	7	55.8	-4	-3.64	-0.553	7	61.6	-4.00	-4.00	-0.89	7.00	63.40
1:19:30	-4	-4.015	-0.221	7	64	-4	-4.006	-0.425	7	54.6	-4	-3.602	-0.559	7	60.4	-4.00	-4.01	-0.90	7.00	63.40
1:19:40	-4	-3.998	-0.232	7	62.8	-4	-4.007	-0.435	7	52.2	-4	-3.6	-0.565	7	46.4	-4.00	-4.00	-0.91	7.00	79.60
1:19:50	-4	-3.994	-0.242	7	67.4	-4	-4.005	-0.443	7	45.2	-4	-3.56	-0.572	7	54.6	-4.00	-4.00	-0.91	7.00	79.60
1:20:00	-4	-4.002	-0.252	7	87.2	-4	-4.006	-0.453	7	67.4	-4	-3.518	-0.578	7	40.6	-4.00	-4.02	-0.92	7.00	69.20
1:20:10	-4	-4.006	-0.262	7	58	-4	-4.01	-0.462	7	59.2	-4	-3.481	-0.584	7	62.8	-4.00	-4.00	-0.93	7.00	63.40
1:20:20	-4	-4.012	-0.273	7	62.8	-4	-4.008	-0.472	7	52.2	-4	-3.445	-0.59	7	44.2	-4.00	-4.02	-0.94	7.00	83.20

1:20:30	-4	-3.993	-0.282	7	66.2	-4	-3.994	-0.481	7	46.4	-4	-3.409	-0.599	7	46.4	-4.00	-4.00	-0.94	7.00	57.60
1:20:40	-4	-4.012	-0.293	7	67.4	-4	-4.01	-0.49	7	62.8	-4	-3.372	-0.607	7	67.4	-4.00	-4.01	-0.96	7.00	72.60
1:20:50	-4	-4.001	-0.303	7	58	-4	-4.002	-0.499	7	52.2	-4	-3.553	-0.616	7	52.2	-4.00	-3.99	-0.98	7.00	79.60
1:21:00	-4	-4.004	-0.313	7	73.2	-4	-4.012	-0.507	7	58.2	-4	-3.794	-0.625	7	54.6	-4.00	-4.01	-1.00	7.00	90.20
1:21:10	-4	-4.002	-0.323	7	68.6	-4	-4.002	-0.517	7	81.4	-4	-4.005	-0.635	7	47.6	-4.00	-4.02	-1.01	7.00	64.60
1:21:20	-4	-4	-0.332	7	66.2	-4	-4.012	-0.525	7	58.2	-4	-4.093	-0.645	7	59.2	-4.00	-4.01	-1.03	7.00	68.00
1:21:30	-4	-3.997	-0.341	7	62.8	-4	-4.014	-0.534	7	79	-4	-4.186	-0.656	7	62.8	-4.00	-4.01	-1.05	7.00	65.60
1:21:40	-4	-4.005	-0.351	7	58	-4	-3.993	-0.544	7	48.8	-4	-4.249	-0.667	7	43	-4.00	-4.00	-1.06	7.00	84.40
1:21:50	-4	-4	-0.361	7	79	-4	-4.018	-0.552	7	65	-4	-4.315	-0.677	7	60.4	-4.00	-4.00	-1.07	7.00	58.60
1:22:00	-4	-4.004	-0.371	7	57	-4	-3.983	-0.561	7	51.2	-4	-4.347	-0.689	7	66.2	-4.00	-4.00	-1.09	7.00	78.40
1:22:10	-4	-4.008	-0.38	7	69.8	-4	-4.019	-0.57	7	60.4	-4	-4.375	-0.699	7	60.4	-4.00	-4.00	-1.10	7.00	58.60
1:22:20	-4	-3.997	-0.389	7	68.6	-4	-3.997	-0.578	7	75.6	-4	-4.403	-0.71	7	50	-4.00	-3.99	-1.11	7.00	89.00
1:22:30	-4	-3.999	-0.398	7	68.6	-4	-4.013	-0.586	7	53.4	-4	-4.407	-0.721	7	52.2	-4.00	-4.02	-1.12	7.00	69.20
1:22:40	-4	-4.008	-0.409	7	64	-4	-4.006	-0.595	7	53.4	-4	-4.411	-0.731	7	71	-4.00	-3.99	-1.14	7.00	69.20
1:22:50	-4	-4.006	-0.418	7	68.6	-4	-4.008	-0.604	7	68.6	-4	-4.396	-0.742	7	44.2	-4.00	-4.00	-1.15	7.00	63.40
1:23:00	-4	-4.004	-0.427	7	60.4	-4	-4.006	-0.612	7	48.8	-4	-4.383	-0.752	7	50	-4.00	-4.00	-1.16	7.00	54.00
1:23:10	-4	-3.996	-0.437	7	67.4	-4	-3.995	-0.619	7	45.2	-4	-4.38	-0.763	7	47.6	-4.00	-4.01	-1.17	7.00	71.40
1:23:20	-4	-4.012	-0.446	7	81.4	-4	-3.997	-0.628	7	68.6	-4	-4.366	-0.772	7	48.8	-4.00	-4.01	-1.18	7.00	79.60
1:23:30	-4	-4.003	-0.456	7	60.4	-4	-4.002	-0.636	7	64	-4	-4.346	-0.782	7	71	-4.00	-4.00	-1.19	7.00	58.60
1:23:40	-4	-4.012	-0.465	7	65	-4	-4.004	-0.644	7	57	-4	-4.33	-0.791	7	50	-4.00	-4.01	-1.19	7.00	68.00
1:23:50	-4	-3.995	-0.474	7	76.8	-4	-4.004	-0.653	7	47.6	-4	-4.323	-0.8	7	44.2	-4.00	-4.00	-1.20	7.00	68.00
1:24:00	-4	-4.003	-0.484	7	65	-4	-3.99	-0.661	7	62.8	-4	-4.286	-0.81	7	69.8	-4.00	-4.01	-1.21	7.00	55.20
