

# Options to Improve Water Quality and Operation of Treatment at Rud Svømmehall (Bærum)

Alternativer for forbedring av vannkvalitet og vannbehandlingsprosesser ved Rud svømmehall (Bærum)

## Bachelor Thesis in Chemical Engineering

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## Preface

Through working with the thesis “Options to Improve Water Quality and Operation of Treatment at Rud Svømmehall (Bærum)” the group has gained knowledge regarding the treatment of pool water treatment. The bachelor thesis was offered to the group by Aquateam COWI through NTNU SIAT, where Bærum kommune is the project owner. Initially, the group found the thesis interesting because it involved different parts of our syllabus, such as microbiology, analytical chemistry, and chemical engineering. As the thesis changed its main focus and developed into a more complex and challenging project, we broadened our chemical engineering knowledge to include water treatment. Through the project, we have gained insight into fieldwork, the development and sudden changes in a project. The group has gained an understanding of the amount of planning necessary to complete a project of this scale, such as organization with different departments at NTNU, and travel organization for fieldwork in Oslo. We have also learned how to organize a project despite sudden changes such as Covid-19 sickness and restrictions. We have found the project very rewarding, and our interest in the topic of water treatment has sparked.

The group recognizes the trust the supervisors have given to us. We appreciate the opportunity to work with a real-life project that provides great insight into what future projects might look like. The group is very grateful for all help, locations and the thesis offered by Aquateam COWI by Dr.-Ing. Wolfgang Uhl. The group also wants to offer a special thanks to Ocelie Kjønnø and Sr. scientist Janka Dibdiakova for help with laboratory work and guidance. We also want to thank Bård Reil for being welcoming and helpful at the facility. Moreover, we want to thank the laboratory personnel at NTNU, who have conducted our analyses, Sr. Ing. Anica Simic, Prof. Øyvind Mikkelsen, and Marina Fernandez-Delgado Juarez. The group also wants to thank Joakim Tafjord for help with mass balances. Lastly, we also want to thank our supervisors AP. Ina Merete Stuen and Sr. Ing. Bjørn Aas for all guidance and help with logistics.

The group hopes that the thesis is helpful for Rud svømmehall, and other swimming facilities, and provides a basis for further research.

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## Abstract

Bathers leave several contaminants while using a swimming pool, such as sweat, urine, hair, cosmetics and dead skin cells. These substances can accumulate over time, thus treatment of the water is crucial. The water treatment mainly consist of the addition of a coagulant, which forms flocs that can be removed in an activated glass (AG) filter, before further removal of organic material in a granular activated carbon (GAC) filter. The last steps of the treatment processes involves the use of UV disinfection and chlorination of the water. The substances present in pool water are often divided into hydrophilic and hydrophobic groups. Smaller hydrophilic substances have a high affinity for the positively charged coagulant. Larger and more hydrophobic particles have a higher affinity for the GAC filter. The coagulant dosage used in a swimming pool should be selected based on the properties of the pool water. The properties of the pool water will also influence the capacity and bed life of the filter.

This thesis is based on the swimming facility Rud svømmehall in Bærum kommune, and is a further work on the bachelor thesis of Alessia Silvestro. The purpose of the thesis is to investigate the optimal coagulant dosage of aluminium chloride for the pool water, along with calculations of the filter capacity and bed life of the GAC filter.

The optimal coagulant dosage for the pool water was determined through a jar test prior to analyses of total particle concentration, DOC concentration and dissolved aluminium concentrations from the ICP-MS. The capacity of the GAC filter was calculated by the addition of different amounts of powdered activated carbon (PAC) to the same volumes of water. Based on the amount of DOC adsorbed, adsorption isotherms were plotted, and further used to calculate the capacity and bed life of the filter. In addition to these measurements, mass balances have been calculated, the amount of disinfectant added to the pool water have been estimated and there has been an investigation of the amount of heavy metals present in the pool water. The results from the particle measurements indicated an optimal coagulant dosage of 6 mg/L. The DOC measurements and the aluminium measurements from the ICP-MS were not conclusive as to which coagulant dosage was the most optimal. The capacity of the GAC filter was calculated to be 5.2 and 70.1 (mg/g)(L/mg)<sup>1/n</sup> with an estimated bed life of 564 days (1.55 years).

Keywords: swimming pool water, total particle concentration, dissolved organic carbon, coagulant, granular activated carbon, chlorine concentrations.

## Sammendrag

Mennesker forurensrer svømmebasseng med ulike stoffer, slik som svette, urin, hår, kosmetikk og døde hudceller. Uten behandling vil disse stoffene lagres i vannet over tid. Det er dermed viktig med gode vannbehandlingsprosesser for å minimere konsentrasjonen av disse stoffene. Vannbehandling involverer ofte tilsetning av en koagulant som danner flokker, hvor disse videre kan fjernes i et aktivert glassfilter (AG). Videre fjernes organiske molekyler fra vannet ved hjelp av et granulært aktivt karbonfilter (GAC). Før vannet reintroduseres til bassenget, desinfiseres det ved hjelp av UV-stråling, og tilsats av klor. Stoffene tilstede i vann klassifiseres gjerne som hydrofobe og hydrofile. Små hydrofile stoffer har ofte en høy affinitet for koagulanten, mens større og mer hydrofobe partikler har en høyere affinitet for GAC-filteret. Koagulantdosen som benyttes i svømmeanlegget burde basere seg på egenskapene til bassengvannet. Bassengvannets egenskaper vil også ha en innvirkning på kapasiteten og levetiden til filteret.

Denne oppgaven tar for seg svømmeanlegget Rud svømmehall i Bærum kommune, og er et viderearbeid av Alessia Silvestros bacheloroppgave. Hensikten med oppgaven er å finne den mest optimale koagulantdoseringen av aluminiumklorid i bassengvannet, i tillegg til beregninger av filterkapasiteten og levetiden til GAC-filteret.

Den optimale koagulantdoseringen i bassengvannet ble bestemt ved bruk av jar-tester før videre analyser av total partikkel-konsentrasjon, DOC-konsentrasjonen og konsentrasjonen av løst aluminium ved hjelp av ICP-MS. Kapasiteten til GAC-filteret ble beregnet ved å gjennomføre forsøk hvor ulike mengder pulverisert aktivert karbon (PAC) ble tilsatt til en bestemt mengde vann. Basert på målingene av adsorbent DOC ble adsorpsjonsisotermer plottet, og videre brukt for å beregne kapasiteten og levetiden til filteret. I tillegg til disse målingene, ble det gjennomført massebalanser, estimeringer av desinfeksjonsmiddel tilsatt badevannet, i tillegg til å undersøke mengden tungmetaller som finnes i bassengvannet. Hovedresultatene i oppgaven er at partikkelmålingene indikerer at en koagulantdosering på 6 mg/L er den mest optimale. Resultatene fra målingene av DOC og mengden oppløst aluminium fra ICP-MS tilsier at det ikke kan trekkes en konklusjon til den mest optimale koagulantdoseringen. Kapasiteten til GAC-filteret ble beregnet til å være  $5.2$  og  $70.1$   $(\text{mg/g})(\text{L/mg})^{1/n}$  med en estimert levetid på 564 dager (1.55 år).

Nøkkelbegreper: bassengvann i svømmehaller, total partikkel-konsentrasjon, oppløst organisk karbon, koagulant, granulært aktivert kull, klorkonsentrasjoner

## Table of Contents

<b>PREFACE</b> .....	<b>2</b>
<b>ABSTRACT</b> .....	<b>3</b>
<b>SAMMENDRAG</b> .....	<b>4</b>
<b>ABBREVIATIONS AND ACRONYMS</b> .....	<b>7</b>
<b>LIST OF FIGURES</b> .....	<b>8</b>
<b>LIST OF TABLES</b> .....	<b>10</b>
<b>1. INTRODUCTION</b> .....	<b>11</b>
<b>2. THEORY</b> .....	<b>12</b>
2.1 REGULATIONS FOR SWIMMING POOL WATER .....	12
2.1.1 Contamination and Treatment of Pool Water.....	12
2.1.2 Laws and Swimming Pool Standards .....	13
2.1.3 Disinfection Criteria.....	14
2.2 COAGULANT, ICP-MS, AND PARTICLE MEASUREMENTS.....	14
2.2.1 COAGULANT.....	14
2.2.1.1 The Importance of Coagulation and Flocculation in Water Treatment.....	14
2.2.1.2 Effect of Coagulants on Particle Stability .....	15
2.2.1.3 The Electrical Double Layer.....	16
2.2.1.4 The Function and Properties of a Coagulant .....	17
2.2.1.5 Jar Test and Coagulant Dosages .....	18
2.2.1.6 The Function of Aluminium and Iron Salts.....	18
2.2.2 FUNCTIONS AND USE OF INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY .....	21
2.2.3 PARTICLE CONCENTRATION MEASUREMENTS.....	21
2.3 FUNDAMENTALS OF ACTIVATED CARBON AND ADSORPTION PHENOMENA.....	23
2.3.1 Dissolved Organic Carbon and Activated Carbon in Water Treatment .....	23
2.3.2 Preparations of Activated Carbon .....	23
2.3.3 Surface Chemistry and Chemical Bonding Responses .....	24
2.3.4 Activated Carbon Types.....	24
2.3.5 Adsorption Phenomena in Water Treatment .....	25
2.3.6 Surface Chemistry and Forces Involved in Physical Adsorption .....	26
2.3.7 Adsorption Isotherm and its Equilibriums Equations .....	26
2.3.7.1 Freundlich Isotherm Equation.....	27
2.3.8 Breakthrough Curve and Filter Capacity.....	28
2.3.9 Spectrophotometric Measurements of DOC.....	30
2.4 FREE, COMBINED, AND TOTAL CHLORINE .....	31
2.5 MASS BALANCE AND CALCULATIONS FROM BATCH TO CONTINUOUS PROCESSES.....	32
<b>3. MATERIALS AND METHODS</b> .....	<b>33</b>
3.1 TREATMENT PROCESSES AND TECHNICAL INFORMATION ABOUT RUD SVØMMEHALL.....	33
3.2 METHOD .....	37
3.2.1 Gathering of Samples at Rud Svømmehall .....	37
3.2.1.1 Free, Total, and Combined Chlorine for sampling points .....	38
3.2.1.2 ICP-MS Analyses of Sampling Points.....	38
3.2.1.3 Particle Measurements.....	39
3.2.1.4 SAC <sub>254</sub> and DOC Measurements.....	40
3.2.2 Determination of the Optimal Coagulant Dosage through Jar Test.....	40
3.2.2.1 Jar Test .....	40
3.2.2.2 Particle concentration measurements.....	42
3.2.2.3 ICP-MS.....	42
3.2.3 Adsorption isotherms.....	42
3.2.3.1 Experiment to Determine Adsorption isotherms .....	42
3.2.3.2 Spectrophotometry and Dissolved Organic Carbon Adsorption Isotherms.....	43

<b>4</b>	<b>RESULTS AND DISCUSSION .....</b>	<b>44</b>
4.1	RESULTS FROM SAMPLING POINTS AT RUD SVØMMEHALL .....	44
4.1.1	Free, Total, and Combined Chlorine .....	44
4.1.1.1	Measurements of Free, Total, and Combined Chlorine .....	44
4.1.1.2	Calculations of Disinfectant Dosage from ICP-MS Results .....	47
4.1.2	SAC and DOC Measurements of the Sampling Points .....	48
4.1.3	Aluminium from ICP-MS Measurements .....	51
4.1.4	Particle measurements .....	53
4.1.5	Trace elements and heavy metals in pool water .....	56
4.2	DETERMINATION OF OPTIMAL COAGULANT DOSAGE .....	58
4.2.1	Particle measurements after jar test .....	58
4.2.2	DOC Removal with Coagulant .....	62
4.2.3	Amount of Dissolved and Particulate Aluminium in Coagulation Tests .....	66
4.2.4	Comparison of Measurements After Jar Test .....	69
4.3	CALCULATION OF FILTER CAPACITY AND BED LIFE THROUGH ADSORPTION ISOTHERMS .....	69
4.3.1	Determination of Filter Capacity .....	69
4.3.2	Calculation of bed life .....	75
4.4	MASS BALANCES .....	76
<b>4</b>	<b>CONCLUSION .....</b>	<b>78</b>
<b>5</b>	<b>OUTLOOK .....</b>	<b>79</b>
	<b>LIST OF REFERENCES .....</b>	<b>80</b>
	<b>APPENDIX 1 – PRODUCT INFORMATION FROM CARBOTECH .....</b>	<b>II</b>
	<b>APPENDIX 2 – CALCULATIONS.....</b>	<b>III</b>
2.1	CALCULATIONS FOR 0.01 M NITRIC ACID .....	III
2.2	CALCULATIONS OF THE ISOTHERMS .....	IV
2.3	CALCULATION OF VOLUME NaOCl AND Ca(OCl) <sub>2</sub> ADDED BASED ON ICP-MS RESULTS .....	VII
2.4	CALCULATIONS OF BED LIFE .....	XI
2.5	DETERMINING DOC <sub>NONADS</sub> AND SAC <sub>254, NONADS</sub> .....	XII
2.6	MASS BALANCE .....	XIV
	<b>APPENDIX 3 – PROCESS SCHEMES OF OPERATION UNITS AT RUD SVØMMEHALL .....</b>	<b>XVIII</b>
	<b>APPENDIX 4 – RISK ASSESSMENT .....</b>	<b>XXIII</b>
	<b>APPENDIX 5 – INSTRUCTION MANUAL, HACH LANGE LCK310 .....</b>	<b>XXVIII</b>
	<b>APPENDIX 6 – TUNE PARAMETERS FOR AGILENT TECHNOLOGIES, AGILENT 8800 QQQ .....</b>	<b>XXXI</b>
	<b>APPENDIX 7 – INSTRUCTION MANUAL KLOTZ PCSS FLUID LITE .....</b>	<b>XXXII</b>
	<b>APPENDIX 8 – TUNE PARAMETERS FOR SHIMADZ TOC-L .....</b>	<b>XLIII</b>
	<b>APPENDIX 9 – SAFETY DATA SHEET FOR COAGULANT, BWT-FLOCK .....</b>	<b>XLIV</b>
	<b>APPENDIX 10 – OPERATING MANUAL, KEMIRA FLOCCULATOR 2000 .....</b>	<b>LIII</b>
	<b>APPENDIX 11 – SAMPLE INFORMATION .....</b>	<b>LXV</b>

## Abbreviations and Acronyms

AF	Acidified before filtration
AG	Activated glass
CCC	Critical coagulation concentration
Cl/N	Ratio of chlorine to nitrogen
DBP	Disinfection byproduct
DGK	CarboTech DGK 8x30/60
DOC	Dissolved organic carbon
EDL	Electrical double layer
FA	Fulvic acid
FA	Filtrated before acidification
GAC	Granular activated carbon
HA	Humic acid
IC	Inorganic carbon
ICP	Inductively Coupled Plasma
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
m/z-value	Mass-charge-ratio
MS	Mass Spectrometry
MTZ	Mass-transfer zone
NOM	Natural organic matter
PAC	Powder activated carbon
SAC <sub>254</sub>	Spectral adsorption coefficient at 254 nm
TOC	Total organic carbon
UV	Ultraviolet
UV-VIS	Ultraviolet-visible spectroscopy
UV <sub>254</sub>	Ultra violet adsorption at 254 nm
W 1-3	CarboTech Pool W 1-3
ZPC	Zero point charge

## List of Figures

Figure 1: Hydrophobic and hydrophilic substances involved in the two main fractions of NOM. [10].....	12
Figure 2: Structure of electric double layer. The zeta potential is marked on the figure and represents the potential at the shear plane. [15] .....	16
Figure 3: Solubility diagram of Al(III) in (a) and of Fe(III) in (b) at 25°C. Only mononuclear species are shown in the two diagrams, and these species are assumed to be in equilibrium with the solid precipitate. Gathered from page 564 from [13].....	19
Figure 4: The figure shows different size ranges for different particles. [23] .....	22
Figure 5: Principle of particle counter measurements. 1: laser beam, 2: lens system, 3: measure area, 4: detection. [6] .....	22
Figure 6: Illustration of activated carbon with different pores (macro, meso and micro), and corresponding pore size radius. [25] [26] [27].....	24
Figure 7: The figure shows adsorption in a real fixed bed and the corresponding breakthrough curve . [32] .....	28
Figure 8: The figure shows the adsorption isotherms for different cases of adsorption through a bed. These are (a) unfavourable, (b) linear and (c) favourable isotherms. The mass transfer zone is also shown at these different cases. In (a) the MTZ will increase, while it will be constant in (b) and decreasing (c) with time. [30] .....	29
Figure 9: Process scheme of the treatment process for the training pool. Inspired by [6].....	34
Figure 10: Process scheme for the treatment process for the training pool with backwash mode (grey). Inspired by [6]. .....	35
Figure 11: Measurement display of the training pool, located at Rud svømmehall. Picture taken the 25 <sup>th</sup> of March at 09:15. ....	35
Figure 12: Process scheme with the sampling points. Inspired by [6].....	37
Figure 13: Free chlorine: 1-3. Total chlorine: 1 followed by 4-6. ....	38
Figure 14: Set up for particle concentration measurements. (a) sample with magnetic stirrer, (b) Particle Counter PSSC Fluid Lite, (c) external device with exported data presented in Protrend, (d) schematic illustration of the measurement. [6].....	39
Figure 15: The figure shows the setup of the jar apparatus Kemira Flocculator 2000. [6] .....	41
Figure 16: Free, total, and combined chlorine for each sampling point. (a) presents the results for 16 <sup>th</sup> of March (sample 34-39) and (b) presents the results from 25 <sup>th</sup> of March (sample 72-77). ....	45
Figure 17: The figure presents the SAC <sub>254</sub> measurements for each sampling point. (a) Oslo 21 <sup>st</sup> of February sample 6-10), (b) Oslo 16.03 (sample 34-39), and (c) Oslo 25.03 (sample 72-77). ....	49
Figure 18: The figure presents the DOC concentrations for each sampling point. (a) 21 <sup>st</sup> of February ( sample 6-10), (b) 16 <sup>th</sup> of March (sample 34-39,) and (c) 25 <sup>th</sup> of March (sample 72-77). ....	50
Figure 19: The figure presents the aluminium concentration in each sampling point. (a) AF 21 <sup>st</sup> of February (sample 1-5), (b) FA (sample 6-10), (c) AF 16 <sup>th</sup> of March (sample 40-45), and (d) FA (sample 32-39).....	52
Figure 20: The figure presents the results from the particle measurements from each sample point at Rud svømmehall, 25.03.22. (a) presents fill up water, (b) pool water, (c) outlet balance tank, (d) inlet AG filter, (e) outlet AG filter, and (f) outlet UV. ....	54
Figure 21: Distribution of metal concentrations in (a) drinking water Trondheim (sample 6), (b) fill up water 22nd of February and 16th of March (sample 6 and 34), and (c) pool water the 22nd of February and 16th of March (sample 7 and 35). ....	57



Figure 22: The figure presents the total particle concentration of fill up water after jar test, 25<sup>th</sup> of March. (a) 0mg/L (b) 2mg/L (c) 4mg/L (d) 6mg/L, and (e) 8mg/L.....59

Figure 23: Total particle concentration of pool water after jar test, 25.03.22. (a) 0mg/L, (b) 2mg/L, (c) 4mg/L, (d) 6mg/L, and (e) 8mg/L..... 60

Figure 24: The figure presents the results from the amount of DOC in fill up water and pool water after jar test. (a) fill up water 16<sup>th</sup>of March (sample 46 to 50) (b) pool water 16<sup>th</sup> of March (sample 51 to 55) (c) fill up water 25<sup>th</sup> of March (sample 78 to 82) and (d) pool water 25<sup>th</sup> of March (sample 83 to 87).....63

Figure 25: The figure presents the concentration of aluminium after different coagulant dosages. (a) drinking water Trondheim 6<sup>th</sup> of March (sample 11-15), (b) fill up water Oslo 16<sup>th</sup> of March (sample 46-50), (c) fill up water Oslo 25<sup>th</sup> of March (sample 78-82), (d) pool water Oslo 16<sup>th</sup> of March (sample 51-55), and (e) pool water Oslo 25<sup>th</sup> of March (sample 83-87). .....67

Figure 26: The figure presents the plots of  $q(\text{DOC})$  against  $\text{DOC}_{\text{ads}}$  along with the freundlich adsorption isotherms for drinking water from the 4<sup>th</sup> of March for w 1-3 in (a) and DGK in (c). The corresponding ln-ln diagrams are plotted in (b) and (d)..... 71

Figure 27:  $q$  plotted against  $\text{DOC}_{\text{ads}}$  for fill up water with DGK. The corresponding ln-ln diagrams of these plots are shown in (b) and (d). (a) and (b) 16<sup>th</sup> of March (sample 58-63), and (c) and (d) 25<sup>th</sup> of March (sample 91-97)..... 72

Figure 28:  $q$  plotted against  $\text{DOC}_{\text{ads}}$  for pool water with DGK, along with their corresponding ln-ln diagrams. (a) and (b) are plots from 16<sup>th</sup> of March (sample 66-71), and (c) and (d) are plotted from th 25<sup>th</sup> of March (sample 100-106). ..... 73

Figure 29: The figure presents  $\text{SAC}_{254}$  vs DOC (a) and (b), DOC vs m/V (c) and (d) for w 1-3 and DGK from Trondheim 4<sup>th</sup> of March..... XII

Figure 30: The figure presents  $\text{SAC}_{254}$  vs DOC (a) and (b), DOC vs m/V (c) and (d) for fill up water and pool water from the 16<sup>th</sup> of March. .... XIII

Figure 31: The figure presents  $\text{SAC}_{254}$  vs DOC (a) and (b), DOC vs m/V (c) and (d) for fill up water and pool water from the 25<sup>th</sup> of March. .... XIII

Figure 32: Step 1 in the mass balance.....XIV

Figure 33: Step 2 in the mass balance.....XV

Figure 34: Step 3 in the mass balance.....XVI

## List of Tables

Table 1: An overview of different criteria for pool water parameters. [12] .....	13
Table 2: An overview of pool water requirements for disinfecting with chlorine at different temperatures. [12] .....	14
Table 3: Information about the training pool and the treatment process. [6].....	36
Table 4: Particle size classes and methods for particle concentration measurements. ....	40
Table 5: Presentation of chlorine values in pool water (free, total, and combined) for the 16 <sup>th</sup> and 25 <sup>th</sup> of March (sample 34-39 and 72-77). Measured at the laboratory. ....	45
Table 6: Presentation of chlorine values in pool water (free, total, and combined) measured at the facility (25 <sup>th</sup> of March).....	45
Table 7: ICP-MS results for sampling points at Rud svømmehall for determining the disinfectant dosage. AF 21 <sup>st</sup> of February (sample 1-5), FA 21 <sup>st</sup> of February (sample 6-10), 16 <sup>th</sup> of March (sample 34-39), and FA 16 <sup>th</sup> of March (sample 40-45). ....	47
Table 8: Consumption of chlorine. Concentration of chlorine according to ICP-MS results. Concentration of chlorine removed during operations units. Addition of NaOCl per cyclus to compensate for the removal of chlorine in operation units.....	48
Table 9: The table presents the SAC <sub>254</sub> and DOC concentrations for the different sampling points.....	49
Table 10: The table presents the aluminium concentrations for the different sampling points from 21 <sup>st</sup> of February (AF, sample 1-5 and FA, sample 6-10) and 16 <sup>th</sup> of March (FA, sample 34-39 and AF, sample 40-45). ....	51
Table 11: Particle measurement results from sampling points at Rud svømmehall. ....	53
Table 12: Metals and heavy metals concentrations presented in drinking water Trondheim, along with the fill up water and pool water samples from Rud svømmehall. ....	56
Table 13: Particle measurement results from fill up water and pool water after jar test (0-8mg/L), 25 <sup>th</sup> of March.....	58
Table 14: The table shows DOC measurements at different coagulant dosages for fill up water and pool water from the 16 <sup>th</sup> and 25 <sup>th</sup> of March 2022. ....	62
Table 15: The table presents the concentration of aluminium at different coagulant dosages, measured after the jar test. ....	66
Table 16: Presentation of equations for the regression line for all ln-ln plots, with the corresponding R <sup>2</sup> value, 1/n and K <sub>A</sub> . ....	70
Table 17: The table shows the DOC <sub>ads</sub> concentrations and q values calculated based on the plotted adsorption isotherms and K <sub>A</sub> above.....	75
Table 18: The table shows the bed life for the log-log diagrams plotted in Figure 26-Figure 28.....	75
Table 19: presentation of central initial DOC concentrations, in addition to the concentration at steady state and how many cycles are needed to reach steady state. ....	76
Table 20: ICP-MS results for sampling points at Rud svømmehall for determining the disinfectant dosage. AF 21 <sup>st</sup> of February (sample 1-5), FA 21 <sup>st</sup> of February (sample 6-10), 16 <sup>th</sup> of March (sample 34-39), and FA 16 <sup>th</sup> of March (sample 40-45). ....	VIII
Table 21: Consumption of chlorine. Concentration of chlorine according to ICP-MS results. Concentration removed during operations units. Addition per cyclus to compensate for the removal in operation units. ....	X

## 1. Introduction

Humans have built swimming pools as far back as 2600 - 3000 BCE. [1] [2] The oldest swimming pools are known from Pakistan, which were used for religious rituals rather than exercise. [1] Later on the Roman and Greek civilisations built heated swimming pools, and swimming was part of the education for young boys. [3] The popularity of swimming pools increased during the 19th century, especially after swimming races were introduced in the Olympic Games in 1896. [1] New technology developed in the 20th century introduced chlorination techniques and filtration systems and replaced old methods of removing and renewing all the water. [1] A sustainability perspective on water treatment favours the use of recycling processes where the water is filtrated and disinfected, rather than wasting water resources. There is continuous development in technology regarding water treatment to optimise the treatment processes to further ensure more economically favourable processes and the use of fewer resources. Today swimming pools are locations for education, exercise, competition and other leisure activities. [4] Bathers release substances such as sweat, urine, cosmetics, and other contaminants, which are referred to as dissolved organic carbon (DOC). Typical processes used in modern swimming facilities involve the use of coagulation, filtration, and disinfection.

Rud svømmehall is a modern swimming facility and is a part of Bærum idrettspark localised in Bærum, Norway. The facility was recently built and was available for the public in the autumn of 2021. The swimming facility is used for elite sports in swimming, as well as educational and rehabilitation purposes. [5] During the initial phase, Rud svømmehall had an interest in assuring the quality of the facility. For this purpose, Alessia Silvestro wrote a Bachelor thesis about the operation of treatment at Rud svømmehall. [6] The primary objective for the thesis was to gain an understanding of the effect of bather load, and particle concentrations in the units of the water treatment, in addition to an understanding of dissolved contaminants in the pool. Silvestro concluded that the number of bathers influenced the particle concentration and not just the contamination of the pool water. [6] The thesis also observed that the granular activated carbon filter was the only operation unit removing organic matter. Measurements concluded that the coagulant did not have the desired effect. [6] As a result of these observations, our bachelor thesis occurred. The primary objective of this thesis is to optimize two parts of the treatment process, the coagulation before the activated glass (AG) filter and the granular activated carbon (GAC) filter. More specifically, this thesis aims to determine the most optimal coagulant dosage. In addition, the thesis aims to determine the capacity and bed life of the GAC filter. Out of interest, the amount of chlorine, trace elements and heavy metals were measured. Mass balances were also modelled for a better understanding of the operation of treatment.

## 2. Theory

### 2.1 Regulations for Swimming Pool Water

#### 2.1.1 Contamination and Treatment of Pool Water

The freshwater added to the balance tank contains contaminations, such as metals from the public water supply. With the addition of bathers, the pool water is continuously contaminated with urine, sweat, and cosmetics, in addition to skin-and hair particles. [7] In general, a bather releases 2.5 mg/L of dissolved organic carbon (DOC). [8] These substances are included in the collective term natural organic matter (NOM). According to Water Reclamation and Sustainability [9], NOM is defined as the generic mixture of organic, slightly water-soluble components such as soil, sediments, and humic substances causing the yellowish colour. The composting activities of microbes, dead organisms, and the excrement of living organisms produce these humic substances. NOM mostly consists of humic acid (HA), fulvic acid (FA), and non-humic fractions, including carbohydrates, amino acids, and proteins. [9] NOM can be divided into two fractions, hydrophobic and hydrophilic NOM as presented in Figure 1. The hydrophobic fractions are generally of a higher molecular weight and have an aromatic character. These fractions tend to exhibit higher ultraviolet absorbance at 254nm ( $UV_{254}$ ). The hydrophilic fractions typically are molecules of lower molecular weight with aliphatic ketones and alcohols. [10] Since the disinfectant is chlorine-based, it is quite reactive with the different contaminants in the pool water where it will oxidize NOM. The products of these reactions are unwanted disinfection byproducts (DBP). Some examples of DBPs are chloramines and trichloromethane. [7]

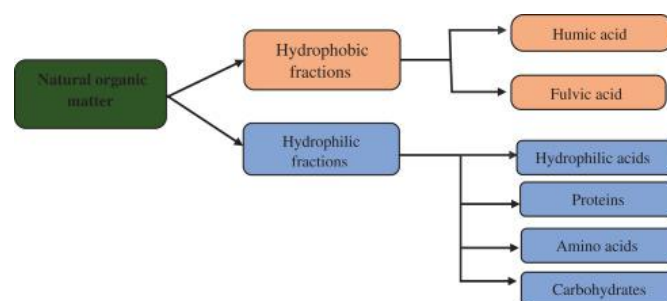


Figure 1: Hydrophobic and hydrophilic substances involved in the two main fractions of NOM. [10]

Pool water is often heated and recycled to minimize the loss of energy and water. This causes the water to have a long retention time in the pool system. [7] These factors can cause a potential growth environment for different microorganisms such as bacteria, viruses, fungi, and protozoans. If the number of microorganisms in the water is not contained, and pathogenic organisms are not removed

completely, the bathers might get an infection from using the pool. These problems are prevented by following regulations for disinfection and by the bathers following the hygienic rules of the facility. [11]

### 2.1.2 Laws and Swimming Pool Standards

To make sure the pool water is of hygienic quality, certain criteria must be fulfilled. The pool water is required to be colourless, clear, transparent and inviting to bathers. In addition to these criteria, the water must fulfil the parameters presented in Table 1. [12]

Table 1: An overview of different criteria for pool water parameters. [12]

Parameter		Lowest added value	Highest added value
Colour value	Mg/l Pt		5
Turbidity	FTU		0.5
Acidity	pH-value	7.2	7.6
Bacterial colony count at 37°C	Pr. mL		10
<i>Pseudomonas aeruginosa</i>	pr. 100 mL		0

There are no requirements for the lowest added value for colour value, turbidity, germinal bacteria, and *Pseudomonas aeruginosa*. This is because these parameters should be as close as possible to zero. *P. aeruginosa* is often used as an indicator organism in swimming pools. Some of the reasoning behind this is because the bacteria are relatively simple to identify, it grows fast at temperatures between 20°C and 42°C, and they can establish biofilm on the pool walls, in the pipe system and in the treatment system. [11]

The chlorination process is most effective at a low pH. However, this can cause other problems such as increased corrosion and greater release of chlorine gas and chlorine amines, and further cause eye irritation. By itself, a low pH value will irritate the eye and mucus membranes. [11] According to §16 in the Norwegian Regulations [12], pool water should therefore have a pH value between 7.2 and 7.6. The pH is usually reduced with either CO<sub>2</sub> or hydrochloric acid and made more alkaline with lye. [11]

To prevent the formation of unpleasant or hygienically questionable matter, the amount of organic matter and amines should be kept at a low level. The precautions taken by bathers are often a thorough shower with soap and not urinate in the water. There are also some criteria in Norway for disinfecting the pool system, as well as the amount of free chlorine used in this process, presented in the upcoming chapter.

### 2.1.3 Disinfection Criteria

According to Norwegian regulations [12], the pool requires an adequate amount of disinfectant to kill harmful microorganisms and prevent the growth of pathogenic microorganisms in the swimming pool system. This is also a measure to prevent microbiological growth that can cause disease.

The disinfectant should be added continuously and when required. The Norwegian regulations states that a maximum value of combined chlorine should be less than 50% of the free chlorine measurement. In addition, the value of combined chlorine should never exceed 0.5 mg Cl/L, and the values of combined chlorine should be kept to a minimum. [12] Table 2 presents the pool water requirements for disinfection with chlorine (hypochlorite) at different temperatures.

Table 2: An overview of pool water requirements for disinfecting with chlorine at different temperatures. [12]

Water temperature [°C]	Minimum content (free chlorine) [mg/L]	Maximum content (total chlorine) [mg/L]
=< 27	0.4	3
27-29	0.5	3
29-33	0.7	4
33-37	0.9	4
>37	1.0	4

## 2.2 Coagulant, ICP-MS, and Particle Measurements

### 2.2.1 Coagulant

#### 2.2.1.1 The Importance of Coagulation and Flocculation in Water Treatment

Coagulation is an important treatment step in Rud svømmehall. The term coagulation is according to MWH's Water Treatment defined as "the addition of a chemical that prepares dispersed particles in a solution for further treatment by flocculation." [13] It could also "involve the addition of a chemical that will lead to conditions where the particles dispersed in the solution can be removed." [13] Flocculation is the process where particles that have been stabilized through coagulation are further aggregated. [13] [14] After the addition of coagulant and further flocculation larger particles, referred to as flocs, are formed. These flocs can be removed in a filter. [14] In Rud svømmehall, this filtration happens in an activated glass filter (AG filter). Particles in water can cause turbidity and undesirable colour. Some of these particles can also cause diseases, as they may be in the form of bacteria, viruses,

and protozoa. [13] In addition, some components in the water can form toxic compounds if they react with the wrong substances, such as NOMs. Coagulation and flocculation are precursors for the removal of particles through sedimentation and filtration. [13] [14]

### 2.2.1.2 Effect of Coagulants on Particle Stability

A coagulant aims to destabilize particulates found in water. These particles can naturally occur as either hydrophobic or hydrophilic. Hydrophobic particles will have a clear barrier from water, due to their low affinity to water. Hydrophilic particles have a high affinity for water, often caused by a polar group or an ionized particle surface. Examples of such particles that can be found in waters are proteins, humic acids, clays or metal oxides. [13] [14]

Particles are usually charged in water, and thus aim to form colloids and settle. This happens because the particles are thermodynamically unstable in suspensions, thus they will flocculate and settle given enough time. Since the process is time-consuming, it will not be economically favourable. Therefore the process is sped up by different techniques, such as the addition of coagulant. [13]

The particles in water acquire surface charges in four principal ways according to MWH's Water Treatment. These are called "isomorphous replacement, structural imperfections, preferential adsorption of specific ions and ionization of inorganic groups on particulate systems". [13] In an isomorphous replacement, there is a replacement of a metal in a metal oxide with another atom that has a lower charge.  $Al^{3+}$  can for instance replace  $Si^{4+}$  in silicon dioxide. [13] Structural imperfections occur when bonds break or crystals form into new shapes, and a negative surface charge takes place. Furthermore, we often talk about NOMs in water treatment systems. Macromolecules such as NOM typically have a negative charge, as they often contain a carboxylic group. The last way of gaining a negative charge is through a change of pH, where an ionization of inorganic groups on particulate surfaces occurs. For instance, silica can both accept and donate a proton, depending on pH, where a pH above two means that silica donates protons, and accepts protons at pH values below two. When referring to different surface charges arising from pH, it is also natural to mention zero point of charge (ZPC), which is the pH at which the particle has a neutral charge. [13] [14]

### 2.2.1.3 The Electrical Double Layer

A particle is usually negatively charged in a suspension. Positively charged counterions are found close to the particle surface to ensure electroneutrality. As seen in Figure 2 a number of layers exist around the particle. [15] One of these layers is called the Helmholtz layer (Stern layer in Figure 2), which is 5 Å thick and consists of cations attached to the negatively charged particles. The forces present are adsorption and electrostatic forces. [13] [16] [17] Another layer, called the diffuse layer, extends from the Helmholtz layer and

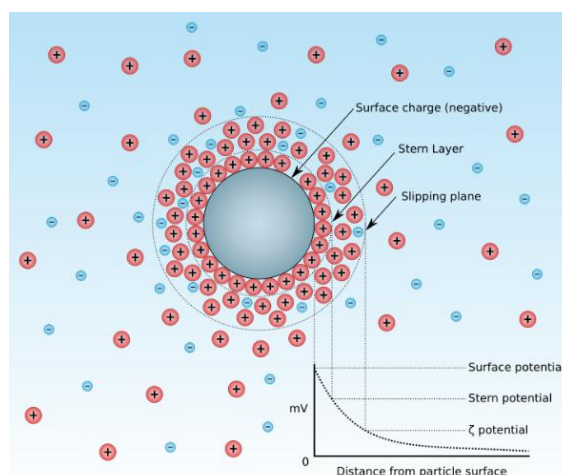


Figure 2: Structure of electric double layer. The zeta potential is marked on the figure and represents the potential at the shear plane. [15]

into the solution until electroneutrality is satisfied where the net charge is zero. [13] [16] [17] The electrical double layer (EDL) consists of the Helmholtz layer and the diffuse layer. The extent of the electrical double layer depends on the properties of the solution.

The stability of the particles in the solution is dependent upon the interactions between the particles, and the particles and the solution. van der Waals forces are present between the particles. These forces arise due to magnetic and electronic resonance that take place when particles approach one another. The van der Waals forces are stronger than the electrostatic repulsion forces, but because the electrical double layer and the electrostatic repulsion extend far into the solution, the van der Waals forces are not strong enough to counteract these forces. Due to this, it is necessary to add a coagulant to make sure that flocculation happens quickly. [13] [17]

The use of counterions can ensure flocculation. Here it is relevant to define the term critical coagulation concentration (CCC) which describes the ionic concentration of the counterion to ensure flocculation. At this concentration, the EDL is sufficiently reduced so that the van der Waals forces ensure coagulation of the particles. The CCC depends on the types of particles in the solution as well as the type of dissolved ions. [13] [18]



#### 2.2.1.4 The Function and Properties of a Coagulant

A particle can be destabilized in several ways, including compression of the EDL, charge neutralization and adsorption, interparticulate bridging and adsorption, and enmeshment in a precipitate, also called sweep floc. The compression of the EDL is not effective. The three other options are therefore more relevant. [13]

In charge neutralization and adsorption, oppositely charged particles (positively charged) are used to destabilize the negatively charged particles in the water. The positively charged particles, such as hydrolysed metal salts, prehydrolysed metal salts and cationic organic polymers all contribute to charge neutralization and thus destabilize the particles. The optimum coagulant dose is found when the particle surface is partially covered, which is less than 50 %. When the proper amount of coagulant has been adsorbed on the particle, the charge is neutralized and flocculation will occur. If the coagulant dosage is increased, and too much coagulant is added, the particle will again receive a positive charge and become stable again. [13]

In interparticle bridging a polymer will adsorb on different sites at particle surfaces, linking them together by a bridge. This bonding between particle and polymer can happen through different forces, involving coulombic, dipole interactions, hydrogen bonding and van der Waals forces of attraction. When a particle has been bound to a polymer, the rest of the polymer can remain extended into the solution and adsorb to other particles, thus forming an interparticle bridge. [13] [19]

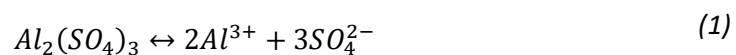
In water treatment, precipitation and enmeshment is one of the most used techniques. This technique specifically involves iron and aluminium. At high enough concentrations these metal ions will form insoluble precipitates and particles that are positioned inside these amorphous precipitates become entrapped. This phenomenon is also called sweep floc. [13] [19] Sweep floc happens in three distinct steps, where the first step involves hydrolysis and polymerization of the metal ions to be used as coagulants. In step two the particle interfaces adsorb the hydrolysed products, and in step three the charge is neutralized. The nucleation and formation of amorphous particle structures, where particles become entrapped, happen most easily at pH values between 6 and 8. [13] [19] The formation of sweep floc is not influenced by the type of particle. Thus, regardless of the particles present, the same concentration of the coagulant will be needed. However, the coagulant dosage needed varies with the pH of the solution. [13]

### 2.2.1.5 Jar Test and Coagulant Dosages

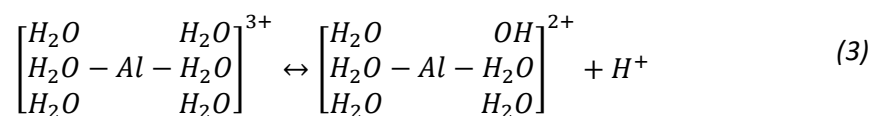
There are a lot of factors that need to be accounted for when choosing an appropriate coagulant. Among these are the number and characteristics of the particles in the water, the characteristics of the coagulant, concentration and characteristics of the NOM in the solution, water temperature and water quality. [13] The two most used coagulants in water treatment are salts made of aluminium or iron, in addition to the prehydrolysed version of these salts. [13] Often, these salts are present as sulphates or chlorides, where they can exist in both solid and liquid forms. The coagulant used in Rud svømmehall is an aluminium-based coagulant (aluminium chloride, 50%). Further on, the actions of the aluminium and iron coagulants will be explained, and typical dosages used in water. The purpose of the Jar test will also be elaborated.

### 2.2.1.6 The Function of Aluminium and Iron Salts

When aluminium (III) and iron (III) are added to water, they will dissociate into  $Al^{3+}$  and  $Fe^{3+}$  as shown in Equations (1) and (2). [13]



The trivalent metal ions  $Al^{3+}$  and  $Fe^{3+}$  will further hydrate to form complexes with water,  $Al(H_2O)_6^{3+}$  and  $Fe(H_2O)_6^{3+}$ . These complexes are called aquometal complexes and have a coordination number of six. The protolysis of the complex is shown in Equation (3).



The aquometal complexes will further go into a series of hydrolytic reactions, with a variety of products ranging from mononuclear (one metal atom, e. g. one aluminium atom) or polynuclear (several metal atoms) species. [13] The mononuclear and polynuclear species formed can interact with the particles in water, depending on the characteristics of the water and the number of

particles. Difficulties in the prediction of which species are active in binding to the particles, has led to the use of prehydrolysed metal salt coagulants. [13] [19]

The solubility of the metal salts at different pH values and concentrations is of importance when deciding the optimal coagulant dosage.

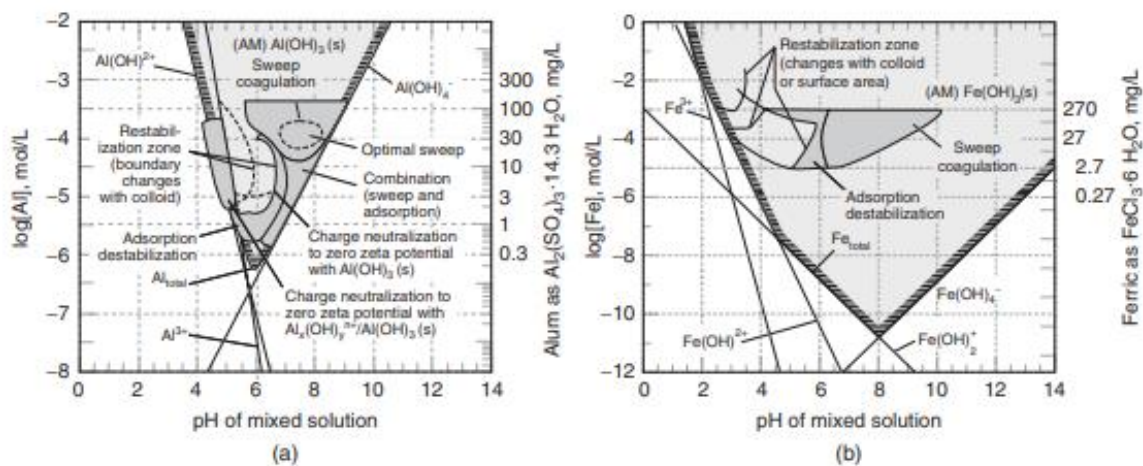
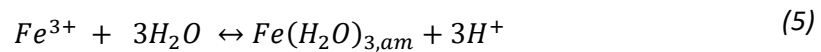
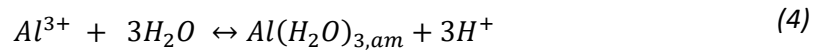


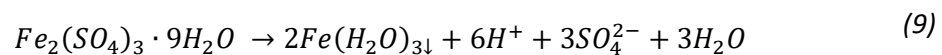
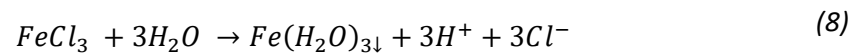
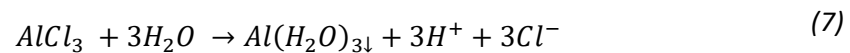
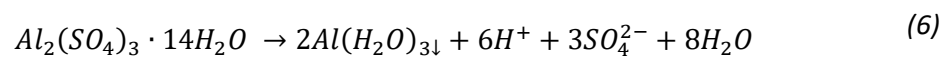
Figure 3: Solubility diagram of Al(III) in (a) and of Fe(III) in (b) at 25°C. Only mononuclear species are shown in the two diagrams, and these species are assumed to be in equilibrium with the solid precipitate. Gathered from page 564 from [13].

