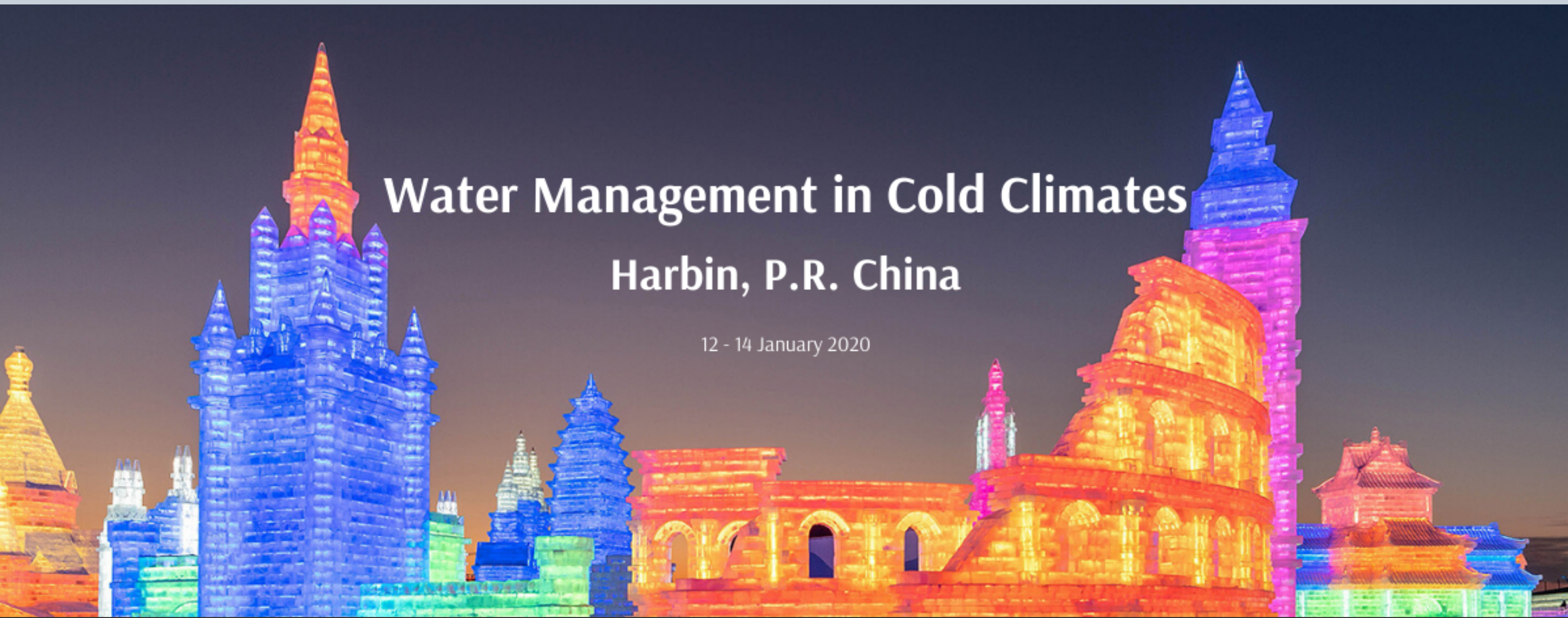
WMCC 2020
Water Management in
Cold Climate

EUROPEAN WATER ASSOCIATION

the international water association

12-14 January 2020, Harbin, P.R. China



Proceedings

WMCC 2020
Water Management in Cold Climates
Harbin, China

Conference Program

Venue 12th January 2020: Orange Crystal Hotel, No.1 Xuanyuan East Road, Harbin

Venue 13th and 14th January: State Key Laboratory of Urban Water Resource and Environment, Harbin Institute of Technology, 6th floor, No. 73, Huanghe Road, Nangang District, Harbin

Sunday 12th January 2020	
12:00-17:00	**Registration, Orange Crystal Hotel, No.1 Xuanyuan East Road, Harbin**
17:00-18:30	**Opening ceremony and reception, Orange Crystal hotel**
	Welcome address, Nanqi Ren, Vice president, Harbin Institute of Technology, China
	Address by the President of the European Water Association (EWA), Bjørn K Jensen, Denmark
	Address by the Executive Director of the International Water Association (IWA), Kala Vairavamoorthy, UK
18:30-20:30	Visit to the Harbin International Ice Sculpture festival
20:30	Dinner

Monday 13th January 2020 Venue: 6th floor, State Key Laboratory of Urban Water Resource and Environment, HiT	
08:30-09:10	**Inaugural session: Chair: Johannes Lohaus and Yifan Li**
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	Address from the EWA, Bjørn K Jensen, President, Denmark
	Address from the IWA, Kala Vairavamoorthy, Executive Director, UK/Netherlands
	Conference history and program, Harsha Ratnaweera, Co-Chair of the organising committee, Norway
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	Johannes Lohaus, General Secretary, EWA
	Kala Vairavamoorthy/Tao Li, IWA
	Yifang Li, HiT, Conference co-chair
19:00	**Dinner**


BJØRN KAARE JENSEN / JOHANNES LOHAUS
PRESIDENT / SECRETARY GENERAL, EUROPEAN WATER ASSOCIATION - EWA

The European Water Association warmly welcomes the initiative of the Harbin Institute of Technology to organise the 2nd conference on the water challenges in cold climates. Most of the water technologies are developed without considering the special needs of cold climate conditions which are faced by many regions in the world. Adopted solutions and further developments are definitely necessary. The water bodies in cold climate must be protected. Water has no boundaries and pollution must be avoided, wherever possible. This conference will bring experts together with a vast experience to exchange knowledge, presents solutions and ideas and elaborate on lessons learned in this field.

The fact that the EWA event will take place in a city with traditions to celebrate winter with a unique ice sculpture festival will make the WMCC-2020 a memorable one. I am glad to note that the conference is sponsored by the IWA, and our two associations have a history of collaboration through a Memorandum of Understanding signed in 2014.
Moreover, EWA invites its cooperation partners in the US, the Water Environment Federation (WEF) and the Japan Sewage Works Association (JWSA) in Japan to join this conference and to contribute with their experiences. We are looking forward to an inspiring conference in a unique water environment.

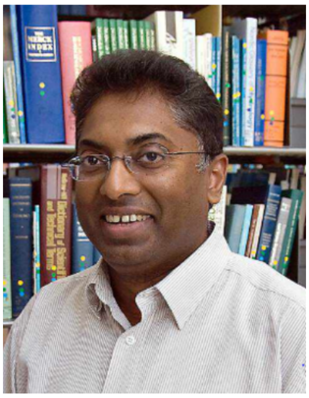
KALA VAIRAVAMOORTHY
EXECUTIVE DIRECTOR, INTERNATIONAL WATER ASSOCIATION - IWA

Drawing on 10,000 exceptional professionals from 130 countries, the membership of the International Water Association (IWA), brings together scientists, researchers, technology companies, and water and wastewater utilities, all working to address the world's most urgent water challenges. A good part of the IWA's membership lives in cold climate regions, with significant annual temperature differences. IWA considers the topic and the thematic priorities of the WMCC 2020 as very relevant and timely, and is very proud to be involved in such an important event. It is important that we reach out beyond narrow approaches to instead, build wide institutional bridges between silos, linking outcomes across sectors, and raising awareness and urgency in the political arena. Further, we need to combine leading-edge scientific breakthroughs, technological developments and creative mindsets from the laboratory with the best water management practices in the field. Hence, the WMCC 2020 is a very important event, in that it provides an excellent platform for researchers and practitioners to share experiences, recognise new and innovative solutions, and generate professional content and programming, that is relevant and widely valued by the international water sector, particularly for those in cold climates.

In 2019, IWA established it a global office in Nanjing, China and is therefore happy to see the WMCC 2020 in China. We especially welcome holding the WMCC 2020 in Harbin, China, a city which represents both the beauty and the harshness that cold climates create. I would like to thank the EWA and the Harbin Institute of Technology, both with whom IWA has a long record of collaboration, for all their efforts in preparing for such an important water event. I wish the conference and the participants great success and hope it will strengthen the potential to be a regular biennial conference which brings IWA, EWA and water professionals closer together.

NANQI REN
VICE PRESIDENT, HARBIN INSTITUTE OF TECHNOOGY, P.R. CHINA
CO - CHAIRMAN OF THE SCIENTIFIC COMMITTEE

Harbin Institute of Technology (HIT) has been a pioneer in basic and applied water research in China for several decades. HIT leads several initiatives focusing on the arctic environment and education, thus it is very appropriate for us to host this very important and relevant conference. We appreciate the trust endowed on us by the two leading water organisations – the European Water Association and the International Water Association. HIT has a long tradition in international joint research and industrial collaborations. We look forward to welcome our collaborators and their partners and students, both from China and abroad, to this unique event.



HARSHA RATNAWEERA
PROFESSOR, NORWEGIAN UNIVERSITY OF LIFE SCIENCES, NORWAY
CO-CHAIRMAN OF THE SCIENTIFIC COMMITTEE

Welcome to Harbin for the 2nd EWA conference on Water management in cold climates (WMCC); a forum where water professionals from colder climates will share their challenges and solutions for the second time, following the great success of Spitsbergen, Norway in 2016. The conference will provide a forum to have a fruitful dialogue among engaged water researchers, suppliers and utility personnel on this important theme, which could be the start of a regular forum. The WMCC conference will be held in a city experiencing extreme cold during winters, hosted by Harbin Institute of Technology. The conference will be held during the renowned ice festival in Harbin, giving the participants a unique experience. We look forward to welcome you in Harbin.

YIFAN LI
PROFESSOR, HARBIN INSTITUTE OF TECHNOLOGY, P.R. CHINA
CO-CHAIRMAN OF THE ORGANIZING COMMITTEE

It is my great honor to welcome you to the second international conference on water management in cold climates, hosted by my university – Harbin Institute of Technology, in the famous city – Harbin, where the city's unique beautifulness is even more enhanced each January when the unique ice sculpture festival takes place. The WMCC 2020 focuses on important aspects of water pollution surveillance and control, which is also the focus of the UArctic-HIT Training Centre and Polar Academy of HIT. The International Arctic School-Winter2020 of HIT will be held back-to-back with the WMCC 2020 conference, providing many participants an opportunity to be involved in both activities. I warmly welcome all water researchers and practitioners to Harbin.

Abstract

Water Bodies in Europe - conditions, trends and prospects

Dipl.- Ing. Johannes Lohaus, Secretary General, European Water Association (EWA)
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Abstract

The European Water Association (EWA) is the pan-European, non-governmental, non-profit making technical and scientific umbrella organisation of and for water in Europe. Since the EU- Water Framework Directive (WFD) has been in force, EWA is observing the development of the water bodies in Europe and consulting the DG Environment of the European Commission regarding the implementation of the WFD by having a guest status of the Strategic Coordination Group hosted by the DG Environment. The EWA is the platform and turntable for discussion, exchange and transfer of information and know how in the European water landscape which results in Water Manifestos and Position Papers on water topics. More information can be found on the website: (http://www.ewa-online.eu/home.html).

The main target of the WFD is to achieve a good status or a good ecological potential in all European water bodies. The WFD is based on the following five main pillars [1]:

- Coordinating action to achieve ‘good status’ for all EU waters (surface and ground waters), plus non-deterioration clause;
- Setting up a water-management system based on natural river basin districts, crossing regional and national boundaries;
- Applying Integrated water management by bringing different water management issues into one framework;
- Actively involving interested parties and consultation of the public;
- Assessing the costs for water-related services reflecting the principle of cost recovery, thus supporting the environmental objective of good status.

In 2018, the European Environment Agency published the EEA Report No 7/2018 “European waters – assessment of status and pressures 2018” [2]. Table 1.1 of this report gives an overview about the European water bodies.