1:24:10	-4	-4.007	-0.493	7	57	-4	-4.004	-0.669	7	50	-4	-4.248	-0.818	7	44.2	-4.00	-4.02	-1.22	7.00	87.80
1:24:20	-4	-3.995	-0.502	7	72	-4	-3.982	-0.677	7	72	-4	-4.243	-0.826	7	64	-4.00	-4.00	-1.23	7.00	54.00
1:24:30	-4	-3.991	-0.511	7	65	-4	-4.009	-0.684	7	48.8	-4	-4.207	-0.835	7	52.2	-4.00	-4.01	-1.24	7.00	65.60
1:24:40	-4	-3.984	-0.519	7	64	-4	-4.008	-0.693	7	55.8	-4	-4.184	-0.843	7	41.8	-4.00	-4.01	-1.24	7.00	61.00
1:24:50	-4	-4.002	-0.517	7	62.8	-4	-4	-0.7	7	71	-4	-4.168	-0.851	7	71	-4.00	-4.00	-1.25	7.00	79.60
1:25:00	-4	-3.987	-0.513	7	72	-4	-4.004	-0.709	7	54.6	-4	-4.155	-0.859	7	50	-4.00	-4.01	-1.26	7.00	66.80
1:25:10	-4	-3.974	-0.521	7	59.2	-4	-4.003	-0.716	7	66.2	-4	-4.108	-0.867	7	58	-4.00	-3.99	-1.27	7.00	72.60
1:25:20	-4	-3.997	-0.53	7	61.6	-4	-4.009	-0.724	7	67.4	-4	-4.102	-0.875	7	79	-4.00	-4.01	-1.27	7.00	73.80
1:25:30	-4	-3.968	-0.539	7	66.2	-4	-3.991	-0.732	7	54.6	-4	-4.085	-0.883	7	57	-4.00	-4.01	-1.28	7.00	80.80
1:25:40	-4	-3.993	-0.547	7	76.8	-4	-4.001	-0.739	7	66.2	-4	-4.078	-0.89	7	69.8	-4.00	-4.00	-1.29	7.00	77.40
1:25:50	-4	-3.98	-0.555	7	62.8	-4	-3.989	-0.747	7	50	-4	-4.035	-0.897	7	68.6	-4.00	-4.00	-1.29	7.00	84.40
1:26:00	-4	-3.976	-0.564	7	71	-4	-3.994	-0.755	7	50	-4	-4.039	-0.905	7	68.6	-4.00	-4.00	-1.30	7.00	57.60
1:26:10	-4	-3.981	-0.573	7	68.6	-4	-3.995	-0.763	7	46.4	-4	-4.011	-0.915	7	64	-4.00	-4.00	-1.31	7.00	69.20
1:26:20	-4	-3.985	-0.581	7	61.6	-4	-4.001	-0.77	7	60.4	-4	-4.013	-0.933	7	50	-4.00	-4.01	-1.31	7.00	80.80
1:26:30	-4	-3.994	-0.591	7	75.6	-4	-3.999	-0.777	7	79	-4	-4.002	-0.951	7	47.6	-4.00	-4.00	-1.32	7.00	64.60
1:26:40	-4	-3.995	-0.599	7	81.4	-4	-4.014	-0.785	7	43	-4	-3.993	-0.967	7	48.8	-4.00	-4.01	-1.33	7.00	63.40
1:26:50	-4	-3.994	-0.608	7	59.2	-4	-3.99	-0.793	7	67.4	-4	-3.989	-0.982	7	71	-4.00	-4.02	-1.33	7.00	79.60
1:27:00	-4	-3.997	-0.617	7	64	-4	-4.012	-0.8	7	53.4	-4	-3.986	-0.995	7	50	-4.00	-4.01	-1.34	7.00	75.00
1:27:10	-4	-3.991	-0.625	7	87.2	-4	-4.008	-0.807	7	57	-4	-3.966	-1.009	7	44.2	-4.00	-4.01	-1.34	7.00	63.40
1:27:20	-4	-3.997	-0.633	7	68.6	-4	-4.001	-0.814	7	48.8	-4	-3.975	-1.02	7	68.6	-4.00	-4.00	-1.35	7.00	56.40
1:27:30	-4	-3.994	-0.642	7	87.2	-4	-4.001	-0.822	7	59.2	-4	-3.966	-1.033	7	60.4	-4.00	-4.01	-1.35	7.00	90.20
1:27:40	-4	-3.993	-0.65	7	68.6	-4	-4.009	-0.828	7	65	-4	-3.981	-1.043	7	67.4	-4.00	-4.00	-1.36	7.00	69.20
1:27:50	-4	-4.012	-0.659	7	74.4	-4	-4.003	-0.836	7	50	-4	-3.97	-1.054	7	81.4	-4.00	-4.01	-1.37	7.00	62.20
1:28:00	-4	-4.011	-0.667	7	62.8	-4	-4.003	-0.843	7	64	-4	-3.96	-1.065	7	60.4	-4.00	-3.98	-1.37	7.00	86.60
1:28:10	-4	-4.005	-0.675	7	62.8	-4	-4.001	-0.85	7	69.8	-4	-3.972	-1.075	7	65	-4.00	-3.99	-1.38	7.00	62.20
1:28:20	-4	-4.012	-0.683	7	71	-4	-4.01	-0.857	7	51.2	-4	-3.951	-1.085	7	76.8	-4.00	-4.00	-1.38	7.00	75.00
1:28:30	-4	-3.993	-0.692	7	66.2	-4	-4.005	-0.865	7	67.4	-4	-3.963	-1.094	7	64	-4.00	-4.00	-1.39	7.00	56.40
1:28:40	-4	-4.004	-0.699	7	75.6	-4	-4.008	-0.871	7	41.8	-4	-3.982	-1.102	7	62.8	-4.00	-3.99	-1.39	7.00	82.00