Figure 3 shows a solubility diagram of Al(III) and Fe(III) at 25°C. The shaded areas in the diagram show precipitated aluminium hydroxide and ferric hydroxide. Outside these areas, there is a formation of polynuclear and polymeric molecules. The solid lines shown in the diagrams represent the amount of soluble aluminium and iron that is left in the solution after precipitation. [13] In most water treatment processes the pH ranges from 6 to 8 and the lower limit is set to avoid corrosion of pipes and similar, which happen at lower pH levels. Aluminium has an operating range between pH values of 5.5 and 7.7, with a minimum solubility at a pH of 6.2 at 25°C. [13] Ferric molecules are more stable than aluminium species at higher pH values, thus they are more used in operations involving higher pH values, such as lime-softening processes. Moreover, the solubility of aluminium is dependent upon temperature, as the minimum solubility shifts with temperature. This needs to be considered when using aluminium in processing operations. [13] At low pH values aluminium is dissolved in the solution.

Addition of aluminium and ferric ions to water forms hydroxide precipitates as shown in Equations (4) and (5). [13]



The subscript “am” in the equations means that the precipitates are amorphous. These amorphous structures exist after the first few hours after coagulation and these products are more soluble than crystalline products. The overall reactions of aluminium hydroxide are shown in Equation (6) and Equation (7) for aluminium chloride. The equivalent reaction is shown for ferric chloride and ferric sulphate in Equations (8) and (9). [13]



When alum or ferric is added, the reaction corresponds to adding a strong acid to water, due to the species that remain in the solution after  $Al(OH)_3$  and  $Fe(OH)_3$  have precipitated. The species remaining corresponds to the same remaining after  $H_2SO_4$  or  $HCl$  are added. [13]

The chemical reactions involving coagulation with alum or iron salts added to water are complex, and it is hard to predict the sequence of these. A jar test can be used to determine the best conditions for the coagulant, and the results from this test are taken into consideration in the full-scale process. There are several important aspects of coagulation practice, including the operating regions of alum and iron, how these ions interact with other particles in the water, dosages of the coagulant and the mixing conditions, also called blending. [13] [19]

Figure 3 shows how alum and iron react with water at different pH values. From part (a) in this figure, it is possible to determine the optimum removal by sweep floc. This happens at a pH between 7 and

8 with an alum dosage of 20 to 60 mg/L. [13] The optimal coagulant dosage depends on the amount and types of particles present in the water. Hydrolysis products of alum and iron can react with ligands such as  $\text{SO}_4^{2-}$ , NOM,  $\text{F}^-$  and  $\text{PO}_4^{3-}$ . The products from these reactions are insoluble in water, and the required coagulant dosage for particle destabilization will be affected. [13] Typical dosages of alum used are between 10 and 150 mg/L, while the typical coagulant dosage for ferric sulphate ( $\text{Fe}_2(\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$ ) is between 10 to 250 mg/L, and it is 5 to 150 mg/L for ferric chloride ( $\text{Fe}_2\text{Cl}_3 \cdot 6\text{H}_2\text{O}$ ). [13] Moreover, it is essential to ensure rapid mixing of the water after the coagulant is added. This is crucial because the sequence of reactions occurs rapidly. At a pH of 4 about half of the aluminium hydrolyses to  $\text{Al}(\text{OH})^{2+}$  within  $10^{-5}$  seconds. [13]

### 2.2.2 Functions and Use of Inductively Coupled Plasma Mass Spectrometry

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is a chemical analytical method used to identify ions and their concentration in a solution. In the ICP-MS the atoms in the sample are excited in the Inductively Coupled Plasma (ICP), while a mass spectrometer (MS) is used to separate and detect the atoms present in the sample. [20]

The first part of the analytical method is to ionize the atoms in the sample. This happens in the ICP. The sample is injected into the sample introduction system. This system is made up of a spray chamber and a nebulizer. [21] The sample will exist as a nebula, which is transported to the base of the plasma. The temperature of the plasma is between 6000-8000°C, and the sample exists as excited ions and atoms within the plasma. The positive ions excited in the ICP can further be separated and detected in a mass spectrometer. [20] [21] In the MS it is possible to identify an atom or species by looking at mass-charge-ratios (*m/z-value*). A detector identifies the ions and presents the results as a mass spectre. [21] The intensity of the signal is proportional to the concentration of the element. [21]

### 2.2.3 Particle Concentration Measurements

There are several types of components creating particles in freshwater. Besides metal ions are NOM a significant component in natural water. NOM has hydrophobic binding and surface-active properties due to the presence of a large amount of carboxylic, phenolic, segregated aromatic, and aliphatic functional groups [9]. As a result of this, they bind to other species. FAs and HAs have the ability to form complexes with metal ions such as  $\text{Al}^{3+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cd}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$ , causing the ability for NOMs to precipitate. [22] Additionally, there is a wide range of magnitudes in the distribution of metal(loids) as dissolved and particulate phases. Generally, the particle sizes of

precipitated NOMs have a particle size range above 0.4  $\mu\text{m}$ . Hence, 0.4  $\mu\text{m}$  is the typical cut-off size of filters used by environmental scientists to separate the filtered fraction from the particulate fraction. [23] Colloids, both inorganic and organic in nature are produced biotically or abiotically and include small organisms such as viruses and some small bacteria and are often operationally defined as the fraction between 0.02  $\mu\text{m}$  and 0.4  $\mu\text{m}$ . Their presence in the filtered fraction can distort estimates of partitioning as they are considered within the dissolved fraction. The accepted explanation for this trend is that the experimentally separated dissolved fraction (0.4  $\mu\text{m}$  filtered) contains both truly dissolved and “colloidal” material and that the relative amount of colloidal material is related to the total suspended solids. [23] Figure 4 illustrates the typical compounds for various fractions in a natural water sample, and the corresponding size ranges.

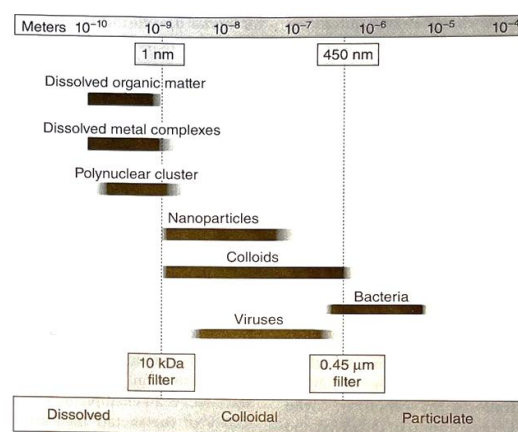


Figure 4: The figure shows different size ranges for different particles. [23]

Particles can be measured with the use of an optical measuring method, a particle counter. The principle of a particle counter is based on comparisons of detected light extinctions of the optical signals. These signals correspond to the single particle flow through a small, illuminated zone with a standard calibration curve, with a set of uniform particles with known diameter. By comparing the signals with the standard calibration curve, particles can be detected. [24] Figure 5 illustrates the measuring principle of a particle counter. [6]

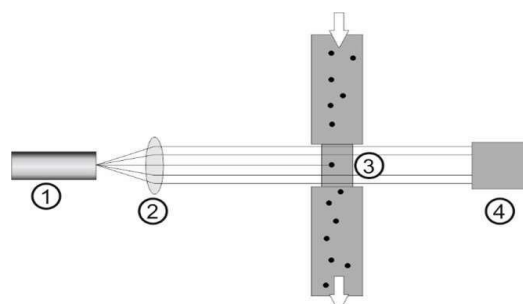


Figure 5: Principle of particle counter measurements.  
 1: laser beam, 2: lens system, 3: measure area, 4: detection. [6]

## 2.3 Fundamentals of Activated Carbon and Adsorption Phenomena

### 2.3.1 Dissolved Organic Carbon and Activated Carbon in Water Treatment

One of the most widely used methods to quantify the amount of NOM in water is by measuring total organic carbon (TOC). [10] By subtracting the amount of inorganic carbon (IC) from TOC, the amount of dissolved organic carbon (DOC) can be determined. DOC is a quality parameter frequently measured in water treatment. It indicates the concentration of organic molecules presented in a sample after filtration through a 0.45 µm pore size filter. These organic substances are typically hydrophobic NOMs in addition to aromatic molecules, chlorinated aromatics, phenolics, and high-molecular-weight molecules including both aliphatic and aromatic substances. Compounds having a low-molecular-weight and high polarity do not tend to adsorb onto activated carbon. The DOC concentration in surface water ranges from 1 to 10 mg/L. Due to the addition of these organic substances, the water must be decontaminated. The major method is adsorption onto activated carbon. Activated carbon is defined as a wide range of amorphous carbon-based materials prepared to have a high degree of porosity and an extended surface area. Due to its large surface area as well as an inert solid material, it is the most common prepare for water and wastewater treatment. In industrial wastewater treatment, activated carbon adsorption is used as a separate unit process where it is often placed after physiochemical treatment steps such as filtration and coagulation. [25]

### 2.3.2 Preparations of Activated Carbon

Activated carbon is produced from raw materials having a high carbon content. The most common materials are coal, wood, lignite, petrol coke, as well as residual materials, such as coconut shells, sawdust, or plastic residuals. Activated carbon is produced in two steps, carbonization and activation. The carbonization process removes undesirable by-products and hydrocarbons using dehydrating chemicals. The dehydration is typically carried out at elevated temperatures from 400-600°C under pyrolytic conditions in an oxygen-deficient atmosphere. The carbonization process removes volatile low-molecular-weight fractions and prepares the material for activation. In the activation process, the carbonized material is brought in contact with an activation gas, such as steam above 800°C, or carbon dioxide up to 1000°C. In the next step, the activation gas reacts with the solid where closed pores are opened, and existing pores are enlarged. Micropores (< 1 nm) are formed during the activation process, in addition to enlarged existing pores as macropores (> 25 nm) and mesopores (1-25 nm). [25] [26] An illustration of the different pores is presented in Figure 6. [26][27], inspired by [28]. The reactions will cause a mass loss of the solid material, where the yield of activated carbon usually is 40-

50%. A higher yield will lead to a decrease in the net surface area because no new pores are opened, but existing pore walls will burn away. [25] [26]

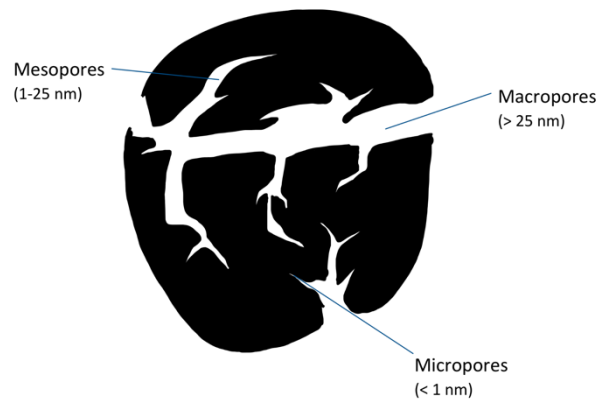


Figure 6: Illustration of activated carbon with different pores (macro, meso and micro), and corresponding pore size radius. [25] [26] [27]

### 2.3.3 Surface Chemistry and Chemical Bonding Responses

The activated carbon structure consists of hexagonal rings of carbon atoms. The structure is similar to graphite, except that the graphite crystallites in activated carbon are randomly orientated. The hexagonal rings of carbon atoms are interconnected by carbon cross-links referred to as crystalline planes. The micropores are formed between two parallel crystalline planes, which typically are of an irregular shape. The adsorption surface area ranges from 500-1500 m<sup>2</sup>/g, in combination with a pore volume between 0.7-1.8 cm<sup>3</sup>/g, resulting in a large amount of material potentially adsorbed. The carbon atoms are connected by covalent bonds, sp<sup>2</sup> hybridization. As a result of this, electron donor-acceptor interactions is established. For instance, activated carbon can possess a delocalized  $\pi$ -electron system that can interact with aromatic structures in the adsorbate to form  $\pi$ - $\pi$ -bonds. [25] [26]

### 2.3.4 Activated Carbon Types

Activated carbon is mainly divided into two categories, Granular Activated Carbon (GAC) and Powdered Activated Carbon (PAC). The main difference is the variation in particle size range, where GAC is in the range from 0.2-5 mm and PAC from 15-25  $\mu$ m. There are several differences between the two types based on principal uses, advantages, and disadvantages. [25] [26] GAC is designed by mesh sizes, corresponding to the particle diameters. For liquid phase applications a 8 x 30 U.S. mesh, corresponding to a particle diameter from 0.6 to 2.36 mm, is common. [25] [29] Activated carbon is widely used in the purification processes of drinking water, groundwater, and wastewater treatment.



Therefore, activated carbon are used as a treatment step for the removal of toxic organic compounds. [25] [26] Depending on the application of the activated carbon, several products are suitable. In this thesis, the focus is on two types of activated carbon delivered from CarboTech, used in different water treatment. Product information about the different activated carbon types from CarboTech is adapted and presented in Appendix 1 – Product Information from *CarboTech*. CarboTech Pool W 1-3 is suitable for the removal of organic contaminants from industrial and landfill leachate. Moreover, it is produced by the reactivation of mineral coal and could therefore contain pollution of trace metals from previous adsorptions. Another option, CarboTech DGK 8x30/60 is a purer activated carbon, produced from coconut shell. The material is not recycled, thus it is more suitable for drinking water treatment.

### 2.3.5 Adsorption Phenomena in Water Treatment

Adsorption is considered an important phenomenon in natural physical, biological, and chemical processes, where activated carbon is the most widely used adsorbent material in water and wastewater treatment. According to Activated Carbon for Water and Wastewater Treatment [25], adsorption is defined as “the accumulation or concentration of substances at a surface or interface”. [25] The substances that adsorb onto a surface is referred to as the adsorbate, e.g. NOM. The solid onto which the constituent is adsorbed is referred to as the adsorbent, e.g. AC. During the adsorption process, dissolved species are transported into the porous solid adsorbent granule by diffusion. Afterwards, they adsorb onto the inner surface of the adsorbent. Dissolved species are physically attracted to the surface, referred to as physical adsorption. Alternatively, the species are concentrated on the solid surface by chemical reactions, called chemisorption. In water treatment, physical adsorption is the most common adsorption mechanism. Physical adsorption is less compound specific for adsorption to surface sites but operates over long distances through multiple layers. The adsorbate will desorb in response to a decrease in solution concentration. The reaction is also reversible, by for instance removing the adsorbate through backwashing. [29] It is nevertheless predominant at temperatures below 150 °C and is characterized by low adsorption energy of a few kcal/mol. [25]

### 2.3.6 Surface Chemistry and Forces Involved in Physical Adsorption

In water treatment, the main interest is the adsorption of adsorbates from water onto a nonpolar adsorbent such as activated carbon. The attraction between an adsorbate and polar solvent is weaker for adsorbates that are less polar or have lower solubility. This can be explained by the fact that physical adsorption is a rapid process caused by nonspecific binding mechanisms such as van der Waals forces. Hence, the adsorbed molecule is free to move within the interface. The adsorbate will also desorb in response to a decrease in solution concentration. The attraction between an adsorbate and activated carbon surface increases with increasing polarity and size, which are directly related to van der Waal forces. Thus, nonpolar, and larger compounds tend to adsorb more strongly onto activated carbon. This adsorption type is also known as hydrophobic bonding, developed by Nemethy and Scheraga in 1962. [29] Generally, aromatic compounds are more adsorbable than aliphatic compounds of similar molecular size. The presence of substituent groups also affects the adsorbability of organic chemicals. The influence does also depend on the position of the substituent group for example, if it is ortho, meta, or para orientated. Compounds with more steric hindrance are usually more adsorbable than straight chain compounds. [25] Important factors for determining the number of adsorption sites and the accessibility of the sites for adsorbates are the surface area and pore size. Generally, there is an inverse relationship between the pore size and surface area. The smaller the pores for a given pore volume, the greater the surface area available for adsorption. [29]

### 2.3.7 Adsorption Isotherm and its Equilibriums Equations

In water treatment applications the quantification of adsorbate adsorbed is valuable. This amount is usually described as a function of the aqueous-phase concentration, determined at constant temperatures. This relationship is referred to as an isotherm. Adsorption isotherms are performed by exposing a known quantity of adsorbate in a fixed volume of liquid to various dosages of adsorbent. If the adsorbent is powdered it can be added directly into glass bottles, and allowed to equilibrate at a constant temperature in a rotating tumbler at a specific rotation and time. [29] At the end of the equilibration period, the aqueous-phase concentration of the adsorbate is measured, and the adsorption equilibrium capacity,  $q_{eq}$ , is calculated for each bottle. To calculate adsorption equilibrium capacity the mass balance expression is used. This formula is based on the equations developed by Langmuir, Freundlich, Braunauer, Emmet, and Teller. The mass balance expression to calculate adsorption equilibrium capacity is shown in Equation (10). Derived equations are presented in Appendix 2 – Calculations.

$$q_{eq} = \frac{V}{m_A} \cdot (c_0 - c_{eq}) \quad (10)$$

Where  $q_{eq}$  is equilibrium adsorbent-phase concentration of adsorbate [mg adsorbate/g adsorbent],  $m_A$  is mass activated carbon [g],  $V$  is volume of aqueous phase [L],  $c_0$  is initial aqueous phase concentration of adsorbate (DOC) [mg/L], and  $c_{eq}$  is the equilibrium aqueous phase concentration of adsorbate (DOC) [mg/L]. [29]

### 2.3.7.1 Freundlich Isotherm Equation

Freundlich's Isotherm equation is one of the main equations used to develop the mass balance shown in Equation (11). The Freundlich adsorption isotherm is used to describe the data for heterogeneous adsorbents such as activated carbon. The Freundlich equation is shown in Equation (11).

$$q_A = K_A \cdot c_A^{1/n} \quad (11)$$

Where  $q_A$  is equilibrium adsorbent-phase concentration of adsorbate [mg adsorbate/g adsorbent],  $K_A$  is Freundlich adsorption capacity parameter [(mg/g) (L/mg)<sup>1/n</sup>],  $c_A$  is the equilibrium aqueous phase concentration of adsorbate/DOC [mg/L], and  $1/n$  is Freundlich adsorption intensity parameter [unitless].

The linear form of Eq. (11) is shown in Equation (12).

$$\ln(q_A) = \ln(K_A) + \left(\frac{1}{n}\right) \cdot \ln(c_A) \quad (12)$$

From Eq. (12) a ln-ln plot of  $q_A$  versus  $c_A$  will theoretically result in a straight line, where  $1/n$  indicates the slope, and  $\ln(K_A)$  is found where the straight line crosses the y-axis. To find  $K_A$ ,  $e$  is raised to the power of the value ( $e^{K_A}$ ). A high value of  $K_A$  is desired, as this indicates that a high amount of adsorbate can adsorb per mass activated carbon.

The Freundlich isotherm equation always provides a more optimal fit than other adsorption isotherm models, while using adsorbates with many layers. Consequently, the Freundlich isotherm equation is

always used when GAC is the adsorbent, since the activated carbon distributes with different adsorption energies and several layers. [29]

### 2.3.8 Breakthrough Curve and Filter Capacity

When installing a filter, it is of great importance to know when the filter needs to be replaced in order to adsorb the expected amount of matter. The capacity of the filter can be determined by using a breakthrough curve. If the fixed bed is considered ideal, it follows certain conditions. The first condition is that the resistances related to both external and internal mass transfer are very small. The second condition is that the flow of the liquid in the bed is considered to be the same across the cross-section of the bed, called plug flow. The condition also states that the plug flow deviation is considered to be negligible. The third, and final condition states that the adsorbent is initially free of the adsorbate. [30] [31]

As the flow enters the filter, it results in a shock wave, called a stoichiometric front. As the front moves through the bed, the adsorbent is saturated with adsorbate and can no longer adsorb any adsorbate. It is possible to define the filter as being upstream or downstream of the front. Upstream of the front, liquid adsorbate has already been adsorbed to the adsorbent, while the downstream has an adsorbate concentration of zero and the adsorbent is free of the adsorbate. As the stoichiometric wavefront travels through the bed, it will eventually reach the end of the bed, and there will be an abrupt increase in the concentration of the fluid. The final concentration will be equal to the inlet value. In Figure 7, this point is seen as  $t_s$ . [30] As the filter is no longer able to adsorb adsorbate, the point is referred to as the breakthrough point,  $t_b$ . It is possible to regenerate the function of the filter.

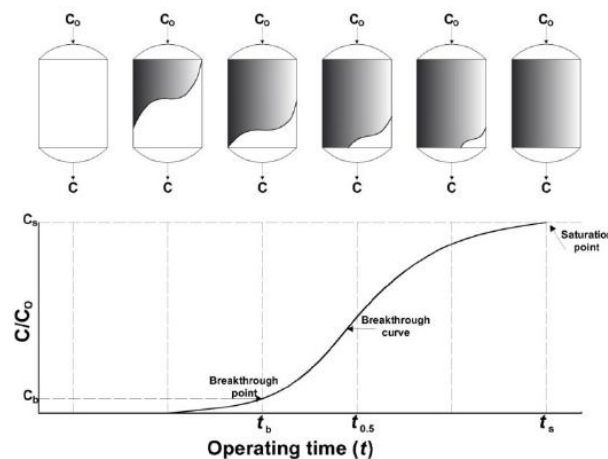


Figure 7: The figure shows adsorption in a real fixed bed and the corresponding breakthrough curve . [32]

The fixed bed rarely operates under ideal conditions. As a result of this, a broader S-shaped front is created, as shown in Figure 7. In a non-ideal system, a mass-transfer zone (MTZ) emerges, seen as the difference between  $t_s$  and  $t_b$ . As the run proceeds, the S-front will eventually reach the breakthrough point,  $t_b$ . [30] This is the point where the MTZ just reaches the end of the filter. When the run proceeds there is a sharp rise in the concentration of the fluid out of the filter. This concentration increases until all of the front reaches the end of the filter, marked as  $t_s$  in Figure 7. [30]

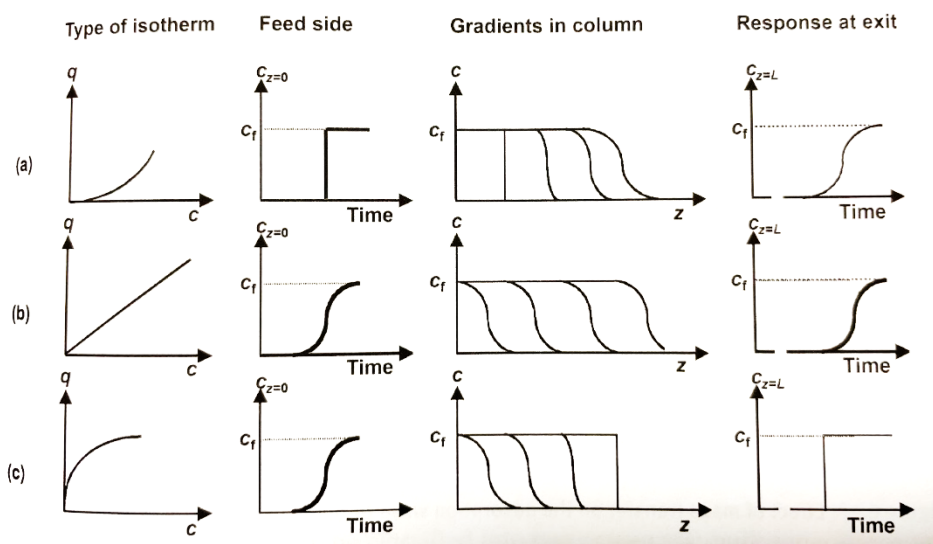


Figure 8: The figure shows the adsorption isotherms for different cases of adsorption through a bed. These are (a) unfavourable, (b) linear and (c) favourable isotherms. The mass transfer zone is also shown at these different cases. In (a) the MTZ will increase, while it will be constant in (b) and decreasing (c) with time. [30]

Ideally the isotherm has a shape like case (c) in Figure 8. In this case the adsorption isotherm follows the conditions stated above, and the breakthrough time will be marked as a straight line in the breakthrough curve. The calculations that follow are the method for calculating the bed life. The bed life reflects how long the filter will last at the current flow rate and empty bed time. The adsorption isotherms can be used to calculate the bed life of the filter. The following calculations are adapted from MWH's Water Treatment. [33] To calculate the bed time of the filter before breakthrough the Freundlich adsorption parameters must be known. These are used to find  $q$ . At breakthrough the concentration out of the filter is equal to the amount of DOC that initially can be adsorbed ( $DOC_{ads}$ ).

Further, the flow rate through the filter  $Q_{filter}$  [ $m^3/h$ ], volume of the filter  $V_{filter}$  [ $m^3$ ] and density  $\rho$  [ $kg/m^3$ ] must be known. These are used to find the mass of GAC in the filters as shown in Equation (13).

$$m_{GAC} = V_{filter} \cdot \rho_{filter} \quad (13)$$

When neglecting kinetics, stoichiometric breakthrough can be found by first finding the amount of DOC adsorbed at stoichiometric breakthrough, as shown in Equation (14).

$$q * m_{GAC} \quad (14)$$

Further, the water that can be treated  $V_{treated}$  [m<sup>3</sup>] at ideal stoichiometric breakthrough needs to be considered, and can be calculated by using Equation (15).

$$V_{treated} = \frac{m_{GAC}}{DOC_{ads}} \quad (15)$$

Where  $DOC_{ads}$  is the amount of adsorbate that can be adsorbed in the filter. Finally the bed life can be found as presented in Equation (16).

$$Bed\ life = \frac{V_{treated,filter}}{Q_{through\ filter}} \quad (16)$$

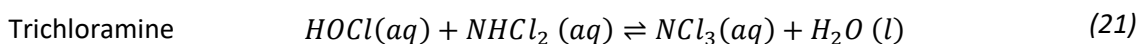
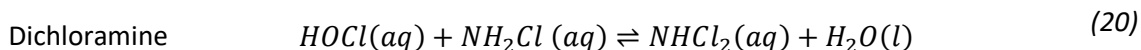
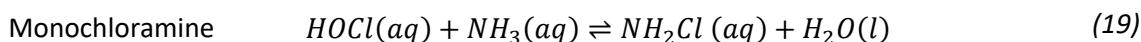
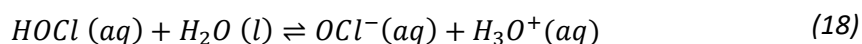
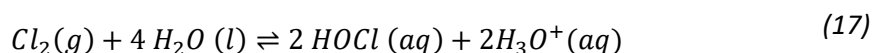
### 2.3.9 Spectrophotometric Measurements of DOC

It is possible to measure the amount of DOC in a sample by measuring its absorbance at 254 nm in a UV-spectrophotometer, often referred to as Spectral Absorption Coefficient ( $SAC_{254}$ ). [34] Cuvettes of different sizes can be used, dependent upon the quality of the water and the instrument. The double and triple bonds in organic compounds have the ability to absorb parts of the UV light that passes through the sample. A detector on the opposite side of the light source measures the absorbed amount of light.  $Sac_{254}$  is often given in  $cm^{-1}$  and  $m^{-1}$ . [34]

## 2.4 Free, Combined, and Total Chlorine

Rud swimming facility is used for exercise, swimming training, and by athletes. This entails that the water is continuously contaminated. Swimmers add many contaminants to the water, such as bacteria from saliva, excretion products, pollution from swimwear, hairs, and cosmetics. [35] Another pollutant from swimmers is nitrogen-containing pollutants, hereinafter referred to as ammonia (NH<sub>3</sub>). [36] To ensure a low concentration of microbiological growth, sodium hypochlorite (NaHClO) is added to the pool water. Nevertheless, when chlorine reacts with ammonia, an unfortunate chemical reaction occurs producing toxic trichloramine. [35]

In the pool water, sodium hypochlorite turns into hypochlorite ions (ClO<sup>-</sup>) that are in equilibrium with hypochlorous acid (HClO). The hypochlorous acid reacts with ammonia, followed by the formation of mono-, di- and trichloramine. The relative amounts of mono-, di- and trichloramine formed in pool water depend on the pH of the water and the ratio of chlorine to nitrogen (Cl/N). At lower pH or when the Cl/N ratio increases, the largest amount of trichloramine is formed. At pH > 8, a larger amount of dichloramine is formed. The protolytic equilibriums are shown in Equations (17)-(21). [35]



The value of combined chlorine is used as a rough estimate of the amount of trichloramine present in the swimming pool water since the pH value is constant around 7. Combined chlorine value can be determined by summarizing the concentrations of mono-, di- and trichloramine, presented in Equation (22). Free chlorine is the amount of chlorine which is still able to disinfect, and can be determined as presented in Equation (23). By summarizing the values of free and combined chlorine, total chlorine can be determined by using Equation (24).

$$\text{Combined Cl} = [\text{NH}_2\text{Cl}] + [\text{NHCl}_2] + [\text{NCl}_3] \quad (22)$$

$$\text{Free Cl} = [\text{HOCl}] + [\text{OCl}^-] + \frac{1}{2}[\text{Cl}_2] \quad (23)$$

$$\text{Total Cl} = \text{Combined Cl} + \text{Free Cl} \quad (24)$$

[35] [37]

## 2.5 Mass Balance and Calculations from Batch to Continuous Processes

A mass balance can be made for the treatment processes at Rud svømmehall. The general mass balance is presented in Equation (25). [38]

$$\text{Input} = \text{Output} + \text{Accumulation} \quad (25)$$

The treatment of the pool water removes contaminants. The treated flow stream is circulated back into the pool, and a dilution of contaminants occur. The dilution can be explained by Equation (26). [39]

$$y(t) = y_0 + \left(1 - e^{-\frac{t}{\tau}}\right) k\Delta u \quad (26)$$

Where y refers to the output, which is the dependent variable (often concentration out of system), u is the input, which is an independent variable (the concentration into the system),  $\tau$  is a time constant, t is the time and k is the gain. [39]

After a certain amount of time, the pool water system is said to be at steady state. Equation (27) presents a measure of how close the system is to reach steady state. When the term expressed in Equation (27) reaches a value of 98% the system is said to be at steady state for all practical purposes. [39]

$$1 - e^{-\frac{t}{\tau}} \quad (27)$$



## 3. Materials and Methods

### 3.1 Treatment Processes and Technical Information About Rud Svømmehall

At Bærum idrettspark there is a facility for swimming called Rud svømmehall. The facility was built and finished in March of 2021, and opened for the public in August 2021. [40] There are two pools at the facility, one is used for exercise and is called sports pool. The other pool is used for training and rehabilitation and is called training pool. This thesis mainly focuses on the training pool.

In all swimming pools, it is essential to have a proper water treatment system to ensure safe and hygienic conditions. The treatment system for training pool is found in Figure 9, where the main treatment processes are shown. Return water from the pool is transported to a balance tank. Regular drinking water, added  $\text{ClO}_2$ , is also added to the balance tank due to requirements of replacing a certain amount of pool water with drinking water. Drinking water will be referred to as fill up water. The fill up water is also added to dilute the concentration of contaminants that can not be removed by the treatment processes. The water flows from the balance tank through a pump before the coagulant is added. Coagulation and flocculation occur before the water reaches the activated glass filter (AG filter). 10% of the filtered water from the AG filter is then filtered through a granular activated carbon filter (GAC filter) while the remaining 90% bypasses this filter. Some of the filtrated water is used for backwashing, while the rest of the water is heated and UV disinfected. Chlorine and acid are added ( $\text{NaClO}$ , 15% and  $\text{H}_2\text{SO}_4$ , 20%) before the water is reintroduced to the pool. The chlorine dosage in Rud svømmehall is automatically adjusted based on the conductivity level in the pool. The GAC filter is marked with a red cross as this filter was not in use when the experimental part of this thesis was carried out.

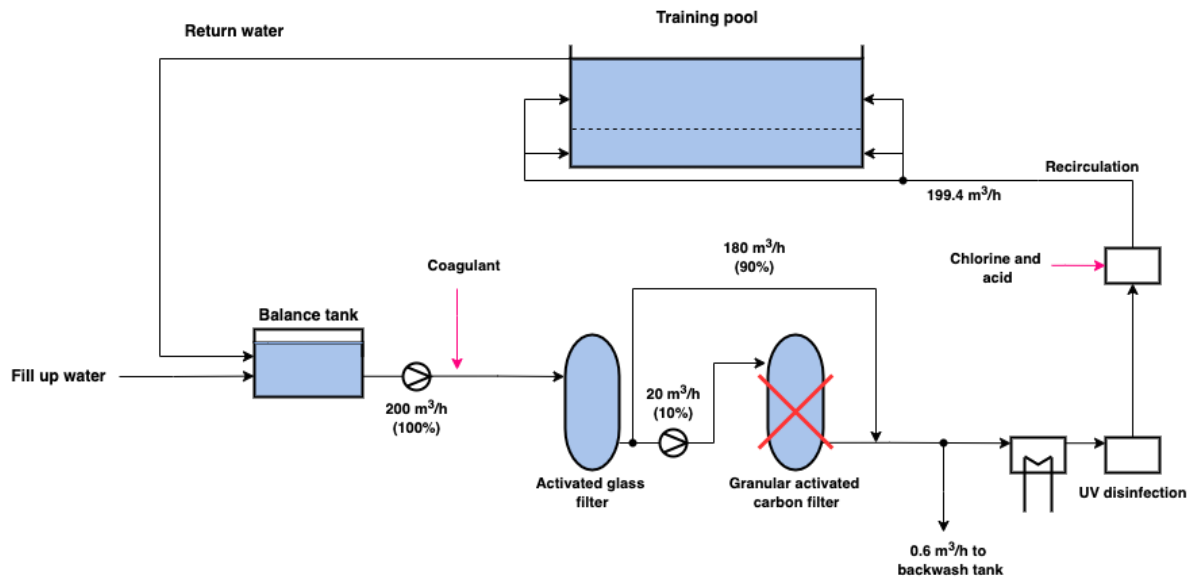


Figure 9: Process scheme of the treatment process for the training pool. Inspired by [6].

The filters at Rud svømmehall are backwashed twice a week for four minutes each. [6] This process uses filtered water, as well as bleed water from the sports pool, to wash particles attached to the surfaces of the filters. This method is used to prevent clogging of the filters and prolongs the filter capacity. The wastewater is then transported to a grey water tank along with wastewater from the showers and from the backwash processes in the sports pool. The backwash process is shown as the grey arrows and lines in Figure 10. Table 3 presents the treatment parameters and operation variables at Rud svømmehall. The complete treatment process schemes of Rud svømmehall are shown in Appendix 3 – Process Schemes of Operation Units at Rud svømmehall.

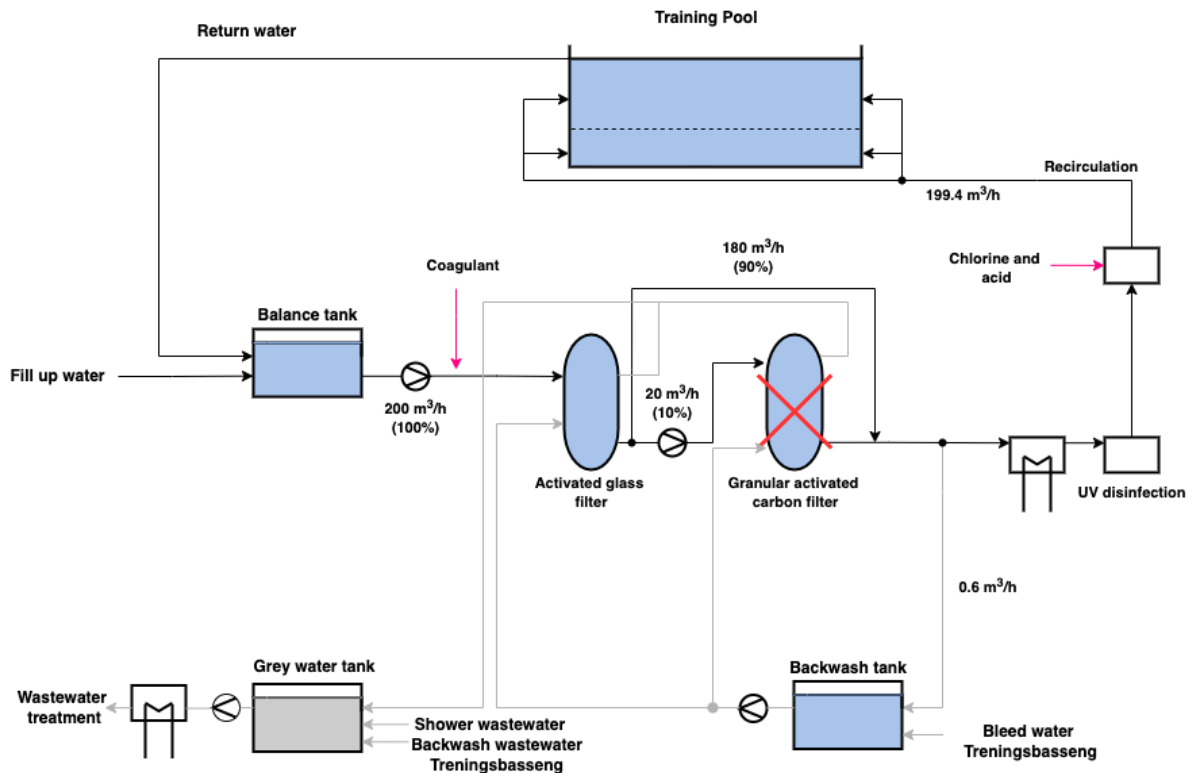


Figure 10: Process scheme for the treatment process for the training pool with backwash mode (grey). Inspired by [6].

At different sites in the treatment system, instruments are placed that continuously measure the pH, conductivity, free and combined chlorine, and oxidation and reduction potential of the water. An example of one of these instrument displays is presented in Figure 11.



Figure 11: Measurement display of the training pool, located at Rud svømmehall. Picture taken the 25<sup>th</sup> of March at 09:15.

Table 3: Information about the training pool and the treatment process. [6]

Description	Training pool data
Typical bather load [bather/h]	10
Nominal load [bather/h]	60
Pool volume [m <sup>3</sup> ]	Total: 274 Available to bathers: 42-190
Pool area [m <sup>2</sup> ]	119
Dimensions [m]	12.5 x 9.5 Depth total: 2.30 Depth available to bathers: 0.35 – 1.60
Flow rate [m <sup>3</sup> /h]	Max: 250 Current: 200
Pool temperature [°C]	32-34
Chemicals	<b>Coagulant:</b> BWT-Flock (aluminium chloride 50%) <b>Chlorine:</b> Sodium hypochlorite (Shock treatment: Calcium hypochlorite) <b>Acid:</b> Sulphuric acid (20 %) <b>Buffer:</b> Sodium bicarbonate
Number of filters	Total: 6 AG: 4 GAC: 2
AG filter information	Bed diameter [m]: 2.00 Bed depth [m]: 1.20 Max flow rate [m <sup>3</sup> /h]: 250 Current flow rate [m <sup>3</sup> /h]: 200
GAC filter information	Bed diameter [m]: 1.05 Bed depth [m]: 1.00 Max flow rate [m <sup>3</sup> /h]: 25 Current flow rate [m <sup>3</sup> /h]: 20

## 3.2 Method

The results of the measurements at Rud svømmehall are used to make recommendations for improvement of the treatment processes in the facility. Thus, the analyses need a high precision and accuracy. The methods used in the thesis are specific for the substances being analysed. The analyses have been carried out at the ICP-MS and DOC analyser, due to the high precision and accuracy of the instruments. The analyses were carried out by external laboratory personell. Alternative analysis methods have been considered, such as gravimetric analysis. However, these methods were not used, as ICP-MS and DOC have a higher precision and accuracy, along with an easy accessibility.

In addition to the specific analyses at the ICP-MS and DOC analyser, a particle counter, spectrophotometer, jar apparatus and a chlorine analysator for free and total chlorine were used at the laboratory. These analyses are accessible and provide the necessary information to make recommendations for improvement. Spectrophotometry is used as a parallel analysis to DOC analysis. The jar apparatus is used for the jar test prior to further analyses. The risk assessment for all activities and chemicals used during the project are presented in Appendix 4 – Risk Assessment.

### 3.2.1 Gathering of Samples at Rud Svømmehall

Water samples were gathered from 6 sampling points presented in Figure 12. The sampling points are A: fill up water, B: pool water, C: outlet balance tank, D: inlet AG filter, E: outlet AG filter and F: outlet UV disinfection.

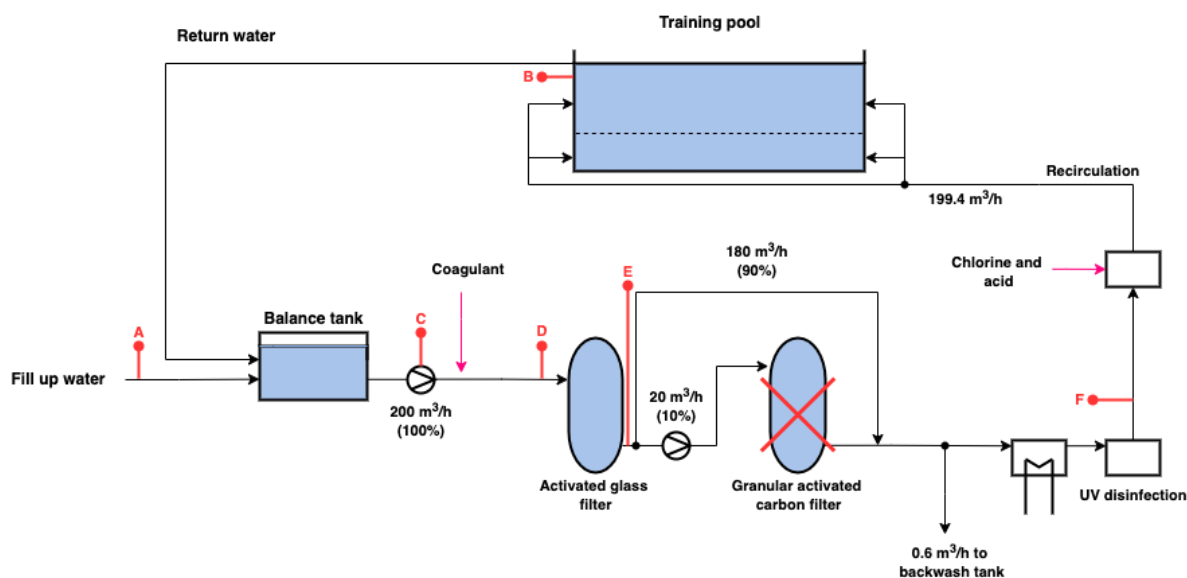


Figure 12: Process scheme with the sampling points. Inspired by [6].

### 3.2.1.1 Free, Total, and Combined Chlorine for sampling points

Free and total chlorine was measured at the sampling points of Rud svømmehall. The measurements were performed by using a chlorine cuvette test set (Hach Lange, LCK310) with analytical reagents. A spectrophotometer (HACH DR5000) with a pre-programmed analysis was used to measure chlorine at 535 nm. The method is illustrated in Figure 13.

Depending on the measurement, further treatment varied. In the free chlorine and total chlorine analysis each sample was added to the cuvette to approximately 1 cm below the cuvette opening (Figure 13.1). Further treatment varied. For free chlorine analysis, the cuvette was inverted and rotated to rid the sample of bubbles (Figure 13.2). Each sample reacted for 1 minute, followed by the spectrophotometry analysis (Figure 13.3). For total chlorine

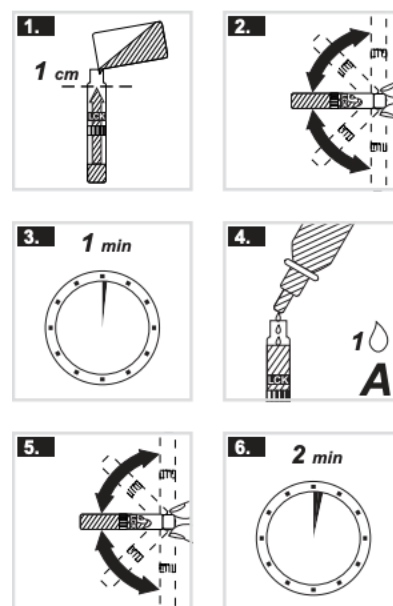


Figure 13: Free chlorine: 1-3.  
Total chlorine: 1 followed by 4-6.

analysis, a drop of potassium iodide (KI) was added (Figure 13.4), and the cuvette was immediately inverted to rid the sample of bubbles (Figure 13.5). Each sample reacted for 2 minutes, before the spectrophotometry analysis (Figure 13.6).