Table 1.1 Number of Member States, RBDs, water bodies, and length or area, per water category

Category	Member States	Number of water bodies	Total length or area	Average length/area
Groundwater	25	13 411	4.3 million km²	323 km²
Rivers	25	89 234	1.2 million km	13.1 km
Lakes	23	18 165	81 800 km²	4.5 km²
Transitional waters	14	782	14 600 km²	19 km²
Coastal waters	20	2 835	290 000 km²	102 km²
Territorial waters	7	46	214 000 km²	13 400 km²

Source: Results are based on the WISE-SoW database including data from 25 Member States (the 28 EU Member States (EU-28 except Greece, Ireland and Lithuania)). Groundwater bodies: Number and Size and Surface water bodies: Number and Size.

Figure 2.3 of this report will summarise the results regarding the ecological status/potential of rivers, lakes, transitional and coastal water as described in the second River Basin Management Plans.

Figure 2.3 **Ecological status/potential of rivers, lakes, transitional and coastal waters in the second RBMPs**

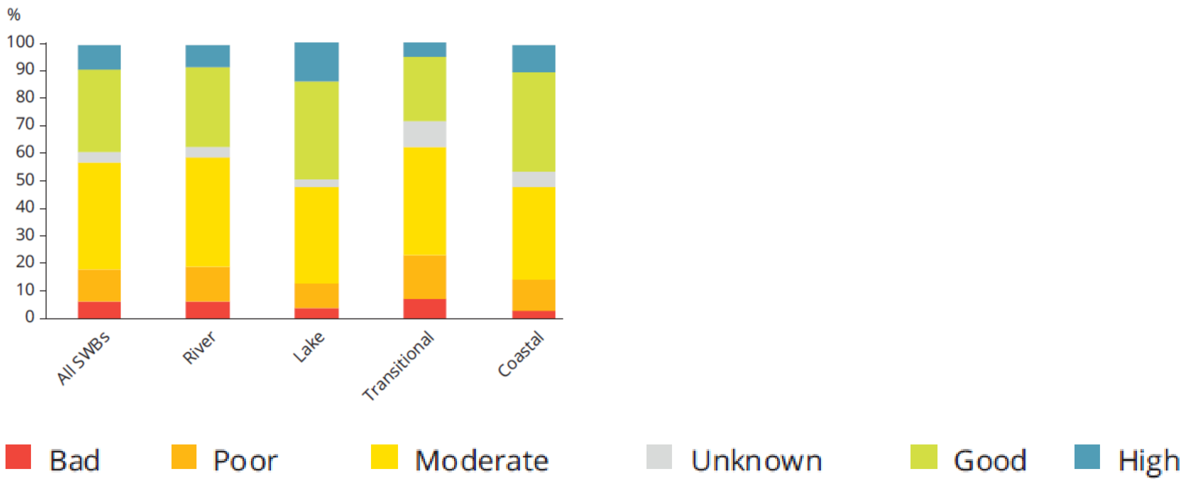
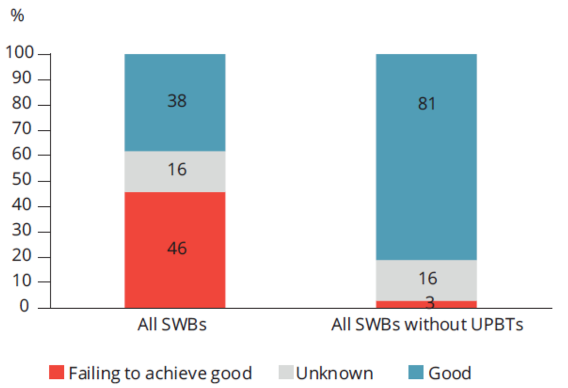


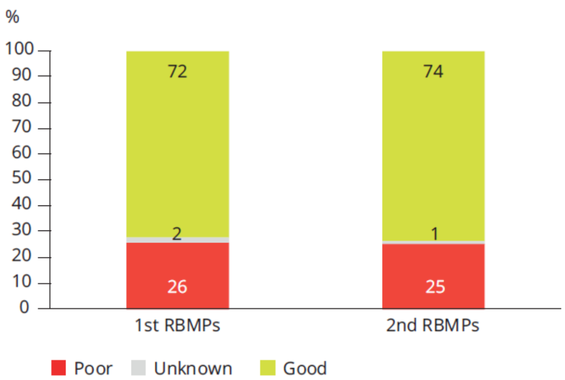
Figure 3.1 of the EEA Report will show the ubiquitous, persistent, bio-accumulative and toxic (uPBT) substances like mercury, polybrominated diphenyl ethers, tributyltin and polyaromatic hydrocarbon are a very relevant and a very big problem:

Figure 3.1 **Chemical status of surface water bodies, with and without uPBTs**



The status of the groundwater bodies is generally better than the status of the surface waters but hardly any improvement is observed over the last years, as shown in figure 4.1 of the EEA report.

Figure 4.1 **Chemical status of groundwater bodies, by area, reported in first and second RBMPs**



The key messages of the EEA Report are:

- Around 40 % of surface waters (rivers, lakes and transitional and coastal waters) are in good ecological status or potential, and only 38 % are in good chemical status.
- Of the different water bodies recognised by the Water Framework Directive (WFD) across Europe, groundwater bodies generally have the best status. Ca. 74 % of the groundwater area achieved good chemical status, while 89 % of the area achieved good quantitative status.
- In most Member States, a few priority substances account for poor chemical status, the most common being mercury. If mercury and other ubiquitous priority substances were omitted, only 3 % of surface water bodies would fail to achieve good chemical status. Improvements for individual substances show that Member States are making progress in tackling the sources of contamination.
- The main significant pressures on surface water bodies are hydromorphological (40 %), diffuse sources (38 %), particularly from agriculture and atmospheric deposition (38 %), mercury in particular, are followed by point sources (18 %) and water abstraction (7 %).
- It can be expected that, by the time the third RBMPs are drafted (2019-2021), some of the several thousand individual measures undertaken in the first and second RBMPs is expected to have a positive effect in terms of achieving good status.

In December 2019, the EU Commission published the results of their Fitness Check regarding the Water Framework Directive, the Groundwater Directive, the Environmental Quality Standards Directive and the Floods Directive [3]. In total, the Commission asserts that the Directives are fit for purpose, with some scope to improve. The results regarding the WFD are mixed. One positive aspect from this is that the governance framework for integrated water management is set up for more than 110,000 water bodies in the EU. That has been a huge task for the Member States. Furthermore, the deterioration of water bodies is slowing down and there is a decrease in chemical pollution (mainly related to point sources). However, they assert as well that no sustainable progress in water bodies´ overall status is detected and only less than half of the EU´s water bodies are in good status.
On 1st December 2019, the new Commission, headed by Ursula von der Leyen, took over office. On the top of their agenda is the "European Green Deal" [4]. The "European Green Deal" was announced on 11 December 2019 and included the general targets of no net emissions of greenhouse gases by 2050, to decouple economic growth from resource use and to protect, conserve and enhance the EU's natural capital and protect the health and well-being of citizens from environment-related risks and impacts. Water related measures would play a central role to achieve these goals. Due to this, there will be a further push for improving the water bodies in Europe.

Keywords: European waters, EU Water Framework Directive, Fitness Check on Water

References

[1] Dr Helmut Bloech - EU Water Policy Seminar 2019, Brussels 6 November 2019
[2] European Environment Agency
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[3] FITNESS CHECK, COMMISSION STAFF WORKING DOCUMENT, SWD (2019) 439 final
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[4] The European Green Deal, COM(2019) 640 final, Brussels, 11.12.2019

Water Supply in Cold Climate – Challenges and Solutions

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1. Introduction

Target 6.1 of the Sustainable Development Goal 6 requires "Access to safe and affordable drinking water for all". This also applies to cold climate regions despite the specific conditions encountered here. In this paper an overview is given on the current state of water supply in these areas, on the actual deficits, and on potential threats due to climate change. Then possible solutions are discussed before three case studies are used to illustrate the actual situation.

In cold climate regions the raw water must usually be abstracted from surface water (shallow lakes, rivers with glacial melt or snowmelt, or wetlands). If there is no permafrost, groundwater can be used. In wintertime it might be necessary to rely on reservoirs or central storage tanks filled in summer, or even on the melting of lake ice, sea ice or snow. However, the latter can be quite expensive, as illustrated by costs of about 80 €/m^3 estimated for remote Greenland villages (Hendriksen, 2016).

With respect to the infrastructural conditions, people often live in small settlements, sometimes with scattered buildings. Therefore there is a lack of expertise with respect to water treatment processes and subsequent water networks. Moreover, the costs for constructing and operating treatment and distribution systems are quite high. In places where no piped supply system is available, drinking water must be delivered by tank trucks and stored in household tanks, the typical size being 1,200 L (Daley et al., 2014).

According to a recent survey among the Arctic Council countries, the situation is satisfactory in urban areas while there are deficits in rural parts of Greenland, Canada (north) and Alaska (Bressler and Hennessy, 2018). So far the quantity standard of 90-100 l/(cap $*$ d) for drinking water is usually met, but late summer drought or depletion of water resources in winter can lead to rationing.

Water-borne diseases (typhoid, cholera, Cryptosporidium and Giardia infections) are frequently observed in small Arctic settlements, and water-washed diseases occur occasionally (Daley et al., 2014; Cooke et al., 2016). The water quality can also be endangered by contaminants from abandoned mining sites (Khan et al., 2019), military camps (Poland et al., 2001) and open landfills.

2. Effect of climate change

Climate change is likely to have multiple effects on water supply in cold climate regions:

- There could be a decrease in **water quantity** due to an increase of air temperature and longer growing seasons, along with the movement of shrubs and the Arctic tree line north that will lead to an increased evapotranspiration in summer. There is also evidence that precipitation increases in winter but decreases in (late) summer (Evengard et al., 2011). Receding glaciers are now obvious in many places, as is the thawing of permafrost which will increase the infiltration of surface water that again might result in an increased drainage of wetlands and lakes in some regions (Medeiros et al., 2017).

- **Water quality** might be deteriorated due to permafrost thaw which can lead to an increased streambank erosion resulting in higher turbidity in surface waters (Bressler and Hennessy, 2018). Longer growing seasons will produce more soil humic matter that is likely to cause higher colour values in water. Thawing in combination with increased runoff can also lead to an increased leakage of contaminants from old waste deposits (Colgan et al., 2016; Medeiros et al., 2017).
- Possible effects on the **infrastructure** include the infiltration of stormwater into wells if groundwater is used. Water collection and water treatment systems might be threatened by floods if no flood prevention measures are applied. Regarding water distribution, the permafrost thaw will cause subsidences which could lead to the damage of pipes.

3. Possible solutions

3.1 Water availability and water abstraction

In a trial conducted on Alaska‘s Coastal Plain 50 km south of Prudhoe Bay, snow fences along lake shores were constructed in order to increase snow melt in spring. An increase by > 20% was achieved illustrating that the approach could be successful (Stuefer and Kane, 2016). Water availability in wintertime can be improved by constructing larger retention basins or tanks that are filled in summer. In areas with subsiding permafrost horizon groundwater abstraction might become an option.

3.2 Water treatment

Data on the raw water sources and treatment processes applied in Arctic Council countries reveal that mostly groundwater is used in North America and Iceland while the situation is more divers in Scandinavia, see Table 1 (Lane et al., 2018). Surface water is generally filtered and disinfected while groundwater disinfection is only applied in North America.

Table 1 Raw water sources and treatment processes applied in Arctic Council countries.

State/Country	Groundwater		Surface water	
	%	Treatment	%	Treatment
Alaska	80	Chem. disinfection	20	Filtration, disinfection
Canada (north)	< 50	Chem. disinfection	> 50	Filtration, disinfection
Iceland	95	–	5	Filtration, UV-disinfection
Norway	10	–	90	Direct filtration, disinfection
Sweden	50	–	50	Direct filtration, disinfection
Finland	70	–	30	Direct filtration, disinfection
Russia	30	–	70	No requirements

According to a survey of water treatment processes used in the 25 Arctic communities of Nunavut (Canada) that was conducted by Medeiros et al. (2017), the following treatment processes are applied: Cartridge filtration (5 facilities), rapid sand filtration (2 facilities), fluoridation (1 facility), UV-disinfection (1 facility) and chlorination (all of the 25 facilities).