1:28:50	-4	-4.012	-0.708	7	77.8	-4	-4.012	-0.878	7	55.8	-4	-3.974	-1.111	7	72	-4.00	-4.01	-1.40	7.00	66.80
1:29:00	-4	-4.02	-0.716	7	75.6	-4	-3.993	-0.886	7	68.6	-4	-3.968	-1.12	7	59.2	-4.00	-3.99	-1.40	7.00	66.80
1:29:10	-4	-4.008	-0.724	7	60.4	-4	-4.005	-0.892	7	51.2	-4	-3.979	-1.129	7	61.6	-4.00	-4.01	-1.41	7.00	84.40
1:29:20	-4	-4.005	-0.732	7	71	-4	-4.016	-0.899	7	60.4	-4	-3.985	-1.137	7	62.8	-4.00	-4.00	-1.41	7.00	83.20
1:29:30	-4	-4.004	-0.739	7	60.4	-4	-3.983	-0.906	7	46.4	-4	-3.977	-1.145	7	71	-4.00	-3.99	-1.42	7.00	72.60
1:29:40	-4	-4.002	-0.748	7	67.4	-4	-3.997	-0.913	7	64	-4	-3.989	-1.152	7	68.6	-4.00	-4.00	-1.42	7.00	63.40
1:29:50	-4	-3.994	-0.755	7	66.2	-4	-3.989	-0.92	7	62.8	-4	-3.984	-1.16	7	65	-4.00	-4.00	-1.43	7.00	55.20
1:30:00	-4	-4.017	-0.763	7	79	-4	-4.01	-0.926	7	50	-4	-3.985	-1.167	7	57	-4.00	-4.01	-1.43	7.00	66.80
1:30:10	-4	-4.009	-0.771	7	80.2	-4	-3.998	-0.933	7	59.2	-4	-3.969	-1.174	7	72	-4.00	-4.01	-1.43	7.00	72.60
1:30:20	-4	-4.001	-0.778	7	58	-4	-3.992	-0.94	7	66.2	-4	-3.994	-1.181	7	65	-4.00	-3.99	-1.44	7.00	83.20
1:30:30	-4	-3.998	-0.786	7	76.8	-4	-4.006	-0.946	7	54.6	-4	-4.011	-1.188	7	69.8	-4.00	-4.00	-1.44	7.00	62.20
1:30:40	-4	-4.001	-0.794	7	64	-4	-3.998	-0.953	7	52.2	-4	-3.986	-1.195	7	44.2	-4.00	-4.00	-1.45	7.00	75.00
1:30:50	-4	-4.007	-0.801	7	61.6	-4	-3.999	-0.97	7	51.2	-4	-3.99	-1.201	7	64	-4.00	-4.00	-1.45	7.00	80.80
1:31:00	-4	-4.006	-0.809	7	69.8	-4	-4	-0.984	7	76.8	-4	-3.999	-1.208	7	52.2	-4.00	-4.01	-1.46	7.00	75.00
1:31:10	-4	-4	-0.816	7	76.8	-4	-3.994	-0.999	7	48.8	-4	-4.009	-1.214	7	41.8	-4.00	-4.02	-1.46	7.00	66.80
1:31:20	-4	-4.006	-0.825	7	72	-4	-3.998	-1.013	7	52.2	-4	-3.998	-1.221	7	43	-4.00	-4.01	-1.47	7.00	84.40
1:31:30	-4	-4.001	-0.831	7	68.6	-4	-3.996	-1.025	7	67.4	-4	-4.007	-1.226	7	74.4	-4.00	-4.01	-1.47	7.00	75.00
1:31:40	-4	-4.007	-0.839	7	62.8	-4	-3.998	-1.037	7	51.2	-4	-4.002	-1.232	7	45.2	-4.00	-4.00	-1.47	7.00	68.00
1:31:50	-4	-4.001	-0.846	7	66.2	-4	-4.014	-1.047	7	51.2	-4	-4.02	-1.238	7	54.6	-4.00	-4.00	-1.48	7.00	57.60
1:32:00	-4	-4.001	-0.854	7	75.6	-4	-4	-1.058	7	61.6	-4	-3.998	-1.243	7	57	-4.00	-4.00	-1.48	7.00	89.00
1:32:10	-4	-3.993	-0.86	7	58	-4	-4.008	-1.067	7	66.2	-4	-3.991	-1.247	7	45.2	-4.00	-4.00	-1.48	7.00	80.80
1:32:20	-4	-4.015	-0.868	7	64	-4	-4.009	-1.077	7	50	-4	-4.005	-1.253	7	73.2	-4.00	-4.00	-1.49	7.00	62.20
1:32:30	-4	-4.004	-0.875	7	75.6	-4	-4.023	-1.086	7	54.6	-4	-4	-1.256	7	71	-4.00	-4.00	-1.49	7.00	65.20
1:32:40	-4	-4.008	-0.883	7	66.2	-4	-4.001	-1.095	7	54.6	-4	-3.993	-1.27	7	50	-4.00	-4.02	-1.49	7.00	73.80
1:32:50	-4	-3.997	-0.89	7	61.6	-4	-4.014	-1.104	7	57	-4	-3.98	-1.279	7	79	-4.00	-4.01	-1.49	7.00	69.40
1:33:00	-4	-4.012	-0.896	7	67.4	-4	-3.989	-1.113	7	61.6	-4	-4.005	-1.285	7	43	-4.00	-4.00	-1.49	7.00	62.20
1:33:10	-4	-3.993	-0.903	7	75.6	-4	-4.004	-1.121	7	69.8	-4	-3.995	-1.292	7	57	-4.00	-3.99	-1.49	7.00	97.20
1:33:20	-4	-4.009	-0.91	7	61.6	-4	-4.011	-1.128	7	54.6	-4	-3.988	-1.298	7	68.6	-4.00	-4.02	-1.49	7.00	77.40
1:33:30	-4	-3.997	-0.917	7	62.8	-4	-4.006	-1.137	7	86	-4	-3.987	-1.305	7	55.8	-4.00	-4.00	-1.49	7.00	72.60
1:33:40	-4	-4.012	-0.925	7	64	-4	-4.008	-1.144	7	44.2	-4	-3.991	-1.311	7	74.4	-4.00	-4.00	-1.49	7.00	40.60
1:33:50	-4	-4.003	-0.931	7	75.6	-4	-4.004	-1.152	7	69.8	-4	-3.994	-1.317	7	59.2	-4.00	-4.01	-1.49	7.00	82.00
1:34:00	-4	-3.994	-0.939	7	64	-4	-4.002	-1.159	7	57	-4	-3.982	-1.323	7	59.2	-4.00	-4.00	-1.49	7.00	87.80
1:34:10	-4	-3.989	-0.945	7	62.8	-4	-4	-1.167	7	52.2	-4	-3.987	-1.329	7	48.8	-4.00	-4.01	-1.49	7.00	71.40
1:34:20	-4	-4.005	-0.952	7	74.4	-4	-4.013	-1.174	7	80.2	-4	-3.997	-1.335	7	55.8	-4.00	-4.00	-1.49	7.00	75.00
1:34:30	-4	-3.99	-0.958	7	60.4	-4	-3.99	-1.182	7	55.8	-4	-3.984	-1.341	7	59.2	-4.00	-3.99	-1.49	7.00	64.60
1:34:40	-4	-4.019	-0.964	7	72	-4	-3.998	-1.188	7	57	-4	-3.99	-1.347	7	52.2	-4.00	-4.00	-1.49	7.00	90.20
1:34:50	-4	-4.008	-0.98	7	66.2	-4	-4	-1.194	7	53.4	-4	-3.989	-1.352	7	67.4	-4.00	-4.01	-1.49	7.00	65.60
1:35:00	-4	-4.012	-0.995	7	66.2	-4	-3.991	-1.201	7	57	-4	-3.982	-1.357	7	57	-4.00	-4.01	-1.49	7.00	63.40
1:35:10	-4	-4.006	-1.009	7	66.2	-4	-4.007	-1.207	7	50	-4	-4.005	-1.355	7	82.6	-4.00	-4.01	-1.49	7.00	86.60
1:35:20	-4	-4.011	-1.023	7	83.8	-4	-4.004	-1.213	7	65	-4	-4.009	-1.357	7	53.4	-4.00	-3.98	-1.49	7.00	80.80
1:35:30	-4	-4.001	-1.036	7	57	-4	-4.003	-1.218	7	52.2	-4	-4.004	-1.357	7	69.8	-4.00	-4.01	-1.46	7.00	73.80
1:35:40	-4	-3.995	-1.048	7	64	-4	-4.011	-1.224	7	64	-4	-3.992	-1.357	7	60.4	-4.00	-4.00	-1.45	7.00	66.80
1:35:50	-4	-4.002	-1.059	7	59.2	-4	-3.998	-1.229	7	52.2	-4	-3.999	-1.358	7	61.6	-4.00	-4.01	-1.47	7.00	94.80
1:36:00	-4	-4	-1.07	7	65	-4	-4.008	-1.235	7	59.2	-4	-3.991	-1.358	7	50	-4.00	-3.99	-1.48	7.00	80.80
1:36:10	-4	-4.008	-1.081	7	61.6	-4	-4.003	-1.24	7	53.4	-4	-3.998	-1.357	7	53.4	-4.00	-4.01	-1.48	7.00	84.40
1:36:20	-4	-3.996	-1.092	7	69.8	-4	-4.008	-1.239	7	43	-4	-4.003	-1.358	7	69.8	-4.00	-4.00	-1.49	7.00	72.60
1:36:30	-4	-3.997	-1.102	7	76.8	-4	-4.002	-1.247	7	67.4	-4	-3.985	-1.357	7	57	-4.00	-4.00	-1.49	7.00	73.80
1:36:40	-4	-3.997	-1.111	7	60.4	-4	-4.011	-1.255	7	57	-4	-4.007	-1.357	7	52.2	-4.00	-4.00	-1.49	7.00	73.80
1:36:50	-4	-4.01	-1.12	7	67.4	-4	-3.996	-1.263	7	82.6	-4	-3.987	-1.357	7	80.2	-4.00	-4.01	-1.49	7.00	70.40
1:37:00	-4	-4.002	-1.13	7	65	-4	-4	-1.27	7	53.4	-4	-4.006	-1.358	7	55.8	-4.00	-4.01	-1.49	7.00	76.20