The method is adapted from Appendix 5 – Instruction Manual, *Hach Lange LCK310*.

### 3.2.1.2 ICP-MS Analyses of Sampling Points

Water samples (15 mL) from each sampling point from Rud svømmehall were sent for analysis at ICP-MS. Trace elements and heavy metals such as nickel, copper, zinc, chromium, arsenic, cadmium, mercury, and lead were analysed to check if there were residual traces of the GAC filter previously turned off. The sampling points were also analysed for aluminium, chlorine, sodium, and calcium. One parallel of the water samples was acidified, filtrated, and then sent to the analysis, while the other was filtrated and then acidified before analysis. This was done to check if the coagulant and AG filter were working.

The ICP-MS instrument (Agilent Technologies (USA), Agilent 8800 QQQ) used was equipped with a prepFAST M5 autosampler (ESI, USA). Hydrogen/helium and oxygen/helium gases mixtures were

used in MS/MS mode. The IC-MS tune parameters are presented in Appendix 6 – Tune Parameters for *Agilent Technologies, Agilent 8800 QQQ*.

### 3.2.1.3 Particle Measurements

Particle concentrations were measured before further treatment of the samples (no filtration or acidification). Particle measurements were carried out for the sampling points at Rud svømmehall (sample 34-39 and 72-77). A particle counter (Markus Klotz GmbH, Particle Counter PCSS fluid lite) with the laser sensor LDS 45/50, was used to measure particle concentration, with the setting “water-based sample”. The measurements were done offline while being connected to a software device (Klotz, Protrend). The data was exported to Microsoft Office Excel for further processing. Figure 14 illustrates the set up for the particle concentration measurement, including a schematic illustration of the measurement. [6]

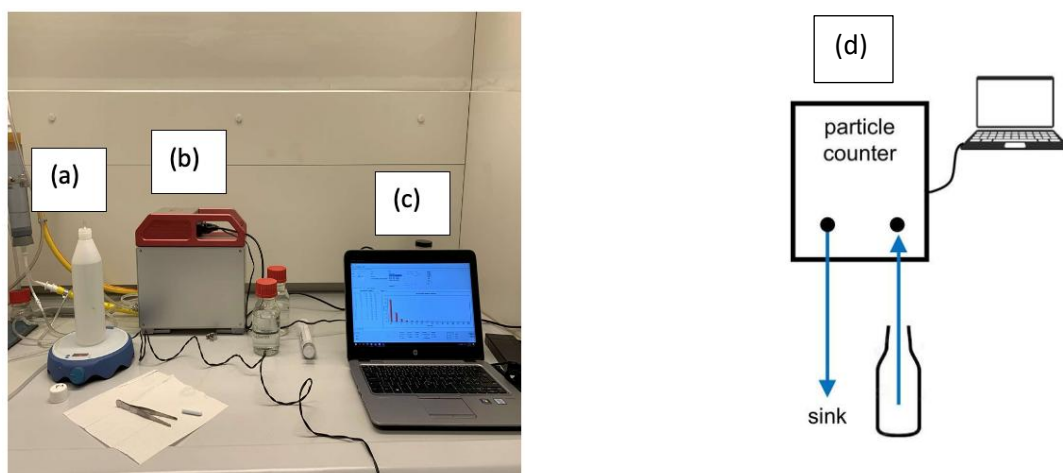


Figure 14: Set up for particle concentration measurements. (a) sample with magnetic stirrer, (b) Particle Counter PSSC Fluid Lite, (c) external device with exported data presented in Protrend, (d) schematic illustration of the measurement. [6]

100 mL of sample volume was required for 10 measuring cycles. Each cycle (10 mL) was measured at a flow rate of 30 mL/min. The 10 cycles for each sample was averaged to achieve a precise result. To ensure a homogenous solution of particles a magnetic stirrer at 250 rev/min was used. Between each sample, the instrument was washed with deionized water (5 cycles).

To acquire information about the size range of the particles, a scan was first run with a program measuring particle sizes from 0.8-100  $\mu\text{m}$  (Bigger). Afterwards, a specific program (Pool water) was made for further analysis based on the results from the scan analysis. The new program had particle sizes ranging from 0.8 - 10  $\mu\text{m}$ , which provides a detailed overview of the particle sizes present in the

water. The particle size classes and methods for measuring particle concentration are presented in Table 4.

Table 4: Particle size classes and methods for particle concentration measurements.

Particle size classes and <i>methods</i> <sup>a)</sup> in $\mu\text{m}$																
Size class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
<i>Bigger</i>	<i>0.8</i>	<i>1.0</i>	<i>2.0</i>	<i>5.0</i>	<i>10.0</i>	<i>15.0</i>	<i>20.0</i>	<i>25.0</i>	<i>30.0</i>	<i>35.0</i>	<i>40.0</i>	<i>45.0</i>	<i>50.0</i>	<i>65.0</i>	<i>85.0</i>	<i>100.0</i>
<i>Pool water</i>	<i>0.8</i>	<i>1.0</i>	<i>1.2</i>	<i>1.4</i>	<i>1.6</i>	<i>1.8</i>	<i>2.0</i>	<i>2.4</i>	<i>2.9</i>	<i>3.0</i>	<i>3.4</i>	<i>3.8</i>	<i>4.0</i>	<i>5.0</i>	<i>7.5</i>	<i>10.0</i>

<sup>a)</sup> The values in italics correspond to the particle size for the specific method.

Appendix 7 – Instruction Manual *Klotz PCSS Fluid lite* contains the adapted manual (Brief Instruction Manual. Markus Klotz GmbH) for the particle counter. The appendix also includes the new setup for a method and how to apply the instrument. [6]

### 3.2.1.4 SAC<sub>254</sub> and DOC Measurements

After being filtered and acidified, the samples were analysed in a cuvette (5 mL) with a Spectrophotometer (PerkinElmer Lambda 650/Hach Lange D500), UV-VIS at 254 nm, is used to find the amount of absorption.

DOC was measured on a DOC analyser (Shimadzu TOC-L). The tune parameters for the instrument are presented in Appendix 8 – Tune Parameters for *Shimadzu TOC-L*. The SAC<sub>254</sub> measurements can be compared to the DOC measurements from Shimadzu TOC-L.

## 3.2.2 Determination of the Optimal Coagulant Dosage through Jar Test

### 3.2.2.1 Jar Test

A stock solution (80 mg/L, total volume 1 L) was made by diluting a concentrated coagulant, BWT-Flock (aluminium chloride 50%, 31 g/L measured by [6]). The safety data sheet (SDS) for BWT-Flock is given in Appendix 9 – Safety Data Sheet for Coagulant, *BWT-Flock*.

Water samples from drinking water Trondheim, fill up water and pool water from Rud svømmehall were used in the jar test. Different volumes of the water samples (1000 mL, 975 mL, 950 mL, 925 mL and 900 mL) were added to the beakers of the jar apparatus (Kemira, Flocculator 2000). Volumes from the stock solution were added to create final coagulant concentrations in each water parallel of 0, 2, 4, 6 and 8 mg/L. To achieve these concentrations 0, 25 mL, 50 mL, 75 mL, and 100 mL of stock solution



were added to each water sample achieving a final volume of 1 L. pH was measured after the addition of coagulant and adjusted to  $7.3 \pm 0.1$  ( $\text{HNO}_3$  (0.01 M) /  $\text{NaOH}$  (0.1 M)). Figure 15 shows the jar apparatus, and the method is presented in Appendix 10 – Operating Manual, *Kemira Flocculator 2000*.



Figure 15: The figure shows the setup of the jar apparatus Kemira Flocculator 2000. [6]

The jar apparatus was started at a high mixing rate to ensure proper mixing of the coagulant for 30 seconds at 400 rev/min. The mixing rate was then slowed down to 40 rev/min to ensure flocculation. After 20 minutes, the mixing was stopped. The samples were then left to settle for 30 minutes before the supernatant (65 mL) was gathered 4 cm below the water surface. The supernatant was filtrated prior to analyses through 0.2  $\mu\text{m}$  (VWR, Polyethersulfone Membrane) or 0.4  $\mu\text{m}$  (Whatman, AOX<sup>®</sup> Nuclepore<sup>®</sup> Polycarbonate Membrane). All samples from Trondheim (sample 11-15) were filtered through the 0.2  $\mu\text{m}$  filters, while the samples from Oslo (sample 46-55 and 78-87) were filtered through the 0.4  $\mu\text{m}$  filters.

The samples were sent to two different analyses, ICP-MS for analysis of aluminium concentration and DOC analysis. The samples (15 mL) sent to ICP-MS, sample 11-15, 46-55 and 78-87, were acidified with  $\text{HNO}_3$  (65%, 14.37 M) to a final concentration of 0.1 M  $\text{HNO}_3$ . The samples (50 mL) sent for DOC analysis, sample 46-55 and 78-87, were acidified to pH 2 with  $\text{HCl}$  (37%, 11.97 M). The method for the jar test is adapted from Rueda. [41]

### 3.2.2.2 Particle concentration measurements

Particle concentrations were measured before further treatment of the samples (no filtration or acidification). Particle measurements were carried out for the samples after the jar test (fill up water samples 46-50 and 78-82, pool water sample 51-55 and 83-87). The method is the same as described earlier.

### 3.2.2.3 ICP-MS

The concentration of aluminium in fill up water and pool water after the jar test was measured on the ICP-MS. The analysis method is the same as previously explained.

## 3.2.3 Adsorption isotherms

### 3.2.3.1 Experiment to Determine Adsorption isotherms

All test bottles and sample bottles were stored with deionized water and added HCl (37%, analytical grade). This was to get any organic matter from the glass-walled bottles to desorb. The bottles were then stored at 4°C for 24 hours.

200 mL of water samples (drinking water, fill up water and pool water) were filled in glass bottles (250 mL, precleaned HCl (37%)). Parallels of two different activated carbons were used in the experiment, CarboTech Pool W1-3 and CarboTech DGK 8x30/60. For each parallel selected amounts of the powdered activated carbon (1.2 mg, 4 mg, 10 mg, 30 mg, 70 mg, 150 mg) were weighed on aluminium foil and added to the glass bottles. There were three blank samples, where no activated carbon was added. These samples are drinking water from Trondheim corresponding to sample 19-21 (blank samples), 22-27 (w 1-3) and 28-33 (DGK).

In Oslo two parallels of both fill up water and pool water were conducted at two different dates (16<sup>th</sup> and 25<sup>th</sup> of March). All samples were added DGK in the same amount as the drinking water samples from Trondheim, except the parallels from the 25<sup>th</sup> of March. These parallels had an additional dosage of 300 mg. The samples are fill up water (16<sup>th</sup>: sample 56-63, 25<sup>th</sup>: sample 89-97), pool water (16<sup>th</sup>: 64-71, 25<sup>th</sup>: 98-106).

The samples were then placed on a shaking table (20°C, 55-60 rev/min, 24-48 hours). [42] The samples from Trondheim were left on the shaking table for 48 hours (sample 19-33), whilst the samples from Oslo were left for 24 hours (sample 56-77, 91-106).

After mixing and settling, the samples were filtered through a 0.2 µm filter (Trondheim) or 0.4 µm filter (Oslo). To prepare the samples for storage, concentrated HCl (Analytical Grade 37%, 11.97 M) was added until the pH, measured with pH strips, was approximately 2.

### 3.2.3.2 Spectrophotometry and Dissolved Organic Carbon Adsorption Isotherms

The method of SAC<sub>254</sub> and DOC measurements for fill up water and pool water was the same as previously explained.

## 4 Results and Discussion

The results are presented in four subchapters based on the main results from the different objectives of the thesis: the sampling points at Rud svømmehall, determination of the optimal coagulant dosage, the capacity and bed life of the activated carbon filter, and mass balances. Information about all samples along with their sample number can be found in Appendix 11 – Sample information. All calculations is presented in Appendix 2 – Calculations.

### 4.1 Results from Sampling Points at Rud svømmehall

#### 4.1.1 Free, Total, and Combined Chlorine

The results from free, total, and combined chlorine measurements, along with the results from the ICP-MS estimate the change in concentration of chlorine during the treatment processes at Rud svømmehall. In addition, the dosages of sodium hypochlorite and calcium hypochlorite are estimated.

##### 4.1.1.1 Measurements of Free, Total, and Combined Chlorine

Free and total chlorine was measured for all the sampling points. Combined chlorine was calculated using Equation (24). Table 5 presents the chlorine measurements for 16<sup>th</sup> of March (sample 24-39) and 25<sup>th</sup> of March (72-77). The samples were transported for measurements at the laboratory. Table 6 presents chlorine measured on 25<sup>th</sup> of March. These were measured directly from the training pool and the corresponding chlorine values from a display with continuous measurements. The samples measured for chlorine were not filtrated or acidified.

Table 5: Presentation of chlorine values in pool water (free, total, and combined) for the 16<sup>th</sup> and 25<sup>th</sup> of March (sample 34-39 and 72-77). Measured at the laboratory.

Sample point	Free chlorine [mg/L]	Total chlorine [mg/L]	Combined chlorine [mg/L]
Sample 34-39			
Fill up water	0.014	0.036	0.022
Pool water	0.556	0.596	0.040
Outlet balance tank	0.585	0.624	0.039
Inlet AG filter	0.590	0.624	0.034
Outlet AG filter	0.535	0.578	0.043
Outlet UV	0.349	0.390	0.041
Sample 72-77			
Fill up water	0.025	0.037	0.012
Pool water	0.583	0.613	0.030
Outlet balance tank	0.600	0.637	0.037
Inlet AG filter	0.565	0.600	0.035
Outlet AG filter	0.524	0.566	0.042
Outlet UV	0.378	0.416	0.038

Table 6: Presentation of chlorine values in pool water (free, total, and combined) measured at the facility (25<sup>th</sup> of March).

	Free chlorine [mg/L]	Total chlorine [mg/L]	Combined chlorine [mg/L]
Training pool	0.992	1.08	0.088
Display	1.05	1.14	0.090

Figure 16 (a) and (b) are based on results from Table 5. Figure 16 presents the chlorine measurements where (a) is sample 34-39, and (b) is sample 72-77. In both figures, blue represents the value of free chlorine, orange the value of total chlorine, and grey the value of combined chlorine, measured in mg/L.

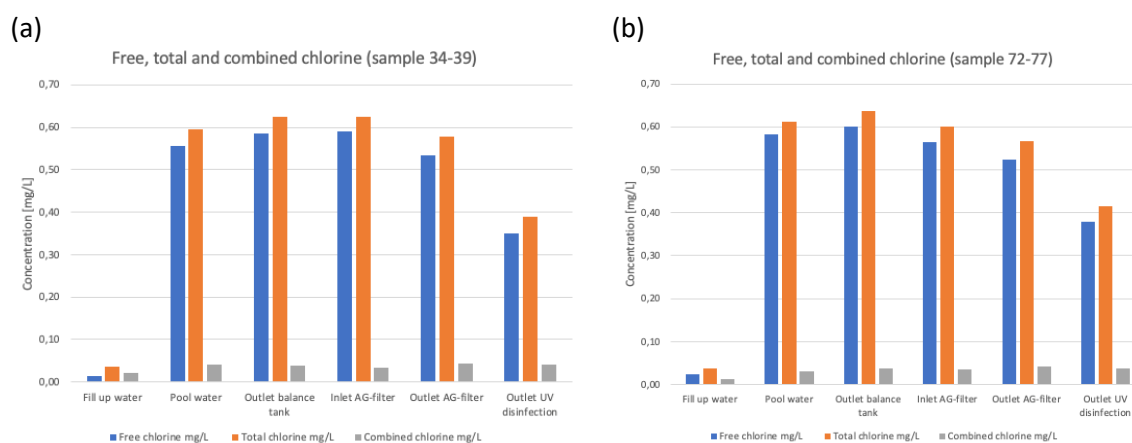


Figure 16: Free, total, and combined chlorine for each sampling point. (a) presents the results for 16<sup>th</sup> of March (sample 34-39) and (b) presents the results from 25<sup>th</sup> of March (sample 72-77).

The chlorine values in Table 5 are lower than those presented in Table 6. Based on these results and the fact that the samples in Table 5 were transported to the laboratory before measurements, it can be concluded that chlorine is lost during transportation. Thus, the values in Table 5 are inaccurate. Therefore, the results presented in Table 6 are more representative. However, the results presented in Table 5 and Figure 16 can be used to show the trend between the different sampling points.

It is observed that the values of free and total chlorine is higher in Figure 16 (b) than in (a) for all samples except inlet and outlet AG filter. The values for inlet and outlet AG filter are higher in (a) than in (b). Values of combined chlorine for each sampling point are higher in (a) than in (b), except for inlet AG filter. There is no major difference between the two measurement parallels. This is expected, as a stable chlorine value is preferred in pool water. [12] However, small changes are observed between the two parallels, which probably have been caused by variations in the added chlorine adjusted after the number of bathers. The deviation from the trend for inlet and outlet AG filter may be caused by different factors. A reason for deviation might be day-to-day variations in the pool water. Moreover, all measurements from the sample points were transported to the laboratory before measurements, which may lead to unprecise results. The values of combined chlorine from all sampling points are approximately the same (less than 0,050 mg/L). As the amount of combined chlorine generally is low, this indicates that little chlorine has reacted with amines to form DBPs such as trichloramines. From Figure 16 and Table 5, it can be concluded that the amount of combined chlorine is approximately 1/10 of the total chlorine present in all sampling points. This is expected, since fill up water added to the system is mainly drinking water from the public water supply, disinfected with  $\text{ClO}_2$ .

The required amount of free chlorine is set by the Norwegian regulations to be at least 0.9 mg/L for 33-37°C. [12] All values presented in Table 5 are below this value. In spite of this, the values presented in Table 6 are above the limit (0.992 mg/L). Thus, it can be concluded that Rud svømmehall fulfils the limit for free chlorine set by Norwegian regulations. Moreover, the maximum value of total chlorine set by Norwegian regulations is 4 mg/L. [12] In Table 6, the presented value for total chlorine is 1.08 mg/L for the training pool. The measured value is within the limit. Finally the maximum value of combined chlorine according to Norwegian regulations is 0.5 mg Cl/L. [12] The measured value in Table 6 is 0.088 mg/L. In conclusion, Rud svømmehall fulfils all requirements regarding free, total, and combined chlorine.

An interesting result is that chlorine is removed in the UV disinfection. The amount of free chlorine removed between outlet AG filter and outlet UV disinfection is approximately 0.16 mg/L. The amount

of combined chlorine removed in the UV disinfection is approximately 0.003 mg/L. This indicates that the UV disinfection removes free chlorine more efficiently than combined chlorine.

#### 4.1.1.2 Calculations of Disinfectant Dosage from ICP-MS Results

Table 7 presents the ICP-MS measurements of sodium, chlorine and calcium. These results are used for the determination of disinfectant dosage. The averaged values presented in bold represents the concentration of elements added through disinfectants.

Table 7: ICP-MS results for sampling points at Rud svømmhall for determining the disinfectant dosage. AF 21<sup>st</sup> of February (sample 1-5), FA 21<sup>st</sup> of February (sample 6-10), 16<sup>th</sup> of March (sample 34-39), and FA 16<sup>th</sup> of March (sample 40-45).

Sample number	Content	AF/FA	Element concentration with dilution rate [mg/L]		
			Na	Cl	Ca
22.02					
1	Fill up water	AF	12	20	26
2	Pool water	AF	403	530	29
3	Outlet balance tank	AF	399	535	29
4	Inlet AG filter	AF	398	533	29
5	Outlet AG filter	AF	400	526	29
<b>Averaged</b>			<b>388</b>	<b>511</b>	<b>3</b>
22.02					
6	Fill up water	FA	11	20	26
7	Pool water	FA	398	529	29
8	Outlet balance tank	FA	395	520	29
9	Inlet AG filter	FA	394	517	29
10	Outlet AG filter	FA	397	527	29
<b>Averaged</b>			<b>385</b>	<b>503</b>	<b>3</b>
16.03					
34	Fill up water	FA	11	18	26
35	Pool water	FA	443	589	29
36	Outlet balance tank	FA	442	601	29
37	Inlet AG filter	FA	447	596	29
38	Outlet AG filter	FA	448	602	29
39	Outlet UV	FA	445	603	30
<b>Averaged</b>			<b>434</b>	<b>580</b>	<b>3</b>
16.03					
40	Fill up water	AF	11	19	27
41	Pool water	AF	446	590	29
42	Outlet balance tank	AF	450	597	30
43	Inlet AG filter	AF	441	593	29
44	Outlet AG filte	AF	447	597	29
45	Outlet UV	AF	440	588	30
<b>Averaged</b>			<b>433</b>	<b>574</b>	<b>3</b>

Table 8: Consumption of chlorine. Concentration of chlorine according to ICP-MS results. Concentration of chlorine removed during operations units. Addition of NaOCl per cyclus to compensate for the removal of chlorine in operation units.

Sampling date	Concentration [mmol/L]	Removed [mg/L]	Addition NaOCl per cyclus [mmol/L]
21.02	14.3	-	-
16.03	16.3	0.05	0.0014
25.03 display	-	0.32	0.0090
Silvestro	-	0.24	0.0068

Table 8 is based on the measurements in Table 7 and measurements provided by Silvestro. [6] The calculations are presented in Appendix 2 – Calculations. The concentration of chlorine in pool water added from disinfectants, NaOCl and Ca(OCl)<sub>2</sub>, is calculated to be 14.3 mmol/L for 21<sup>st</sup> of February, and 16.3 mmol/L for 16<sup>th</sup> of March. Based on the low concentration of calcium added to the pool water, there had not been any fecal occurrence. Therefore, the amount of Ca(OCl)<sub>2</sub> is negligible, and NaOCl is the main disinfectant source to chlorine in the pool water. The differences in the concentration of chlorine removed is caused by the function of GAC filter. For measurements provided by Silvestro the GAC filter was in use, while it was not in the remaining sampling dates. The markable difference between 16<sup>th</sup> and 25<sup>th</sup> of March is caused by the loss of chlorine during transport at the 16<sup>th</sup> of March. The measurements on 25<sup>th</sup> of March was conducted in situ. Therefore, they are considered more precise than the measurements from 16<sup>th</sup> of March. The addition of NaOCl per cyclus to compensate for the removal of chlorine during operation units is determined to be 0.0090 mmol/L for the 25<sup>th</sup> of March, and 0.0068 mmol/L for Silvestro's measurements. The difference is caused by the impact of GAC filter. Hence, it can be concluded that the addition of NaOCl is less when the GAC filter is operative.

#### 4.1.2 SAC and DOC Measurements of the Sampling Points

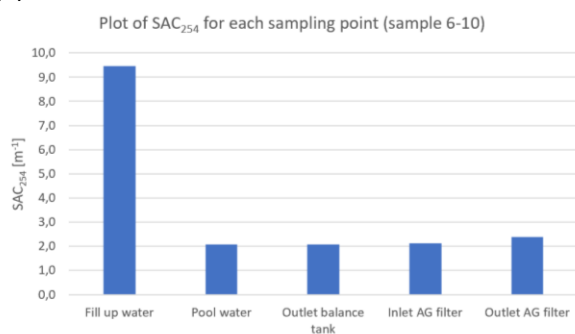
Figure 17 presents the plot of SAC<sub>254</sub> for each sampling point, while Figure 18 presents the plot of DOC for each sampling point. All measurements of SAC<sub>254</sub> and DOC are shown in Table 9. There were conducted three different parallels on different dates, parallel 1: 21<sup>st</sup> of February (sample 6-10), parallel 2: 16<sup>th</sup> of March (sample 34-39), and parallel 3: 25<sup>th</sup> of March (sample 72-77).



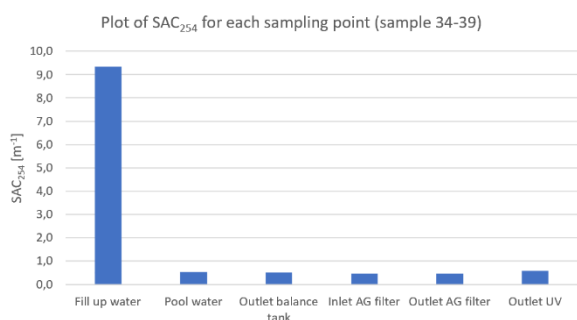
Table 9: The table presents the SAC<sub>254</sub> and DOC concentrations for the different sampling points.

Sample point	SAC <sub>254</sub> [m <sup>-1</sup> ]			DOC [mg/L]		
	Sample 6-10 (21.02)	Sample 34-39 (16.03)	Sample 72-77 (25.03)	Sample 6-10 (21.02)	Sample 34-39 (16.03)	Sample 72-77 (25.03)
Fill up water	9.45	9.34	9.32	5.10	3.60	2.87
Pool water	2.06	0.54	0.96	4.68	5.00	3.79
Outlet balance tank	2.06	0.50	0.92	4.64	4.59	3.89
Inlet AG filter	2.12	0.46	0.92	4.65	4.85	3.74
Outlet AG filter	2.37	0.46	0.92	5.35	4.67	3.70
Outlet UV	-	0.58	0.90	-	4.96	3.82

(a)



(b)



(c)

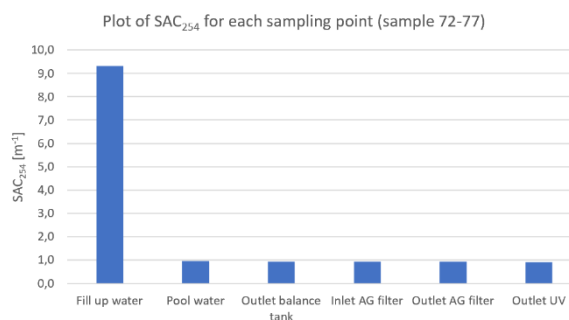
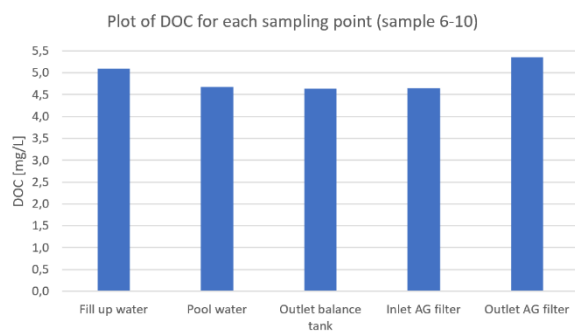
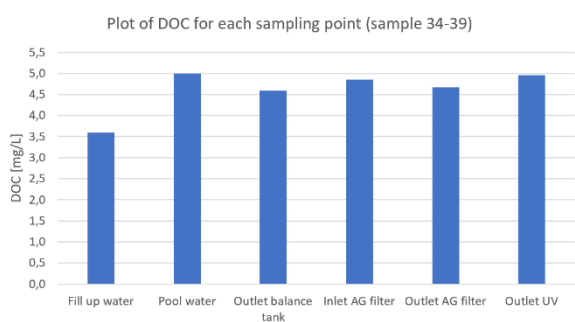


Figure 17: The figure presents the SAC<sub>254</sub> measurements for each sampling point. (a) Oslo 21<sup>st</sup> of February sample 6-10), (b) Oslo 16.03 (sample 34-39), and (c) Oslo 25.03 (sample 72-77).

(a)



(b)



(c)

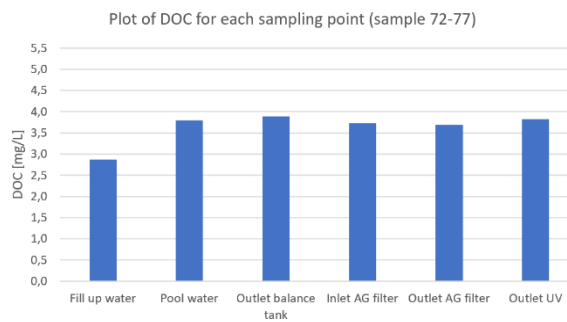


Figure 18: The figure presents the DOC concentrations for each sampling point. (a) 21<sup>st</sup> of February (sample 6-10), (b) 16<sup>th</sup> of March (sample 34-39,) and (c) 25<sup>th</sup> of March (sample 72-77).

In Figure 17, fill up water generally has  $SAC_{254}$  measurements above  $9 \text{ m}^{-1}$ . For (a), the rest of the sample points have similar values around  $2 \text{ m}^{-1}$ , with a maximum deviation of  $0.31 \text{ m}^{-1}$ . The  $SAC_{254}$  values indicate that there is a low but constant amount of DOC that can adsorb a wavelength of 254 nm. The  $SAC_{254}$  value is greater for fill up water, as the DOC present in fill up water are molecules of high molecular weight. These molecules are able to adsorb wavelengths of 254 nm. Pool water usually consists of small molecules with a negative charge which do not adsorb wavelength 254 nm to the same extent. [10] Due to this, the  $SAC_{254}$  measurement of fill up water is of a much greater magnitude than the rest of the sampling points, which mainly consist of pool water. The same trend applies to (b) and (c), where the  $SAC_{254}$  measurements are approximately  $0.5 \text{ m}^{-1}$ , with a maximum deviation of  $0.12 \text{ m}^{-1}$  in (b). In (c) the sampling points had  $SAC_{254}$  measurements around  $0.9 \text{ m}^{-1}$ , with a maximum deviation of  $0.06 \text{ m}^{-1}$ . The differences in Figure 17 (a), compared to (b) and (c), could be caused by differences in the time between gathering of the samples and analysis. The samples in (a) were left for 2 weeks before analysis, which could have led to bacterial growth or similar. The samples in (b) and (c) were analysed the same day. Contaminants such as bacteria or similar could give a higher  $SAC_{254}$  measurement. In addition, the spectrophotometric analyses from the 21<sup>st</sup> of February were carried out in a spectrophotometer in Trondheim, which was different from the spectrophotometer used in Oslo for the samples from the 16<sup>th</sup> and the 25<sup>th</sup> of March. Figure 18 does not show the same

trend between the sampling points as the SAC<sub>254</sub> measurements. Generally, the three different parallels present different trends. For (a) the DOC concentrations ranges from 4.64 to 5.35 mg/L, which is a deviation of 0.71 mg/L. The DOC concentrations in (b) have a deviation of 1.40 mg/L, with a range from 3.60-5.00 mg/L. For (c) the maximum deviation is of 1.02 mg/L, with a range of 2.87-3.89 mg/L. The greatest deviation is between fill up water and pool water in (b) and fill up water and outlet balance tank in (c). Figure 18 (a) is the only parallel where the highest DOC concentration is for fill up water. The variations in DOC concentrations are most likely caused by differences in water quality at the different dates. There could also be some uncertainties associated with the DOC analyser.

#### 4.1.3 Aluminium from ICP-MS Measurements

Figure 19 presents the different sampling points and the amount of aluminium in each of these. Table 10 shows the data for each of the sampling points, both AF and FA for the 21<sup>st</sup> of February and 16<sup>th</sup> of March. Two parallels at two different dates have been analysed of aluminium, 21<sup>st</sup> of February ((a) and (b)) and 16<sup>th</sup> of March ((c) and (d)). For each of these dates one parallel of the samples have been acidified before filtration (AF), (a) and (c), while the other have been filtrated before acidification (FA), (b) and (d).

Table 10: The table presents the aluminium concentrations for the different sampling points from 21<sup>st</sup> of February (AF, sample 1-5 and FA, sample 6-10) and 16<sup>th</sup> of March (FA, sample 34-39 and AF, sample 40-45).

Sample number	Content	AF/FA	Aluminum concentration [mg/L]
21.02			
1	Fill up water	AF	0.2
2	Pool water	AF	0.3
3	Outlet balance tank	AF	0.3
4	Inlet AG filter	AF	0.3
5	Outlet AG filter	AF	0.2
21.02			
6	Fill up water	FA	0.2
7	Pool water	FA	0.3
8	Outlet balance tank	FA	0.3
9	Inlet AG filter	FA	0.2
10	Outlet AG filter	FA	0.2
16.03			
34	Fill up water	FA	0.3
35	Pool water	FA	0.3
36	Outlet balance tank	FA	0.3
37	Inlet AG filter	FA	0.3
38	Outlet AG filter	FA	0.3
39	Outlet UV	FA	0.3
16.03			
40	Fill up water	AF	0.3
41	Pool water	AF	0.3
42	Outlet balance tank	AF	0.3
43	Inlet AG filter	AF	0.3
44	Outlet AG filter	AF	0.3
45	Outlet UV	AF	0.3

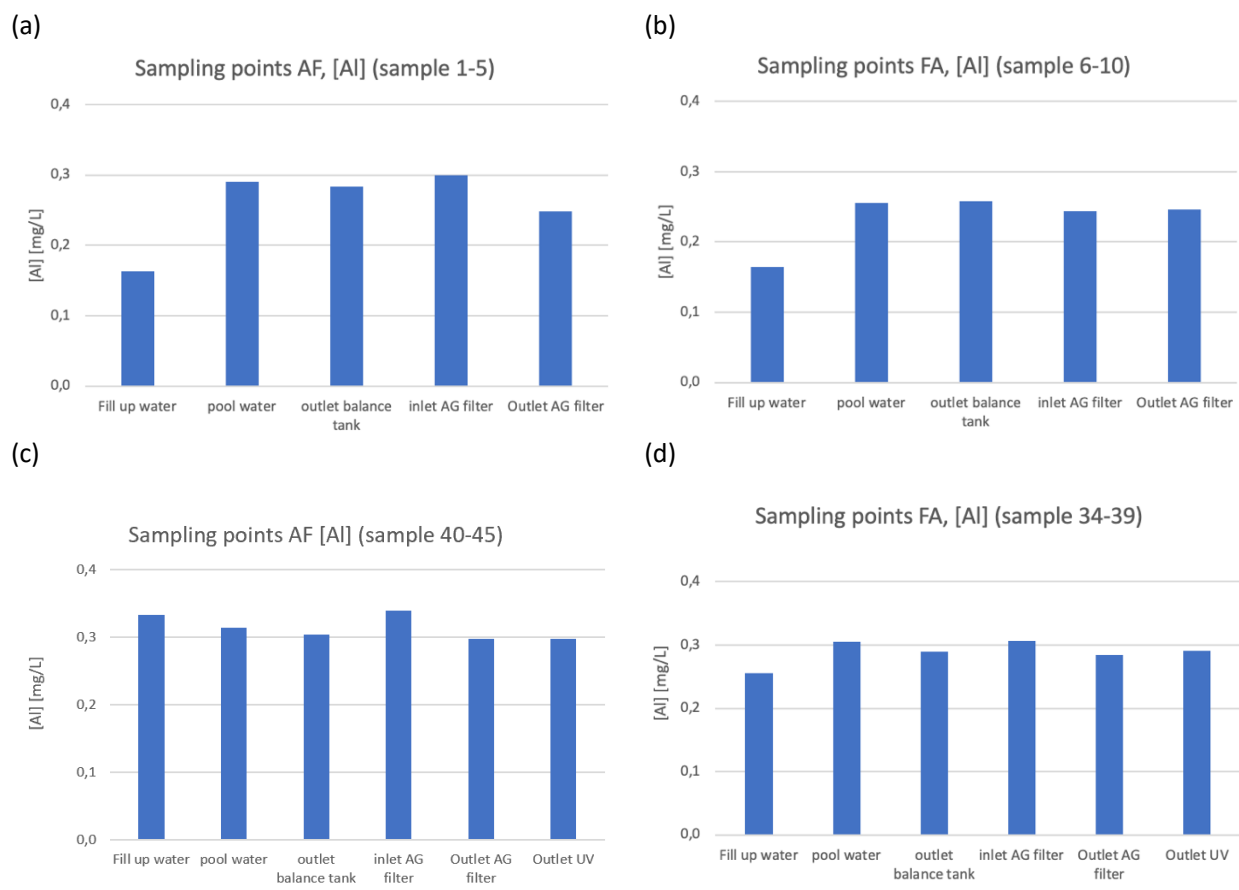


Figure 19: The figure presents the aluminium concentration in each sampling point. (a) AF 21<sup>st</sup> of February (sample 1-5), (b) FA (sample 6-10), (c) AF 16<sup>th</sup> of March (sample 40-45), and (d) FA (sample 32-39).

The main interest for the ICP-MS analyses is the outlet balance tank, inlet AG filter and outlet AG filter. These points are in focus as coagulant is added between the outlet balance tank and inlet AG filter. Outlet AG filter provides a measurement of the flocs removed in the AG filter. The coagulant is added after the outlet balance tank, thus the aluminium concentration at this sampling point should be lower than at inlet AG filter, for the AF samples. Outlet AG filter should have a lower aluminium concentration than inlet AG filter for AF, as flocs have been removed in the filter. For FA samples, the three sampling points should ideally have the same concentrations of aluminium. This is because the flocs formed by the coagulant are removed when the samples are filtrated.

Figure 19 (a) follows the ideal trend describes above, where the aluminium concentration in inlet AG filter is higher than both outlet balance tank and outlet AG filter. Figure 19 (b) only partly follows the ideal trend for FA as described above. Outlet balance tank has a higher concentration than inlet AG filter and outlet AG filter, where the inlet and outlet AG filter have approximately the same aluminium concentrations. The deviation from the trend of outlet balance tank have no obvious explanation, but might be caused by contaminations of aluminium from the bathers. The should be no contamination

from pipes or similar, as pool water has the same aluminium concentration. Figure 19 (c) follows the expected trend for AF samples. Figure 19 (d) seems to follow the trend of AF samples, as inlet AG filter has a higher concentration than both outlet balance tank and outlet AG filter. This might have been caused by variations in the type of particles present in the water. A high aluminium concentration of FA samples may indicate that few flocs were formed. However, if this was the case the aluminium concentration at outlet AG filter should be the same as inlet AG filter as the dissolved aluminium would go through the filter.

An observation made in all of the plots is that there is little variation in aluminium concentrations. The maximum variation is approximately 0.15 mg/L between fill up water and the rest of the samples. The remaining sample points have a variation of < 0.05 mg/L. This may indicate that the coagulant dosage is too low or that it is not optimal/efficient for the particles present in the water.

#### 4.1.4 Particle measurements

Particle measurements were carried out at the different sampling points to ensure that the treatment processes work properly when removing particles flocculated by the coagulant. The coagulant is added to the water before it reaches the AG filter where the flocculated particles are removed. Thus, the inlet and outlet AG filter are the most interesting measurements. All particle measurements are repeated 10 times, and the results presented below are an average of these measurements. Figure 20 presents the particle concentration from each sampling point at Rud svømmehall on the 25<sup>th</sup> of March in Oslo (sample 72-77). Table 11 presents the total particle concentration from each sampling point.

Table 11: Particle measurement results from sampling points at Rud svømmehall.

Sampling point	Total particle concentration [mL <sup>-1</sup> ]
Fill up water	3694
Pool water	199
Outlet balance tank	182
Inlet AG filter	249
Outlet AG filter	27
Outlet UV	99

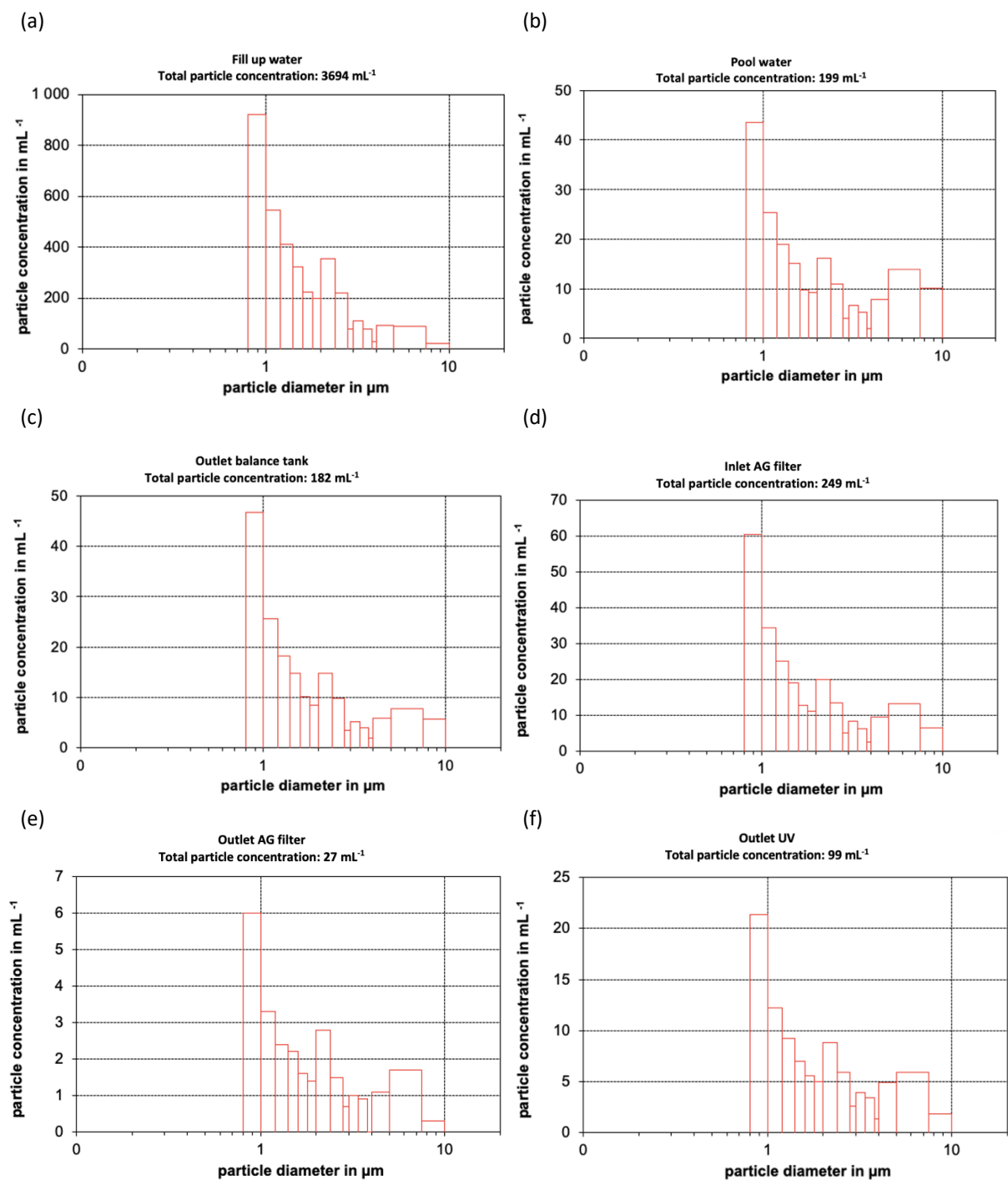


Figure 20: The figure presents the results from the particle measurements from each sample point at Rud svømmehall, 25.03.22. (a) presents fill up water, (b) pool water, (c) outlet balance tank, (d) inlet AG filter, (e) outlet AG filter, and (f) outlet UV.

The values from Table 11 present the total particle concentration measured per mL for each sampling point. The total particle concentrations in Table 11 are based on the particle measurements presented in Figure 20. The figure also show the different particle size ranges, and the number of particles present in each range. All the particle measurements have a comparable size trend, where the number

of particles in each size range decreases with size. Even though the measurements have a comparable size trend, the total concentration of particles in each measurement differ. This is shown in Figure 20 (a) and (b), where (a) has a maximum particle concentration per size range approaching  $1000 \text{ mL}^{-1}$ , while it is approaching  $50 \text{ mL}^{-1}$  for (b). The size trend is comparable in both (a) and (b).

The purpose of the coagulant is to ensure effective precipitation, without oversaturating the solution. Therefore, a high particle concentration is optimal. In Table 11, fill up water has the highest particle concentration of  $3694 \text{ mL}^{-1}$ . When taking the flow rate into consideration, the number of particles from fill up water will be negligible. When the streams from pool water and fill up water are mixed in the balance tank, the total particle concentration decreases. This decrease can be caused by sedimentation or similar in the balance tank, but it can also be caused due to dilution with the water already present in the balance tank. Moreover, the particle concentration increases from outlet AG filter to the UV filter, which is unexpected. The UV filter should have a lower or the same particle concentration as outlet AG filter, as there is no further addition of particles to the system. Chemical reactions triggered by the UV disinfection could be a reason for the increased particle concentration. The reason for the increased particle concentration can be determined through more parallels.