The water quality parameters of concern in cold climate regions are turbidity, colour and microorganisms**.** Most often hygienic problems have been reported, in particular in places with truck delivery of drinking water and in-house storage tanks. There is evidence that biofilms might consume residual disinfectant quite rapidly (Truelstrup Hansen et al., 2016).

Technical solutions for the quality problems exist, but they must be implemented properly. This applies to a proper removal of turbidity and colour, and to reliable disinfection in particular. Moreover, disinfection must be adapted to the local conditions. In the case of non-piped supply, in-house storage tanks must be kept clean and disinfected regurlarly.

3.3 Water distribution

The requirement for using pipes for water distribution without heating is that they are laid below the groundfrost line which usually means at a depth of > 2 m. Alternatively an insulation layer (e.g. polystyrene) around the pipes can be used, or the water can be circulated constantly by bleeding valves in households (not sustainable), or by operating recirculation systems (Schubert et al., 2013).

In areas with long frost periods heated water pipe utilidor systems (above and below ground) are common. The heat transfer can be achieved by electrical heating wires inside or around the pipes, or from district heating systems which are installed in parallel in the same trench. In the latter case a control of the temperature is needed (Pericault et al., 2016).

With respect to the impact of climate change on water infrastructure, a proper maintenance of the technical installations and new planning rules for the distribution systems will be required.

3.4 The Water Safety Plan (WSP) Concept

The WSP concept was introduced by WHO in 2011 (WHO, 2011). So far, 35 countries worldwide have adopted it. Of the Arctic Council countries, only Iceland has adopted the concept completely (Lane et al., 2018). EU countries have included most of the approach in their national legislations. Moreover, EU utilities that serve more than 5,000 people have to report their drinking water quality to the European Commission every 3 years.

4. Case studies

The following municipalities are described with respect to their local water supply systems:

- Helsinki (Finland) as an example for large cities in Nordic countries (Sillfors 2000).
- Longyearbyen (Spitsbergen) as a small town exposed to Arctic conditions (Nowak and Hodson, 2013; Olsen, 2016).
- The villages Shishmaref and White Mountain in Northwestern Alaska (USA) as an example for places where indigenous people live (Marino et al., 2009).

The aspects size of the system, raw water source, water treatment and distribution, and consumer-related issues are addressed. In order to obtain a general acceptance of the supply system in small places, it is important to practice consumer participation.

Keywords: Case studies, Cold climate, Drinking water supply, Water distribution, Water treatment

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Wastewater management in cold climates

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Abstract: Wastewater collection and treatment are affected by several factors in cold climates: lower temperatures in wastewater, higher inflows with diluted wastewater during snow melting and freezing of infrastructure. Unit processes in centralized wastewater treatment could be severely affected in colder climates; settling velocity reductions, lower activity of microorganisms, slower floc build up, etc. Thus, treatment plants must be bigger and will require higher coagulant dosages and polymers to achieve the same treatment capacities and efficiencies as during summer. Despite these challenges, there are promising concepts to solve Cold Climate challenges to a greater degree.

Keywords: sewers, wastewater treatment, cold climates

United Nations (WWAP, 2017) estimates that well over 80 per cent of wastewater worldwide (over 95 per cent in some developing countries) is released into the environment without treatment. The consequences are alarming; human health, livelihoods, food chains and the environment severely suffer. Climate Change impacts complicate the existing challenges even further. In addition, financial and technical aspects represent enormous obstacles, despite the urgent need to act.

Cold Climates add new dimensions to the technical, financial and human resources challenges mentioned above. The "Cold Climates" in this context refers to both extreme cold regions as well as temperate climate regions where the temperature fluctuates e.g. by more than 10 degrees of Celsius. This paper looks at some of the challenges faced by such regions.

Wastewater management in Cold Climates includes collection, treatment and disposal of wastewater and the residue generated during these processes. These three aspects are addressed in the following sections, with a focus on domestic wastewater.

Small scale, local wastewater management – septic tanks

In general, sparsely populated areas represent an own set of challenges, especially for centralized wastewater management. In this aspect, extreme cold regions are distinguishable by their extremely low population densities, smaller agglomerations and long distances between such cities and villages. These conditions make local small scale and decentralized wastewater management more feasible.

The use of septic tanks, to the extent adequate sanitary facilities are available, is probably the most widespread and feasible concept to manage domestic wastewater in such areas. Frozen tank components and improperly functioning pipes are the biggest challenges in septic tank systems. These challenges may disturb the transfer of wastewater and retard the degradation process, both due to freezing and low temperature. Insulating the septic tanks, vegetation around the tanks and prompt repair of leaking pipes are potential solutions (ADB Septic, 2019). Compacted snow and soil over the septic tanks due to driving or other activities may reduce the insulation effect from the top, which should be avoided. It is also important that septic tanks are emptied with adequate frequency.

Wastewater collection

Wastewater should be collected by sewers from houses and other municipal installations to either be treated in decentralized or centralized WWTPs. Decentralized WWTPs usually have shorter sewers and are less costly or complicated to maintain operation also during colder periods. However, it is certainly a challenge to maintain longer sewers leading to centralized WWTPs. The sewers will normally not freeze as long as there is a continuous flow of warm wastewater. However, leaks, reduction of sewer diameters due to internal growth/debris and other blockages may lead to frozen sewers, which may require major repairs and costs. Climate Change in many cold climates have resulted in increased and more frequent precipitation, leading to excessive wastewater in sewers and more frequent overflows polluting the surrounding environment (Fortier and Maihot, 2014). A general increase in the air temperature is reported during winters, which result in more days around zero degrees that lead to more frequent snow melting. This results in more wastewater and lower temperature in wastewater, which reduces the treatment efficiencies (Plosz, et al, 2009). These challenges are addressed in the next section.

Decentralized wastewater treatment

Operations in wetlands in cold climates have been well studied for decades (Jenssen, et al, 2005). Wetlands are quite competitive in operational costs compared with centralized conventional WWTPs. They may, if well operated, achieve intended treatment results (Chouinard, et al, 2015). Measures such as subsurface-flow constructed wetlands covered with an insulating mulch layer has been demonstrated to prevent freezing, although it may affect oxygen transfer rates, pollutant removal performance and plant establishment. Optimal operations can be achieved by design optimizations (Wallace, et al, 2005).

Centralized wastewater treatment plants

Ødegaard et al (2016) argued that the low temperatures in sewers and wastewater are not mainly caused by cold ambient temperature per say, but rather by the combined sewers with much external intrusion waters. Plozs et al (2009) documented that the reduction in wastewater temperature reduces when air temperature increases. Biological performances are generally retarded during cold climates. Operational experiences show that for each 10 degrees reduction e.g. the nitrification rate will reduce by 50% (Henze, et al, 2014). Such a reduction in performance means a needed doubling of reactor volumes for winter operations compared with summer periods. There are various approaches to enhance the activities in cold temperatures, where enhancement of activated sludge with iron salts was proposed as an efficient solution (Cheng, et al, 2010). The use of pretreatment with fine sieves and MBBR combined with coagulation stages are reported to be efficient in cold climates (Ødegaard, etc. al, 2016). Floc growth and floc size are also affected by cold temperatures, requiring either increased dosages of coagulants and flocculants or/and increased sedimentation times in coagulation (Ødegaard, et al, 2016). Thus, despite centralized WWTPs being severally affected by lower temperature, there are promising concepts to solve Cold Climate challenges to a greater degree.

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Plastic and microplastics in Arctic marine environment

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Microplastics (MPs), a kind of plastic particle with diameter less than 5 mm, are semi-persistent and one of main carriers of pollution. MPs in the marine environment mainly come from industrial activities such as commercial fishing, use of plastic abrasives, and spillage of plastic pellets, but also from domestic applications such as washing of plastic microfiber clothes, use of personal care products containing MPs. There are several pathways for MPs to get into the Arctic. Owing to the great connectivity between the Arctic Ocean and adjacent seas through Fram Strait and the Bering Strait, the problem of plastic litter is likely to extend into the Arctic Ocean. The local sources are also play an important role for MPs in the Arctic Ocean. Although marine plastic has been observed globally and in the Arctic for decades, only recently have national and international scientific efforts begun to understand the sources, occurrence and fate of marine plastics in the Arctic. This talk will review the MPs in the Arctic marine environment, their sources, pathways, occurrence and fate in the Arctic Ocean.

Microplastic in wastewater treatment plants in a northeast city of China: distribution and characteristics

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Abstract: Domestic sewage was collected from 17 treatment plants in the city of Dalian, a northeast city of China, in winter (at the temperature of ~ -10℃). The microplastics (MPs) were detected in the influent and effluent to derive their distribution and characteristics.

Keywords: microplatic; sewage; characteristic

Domestic sewage was collected from 17 treatment plants in the city of Dalian, a northeast city of China, and the microplastics (MPs) were detected in the influent and effluent. The concentrations of MPs were 12 ± 9.0 items/L and 2.7 ± 2.2 items/L in influent and effluent, respectively. The concentrations of MPs were significant lower in effluent than those in influent. The removal rate of MPs is from 44% to 95% and averaged 77 ± 13%. The Fourier infrared spectrometer analysis indicated that these MPs were mainly plastic polymers (70%), including propylene (29%), polyethylene (23%), propylene/ethylene copolymer (10%), polystyrene (9.1%). The color of MPs was dominant by white (32%), and followed by clears (25%). The main shape of MPs was granules (39%), followed by fragments (32%) and fibers (25%). The size of MPs were from 9.7 to 0.011 mm in influent, which were not significant different to those in effluent (6.6 to 0.015 mm, $p < 0.05$).

Solvothermal synthesis of carbonaceous material for degradation of organic pollutants in wastewater

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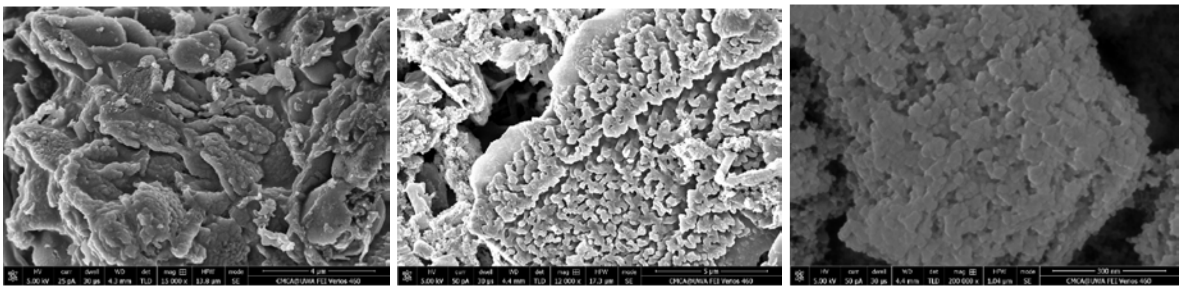
Abstract

Water pollution has become a world-wide issue and imposes extra challenges in cold climate. Very recently, it was reported that due to the "cold-trapping" process, persistent organic pollutants (POPs) can be transported to seawater, soils, and snow. (Casal *et al.* 2019) The use of specific chemicals, for instance, deicing chemicals in cold region, has also worsened the water quality. Photocatalysis, a promising technology for degradation of organic pollutants, might be a solution for water remediation in cold regions as it can be less influenced by temperature than conventional wastewater treatment. Graphitic carbon nitride (GCN) has been considered as one of the most promising metal-free photocatalyst owing to its unique merits, e.g., cost-efficiency, feasible and stable structure. (Cao *et al.* 2015, Wang *et al.* 2009) Recently, GCN has inspired many applications in the fields of energy conversion and environmental remediation. A variety of methods have been developed to enhance the photocatalytic performance of g-C_3N_4 and coupling with other nanocarbons appears to be a more promising option to maintain the metal-free nature and the required reaction efficiency.(Sun *et al.* 2014)



(a) **(b)** **(c)**

Fig. 1 SEM images of g-C_3N_4 (a), g-C_3N_4-DMF (b) and 0.01g g-C_3N_4/0.05g nanodiamond

In this work, GCN was prepared by a thermal condensation method using melamine as a precursor (Zheng *et al.* 2015), and then hybridized with nanodiamonds. The samples were subjected to a variety of characterizations, such as X-ray diffraction (XRD), N_2 sorption isotherms, Raman, UV-visible diffuse reflectance spectroscopy (UV-vis DRS), and photoelectrochemical tests. For photodegradation test, 0.01 g photocatalyst was added in an aqueous methylene blue (MB) solution (200 mL, 10 ppm) under a 300 W Newport Oriel Universal Xenon arc lamp light. After 30 mins in dark for adsorption-desorption equilibrium, at each time interval, the sample solution was taken and tested by UV-visible spectroscopy (λ = 664 nm). The photoelectrochemical performance was investigated in an electrochemical workstation (Zahner Zennium) and 0 voltage was applied. A solar simulator (TriSOL, OAI) provided the light irradiations and a three-electrode photoelectrochemical cell was employed using Na_2SO_4 solution (0.02 mol/L) as the electrolyte.