1:37:10	-4	-3.997	-1.139	7	64	-4	-4	-1.277	7	69.8	-4	-4.007	-1.357	7	53.4	-4.00	-3.99	-1.49	7.00	93.60
1:37:20	-4	-4.005	-1.147	7	55.8	-4	-4.008	-1.285	7	60.4	-4	-4.001	-1.357	7	43	-4.00	-4.01	-1.49	7.00	76.20
1:37:30	-4	-3.981	-1.156	7	76.8	-4	-4.009	-1.292	7	61.6	-4	-4.009	-1.358	7	54.6	-4.00	-4.01	-1.49	7.00	70.40
1:37:40	-4	-4.01	-1.164	7	74.4	-4	-3.998	-1.298	7	50	-4	-3.997	-1.358	7	64	-4.00	-3.99	-1.49	7.00	78.40
1:37:50	-4	-4	-1.173	7	61.6	-4	-3.995	-1.305	7	53.4	-4	-3.988	-1.358	7	55.8	-4.00	-4.01	-1.49	7.00	68.00
1:38:00	-4	-4.006	-1.18	7	65	-4	-3.999	-1.311	7	53.4	-4	-4.029	-1.357	7	46.4	-4.00	-3.99	-1.49	7.00	79.60
1:38:10	-4	-3.992	-1.188	7	65	-4	-3.992	-1.317	7	52.2	-4	-4.01	-1.357	7	59.2	-4.00	-4.01	-1.49	7.00	64.60
1:38:20	-4	-4.019	-1.196	7	66.2	-4	-3.994	-1.323	7	55.8	-4	-4.006	-1.357	7	53.4	-4.00	-4.00	-1.49	7.00	100.60
1:38:30	-4	-3.998	-1.203	7	57	-4	-4.008	-1.329	7	79	-4	-4	-1.357	7	43	-4.00	-3.99	-1.49	7.00	56.40
1:38:40	-4	-4.006	-1.211	7	62.8	-4	-3.999	-1.335	7	44.2	-4	-3.999	-1.357	7	67.4	-4.00	-4.01	-1.49	7.00	71.40
1:38:50	-4	-3.998	-1.218	7	77.8	-4	-4.021	-1.341	7	60.4	-4	-4.012	-1.357	7	52.2	-4.00	-4.00	-1.49	7.00	72.60
1:39:00	-4	-4.003	-1.225	7	62.8	-4	-4.003	-1.347	7	58.2	-4	-4.007	-1.357	7	59.2	-4.00	-4.00	-1.49	7.00	68.00
1:39:10	-4	-4.005	-1.231	7	61.6	-4	-4.003	-1.352	7	60.4	-4	-4.008	-1.357	7	53.4	-4.00	-4.00	-1.49	7.00	86.60
1:39:20	-4	-4.013	-1.238	7	64	-4	-3.996	-1.357	7	51.2	-4	-3.999	-1.357	7	43	-4.00	-4.00	-1.49	7.00	82.00
1:39:30	-4	-4.008	-1.244	7	76.8	-4	-4.001	-1.355	7	60.4	-4	-3.997	-1.357	7	67.4	-4.00	-3.99	-1.49	7.00	62.00
1:39:40	-4	-4.003	-1.25	7	57	-4	-3.992	-1.354	7	79	-4	-4	-1.357	7	51.2	-4.00	-4.01	-1.49	7.00	70.40
1:39:50	-4	-4.013	-1.256	7	61.6	-4	-3.994	-1.354	7	53.4	-4	-4.006	-1.357	7	73.2	-4.00	-4.00	-1.49	7.00	82.00
1:40:00	-4	-4.001	-1.261	7	71	-4	-3.998	-1.355	7	66.2	-4	-3.989	-1.357	7	65	-4.00	-3.99	-1.49	7.00	80.80
1:40:10	-4	-3.992	-1.268	7	65	-4	-4.016	-1.355	7	69.8	-4	-4.012	-1.357	7	60.4	-4.00	-4.01	-1.49	7.00	79.60
1:40:20	-4	-3.997	-1.273	7	64	-4	-3.993	-1.355	7	55.8	-4	-3.997	-1.358	7	73.2	-4.00	-4.00	-1.49	7.00	63.40
1:40:30	-4	-4.006	-1.278	7	64	-4	-3.995	-1.355	7	44.2	-4	-4.008	-1.358	7	48.8	-4.00	-3.99	-1.49	7.00	100.60
1:40:40	-4	-4.006	-1.284	7	87.2	-4	-4.005	-1.355	7	68.6	-4	-4.003	-1.357	7	57	-4.00	-4.01	-1.49	7.00	80.80
1:40:50	-4	-4.007	-1.289	7	58	-4	-3.999	-1.355	7	60.4	-4	-4.008	-1.357	7	77.8	-4.00	-4.00	-1.49	7.00	57.20
1:41:00	-4	-3.999	-1.295	7	62.8	-4	-4.008	-1.355	7	76.8	-4	-4.008	-1.357	7	57	-4.00	-4.01	-1.49	7.00	66.80
1:41:10	-4	-4.005	-1.299	7	72	-4	-3.995	-1.355	7	48.8	-4	-4.002	-1.357	7	82.6	-4.00	-4.00	-1.49	7.00	76.20
1:41:20	-4	-3.993	-1.305	7	62.8	-4	-3.996	-1.355	7	64	-4	-3.999	-1.358	7	57	-4.00	-4.00	-1.49	7.00	84.40
1:41:30	-4	-4.004	-1.31	7	66.2	-4	-4.018	-1.355	7	51.2	-4	-4.004	-1.358	7	53.4	-4.00	-4.00	-1.49	7.00	62.20
1:41:40	-4	-4	-1.314	7	71	-4	-3.998	-1.355	7	75.6	-4	-3.987	-1.358	7	57	-4.00	-4.00	-1.49	7.00	70.20
1:41:50	-4	-3.999	-1.319	7	73.2	-4	-4.013	-1.355	7	46.4	-4	-4.005	-1.357	7	57	-4.00	-4.00	-1.49	7.00	63.60
1:42:00	-4	-4.004	-1.323	7	62.8	-4	-4.003	-1.355	7	55.8	-4	-3.999	-1.358	7	50	-4.00	-3.99	-1.49	7.00	72.60
1:42:10	-4	-4.003	-1.328	7	73.2	-4	-4.004	-1.355	7	74.4	-4	-3.995	-1.358	7	65	-4.00	-4.01	-1.49	7.00	72.60
1:42:20	-4	-4.008	-1.33	7	62.8	-4	-4.005	-1.355	7	59.2	-4	-4	-1.358	7	50	-4.00	-4.00	-1.49	7.00	78.40
1:42:30	-4	-4.011	-1.333	7	75.6	-4	-3.997	-1.355	7	59.2	-4	-4.007	-1.358	7	52.2	-4.00	-4.01	-1.49	7.00	79.60
1:42:40	-4	-3.993	-1.336	7	64	-4	-4.009	-1.355	7	48.8	-4	-4.003	-1.358	7	64	-4.00	-4.00	-1.49	7.00	72.60
1:42:50	-4	-3.99	-1.337	7	79	-4	-4	-1.356	7	55.8	-4	-3.993	-1.358	7	52.2	-4.00	-4.00	-1.49	7.00	69.20
1:43:00	-4	-4.01	-1.338	7	71	-4	-4.006	-1.355	7	59.2	-4	-4.008	-1.358	7	69.8	-4.00	-4.01	-1.49	7.00	92.40
1:43:10	-4	-4.001	-1.338	7	61.6	-4	-4.011	-1.355	7	52.2	-4	-4	-1.358	7	60.4	-4.00	-3.99	-1.49	7.00	70.40
1:43:20	-4	-4.007	-1.338	7	71	-4	-4.004	-1.355	7	51.2	-4	-3.99	-1.358	7	61.6	-4.00	-4.01	-1.49	7.00	68.00
1:43:30	-4	-3.999	-1.338	7	67.4	-4	-4.01	-1.355	7	73.2	-4	-4.004	-1.358	7	50	-4.00	-4.00	-1.49	7.00	86.60
1:43:40	-4	-4.006	-1.338	7	64	-4	-3.994	-1.355	7	53.4	-4	-3.99	-1.358	7	53.4	-4.00	-4.00	-1.49	7.00	73.80
1:43:50	-4	-4.008	-1.337	7	66.2	-4	-4.005	-1.355	7	43	-4	-4.011	-1.358	7	53.4	-4.00	-4.00	-1.49	7.00	75.20
1:44:00	-4	-3.995	-1.338	7	87.2	-4	-4.004	-1.355	7	54.6	-4	-4.004	-1.358	7	52.2	-4.00	-3.99	-1.49	7.00	68.00
1:44:10	-4	-4.015	-1.337	7	57	-4	-4.014	-1.355	7	64	-4	-4.011	-1.358	7	55.8	-4.00	-4.00	-1.49	7.00	98.20
1:44:20	-4	-3.996	-1.337	7	66.2	-4	-4.003	-1.355	7	55.8	-4	-4.006	-1.358	7	79	-4.00	-3.99	-1.49	7.00	71.40
1:44:30	-4	-4.005	-1.337	7	64	-4	-4.006	-1.355	7	46.4	-4	-4.002	-1.358	7	44.2	-4.00	-4.00	-1.49	7.00	68.00
1:44:40	-4	-4.004	-1.336	7	67.4	-4	-3.991	-1.355	7	65	-4	-3.996	-1.358	7	58.2	-4.00	-4.02	-1.49	7.00	73.80
1:44:50	-4	-3.999	-1.337	7	59.2	-4	-3.987	-1.355	7	60.4	-4	-3.988	-1.358	7	60.4	-4.00	-3.99	-1.49	7.00	71.40
1:45:00	-4	-4.004	-1.337	7	73.2	-4	-3.994	-1.355	7	73.2	-4	-4.008	-1.358	7	51.2	-4.00	-3.99	-1.49	7.00	64.40
1:45:10	-4	-4	-1.337	7	74.4	-4	-3.989	-1.356	7	48.8	-4	-4.004	-1.358	7	60.4	-4.00	-3.99	-1.49	7.00	73.60