There is an expected increase in the particle concentration from outlet balance tank and the inlet AG filter. The addition of coagulant between these sampling points causes the increase in particle concentration. The addition of the coagulant form flocs. These flocs are removed in the AG filter. According to the producer, the AG filters can remove 97% of particles with diameters down to  $5.0 \mu\text{m}$ , without the aid of a coagulant. [6] Due to this, particles with a diameter less than  $5 \mu\text{m}$  will travel through the filter. These small particles will only be removed after forming bigger flocs with the addition of the coagulant. [13] As observed in Figure 20 (d) and (e), approximately 90% of all particle sizes are removed after the addition of coagulant and filtration in the AG filter. These results are not in accordance with the particle removal percentage of the filter. It is expected that the number of particles ranging from  $0.8 \mu\text{m}$  to  $5.0 \mu\text{m}$  would stay constant, and the total particle concentration above  $5.0 \mu\text{m}$  would decrease. A reason to the decrease in the total particle concentration can be that the filter only guaranteed a 97% removal of particles above  $5.0 \mu\text{m}$ , but does not guarantee the removal of particles smaller than  $5.0 \mu\text{m}$ . Even though the results do not reflect the particle removal stated by the producer, the filter removes a sufficient amount of particles (90%) in all size ranges.

#### 4.1.5 Trace elements and heavy metals in pool water

Rud svømmehall is changing GAC filters, where ICP-MS analyses show whether there are any remaining elements, such as trace elements and heavy metals, from the previously used GAC filter.

The results presented in this part show a comparison of the amount of metal and heavy metals. Table 12 presents metal concentrations in µg/L for drinking water in Trondheim (sample 6), fill up water (22<sup>nd</sup> of February and 16<sup>th</sup> of March, sample 6 and 34), and pool water (22<sup>nd</sup> of February and 16<sup>th</sup> of March, sample 7 and 35).

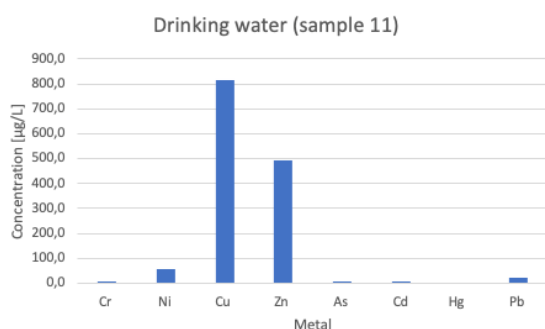
Table 12: Metals and heavy metals concentrations presented in drinking water Trondheim, along with the fill up water and pool water samples from Rud svømmehall.

Sampling point date	Metal concentration [µg/L]							
	Cr	Ni	Cu	Zn	As	Cd	Hg	Pb
Drinking water 0mg/L Trondheim 06.03, (sample 11)	0.7	57.6	813.0	492.5	0.7	0.0	<0.225	19.6
Fill up water 21.02, (sample 6)	0.6	1.8	44.4	20.4	0.6	0.0	<0.225	0.2
Fill up water 16.03, (sample 34)	0.6	1.3	61.2	15.1	0.6	0.0	<0.225	1.2
Pool water 21.02, (sample 7)	8.4	15.1	78.1	14.4	0.9	0.0	<0.225	0.0
Pool water 16.03, (sample 35)	7.7	18.6	109.7	4.4	0.8	0.0	<0.225	0.1

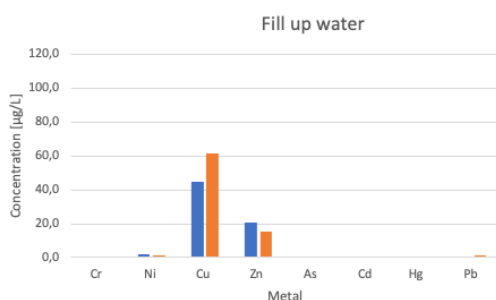
Figure 21 presents the distribution of metals in the different water types, where (a) is drinking water in Trondheim (sample 11), (b) is fill up water 21<sup>st</sup> of February and 16<sup>th</sup> of March (samples 6 and 34), and (c) for pool water 21<sup>st</sup> of February and 16<sup>th</sup> of March (sample 7 and 35). The figure is based on the values in Table 12.



(a)



(b)



(c)

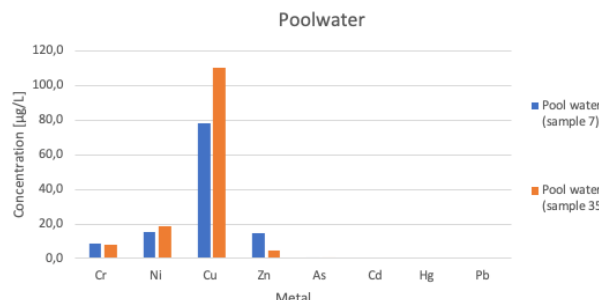


Figure 21: Distribution of metal concentrations in (a) drinking water Trondheim (sample 6), (b) fill up water 22nd of February and 16th of March (sample 6 and 34), and (c) pool water the 22nd of February and 16th of March (sample 7 and 35).

A comparison of the different water types presented in Table 12 shows that the concentrations of metals generally are higher on the 16<sup>th</sup> of March (samples 6 and 7), than on the 22<sup>nd</sup> of February (samples 34 and 35). The exceptions are chromium, zink, and arsenic in pool water, and nickel and zink in fill up water. Although, the measured values do not vary that much. The differences can be caused by the day-to-day concentration of metals in the pool water. Considering the hypothesis that CarboTech Pool W 1-3 possibly leaked heavy metals, the measured values in Table 12 could not verify this hypothesis. This is because the concentrations of heavy metals in pool water are higher on the 16<sup>th</sup> of March than on the 21<sup>st</sup> of February. However, to ensure this hypothesis several measurements should be considered directly from the samples where PAC is added, for example equal to samples 22-33, measured for DOC. The metal concentrations in drinking water Trondheim (sample 6) stand out with a high value compared to the facility samples, considering copper, zink, and lead. This can be caused by high metal concentrations in the pipes or variations in the day-to-day concentration in the water. However, several analyses should be considered due to health and environmental factors.

## 4.2 Determination of Optimal Coagulant Dosage

To determine the effect of the coagulant three variables are investigated. The first variable is the removal of DOC at different coagulant dosages. The second parameter investigated is the number of particles present after the use of coagulant at different dosages. The third part of the coagulant investigations is to determine the amount of dissolved and particulate aluminium after coagulation, using ICP-MS.

### 4.2.1 Particle measurements after jar test

As a way of determining the most effective coagulant dosage, the number of particles at different coagulant dosages was measured after the jar test on the 25<sup>th</sup> of March. The coagulant dosages range from 0-8 mg/L. All particle measurements are repeated 10 times, and the results presented below are an average of these.

Table 13 presents the total particle concentrations from jar tests for fill up water and pool water, based on particle measurements presented in Figure 22 (sample 78-82) and Figure 23 (sample 83-87). These measurements are based in coagulat dosages ranging from 0-8 mg/L. The figures also show the different particle size ranges, and the number of particles present in each range.

Table 13: Particle measurement results from-fill up water and pool water after jar test (0-8mg/L), 25<sup>th</sup> of March.

Concentration of coagulant [mg/L]	Total particle concentration [mL <sup>-1</sup> ]	
	Fill up water	Pool water
0	3280	281
2	3242	335
4	10 025	472
6	4121	3613
8	5372	446

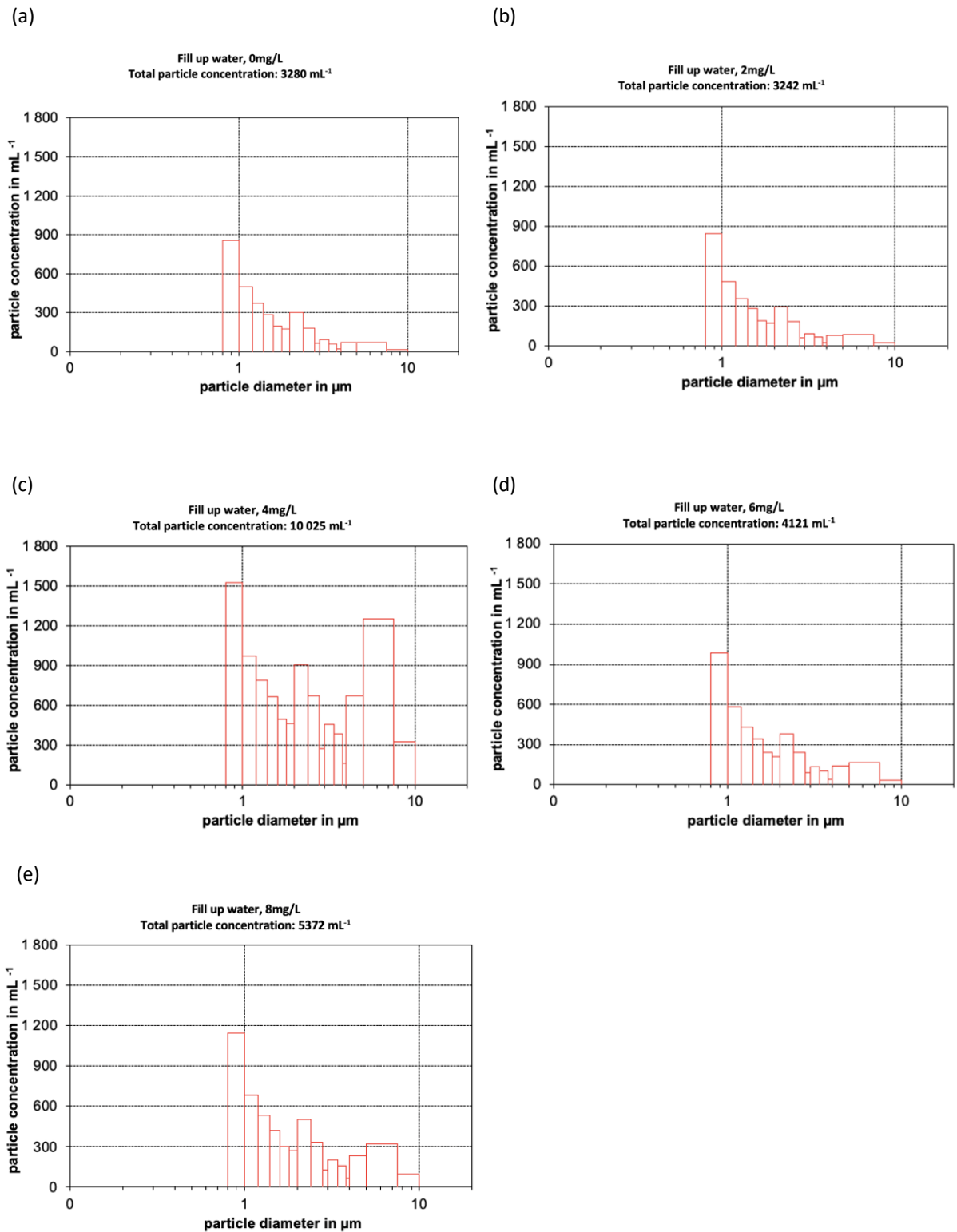


Figure 22: The figure presents the total particle concentration of fill up water after jar test, 25<sup>th</sup> of March. (a) 0mg/L (b) 2mg/L (c) 4mg/L (d) 6mg/L, and (e) 8mg/L.

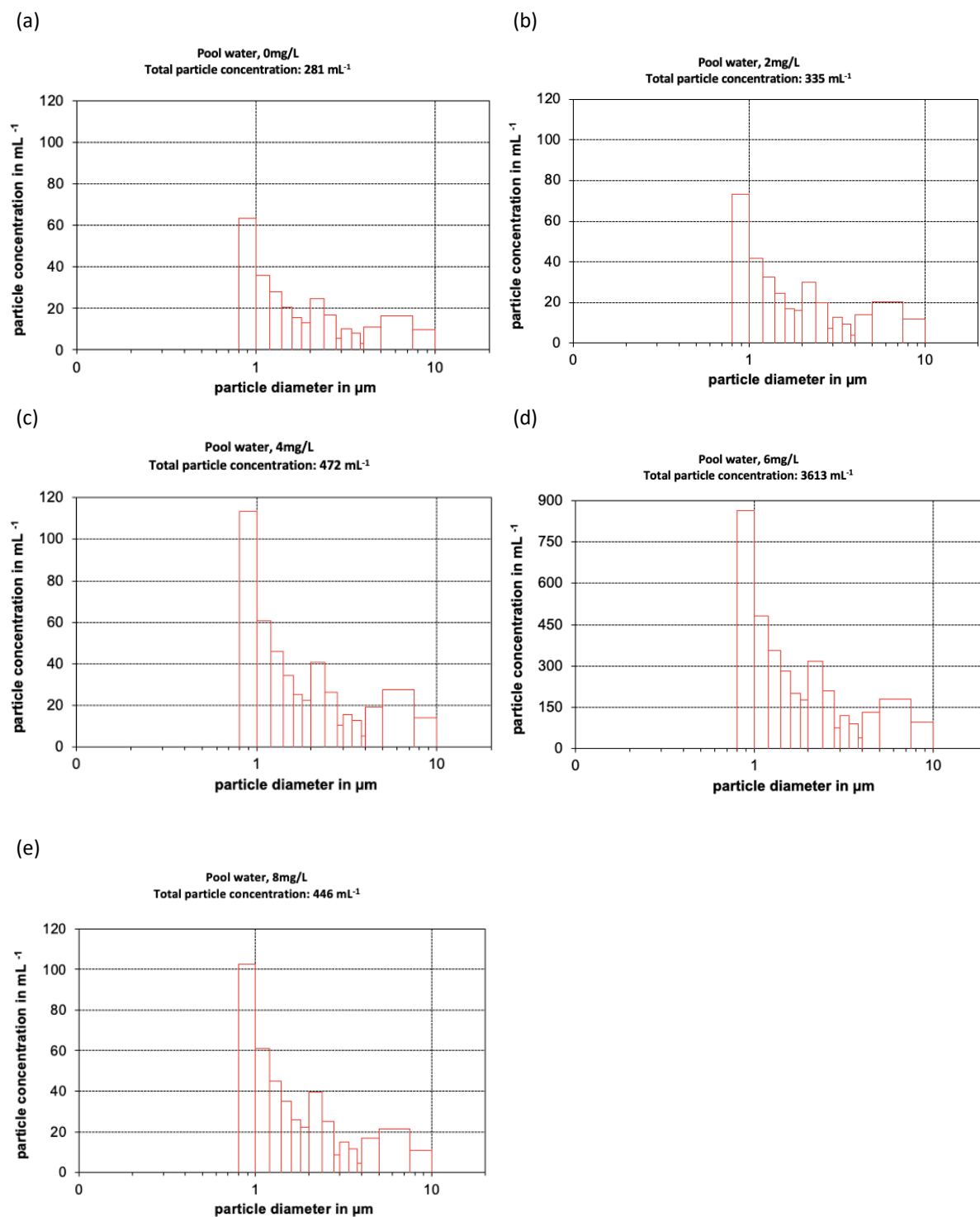


Figure 23: Total particle concentration of pool water after jar test, 25.03.22. (a) 0mg/L, (b) 2mg/L, (c) 4mg/L, (d) 6mg/L, and (e) 8mg/L.

All particle measurements have a comparable size trend, where the number of particles in each size range decreases with size. Even though the measurements have a comparable size trend, the total concentration of particles in each measurement differ.

Table 13, Figure 22 and Figure 23 displays the results from jar test with fill up water and pool water. The highest particle concentration in fill up water after jar test is  $10\,025\text{ mL}^{-1}$  at a coagulant dosage of 4 mg/L. A high particle concentration indicates that charged particles dissolved in the water have created flocs with the coagulant. [13] Addition of a coagulant dosage of 4 mg/L to the fill up water increases the particle concentrations of all particle sizes. There is a notable increase in the number of larger particles with sizes of 2.0  $\mu\text{m}$ , 4.0  $\mu\text{m}$ , and 5.0  $\mu\text{m}$ , shown in Figure 22 (c) compared to Figure 22 (a) and (b). This indicates that the coagulant forms flocs with smaller particles, as seen in the steep increase in the particle concentrations of particles of these sizes. As observed in Figure 22, the total particle concentration decrease when the coagulant dosage increases to 6 mg/L. This happens due to an oversaturation, where aluminium ions in excess dissolves already neutralized flocs, as they now gain a net positive charge. [13] Further increase in the coagulant dosage to 8 mg/L leads to a new increase in the number of particles. The increase in particle concentration is caused by the formation of sweep floc. [13]

In Figure 23 (d), it is observed that a coagulant dosage of 6 mg/L in pool water provides a maximum particle concentration of  $3613\text{ mL}^{-1}$ . Pool water after jar test has a similar trend to the fill up water particle measurements, where there is a high concentration of particles at the smallest size ranges. However, at a coagulant dosage of 6 mg/L there is an increase in the number of particles in all size ranges. There is no increase in the concentration of bigger particles compared to the observations for the optimal coagulant dosage for fill up water. The reason for the differences might be the presence of particles with different chemical and physiological properties in pool water and fill up water.

Based on the particle measurements presented in Figure 22 and Figure 23, the coagulant appears to be more efficient for fill up water than pool water. In spite of this, the flow of pool water is greater than that of fill up water, thus the optimal coagulant dosage, based on the presented results, is 6 mg/L for pool water. According to Silvestro, Rud svømmehall is currently using an ineffective coagulant dosage of 30 mL/h ( $4.65\ \mu\text{g}/(\text{L}\cdot\text{h})$ ). [6] Based on the particle measurements presented above, an increase in coagulant dosage is advisable. To support the recommendation of the coagulant dosage more parallels should be conducted.

#### 4.2.2 DOC Removal with Coagulant

The amount of DOC was measured in the samples after jar test to investigate the ability of the coagulant to remove DOC. The DOC measurements after jar test are measured out of interest to evaluate the effect of the coagulant on DOC removal. The plotted graphs provide a minimum concentration of DOC. The DOC measurements at different coagulant dosages are presented in Table 14. Figure 24 shows the results graphically.

Table 14: The table shows DOC measurements at different coagulant dosages for fill up water and pool water from the 16<sup>th</sup> and 25<sup>th</sup> of March 2022.

Coagulant dosage [mg/L]	Date and sample information			
	16.03.2022		25.03.2022	
	DOC fill up water [mg/L]	DOC pool water [mg/L]	DOC fill up water [mg/L]	DOC pool water [mg/L]
0	3.82	5.05	3.14	3.87
2	2.27	4.62	1.70	3.47
4	2.43	4.60	1.18	3.47
6	2.33	4.46	1.76	3.26
8	2.49	4.47	1.69	3.39

Figure 24 (a) presents DOC analysis with increasing coagulant dosage for fill up water carried out 16<sup>th</sup> of March 2022 (sample 46-50). At a coagulant concentration of 0 mg/L, the fill-up water has a DOC concentration of 3.82 mg/L. At a coagulant dosage of 2 mg/L, the DOC concentration is measured to be 2.27 mg/L. This is approximately half of the initial concentration of DOC. With increasing amounts of coagulant, the DOC concentration seems to stabilize between 2.30 mg/L and 2.50 mg/L, with a maximum decrease in DOC concentration of 1.55 mg/L.

Figure 24 (b) shows a DOC analysis with increasing amounts of coagulant for pool water from the 16<sup>th</sup> of March 2022 (sample 51-55). With a coagulant dosage of 0 mg/L, the pool water has a DOC concentration of 5.05 mg/L. As the coagulant dosage increases the DOC concentration stabilizes around 4.40 mg/L and 4.60 mg/L, with a minimum DOC concentration of 4.46 mg/L at a coagulant dosage of 6 mg/L. The DOC concentration in the pool water does not decrease with the same magnitude as the fill up water, with a maximum decreases of 0.59 mg/L.

Figure 24 (c) shows the same results as Figure 24 (a) but for fill up water from the 25<sup>th</sup> of March 2022 (sample 78-82). The initial concentration of DOC with no coagulant added is 3.14 mg/L. The minimum amount of DOC was measured when the coagulant dosage was 4 mg/L, with a DOC concentration of 1.18 mg/L. The maximum amount of DOC removed compared to the initial coagulant concentration

of 0 mg/L was 1.95 mg/L. The DOC concentration seems to stabilize around 1.5 mg/L at a coagulant dosage of 8 mg/L.

The results of DOC removal with increasing coagulant dosage from pool water were also measured on the 25<sup>th</sup> of March 2022 (sample 83-87). These results are presented in Figure 24 (d). The initial concentration of DOC in the pool water was 3.87 mg/L. A small amount of DOC is removed with increasing coagulant dosage, and the DOC concentration is stable at around 3.50 mg/L. The lowest concentration of DOC, 3.26 mg/L, was at a coagulant dosage of 6 mg/L. This results in a maximum removal of 0.61 mg/L.

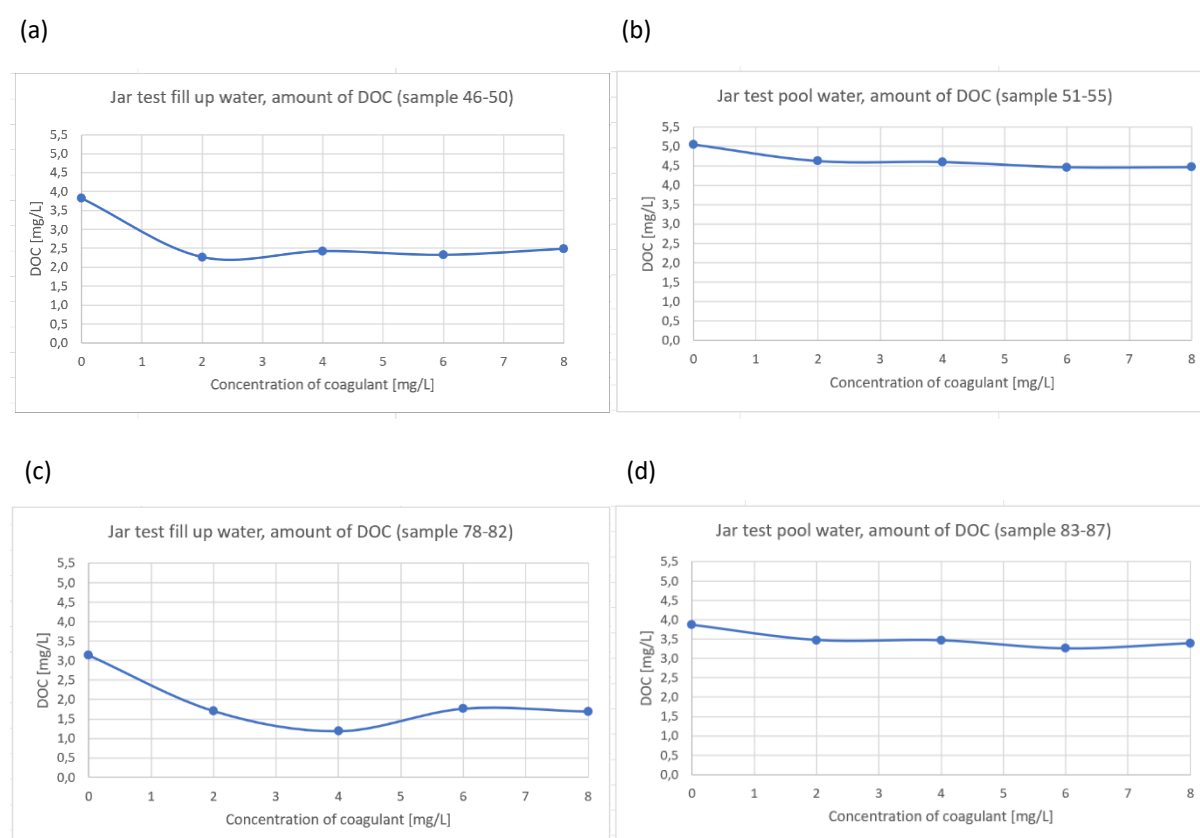


Figure 24: The figure presents the results from the amount of DOC in fill up water and pool water after jar test. (a) fill up water 16<sup>th</sup> of March (sample 46 to 50) (b) pool water 16<sup>th</sup> of March (sample 51 to 55) (c) fill up water 25<sup>th</sup> of March (sample 78 to 82) and (d) pool water 25<sup>th</sup> of March (sample 83 to 87).

The initial concentration of DOC was higher in Figure 24 (a) compared to Figure 24 (c), with concentrations of 3.82 mg/L compared to 3.14 mg/L. In spite of this, less DOC is removed in (a) than in (c), 1.55 mg/L compared to 1.95 mg/L. Moreover, a higher coagulant dosage is required for maximum DOC removal in (a) than (c), 2 mg/L versus 4 mg/L. These results can be explained by the DOC particle sizes in fill up water. The DOC particles may be bigger in (c), which will require a higher coagulant dosage for removal and lead to a greater DOC removal. In (a) the particles could be smaller

than in (c) and would thus be harder to remove by the coagulant. It would be possible to verify this hypothesis by looking at the measurements carried out by a particle counter. A particle counter was used to measure the amount and size of particles both for fill up water on the 16<sup>th</sup> of March (sample 46-50) and 25<sup>th</sup> of March (78-82). The particle measurements for the 16<sup>th</sup> of March (sample 46-50) were lost. Due to this, it is not possible to compare the particle measurements on the two different dates. For further experiments, additional parallels should be carried out with particle measurements. These particle measurements could be used to support the hypothesis.

The coagulant consists of positive ions that are able to neutralize negatively charged particles. High molecular DOC is also able to adsorb onto the coagulant. [13] [41] Further, the coagulant can form interparticulate bridges, which can lead to the entrapment of more particles, where the precipitate formed is called a sweep floc. Particles of greater size than 0.1  $\mu\text{m}$  in diameter are rapidly removed by the coagulant, but smaller particles are harder to remove. [43] This theory supports the hypothesis that the measurements for fill up water on for 25<sup>th</sup> of March contains DOC of greater size than for the 16<sup>th</sup> of March, even though the initial DOC concentration is lower. The variations in DOC levels can be caused by variations in the contamination of the water from day to day, as the water can contain bigger particles one day, but have a lower total concentration of particles. The variation in the measured DOC concentrations can also be caused by experimental errors of the DOC instrument or different treatment of the samples as they were carried out on two different dates.

Figure 24 (b) and (d) present differences in the initial DOC concentrations in pool water, which are 5.05 mg/L in (b) compared to 3.87 mg/L in (d). Less DOC is removed in (b) than in (d), with concentrations 0.59 mg/L compared to 0.61 mg/L. However, the maximum removal of DOC in both (b) and (d) happens at a coagulant dosage of 6 mg/L. Based on these results it can be concluded that little DOC is removed from the pool water compared to the initial concentration of DOC. Even though the initial DOC-concentration is greater for the 16<sup>th</sup> of March (sample 51-55) compared to the 25<sup>th</sup> of March (sample 83-87), approximately the same amount of DOC is removed. The variation in the initial DOC concentration can be caused by the daily variation of the DOC concentration in the pool water, which correlates with the number of bathers. The samples in Figure 24 (b) were obtained at 13:10, whilst at 09:15 in (d). Due to this, a higher number of bathers could have contaminated the pool water by 13:10 compared by 09:15. Another interesting aspect is that the amount of DOC removed seems to be constant. This indicates that there is a constant, but low level of DOC in the pool water that can be removed by the coagulant. Thus, most of the DOC particles added from the bathers are smaller than what the coagulant is able to remove.



Overall, little DOC is removed from the pool water by the coagulant for all coagulant dosages. As there might have been variations in DOC measurements, it can be discussed whether a coagulation dosage of 6 mg/L is the most optimal. Approximately the same amount of DOC is removed at a lower coagulant dosage of 2 mg/L. Hence, a more sustainable approach suggests that a lower coagulant dosage can be used to remove approximately the same amount of DOC per litre. This will save resources, but still ensure the removal of some DOC. Further experiments should be conducted with lower coagulant dosages than 2 mg/L at intervals of 0.5 mg/L, to investigate whether lower dosages may be more effective.

The initial DOC concentrations vary between the fill up water and pool water. The DOC concentrations in the pool water are generally higher than for the fill up water. This difference in concentration is caused by the contamination from bathers. Despite this, more DOC is removed from the fill up water than from the pool water. This is probably caused by differences in particle sizes, as discussed above. The bathers in pool water generally emit smaller organic particles, such as urea and viruses, which are harder to remove by the coagulant than bigger organic molecules often found in freshwater, such as clays and humic acids. [10] [13] Thus, the use of coagulant is mainly effective for removal of DOC in fill up water. The most effective coagulant dosage varies with fill up water and pool water and is higher for pool water. The coagulant is most effective for fill up water, based on the amount of DOC removed compared to the initial DOC concentrations. However, taking the flow rate into account, the amount of DOC removed in pool water is approximately 100 times greater than for fill up water. Consequently, it is advisable to use a coagulant dosage best fitted for pool water. Based on these graphs the most effective coagulant dosage for fill up water is between 2-4 mg/L, and at 6 mg/L for pool water. Depending on the requirements for Rud svømmehall, a coagulant dosage of 2 mg/L could also be used.

Ideally, DOC should have been measured after the jar test of drinking water in Trondheim (sample 11-15). Due to conflicts in analysis requirements these samples were not analysed for DOC.

#### 4.2.3 Amount of Dissolved and Particulate Aluminium in Coagulation Tests

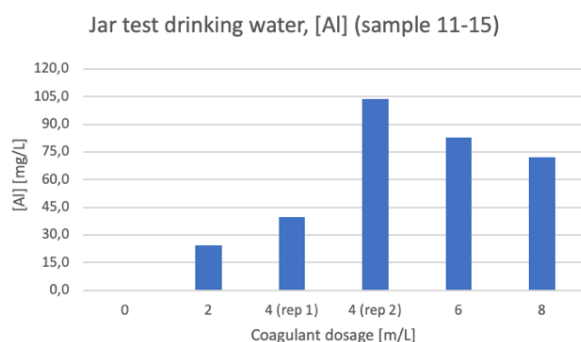
Results from the ICP-MS are used to find the amount of dissolved aluminium after filtration of the flocs formed in the jar test. This is used to find the surplus aluminium that will not react to form flocs. Table 15 presents the concentrations of dissolved aluminium after jar test for the different water samples on the different dates. The aluminium concentrations plotted against coagulant dosage are presented in Figure 25.

Figure 25 (a) presents the plot of dissolved aluminium against coagulant dosage for drinking water Trondheim (6<sup>th</sup> of March, sample 11-15). (b) and (c) presents the plots for fill up water for the 16<sup>th</sup> (sample 46-50) and 25<sup>th</sup> of March (78-82). Figure 25 (d) and (e) shows the plots for pool water from the 16<sup>th</sup> (sample 51-55) and 25<sup>th</sup> of March (sample 83-87).

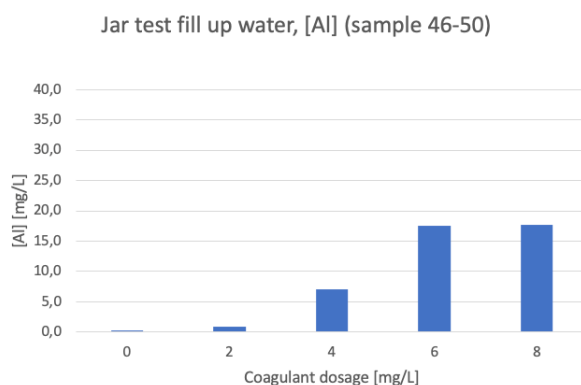
Table 15: The table presents the concentration of aluminium at different coagulant dosages, measured after the jar test.

Concentration of coagulant [mg/L]	Concentration of aluminium [mg/L]				
	06.03.22	16.03.22		25.03.22	
	Drinking water (sample 11-15)	Fill up water (sample 46-50)	Pool water (sample 51-55)	Fill up water (sample 78-82)	Pool water (sample 83-87)
0	0.2	0.2	0.3	Rep 1: 0.2 Rep 2: 0.2	0.4
2	24.7	0.9	0.8	0.1	1.6
4	Rep 1: 39.9 Rep 2: 103.8	7.1	1.0	4.0	2.8
6	83.1	17.5	5.6	16.3	3.4
8	72.2	17.6	36.0	35.4	2.3

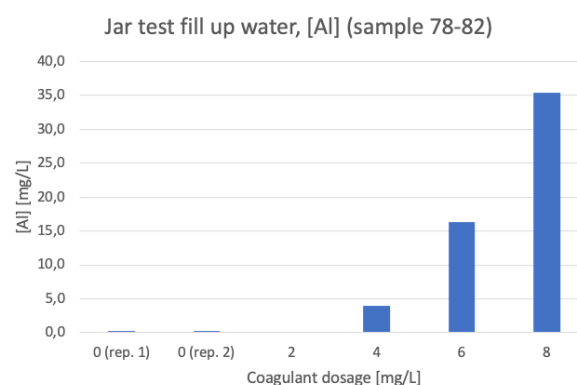
(a)



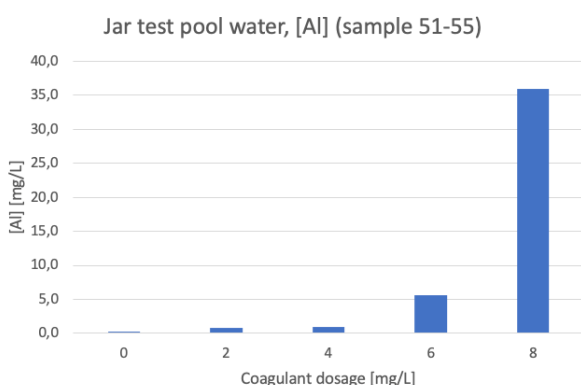
(b)



(c)



(d)



(e)

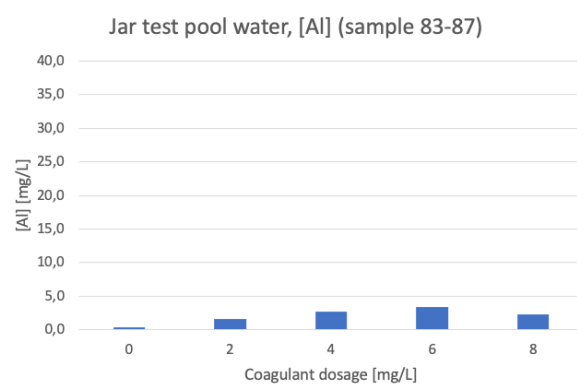


Figure 25: The figure presents the concentration of aluminium after different coagulant dosages. (a) drinking water Trondheim 6<sup>th</sup> of March (sample 11-15), (b) fill up water Oslo 16<sup>th</sup> of March (sample 46-50), (c) fill up water Oslo 25<sup>th</sup> of March (sample 78-82), (d) pool water Oslo 16<sup>th</sup> of March (sample 51-55), and (e) pool water Oslo 25<sup>th</sup> of March (sample 83-87).

The samples are filtrated after jar test, before acidification and ICP-MS analysis. Thus, the amount of aluminium which have not formed flocs, or flocs that are smaller than the filter pore size and dissolved in the acid, are detected in the ICP-MS. Ideally all of the coagulant will react with negative particles in the solution to form flocs. Thus, there should be no dissolved aluminium left in solution, as all aluminium is present in flocs. The most optimal coagulant dosage will be the dose where the lowest amount of dissolved aluminium is present.

In Figure 25 (a) the second repetition of the two measurements of the coagulant dosage of 4 mg/L is considered an outlier. This measurement is both higher than repetition 1 and the aluminium

measurement of the coagulant dosage of 6 mg/L. When taking the average of the two repetitions, the concentration of dissolved aluminium is at 71.9 mg/L, which is lower than the aluminium concentration at 6 mg/L. The trend for (a) will therefore be an increase in the concentration of dissolved aluminium until a dosage of 6 mg/L is reached. At an coagulant dosage of 8 mg/L the aluminium concentration decreases. This might be due to the formation of sweep floc. [13]

Figure 25 (b) and (c) shows the same trend until the coagulant dosage of 6 mg/L. The two plots have similar aluminium concentrations for the different coagulant dosages, where (b) have slightly higher aluminium concentrations for coagulant dosages of 2-6 mg/L. The two plots deviate for 8 mg/L. There is no clear explanation to the higher aluminium concentration in (c) than in (b). This deviation could be caused by analytical errors, or trace elements present in the glass beakers before analysis.

There is no comparable trend in Figure 25 (d) and (e). In (d) the concentration of dissolved aluminium slowly increase between coagulant dosages of 2-6 mg/L, and has a significant increase between the coagulant dosage of 6 and 8 mg/L. This trend is not shown in (e), where the increase in dissolved aluminium is slow and for all coagulant dosages, the aluminium concentration stays below 4 mg/L. There is an increase in aluminium concentration from 2-6 mg/L, and a drop when the coagulant dosage is 8 mg/L. The deviations in the dissolved aluminium concentrations for (d) and (e) can be explained by trace elements present in the glass beakers of the jar apparatus or analytical errors.

pH has great influence on the solubility of aluminium, and is probably the biggest factor for variations in the measurements. There were some variations in the pH after adjustment, where the range was  $7.3 \pm 0.1$ . A pH variation of 0.1 will have a great impact on the solubility of aluminium in water, thus explaining the variations seen in the parallels. [13] As there is no comparable trend between the aluminium concentrations of the different parallels, no clear conclusion can be made about the optimal coagulant dosage based on these results. Moreover, the pH should be measured accurately after the addition of coagulant and after the jar test to ensure equal reaction conditions for all samples.

#### 4.2.4 Comparison of Measurements After Jar Test

The outlook in Silvestro's bachelor thesis concluded that Rud svømmehall are currently using an ineffective coagulant dosage. [6] During the analyses after jar test, the Silvestro's conclusion was verified, and a new coagulant dosage should be considered. After measurements of total particle concentration, DOC and dissolved aluminium after jar test, it is challenging to draw a definite conclusion of the optimal coagulant dosage. The DOC measurements indicated that a coagulant dosage of 2 mg/L showed approximately the same removal of DOC as the coagulant dosage of 6 mg/L. The low removal of DOC indicates that DOC should be removed by other means than a coagulant. Based on the measurements of total particle concentration the optimal coagulant dosage for pool water is 6 mg/L. The measurements of dissolved aluminium show no clear optimal coagulant dosage for any of the parallels. Through the measurements, it was discovered that the removal of DOC from fill up water and the formation of bigger flocs by the use of coagulant, was more effective than for pool water. Therefore, a pretreatment of the fill up water with coagulant should be considered. Moreover, as a way to further optimize the treatment processes at Rud svømmehall, experiments with different coagulants and another concentration of aluminium chloride should be carried out.

#### 4.3 Calculation of Filter Capacity and Bed Life through Adsorption Isotherms

The capacity of the GAC filter is determined through DOC measurements. From the DOC concentrations adsorption isotherms can be plotted. The adsorption isotherms are further plotted as In-In diagrams, where the linear equation is used to determine filter capacity and bed life.

##### 4.3.1 Determination of Filter Capacity

Adsorption isotherms are plots of  $q$  against  $DOC_{ads}$ .  $q$  expresses the amount of adsorbate (mg DOC) that has been adsorbed per gram adsorbent (g GAC) at equilibrium. In addition, the logarithmic values of these measurements were plotted. Plots of  $SAC_{254}$  against DOC are used to identify outliers. Plots of  $SAC_{254}$  against the mass-volume ratio (m/V) and DOC against m/V-ratio were used to identify  $SAC_{254,nonads}$  and  $DOC_{nonads}$ . These plots are presented in Appendix 2 – Calculations. The regression line of the In-In plots can be used to determine the capacity of the GAC filters,  $K_A [(mg/g)(L/mg)^{1/n}]$ . The filter capacity is a constant, which indicates the amount of DOC that can be adsorbed per gram GAC. The amount of DOC was measured in a DOC analyser and  $SAC_{254}$  was measured in a spectrophotometer (UV-VIS) at 254 nm.

Figure 26 to Figure 28 show the adsorption isotherms and their In-In diagrams. Figure 26 shows the plots for drinking water for Trondheim from the 4<sup>th</sup> of March for w 1-3 and DGK (sample 22-27 and 28-33). Figure 27 presents the plots for fill up water from the 16<sup>th</sup> of March (sample 58-63) and the 25<sup>th</sup> of March (sample 91-97). Figure 28 presents the plots for pool water from the 16<sup>th</sup> of March (sample 66-71) and from the 25<sup>th</sup> of March (sample 100-106). Outliers are displayed as points with surrounding red rings, and are not included in the regression line. The regression lines and R<sup>2</sup> for the In-In diagrams are presented in Table 16, along with the Freundlich isotherm parameters, K<sub>A</sub>, and 1/n. The calculation for K<sub>A</sub> is presented in Appendix 2 – Calculations.

Table 16: Presentation of equations for the regression line for all In-In plots, with the corresponding R<sup>2</sup> value, 1/n and K<sub>A</sub>.

Figure number	Equation	R <sup>2</sup>	1/n	K <sub>A</sub> [(mg/g)(L/mg) <sup>1/n</sup> ]
Figure 26				
(b)	y = 0.79x + 3,45	0.94	0.79	31.5
(d)	y = 0.50x + 1.79	0.94	0.50	6.0
Figure 27				
(b)	y = 1.02x + 2.31	0.87	1.02	10.1
(d)	y = 0.63x + 1.64	0.96	0.63	5.2
Figure 28				
(b)	y = 0.93x + 2.85	0.95	0.93	17.3
(d)	y = 1.15x + 4.25	0.99	1.15	70.1

In Figure 26, (a) and (c) the plots of q against DOC<sub>ads</sub> follow a trend close to the ideal adsorption, shown as the Freundlich adsorption isotherm. The In-In plots in the figure show the linearity of the regression line. A perfectly linear regression line has a R<sup>2</sup> value of 1. [44] The regression lines for the In-In plots in Figure 26 (b) and (d) have R<sup>2</sup> values above 0.900. This indicates that the In-In plots are nearly linear. The In-In diagrams of q(DOC) against DOC<sub>ads</sub> gives K<sub>A</sub> values of 31.5 (mg/g)(L/mg)<sup>0.79</sup> for drinking water Trondheim w 1-3 (sample 22-27), while it is 6.0 (mg/g)(L/mg)<sup>0.50</sup> for drinking water Trondheim DGK (sample 28-33). The K<sub>A</sub> values, along with the R<sup>2</sup> values for the regression lines for the In-In plots in Figure 26 are given in Table 16.

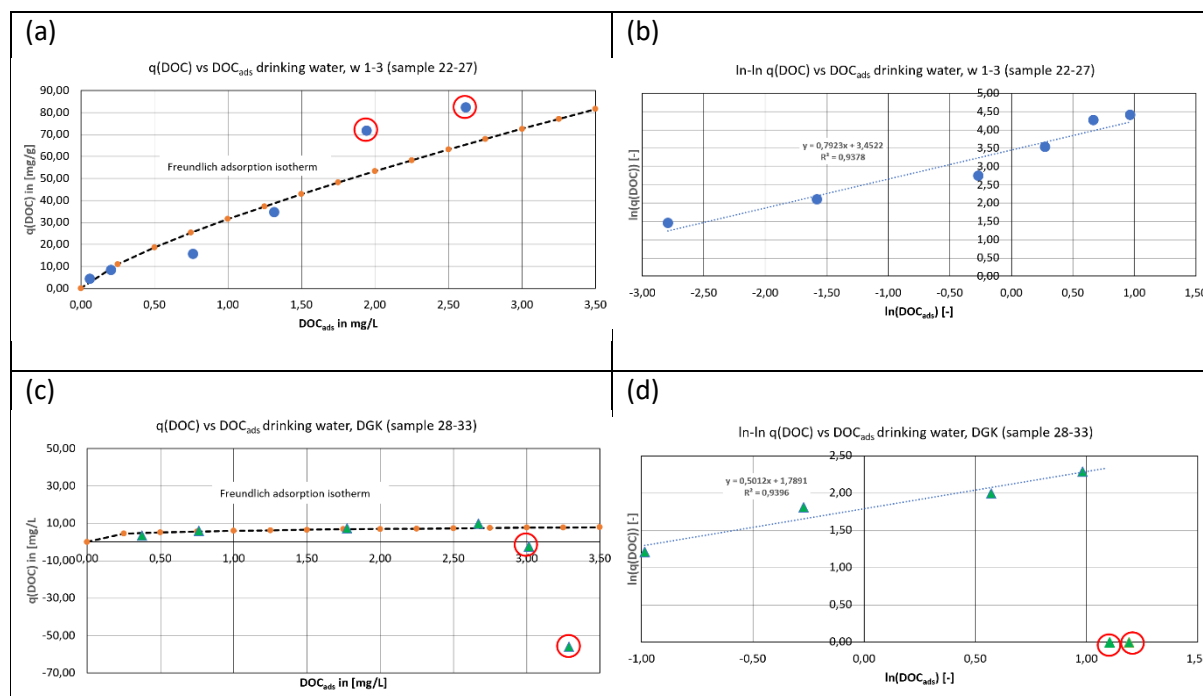


Figure 26: The figure presents the plots of  $q(\text{DOC})$  against  $\text{DOC}_{\text{ads}}$  along with the Freundlich adsorption isotherms for drinking water from the 4<sup>th</sup> of March for w 1-3 in (a) and DGK in (c). The corresponding ln-ln diagrams are plotted in (b) and (d).