XRD patterns confirm the formation of graphitic structure, which was not destroyed after the solvothermal treatment. N_2 sorption suggests that BET surface area was increased after the introduction of nanodiamonds by the solvothermal treatment. Also, the visible light absorption was significantly increased by the addition of nanodiamonds. Fig. 1 displays the SEM images of g-C_3N_4, g-C_3N_4-DMF and 0.1GCN-0.05N. As can be seen, pristine g-C_3N_4 became porous after the treatment in DMF, which might enhance the activity of 0.1GCN-0.05N.

Fig 2 shows the photocatalytic activity of these samples for MB degradation under UV-vis light irradiations. As observed, sample of 0.1GCN-0.05N had the highest activity. Only 25% MB was degraded by pristine g-C_3N_4 in 180 min while more than 45% of photodegradation was obtained on porous 0.1GCN-0.05N. We also found the optimal modified ratio (g-C_3N_4: nanodiamon) should be controlled at 2:1.

Fig. 3 depicts the transient photocurrent densities of g-C_3N_4, GCN-DMF and 0.1GCN-0.05N. The g-C_3N_4/nanodiamond demonstrates the highest electron-transfer efficiency between the light irradiations and dark.

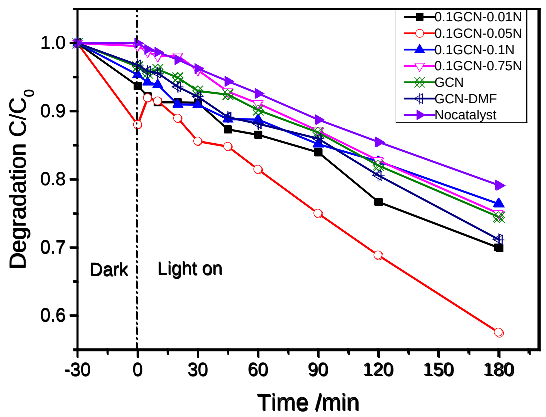


Fig. 2 Photodegradation of MB solutions under UV-vis light irradiations

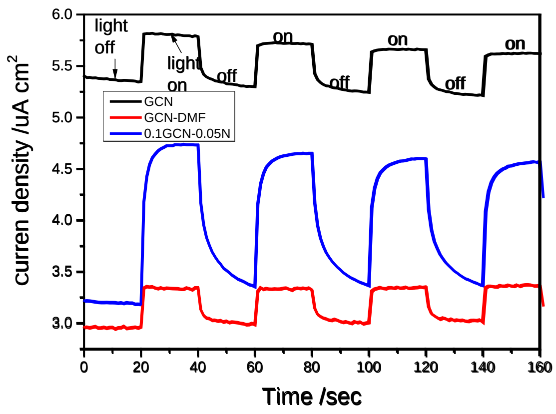


Fig. 3 Transient photocurrent densities at 0 voltage. [catalyst: 0.05 g/L, temperature:25 °C, MB initial: 10 ppm]

In summary, a metal-free photocatalyst, nanodimond/graphitic carbon nitride was prepared and characterized. The metal-free material shows excellent photodegradation and photo-electrochemical performances. This study proposes a feasible strategy to develop metal-free photocatalysts for degradation the organic pollutants, which might be helpful for micropollution control in cold climate.

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Biofiltration for water Treatment at Cold Temperatures: BAC vs. BIEX

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Abstract

Biofiltration is an effective means of removing natural organic matter (NOM) from raw water sources. However, because low temperatures can reduce the activity of microbial communities present in biofiltration systems, operation at temperatures typical of cold climates can reduce the effectiveness of biofiltration for NOM removal (Basu et al., 2015).

Biological Ion Exchange (BIEX) is emerging as an effective biofiltration technology for the removal of NOM (Winter et al, 2018). Unlike Biological Activated Carbon (BAC), which removes NOM only through biodegradation, BIEX removes NOM through a combination of ion exchange and biodegradation (Amini et al, 2018). Because temperature generally impacts biological NOM removal mechanisms to a greater extent than chemical NOM removal mechanisms (Amini et al, 2018), BIEX is not expected to be as impacted by temperatures typical of cold climates as BAC. The present study assessed the impact of operation at temperatures ranging from 4C to 20C, on NOM removal with BIEX and BAC. NOM removal was quantified based on Total Organic Carbon (TOC) removal.

For all conditions investigated, BIEX consistently removed NOM more rapidly than BAC. Temperature had a substantially greater impact on NOM removal for BAC than for BIEX. The temperature activity coefficient for BIEX and BAC were 1.044 (1.042-1.047 based on a 90% confidence interval) and 1.066 (1.058 to 1.077 based on a 90% confidence interval), respectively. A greater temperature activity coefficient indicates a greater impact of temperature on NOM removal. BIEX also consistently removed NOM to a greater extent than BAC. The residual normalized TOC for BIEX was approximately 0.2, while that for BAC was 0.6.

The results indicate that the treatment efficacy is expected to be greater for BIEX than BAC, especially at colder temperatures. In addition, the capital costs are expected to be substantially lower for BIEX than BAC, especially for operation at temperatures typical of cold climates. At low temperatures, [empty bed] contact times for BAC are expected to be approximately 50% greater than for BIEX.

Keywords: Biofiltration; temperature; BAC; BIEX

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Prediction of Trihalomethanes Formation Potential in disinfection of drinking water in Northern Europe

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Abstract

According to the WHO and UNICEF, 71% of the world's population used a safely managed drinking water service (SDG indicator 6.1.1) in 2017. It is to a great extent due to an effective disinfection inactivating pathogenic microorganisms during water treatment and preventing their regrowth in water distribution systems.

Many common disinfectants such as free chlorine, ozone, chlorine dioxide and chloramines, can react with natural organic matter (NOM) dissolved in natural water generating undesirable disinfection by-products (DBPs) that are considered as potentially cytotoxic, genotoxic or carcinogenic. Trihalomethanes (THMs) and haloacetic acids (HAAs) are the two major classes of regulated DBPs.

Concentration and properties of the water-dissolved NOM affect the formation of THMs. A higher concentration of NOM induces higher disinfectant demand and increases the formation of THMs. There is substantial scientific evidence that global warming leads to concentration increase and properties change of NOM in water supply sources of the UK, some regions of Europe and North America (Huang et al. 2019). Temperature increase affects dissolution, degradation and complexation of NOM. It leads to an unexpected increase of THMs levels in the water produced by the DWTPs designed 20-30 years ago without accounting climate change effects.

Therefore, there is an urgent need to predict the formation of THMs in disinfection of drinking water in the cold and temperate climate zones, where climate change alters properties and concentration of the water-dissolved precursors of DBPs.

The current study has been conducted for nine surface water sources used for drinking water supply in the Oslo region. Sampling has been done during the coldest winter month (February 2019) from the locations previously studied by Gjessing E. T et al. in 1991 who produced extensive data on NOM characterization.

Direct chlorination and chlorination with pre-ozonation were applied to the samples varying chlorine/ozone doses and contact time. Raw and treated water samples were characterized by the THMs Formation Potential (THMFP), conductivity, turbidity, UV254, colour, TOC, TOD and pH. Besides, UV-VIS spectra have been recorded for the raw and treated samples.

The results (Figure 1, 2) show a significant correlation between THMFP and NOM concentration expressed as TOD (93%), TOC (92%) and UV254 (91%). Dozing of ozone significantly reduces the formation of the THMs. This effect positively correlates with the time of ozonation, however, is influenced by the raw water source and supposedly NOM properties.

Predictive models have been derived from the obtained results that can be used for maintaining disinfection parameters based on the water source and NOM concentration.

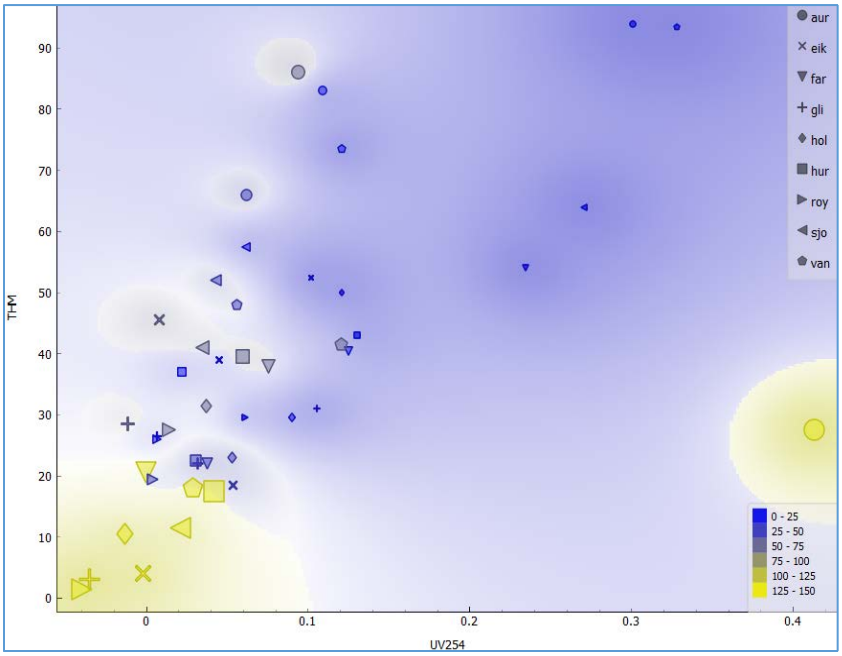

Figure 1 THMFP of 9 surface waters at different ozonation time

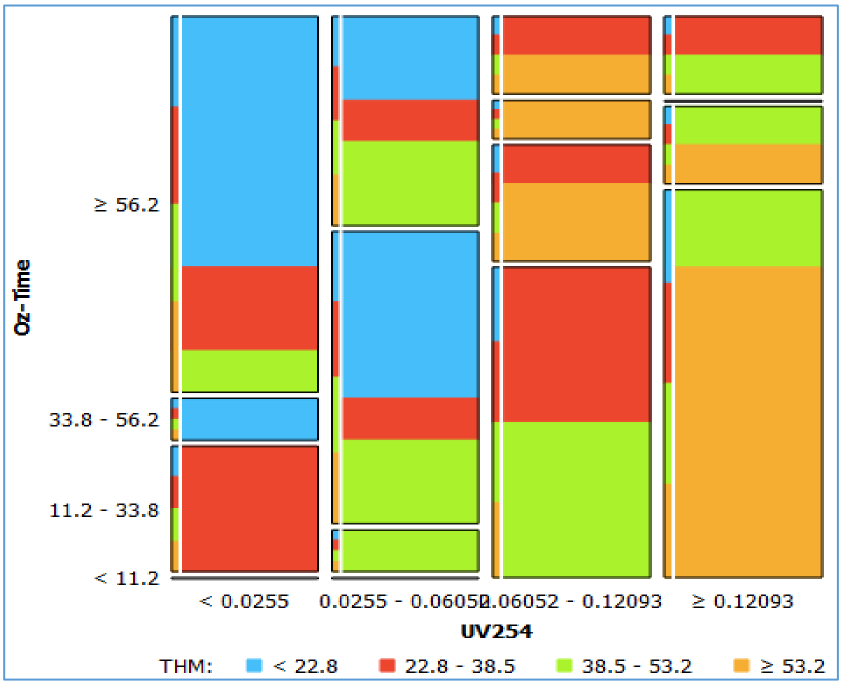

Figure 2 Influence of raw water UV254 and ozonation time on THMFP

Keywords: water disinfection, disinfection by-products, cold climate.