1:45:20	-4	-4.01	-1.336	7	68.6	-4	-4.009	-1.356	7	57	-4	-3.993	-1.357	7	57	-4.00	-4.00	-1.49	7.00	86.60
1:45:30	-4	-3.996	-1.334	7	64	-4	-3.997	-1.356	7	77.8	-4	-4.003	-1.357	7	82.6	-4.00	-4.00	-1.49	7.00	76.20
1:45:40	-4	-4.007	-1.336	7	69.8	-4	-3.982	-1.355	7	47.6	-4	-4.004	-1.357	7	53.4	-4.00	-4.00	-1.49	7.00	78.40
1:45:50	-4	-3.995	-1.336	7	82.6	-4	-3.999	-1.356	7	65	-4	-3.993	-1.358	7	60.4	-4.00	-4.01	-1.49	7.00	86.60
1:46:00	-4	-4.008	-1.336	7	58	-4	-3.99	-1.356	7	65	-4	-4.008	-1.358	7	65	-4.00	-4.00	-1.49	7.00	66.80
1:46:10	-4	-4.006	-1.336	7	77.8	-4	-3.985	-1.356	7	53.4	-4	-4.007	-1.357	7	52.2	-4.00	-4.01	-1.49	7.00	94.80
1:46:20	-4	-4	-1.336	7	73.2	-4	-3.989	-1.355	7	67.4	-4	-3.995	-1.357	7	64	-4.00	-4.00	-1.49	7.00	77.40
1:46:30	-4	-3.988	-1.336	7	68.6	-4	-3.985	-1.356	7	51.2	-4	-4.007	-1.357	7	53.4	-4.00	-3.99	-1.49	7.00	66.60
1:46:40	-4	-4.002	-1.336	7	68.6	-4	-3.994	-1.356	7	65	-4	-3.99	-1.357	7	52.2	-4.00	-4.00	-1.49	7.00	75.00
1:46:50	-4	-3.998	-1.336	7	69.8	-4	-3.986	-1.356	7	48.8	-4	-4.017	-1.358	7	55.8	-4.00	-4.00	-1.49	7.00	85.40
1:47:00	-4	-3.99	-1.336	7	86	-4	-4.002	-1.356	7	59.2	-4	-3.987	-1.358	7	79	-4.00	-3.99	-1.49	7.00	79.60
1:47:10	-4	-4.001	-1.336	7	74.4	-4	-3.993	-1.356	7	58.2	-4	-3.997	-1.358	7	44.2	-4.00	-4.00	-1.49	7.00	75.00
1:47:20	-4	-4.013	-1.335	7	65	-4	-3.997	-1.356	7	57	-4	-4.009	-1.357	7	60.4	-4.00	-3.99	-1.49	7.00	76.20
1:47:30	-4	-3.994	-1.336	7	61.6	-4	-4	-1.356	7	68.6	-4	-3.998	-1.358	7	58.2	-4.00	-4.00	-1.49	7.00	61.40
1:47:40	-4	-4.006	-1.336	7	65	-4	-4.001	-1.356	7	61.6	-4	-3.999	-1.358	7	68.6	-4.00	-3.99	-1.49	7.00	79.60
1:47:50	-4	-3.988	-1.334	7	66.2	-4	-4.007	-1.356	7	60.4	-4	-4.009	-1.358	7	60.4	-4.00	-3.99	-1.49	7.00	70.40
1:48:00	-4	-4	-1.334	7	68.6	-4	-4.002	-1.356	7	48.8	-4	-4	-1.358	7	67.4	-4.00	-4.01	-1.49	7.00	73.80
1:48:10	-4	-3.989	-1.335	7	59.2	-4	-4.01	-1.356	7	59.2	-4	-4.001	-1.358	7	81.4	-4.00	-4.00	-1.49	7.00	82.00
1:48:20	-4	-3.987	-1.335	7	72	-4	-4.015	-1.356	7	73.2	-4	-4.01	-1.358	7	60.4	-4.00	-4.01	-1.49	7.00	71.40
1:48:30	-4	-4.01	-1.335	7	66.2	-4	-4.003	-1.356	7	67.4	-4	-4.011	-1.358	7	65	-4.00	-4.00	-1.49	7.00	85.40
1:48:40	-4	-4	-1.335	7	68.6	-4	-4.001	-1.356	7	45.2	-4	-4.004	-1.358	7	76.8	-4.00	-4.01	-1.49	7.00	75.40
1:48:50	-4	-3.986	-1.335	7	62.8	-4	-3.993	-1.356	7	71	-4	-4.009	-1.358	7	64	-4.00	-3.99	-1.49	7.00	73.80
1:49:00	-4	-4.001	-1.335	7	64	-4	-4.006	-1.356	7	54.6	-4	-4	-1.358	7	74.8	-4.00	-4.01	-1.49	7.00	77.40
1:49:10	-4	-3.99	-1.335	7	67.4	-4	-3.998	-1.356	7	82.6	-4	-4.002	-1.358	7	72	-4.00	-4.00	-1.49	7.00	66.80
1:49:20	-4	-4	-1.335	7	62.8	-4	-4.01	-1.356	7	41.8	-4	-4.003	-1.358	7	59.2	-4.00	-3.99	-1.49	7.00	63.60
1:49:30	-4	-3.997	-1.335	7	76.8	-4	-4.017	-1.356	7	57	-4	-4.004	-1.358	7	61.6	-4.00	-4.00	-1.49	7.00	70.40
1:49:40	-4	-3.995	-1.335	7	71	-4	-3.998	-1.356	7	51.2	-4	-3.999	-1.358	7	62.8	-4.00	-4.01	-1.48	7.00	85.40
1:49:50	-4	-3.992	-1.335	7	68.6	-4	-4.01	-1.356	7	50	-4	-4.003	-1.358	7	71	-4.00	-3.99	-1.47	7.00	71.00
1:50:00	-4	-4.003	-1.335	7	67.4	-4	-3.995	-1.356	7	65	-4	-4.001	-1.358	7	68.6	-4.00	-4.00	-1.47	7.00	70.40
1:50:10	-4	-4.01	-1.335	7	60.4	-4	-4.004	-1.356	7	47.6	-4	-3.999	-1.359	7	65	-4.00	-4.00	-1.47	7.00	73.60
1:50:20	-4	-4.01	-1.335	7	75.6	-4	-4.011	-1.356	7	71	-4	-3.992	-1.358	7	57	-4.00	-3.99	-1.47	7.00	68.00
1:50:30	-4	-4.011	-1.335	7	71	-4	-3.994	-1.356	7	57	-4	-4.001	-1.358	7	72	-4.00	-4.01	-1.47	7.00	103.00
1:50:40	-4	-4	-1.335	7	73.2	-4	-3.998	-1.356	7	52.2	-4	-4.002	-1.358	7	65	-4.00	-3.99	-1.47	7.00	96.20
1:50:50	-4	-3.999	-1.335	7	80.2	-4	-4.014	-1.356	7	48.8	-4	-4	-1.358	7	69.8	-4.00	-4.00	-1.47	7.00	77.20
1:51:00	-4	-3.997	-1.335	7	61.6	-4	-4.007	-1.356	7	66.2	-4	-4.012	-1.357	7	44.2	-4.00	-4.00	-1.47	7.00	83.20
1:51:10	-4	-4.006	-1.335	7	80.2	-4	-4.009	-1.356	7	58.2	-4	-3.993	-1.356	7	64	-4.00	-3.99	-1.47	7.00	96.00
1:51:20	-4	-3.994	-1.335	7	59.2	-4	-4.012	-1.356	7	65	-4	-4.005	-1.356	7	52.2	-4.00	-4.00	-1.47	7.00	75.00
1:51:30	-4	-3.997	-1.335	7	87.2	-4	-4.009	-1.356	7	52.2	-4	-3.995	-1.356	7	61.8	-4.00	-3.99	-1.48	7.00	71.20
1:51:40	-4	-4.007	-1.335	7	57	-4	-4.001	-1.356	7	75.6	-4	-4.004	-1.356	7	75.6	-4.00	-4.01	-1.49	7.00	68.00
1:51:50	-4	-4.006	-1.335	7	67.4	-4	-4.012	-1.356	7	51.2	-4	-3.984	-1.356	7	51.2	-4.00	-4.02	-1.49	7.00	78.00
1:52:00	-4	-3.995	-1.335	7	68.6	-4	-4.004	-1.356	7	45.2	-4	-4.004	-1.356	7	45.2	-4.00	-4.01	-1.49	7.00	97.20
1:52:10	-4	-4.002	-1.335	7	68.6	-4	-4.016	-1.357	7	68.6	-4	-3.998	-1.356	7	68.6	-4.00	-4.01	-1.49	7.00	71.40
1:52:20	-4	-3.998	-1.335	7	62.8	-4	-4.001	-1.356	7	57	-4	-3.995	-1.356	7	57	-4.00	-4.01	-1.49	7.00	76.80
1:52:30	-4	-4.007	-1.335	7	69.8	-4	-4.007	-1.356	7	55.8	-4	-4.003	-1.356	7	55.8	-4.00	-4.00	-1.49	7.00	60.20
1:52:40	-4	-4.01	-1.335	7	86	-4	-3.999	-1.356	7	58.2	-4	-3.989	-1.357	7	58.2	-4.00	-4.00	-1.49	7.00	84.40
1:52:50	-4	-3.993	-1.334	7	59.2	-4	-4.008	-1.357	7	71	-4	-3.999	-1.356	7	71	-4.00	-4.00	-1.49	7.00	70.20
1:53:00	-4	-4.003	-1.335	7	73.2	-4	-4.004	-1.356	7	52.2	-4	-3.99	-1.356	7	52.2	-4.00	-4.00	-1.49	7.00	106.40
1:53:10	-4	-3.998	-1.334	7	76.8	-4	-4.009	-1.356	7	60.4	-4	-4.002	-1.356	7	60.4	-4.00	-4.00	-1.49	7.00	85.40
1:53:20	-4	-3.999	-1.335	7	66.2	-4	-3.999	-1.357	7	51.2	-4	-3.995	-1.357	7	51.2	-4.00	-4.00	-1.49	7.00	71.00