In Figure 27 (a) and (c) for fill up water, the plots follow a linear trend and increases exponentially towards the last two points of the graphs, and (a) has a more linear trend for the Freundlich adsorption isotherm than (c). The ln-ln diagrams for  $q(\text{DOC})$  against  $\text{DOC}_{\text{ads}}$  gives  $K_A$  values of  $10.1 \text{ (mg/g)(L/mg)}^{1.02}$  for (b) and a  $K_A$  value of  $5.2 \text{ (mg/g)(L/mg)}^{0.63}$  for (d). The ln-ln plots for (b) and (d) follow the same trend as (a) and (c). Figure 27 (b) has a  $R^2$  value of 0.87, while (d) has a  $R^2$  value of 0.96. These  $R^2$  values indicate a trend close to linearity. The regression lines for the ln-ln plots in Figure 27 are shown in Table 16 along with their  $K_A$  values.

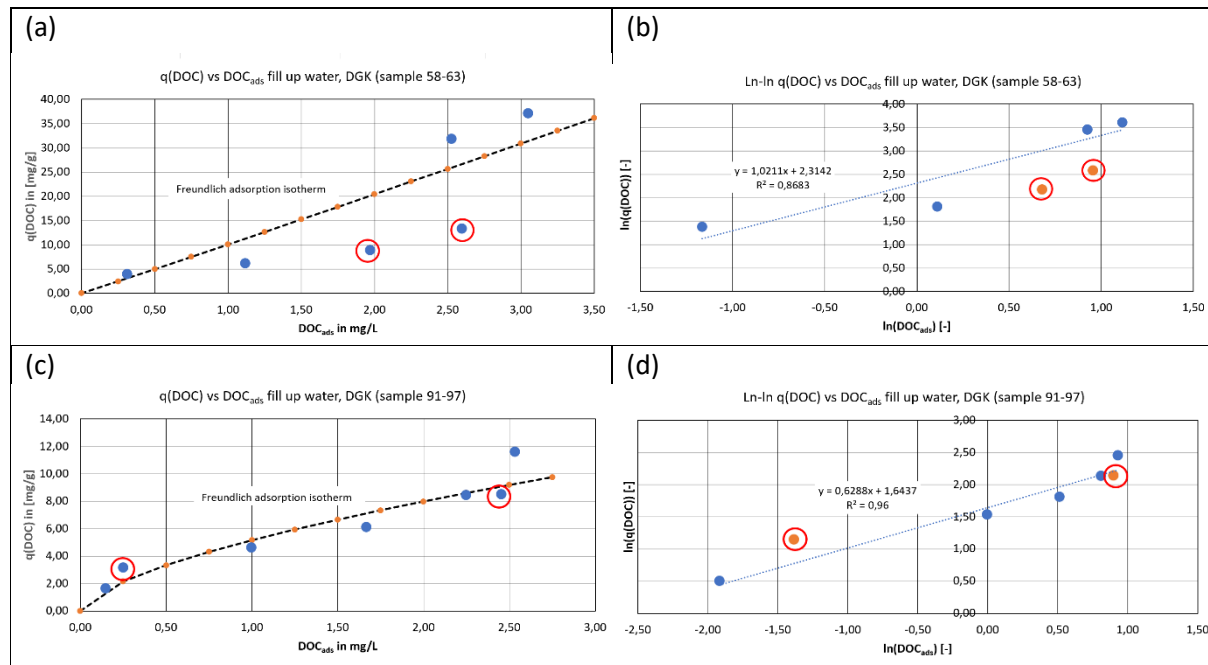


Figure 27:  $q$  plotted against  $DOC_{ads}$  for fill up water with DGK. The corresponding  $\ln$ - $\ln$  diagrams of these plots are shown in (b) and (d). (a) and (b) 16<sup>th</sup> of March (sample 58-63), and (c) and (d) 25<sup>th</sup> of March (sample 91-97).

Figure 28 (a) and (c) for pool water, have an increasing trend in  $q$  with increasing  $DOC_{ads}$ . The plots of the different dates of (a) (16<sup>th</sup> of March) and (c) (25<sup>th</sup> of March) present a similar trend, but differences are observed in the  $\ln$ - $\ln$  plots. The  $R^2$  value is 0.95 for (b) and 0.99 for (d). This indicates a nearly perfect linear trend. It is important to note the outliers here. However, as these are not included in the regression lines, they have no impact on the result. The regression lines,  $R^2$  values and the  $K_A$  values for Figure 28 are presented in Table 16.



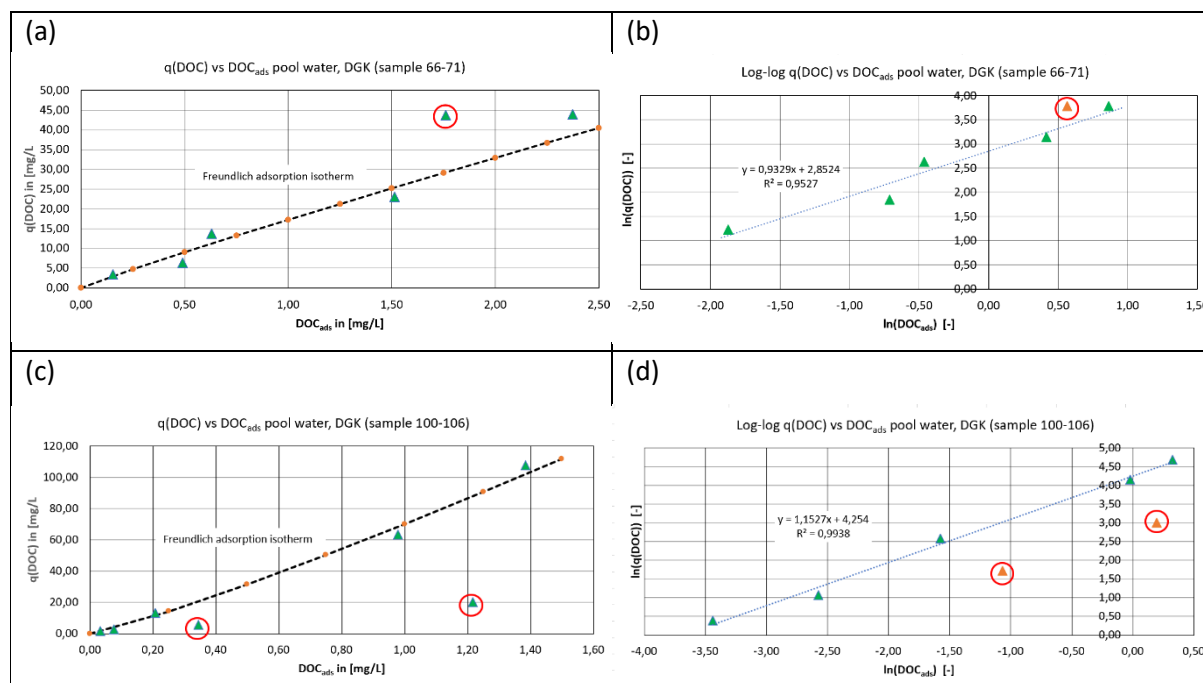


Figure 28:  $q$  plotted against  $\text{DOC}_{\text{ads}}$  for pool water with DGK, along with their corresponding  $\ln$ - $\ln$  diagrams. (a) and (b) are plots from 16<sup>th</sup> of March (sample 66-71), and (c) and (d) are plotted from the 25<sup>th</sup> of March (sample 100-106).

Figure 26, Figure 27, and Figure 28 present the plots of  $q(\text{DOC})$  against  $\text{DOC}_{\text{ads}}$ . The Freundlich adsorption isotherms plotted with the Freundlich adsorption parameters are included in the same plots. Figure 26 presents the plots for drinking water from Trondheim with w 1-3 and DGK. In Figure 27, the plots for fill up water from Rud svømmehall are presented, and Figure 28 displays the plots for pool water from Rud svømmehall.

According to Industrial Separation Processes Fundamentals [30], an ideal adsorption isotherm should have a shape similar to a logarithmic curve, shown in Figure 8 (c). The adsorption isotherms plotted in Figure 26, Figure 27, and Figure 28 have a shape similar to the unfavourable and linear isotherms illustrated in Figure 8 (a) and (b). This suggests that the activated carbon does not adsorb DOC ideally, but will have a s-shaped breakthrough curve. [30] The graphs generally follow the same trend, which indicates that the deviations from the ideal isotherms can be caused by several variables. A reason for the deviations can be analysis errors. Especially measurements from the DOC analyser provided varying DOC concentrations. Some of these errors in DOC measurements causes negative  $q$  values, shown by outliers with red rings. The outliers are included in the figures, but not in the trend lines, as they affect the graph by dragging it in the direction of the outlier. During the DOC analysis there was a significant amount of inorganic carbon present in some of the samples. The inorganic carbon measured in the samples might be a leakage from the GAC filters. This may have caused some inaccuracies in the DOC measurements, resulting in too high or too low DOC concentrations. [45] The same outliers are not observed in the  $\text{SAC}_{254}$  measurements. This supports the assumption that the

inorganic carbon has interfered with the DOC measurements from the DOC analyser. Some of the points in the adsorption isotherm graphs deviated from the trend. These points are marked with red rings.

Another reason for unfavourable adsorption isotherms could be that the samples with GAC were not left to reach equilibrium for long enough time. The adsorption isotherms presented in Figure 26, have a more ideal trend compared to Figure 27 and Figure 28. The reason for this might be different mixing times on the shaking table. The samples in Figure 26 were mixed for 48 hours, while the samples presented in Figure 27 and Figure 28 were mixed for 24 hours. Based on these results, a greater mixing time may give the solution enough time to reach equilibrium.

The capacity of the GAC filter is determined by the  $K_A$  values. The  $K_A$  value is a measure of the amount of adsorbate (DOC) adsorbed per mass adsorbent (GAC). [33] The  $K_A$  values differ for each plot presented above. Variations in the  $K_A$  values may have been caused by experimental errors as discussed above, but could also be caused by differences in water quality for each sample. Some of the water samples may have a higher level of aromatic and hydrophobic molecules compared to the rest. This may be the case if the initial solution is not homogenic, but varies with time. Usually,  $K_A$  are given as molecule-specific values. Hydrophobic molecules with a particle size matching the pore sizes of the filter are easily adsorbed on the activated carbon filters. According to MWH's Water Treatment (chapter 15, table 15-6) [29], molecules that easily adsorb on the GAC filters have high  $K_A$  values. [33] Hydrophilic molecules, that are not removed by the coagulant and activated glass filter, are not removed in the GAC filters. This can be explained by the low affinity of hydrophilic molecules for the nonpolar GAC filter, thus these molecules have low  $K_A$  values. As there are usually few hydrophobic substances in pool water, but rather a presence of hydrophilic molecules of small particles sizes, this will affect plotted adsorption isotherms and the calculated  $K_A$  values. Pool water contains a mixture of different dissolved organic molecules, where the type and amount of particles present varies with time.

According to Adsorption Technology in Water Treatment [26], and Disinfection By-products in Drinking Water [10], NOM are divided into two fractions, hydrophobic and hydrophilic compounds. The hydrophobic aromatic compounds are substances which adsorb the best on GAC, due to the interactions forming  $\pi$ - $\pi$ -bonds with the adsorbent. By comparing the plots presented in Figure 26, Figure 27 and Figure 28, it can be concluded that GAC is more efficient for fill up water than pool water. A possible reason for this is that fill up water contains a higher amount of hydrophobic aromatic compounds compared to pool water. In pool water DOC is present as hydrophilic aromatic compounds, which tend to have a lower adsorption to GAC. However, from the DOC removed in jar

test it is also observed that a lower level of DOC is removed from the pool water, compared to fill up water. This could be explained upon the different fractions of NOM. The coagulant is more efficient for smaller, aliphatic compounds such as humic acids. [10] It could therefore be discussed whether experiments with other types of coagulant and the use of GAC are the most optimal for Rud svømmehall. The most optimal coagulant dosage and GAC filter may be investigated through further experiments by using different filters and different types of coagulant. Qualitative analysis could be considered to identify the compounds present in pool water. For example, chromatography with standards of commonly occurring hydrophilic and hydrophobic molecules in pool water could be used for this purpose.

#### 4.3.2 Calculation of bed life

Table 17 and Table 18 show the values for DOC<sub>ads</sub> for fill up water and pool water for the 16<sup>th</sup> and 25<sup>th</sup> of March. The calculations of these values and an example of q is shown in Appendix 2 – Calculations.

Table 17: The table shows the DOC<sub>ads</sub> concentrations and q values calculated based on the plotted adsorption isotherms and K<sub>A</sub> above.

Figure name	DOC <sub>ads</sub> [mg/L]	q in [mg/g]
Figure 27 (DGK)		
(b) (DOC <sub>ads</sub> , fill up water, 16 <sup>th</sup> )	3.30	34.0
(d) (DOC <sub>ads</sub> , fill up water, 25 <sup>th</sup> )	2.60	9.4
Figure 28 (DGK)		
(b) (DOC <sub>ads</sub> , pool water, 16 <sup>th</sup> )	2.70	43.5
(d) (DOC <sub>ads</sub> , pool water, 25 <sup>th</sup> )	2.30	182.7

The experimental results are scattered, thus it is reasonable to use a q in the range of 9.4- 34.0 mg/g. The calculated values for the amount of DOC removed at the stoichiometric breakthrough are presented in Table 18, along with the value for the bed life until breakthrough.

Table 18: The table shows the bed life for the log-log diagrams plotted in Figure 26-Figure 28.

Value of q [mg/g]	DOC adsorbed at stoichiometric breakthrough [g DOC <sub>ads</sub> ]	Bed life
9.4	6 900	564 days = 1.55 years
10.0	7 400	
16.7	12 300	
34.0	25 400	

The bed life until breakthrough is 564 days, or 1.55 years. This is a reasonable bed life, as GAC filters can last from weeks and up to 10 years, depending on the adsorbate. [46] The full calculation of the bed life is shown in Appendix 2 – Calculations.

## 4.4 Mass Balances

Mass balances have been modelled for the removal of DOC in three steps based on the results from the coagulant and activated carbon experiments. In the first step, all the water in the pool system is initially fill up water. Some DOC is removed by the coagulant, reducing the DOC concentration over time until a steady state is reached after 7 cycles. The DOC concentration is calculated to be 1.985 mg/L when the system is at a steady state.

In the second step, bathers are added to the mass balance, and an amount of 2.5 mg DOC/L is added per bather. The model presents DOC accumulation over time as there is more added DOC than removed by the coagulant. In this step, the system will not reach a steady state.

The GAC filters are introduced in the third and final step. The GAC filters remove DOC from fill up water and from bathers. This model presents the optimal treatment processes at Rud svømmehall. The calculated DOC is at 2.419 mg/L at a steady state. This is after 6 cycles.

*Table 19: presentation of central initial DOC concentrations, in addition to the concentration at steady state and how many cycles are needed to reach steady state.*

Step	Initial DOC concentration [mg/L]	DOC concentration at steady state [mg/L]	Cycle at steady state [h]
1	3.478	1.985	7
2	1.985	-	-
3	3.337	2.419	6

The DOC concentrations in Table 15 present the initial DOC concentration for the different steps and the concentration at a steady state. In Step 1, the initial concentration in the water is based on DOC measurements before any coagulant is added to the jar test. The DOC concentration is determined by how many flocs were formed after coagulation and removed by filtration. In Step 1, it took 7 cycles, 7 hours, to reach a steady state. This DOC concentration is estimated to be at a steady state because the system has reached a  $1-e^{-t/\tau}$  value of 98%. [39]

In Step 2, DOC from bathers is added. From the jar test, it was observed that little DOC was removed by the coagulant. Therefore, only DOC from the fill up water is being removed in this step. In this scenario, the amount of DOC in the water will continue to increase. The system will not reach a steady state because there is more DOC added to the system than being removed. After 12 cycles, which correlates to the opening hours of the facility, the DOC concentration is estimated to increase to 3.34 mg/L.

In the final step, Step 3, GAC filters are introduced. These filters remove DOC from the fill up water, as well as the DOC from the water contaminated by bathers. The initial concentration of DOC in this step is the estimated DOC concentration from Step 2 after 12 hours. With the addition of the GAC filters, the system reaches a steady state after 6 cycles. The steady state concentration is an estimate from the average concentration of the DOC measurements after the jar test. In this scenario, the DOC concentration will increase after the first cycle before it starts to decrease in further cycles. This step shows the effect the GAC filter has in the removal of DOC from bathers. A comparison between Step 1 and Step 3 shows that the addition of bathers will lead to an increase in the DOC concentration at a steady state.

Based on the mass balances in Step 1 and Step 2, there will theoretically be an infinite increase in the DOC concentration without any other treatment for removal of DOC than the coagulant. When the GAC filter is introduced, the DOC concentration decreases, and reaches steady state. This supports the use of GAC as a treatment process.

## 4 Conclusion

In this thesis, options to improve water quality and treatment operations at Rud svømmehall have been investigated. Determination of the most optimal coagulant dosage have been investigated, in addition to determine the capacity and bed life time of a granular activated carbon filter.

Based on results from total particle concentration measurements, it have been concluded that a coagulant concentration of 6 mg/L is the most optimal. The results from ICP-MS and measurements of DOC do not show a clear optimal coagulant dosage. The capacity of the GAC filter is calculated from measurements with activated carbon, and determined to be between 5.2 and 70.1 (mg/g)(L/mg)<sup>1/n</sup> depending on the water type. Bed life time of the filter is determined to 564 days (1.55 years). Chlorine measurements to determine the addition of disinfectants have also been investigated. From ICP-MS and chlorine measurements the addition of NaOCl per cyclus to compensate for the removal of chlorine during operation units is determined to be 0.0090 mmol/L for the 25<sup>th</sup> of March.

For all measurements regarding coagulant and activated carbon, it has been concluded that the treatment processes are more effective for fill up water than for pool water.

## 5 Outlook

Our thesis was written with the focus on the improvement of water quality and operation treatment at Rud svømmehall. This project has the opportunity of continuous improvements as parts of the treatment system always can be improved. Throughout the thesis, analyses of the different treatment processes have been conducted. Where the focus have been on investigating the sampling points at Rud svømmehall, determining the optimal coagulant dosage, and calculating the capacity and bed life for the GAC filter. In order to conclude on the main objectives, analyses were carried out at the ICP-MS, and the total particle concentration, DOC concentrations and chlorine were measured. The results of some of the measurements have been inconclusive, thus more parallels should be conducted to get an accurate conclusion based on thorough research.

From the sampling point at Rud svømmehall, it was noted that chlorine measurements needs to be conducted on site, as chlorine is lost during transport. The measurements conducted at outlet UV disinfection detected a decrease in the amount of free chlorine. Thus, another part of the treatment system that should be further investigated is the inlet and outlet of UV disinfection.

During experiments carried out in this thesis regarding the use of an aluminium based coagulant, it was noted that pH should be carefully monitored. If further measurements of the DOC removal by coagulant is to be investigated, the dosages of coagulant should have shorter intervals i. e. 0.5 mg/L. The same could be considered for further measurements of total particle concentrations and dissolved aluminium concentrations. Another interesting experiment would be to investigate the effect of different types of coagulants on the pool water. The different types of coagulants that could be considered are iron based coagulants and polymers.

It would also be interesting to investigate how the mixing time of the activated carbon samples would affect the adsorption isotherms and further calculations of capacity and bed life. Moreover, experiments where the jar test is performed before activated carbon experiments could be interesting. These would give an insight into the amount of DOC removed in the GAC filter, which is not removed by the coagulant. Here, particle measurements could provide an overview of the types of particles removed in the different treatment processes.

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## Appendix 1 – Product Information from CarboTech

### CarboTech Pool W 1-3

#### Technical Information



#### Product Description

CarboTech Pool W 1-3 is a reactivated activated carbon, suitable for the removal of organic contaminants from industrial wastewater and landfill leachate. This activated carbon is produced by the reactivation of mineral coal based, used activated carbons at temperatures above 850°C in a fluidized bed oven. During this high temperature treatment, the used activated carbon is relieved of all organic residues; it can subsequently be reused. The reactivation process employed by CarboTech results in an activated carbon with a very special pore structure, and with optimal properties for many different applications. It is possible to achieve high loadings; therefore this activated carbon offers an economically attractive solution to many problems.

#### Product Application

CarboTech Pool W 1-3 activated carbon is especially suitable for the treatment of landfill leachate, and also of industrial wastewaters with high amounts of contaminations. It has often been successfully used in soil rehabilitation for the treatment of accumulating wastewater, which is contaminated with organic compounds.

#### Specific Characteristics

CarboTech Pool W 1-3 activated carbon offers the following advantages:

- Unique pore structure and high pore volume
- Exceptionally high loading capacity for heavy organic contaminations
- Excellent reactivation properties
- Economically attractive price/performance ratio
- Consistently high product quality guaranteed by CarboTech

#### Packaging

- 350 kg and 650 kg in Big Bags
- 16 kg Paper Bags, 480 kg on pallet
- In bulk by silo truck

#### Technical Description

Specification	
Apparent density	430±30 g/l
Moisture (as packed)	max. 5 %
Iodine number	min. 750 mg/g
Particle size distribution	
>3.55 mm	max. 5 %
<0.5 mm	max. 1 %

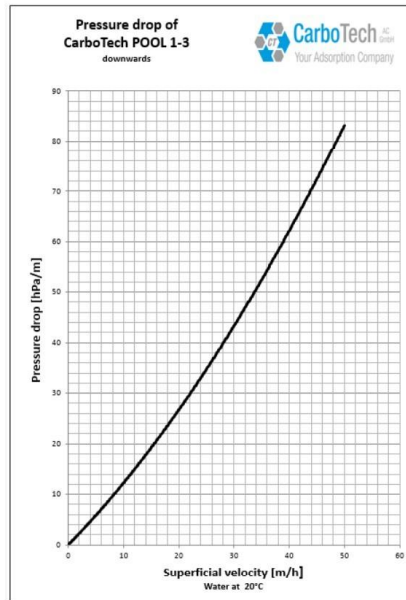
Methods of analysis are available upon request



Due to the fact that the products are manufactured on the basis of natural raw materials the typical properties may vary, but represent the average of continuous product/quality control.

## CarboTech Pool W 1-3

### Technical Information



### Safety Advice

Wet activated carbon removes oxygen from the surrounding air. In closed or partially closed rooms or containers, oxygen depletion may reach hazardous levels. The directives on entering closed, potentially oxygen depleted rooms, as well as the warnings in CarboTech's Safety Data Sheets have to be observed.

### Quality

CarboTech guarantees the specifications through representative sampling and analysis.

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Ein Unternehmen der

**ICIG** *International Chemical Investors Group*

CARBOTECH® activated carbon is produced from natural raw materials. Product specifications can be customized. It is up to the user to check the suitability of the product for each application. Carbotech is not liable for damages arising from use of the product in non-approved applications. Sales are subject to our terms and conditions.

**Note: CarboTech reserves the right to change the specifications without notice. Reprinting - even as excerpts - is only allowed with prior approval by CarboTech.**

Last revised: July 2016

# CarboTech DGK 8x30/60

## DATENBLATT



CarboTech DGK 8x30/60 is a granulated activated carbon, produced from coconut shells as base material by steam activation. This activated carbon has a very fine pore structure and is therefore especially suited to remove organic trace substances from water. Very high loadings can be achieved together with an excellent adsorption performance. Because it is produced from coconut shell as base material, this activated carbon has excellent mechanical stability and an exceptionally low ash content.



### SPEZIFICATION

Apparent Density	[kg/m <sup>3</sup> ]	500± 30
Moisture	[%]	max. 5
Iodine Number	[mg/g]	min. 1050

### TYPICAL PROPERTIES

Ash- Content	[%]	3
Particle size Distribution		
> 8 MESH (2,36 mm)	[%]	5
< 30 MESH (0,6 mm)	[%]	5

### QUALITY

CarboTech guarantees the specifications through representative sampling and analysis.

### SAFETY ADVICE

Wet activated carbon removes oxygen from the surrounding air. In closed or partially closed rooms or containers, oxygen depletion may reach hazardous levels. The directives on entering closed, potentially oxygen depleted rooms, as well as the warnings in CarboTech's Safety Data Sheets have to be observed.

CARBOTECH® activated carbon is produced from natural raw materials. Product specifications can be customized. It is up to the user to check the suitability of the product for each application. Carbotech is not liable for damages arising from use of the product in non-approved applications. Sales are subject to our terms and conditions.

Note: CarboTech reserves the right to change the specifications without notice. Reprinting - even as excerpts - is only allowed with prior approval by CarboTech.

Last revised: November 2020

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## Appendix 2 – Calculations

### 2.1 Calculations for 0.01 M nitric acid

In order to add the right volume of the nitric acid, it was necessary to calculate the concentration of the acid. Information such as the density, volume, molar weight, and the percentage of acid in the solution was helpful in this calculation.

$$\rho_{bottle} = 1.39 \frac{kg}{L}$$

$$V_{bottle} = 0.02L$$

$$MW_{HNO_3} = 63.01 \frac{g}{mol}$$

$$\% HNO_3 \text{ in bottle} = 65\%$$

$$m_{bottle} = \rho_{bottle} \cdot V_{bottle} = 1.39 \frac{kg}{L} \cdot 0.02L = 0.0278 kg$$

$$m_{HNO_3} = 0.0278 kg \cdot 1000 \frac{g}{kg} \cdot 0.65 = 18.07 \frac{g HNO_3}{L}$$

$$c_{HNO_3} = \frac{n_{HNO_3}}{V_{bottle}} = \frac{\left( \frac{18.07 g}{63.01 \frac{g}{mol}} \right)}{0.02L} = \frac{0.28677 mol}{0.02L} = 14.34 \frac{mol}{L} = 14.34 M$$

The preferred concentration of the diluted acid was 0.01 M. For a more precise concentration, 1.0 mL of concentrated acid was used to exclude uncertainty in the volume of concentrated acid. Therefore, the volume of the diluted solution had to be 1000 mL (1.0L). The new concentration was then 0.01433M, round off to 0.01 M. The dilution formula was used to calculate the new concentration and volume.

$$c_1 \cdot v_1 = c_2 \cdot v_2$$

$$c_2 = \frac{c_1 \cdot v_1}{v_2} = \frac{14.33 M \cdot 1 mL}{1000 mL} = 0.01433 M \approx (0.01M)$$

## 2.2 Calculations of the isotherms

Equation 9 is used to calculate  $q(\text{DOC})$ . To determine this variable, information such as the activated carbon mass, the DOC concentration measured, and the DOC measured for the blank is needed. This information is given in Appendix 2.

$$q_{eq} = \frac{V}{m_A} \cdot (C_0 - C_{eq}) \quad (9)$$

$q_{eq}$ : the amount of adsorbed matter pr. mass

$C_0$ : found when measuring DOC of the sample with no added activated carbon

$C_{eq}$ : found when measuring DOC of the samples with added activated carbon.

$V/m_A$ : sample volume divided by activated carbon mass

The same equation can also be used to calculate  $q(\text{SAC}_{254})$ .

### Example:

Fill up water 1,2 (sample 58)

Mass:	1.3 mg
Sample volume:	200 mL
DOC blank:	3.869 mg/L
DOC sample 19:	3.748 mg/L
SAC <sub>254</sub> blank:	0.4590 1/5 cm
SAC <sub>254</sub> sample 19:	0.4420 1/5 cm

To find  $q(\text{DOC})$ :

$$q(\text{DOC}) = \left( \frac{(200 \cdot 10^{-6}) \text{m}^3}{(1.3 \cdot 10^{-3}) \text{g}} \right) 1000 \frac{\text{L}}{\text{m}^3} \cdot (3.869 - 3.748) \frac{\text{mg}}{\text{L}} = 18.62 \frac{\text{mg}}{\text{g}}$$



To find  $q(\text{SAC}_{254})$ :

To calculate the correct  $q(\text{SAC}_{254})$ , the  $\text{SAC}_{254}$  value measured (abs/5 cm) must be converted to abs/cm. This is then converted to 1/m. This calculation for  $\text{SAC}_{254}$  blank is shown in the example below.

$$\text{SAC}_{254} \text{ blank} = \frac{\text{abs}}{5 \text{ cm}} \cdot 100 \frac{\text{cm}}{\text{m}} = \left(\frac{0.4590}{5}\right) \frac{1}{\text{cm}} \cdot 100 \frac{\text{cm}}{\text{m}} = 9.1800 \frac{1}{\text{m}}$$

$$\text{SAC}_{254} \text{ sample 58} = 8.8400 \frac{1}{\text{m}}$$

$$q(\text{SAC}_{254}) = \left(\frac{(200 \cdot 10^{-6}) \text{ m}^3}{(1.3 \cdot 10^{-3}) \text{ g}}\right) \cdot 1000 \frac{\text{L}}{\text{m}^3} \cdot (9.1800 - 8.8400) \frac{1}{\text{m}} = 52.31 \frac{\text{L}}{\text{m} \cdot \text{g}}$$

To determine the equilibrium adsorbent-phase concentration of the adsorbate ( $q_A$ ), the Freundlich equation, Equation (10), is used.

$$q_A = K_A \cdot c_A^{\frac{1}{n}} \quad (10)$$

$q_A$ : equilibrium adsorbent-phase concentration of adsorbate A, [mg adsorbate / g adsorbent], in this example it is [mg DOC/g activated carbon]

$K_A$ : Freundlich adsorption capacity parameter, [(mg/g) (L/mg)<sup>1/n</sup>]

$1/n$ : Freundlich adsorption intensity parameter, [-]

Further, the linear form of this equation, equation (10), is used to determine  $q_A$ . These variables can be found in ln-ln diagrams for the isotherms.

$$\ln(q_A) = \ln(K_A) + \left(\frac{1}{n}\right) \cdot \ln(c_A) \quad (10)$$

### Example:

By using the ln-ln diagram in Figure 27 (b) it is possible to calculate  $q_A$ . The linear trend of the graph includes the different variables needed for the calculation. The linear trend for Figure 27 (b) is  $y = 1.02x + 2.31$ .  $1/n$  represents the slope of the graph, whilst  $\ln(K_A)$  is the interception of the y-axis.

$$\frac{1}{n} = 1.02$$

$$\ln(K_A) = 2.31$$

$$K_A = e^{2.31} = 10.1 \left(\frac{mg}{g}\right) \left(\frac{L}{mg}\right)^{1.02}$$

$$q_A = K_A \cdot c_A^{\left(\frac{1}{n}\right)}$$

$$q_A = 10.1 \left(\frac{mg}{g}\right) \left(\frac{L}{mg}\right)^{1.02} \cdot c_A^{(1.02)}$$

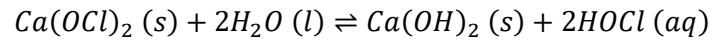
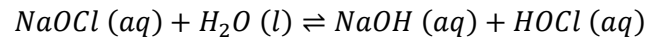
The average  $DOC_{ads}$  concentration is 2.73 mg/L, which corresponds to  $c_A$  in the equation.

$$q_A = 10.1 \cdot 2.73^{1.02}$$

$$q_A = 28.1 \text{ mg/g}$$

## 2.3 Calculation of Volume NaOCl and Ca(OCl)<sub>2</sub> Added Based on ICP-MS Results

The chemical equilibriums of NaOCl and Ca(OCl)<sub>2</sub> introduced into the water.



Since the interest is calculating the concentration of sodium and calcium added to the water, the stoichiometric coefficient must be reckoned. From the equilibrium equations it occurs that the number of mol NaOCl is equal to the number of Na, and the number of Ca(OCl)<sub>2</sub> is equal to the number of Ca. Since the fill up water is not disinfected with NaOCl or Ca(OCl)<sub>2</sub>, only ClO<sub>2</sub>, the concentration in fill up water must be subtracted from the measured values in the operation system. To calculate the average concentration of each element from the addition of disinfectant, the measured values of each sampling point besides fill up water is averaged. The concentration of element in fill up water is then subtracted. Results from ICP-MS for further calculations is presented in Table 7.

Table 20: ICP-MS results for sampling points at Rud svømmehall for determining the disinfectant dosage. AF 21<sup>st</sup> of February (sample 1-5), FA 21<sup>st</sup> of February (sample 6-10), 16th of March (sample 34-39), and FA 16<sup>th</sup> of March (sample 40-45).

Sample number	Content	AF/FA	Element concentration with dilution rate [mg/L]		
22.02			Na	Cl	Ca
1	Fill up water	AF	12	20	26
2	Pool water	AF	403	530	29
3	Outlet balance tank	AF	399	535	29
4	Inlet AG filter	AF	398	533	29
5	Outlet AG filter	AF	400	526	29
<b>Averaged</b>			<b>388</b>	<b>511</b>	<b>3</b>
22.02					
6	Fill up water	FA	11	20	26
7	Pool water	FA	398	529	29
8	Outlet balance tank	FA	395	520	29
9	Inlet AG filter	FA	394	517	29
10	Outlet AG filter	FA	397	527	29
<b>Averaged</b>			<b>385</b>	<b>503</b>	<b>3</b>
16.03					
34	Fill up water	FA	11	18	26
35	Pool water	FA	443	589	29
36	Outlet balance tank	FA	442	601	29
37	Inlet AG filter	FA	447	596	29
38	Outlet AG filter	FA	448	602	29
39	Outlet UV	FA	445	603	30
<b>Averaged</b>			<b>434</b>	<b>580</b>	<b>3</b>
16.03					
40	Fill up water	AF	11	19	27
41	Pool water	AF	446	590	29
42	Outlet balance tank	AF	450	597	30
43	Inlet AG filter	AF	441	593	29
44	Outlet AG filter	AF	447	597	29
45	Outlet UV	AF	440	588	30
<b>Averaged</b>			<b>433</b>	<b>574</b>	<b>3</b>

Based on the chlorine values from Table 5 the value of free and total chlorine was measured. Display values from Table 6 of free and total chlorine in pool water 25<sup>th</sup> of March is also used to calculate the consumption of chlorine. In addition to these, measurements developed by Silvestro is added for several parallels. Measured values of total chlorine in addition to flow rate at different sampling points is presented in Table 3. 1. Concentrations corresponds to the chlorine concentrations calculated above. Removed is the amount of chlorine removed from the operation units (inlet AG filter and GAC filter). Addition per cylcus is the concentration of NaOCl that must be added to compensate for the concentration removed of chlorine removed in the operation units.

Table 3. 1: Total chlorine concentrations at different sampling points with corresponding flow rate.

Sampling point	Total chlorine [mg/L]			Volumetric flow [fraction %]
	Silvestro	16.03	25.03 display	
Pool water	0.91	0.57	0.99	1
Outlet AG filter	0.74	0.58	-	0.9
Outlet GAC filter	0.05	-	-	0.1
Pool display	-	-	-	-

To calculate the concentration added, a calculation example for 21<sup>st</sup> of February (sample 1-10) is presented. Calculations for all measurements is presented in **Feil! Fant ikke referansebildet.**

The averaged concentration of Na is 388 mg/L, Cl is 511 mg/L, and Ca 3 mg/L. Molecular weights are  $Mw_{Na} = 22.99$  g/mol,  $Mw_{Cl} = 35.45$  g/mol, and  $Mw_{Ca} = 40.08$  g/mol.

The concentration of sodium added:

$$\frac{c_{Na}}{Mw_{Na}} = \frac{\left(388 \frac{mg}{L}\right)}{22.99 \text{ g/mol}} = 16.9 \text{ mmol /L}$$

The concentration of chlorine added:

$$\frac{c_{Cl}}{Mw_{Cl}} = \frac{\left(505 \frac{mg}{L}\right)}{35.45 \text{ g/mol}} = 14.2 \text{ mmol /L}$$

The concentration of calcium added. Thus, based on the measured value compared to sodium and chlorine it can be neglected:

$$\frac{c_{Ca}}{Mw_{Ca}} = \frac{\left(3 \frac{mg}{L}\right)}{40.08 \text{ g/mol}} = 0.075 \text{ mmol /L}$$

### Consumption of chlorine / chlorine in pool

Pool: 0.91 mg/L

Outlet AG filter: 0.74 mg/L (90% of volumetric flow)

Outlet GAC filter: 0.05 mg/L (10 %)

Consumption of chlorine pr. cyclus =  $(0.91 - (0.74 \cdot 0.9 + 0.05 \cdot 0.1)) \text{ mg/L} = 0.24 \text{ mg/L}$

To ensure a constant concentration of chlorine in the pool, to fulfill Norwegian regulations, the pool water must be added NaOCl. Hence, 0.24 mg/L chlorine as NaOCl must be added. The addition of chlorine added through NaOCl is then:

$$\begin{aligned} \text{Molstrøm per cyclus} &= \frac{\text{consumption of chlorine}}{Mw_{Cl}} = \frac{0.24 \frac{mg}{L}}{35.45 \frac{g}{mol}} \\ &= 0.0069 \frac{mmol}{L} \text{ per cyclus} \end{aligned}$$

Table 21: Consumption of chlorine. Concentration of chlorine according to ICP-MS results. Concentration removed during operations units. Addition per cyclus to compensate for the removal in operation units.

Sampling date	Concentration [mmol/L]	Removed [mg/L]	Addition NaOCl per cyclus [mmol/L]
21.02	14.3	-	-
16.03	16.3	0.05	0.0014
25.03 display	-	0.32	0.0090
Silvestro	-	0.24	0.0068

## 2.4 Calculations of bed life

From the plots of  $q$  against DOC, it is possible to calculate the Freundlich adsorption parameters. These parameters are used to find  $q$ . The values for the Freundlich parameters  $1/n$  and  $K_A$  are presented in Table 16: Presentation of equations for the regression line for all In-In plots, with the corresponding  $R^2$  value,  $1/n$  and  $K_A$ . Table

When the break through of the filter has been reached  $c = DOC_{ads}$ . To calculate the time until breakthrough an average of the  $DOC_{ads}$  is used, which is at 2.73 mg/L. This, along with a  $q$ -value of 10 mg/L is used to find the bed life before breakthrough.

The flow rate through the GAC filters at Rud svømmehall are gathered from [6] to be 10 % of the volumetric flow rate of 200 m<sup>3</sup>/h, which equals a flow of 20 m<sup>3</sup>/h. The bed volume of each filter is 1.13 m<sup>3</sup>, which corresponds to a total bed volume of 2.26 m<sup>3</sup> for two AC filters. [6] The apparent bed density of the GAC DGK filter is 490 +30 kg/m<sup>3</sup>, gathered from datasheet Carbotech (**Feil! Fant ikke referansekinden.**). The apparent density refers to wet carbon, and needs to be divided by 1.5 to find the density of dry carbon. The filter mass is found by multiplying the total bed volume with the density of the filters:

$$m_{filter} = V_{filter} \cdot \rho_{filter} = 2,26 \text{ m}^3 * 490 \frac{\text{kg}}{\text{m}^3} * \frac{1}{1.5} = 740 \text{ kg GAC in the two filters}$$

When neglecting kinetics stoichiometry can be found through by firstly finding the amount of DOC adsorbed at stoichiometric breakthrough.

$$q \cdot m_{GAC} = 10 \frac{\text{mg}}{\text{g}} * 740000 \text{ g} = 7.4 * 10^6 \text{ mg} = 7400 \text{ g } DOC_{ads}$$

Further, the water that can be treated at ideal stoichiometric breakthrough needs to be considered:

$$\frac{m_{GAC}}{DOC_{ads}} = \frac{740000 \text{ g}}{2.73 \frac{\text{g}}{\text{m}^3}} = 271 \text{ 000 m}^3 \text{ water treated and all } DOC_{ads} \text{ is removed}$$

Finally the bed life can be found

$$\frac{V_{treated,filter}}{Q_{through filter}} = \frac{271 \text{ 000 m}^3}{20 \frac{\text{m}^3}{\text{h}}} = 13 \text{ 550 h} = 564 \text{ days} = 1.55 \text{ years}$$

## 2.5 Determining $DOC_{nonads}$ and $SAC_{254, nonads}$

Figure 29 presents the graphs used to determine outliers and  $DOC_{ads}$  for drinking water in Trondheim for 4<sup>th</sup> of March. The first step to determining the capacity from the adsorption isotherms is to determine the outliers by plotting  $SAC_{254}$  against DOC. Further DOC and  $q(DOC)$  are plotted against the mass-volume ratio ( $m/V$ ) to verify the values found for  $DOC_{ads}$ , and lastly  $q(DOC)$  is plotted against DOC. From (a)  $DOC_{ads}$  is found to be 0.40 mg/L for w 1-3 drinking water, which fits with (c). From (b)  $DOC_{ads}$  is found to be 0.7 mg/L for DGK drinking water, which fits with (d).

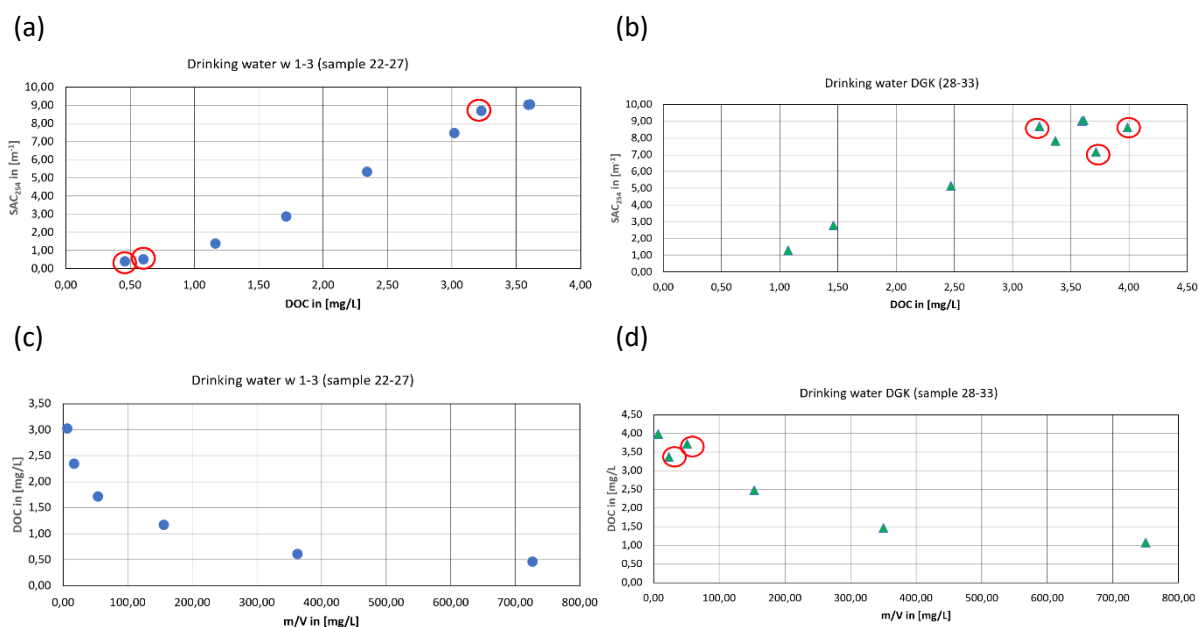


Figure 29: The figure presents  $SAC_{254}$  vs DOC (a) and (b), DOC vs  $m/V$  (c) and (d) for w 1-3 and DGK from Trondheim 4<sup>th</sup> of March.