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Rapid Characterization of Natural Organic Matter and Precursors to Disinfection By-Products in Cold Climate Water Sources

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Abstract

Total organic carbon (TOC) analysis has been typically used as an aggregate measure of NOM in water. It is widely known that during the disinfection process with chlorine, which is a common treatment technique in municipal water supply facilities, the organic matter could be converted to potentially harmful disinfection by-products (DBPs) such as trihalomethanes (THMs). Treatment techniques for the removal of organic matter and precursors to THMs do exist but usually at a high cost.

In this research, NOM from surface water sources were isolated and fractionated by resin adsorption techniques into hydrophobic acid (HPOA), hydrophobic neutral (HPON), hydrophobic base (HPOB), hydrophilic acid (HPIA), hydrophilic neutral (HPIN) and hydrophilic base (HPIB) by using three types of resin per the method (Marhaba et al, 2003). Papinyopol et al. (2005) found that the most active THM precursors were the HPOB and HPIB fractions. The Spectral Fluorescent Signatures (SFS) technique was used for identifying and predicting the level of each of the six fractions. Fluorescence measurement was accomplished by using a fluorescence spectrophotometer equipped with a 150-W ozone free xenon lamp. Measurements were performed by exciting samples from 225 to 525 nm and measuring emission from 220 to 730 nm. SFS database was created from the data of excitation, emission and intensity. A typical SFS is shown in Figure 1 below.

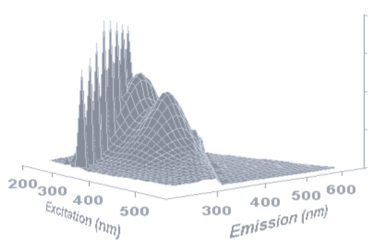

Figure 1 Spectral Fluorescent Signature (SFS) acts as a fingerprint of organic material in water that can be obtained within seconds and used in spatial and temporal characterization.

Marhaba (2000) developed an algebraic model that predicts the concentrations of the six organic fractions at 20 deg C.

$$C = a + b * P + c * A + d * S + e * S * A \quad (1)$$

$$S = \frac{(P - P_i)}{(Em_p - Em_i)} \quad (2)$$

where *a*, *b*, *c*, *d*, and *e* = regression coefficients that are different for each fraction (Table 1); *C* = predicted fraction concentration (mg/L); *P* = intensity at the location of the fraction major peak (intensity units) (see Table 2, Columns 2 and 3); *Pi* = spectrum intensity at Em_i (intensity units); Em_i = starting *Em* of spectrum = *Ex* + 24 (nm) (Table 2, Column 2, for fraction *Ex*); Em_p = *Em* at fraction major peak location (nm) (see Table 2, Columns 2 and 3, for location of fraction major peak); *A* = area of emission spectrum where the fraction major peak exists (intensity units*nm) (Table 2, Column 2, for fraction *Ex* emission spectrum); and *S* = rising slope of the corresponding fraction spectral major peak (intensity units*nm).

Table 1 Regression model constants (Marhaba, 2000)

Fraction (1)	Regression Coefficient				
	a (2)	*b* (3)	*c* (4)	*d* (5)	*e* (6)
HPOB	−0.307	0.0659	0.000236	24	−0.0235
HPOA	−0.00445	0.0300	−0.000092	27.9	0.03127
HPON	0.0948	−0.549	0.000343	106	−0.0410
HPIB	0.0817	0.0135	0.000016	−4.0	0.00348
HPIA	0.161	0.358	0.000663	25.7	−0.0368
HPIN	0.256	0.302	0.000225	28.4	−0.120

Table 2 Location of Fractions Major Peaks (Marhaba, 2000)

Fraction (1)	*Ex* (nm) of *Em* spectrum (2)	*Em* (nm) in *Ex* spectrum (3)
HPOB	237	381
HPOA	249	429
HPON	225	321
HPIB	237	369
HPIA	225	345
HPIN	225	621

In this research, the model was modified for the variation of temperature down to 1 deg. C for application in cold climates. It was found that the intensity values increased by 1% for every drop in a deg. C. Hence, the intensity values in the model can be adjusted for lower temperatures between 1 deg. C and 19 deg. C as follows:

$$P = P_T + P_T(0.2 - 0.01T) \quad (3)$$

$$P_i = P_{iT} + P_{iT}(0.2 - 0.01T) \quad (4)$$

where *P* = adjusted intensity at the location of the fraction major peak (intensity units); P_T = intensity at the location of the fraction major peak (intensity units) at temperature *T*; P_i = adjusted spectrum intensity at Em_i (intensity units); P_{iT} = spectrum intensity at Em_i (intensity units) at temperature *T*; *T* = Temperature of the water in deg. C, $1 \leq T \leq 19$

The application of the above temperature adjustment to the model for predicting the concentrations of the six organic fractions gives insight into the character of the organic matter and the potential for THM formation for cold climates.

Keywords: SFS; NOM; THMs

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Integration of advanced physico-chemical processes (MPUV/PAA) for advanced oxidation process in cold climates

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Abstract

In recent years, peracetic acid (PAA) has been proposed as an alternative disinfectant for replacing chlorine-based oxidants in water and wastewater treatment. Compared with traditional chlorine disinfection, PAA has little toxic disinfection by-products and ecotoxicological effect. Besides, PAA has a low freezing point and can show good performance on disinfection even at very low temperatures. Ultraviolet (UV) disinfection has been well documented due to the effectiveness of inactivation of waterborne pathogens. Nowadays, UV disinfection has become more and more popular in water treatment plants in China. Several studies have observed the enhancement of inactivation of pathogens by UV/PAA in comparison with UV or PAA alone, due to the formation of reactive radicals. In addition, for cold regions, it is important to have a dual barrier for disinfection to overcome the temperature-dependencies of UV lamp output and the consequent impact on microbial inactivation kinetics. In this case, PAA is an ideal candidate for complementing UV disinfection as it can be instantly applied and integrated into the plant with minor cost.

In fact, except for the microbial risks, water and wastewater treatment plants have to face some new challenges, such as removing the emerging micropollutants (*e.g.* PPCPs) from water. As a novel advanced oxidation process (AOP), only few studies have investigated the degradation of micro-pollutants by UV/PAA, what's more, these studies all employed low pressure UV (LPUV) to activate PAA. Unlike LPUV lamps emitting UV light, medium pressure UV (MPUV) lamps emit strong polychromatic UV light and are more efficient for the photodegradation of organic pollutants. To our knowledge, MPUV lamp has not been applied to activate PAA.

In this work, MPUV/PAA, an emerging AOP, was applied to degrade fluoroquinolone antibiotics (FQs) in water. FQs has been frequently detected in the aquatic environment and their adverse effect on ecosystem and human health has raised growing concern. As the conventional water treatments were inefficient, there is a need to develop an available technology for FQs remediation. Levofloxacin (LEV), a typical FQs, was selected as the target compounds. The degradation kinetics of LEV by MPUV/PAA was studied. The reactive species responsible for the LEV degradation under MPUV/PAA were systematically evaluated by a combination of experiments and kinetic simulations. The transformation products (TPs) of LEV by UV/PAA were also evaluated. It is also worth noting that some TPs with higher toxicity may be generated during the water treatments. Therefore, in this work, the ecotoxicity and mutagenicity of LEV and its TPs were predicted using quantitative structure-activity relationship (QSAR) analysis.

The new knowledge obtained in this study can help us to better understand the degradation mechanisms and toxicity change of LEV by MPUV/PAA, which might be

beneficial for developing better FQs treatment strategies for water and wastewater treatment, especially in cold climates.

Keywords: Peracetic acid (PAA); Medium pressure UV (MPUV); Fluoroquinolone antibiotics

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Managing sewage treatment in the extreme cold in Cambridge Bay, Nunavut, northern Canada

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Abstract

The community of Cambridge Bay is the largest community in the western region of the Nunavut Territory, in Northern Canada, and located at 69° 07' N latitude and 105°03' W longitude. It is approximately 300 kms above the Arctic Circle, and it is one of the largest communities in Nunavut, with a 2016 population estimate of 1,620.

The community is located in the region of Arctic tundra with continuous permafrost and very limited vegetation. The climate may be characterized by long cold winters and short cool summers. The July mean high temperature is plus 12 degrees Centigrade and the January mean high temperature is minus 29 degrees Centigrade.

Sewage is collected from 1000 litre tanks in each of the community houses with sewage pump out trucks, and originally discharged into a series of ponds; the sewage was treated to some degree as it flowed through the ponds and into the ocean. Wastewater collected from the community is classified as "high strength" waste because of the trucked water supply and trucked sewage collection, which limits water use to about 120 litres per capita per day.

This type of sewage treatment system is common for communities in northern Canada. The ponds are often improved to increase containment with earth berms and flow control structures, however the poor performance of the pond system in Cambridge Bay was a source of concern for both the community and the regulatory organizations. In response, a project was initiated to improve the sewage treatment system.

A planning study was completed to identify alternate locations for a new “engineered” lagoon system. A series of potential lagoon sites were identified in consideration of proximity to the community, road access, capital and operation and maintenance costs; and general site development. The community ultimately decided to complete engineered improvements to the existing pond system.

The improvements to the existing pond system were based upon developing an engineered 2 cell sewage lagoon system. The system operates as a facultative treatment process, with a primary cell, a retention cell, and a controlled discharge from the retention cell during the summer months – see Figure 1.

In support of advancing the redevelopment of the existing pond system, a topographical survey, and a geotechnical investigation were completed. The geotechnical investigation provided information on the soil conditions of the site, and also information on the soil materials around the community that would be used for construction.

The primary cell was constructed on the northwest side of the retention pond, where the sewage pump out trucks discharge. The primary cell pre-treats the sewage to remove much of the suspended solids before the sewage enters the retention cell. The

sludge settled in primary cell will be removed every 10 to 15 years and placed in a sludge drying bed.

The lagoon is annually decanted from the retention cell using a mobile diesel engine driven self-priming pump. The lagoon system has a capacity of 120,000 cubic metres per year, which will provide enough capacity until the community reaches a population of approximately 2500 people.

An engineered wetland was also constructed to further treat the discharge from the annual discharge from the retention cell. The process of a seasonal discharge from a lagoon to a wetlands has been demonstrated to provide significant effluent quality improvements in the Canadian Arctic. The effluent quality discharged into the ocean by the community of Cambridge Bay is generally less than 30 mg/L for Biological Oxygen Demand (5 day), less than 60 mg/L for total suspended solids, and less than 4000 for faecal coliforms.

The improvements to the existing lagoon system were planned and executed over several years in order to provide the community with funding and manpower flexibility for the project. The construction cost of the improvements was approximately 3 million dollars (CDN).