1:53:30	-4	-4.006	-1.335	7	60.4	-4	-3.999	-1.356	7	60.4	-4	-3.997	-1.356	7	60.4	-4.00	-4.01	-1.49	7.00	70.40
1:53:40	-4	-3.985	-1.335	7	74.4	-4	-4.005	-1.356	7	67.4	-4	-3.998	-1.356	7	67.4	-4.00	-3.99	-1.49	7.00	82.20
1:53:50	-4	-4.006	-1.335	7	71	-4	-3.999	-1.357	7	48.8	-4	-4	-1.357	7	48.8	-4.00	-4.02	-1.49	7.00	73.60
1:54:00	-4	-3.999	-1.335	7	68.6	-4	-4.007	-1.357	7	51.2	-4	-4.004	-1.356	7	51.2	-4.00	-4.00	-1.49	7.00	68.00
1:54:10	-4	-4.008	-1.335	7	83.8	-4	-4.006	-1.357	7	86	-4	-4.003	-1.356	7	86	-4.00	-4.00	-1.49	7.00	103.0 0
1:54:20	-4	-4.007	-1.335	7	75.6	-4	-4	-1.357	7	45.2	-4	-4.006	-1.356	7	52.2	-4.00	-4.01	-1.49	7.00	96.20
1:54:30	-4	-3.995	-1.335	7	81.4	-4	-3.99	-1.357	7	55.8	-4	-3.995	-1.355	7	54.6	-4.00	-3.99	-1.49	7.00	77.20
1:54:40	-4	-3.996	-1.335	7	60.4	-4	-4.004	-1.357	7	61.6	-4	-4.001	-1.356	7	64	-4.00	-4.00	-1.49	7.00	83.20
1:54:50	-4	-4.005	-1.334	7	74.4	-4	-3.997	-1.357	7	72	-4	-3.995	-1.356	7	47.6	-4.00	-3.99	-1.49	7.00	96.00
1:55:00	-4	-3.989	-1.335	7	73.2	-4	-4	-1.357	7	52.2	-4	-4.01	-1.356	7	60.4	-4.00	-4.00	-1.49	7.00	68.00
1:55:10	-4	-4	-1.335	7	67.4	-4	-3.996	-1.357	7	54.6	-4	-4.007	-1.356	7	54.6	-4.00	-3.99	-1.49	7.00	78.00
1:55:20	-4	-3.999	-1.334	7	68.6	-4	-4.008	-1.357	7	64	-4	-3.998	-1.356	7	69.8	-4.00	-4.00	-1.49	7.00	87.20
1:55:30	-4	-3.995	-1.335	7	67.4	-4	-3.991	-1.357	7	47.6	-4	-4.002	-1.356	7	48.8	-4.00	-4.00	-1.49	7.00	63.60
1:55:40	-4	-4.005	-1.335	7	62.8	-4	-4.007	-1.357	7	60.4	-4	-4.015	-1.356	7	68.6	-4.00	-4.02	-1.49	7.00	70.40
1:55:50	-4	-3.999	-1.335	7	68.6	-4	-3.991	-1.357	7	54.6	-4	-4.005	-1.356	7	60.4	-4.00	-4.00	-1.49	7.00	70.40
1:56:00	-4	-4.008	-1.335	7	67.4	-4	-3.988	-1.357	7	69.8	-4	-4.004	-1.356	7	54.6	-4.00	-3.99	-1.49	7.00	73.60
1:56:10	-4	-3.992	-1.329	7	62.8	-4	-3.997	-1.357	7	48.8	-4	-4.017	-1.356	7	75.6	-4.00	-4.01	-1.49	7.00	68.00
1:56:20	-4	-4.006	-1.326	7	65	-4	-3.987	-1.358	7	68.6	-4	-3.999	-1.356	7	60.4	-4.00	-4.01	-1.49	7.00	103.0 0
1:56:30	-4	-3.992	-1.325	7	74.4	-4	-3.999	-1.358	7	60.4	-4	-4.006	-1.356	7	50	-4.00	-3.99	-1.49	7.00	96.20
1:56:40	-4	-4.005	-1.318	7	65	-4	-3.996	-1.357	7	54.6	-4	-4.012	-1.356	7	52.2	-4.00	-4.00	-1.49	7.00	71.20