Figure 30 presents the graphs used to determine outliers and  $DOC_{ads}$  for fill up water and pool water from the 16<sup>th</sup> of March. The first step to determining the capacity from the adsorption isotherms is to determine the outliers by plotting  $SAC_{254}$  against DOC. Further DOC and  $q(DOC)$  are plotted against the mass-volume ratio ( $m/V$ ) to verify the values found for  $DOC_{ads}$ , and lastly  $q(DOC)$  is plotted against DOC. From (a)  $DOC_{ads}$  is found to be 3.30 mg/L for fill up water, which fits with (c). From (b)  $DOC_{ads}$  is found to be 2.70 mg/L for pool water, which fits with (d).



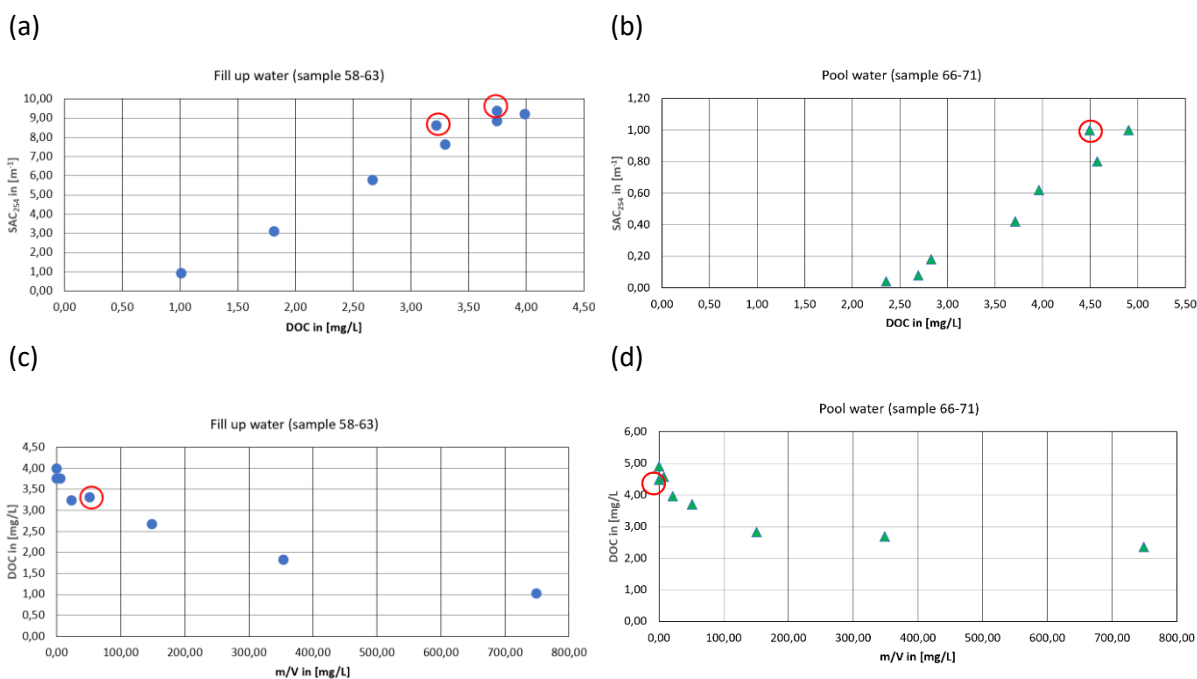


Figure 30: The figure presents SAC<sub>254</sub> vs DOC (a) and (b), DOC vs m/V (c) and (d) for fill up water and pool water from the 16<sup>th</sup> of March.

Figure 31 presents the graphs used to determine outliers and DOC<sub>ads</sub> for fill up water and pool water in for th 25<sup>th</sup> of March. The first step to determining the capacity from the adsorption isotherms is to determine the outliers by plotting SAC<sub>254</sub> against DOC. Further DOC and q(DOC) are plotted against the mass-volume ratio (m/V) to verify the values found for DOC<sub>ads</sub>, and lastly q(DOC) is plotted against DOC. From (a) DOC<sub>ads</sub> is found to be 2.60 mg/L for fill up water, which fits with (c). From (b) DOC<sub>ads</sub> is found to be 2.30 mg/L for pool water, which fits with (d).

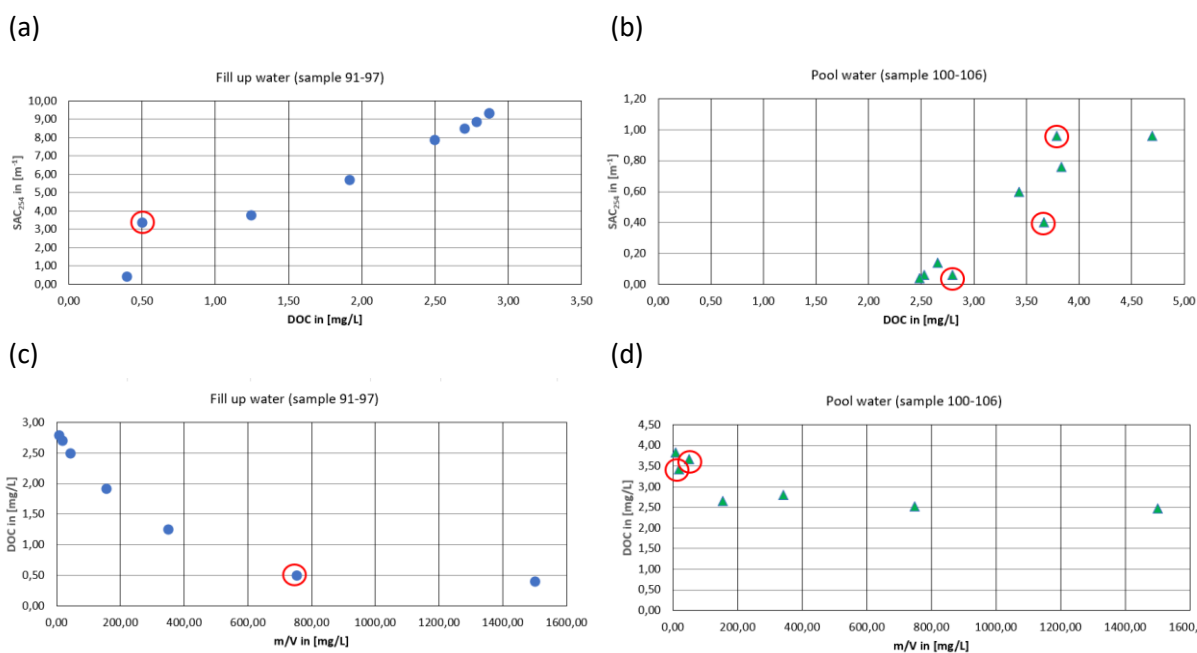


Figure 31: The figure presents SAC<sub>254</sub> vs DOC (a) and (b), DOC vs m/V (c) and (d) for fill up water and pool water from the 25<sup>th</sup> of March.

## 2.6 Mass balance

In step 1, the source of DOC is the fill up water. DOC in step 1 is removed by using a coagulant and AG filter. To calculate the addition and removal of DOC till its steady state, it is necessary to know the initial concentration of DOC,  $t/\tau$  and the minimum of DOC after filtration. The initial DOC concentration,  $c_0$ , in the water is a measured value of 3.478. The minimum DOC after filtration is measured after the jar test to be 1,985.  $T$  is the pool's volume divided by the volume flow from the pool. Each cycle is of one hour. The new concentration from each cycle is calculated until the system reaches a steady flow. Figure 32 shows the 1<sup>st</sup> step in the mass balance. **Feil! Fant ikke referanseilden.**

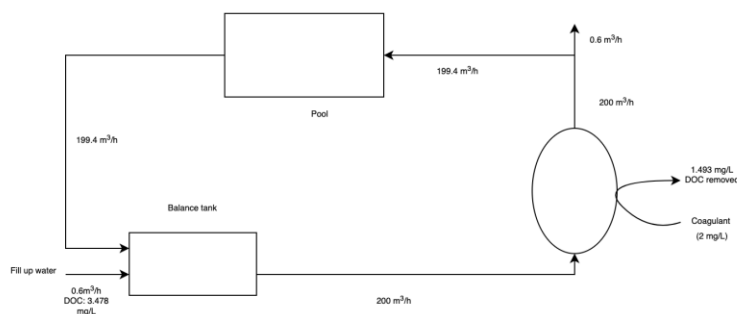


Figure 32: Step 1 in the mass balance.

Example:

In cycle 3, the initial DOC concentration is found in the previous cycle to be 2,333 mg/L. The new concentration after cycle 3 is then calculated to be 2.024 mg/L.

$$y(t) = y_0 + \left(1 - e^{-\frac{t}{\tau}}\right) k \Delta u$$

$$c_A(3) = 2.333 + \left(1 - e^{-\frac{3}{1.374}}\right) \cdot (1.985 - 2.333) = 2.024$$

In step 2, there is an addition of DOC from bathers, illustrated in Figure 33. The initial DOC concentration in this system is 1,985, which is the DOC concentration at a steady state from step 1.

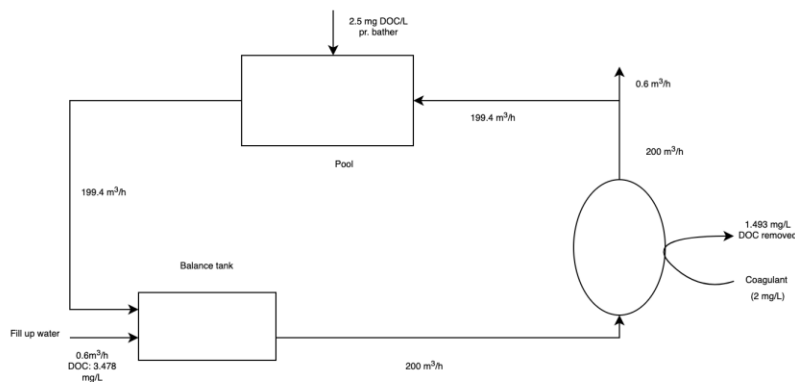


Figure 33: Step 2 in the mass balance.

Example:

In the table, relevant information for the calculation is presented.

DO	2.5 = 28.5 g/h
C per bather [mg/L]	
Bathers per hour [60 bathers/h]	60
Opening hours [h]	12
Maximum pool water volume available [L]	190
MaximTital volum pool water [m <sup>3</sup> ]	274
Initial concentration in cycle 12 [mg/L]	3.233

$$\begin{aligned} \text{DOC already in pool} &= \text{initial concentration pr. hour} \cdot \text{total pool volume} \\ &= 3.233 \frac{\text{mg}}{\text{L}} \cdot 274 \text{ m}^3 = 885.89 \text{ g/h} \end{aligned}$$

$$\begin{aligned} \text{Total DOC} &= \text{DOC already in pool} + \text{DOC added by bathers} \\ &= 885.89 \frac{\text{g}}{\text{h}} + 28.5 \frac{\text{g}}{\text{h}} = 914,39 \text{ g/h} \end{aligned}$$

$$\begin{aligned} \text{New DOC concentration in pool} &= \frac{\text{total DOC}}{\text{total pool volume}} \\ &= \frac{914,39 \frac{\text{g}}{\text{h}}}{274 \text{ m}^3} = 3.337 \frac{\text{mg}}{\text{L} \cdot \text{h}} \end{aligned}$$

After a day, 12 hours, the DOC concentration in the water is calculated to be 3.337 mg/L. This value is based on there not being any DOC removed from the “pool” water, only from the fill up water.

In step 3, the initial concentration is 3.337 mg/L, which is the concentration of DOC after 12 hours in step 2. In this system, the GAC filters are added. DOC from the fill up water is removed in both the AG filter and the GAC filter, which is presented in Figure 34. DOC in pool water contaminated by bathers

is removed in the GAC filter. The following calculations were done to find the new concentration of DOC out of the pool with dilution rate, in cycle 0.

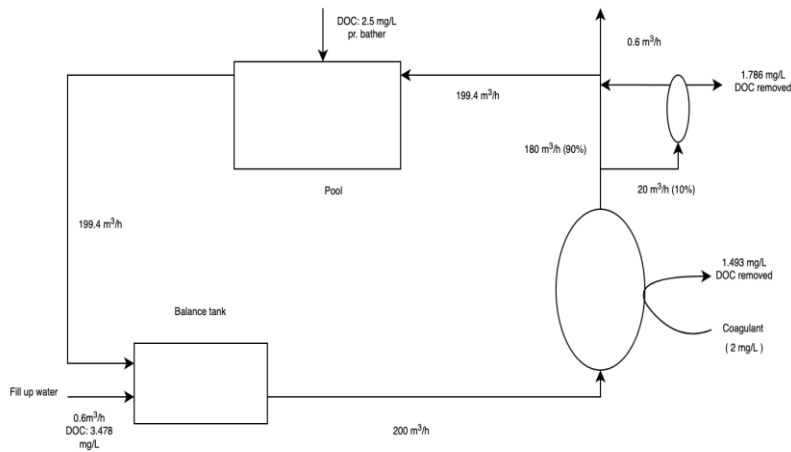


Figure 34: Step 3 in the mass balance.

Example :

Mass DOC in pool water:

$$= \text{volumetric flow to pool} \cdot \text{initial concentration} = \frac{199.4L}{h} \cdot 3.337 \frac{mg}{L} = 665,436 \text{ g/h}$$

Mass of DOC removed from pool water in GAC filter:

$$= \text{initial concentration} \cdot \text{DOC}_{non\ ads} = 3.337 \frac{mg}{L} - 2.418 \frac{mg}{L} = 0,919 \text{ g/h}$$

Mass DOC removed pool water (10%)

$$\begin{aligned} &= \text{Mass DOC removed from pool water in GAC filter} \\ &\quad \cdot \text{flow of waterpoolwater to GAC filter (10\%)} \\ &= 0,919 \frac{g}{h} \cdot 19.94/h = 18.329 \frac{g}{h} \end{aligned}$$

Mass DOC out of GAC filter, poolwater (10%)

$$\begin{aligned} &= \text{initial concentration} \cdot \text{flow of pool water to GAC filter (10\%)} \\ &\quad - \text{mass DOC removed in GAC filter} \cdot \text{flow of pool water to GAC filter (10\%)} \\ &= 3.337 \frac{mg}{L} \cdot 19.94 \text{ L/h} - 0.919 \frac{g}{h} \cdot 19.94 \text{ L/h} = 48.215 \frac{g}{h} \end{aligned}$$

Mass of DOC in pool water outside GAC filter (90%)

$$\begin{aligned} &= \text{initial concentration} \cdot \text{flow of pool water outside of GAC filter (90\%)} \\ &= 3.337 \frac{mg}{L} \cdot 179.46 \text{ L/h} = 598,892 \text{ g/h} \end{aligned}$$

New DOC concentration into pool:

$$\begin{aligned} &= \frac{(\text{total mass of fill up water (90 \% + 10\%)} + \text{total mass of pool water (90\% + 10\%)})}{\text{volume flow to pool}} \\ &= \frac{1.0719 \frac{g}{h} + 0.04227 \frac{g}{h} + 598.89 \frac{g}{h} + 48.215 \frac{g}{h}}{199.4L/h} = 3.251 \text{ mg/L} \end{aligned}$$

New concentration in pool with addition of bathers:

$$\begin{aligned} &= \frac{(\text{initial concentration} \cdot \text{volume pool water}) + \text{DOC from bathers}}{\text{volume pool water}} \\ &= \frac{\left(3.337 \frac{\text{mg}}{\text{L}} \cdot 274 \text{ m}^3\right) + 28.5 \frac{\text{g}}{\text{h}}}{274 \text{ m}^3} = 3.441 \text{ mg/L} \end{aligned}$$

New concentration of DOC with dilution rate:

$$c_A(0) = 3.441 \frac{\text{mg}}{\text{L}} + \left(1 - e^{-\frac{0}{1.374}}\right) \cdot \left(2.418 - 23.441 \frac{\text{mg}}{\text{L}}\right) = 3.441 \text{ mg/L}$$

## Appendix 3 – Process Schemes of Operation Units at Rud svømmehall

Content	Drawing number	Date	Revision
drinking water system	1115-V-B---310-70-101	25.10.21	4
Opplæringsbasseng part 1	1115-V-B-1-383-70-121	19.05.21	F
Opplæringsbasseng part 2	1115-V-B-1-383-70-122	27.11.20	E

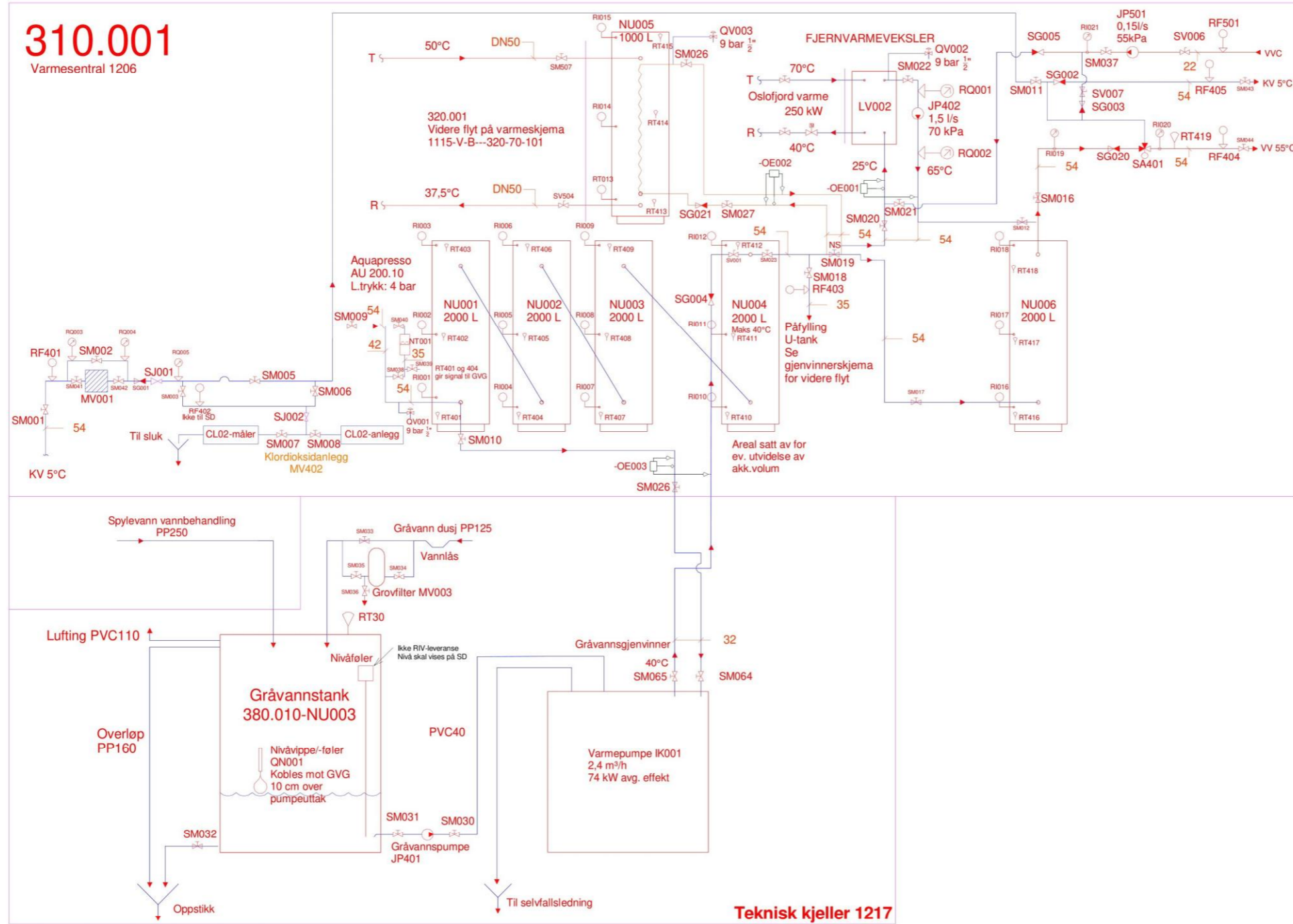
Instrument list of pool water systems:

<b>project</b>	Rud Svømmehall
<b>object</b>	Opplæringsbasseng
<b>date</b>	04.10.2021

identification	measuring parameter	measuring position
XP001	pH temperature free chlorine combined chlorine conductibility redox potential	20 cm below water level
RF001	flow	outlet Utjevningstank / inlet glass filter (after pump)
RF002	flow	outlet glassfilter / inlet kullfiltere (after pump)
RF003	flow	outlet Spylevannstank Felles => inlet kullfiltere backwash
RF004	flow	Kjemirom (before chlorine and acid dosing)
RP001	pressure	Utjevningstank
RP002	pressure	collecting pipe inlet glass filter
RP003	pressure	collecting pipe outlet glass filter
RP004	pressure	collecting pipe inlet kullfiltere
RP005	pressure	collecting pipe outlet kullfiltere

# 310.001

Varmesentral 1206



Korrigert plassering av tilbakeslagsventil	4	25.10.21	JH
Lagt inn ettermonterte tilbakeslagsventiler	3	11.06.21	JH
Korrigert AS BUILT	2	09.08.21	JH
AS BUILT	1	25.11.20	JH
HEV	INDEXS	DATA	ISIGN

**Bærum RØRLEGGJERBEDRIFT**

Titelshaver:  
**BÆRUM KOMMUNE**  
 EIENDOM

Teigringsprodusent:  
**RIV**  
 Teigring levert av:  
 Asplan Væk AS  
 Kjerfjordveien 20, 1337 Sandvika  
 417 99 417  
 asplanvæk@asplanvæk.no

Underlag levert av:  
**ARK**  
 Underlag levert av:  
 Nuno Arkitektur AS  
 Akersbakken 12, 0172 Oslo  
 23 01 49 20  
 fmp@post@nunoarkitektur.no

Navn Eiendom/Prosjekt:  
 Bærum Idrettspark  
 Rud Svømmehall

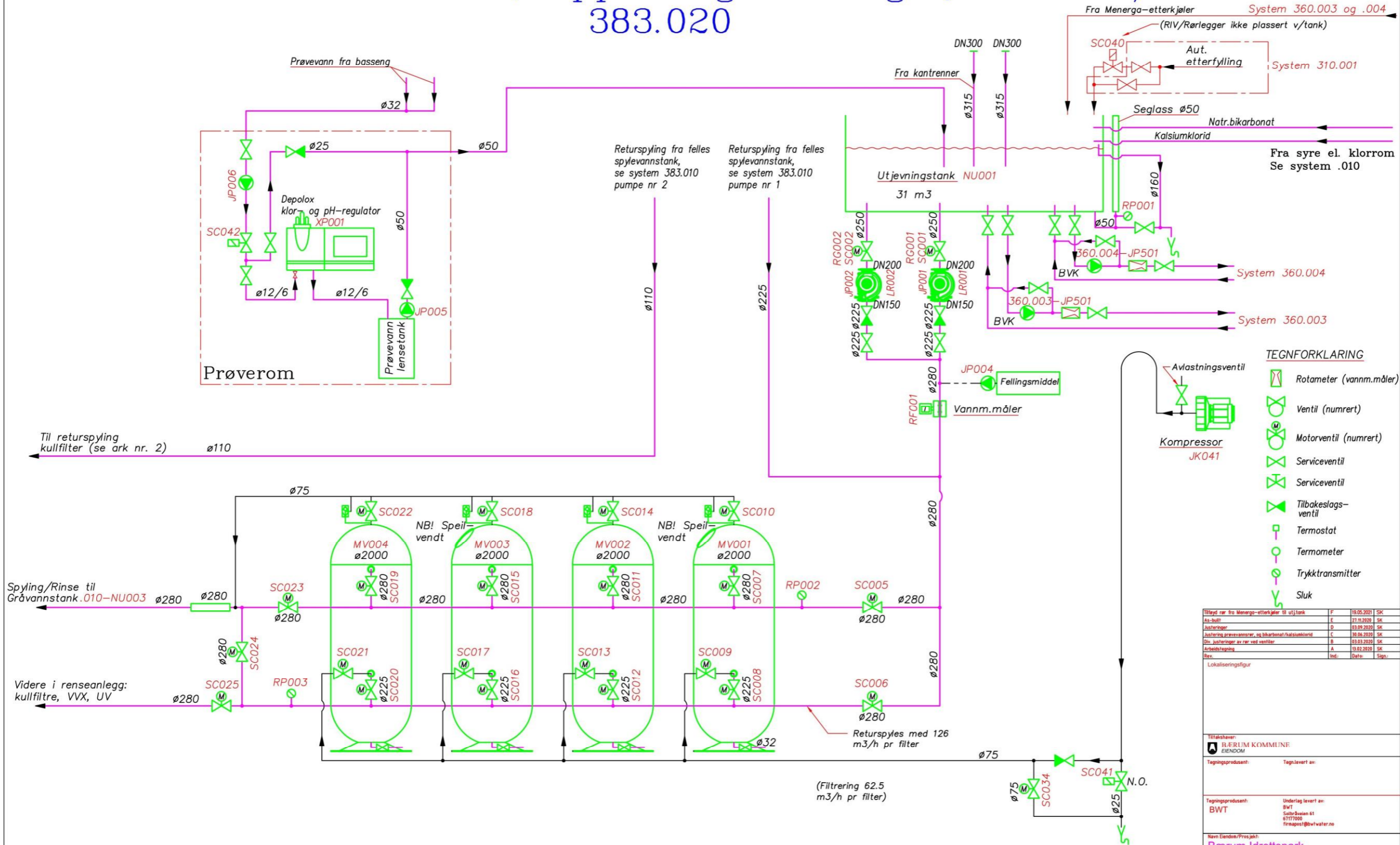
Innhold:  
**Rør**  
 Tappevannsskjema

FDV nr.:  
 Filnavn:  
 Tappevannsskjema

Bladnr.: 29/11/19 | Målestokk: | Teigringsnummer: 1115-V-B-310-70-101 | REV: **4**

#Bilubegjensker: Oppdrag: 618029-01-04; Revisjonsdato: 25.10.21; Revisjonskommentar: Korrigert plassering av tilbakeslagsventil; Tittel: Tappevannsskjema; Dokumentnavn: 1115-V-B-310-70-101#

# Rud Svømmehall, Opplæringsbasseng Q=250 m<sup>3</sup>/h 383.020



- TEGNFORKLARING**
- Rotameter (vannm.måler)
  - Ventil (numrert)
  - Motorventil (numrert)
  - Serviceventil
  - Serviceventil
  - Tilbakeslagsventil
  - Termostat
  - Termometer
  - Trykkt transmitter
  - Sluk

Tilbyrd rar fra Menerga-etterkjøler til utj tank	F	19.05.2021	SK
Asi-belt	E	21.11.2020	SK
Justeringer	D	03.09.2020	SK
Justering gressmåler og bikarbonat/kalsiumklorid	C	19.06.2020	SK
Div. justeringer av rar ved ventiler	B	03.03.2020	SK
Arbeidsrapport	A	19.02.2020	SK
Rev.	Indt.	Date:	Sign.

Lokaliseringsfigur

Tilråkshaver: ELFERUM KOMMUNE  
 EIGENDOM

Tegningsprodusent: Tegnløst av:

Tegningsprodusent: Underlag levert av:  
 BWT  
 Solbråveien 61  
 0177 Trondheim  
 Finnpost@bwtwater.no

Navn Eiendom/Prosjekt:  
**Bærum Idrettspark  
 Rud Svømmehall**

Innhold:  
**Vannbehandling  
 Systemskjema  
 Opplæringsbasseng, ark 1**

Rev.nr.:  
 Filnavn:  
 Opplæringsbasseng

Etablet:	Revisjon:	Tegningsnummer:	REV
11.10.2019	-	1115-V-B-1-383-70-121	F

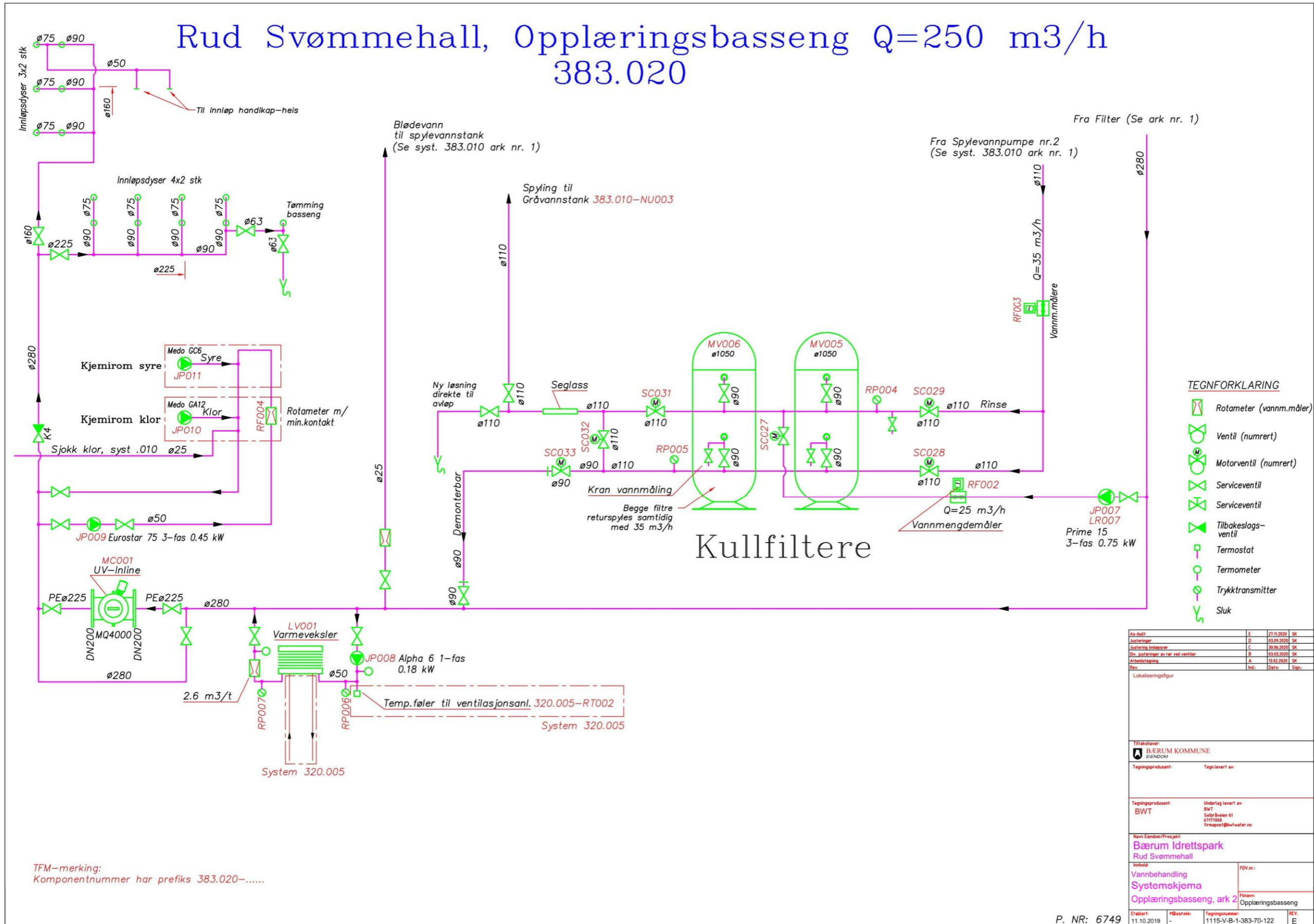
TFM-merking:  
 Komponentnummer har prefiks 383.020-.....

NB! Husk å drenere tanken for luftkompressor regelmessig

P. NR: 6749



# Rud Svømmehall, Opplæringsbasseng Q=250 m<sup>3</sup>/h 383.020



TFM-merking:  
 Komponentnummer har prefiks 383.020-.....

P. NR: 6749

## Appendix 4 – Risk Assessment

Table 1. 1 presents the risk value as the correlation between probability and consequence, fetched from NTNUs Risk Assessment<sup>1</sup>. Table 1.2 displays the colour codes for the extent of risk factors. CAS-numbers, hazard and precautionary statements are developed from the safety data sheet for each compound, fetched from Sigma Aldrich (acids and base) and Aquateam COWI (remaining). The value of risk is evaluated and determined based on comparing hazard and precautionary statement with Table 1.1.

### Value of risk = Probability · Consequence

Table 1. 1 Risk matrix.

Consequence	5 – Permanent disability	5	10	15	20	25
	4 – Serious injury	4	8	12	16	20
	3 - Moderate	3	6	9	12	15
	2 - Injury	2	4	6	8	10
	1 – Minor injury	1	2	3	4	5
		1 - Quite small	2 - Small	3 - Moderate	4 - High	5 - Quite high
Probability						

Table 1. 2 Extent of risk.

Red		Unacceptable risk. Measures need to be implemented.
Yellow		Medium risk. Measures need to be considered.
Green		Acceptable risk. Measures can be considered.

<sup>1</sup>Risk value templat approved by the Director of HSE at NTNU - 03.12.2013 - HMSRV2608E.

Table 1. 3 presents the risk evaluation, based on hazard and precautionary statements for each chemical. The CAS-number is implemented in the table as well.

Table 1. 3 Risk evaluation of chemicals and actions.

Incident	CAS-number	Description	Hazard and precautionary statements				Risk [Probability x Consequence]
			Hazard statements		Precautionary statements		
			H number	H statement	P number	P statement	
Aluminium chlorine AlCl <sub>3</sub> (50%)	1327-41-9	Coagulant.	H290  H318	May be corrosive to metals  Corrosion damage to skin and eyes.	P102  P261 P280  P302+P352 P361  P305+P351+P338  P313	Keep out of the reach of children.  Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.  Wear protective gloves/ protective clothing/ eye protection/ face protection/ hearing protection.  IF ON SKIN. Wash with plenty of water.  Contaminated clothing must be removed immediately.  IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.  Get medical attention	Small, Small 4
Hydrochloric acid HCl (37%)	7647-01-0	pH adjustment for DOC-analysis.  Desorber of carbon on glass walls.	H290  H314  H335	May be corrosive to metals.  Causes severe skin burns and eye damage.  May cause respiratory irritation.	P234  P261 P271  P280  P303+P361+P353  P305+P351+P338	Keep only in original packaging.  Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.  Use only outdoors or in a well-ventilated area.  Wear protective gloves/ protective clothing/ eye protection/ face protection/ hearing protection.  IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water.  IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.	Quite small, Small 2

Incident	CAS-number	Description	Hazard and Precautionary Statement				Risk [Probability x Consequence]
			Hazard statement		Precautionary statement		
			H number	H statement	P number	P statement	
Nitric acid HNO3 (65%)	7697-37-2	pH adjustment for Jar test.	H272	May intensify fire; oxidizer	P210	Keep away from heat, hot surfaces, sparks, open flames, and other ignition sources. No smoking.	Medium, Small 6
			H290	May be corrosive to metals.	P220	Keep away from clothing and other combustible materials.	
		Pre-treatment for ICP-MS-analysis.	H314	Causes severe skin burns and eye damage.	P280	Wear protective gloves/ protective clothing/ eye protection/ face protection/ hearing protection.	
			H331	Toxic if inhaled.	P303+P361+P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water.	
P304+P340+P310	IF INHALED: Remove person to fresh air and keep comfortable for breathing. Immediately call a POISON CENTER/ doctor.						
Sodium hydroxide (NaOH, 0.1M)	1310-73-2	pH adjustment for Jar test.	H290	May be corrosive to metals.	P234	Keep only in original packaging.	Small, Small 4
			H314	Causes severe skin burns and eye damage.	P280	Wear protective gloves/ protective clothing/ eye protection/ face protection/ hearing protection.	
		P303+P361+P353			IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water.		
		P304+P340+P310	IF INHALED: Remove person to fresh air and keep comfortable for breathing. Immediately call a POISON CENTER/ doctor.				
P305+P351+P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.						

Incident	CAS-number	Description	Hazard and Precautionary Statement				Risk [Probability x Consequence]
			Hazard statement		Precautionary statement		
			H number	Hazard statement	P number	P statement	
Activated Carbon powder (100% carbon)	7440-44-0	Adsorbent in GAC filters.	H319  H335	Cause serious eye irritation.  May cause respiratory irritation.	P102  P261  P305+P351+P337+ P313	Keep out of the reach of children.  Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray  IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. In case of persistent eye irritation: Get medical assistance.	Medium, Quite small 3
Potassium dihydrogen phosphate (<50%)  disodium hydrogen phosphate (<27%)  N, N-Diethyl-1,4- phenylenediammonium sulfate (<25%)  Ethylenediaminetetraacetic acid disodium salt dihydrate (<0.5%)	7778-77-0  7558-79-4  6283-63-2  6381-92-6	Chlorine kit LCK310-1	H302  H312  H315  H319	Harmful if swallowed.  Harmful in contact with skin.  Irritates the skin.  Cause serious eye irritation.	P280  P302+P352  P305+P351+P338  P337+P313	Wear protective gloves/ protective clothing/ eye protection/ face protection/ hearing protection.  IF ON SKIN. Wash with plenty of water.  IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.  In case of persistent eye irritation: Get medical assistance.	Quite small, Medium 3
Potassium iodide (<10%) Water (>90%)	7681-11-0	Chlorine kit LCK310-2	H372	May cause damage to organs through prolonged or repeated exposure.	P314	Seek medical assistance in case of discomfort.	Small, Small 4

Orthophosphoric acid ≥85% ACS	7664-38-2	Determination of DOC	H290  H302  H314	May be corrosive to metals.  Harmful if swallowed. Causes severe skin burns and eye damage.	P234  P270  P280  P301 + P312  P303+P361+P353  P305+P351+P338	Keep only in original packaging.  Do not eat, drink or smoke when using this product.  Wear protective gloves/ protective clothing/ eye protection/ face protection/ hearing protection.  IF SWALLOWED: Call a POISON CENTER/ doctor if you feel unwell.  IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water.  IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.	Medium, Small 6
Incident	Reflected Hazard statement		Reflected Precautionary statement			Risk	
Detemination of DOC and Tot N. <sup>2</sup>	The instrument uses oxygen gas and synthetic air. The system has a built-in gas flow meter that regulates the pressure. Possible event will therefore not be related to the instrument itself, but rather to the possibility of gas leakage in the external hoses or valves.  A smaller amount of dilute phosphoric acid is used which is automatically dosed by the instrument. Possible event will therefore not be related to the operation of the instrument, but rather in connection with the preparation of the phosphoric acid solution		Regarding operation of the instrument (quite small - 1). Gas hoses, valves are checked regularly for gas leakage or if additional consumption of gas is observed during operation.  Regarding maintenance and preparation of solutions (small - 2). Protective gloves, clothing, and eye protection is worn while the phosphoric acid is prepared.			Quite small, Quite small 1	
Transport of samples from Oslo to Trondheim.	Something can be crushed or leak of samples.		Safe packing of the samples. The containers must stand upwards. Treat the samples with caution.			Medium, Small 6	
Handling of samples during laboratory work.	Something may shatter or the samples may tip over and the content goes to waste.		Treat the samples with caution.			Small, Quite small 2	

<sup>2</sup> Risk value recieved from external laboratory, by Øyvind Mikkelsen. Approved by the Director of HSE at NTNU - 04.03.2010 - HMSRV2603.

## Appendix 5 – Instruction Manual, Hach Lange LCK310



# LCK 310/343

0.05–2.0 mg/L Cl<sub>2</sub> / 0.05–2.0 mg/L O<sub>3</sub>  
 0.09–3.80 mg/L ClO<sub>2</sub>



**NIEUWE · NEW**

**LCK 410**

**Chloor vrij / Chlorine free**  
 0.05–2.0 mg/L Cl<sub>2</sub> (F):  
 DR 1900 / DR 2800 / DR 3800 /  
 DR 3900 / DR 5000 / DR 6000

**Datatablel · Data table**

**LP2W** 06/1990

Cl<sub>2</sub> · F1 = 0 · F2 = 3.36 · K = 0  
 O<sub>3</sub> · F1 = 0 · F2 = 2.18 · K = 0  
 ClO<sub>2</sub> · F1 = 0 · F2 = 3.36 · K = 0

**CADAS 30/30S/50/50S** 06/1990

Cl<sub>2</sub> · A: 510 nm · Pro.: 8 · F1 = -2.942 · F2 = 2.942 · K = 0  
 O<sub>3</sub> · A: 510 nm · Pro.: 8 · F1 = -1.907 · F2 = 1.907 · K = 0  
 ClO<sub>2</sub> · A: 510 nm · Pro.: 8 · F1 = -5.588 · F2 = 5.588 · K = 0

**ISIS 6000/9000** 06/2001

Cl<sub>2</sub> · A: 545 nm · Pro.: 8 · F1 = -3.042 · F2 = 3.041 · K = 0  
 O<sub>3</sub> · A: 545 nm · Pro.: 8 · F1 = -1.970 · F2 = 1.971 · K = 0  
 ClO<sub>2</sub> · A: 545 nm · Pro.: 8 · F1 = -5.773 · F2 = 5.773 · K = 0

**CADAS 100/LPG 158** 06/1990

Cl<sub>2</sub> · A: 552 nm · F = 2.82  
 O<sub>3</sub> · A: 552 nm · F = 1.83  
 ClO<sub>2</sub> · A: 552 nm · F = 2.82

**CADAS 100/LPG 210** 06/1990

Cl<sub>2</sub> · A: 552 nm · F1 = 2.82  
 O<sub>3</sub> · A: 552 nm · F1 = 1.83  
 ClO<sub>2</sub> · A: 552 nm · F1 = 2.82

**DR 3900** 02/2011

Chloor vrij / Chlorine free: Cl<sub>2</sub> (F)  
 Chloor totaal / Chlorine total: Cl<sub>2</sub> (T)  
 Ozon / Ozone: O<sub>3</sub>  
 Chloordioxide / Chlorine dioxide: ClO<sub>2</sub>

**NL** LCK 310/343

Chloor vrij en totaal / ozon / chloordioxide

Let a.u.b. op de "Uitgave datum" (zie datatablel) en lees de "Opmerking". Veiligheidsadvies en houdbaarheidsdatum op de verpakking.

**Principe**  
 Oxidatiemiddelen reageren met diethyl-p-fenyleendiamine (DPD), waarbij een rode kleurstof ontstaat.

**Toepassingsgebied**  
 Afvalwater, drinkwater, zwembadwater

**Oxidatiemiddelmengsels**  
 Oxidatiemiddelmengsels als chloor/ozon of chloordioxide kunnen bepaald worden. Andere oxidatiemiddelmengsels reageren met DPD niet steeds op dezelfde manier, maar ieder mengsel heeft zijn eigen, specifieke voorwaarden. Voor deze metingswijzen heeft HACH LANGE een speciaal procedé ontwikkeld, dat u gratis bij HACH LANGE Benelux kunt bestellen.

**Storingen**  
**Te hoge resultaten:**  
 Alle oxidatiemiddelen (bijv. ozon, jood, chloordioxide, mangaanoxide, chromaat) worden eveneens geregistreerd (zie oxidatiemiddelmengsels).  
**Resultaat te laag:**  
 Is er sprake van een overmaat aan oxidatiemiddel (meer dan het aangegeven meetbereik), dan kan dit het resultaat binnen het meetbereik beïnvloeden. De meetresultaten zijn via een plausibiliteitsonderzoek te controleren (verdunding en/of standaard-additie).

**Opheffen van storingen**  
 Troebeling kan worden opgeheven door middel van een langzame membraanfiltratie (LCW 904).  
**De watermonsters mogen niet worden gepipetteerd, omdat dit tot verlies, als gevolg van gasvorming, leidt.**  
 pH-waarde monster ..... 3–10  
 Temperaturen monster/reagentia ..... 15–25 °C  
**De analyse moet onmiddellijk na de monstername worden uitgevoerd.**

**EN** LCK 310/343

Chlorine free and total / Ozone / Chlorine dioxide

Please check the "Edition Date" (see data table) and read the "Note". Safety advice and expiry date on package.

**Principle**  
 Oxidizing agents react with diethyl-p-phenylenediamine (DPD) to form a red dye.

**Range of Application**  
 Waste water, drinking water, swimming bath water

**Mixtures of Oxidizing Agents**  
 Mixtures of oxidizing agents do not all react with DPD in the same way, but under conditions which are specific for each of them. HACH LANGE has produced an application method for these further types of evaluation which can be obtained free of charge from your HACH LANGE Agency.

**Interferences**  
**High-Bias Results:**  
 All oxidizing agents, e.g. ozone, iodine, chlorine dioxide, manganese dioxide, chromate are also determined (see mixtures of oxidizing agents).  
**Low-Bias Results:**  
 A large excess of oxidizing agents (outside the measuring ranges given above) can cause result displays within the measuring range. The measurement results must be subjected to plausibility checks (dilute and/or spike the sample).