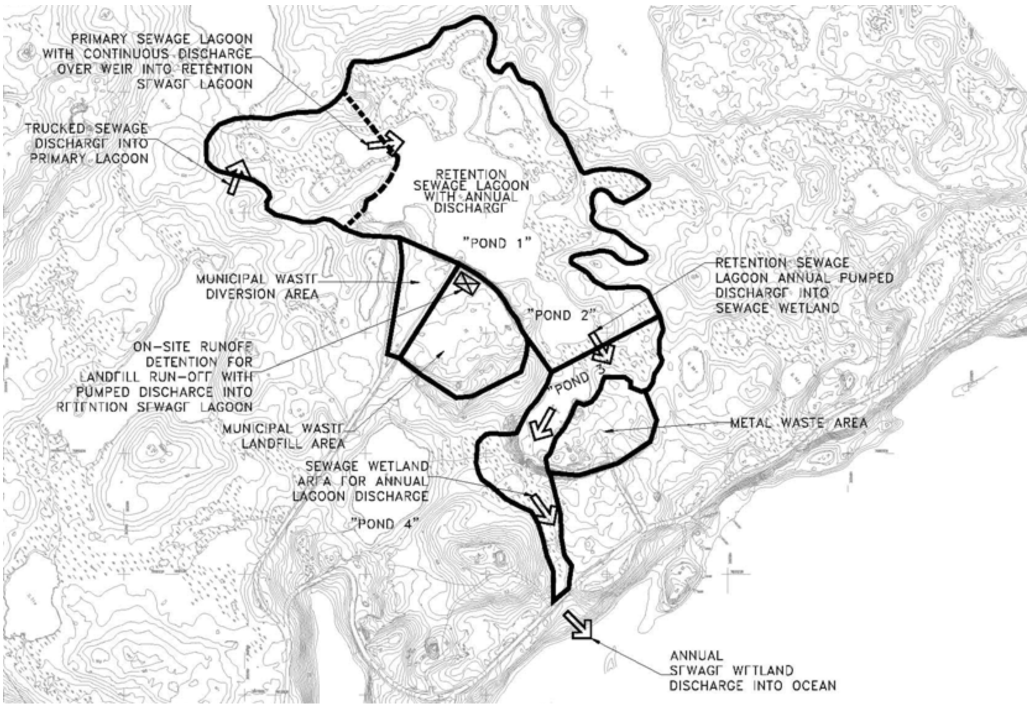

Figure 1. Cambridge Bay sewage lagoon system including primary cell, retention cell, pumped discharge, and sewage wetland before discharge into the ocean.

Keywords: Wastewater treatment, northern Canada, lagoon system, wetland system

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Phthalates in Drinking Water in Cold Climate: Occurrence and Implications for Human Exposure

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Abstract

Phthalates are a group of synthetic compounds with high production, and they are used as plasticizers in many applications, such as polyvinyl chloride products, building materials, furnitures, etc (Schettler, 2006). Widespread applications of phthalates result in ubiquitous pollutions in environments, including air, dust, water, etc., which have elevated human exposure to phthalates (Li et al. 2019). Though phthalates have been removed from drinking water in water treatment plant, the procedure of transportation through pipelines, plastic bottles, and storage, may increase the presence of phthalates in drinking water. In this study, twenty-five drinking water samples were collected in homes from Harbin, China, to analyze six most common phthalates. Phthalates were detected in all drinking water samples, suggesting phthalates are ubiquitous in drinking water. The concentrations of the total phthalates ranged from 191 ng/L to 23900 ng/L, with a median level of 1320 ng/L. Among the six phthalates, dibutyl phthalate (DBP) has become the most abundant phthalate, accounting for 42.4±28.6% of the total phthalate concentration, followed by di-iso-butyl phthalate (DiBP), dimethyl phthalate (DMP), and bis(2-ethylhexyl) phthalate (DEHP). Diethyl phthalate (DEP) and benzyl butyl phthalate (BBP) contributed the least. The daily intakes of phthalates from drinking water were in a range of 0.54 to 3070 ng/kg-bw/day, with a median value of 33.6 ng/kg-bw/day. Among the six phthalates, DBP contributed the most, with a median daily intake of 5.07 ng/kg-bw/day, followed by DiBP, DMP, and DEHP. Compared with the reference doses of phthalates recommended by the United States Environmental Protection Agency (U.S.EPA), the daily intakes of phthalates were within the acceptable levels, suggesting that phthalates in drinking water have not affected the human health.

Keywords: Phthalates; drinking water; human exposure

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Impact of Chemical Coagulant on Phosphors Removal and Costs in Advanced Wastewater Treatment of Urban Sewage Treatment Plant

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Abstract: In order to qualifying the improved wastewater treatment standard, phosphors in wastewater are usually not only removed by biological treatment but also by advanced wastewater treatment. Thus, the most urban sewage treatment plants prefer to dose coagulant in the advanced treatment stage for the further phosphors removal. Due to the different wastewater qualities after the secondary sedimentation tank, the coagulant type in advanced treatment stage should distinguish with the previous process. In addition to consider the chemical cost saving, the type of coagulant selection become more important than before. Therefore, this paper will focus on selecting the coagulant for the advanced treatment stage on purpose of further performance phosphors removal and chemical costs saving. In detail, by jar tests, this paper will compare polyaluminum chloride and polyferric sulfate in aspects of phosphors removal efficiencies and costs. In conclusion, there is obvious difference between two tested coagulant in aspects of total phosphorus removal and costs.

Keywords: Phosphors removal; Advanced wastewater treatment; Chemical coagulation

Introduction

Chemical coagulation is one of the most important treatment processes for phosphors removal in sewage treatment plants. On the purpose of meeting the improved wastewater treatment standard, the advanced treatment process including the chemical coagulation is responsible for further phosphorus removal. The performance of coagulation process depends on inlet water qualities, coagulant type and dosage (Ratnaweera et al., 2005). However, inlet water qualities (pH, suspend solid, pH and so on) of advanced wastewater treatment are quite different from previous process, like biological treatment and coagulation coupling with secondary sedimentation tank which share the removal load of phosphors (Wei et al., 2013). Hence, previous-used coagulant typed could not work well for the different water qualities and thus it is very necessary to select suitable coagulant for the advanced treatment process. On the other hand, dosing coagulant in advanced treatment process definitely increases the treatment costs, which sewage treatment plants pay close attention to (Wei et al., 2014). Therefore, coagulant type deciding phosphors removal efficiency and related chemical cost becomes very significant for coagulation of advanced treatment process. In aspects of treatment efficiency and cost, this paper will compare two typical coagulants using jar tests.

Material and Method

Wastewater samples for jar tests are collected from outlet of secondary sedimentation tank following biological treatment, Hohhot Xinxinban WWTP (capacity: 200 000 ton /d). The treatment flowsheet shows in Fig. 1.

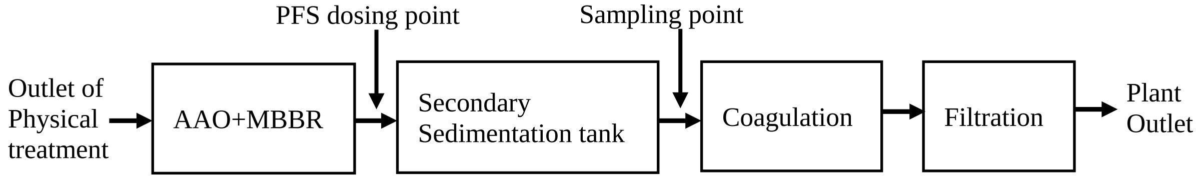

Figure 1. Treatment flow sheet of Hohhot Xinxinban WWTP

Two types of coagulant used for jar tests are polyaluminum (PAC) and polyferrous sulphate (PFS), these two coagulants are commercially available.

Result and Analysis

Using the same operation procedure and water samples from outlet of secondary sedimentation tank following biological treatment, total phosphorus (TP) removal efficiencies and chemical costs of these two coagulants are shown in Fig.2. X and Y axis display costs of coagulation dosage and TP removal efficiencies respectively. Overall, the TP removal efficiencies by PAC and PFS are not high, this could be the result of low suspend solid in outlet of sedimentation tank, which gives less contribution on floc. Basically, achieving same TP removal efficiency costs more for PFS than PAC, which trend lines of costs display. Even when adding jar tests of PFS with increased dosage, the TP removal efficiencies stay in low level. Actually, the WWTP is dosing PFS in the inlet of sedimentation tank, as shown in the Fig.1. Therefore, PFS is not suitable as coagulant for advanced treatment process while PAC perform better treatment efficiencies and economy.

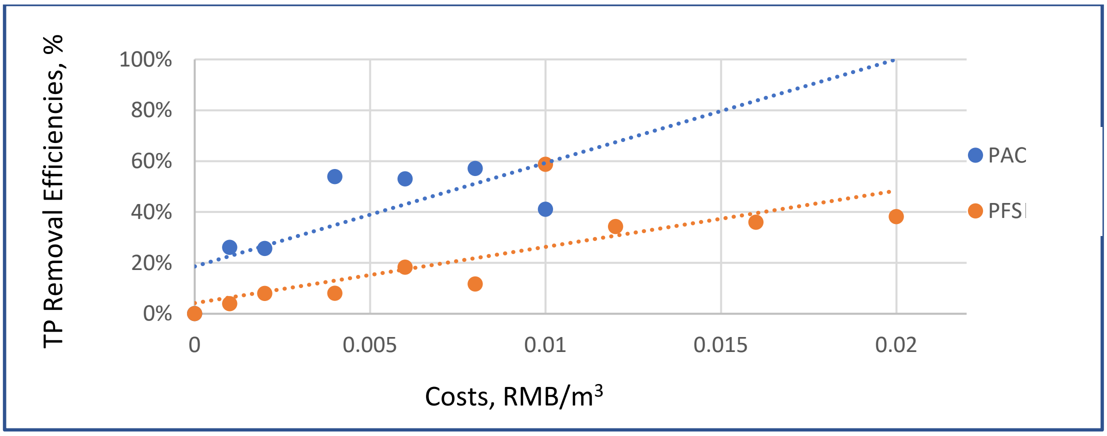

Figure 2. Costs Comparison of Total Phosphorus Removal by PAC and PFS

Conclusions and Suggestions

It is necessary to select coagulant for advanced treatment process on purpose of defining better TP treatment efficiencies and economy. And the coagulant used in the previous treatment process could be not suitable to coagulation of advanced treatment process probably due to the different water qualities.

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Acknowledgement

The authors gratefully acknowledge the assistance given by Hohhot Xinxinban WWTP during the experiments.

An investigation of energy metabolism improvement in the anoxic-anaerobic-oxic process (reversed AAO): A new insight

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Abstract: A comparison of energy metabolism between the conventional anaerobic-anoxic-oxic process (AAO) and the anoxic-anaerobic-oxic process (reversed AAO) was carried out. Although in terms of biological-nutrient removal, both processes offer excellent removal efficiencies for organic matter and total phosphorus, there is a significant difference in regards to nitrogen removal. This study investigated whether reversing the anaerobic and anoxic compartments could change the microbial activity and eventually promote efficient microorganism removal. Several key enzymatic indicators such as 2, 3, 5-triphenyltetrazolium chloride dehydrogenase activity (TTC-DHA), 2-(p-iodophenyl)-3-(p-nitrophenyl)-5-phenyl tetrazolium chloride electron transport system (INT-ETS), and adenosine triphosphate (ATP) were measured and confirmed the improvement in energy metabolism in the reversed AAO process.

Keywords: Reversed AAO; Microbial activity; Energy metabolism.

The AAO process, which was developed for the simultaneous biological removal of nitrogen and phosphorus from wastewater, has been shown to have high efficiency and stability, low energy consumption, and relatively low operational costs. However, in the face of stricter wastewater treatment standards, the AAO process has shown some deficiencies. Zhang and Gao (2000) developed a new AAO process to improve wastewater treatment by placing the anoxic compartment before the anaerobic compartment, which they named reverse AAO (from anaerobic-anoxic-oxic to anoxic-anaerobic-oxic). The reversed AAO process is shown to cost 19.4% less in operational energy consumption in WWTPs than the AAO process (Kang et al., 2011b). Although widely adopted in WWTPs, few studies have investigated the metabolic microorganism changes using the reversed AAO process, which is crucial for explaining the enhanced nutrient-removal mechanisms. We hypothesize that shifting the sequence of the anaerobic and anoxic compartments exerts a significant influence on microbial metabolism and activity.