8.11 Manual for using the 15L EFC reactor

Installation, Operation and Maintenance of a 15L Eutectic Freeze Crystalliser

Hon-Chuk Yu Varun Gupta Prof. Geert-Jan Witkamp

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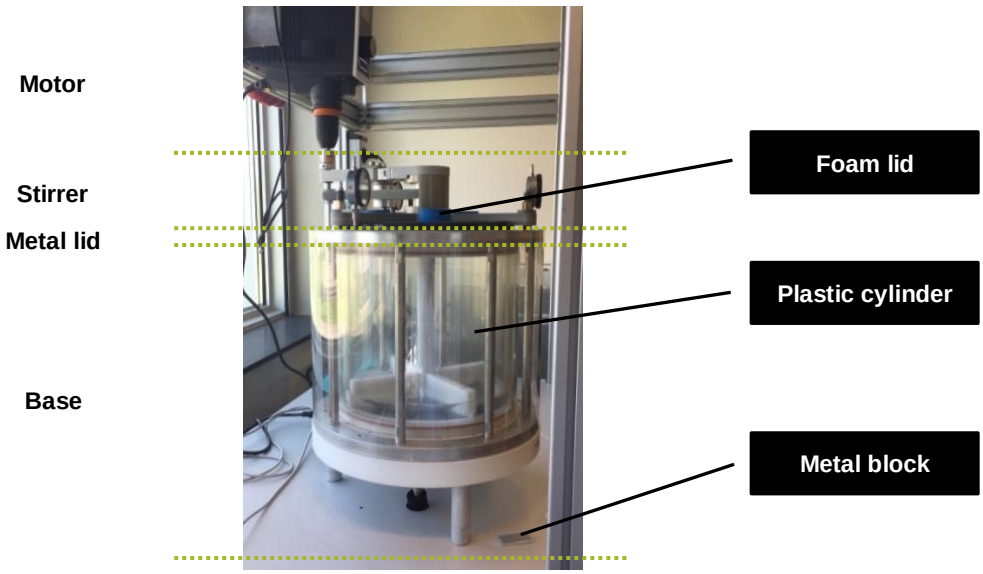
1. Introduction

This manual is for the use of installing, operating and maintaining a 15L eutectic freeze crystalliser. The following equipment are involved in the subject matter:

- 15L eutectic freeze crystalliser designed by DEMO, TU Delft
- LAUDA Proline Kryomat RP 4090 CW Cooling thermostat
- Heidolph Hei-TORQUE 400

2. Installation

The following is the assembling order of the crystalliser and the corresponding remarks for each step:



Side view of the crystalliser

2.1. Base

3 legs of the base should be fixed with screws and screw nuts, two legs at the front and one leg at the back. The outlet should be expected to be at the front right side.