**Removal of Interferences**  
 Turbidities can be removed by slow pressure filtration (Membrane Filtration Set LCW 904).  
**The water samples must not be pipetted, as this can cause gas stripping losses.**  
 pH sample ..... 3–10  
 Temperature sample/reagents ..... 15–25 °C  
**The analysis must be carried out immediately after the sample has been taken.**



# LCK 310/343

0.05–2.0 mg/L Cl<sub>2</sub> / 0.05–2.0 mg/L O<sub>3</sub>  
 0.09–3.80 mg/L ClO<sub>2</sub>



**NEU · NOUVEAU · NUOVO**

**LCK 410**

**Chlor frei / Chloro libre / Cloro libero**  
 0.05–2.0 mg/L Cl<sub>2</sub> (F):  
 DR 1900 / DR 2800 / DR 3800 /  
 DR 3900 / DR 5000 / DR 6000

**Datentabelle · Table des données · Tabella dati**

**LP2W** 06/1990

Cl<sub>2</sub> · F1 = 0 · F2 = 3.36 · K = 0  
 O<sub>3</sub> · F1 = 0 · F2 = 2.18 · K = 0  
 ClO<sub>2</sub> · F1 = 0 · F2 = 3.36 · K = 0

**CADAS 30/30S/50/50S** 06/1990

Cl<sub>2</sub> · A: 510 nm · Pro.: 8 · F1 = -2.942 · F2 = 2.942 · K = 0  
 O<sub>3</sub> · A: 510 nm · Pro.: 8 · F1 = -1.907 · F2 = 1.907 · K = 0  
 ClO<sub>2</sub> · A: 510 nm · Pro.: 8 · F1 = -5.588 · F2 = 5.588 · K = 0

**ISIS 6000/9000** 06/2001

Cl<sub>2</sub> · A: 545 nm · Pro.: 8 · F1 = -3.042 · F2 = 3.041 · K = 0  
 O<sub>3</sub> · A: 545 nm · Pro.: 8 · F1 = -1.970 · F2 = 1.971 · K = 0  
 ClO<sub>2</sub> · A: 545 nm · Pro.: 8 · F1 = -5.773 · F2 = 5.773 · K = 0

**CADAS 100/LPG 158** 06/1990

Cl<sub>2</sub> · A: 552 nm · F = 2.82  
 O<sub>3</sub> · A: 552 nm · F = 1.83  
 ClO<sub>2</sub> · A: 552 nm · F = 2.82

**CADAS 100/LPG 210** 06/1990

Cl<sub>2</sub> · A: 552 nm · F1 = 2.82  
 O<sub>3</sub> · A: 552 nm · F1 = 1.83  
 ClO<sub>2</sub> · A: 552 nm · F1 = 2.82

**DR 3900** 02/2011

Chlor frei / Chloro libre / Cloro libero: Cl<sub>2</sub> (F)  
 Chloro gesamt / Chloro total / Cloro totale: Cl<sub>2</sub> (T)  
 Ozon / Ozone / Ozono: O<sub>3</sub>  
 Chloordioxid / Dioxyde de Chlore / Diossido di cloro: ClO<sub>2</sub>

**DE** LCK 310/343

Chlor frei und gesamt / Ozon / Chloordioxid

Bitte "Ausgabedatum" (s. Datentabelle) und "Hinweis" beachten. Sicherheitshinweise und Verfallsdatum auf der Packung.

**Prinzip**  
 Oxidationsmittel reagieren mit Diethyl-p-phenylenediamin (DPD) unter Bildung eines roten Farbstoffes.

**Anwendungsbereich**  
 Abwasser, Trinkwasser, Badewasser

**Oxidationsmittelgemische**  
 Oxidationsmittelgemische reagieren mit DPD nicht in gleicher Art und Weise, sondern unter jeweils spezifischen Bedingungen. Für diese weiteren Auswerteformen hat HACH LANGE eine Applikation ausgearbeitet, die Sie kostenlos bei HACH LANGE Düsseldorf anfordern können.

**Störungen**  
**Mehrfunde:**  
 Alle Oxidationsmittel, z. B. Ozon, Jod, Chloordioxid, Manganoxid, Chromat werden mit erfasst (siehe Oxidationsmittelgemische).  
**Minderbefunde:**  
 Ein hoher Überschuss an Oxidationsmittel (oberhalb des angegebenen Messbereiches) kann zu Ergebnisanzeigen innerhalb des Messbereiches führen.  
 Messergebnisse sind durch eine Plausibilitätskontrolle zu überprüfen (Verdünnung und/oder Aufstockung).

**Beseitigung von Störungen**  
 Trübungen können durch langsame Druckfiltration (Membranfiltrationssatz LCW 904) beseitigt werden.  
**Die Wasserproben dürfen nicht pipettiert werden, da dieses zu Ausgasungsverlusten führt.**  
 pH-Wert Probe ..... 3–10  
 Temperatur Probe ..... 15–25 °C  
**Die Analyse muss unmittelbar nach Probenahme erfolgen.**

**FR** LCK 310/343

Chlore libre et total / Ozone / Dioxyde de Chlore

Vérifier la date d'édition (voir table des données) et lire la "Remarque". Conseils de sécurité et date de péremption sur l'emballage.

**Principe**  
 Les agents d'oxydation réagissent avec la diéthyl-p-phénylènediamine (DPD) en formant une couleur rouge.

**Domaine d'application**  
 Eaux de rejet, eaux potables, eaux de baignade

**Mélanges d'agents oxydants**  
 Les mélanges d'agents oxydants ne réagissent pas de la même façon en présence de DPD mais chaque fois selon les conditions spécifiques. La société HACH LANGE propose une application, permettant leur détermination. Demandez-la au représentant HACH LANGE de votre pays.

**Perturbations**  
**Résultats trop élevés:**  
 Tous les agents oxydants, comme par exemple l'ozone, l'iode, le dioxyde de chlore, l'oxyde de manganèse, les chromates sont aussi déterminés (voir mélanges d'agents oxydants).  
**Résultats trop faibles:**  
 Un excédent d'agents oxydants dans l'échantillon (au-dessus de la gamme de mesure indiquée) peut tout de même faire apparaître des résultats d'analyse compris dans la gamme de mesure. Les résultats des mesures sont à vérifier par un contrôle de plausibilité (dilution et/ou addition).

**Solutions aux perturbations**  
 Les turbidités sont éliminées en filtrant lentement l'échantillon sous pression (Ensemble de filtres à membrane LCW 904).  
**Ne pas pipetter l'échantillon d'eau pour éviter un dégazage.**  
 pH échantillon ..... 3–10  
 Température échantillon/réactifs ..... 15–25 °C  
**L'analyse doit être réalisée immédiatement après la prise d'échantillon.**

**IT** LCK 310/343

Cloro libero e totale / ozono / diossido di cloro

Si prega di verificare la "Data di Edizione" (vedi tabella dati) e di leggere la "Nota". Avvertenze e data di scadenza sulla confezione.

**Principio**  
 Gli ossidanti reagiscono con la dietil-p-fenilendiamina (DPD) formando una colorazione rossa.

**Applicazione**  
 Acqua potabile, acque di scarico, acqua di balneazione

**Interferenze**  
**Valori in eccesso:**  
 Valori in eccesso sono possibili dato che vengono analizzati tutti i mezzi ossidanti quali ozono, iodio, diossido di cloro, ossido di manganese, cromati  
**Valori ridotti:**  
 Valori ridotti possono essere dovuti a quantità eccessive di ossidanti (superiori al campo di misura) che danno valori entro i limiti di misura. I risultati sono da verificare con un controllo (diluzione e/o soluzione additiva).

**Eliminazione interferenze**  
 Le eventuali torbidità vanno eliminate con la lenta filtrazione a membrana (LCW 904).  
**I campioni non vanno pipettati causa possibile eliminazione gassosa del cloro!**  
 pH campione ..... 3–10  
 Temperatura campione/reagenti ..... 15–25 °C  
**Fare l'analisi subito dopo aver prelevato il campione.**

AD 310K / Druckierte schwarz / 1

LCK 310/343 – Cl<sub>2</sub> / O<sub>3</sub> / ClO<sub>2</sub> 02/2011

**DE**

- Küvette mit Probe bis **1 cm** unterhalb der Küvettenöffnung auffüllen.
- Küvette **vorsichtig** schwenken (**nicht schütteln**) und dabei etwas drehen, um anhaftende Luftbläschen zu entfernen.
- Nach **1 min** Küvette außen gut säubern und **auswerten**.
- Sofort 1 Tropfen** Kaliumjodidlösung **A** zutropfen.
- Küvette verschließen und schwenken.
- Nach **2 min** Küvette außen gut säubern und auswerten.

**FR**

- Remplir la cuve avec l'échantillon jusqu'à **1 cm** sous l'ouverture de la cuve.
- Mélanger **avec précautions** en tournant légèrement la cuve pour ainsi éliminer les bulles d'air qui adhèrent aux parois de la cuve (**ne pas agiter**).
- Attendre **1 min**, bien nettoyer l'extérieur de la cuve et **mesurer**.
- Ajouter au compte-gouttes **1 goutte** de solution de iode de potassium **A** **immédiatement**.
- Fermer la cuve et mélanger le contenu en la retournant plusieurs fois de suite.
- Attendre **2 min**, bien nettoyer l'extérieur de la cuve et mesurer.

**IT**

- Riempire con il campione fino a **1 cm** circa dall'orlo della cuvetta.
- Mescolare **attentamente (non agitare)** ed eventualmente ruotare la cuvetta per eliminare le bollicine.
- Dopo **1 min** pulire bene la cuvetta esternamente e **leggere**.
- Subito**, aggiungere, **1 goccia** di soluzione di ioduro di potassio **A**.
- Tappare la cuvetta e mescolare.
- Dopo **2 min** pulire bene la cuvetta esternamente e leggere.

**NL**

- Het kuwet met het monster tot **1 cm** beneden de opening van het kuwet vullen.
- Kuwet **voorzichtig** zwenken (**niet schudden**) en daarbij een beetje draaien om luchtbelletjes te verwijderen.
- Na **1 min** het kuwet van buiten goed reinigen en **meten**.
- Onmiddellijk 1 druppel**s kaliumjodide-oplossing **A** toevoegen.
- Kuwet sluiten en zwenken.
- Na **2 min** het kuwet van buiten goed reinigen en meten.

**EN**

- Fill the cuvette with the sample up to about **1 cm** below the cuvette opening.
- Carefully** invert the cuvette a few times (**do not shake**) and rotate it slightly to remove any bubbles sticking to the sides.
- After **1 min** thoroughly clean the outside of the cuvette and **evaluate**.
- Immediately** add **1 drop** of potassium iodide solution **A**.
- Close cuvette and invert a few times.
- After **2 min** thoroughly clean the outside of the cuvette and evaluate.

**1. - 3.**  
 Freies Chlor oder Chlordioxid  
 Chlore libre ou dioxyde de chlore  
 Cloro libero o diossido di cloro  
 Vrij chloor of chloordioxide  
 Free Chlorine or Chlorine dioxide

**1. - 6.**  
 Gesamt-Chlor  
 Chlore total  
 Cloro totale  
 Chloor totaal  
 Total Chlorine

**1. 7. 5. - 6.**  
 Ozon  
 Ozone  
 Ozono  
 Ozon  
 Ozone

Auswertung - Evaluation - Lettura - Meting

	DE: Für folgende Barcode-Geräte erfolgt nach Einsetzen der Nulllösung eine automatische Auswertung:	FR: Si vous utilisez un des instruments avec codes à barres suivants, une évaluation automatique est réalisée après l'insertion de la Solution zéro :	IT: Se si utilizza uno qualsiasi dei seguenti strumenti con codice a barre, dopo aver inserito il bianco viene automaticamente visualizzato il risultato della misura:	NL: Wanneer een van de volgende barcode instrumenten worden gebruikt, wordt een automatische uitwaardering uitgevoerd zodra de nulkuwet geplaatst wordt:	EN: If any of the following barcode instruments is used, an automatic evaluation is carried out after the zero-solution is inserted:
--	---	---	--	--	--

**LASA 50, LASA 100, XION 500, CADAS 200 Barcode, DR 2800 / DR 3800 / DR 3900 / DR 5000 / DR 6000**






DE	FR	IT	NL	EN	↓	LASA aqua	LASA 1 / plus	LASA 20	CADAS 200 Basis	ISIS 6000	LASA 30	DR 1900
Filter	Filtre	Filtro	Filter	Filter	<b>1</b>	Δ310	540 nm	-	-	-	535 nm	-
Eprom	Eprom	Eprom	Eprom	Eprom	<b>2</b>	_ : 12	_ : 18	_ : 46	_ : 38	_ : 46	-	-
Mode	Mode	Mode	Mode	Mode	<b>3</b>	-	-	-	-	KÜVETTEN-TEST <sup>1)</sup>	Dr. Lange	BARCODE-PROGRAMME <sup>2)</sup>
Test anwählen	Test choisir	Test selezionare	Test oproepen	Test select	<b>4</b>	Δ310	Cl <sub>2</sub> : Chlor <sup>3)</sup> LCK 310 O <sub>3</sub> : Ozon <sup>3)</sup> LCK 310/343 ClO <sub>2</sub> : ClO <sub>2</sub> LCK 310	Cl <sub>2</sub> : Chlor <sup>3)</sup> LCK 310 O <sub>3</sub> : Ozon <sup>3)</sup> LCK 310/343 ClO <sub>2</sub> : ClO <sub>2</sub> LCK 310	310	310	310	310
Kontrollnr.	No. de contrôle	No. di controllo	Controlegetal	Control no.	<b>5</b>	-	-	2	5	5	5	5
Nulllösung	Solution zéro	Bianco	Nulkuwet	Zero-solution	<b>6</b>	✓	✓	✓	-	-	-	-
Analysenküvette	Cuve d'analyse	Cuvetta d'analisi	Analyse-kuwet	Sample cuvette	<b>7</b>	✓	✓	✓	-	-	-	-
Nulllösung, blaue Taste / Null ▲	Solution zéro, touche bleue / Zéro ▲	Bianco, tasto blu / Zero ▲	Nulkuwet, blauwe toets / Nulstellen ▲	Zero-solution, blue key / Zero ▲	<b>8</b>	-	-	-	✓	✓	✓	✓
Analysenküvette, grüne Taste / Messen	Cuve d'analyse, touche verte / Mesurer	Cuvetta d'analisi, tasto verde / Lettura	Analyse-kuwet, grüne toets / Meten	Sample cuvette, green key / Read	<b>9</b>	-	-	-	✓	✓	✓	✓
Messergebnis (Chlor) multiplizieren mit ... (Das errechnete Ergebnis muss innerhalb des Messbereichs liegen.)	Multiplier le résultat (Chlore) par ... (Le résultat calculé doit être dans la gamme de mesure.)	Moltiplicare il risultato (Cloro) per ... (Il risultato così calcolato deve rientrare nel campo di misura.)	Resultaat (Chloor) vermenigvuldigen met ... (Let op de grenzen van het meetbereik.)	Result (Chlorine) must be multiplied with ... (Please observe the measuring range limits.)	<b>10</b>	O <sub>3</sub> : 0.65 ClO <sub>2</sub> : 1.9	-	-	-	-	-	-

FR: <sup>1)</sup> TEST EN CUVE <sup>2)</sup> Chlore <sup>3)</sup> Ozone <sup>4)</sup> PROGR. CODE BARRE  
 IT: <sup>1)</sup> CUVETTE-TEST <sup>2)</sup> Cloro <sup>3)</sup> Ozono <sup>4)</sup> PROGRAMMI COD A BARRE  
 NL: <sup>1)</sup> KUVETTENTEST <sup>2)</sup> Chloor <sup>3)</sup> Ozon <sup>4)</sup> BARCODE-PROGRAMMA'S  
 EN: <sup>1)</sup> CUVETTE TEST <sup>2)</sup> Chlorine <sup>3)</sup> Ozone <sup>4)</sup> BARCODE PROGRAMS

AD 310 K / Druckfarbe schwarz / 2



Auswertung · Evaluation · Lettura · Meting

DE	FR	IT	NL	EN		LP1W	LP2W	CADAS 100 LPG158	CADAS 100 LPG210
Filter	Filtre	Filtro	Filter	Filter	1	535 nm	535 nm	-	-
Mode	Mode	Mode	Mode	Mode	2	-	-	TEST	TEST
Symbol	Symbole	Simbolo	Symbool	Symbol	3	-	-	Cl <sub>2</sub> / ClO <sub>2</sub> : 310 O <sub>3</sub> : 343	Cl <sub>2</sub> / ClO <sub>2</sub> : 310 O <sub>3</sub> : 343
Test anwählen	Test choisir	Test selezionare	Test oproepen	Test select	4	-	Cl <sub>2</sub> /ClO <sub>2</sub> : Cl2 LCK 310 O <sub>3</sub> : Ozon <sup>®</sup> LCK 343	-	-
Faktor	Facteur	Fattore	Factor	Factor	5	Cl <sub>2</sub> : 3.36 O <sub>3</sub> : 2.18 ClO <sub>2</sub> : 6.39	-	-	-
Kontrollnr.	No. de contrôle	No. di controllo	Controlegetal	Control no.	6	-	Cl <sub>2</sub> : 3 O <sub>3</sub> : 2	-	6
Nulllösung	Solution zéro	Bianco	Nulkuvet	Zero-solution	7	✓ NULL ↑	✓ NULL ↑	✓ NULL ↑	✓ NULL ↑
Analysenküvette	Cuve d'analyse	Cuvetta d'analisi	Analyse-kuvet	Sample cuvette	8	✓ ERGEBNIS ↑	✓ ERGEBNIS ↑	✓ MESS ↑	✓ MESS ↑
 Messergebnis (Chlor) multiplizieren mit ... (Das errechnete Ergebnis muss innerhalb des Messbereichs liegen.);	 Multiplier le résultat (Chlore) par ... (Le résultat calculé doit être dans la gamme de mesure.);	 Moltiplicare il risultato (Cloro) per ... (Il risultato così calcolato deve rientrare nel campo di misura.);	 Resultaat (Chloor) vermenigvuldigen met ... (Let op de grenzen van het meetbereik.);	 Result (Chlorine) must be multiplied with ... (Please observe the measuring range limits.);	9	-	ClO <sub>2</sub> : 1.9	ClO <sub>2</sub> : 1.9	ClO <sub>2</sub> : 1.9

FR: <sup>®</sup> Ozone  
 IT: <sup>®</sup> Ozono  
 NL: <sup>®</sup> Ozon  
 EN: <sup>®</sup> Ozone

## Appendix 6 – Tune Parameters for *Agilent Technologies, Agilent 8800 QQQ*

**Agilent 8800 ICP-QQQ operating conditions**

Parameter	Value	Range	Unit
Scan Type	MS/MS		
<b>Plasma</b>			
All Parameters			
RF Power	1600	500 - 1600	[W]
RF Matching	1.80	0.20 - 3.00	[V]
Smpl Depth	8.0	3.0 - 28.0	[mm]
Nebulizer Gas	0.80	0.00 - 2.00	[L/min]
Optim Gas	0.0	0.0 - 100.0	[%]
Nebulizer Pump	0.10	0.00 - 0.50	[rps]
S/C Temp	2	-5 - 20	[°C]
Gas Switch: <input checked="" type="radio"/> Makeup Gas <input type="radio"/> Dilution Gas			
Makeup Gas	0.39	0.00 - 2.00	[L/min]

Labels for the above table:  
 Sampling depth (mm)  
 Nebulizer gas flow rate (L/min) (Ar)  
 Spray chamber temp. (°C)  
 Make-up gas flow rate (L/min) (Ar)

Parameter	Value	Range	Unit
<b>Cell</b>			
Use Gas			
He Flow	1.5	0.0 - 12.0	[mL/min]
H2 Flow	5.8	0.0 - 10.0	[mL/min]
3rd Gas Flow	0	0 - 100	[%]
4th Gas Flow	0	0 - 100	[%]
OctP Bias	-20.0	-150.0 - 20.0	[V]
OctP RF	200	30 - 200	[V]
Energy Discrimination	-8.0	-20.0 - 150.0	[V]

Parameter	Value	Range	Unit
<b>Cell</b>			
Use Gas			
He Flow	1.0	0.0 - 12.0	[mL/min]
H2 Flow	7.0	0.0 - 10.0	[mL/min]
3rd Gas Flow	0	0 - 100	[%]
4th Gas Flow	45	0 - 100	[%]
OctP Bias	-20.0	-150.0 - 20.0	[V]
OctP RF	200	30 - 200	[V]
Energy Discrimination	-8.0	-20.0 - 150.0	[V]

## Appendix 7 – Instruction Manual *Klotz PCSS Fluid lite*

### Brief Instruction Manual *Measurements with the LDS-Box*

Version (05/2018), © 2018 Markus Klotz GmbH

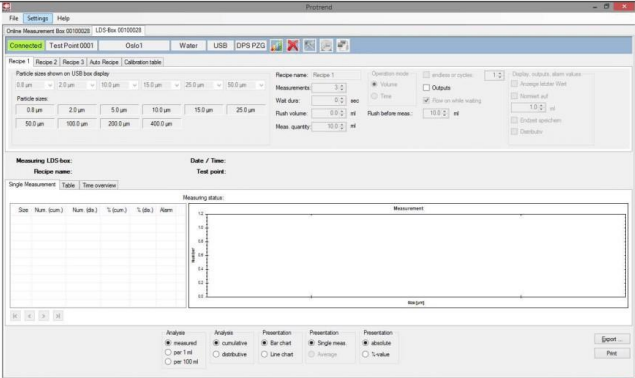
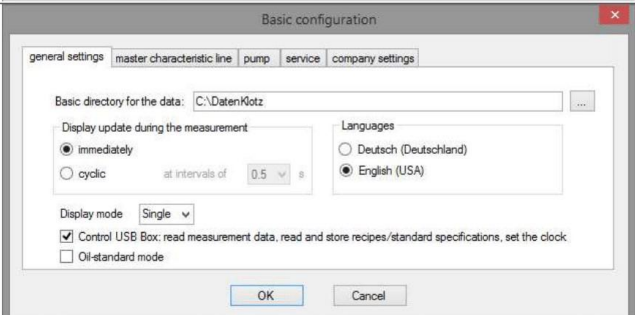
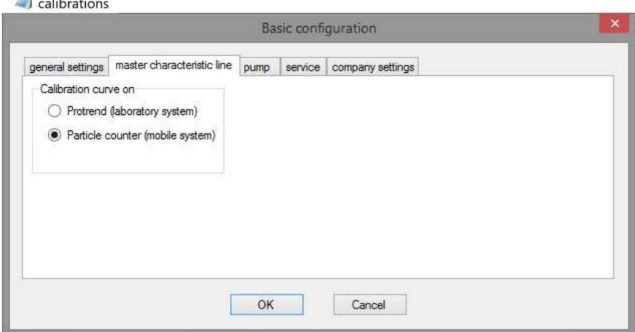
(12/2021), supplemented by Alessia Silvestro during her thesis at AquateamCOWI

## Table of Contents

1 Adjust the Software Protrend .....	3
2 Difference between the Online and Offline Measurement .....	5
3 Prepare the LDS-Box.....	6
4.2 Single Online Measurement.....	7
6 Export the Results.....	10

## 1 Adjust the Software Protrend

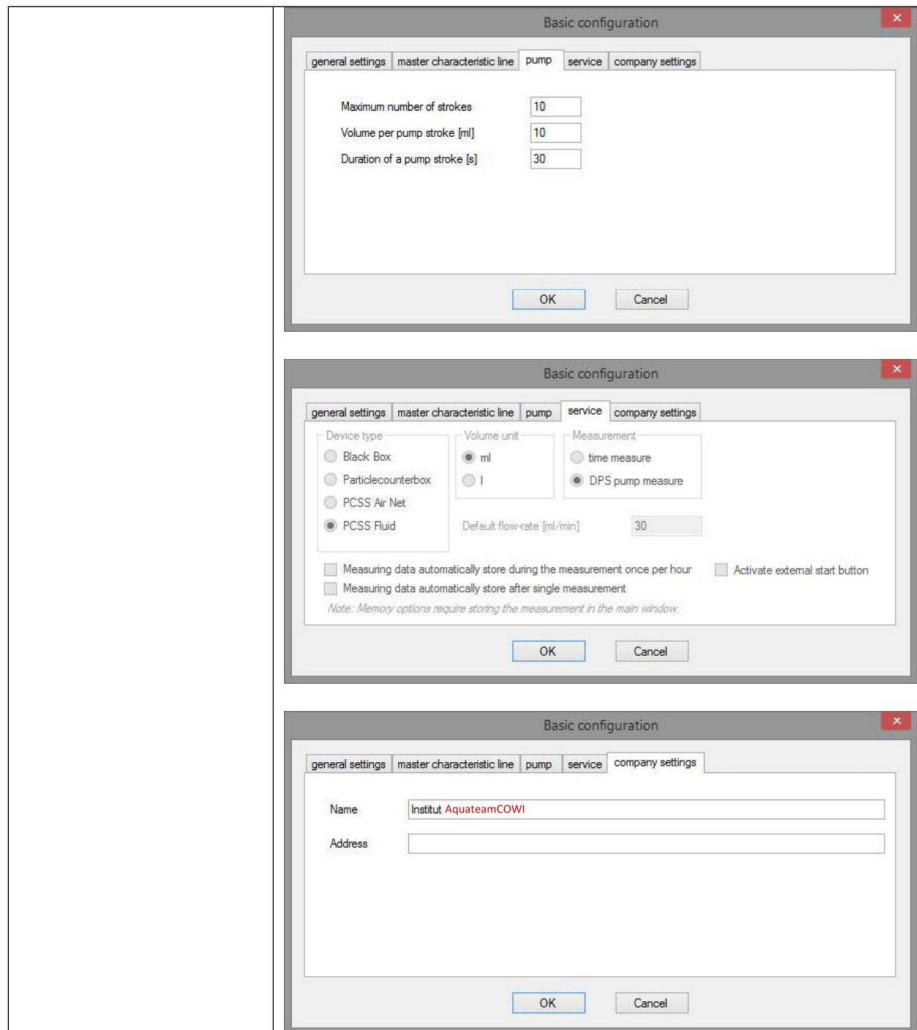
After installing and before using the software Protrend the basic configurations need to be set.  
 => The software is on the USB stick, which is in the folder. The folder is in the pocket where the particle counter itself is (the certificate and the delivery note are also in the folder).

<p>Start the software Protrend.</p> <p>Open the basic configuration in the menu bar: 'Settings' → 'basic configuration ...'.</p>	
<p>Adjust all the values in every tab.</p> <p>In the tab 'general settlings' the Display mode must be set according to the type of measurement. If a Single Measurement shall be performed, select 'Single' and for a Dual Measurement set the value to 'Dual'.</p> <p>If the values agree, confirm with 'OK'.</p> <p>In case of changing the basic configuration, the software Protrend must be restarted.</p>	 <p>=&gt; 'Basic directory for the data': choose a suitable location (the following folders are automatically created in the folder =&gt; don't delete them!)</p> <ul style="list-style-type: none"> <li>■ Data</li> <li>■ ExcelN</li> <li>■ ExcelV</li> <li>■ Methods</li> <li>■ Normen</li> <li>■ calibrations</li> </ul> 

supplemented

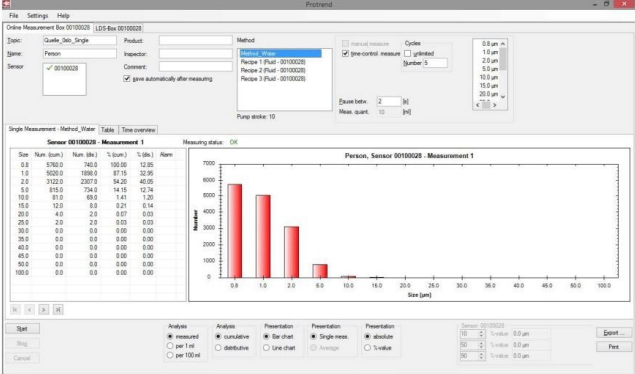
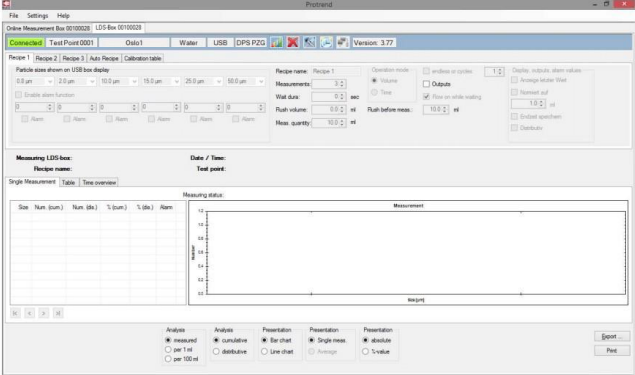
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3



## 2 Difference between the Online and Offline Measurement

In the top line of the software Protrend there are two tabs:

<p><b>Online Measurement:</b>                  Online Measurement Box 00100028</p> <p>The LDS-Box is connected to the computer before and during the measurement.                  =&gt; in our case we do not have an LDS-Box := we connect the PC directly to the laptop, which must then remain connected during the measurement</p> <p>Before performing the measurement, the measurement method can be created, configured and selected.</p>	
<p><b>Offline Measurement:</b>                  LDS-Box 00100028</p> <p>The LDS-Box must be connected to the computer (top left corner button turns into <b>Connected</b>) before performing the measurement to set the recipe of the measurement method.</p> <p>During the measurement the LDS-Box is not connected to the computer.</p>	

supplemented


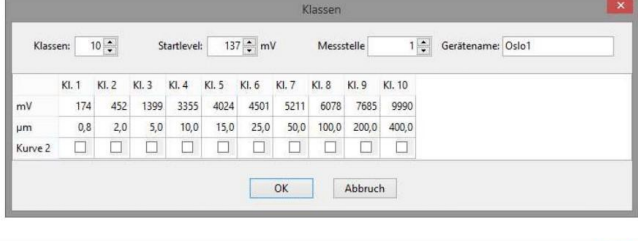
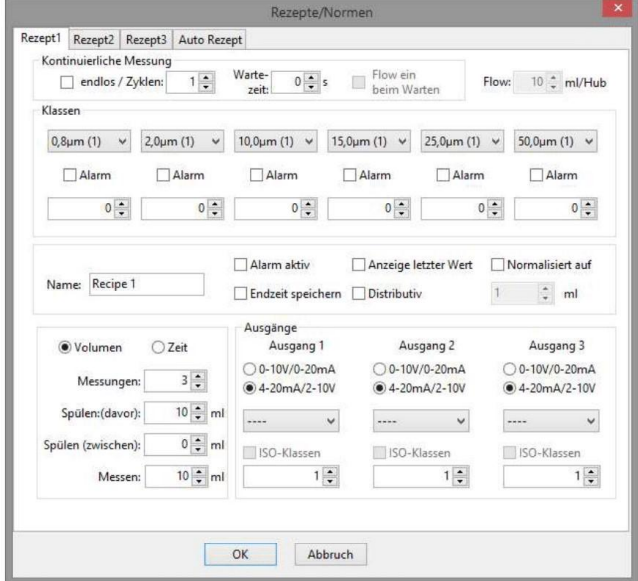
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5

### 3 Prepare the LDS-Box

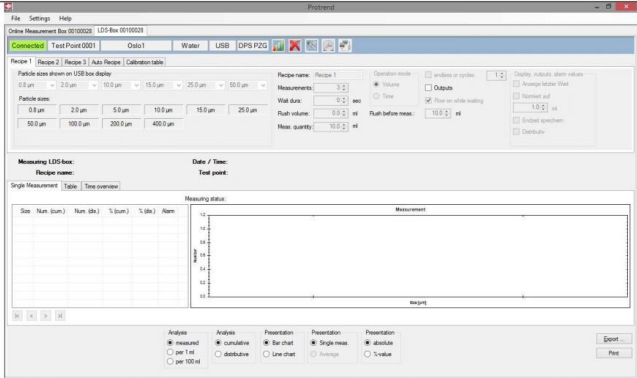
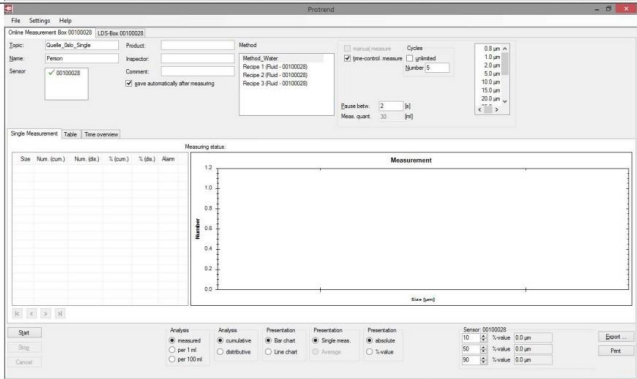
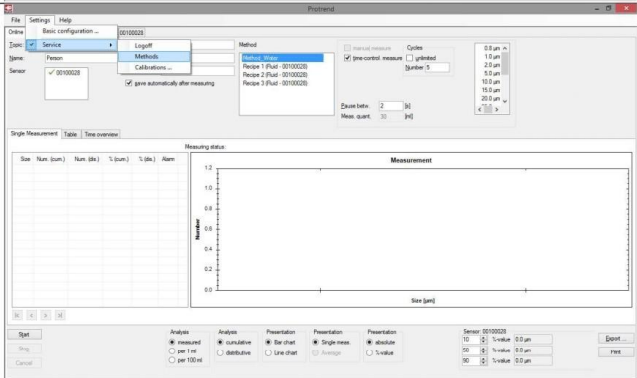
Before performing the Offline Measurement with the LDS-Box, the required measurement methods need to be set with the software partikel\_3.3.3.1. The LDS-Box has to be connected with the computer.

=> The calibration should already be set

<p>Start the software partikel_3.3.3.1.</p>	
<p>Open the classes by clicking the button 'Classes'.</p> <p>Control the calibration points.</p> <p>Click 'OK' to return to the main menu.</p>	
<p>Open the recipes by clicking the button 'Recipes'.</p> <p>Before performing the measurement, the measurement method can be configured.</p> <p>There are up to three recipes available for the Offline Measurement.</p> <p>The settings of the recipe are confirmed with 'Yes'.</p>	



#### 4.2 Single Online Measurement

<p>Open the software Protrend and connect the LDS-Box* to the computer (top left corner button turns into <b>Connected</b>).</p> <p><b>*connect the laptop with the particle counter</b></p>	 <p>The screenshot shows the Protrend software interface. At the top left, the status is 'Connected'. The 'Recipe' section shows 'Recipe 1' selected. The 'Measuring LDS-box' section is visible, and the 'Measurement' graph shows a flat line at zero.</p>
<p>Switch to the tab 'Online Measurement Box 00100028'</p> <p>=&gt; in our case it's the same name but another number</p>	 <p>The screenshot shows the Protrend software interface with the 'Online Measurement Box 00100028' tab selected. The 'Measuring LDS-box' section is visible, and the 'Measurement' graph shows a flat line at zero.</p>
<p>Create a new measurement method in the menu bar: 'Settings' → 'Service' → 'Methods'.</p> <p>=&gt; You must be logged in for this step!          password: [REDACTED]          (also noted in the folder in the in pocket)</p>	 <p>The screenshot shows the Protrend software interface with the 'Settings' → 'Service' → 'Methods' menu path highlighted. The 'Measuring LDS-box' section is visible, and the 'Measurement' graph shows a flat line at zero.</p>

supplemented

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7

In the window 'Methods' the measurement method can be defined.  
 => choose 'New Method':  
 - 'Number' and 'Pause betw.' can also be changed afterwards, for example: if you want every 15 minutes a measurement, enter 900 s for the pause and by number the corresponding number of cycles  
 - Activate this field (useful for online measurements)

Confirm the settings with 'Close'.

Start the Online Measurement by clicking 'Start' in the bottom left corner  
 => The desired method can be selected here  
 - The number of cycles and the pause time can be changed here  
 - important: check the 'save automatically after measurement' field

The results are automatically updated and displayed during the measurement.

Size	Num. (part.)	Num. (lit.)	% (part.)	% (lit.)	Alarm
0.8	725.0	64.0	100.00	11.27	
1.0	655.0	228.0	89.83	30.25	
2.0	425.0	245.0	57.78	41.98	
5.0	117.0	103.0	15.83	13.94	
10.0	16.0	14.0	1.89	1.89	
15.0	0.0	0.0	0.00	0.00	
20.0	0.0	0.0	0.00	0.00	
25.0	0.0	0.0	0.00	0.00	
30.0	0.0	0.0	0.00	0.00	
40.0	0.0	0.0	0.00	0.00	
45.0	0.0	0.0	0.00	0.00	
50.0	0.0	0.0	0.00	0.00	
100.0	0.0	0.0	0.00	0.00	

8

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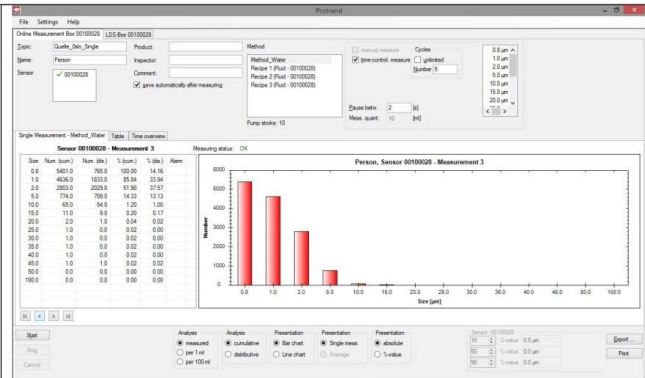
supplemented

aquateam | COWI | NTNU Department of Materials Science and Engineering | NTNU SAT - Centre for Sport Facilities and Technology

XXXIX

After the measurement is completed all results can be seen.

The different graphical representations of the measurement results is explained in the end of chapter 4.1.2. => is subsequent



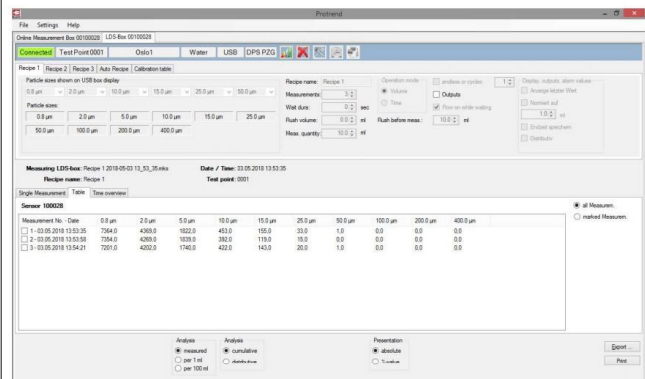
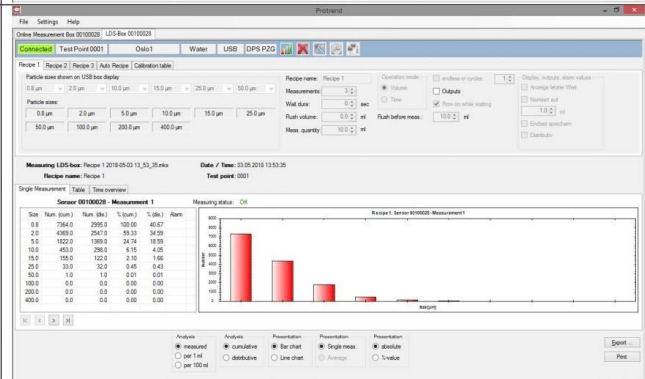
To display the result, load the data file in the menu bar: 'File' → 'Open Box-Measurement ...'.

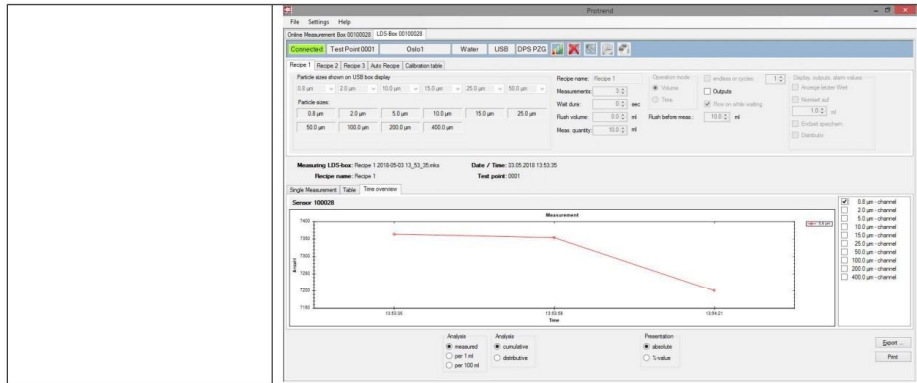
There are three different graphical representations of the measurement results.

The first tab 'Single Measurement' shows only the results of a partial measurement. By clicking the arrow buttons underneath the table, the results of the different partial measurements can be seen.

The second tab 'Table' lists all partial measurements and their results in a single table.

In the third tab 'Time Overview' the development of the results of the different particle sizes are displayed.



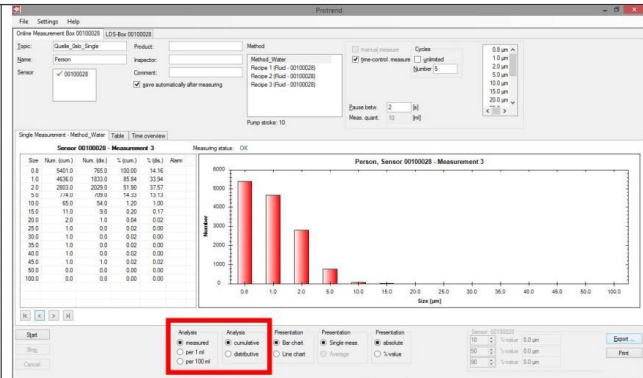


## 6 Export the Results

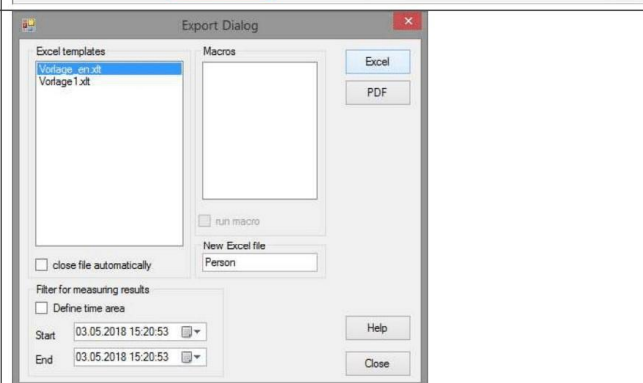
The measurement results can be exported into an MS Excel or PDF file.

To export the results click 'Export ...' in the bottom right corner.

=> **important:** only the settings with 'Analysis' are exported (rectangle), but only the information whether 'cumulative / distributive'; which volume is referenced doesn't appear!  
 => the easiest way is to export 'per 1 ml' and then note it in the file or name.



In the window 'Export Dialog' fill in the name of the new Excel file and choose between Excel and PDF.



The Excel export displays all the results of each sensor in an own table.  
 => don't change/mark anything in excel before it has finished exporting, it may be that excel is then no longer storable... (with longer online measurements it can take a few minutes)

=> In the picture below is an example of this thesis: if the volume is 'per 1 ml' in the filename, you will see it when you open the Excel file (distributive is exported by itself)

Topic	Outlet_01rs_Single	Name	Person											
Measurement duration	22.8 s	Comment												
Pause duration	1 s	Product												
Number of measurement cycles	5	Inspector												
Flow rate	30 ml/min	Method	Baerum_AS_LIX_0.8											
Measurement quantity	10 ml													
Flush vol. before meas. series	10 ml													
Flush vol. single meas.	0 ml													
Date	03.05.2018	Time	15:16:37											
Sensor-ID	100231													
Measurement data														
	0.8 µm	1.0 µm	2.0 µm	5.0 µm	10.0 µm	15.0 µm	20.0 µm	25.0 µm	30.0 µm	35.0 µm	40.0 µm	45.0 µm	50.0 µm	200.0 µm
03.05.2018 15:16:47	5760	3025	3123	853	81	21	4	2	0	0	0	0	0	0
03.05.2018 15:16:12	5466	4733	2981	859	87	13	4	1	1	0	0	0	0	0
03.05.2018 15:16:37	5461	4636	2853	774	95	11	2	1	1	1	1	1	0	0
03.05.2018 15:17:02	5333	4634	2924	773	81	7	2	1	0	0	0	0	0	0
03.05.2018 15:17:26	5376	4621	2894	796	90	11	3	0	0	0	0	0	0	0

Topic	B	C	D	E	F
Topic	20211203_7B	Name	outletcarbonfite	per1ml	
Measurement duration	32 s	Comment			
Pause duration	1 s	Product			
Number of measurement cycles	35	Inspector			
Flow rate	30 ml/min	Method	Baerum_AS_LIX_0.8		
Measurement quantity	10 ml				
Flush vol. before meas. series	20 ml				
Flush vol. single meas.	0 ml				
Date	03.12.2021	Time	12:42:08		
Sensor-ID	100231				
Measurement data	distributive				

## Appendix 8 – Tune Parameters for *Shimadzu TOC-L*

To analyse the samples, the DOC analyser Shimadzu TOC-L, with sample exchanger ASI-L, was used with the software Shimadzu TOC-Control L (version 1.09).