Fig. 1 shows the ATP concentration, INT-ETS activity and the TTC-DHA activity in both systems. In anaerobic and anoxic conditions (the first 3 hours), ATP levels were relatively low in both processes. In the aerobic condition, ATP had a significant increase. The rapid change in ATP is a potential indicator of microbial metabolic response to the significant improvement in the phosphorus uptake in the reversed AAO. The average and maximum levels of ATP produced in the reversed process were 5.8% and 9.5% higher than the AAO process. As shown in Fig. 1(b), the ETS activity in the reversed AAO was higher than in the AAO over the whole operation period. The average ETS activity in the oxic compartment was 180.21 and 129.66 mgTF/(gVSS·h), respectively in the reversed AAO and AAO processes (38.99% higher in the reversed AAO). As given in Fig. 1(c), the average DHA activity in the oxic compartment was 9.66 and 9.02 mgTF/(gVSS·h), respectively, in the reversed AAO and AAO processes (c.a. 7.1 % higher in the reversed AAO). The maximum DHA activity in the oxic compartment was 10.45 and 9.58 mgTF/(gVSS·h), respectively, in the reversed AAO and AAO processes (c.a. 9 % higher in reversed AAO). The TTC-DHA activity of reversed AAO and AAO have a similar dependence on aeration hours. However, the TTC-DHA in the reversed AAO increased more rapidly than the AAO process, while the nutrients were also more rapidly removed in the reversed AAO. Therefore, the aeration time in the oxic compartment was reduced, which reduced energy consumption and HRT. The effect that perfectly correlates the high values of INT-ETS in the reversed AAO. In addition, the DHA and ETS trends were in agreement, indicating that the reversing of two compartments enhanced the microbial activity in the reversed AAO. With higher DHA activity, microorganisms in the reversed AAO process likely have stronger respiration activity. Higher ETS activity in the reversed AAO process means that more electrons are available to ultimate hydrogen acceptor than in the AAO process. The effect of the DHA and ETS in the reversed AAO process strengthens the hypothesis that with higher microbial activity, the amount of the phosphorus uptaken by the PAOs can be improved even under the condition that the PAOs released do not provide sufficient phosphorus in the former compartment.

Fig. 2 shows the concentrations of ammonia and phosphate present in time sequence. In the first 3 hours, the concentrations of ammonia in the two systems remained constant due to the absence of oxygen. The concentrations of ammonia in the reversed AAO and AAO were reduced to 1.53 and 3.45 mg L^{-1}, respectively. A significant difference in phosphate removal was observed for the two different systems. The phosphate in the AAO process increased to 47 mg L-1 and remained at the high level compared to the reversed AAO process. However, both processes had the same concentration of phosphate in the effluent, while less phosphate was released in the reversed AAO process. We believe that the high microorganism activity changed the behaviour of the phosphorus uptake in PAOs.

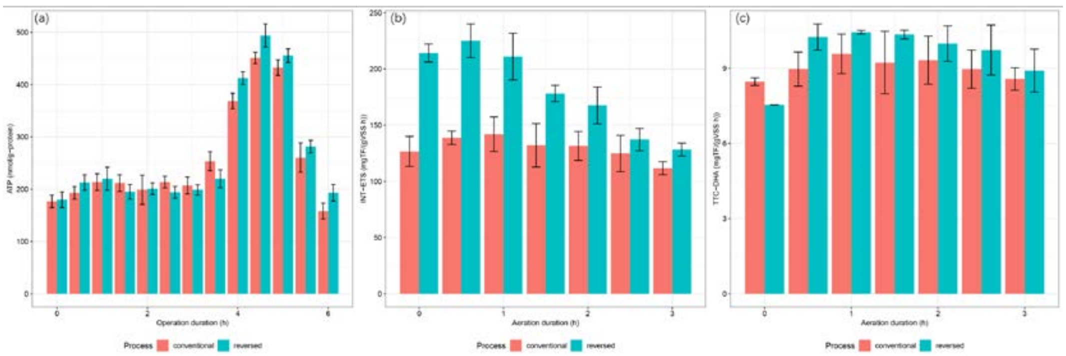

Figure 1. (a) ATP concentration, (b) INT-ETS activity, and (c) TTC-DHA activity in the two systems.

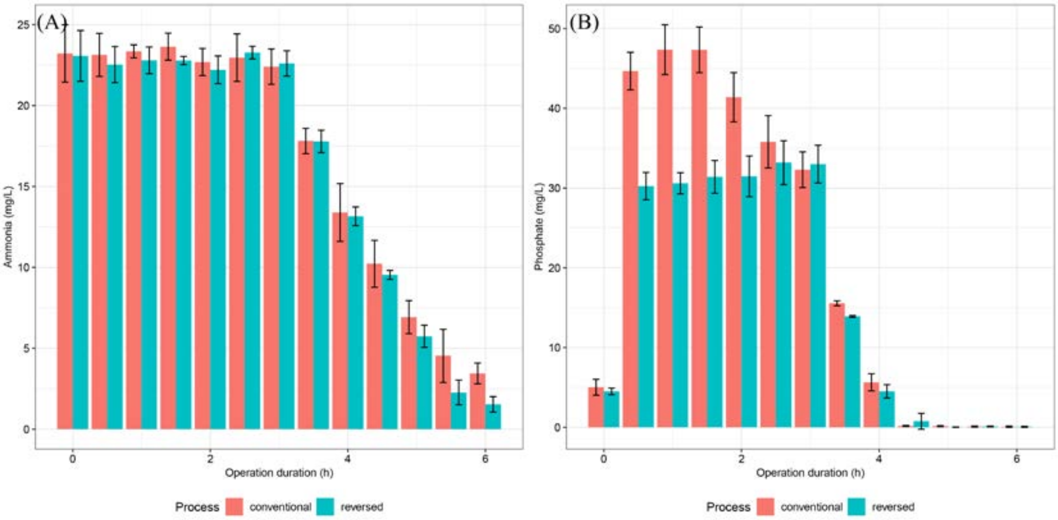

Figure 2. (A) Ammonia concentration and (B) phosphate concentration in two systems.

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Degradation of Bisphenol A by Ozonation in Rotating Packed Bed

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Abstract

Wastewater treatment by biological processes in cold climate poses a challenge because of the slower metabolism of microorganisms (Virpiranta et al. 2019). In this case ozonation, which can degrade the contaminants efficiently and improve the biodegradability of wastewater, is an attractive alternative to conventional processes. However, poor solubility caused by low temperature and the low mass transfer efficiency of conventional equipment for ozone absorption limit the process capability (Lee et al. 2003). In this study, Bisphenol A (BPA), a typical endocrine-disrupting chemical presented in various aqueous environments, was treated as the target contaminant in a rotating packed bed (RPB, Figure 1) by ozonation. A high-gravity environment is created in RPB, leading to the intensification of the ozone mass transfer and thus enhancement of the BPA treatment effect. The BPA containing wastewater was pumped into RPB via liquid inlet, then split and spread into droplets, threads and thin film due to centrifugal force. Meanwhile, ozone was introduced from gas inlet and contacted the liquid countercurrently to achieve the ozone mass transfer and BPA degradation. The effects of different operational parameters, such as ozone concentration, BPA concentration, RPB rotation speed, pH, gas flow rate and liquid flow rate, on the BPA degradation efficiency and total volumetric mass transfer coefficient (K_Ga) were investigated. The results show that the BPA degradation increases with higher RPB rotation speed, pH value, ozone concentration and gas flow rate, while it decreases with rising BPA concentration and liquid flow rate. K_Ga is enhanced by elevated RPB rotation speed, pH value, BPA concentration, gas and liquid flow rate, but it is weakened by increasing ozone concentration. Besides, the operational parameters in ozonation were optimized by Box-Behnken designed response surface method. A quadratic model was established and shows the influence priority on BPA removal is pH, ozone concentration, liquid flow rate and RPB rotation speed. It is found that the quadratic model fit well with the experimental data with a deviation no more than 12%. And BPA can be totally degraded under the optimum conditions determined by the model. This study is conducive to further research and application of ozone-based wastewater treatment methods in cold climate.

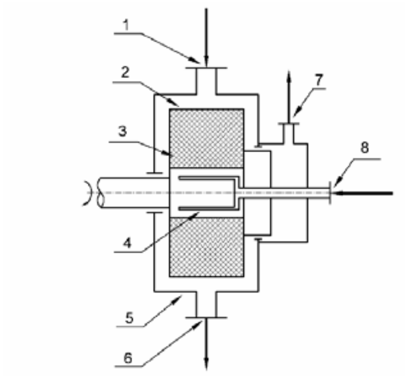

Figure 1 Structure of rotating packed bed.

(1) gas inlet; (2) rotator; (3) packing; (4) liquid distributor; (5) casing; (6) liquid outlet; (7) gas outlet; (8) liquid inlet

Keywords: Bisphenol A, Ozonation, Rotating packed bed

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Prototyping an image analysis sensor for coagulation process in wastewater treatment in cold climate conditions

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Abstract

Coagulation is one of the methods in wastewater treatment used to remove suspended solids, phosphates and other water contaminants. Proper control of the coagulation process ensures optimal process conditions with associated chemicals savings, lower accumulation of sludge and better wastewater characteristics in the outlet. Different control strategies for the coagulation process are used in water and wastewater treatment plants, but there is still a need to provide an accurate, reliable and cost-effective control solution (Ratnaweera & Fettig, 2015). Advanced dosing control systems based on multiple water quality parameters from online measurements have been confirmed to be successful (VA-Support, 2012). During the last decades, image analysis techniques were often applied in water and wastewater treatment industry to determine particle characteristics such as floc size, fractal dimension, strength and breakage (Chakraborti et al., 2003; Vlieghe et al., 2014). Feedback control systems in WWTPs suffer from long residence times which causes dead time in the signal response. A floc sensor based on image analysis may significantly reduce the dead time by adding the feedback control signal directly from the coagulation and/or flocculation chamber. This means the delay between a dosage point and the corresponding feedback signal from the process can be reduced compared to waiting for the wastewater quality parameters measured after the separation stage.

The image analysis of flocs appearing during the coagulation process was evaluated as a potential method for further floc sensor prototype development (Sivchenko et al., 2016; Sivchenko et al., 2017). The first sensor prototype and image analysis concept were tested in Skiphelle wastewater treatment plant (Drøbak, Norway) with the published results (Sivchenko et al., 2018). The prototype is being further developed to reach the ambition of an automized low-cost image analysis sensor.

The coagulation process and flocculants are affected by temperature, typically lowering the effectiveness with lower temperature (Fitzpatrick et al., 2004; Lou et al., 2012). The water temperature of the influent sewage was 8.5 $°C$ during the trial period with a maximum of 13.3 $°C$ and minimum of 6.4 $°C$. The low temperature may cause different floc characteristics and can therefore affect the image statistics captured by the sensor.

The prototype sensor is implemented on a Raspberry pi 3 B+ (RPi) connected to an IR-camera with UPS. The RPi is a relatively low-cost and flexible SBC which supports a plethora of practical software libraries and extensions. This allows for easy set-up and modification of the sensor during development. The IR-camera comes with an infra-red light-source which allows for image capture in dark environments. As the sensor will be working in wet environments the sensor hardware is encased in an IP68-rated box which has a transparent window for the camera. The entire apparatus is lowered into a flocculation chamber during operation. In this solution the RPi is set up

to perform the image capture, analysis and prediction on site. Once an analysis has been performed a control signal is generated and the unit transfers the results to an SQL server for easy access. The data-transfer is secured via a TLS/SSL connection over either IEEE 802.11ac or through IEEE 802.3. In case of bandwidth constraints images can be retrieved from the device itself during maintenance. The RPi has an ARM Cortex-A53 1.4GHz processor and a Broadcom VideoCore IV GPU which makes it suited for most image analysis tasks. However, to get high enough frequency of measurements to be useful in process control, careful selection and optimization of the analysis algorithm must be done. The current algorithm being evaluated uses the Grey level co-occurrence matrix (GLCM) texture analysis technique which is relatively light on computationally power requirements and has minimal image pre-processing needs. The technique produces GLCM feature vectors Contrast, Entropy, Homogeneity which are used with a PLSR model to create dosage predictions. The overall steps of the sensor algorithm are shown in Figure 1.