2.2. Metal lid

8 holes should be fixed with screws and screw nuts on the rods of the Base, a smaller side hole for vacuum should be at 2 o'clock position back right. Be aware of the fitting of O-rings when installing.

2.3. Plastic cylinder

A plastic cylinder for protecting purpose should be installed from the top of the reactor and sat perfectly on the base.

2.4. Stirrer

Each screw thread of the 3 suspended arms should be installed on top of the Metal lid, the belt should be positioned at the straight back. Screw down the stirrer evenly until all suspended arms are leveled 1mm above the Metal lid. A specialized metal block should be used for ensuring the leveling, the gaps should be just wide enough to have the block placed and removed. Last, three dials on the stirrer should have their zeros pointed, if not, rotate the dials by the surrounded black rings to ensure the pointers pointed to the zeros.

2.5. Motor

Ensure the orange piece is put between the joints of the motor and the stirrer. A slight gap should be remained in between in case of whirring.

2.6. Tubes from vacuum pump and thermostat

A vacuum tube should be connected on the back right part of the Metal lid. Tubes for transporting coolant should be connected to the Base bottom, left in and right out.

2.7. Foam lid

3 lids should be put above Metal lid for coverage. One lid with a dent on the side should be installed at the back. Another one with a small hole on top should have the thermo-prop of the thermostat inserted and placed on the left. The complete one is for the right.

3. Operation

The steps below are important for a successful eutectic freeze crystallization.

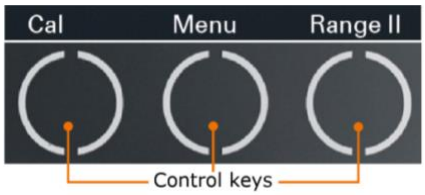
3.1 Start by turning on the thermostat and check if there is enough cooling liquid in the bath. Turn on the water tap linked to the thermostat to ensure sufficient water go through the thermostat for its own cooling.

3.2 Remove the foam lid and pour desired testing solution into the EFC. Place the lids back when it is done.

3.3 Insert the external thermometer of the thermostat in the EFC solution. Make sure the thermometer gets contact with the solution and cannot hit the scraper.

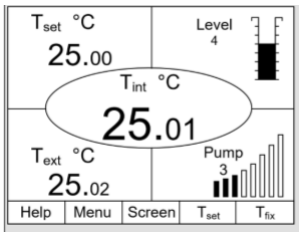
3.4 Make sure the scraper is perfectly calibrated by using the calibration blocks (1mm thick). Start the scraper with desired RPM.

3.5 Run the scraper for 20-30 minutes, so it is heated up. Press “Cal” on the scraper so the torque is calibrated to 0. This makes it easier to spot scaling later on.



Main buttons of the Hei-TORQUE Precision 400

3.6 Input set temperature of the thermostat and press run. This can be done on either the computer or the bath itself. Input other desired settings as well, such as pump speed.



Home Screen of Lauda. Press Menu to adjust many settings. Press "T_{set}" to change target temperature. Press Screen to showcase a different home screen.

3.7 Remove thermostat from standby mode so it starts running. Make sure the cooling tubes are not leaking, otherwise stop the reactor immediately.

3.8 Make sure the difference between the cooling liquid and the EFC liquid is not too large. Big gaps between the two might cause scaling. Set temperature to 0 first and wait for it to stabilize. Once stabilized, slowly drop the temperature to designated eutectic temperature. By rule of thumb, at steady condition, the temperature difference between the coolant and solution is 3 °C.

3.9 Once nearing the eutectic point, add ice crystals in order to seed ice crystal growth on the top of the reactor. If the ice seeds do not melt, the eutectic point is (nearly) reached.

3.10 Monitor the torque of the scraper once the eutectic point is reached. A sudden increase in torque means scaling is occurring. By rule of thumb, the torque will increase to about 150Ncm and scaling ice will be broken and large pieces of ice would be observed floating on solution top. If not, scaling can be removed by either increasing the pressure of the scraper or by temporarily increasing the thermostat temperature.

3.11 Salt and slurry samples can be taken from the bottom outlet.

3.12 Increase the thermostat temperature when the experiment is finished. Make sure all ice is melted and most salt crystals are dissolved back into the solution. The liquid can then be removed. Solution removal can be done through the sample outlet. Then, follow *Section 4. Maintenance* to fully clean the reactor.

4. Maintenance

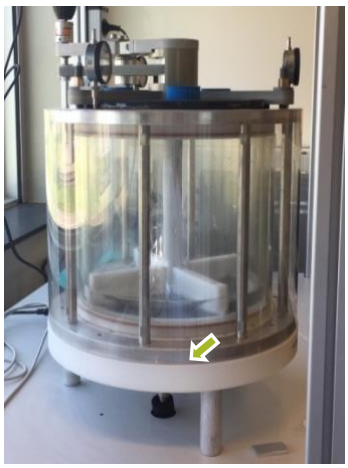
Actions below are required to be aware and taken for maintaining the crystalliser:

4.1. The container of the reactor needs to be drained (from the bottom tap) after every experiment.

4.2. At least four times of rinsing inside the container is preferred as to ensure no salt or salt ion is remained. Ensure the blade and its connecting rod are also been rinsed.

4.3. Wipe everything inside the container with fresh tissue towel to make sure the container is dry and clean.

4.4. As there is a minimal leakage issue and condensation occurred on the reactor, do wipe away the crystals, which are formed around the outer base of the reactor, during and after the experiment.



Pointed area mostly has crystal formation.

4.5. If anything gets into the vacuum chamber of the crystalliser, stop the experiment immediately. Then, disassemble the motor and the lid of the reactor. Use a narrow long needle to insert into the chamber and suck out the matter. Last, if non-solids are involved, use tissues or thin cottons to absorb the remaining inside the chamber to ensure the chamber is clean. Noted the chamber is 3mm wide and be aware of not making any scratches on the glass walls.

5. Connection to the computer

These steps allow you to connect the thermostat and the motor to the computer.

Thermostat

5.1 Thermostat can be connected to the computer using a serial cable. Connect the serial cable to the back of the thermostat controller and the computer.

5.2 Install Wintherm Plus from www.lauda-brinkmann.com/software-downloads.html

5.3 Run Wintherm Plus and add a new device. Select correct cable number and choose RS-232 connection and a Baudrate of 9600. The device is now connected. This program can then be used to control the Lauda.

Motor

5.4 The motor can be connected to the computer with a USB cable. The motor supplies its software with a USB stick, but can also be found on https://heidolph-instruments.com/en/service/downloads/software

5.5 The program can be used to make certain RPM schedules and record the torque.

6. Further readings

- Manual for LAUDA Proline Kryomat RP 4090 CW Cooling thermostat:
  http://www.lauda-brinkmann.com/downloads/manuals/RP_3050_4050_3090_4090_C_CW.PDF

- Manual for Heidolph Hei-TORQUE 400:
  https://pdfs.wolflabs.co.uk/service/Heidolph_overhead_stirrer_Hei-Torque_manual.pdf

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