The removal of inorganic carbon from the samples was carried out using a diluted orthophosphoric acid. 50 mL orthophosphoric acid (85% ACS Reagent grade) was diluted to 250 mL with MQ-water Elix3.

	Standards
Total Carbon	1000 mgC/L made from Reagent grade (VWR) Potassium hydrogen phthalate – diluted to a fitting standard solution
Inorganic Carbon	1000mg/L made from Reagent grade (VWR) sodium hydrogen carbonate (bicarbonate) and sodium carbonate
Control	10ppmC/L made from 1000ppmC/L KHP-solution (Teledyne Tekmar)
Gas	HiQ synthetic air (5.5)

## Appendix 9 – Safety Data Sheet for Coagulant, *BWT-Flock*

BWT-FLOCK - Versjon 7

Side 1 av 9

<b>SIKKERHETSATABLAD</b>		
	<b>BWT-FLOCK</b>	

Sikkerhetsdatabladet er i samsvar med Kommissjonsforordning (EU) 2015/830 av 28 mai 2015 om endring av europaparlaments- og rådsforordning (EF) nr. 1907/2006 om registrering, vurdering, godkjenning og begrensning av kjemikalier (REACH)

### AVSNITT 1: IDENTIFIKASJON AV STOFFET / STOFFBLANDINGEN OG AV SELSKAPET / FORETAKET

Utgitt dato	26.03.2008
Revisjonsdato	03.10.2020

#### 1.1. Produktidentifikator

Kjemikaliet navn	BWT-FLOCK
------------------	-----------

#### 1.2. Relevante identifiserte bruksområder for stoffet eller stoffblandingen og bruk som frarådes

Kjemikaliet bruksområde	Vannbehandling
-------------------------	----------------

#### 1.3. Opplysninger om leverandøren av sikkerhetsdatabladet

##### Distributør

Firmanavn	BWT BIRGER CHRISTENSEN AS
Besøksadresse	Solbråveien 61
Postadresse	Postboks 136
Postnr.	1386
Poststed	Asker
Land	Norway
Telefon	67 17 70 00
Telefaks	67 17 70 01
E-post	<a href="mailto:kad@bwtwater.no">kad@bwtwater.no</a>
Hjemmeside	<a href="http://www.bwtwater.no">www.bwtwater.no</a>
Org. nr.	911031329
Kontaktperson	Kjell Arne Dahl; e-post: <a href="mailto:kad@bwtwater.no">kad@bwtwater.no</a>

#### 1.4. Nødtelefonnummer

Nødtelefon	Telefon: 22 59 13 00 Beskrivelse: Giftinformasjonen
------------	--

Dette dokumentet er utarbeidet i Publisher (EcoOnline)

Revisjonsdato 03.10.2020

## AVSNITT 2: FAREIDENTIFIKASJON

### 2.1. Klassifisering av stoffet eller stoffblandingen

Klassifisering i henhold til CLP (EC) No 1272/2008 [CLP / GHS]      Eye Dam. 1; H318  
Met. Corr. 1; H290

### 2.2. Merkingselementer

#### Farepiktogrammer (CLP)



Sammensetning på merkeetiketten      aluminiumklorid 50 %

Varselord      Fare

Faresetninger      H290 Kan være etsende for metaller.  
H318 Gir alvorlig øyeskade.

Sikkerhetssetninger      P102 Oppbevares utilgjengelig for barn. P261 Unngå innånding av støv / røyk / gass / tåke / damp / aerosoler. P280 Benytt vernehansker / verneklær / øyevern / ansiktsvern. P302+P352 VED HUDKONTAKT: Vask med mye vann / . P361 Tilsølte klær må fjernes straks. P305+P351+P338 VED KONTAKT MED ØYNENE: Skyll forsiktig med vann i flere minutter. Fjern eventuelle kontaktlinser dersom dette enkelt lar seg gjøre. Fortsett skyllingen. P313 Søk legehjelp.

### 2.3. Andre farer

PBT / vPvB      Dette produktet er ikke selv og inneholder ikke en PBT eller vPvB.

## AVSNITT 3: SAMMENSETNING/OPPLYSNINGER OM BESTANDDELER

### 3.2. Stoffblandinger

Komponentnavn	Identifikasjon	Klassifisering	Innhold	Noter
aluminiumklorid	CAS-nr.: 1327-41-9 EC-nr.: 215-447-2	Eye Dam. 1; H318 Met. Corr. 1; H290	50 %	
Komponentkommentarer	Se avsnitt 16 for full tekst av klassifisering (1272/2008/EC)			

## AVSNITT 4: FØRSTEHJELPSTILTAK

### 4.1. Beskrivelse av førstehjelpstiltak

Innånding      Sørg for rikelig med frisk luft.

Hudkontakt      Fjern tilsølt tøy. Vask med såpe og vann.

Øyekontakt      Skyll straks med mye vann mens øyelokket løftes.  
Fortsett å skylle i minst 15 minutter. Kontakt lege.

Svelging      Skyll munnen godt. Drikk mye vann. Ikke fremkall brekning. Kontakt lege.



## 4.2. De viktigste symptomene og virkningene, både akutte og forsinkede

Generelle symptomer og virkninger Se avsnitt 11.

## 4.3. Angivelse av om umiddelbar legehjelp og spesialbehandling er nødvendig

Medisinsk behandling Symptomatisk behandling.

Annen informasjon Kontakt alltid lege ved ubehag, irritasjon eller andre vedvarende symptomer.

## AVSNITT 5: BRANNSLOKKINGSTILTAK

### 5.1. Slökkingsmidler

Egnede slökkingsmidler Eget middel med hensyn til omgivende brann.

### 5.2. Særlige farer knyttet til stoffet eller stoffblandingen

Brann- og eksplosjonsfarer Termisk dekomponering under dannelse av hydrogenklorid (HCl) som er en giftig/etsende gass.

### 5.3. Råd til brannmannskaper

Personlig verneutstyr Bruk friskluftsmaske ved slukningsarbeid.

Brannslökkingsmetoder Fjern produktet fra brannstedet hvis mulig uten risiko.  
Bruk vandusj for å kjøle beholdere og spre damper.

## AVSNITT 6: TILTAK VED UTILSIKTEDE UTSLIPP

### 6.1. Personlige forsiktighetsregler, personlig verneutstyr og nødrutiner

Generelle tiltak Håndtering i henhold til avsnitt 7.

Verneutstyr Bruk verneutstyr som beskrevet i avsnitt 8.

For innsatspersonell Bruk verneutstyr som beskrevet i avsnitt 8.  
Se også avsnitt 5 ved brann.

### 6.2. Forsiktighetsregler med hensyn til miljø

Sikkerhetstiltak for å beskytte ytre miljø Forhindre utslipp til avløp. Forhindre spredning ved utslipp til gater/mark.  
Ved utslipp til vannkilde må impliserte brukere og offentlig myndighet varsles.

### 6.3. Metoder og materialer for oppsamling og rensing

Opprydding Samle opp med egnet absorpsjonsmiddel. Spyl med mye vann.

### 6.4. Henvisning til andre avsnitt

Andre anvisninger For videre behandling se avsnitt 13.

## AVSNITT 7: HÅNTERING OG LAGRING

### 7.1. Forsiktighetsregler for sikker håndtering

Håndtering Unngå kontakt med huden og øynene.

## 7.2. Vilkår for sikker lagring, herunder eventuelle uforenligheter

Oppbevaring Oppbevares kjølig men frostfritt i lukket original emballasje.

## 7.3. Særlig(e) sluttanvendelse(r)

Spesielle bruksområder Vannbehandling

## AVSNITT 8: EKSPONERINGSKONTROLL / PERSONLIG VERNEUTSTYR

### 8.1. Kontrollparametrer

### 8.2. Eksponeringskontroll

#### Varselsskilt



#### Forholdsregler for å hindre eksponering

Egnede tekniske tiltak Sørg for tilgang til øyeskyllestyr.

#### Øye- / ansiktsvern

Egnet øyebeskyttelse Vernebriller/ansiktsskjerm.  
Øyevernustyr Beskrivelse: Bruk tettsittende vernebriller.  
Referanser til relevante standarder: EN 166

#### Håndvern

Egnede hansker Vernehansker  
Egnede materialer Neopren, nitril, polyetylen, eller PVC.  
Håndvernutsstyr Referanser til relevante standarder: EN 374

#### Hudvern

Anbefalte verneklær Referanser til relevante standarder: EN 20345  
Hudbeskyttelse, kommentar Bruk hensiktsmessige verneklær hvis hudkontakt er sannsynlig.

#### Åndedrettsvern

Åndedrettsvern, kommentarer Ikke nødvendig ved forskriftsmessig bruk.

## AVSNITT 9: FYSISKE OG KJEMISKE EGENSKAPER

### 9.1. Opplysninger om grunnleggende fysiske og kjemiske egenskaper

Tilstandsform Fargeløs væske

Lukt	Ingen
pH	Status: I løsnings Verdi: < 2 Temperatur: 20 °C
Frysepunkt	Verdi: ~ 0 °C
Kokepunkt / kokepunktintervall	Verdi: ~ 100 °C
Damptrykk	Verdi: 23 hPa Temperatur: 20 °C
Relativ tetthet	Verdi: ~ 1,3 g/cm <sup>3</sup>
Løslighet	Medium: Vann Kommentarer: Løselig

## 9.2. Andre opplysninger

### Andre fysiske og kjemiske egenskaper

Kommentarer	Dette sikkerhetsdatabladet inneholder kun informasjon som dekker sikkerhet og erstatter ikke produktinformasjon eller produktspesifikasjon.
-------------	---

## AVSNITT 10: STABILITET OG REAKTIVITET

### 10.1. Reaktivitet

Reaktivitet	Ingen reaktivitet er kjent.
-------------	-----------------------------

### 10.2. Kjemisk stabilitet

Stabilitet	Stabil ved normale håndterings- og lagringsbetingelser.
------------	---

### 10.3. Risiko for farlige reaksjoner

Risiko for farlige reaksjoner	Termisk dekomponering under dannelse av hydrogenklorid (HCl) som er en giftig/etsende gass.
-------------------------------	---

### 10.4. Forhold som skal unngås

Forhold som skal unngås	Høye temperaturer.
-------------------------	--------------------

### 10.5. Uforenlige materialer

Materialer som skal unngås	Sterke baser, sterke oksidasjonsmidler, organiske nitrogenforbindelser.
----------------------------	---

### 10.6. Farlige nedbrytningsprodukter

Farlige spaltningsprodukter	Ingen spesiell informasjon
-----------------------------	----------------------------

### Annen informasjon

Annen informasjon	Ved brann: Se avsnitt 5
-------------------	-------------------------

## AVSNITT 11: TOKSIKOLOGISKE OPPLYSNINGER

### 11.1. Opplysninger om toksikologiske virkninger

Komponent	aluminiumklorid
Akutt giftighet	<b>Type toksisitet:</b> Akutt <b>Testet effekt:</b> LD50 <b>Eksponeringsvei:</b> Oral <b>Verdi:</b> 3450 mg/kg <b>Forsøksdyreart:</b> rotte
	<b>Type toksisitet:</b> Akutt <b>Testet effekt:</b> LD50 <b>Eksponeringsvei:</b> Dermal <b>Verdi:</b> > 2000 mg/kg <b>Forsøksdyreart:</b> kanin

### Øvrige helsefareopplysninger

Innånding	Damp/sprøytetåke kan virke irriterende på slimhinnene i svelg og luftveier.
Hudkontakt	Kan irritere huden ved hyppig eller langvarig eksponering.
Øyekontakt	Sterkt irriterende. Permanent øyeskade kan ikke utelukkes.
Svelging	Kan gi irritasjon på slimhinner i munn, svelg og mage- tarmsystem. Kontakt lege hvis større mengder er svelget.

## AVSNITT 12: ØKOLOGISKE OPPLYSNINGER

### 12.1. Giftighet

### 12.2. Persistens og nedbrytbarhet

Beskrivelse / vurdering av persistens og nedbrytbarhet	Ingen spesielle opplysninger.
--	-------------------------------

### 12.3. Bioakkumuleringsevne

Bioakkumulering, kommentarer	Ingen spesielle opplysninger.
------------------------------	-------------------------------

### 12.4. Mobilitet i jord

Mobilitet, kommentarer	Ingen spesielle opplysninger.
------------------------	-------------------------------

### 12.5. Resultater av PBT- og vPvB-vurdering

Resultat av vurderinger av PBT og vPvB	Dette produktet er ikke selv og inneholder ikke en PBT eller vPvB.
--	--

### 12.6. Andre skadevirkninger

Økologisk tilleggsinformasjon	Ingen flere opplysninger tilgjengelig.
-------------------------------	--

## AVSNITT 13: SLUTTBEHANDLING

### 13.1. Avfallsbehandlingsmetoder

Egnede metoder til fjerning av kjemikaliet	Behandles som farlig avfall.
Avfallskode EAL	Avfallskode EAL: 06 03 04 Klassifisert som farlig avfall: Ja
Nasjonal avfallsgruppe	Avtal avfallsdisponering med kommuneing./miljøsjef/Miljødirektoratet. Konf. forskriftene vedrørende avfallsgruppe. Se avfallsforskriften av 02.02.09.
Annen informasjon	Avfallstoffnummer: 7091

## AVSNITT 14: TRANSPORTOPPLYSNINGER

Farlig gods Ja

### 14.1. FN-nummer

ADR/RID/ADN	2581
IMDG	2581
ICAO/IATA	2581
Kommentarer	Se transportuhellskort/skriftelige instruksjoner. (www.DSB.no).

### 14.2. FN-forsendelsesnavn

Teknisk betegnelse/farlig utslippstoff engelsk ADR/RID/ADN	Aluminiumchloride Solution
ADR/RID/ADN	ALUMINIUMKLORID LØSNING
IMDG	ALUMINIUM CHLORIDE SOLUTION
ICAO/IATA	ALUMINIUM CHLORIDE SOLUTION

### 14.3. Transportfareklasse(r)

ADR/RID/ADN	8
Klassifiseringskode ADR/RID/ADN	8
IMDG	8
ICAO/IATA	8

### 14.4. Emballasjegruppe

ADR/RID/ADN	III
IMDG	III
ICAO/IATA	III

### 14.5. Miljøfarer

ADR/RID/ADN	Se seksjon 12
-------------	---------------

### 14.6. Særlige forsiktighetsregler ved bruk

Spesielle forholdsregler Se avsnitt 10/11

## 14.7. Maritim transport i bulk i henhold til IMO-instrumenter

### ADR/RID Annen informasjon

Tunnelbegrensningskode	E
Begrenset kvantum	5 L
Farenr.	80

### IMDG Annen informasjon

EmS F-A, S-B

## AVSNITT 15: OPPLYSNINGER OM REGELVERK

### 15.1. Særlige bestemmelser/særskilt lovgivning om sikkerhet, helse og miljø for stoffet eller stoffblandingen

#### Referanser (Lover/Forskrifter)

Europaparlaments- og rådsforordning (EF) nr. 1907/2006 om registrering, vurdering, godkjenning og begrensning av kjemikalier (REACH).  
Kommissjonsforordning (EU) 2015/830 av 28 mai 2015 om endring av europaparlaments- og rådsforordning (EF) nr. 1907/2006 om registrering, vurdering, godkjenning og begrensning av kjemikalier (REACH).  
Europa-parlamentets og rådets forordning (EF) Nr. 1272/2008 Forskrift om klassifisering, merking og emballering av stoffer og stoffblandinger (CLP-forskriften). Sist endret 24.09.2018.  
Forskrift om tiltaksverdier og grenseverdier for fysiske og kjemiske faktorer i arbeidsmiljøet samt smitterisikogrupper for biologiske faktorer. Sist endret ved forskrift 20. desember 2018.  
Avfallsforskriften. Sist endret 20. desember 2018.  
Prioritetsliste/Godkjenningsliste.  
Produsent/importør.  
ECHA (European Chemicals Agency) C&L Inventory database.  
ADR/RID 2019 – Forskrift om endring i forskrift om landtransport av farlig gods.

### 15.2. Vurdering av kjemikaliesikkerhet

Kjemikaliesikkerhetsvurdering	Informasjonen i dette sikkerhetsdatabladet skal ikke betraktes som brukerens egen risikovurdering. Det er alltid brukerens ansvar at alle nødvendige forholdsregler er fulgt for å oppfylle kravene i henhold til lokale regler og bestemmelser.
Ytterligere regulatorisk informasjon	Opplysningene støtter seg til dagens kjennskaper og erfaringer. Sikkerhetsdatabladet beskriver produkter med henblikk på sikkerhetskrav.

## AVSNITT 16: ANDRE OPPLYSNINGER

Leverandørens anmerkninger Annen informasjon vedrørende avsnitt 11 og 12:  
LD50 dødelig dose, 50% drept

Liste over relevante H-setninger (i avsnitt 2 og 3).

H290 Kan være etsende for metaller.  
H318 Gir alvorlig øyeskade.

Ytterligere informasjon

Databladet er laget etter vår nåværende kunnskap, norsk regelverk og produsentens opplysninger. Da brukerens arbeidsforhold ligger utenfor vår kontroll, vil det være brukerens ansvar at de nødvendige forholdsregler blir tatt. Det er den enkelte mottakers plikt å sørge for at informasjon gitt i dette sikkerhetsdatablad blir lest og forstått av alle som bruker, behandler, avhender eller på noen måte kommer i kontakt med produktet. Dette produktet skal bare brukes til det formål det er beregnet for og i henhold til spesifiserte instruksjoner. Opplysningene gjelder kun for det materialet som er angitt her, og gjelder ikke i forbindelse med bruk av noe annet materiale eller i noen form for bearbeidelse.

Versjon

7

## Appendix 10 – Operating Manual, *Kemira Flocculator 2000*

Operating Manual | Flocculator 2000 **kemira**





<b>INDEX</b>	<b>5</b>
<b>FOREWORD</b>	<b>5</b>
<b>1 GENERAL DESCRIPTION</b>	<b>5</b>
<b>2 FLOCCULATOR 2000 - CONTROL UNIT</b>	<b>5</b>
2.1 Start	6
2.2 Time settings - flocculation menu	6
2.3 Adjusting rotation speed - the RPM menu	7
2.4 Saving programs - programming - save program	8
2.5 Loading a saved flocculation program - programming - load program	9
2.6 Conducting flocculation tests	10
2.7 pH Measurement	10
2.8 Calibration	11
2.9 Measuring pH	11
2.10 Autotest	12
<b>3 TECHNICAL DATA</b>	<b>12</b>
3.1 Control unit	12
3.2 Power supply	12
3.3 Agitators	12
3.4 Glass beakers	12
3.5 Transport/storage box	12
<b>4 CONTACT DATA</b>	<b>12</b>
<b>APPENDIX 1 REVISIONS IN OPERATING MANUAL</b>	<b>13</b>

## Foreword

*Congratulations on your choice of Flocculator 2000. You now have access to a highly advanced aid in rendering evaluations of flocculation tests in a more effective laboratory environment.*

*We recommend that you read through these instructions to be familiar with all functions. This manual will provide you with all the information you need to use the equipment properly, and give you thorough knowledge of its versatility in a whole range of different areas of application.*

## 1 General description

Flocculator 2000 has been designed for flocculation tests under laboratory conditions, and aims to simulate the stages of the process more effectively.

Six agitators can be connected to each control unit, and each agitator can be controlled individually. Flocculator 2000 is fitted with timers and speed controls which allow precise setting of mixing speed, irrespective of whether the beaker contains viscous sludge or drinking water.

Two pH electrodes can also be fitted to the control unit.

## 2 Flocculator 2000 - control unit

### 2.1 Start

Connect the enclosed mains unit to the wall socket. Then connect the control unit by connecting the power cable to the socket marked "DC IN 18V" on the rear of the control unit. Agitators should be connected to the sockets on the front of the control unit.

As a preliminary check, rotate all connected agitators at high speed for approx. 2 seconds. The following message should then appear in the display for a few seconds:

KEMIRA  
FLOCCULATOR 2000  
VER. 4.B DI # 02546  
MARCH 21 1996

The following message will then appear in the display in "MAIN MENU":

→ PROGRAMMING  
FLOCCULATION  
RPM MENU  
pH/REMOTE CTRL

## 2.2 Time settings - flocculation menu

- Press ENTER.

The time settings menu for the standard program will now appear:

Flocculator 2000	
M FAST	30 30 30 30 30 30
O SLOW	→ 10 10 10 10 10 10
D SED	10 10 10 10 10 10
E FAST 2	00 00 00 00 00 00

### Clarifications:

*FAST: Fast stirring, 0-60 seconds*  
*SLOW: Slow stirring, 0-60 minutes*  
*SED: Sedimentation, 0-60 minutes*  
*FAST 2: Fast stirring 2, 0-60 seconds*

The values can be altered by using the plus or minus buttons under "SETTINGS". Holding the buttons down for more than approx. 3 seconds will increase/decrease values automatically until pressure is released.

The cursor (arrow) in the display window indicates the channel and parameter to be altered. The cursor can be moved horizontally using the MIXER button and vertically using the MODE button.

Please note that all set values - i.e. both stir-rate and flocculation time - can also be changed while in operation. The value "00" indicates that the program will skip this stage. "oo" indicates that this program stage will run until the mixer is stopped by pressing "MIXER ON/OFF".

## 2.3 Adjusting rotation speed - the RPM menu

The agitators can be individually set at different rotation speeds.

Instructions:

- Go to "MAIN MENU" by pressing MAIN MENU
- Press the MODE button until "RPM MENU" appears
- Press ENTER

Flocculator 2000	
M FAST	R 40 40 40 40 40 40
O SLOW	P → 50 50 50 50 50 50
D SED	M
E FAST 2	40 40 40 40 40 40

### Clarifications:

*Fast stirring, rotation x 10 (100-400 RPM)*  
*Slow stirring, rotation (10-99 RPM)*  
*Fast stirring 2, rotation x 10 (100-400 RPM)*

The values can be altered by using the plus or minus buttons under "SETTINGS". Holding the buttons down for more than approx. 3 seconds will increase/decrease values automatically until pressure is released.

The cursor (arrow) in the display window indicates the channel and parameter to be altered.

The cursor can be moved horizontally using the MIXER button and vertically using the MODE button.

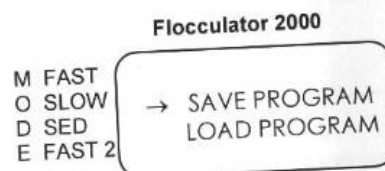
## 2.4 Saving programs - programming - save program

Pre-set standard programs are automatically installed when the control unit is started up.

Up to three special programmes can be saved in the control unit for later use. Set the required times and rotation speeds.

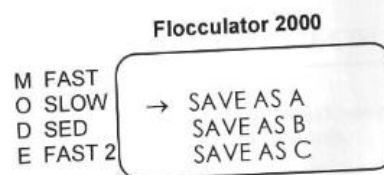
Instructions:

- Press the MAIN MENU button
- Press the MODE button until "PROGRAMMING" appears
- Press ENTER
- Select "SAVE PROGRAM"



- Press ENTER
- Save the program as "A", "B" or "C" by using the arrow to select

The window will display the following message:



- Press ENTER

The program has now been saved and will remain stored in the memory even when the power supply is switched off. The standard program is always installed at first start-up (when the power is connected).

## 2.5 Loading a saved flocculation program - programming - load program

- Go to "MAIN MENU" and press the MODE button until "PROGRAMMING" appears
- Press ENTER
- Press the MODE button

The window will display the following information:

**Flocculator 2000**

M FAST	→	SAVE PROGRAM
O SLOW		LOAD PROGRAM
D SED		
E FAST 2		

- Press ENTER

The window will display the following information:

**Flocculator 2000**

M FAST	→	LOAD STANDARD
O SLOW		LOAD A
D SED		LOAD B
E FAST 2		LOAD C

- Select the program you wish to load using the MODE button.
- Press ENTER

The window will now display the "MAIN MENU".

→ PROGRAMMING  
FLOCCULATION  
RPM MENU  
pH/REMOTE CTRL

The selected program has now been loaded and Flocculator 2000 is ready to be used for evaluating flocculation tests.

## 2.5 Loading a saved flocculation program - programming - load program

- Go to "MAIN MENU" and press the MODE button until "PROGRAMMING" appears
- Press ENTER
- Press the MODE button

The window will display the following information:

```
Flocculator 2000
M FAST
O SLOW
D SED
E FAST 2
→ SAVE PROGRAM
LOAD PROGRAM
```

- Press ENTER

The window will display the following information:

```
Flocculator 2000
M FAST
O SLOW
D SED
E FAST 2
→ LOAD STANDARD
LOAD A
LOAD B
LOAD C
```

- Select the program you wish to load using the MODE button.
- Press ENTER

The window will now display the "MAIN MENU".

```
PROGRAMMING
→ FLOCCULATION
RPM MENU
pH/REMOTE CTRL
```

The selected program has now been loaded and Flocculator 2000 is ready to be used for evaluating flocculation tests.

## 2.6 Conducting flocculation tests

- Press ENTER

The window will display the following (values may vary according to selected program):

**Flocculator 2000**

M FAST	→	35 35 35 35 35 35
O SLOW	→	10 10 10 10 10 10
D SED		15 15 15 15 15 15
E FAST 2		00 00 00 00 00 00

### Clarifications:

*Fast stirring (350 RPM, 10x35)*  
*Slow stirring (10 MIN)*  
*Sedimentation (15 MIN)*  
*Fast stirring 2 (this stage skipped)*

- Use the MIXER button to select which of the six mixers is to be used.
- Prepare dosing of flocculation agent. For maximum precision, use a micro-pipette, which allows dosage to be adjusted.
- Press MIXER ON/OFF

The selected mixer will now start, and elapsed time can be read from the display window. Dose the flocculation agent during the fast stirring phase.

Experience has shown us that dosing should be performed from the "600 ml" mark on the glass beaker to achieve optimum mixing. Place the end of the pipette at this level and dose by emptying the pipette several times, squeezing repeatedly to ensure no flocculation agent remains in the pipette. Select the next agitator/channel and repeat the procedure.

When flocculation is complete, a signal sounds and the relevant channel in the display window flashes with zeroes until confirmation is entered by pressing BUZZER OFF.

The mixers may be stopped at any time during the flocculation process by pressing the MIXER ON/OFF button.

**Flocculator 2000**

M FAST	→	35 35 00 35 35 35
O SLOW	→	10 10 00 10 10 10
D SED		15 15 00 15 15 15
E FAST 2		00 00 00 00 00 00

### Clarification:

*The third channel is complete, and flashes while a signal sounds.*

## 2.7 pH Measurement

Two pH electrodes can be attached to the control unit, for simultaneous measurement in e.g. two beakers during flocculation.

The accuracy of the pH measurement depends on the condition of the electrode, and the fact that calibration has been carried out correctly using fresh buffer solutions. Calibration is based on a temperature of 20°C (68°F). The value is presented in decimal format. We recommend using an electrode intended for ion-weak media and also buffer solutions for similar electrodes. Avoid strong radiation or magnetic fields.

The pH electrodes are connected to the rear of the control unit (PROBE A and PROBE B respectively) which is fitted with a BNC connector for the pH cable. Connect the pH electrode.

## 2.8 Calibration

Calibration is carried out using two buffer solutions (two-point calibration) of pH 7.0 and 4.0 respectively.

Instructions:

- Go to "MAIN MENU"
- Press the MODE button until "pH/REMOTE CTRL" appears
- Press ENTER
- Press ENTER again

The window will display the following:

```
Flocculator 2000
M FAST  pH A = 6.7
O SLOW  pH B OUT OF RANGE
D SED   MODE=NEW CAL. CH A
E FAST 2 ENTER=NEW CAL. CH B
```

### Clarifications:

The pH electrode is connected to the "PROBE A" socket. No electrode is connected to "PROBE B".

- Press MODE if the pH electrode connected to the PROBE A socket is to be calibrated
- Press ENTER if the pH electrode connected to the PROBE B socket is to be calibrated

The following example explains the calibration of a pH electrode connected to the PROBE A socket.

The window will display the following information:

```
Flocculator 2000
M FAST  PUT PROBE A
O SLOW  IN pH 7.0
D SED   AND PRESS ENTER
E FAST 2
```



- Rinse the electrode with de-ionised water and put it into the pH 7.0 buffer solution. Stir it carefully around in the solution.
- Press ENTER. After approx. 30 seconds a signal is sounded and the display window indicates that the buffer solution should be changed to the pH 4.0 buffer:

#### Flocculator 2000

M FAST O SLOW D SED E FAST 2	PUT PROBE A IN pH 4.0 AND PRESS ENTER
---------------------------------------	---

- Rinse the electrode with deionised water and put it into the pH 4.0 buffer solution. Stir it carefully around in the solution.
- Press ENTER. After approx. 30 seconds a signal is sounded and the window displays the following message:

#### Flocculator 2000

M FAST O SLOW D SED E FAST 2	CALIBRATION READY PRESS ENTER TO ACCEPT
---------------------------------------	--

Press ENTER to accept calibration. The control unit returns to "CALIBRATION MENU".

If MAIN MENU is pressed, calibration is interrupted and the control unit returns to "MAIN MENU" without calibrating the electrode.

## 2.9 Measuring pH

Instructions for measuring pH:

- Press the MODE button until "pH/REMOTE CTRL" appears under "MAIN MENU"
- Press ENTER
- Press ENTER again

The pH value can now be read in the display window. Other menus can be accessed by returning to "MAIN MENU" while the test is in progress. The pre-set values can be altered even while the relevant channel is in action.

## 2.10 Autotest

Holding the Enter button down for 5 seconds initiates an autotest sequence which tests the agitators.

### 3 Technical data

#### 3.1 Control unit

- Six separate channels each with four timer functions and adjustable speed
- Sockets for two pH electrodes
- RS2032 socket - potential to control Flocculator 2000 via computer
- Splash-proof design
- Dimensions: L 190 x W 130 x H 50 mm
- Weight: 575 grams

#### 3.2 Power supply

- Mains unit 100-240 V, 50/60 Hz, 0.3 A
- Output: 18 V, 1.5 A

#### 3.3 Agitators

- Six, made of injection-moulded thermoplastic, specially made to fit 1-litre glass beakers of tall model
- Tachometer-controlled electric motor with gears, enabling constant rotation speed regardless of solution viscosity (e.g. sludge or drinking water)
- Holes for dosing, pH electrode and sampling

#### 3.4 Glass beakers

- Six 1-litre glass beakers, tall form

#### 3.5 Transport/storage box

- The box has been specially made to accommodate the control unit, six agitators and glass beakers, as well as with extra room for micro-pipettes and other accessories
- Dimensions: L 600 x W 400 x H 350 mm
- Total weight: 12 kg

### 4 Contact data

If you have any questions please contact:  
e-mail: [flocculator@kemira.com](mailto:flocculator@kemira.com)  
[www.kemira.com](http://www.kemira.com)

## Appendix 1 Revisions in Operating Manual

Date	Revision	Page
2003-01-xx	First English version	
2009-10-05	Taken out info about computer program	4-12
	Tech data; Power supply 100-240 V, Removed light fitting accessory	12
	Updated contact data	12



## Appendix 11 – Sample information

Table 2.1 presents sample information for all samples measured. Independent parameters, such as terms of analysis from extern laboratories are inscribed in blue. For ICP-MS a total concentration of 0.1M HNO<sub>3</sub> was required due to background equivalent concentration. Hence, the laboratory personal required 3 drops of HNO<sub>3</sub> (65%) to 15mL. According to the required pH value of 7.3, the samples with jar test was pH adjusted with acid or base. HNO<sub>3</sub> (0.01M) or NaOH (0.1M) were used based on the alkalinity of the sample. For DOC analysis a pH value of 2 was required due the analysis program. All samples are either acidified-filtrated (AF), or filtrated-acidified (FA). Dependent parameters such as location and date in addition to the choice of filter is inscribed in orange. Jar test settings is also inscribed as a dependent parameter. Addition of activated carbon to the DOC samples are either CarboTech GAC DGK 8x30/60 (shortened DGK in the table) or CarboTech Pool W1-3 (shortened w 1-3 in the table). Information of mass activated carbon added, and results of DOC and SAC<sub>254</sub> measured is presented in the tables.

Table 2. 1 Sample information of all samples.

Sample number	Content	ICP-MS [15mL]						Total Organic Carbon analyzer (Shimadzu TOC-L) [50mL]		
		Measure requirements ICP-MS: 3 drops HNO <sub>3</sub> (65%) ~ 0.1M						Measure requirements DOC: 3 drops HCl (37%), pH ~ 2. All samples FA		
		FA/ AF	pH adjustment, pH ~ 7.3	Element concentration [mg/L]				Mass PAC added [mg]	DOC measured [mg/L]	SAC measured [1/cm] (Abs. pr 5cm)
	Al	Na		Ca	Cl					
Oslo, 21.02.2022 at 14:30   No tests for Jar/PAC										
Polyethersulfone filter (0.2 µm)										
1	Fill up water	AF		0.2	12	26	20			
2	Pool water	AF		0.3	403	29	530			
3	Outlet Balance Tank	AF		0.3	399	29	535			
4	Inlet AG-filter	AF		0.3	398	29	533			
5	Outlet AG- filter	AF		0.2	400	29	526			
6	Fill up water	FA		0.2	11	26	20		5.0960	0.4726
7	Pool water	FA		0.3	398	29	529		4.6790	0.1032
8	Outlet Balance Tank	FA		0.3	395	29	520		4.6350	0.1032
9	Inlet AG-filter	FA		0.2	394	29	517		4.6470	0.1062
10	Outlet AG- filter	FA		0.2	397	29	517		5.3500	0.1187
Trondheim, 06.03.2022										
Polyethersulfone filter (0.2 µm)										
Jar-test settings Fast: 60 rev/min – 30 sec   Slow: 20 rev/min – 30 min Sedimentation time > 1 hour										
11	Drinking water Jar, 0 mg/L	FA	HNO <sub>3</sub> (0.01M)	0.2	19	103	27			
12	Drinking water Jar, 2 mg/L	FA	HNO <sub>3</sub> (0.01M)	24.7	4	19	8			
13	Drinking water Jar, 4 mg/L	FA	HNO <sub>3</sub> (0.01M)	39.9/103.8	8/20	36/93	18/45			
14	Drinking water Jar, 6 mg/L	FA	HNO <sub>3</sub> (0.01M)	83.1	19	91	51			
15	Drinking water Jar, 8 mg/L	FA	HNO <sub>3</sub> (0.01M)	72.2	19	89	59			
16	Diluted HNO <sub>3</sub> , 1	-								
17	Diluted HNO <sub>3</sub> , 2	-								
18	Deionized water	-								
Trondheim, 04.03.2022										
Polyethersulfone filter (0.2 µm)										
Activated Carbon Shaking, 48 hours										
19	Drinking water blank 1	FA						-	3.5960	0.4509
20	Drinking water blank 2	FA						-	3.6100	0.4522
21	Drinking water blank 3	FA						-	3.2310	0.4346
22	Drinking water 1.2 mg, w 1-3	FA						1.4	3.0200	0.3729
23	Drinking water 4 mg, w 1-3	FA						3.5	2.3430	0.266
24	Drinking water 10 mg, w 1-3	FA						10.9	1.7150	0.1432
25	Drinking water 30 mg, w 1-3	FA						31.2	1.1640	0.0680
26	Drinking water 70 mg, w 1-3	FA						72.6	0.6055	0.0244
27	Drinking water 150 mg, w 1-3	FA						145.4	0.4612	0.0197
28	Drinking water 1.2 mg, DGK	FA						1.4	3.9880	0.4319
29	Drinking water 4 mg, DGK	FA						4.6	3.3690	0.3909
30	Drinking water 10 mg, DGK	FA						10.2	3.7160	0.3580
31	Drinking water 30 mg, DGK	FA						30.6	2.4720	0.2563
32	Drinking water 70 mg, DGK	FA						70.0	1.4620	0.1384
33	Drinking water 150 mg, DGK	FA						150.0	1.0730	0.0648

Sample number	Content	ICP-MS [15mL]						Shimadzu TOC-L [50mL]		
		Measure requirements ICP-MS: 3 drops HNO <sub>3</sub> (65%) ~ 0.1M						Measure requirements DOC: 3 drops HCl (37%), pH ~ 2. All samples FA		
		FA/ AF	pH adjustment, pH ~ 7.3	Element concentration [mg/L]				Mass PAC added [mg]	DOC measured [mg/L]	SAC measured [1/cm] (Abs. pr 5cm)
	Al	Na		Ca	Cl					
Oslo, 16.03.2022 at 13:10								Polycarbonate filter (0.4 µm)		
34	Fill up water	FA		0.3	11	26	18		3.600	0.467
35	Pool water	FA		0.3	443	29	589		4.995	0.027
36	Outlet Balance Tank	FA		0.3	442	29	601		4.587	0.025
37	Inlet AG-filter	FA		0.3	447	29	596		4.851	0.023
38	Outlet AG- filter	FA		0.3	448	29	602		4.674	0.023
39	Outlet UV	FA		0.3	445	30	603		4.958	0.029
40	Fill up water	AF		0.3	11	27	19			
41	Pool water	AF		0.3	446	29	590			
42	Outlet Balance Tank	AF		0.3	450	30	597			
43	Inlet AG-filter	AF		0.3	441	29	593			
44	Outlet AG- filter	AF		0.3	447	29	597			
45	Outlet UV	AF		0.3	440	30	588			
Oslo, 16.03.2022 at 13:10								Polycarbonate filter (0.4 µm)		
		Jar-test settings Fast: 400 rev/min – 30 sec   Slow: 40 rev/min – 20 min Sedimentation time > 30 min								
46	Fill up water Jar, 0 mg/L	FA	NaOH (0.1M)	0.2	12	27	20		3.819	
47	Fill up water Jar, 2 mg/L	FA	NaOH (0.1M)	0.9	12	26	25		2.268	
48	Fill up water Jar, 4 mg/L	FA	NaOH (0.1M)	7.1	13	25	30		2.426	
49	Fill up water Jar, 6 mg/L	FA	NaOH (0.1M)	17.5	14	25	36		2.325	
50	Fill up water Jar, 8 mg/L	FA	NaOH (0.1M)	17.6	14	24	42		2.487	
51	Pool water Jar, 0 mg/L	FA	NaOH (0.1M)	0.3	429	29	583		5.054	
52	Pool water Jar, 2 mg/L	FA	NaOH (0.1M)	0.8	428	29	573		4.623	
53	Pool water Jar, 4 mg/L	FA	NaOH (0.1M)	1.0	420	28	570		4.599	
54	Pool water Jar, 6 mg/L	FA	NaOH (0.1M)	5.6	406	27	567		4.462	
55	Pool water Jar, 8 mg/L	FA	NaOH (0.1M)	36.0	397	27	554		4.465	
Oslo, 16.03.2022 at 13:10								Polycarbonate filter (0.4 µm)		
								Activated Carbon Shaking, 24 hours		
56	Fill up water blank 1	FA							3.989	0.459
57	Fill up water blank 2	FA							3.749	0.468
58	Fill up water 1.2 mg, DGK	FA						1.3	3.748	0.442
59	Fill up water 4 mg, DGK	FA						4.8	3.225	0.430
60	Fill up water 10 mg, DGK	FA						10.4	3.298	0.380
61	Fill up water 30 mg, DGK	FA						29.8	2.672	0.288
62	Fill up water 70 mg, DGK	FA						70.9	1.818	0.154
63	Fill up water 150 mg, DGK	FA						149.9	1.1012	0.045
64	Pool water blank 1	FA							4.902	0.050
65	Pool water blank 2	FA							4.902	0.050
66	Pool water 1.2 mg, DGK	FA						1.5	4.572	0.040
67	Pool water 4 mg, DGK	FA						4.3	3.961	0.031
68	Pool water 10 mg, DGK	FA						10.3	3.713	0.021
69	Pool water 30 mg, DGK	FA						30.2	2.830	0.009
70	Pool water 70 mg, DGK	FA						69.7	2.691	0.004
71	Pool water 150 mg, DGK	FA						149.8	2.354	0.002

Sample number	Content	ICP-MS [15mL]						Total Organic Carbon analyzer (Shimadzu TOC-L) [50mL]		
		FA/ AF	pH adjustment, pH ~ 7.3	Measure requirements ICP-MS: 3 drops HNO <sub>3</sub> (65%) ~ 0.1M				Measure requirements DOC: 3 drops HCl (37%), pH ~ 2. All samples FA		
				Element concentration [mg/L]				Mass PAC added [mg]	DOC measured [mg/L]	SAC measured [1/cm] (Abs. pr 5cm)
		Al	Na	Ca	Cl					
Oslo, 25.03.2022 at 09:15   No tests for Jar/PAC]								Polycarbonate filter (0.4 µm)		
72	Fill up water	FA						2.870	0.466	
73	Pool water	FA						3.790	0.048	
74	Outlet Balance Tank	FA						3.892	0.046	
75	Inlet AG-filter	FA						3.737	0.046	
76	Outlet AG- filter	FA						3.697	0.046	
77	Outlet UV	FA						3.824	0.045	
Oslo, 25.03.2022 at 09:15								Polycarbonate filter (0.4 µm)		
		<b>Jar-test settings</b> Fast: 400 rev/min – 30 sec   Slow: 40 rev/min – 20 min Sedimentation time> 30 min								
78	Fill up water Jar, 0 mg/L	FA	NaOH (0.1M)	0.2	11	27	19/28	3.137		
79	Fill up water Jar, 2 mg/L	FA	NaOH (0.1M)	0.1	12	26	24	1.703		
80	Fill up water Jar, 4 mg/L	FA	NaOH (0.1M)	4.0	13	26	21	1.184		
81	Fill up water Jar, 6 mg/L	FA	NaOH (0.1M)	16.3	14	25	36	1.763		
82	Fill up water Jar, 8 mg/L	FA	NaOH (0.1M)	35.4	14	25	42	1.687		
83	Pool water Jar, 0 mg/L	FA	NaOH (0.1M)	0.4	434	29	605	3.865		
84	Pool water Jar, 2 mg/L	FA	NaOH (0.1M)	1.6	433	29	598	3.474		
85	Pool water Jar, 4 mg/L	FA	NaOH (0.1M)	2.8	425	28	587	3.467		
86	Pool water Jar, 6 mg/L	FA	NaOH (0.1M)	3.4	416	27	578	3.257		
87	Pool water Jar, 8 mg/L	FA	NaOH (0.1M)	2.3	406	27	570	3.392		
88	NaOH (0.1M)	-	-							
Oslo, 25.03.2022 at 09:15								Polycarbonate filter (0.4 µm)		
								Activated Carbon Shaking, 24 hours		
89	Fill up water blank 1	FA						2.870	0.466	
90	Fill up water blank 2	FA						2.870	0.466	
91	Fill up water 1.2 mg, DGK	FA						1.5	0.442	
92	Fill up water 4 mg, DGK	FA						3.9	0.424	
93	Fill up water 10 mg, DGK	FA						8.8	0.393	
94	Fill up water 30 mg, DGK	FA						31.1	0.285	
95	Fill up water 70 mg, DGK	FA						70.2	0.188	
96	Fill up water 150 mg, DGK	FA						150.1	0.168	
97	Fill up water 300mg, DGK	FA						300.1	0.021	
98	Pool water blank 1	FA						3.790	0.048	
99	Pool water blank 2	FA						4.697	0.048	
100	Pool water 1.2 mg, DGK	FA						1.6	0.038	
101	Pool water 4 mg, DGK	FA						4.0	0.030	
102	Pool water 10 mg, DGK	FA						10.2	0.020	
103	Pool water 30 mg, DGK	FA						30.9	0.007	
104	Pool water 70 mg, DGK	FA						68.4	0.003	
105	Pool water 150 mg, DGK	FA						149.5	0.003	
106	Pool water 300 mg, DGK	FA						300.2	0.002	