This method shows promise in reducing coagulant usage in coagulation chambers by providing accurate dosage predictions with reduced time lag.

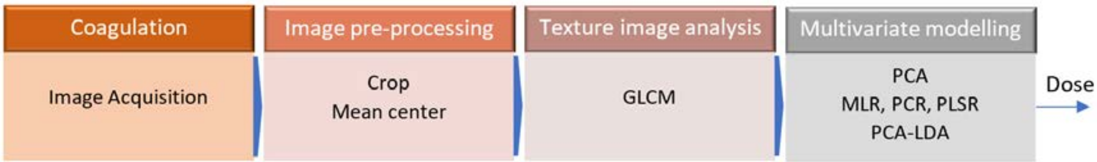

Figure 1 Algorithm steps of the floc sensor.

Keywords: image analysis; floc sensor; wastewater coagulation

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Electrode materials of Spent Li Ion Battery As Adsorbents For Removing heavy metals From the Aqueous Solutions

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Abstract

With the rapid development of industrialization and urbanization in China, the discharge of industrial wastewater continues to increase, which leads to serious heavy metal pollution in water body (Wang et al. 2013; Lu et al. 2017). At present, biofiltration is often used to remove heavy metals in cold climate (Monrabal-Martinez et al. 2017; Monrabal-Martinez 2018). Furthermore, plant uptake and biofilm adsorption may also be influenced by temperature, and temperature did not affect heavy metal removals in general (Blecken et al. 2011). Therefore, it is very vital to find a material to remove water heavy metals in cold climate.

Recently, Li ion battery production has increased rapidly, and the problem of recycling a large number of spent batteries is becoming increasingly prominent (Zeng et al. 2017; Huang et al. 2018). Using traditional methods such as landfill and incineration to dispose of spent batteries causes pollution to the environment (Malkoc & Nuhoglu 2007; Zeng *et al.* 2015). The cathode of LIBs is the lithium mixed oxides, such as $LiFePO_4$, $LiMn_2O_4$, $LiNiO_2$, $LiCoO_2$, and $Li(NiCoMn)O_2$ (Zhang *et al.* 2018). Spent Li ion batteries anode material is mainly composed of carbon-based material residues, which is considered as the potential alternatives for preparation of mesocarbon microbeads in the process of wastewater treatment (Demiral & Güngör 2016). Mesocarbon microbeads is a common adsorbent with high adsorption capacity, large specific surface area and chemical stability (Inyang *et al.* 2014; Wang *et al.* 2014). In recent years, the removal of heavy metals from water by using spent cathode and anode materials as adsorbents has been studied. (Jung *et al.* 2016; Zhang *et al.* 2016).

Firstly, spent Li ion batteries were discharged and disassembled, the separated cathode and anode material is ground and sieved to obtain mesocarbon microbeads (MCMB) and $LiFePO_4$ having a particle diameter of less than 0.2 mm. Add 3% Na_2S into the 100 mL beaker, then add MCMB (Mass ratio of liquid/solid for MCMB/Na_2S is 1/10), and keep it in a homoeothermic water bath at 60 °C for 24 h. After oscillating at 60 °C for 2 h in an oscillating water bath, the filtered carbon materials are washed with distilled water till the pH of the solutions is neutral, and dried at 105 °C to obtain Na_2S modified mesocarbon microbeads (SMCMB).

The effects of adsorption time and initial concentration of Pb(II) on the adsorption of Pb(II) by SMCMB and $LiFePO_4$ were analysed, and discussed the adsorption isotherm and kinetics of adsorbent material. The adsorption effect of SMCMB and $LiFePO_4$ on Pb(II) is significant, the removal rate of Pb (II) was over 85% at the conditions of $Pb(NO_3)_2$ concentration is 100 mg/L, solid/liquid ratio is 5 g/L, pH value is 5.0, and contact time is 10 h, and the saturated adsorption capacity was 37.30 and 33.08 mg/g, respectively. **Figure 1** shows the adsorption isotherm and kinetics fitting curves of Pb(II) solution by SMCMB and $LiFeOP_4$. Adsorption isotherm experiments showed that the adsorption process of Pb(II) by SMCMB and $LiFePO_4$ can be described by Langmuir isotherm model (R^2 = 0.994 and 0.991, respectively) indicating that the adsorption of Pb(II) by SMCMB and $LiFePO_4$ could be a monolayer adsorption, and $0 < K_L < 1$ indicated that is beneficial to adsorption of Pb(II) by SMCMB and $LiFePO_4$. Adsorption kinetics experiments showed that the adsorption process of Pb(II) by SMCMB and $LiFePO_4$ can be described by pseudo second-order kinetic model (R^2 = 0.997 and 0.990, respectively), indicating that the adsorption of Pb(II) by $LiFePO_4$ and MCMB could be chemisorption.

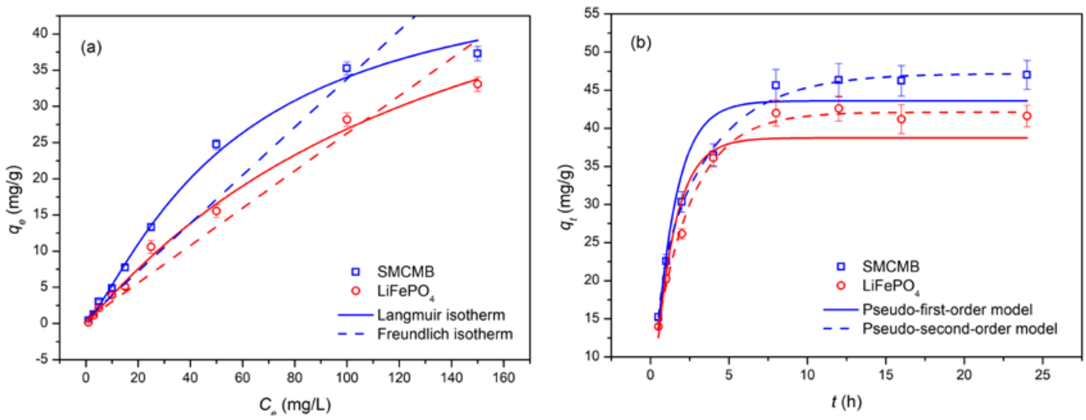

Figure 1 Fitting for the adsorption (a) isotherm and (b) kinetics of Pb(II)

Keywords: Spent Li ion battery; adsorption; heavy metal; wastewater treatment

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Energy- and reagents-saving analytical systems for monitoring of water quality in cold climate

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Abstract

Water quality monitoring is a unique challenge for communities in colder climates. The introduction of the principles of Green Chemistry (saving energy, reagents, etc.) into the analytical methods is a natural development trend in chemistry. ”Green” water monitoring stations should facilitate water quality control in such conditions.

Reduction in consumption of electrical energy, waste production and the costs of analysis ca n be achieved through automation of the analytical process. Flow analysis can be applied. The sample and the reagents can be inserted into a stream of liquid flowing into the detector. The most popular, commercially available flow systems, mainly used in clinical and environmental laboratories, rely on technology of continuous flow analysis (CFA) and flow injection analysis (FIA). The main disadvantages of these techniques are: low level of automation, consumption of a relatively large amount of energy and reagents. Peristaltic pumps commonly used in FIA are expensive, relatively bulky and heavy (1.5-5 kg), work with supply power of 125 V or 220-240 V and need periodic supervision. The complexity of such flow systems impedes their use in everyday lab work, especially in automatic monitoring stations.

A multi-pumping flow system (MPFS) based on the use electronically controlled actuators, solenoid-operated micropumps (Fig.1), offer excellent opportunities to reduce the supply power to 12 V and miniaturize the propulsion system. Solenoid micropumps work as automatic micropipettes and are responsible for accurate and precise dosing of reagents and propulsion of the reagents in a flow system.

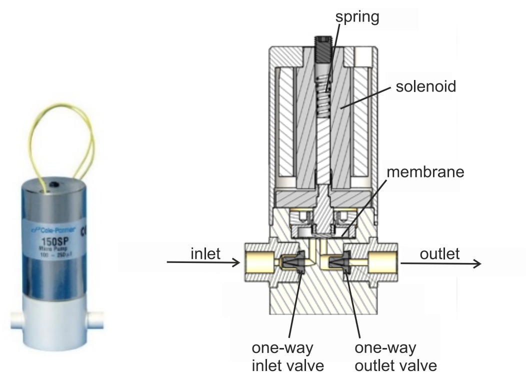

Figure 1. Photo and schematic drawing of a solenoid self-priming micropump. Typical volume of injected solution: 10-250 µL.

The operation of solenoid micropumps can be programmed with a computer. Micropumps can be connected with other elements (e.g. solenoid-operated valves), resulting in the flow network.

To save the reagents used and reduce time of analysis, the concept of several direct-injection detectors (DID) has been developed (Kalinowski and Koronkiewicz 2013-2018). The micropumps inject the sample and reagents directly into the reaction-detection chamber of the DID. Volumes of the injected solutions are in a range of 10-20 µL (lower than the total volume of the DID chamber). Unnecessary dilution of reagents and dispersion process are avoided. Two flow systems dedicated for monitoring water quality have been developed so far: one system for photometric determination of total iron (Koronkiewicz and Kalinowski 2012) and another for determination of dissolved reactive phosphorus (Fig. 2, Koronkiewicz et al. 2018).

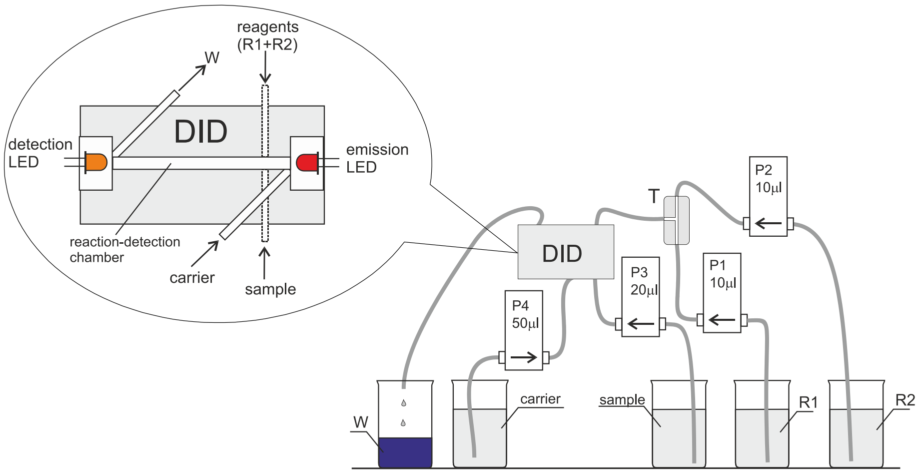

Figure 1. The flow system for orthophosphate determination. DID - direct-injection detector; P1, P2, P3, P4 - solenoid micropumps; T - three-way connector; R1 - ammonium molybdate; R2 - ascorbic acid.

Our results indicate that the chief advantages of the presented systems are: simple and compact construction, very good analytical characteristics, i.e. very high stability and repeatability, high sampling frequency, good sensitivity and accuracy, low volume of the reagents used and very low energy consumption. Therefore, these systems can be recommended for use in Green Chemistry monitoring stations powered e.g. by solar or wind energy. Such stations could work independently in cold climate conditions ensuring monitoring of key water parameters in order to ensure its proper quantity and quality.

Keywords: Flow analysis; Direct-injection detector; Water monitoring

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Problems and Countermeasures of Utilization of Micro-Polluted Surface Water Resource in Tianjin Binhai New Area (TBNA)

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Tianjin Binhai New Area (TBNA), located in the downstream of Hai River, is a city with serious water shortage. The average of water resource for each person there is less than 140 m^3/a. The water for living and production in TBNA is mainly from diverted water from Luan River and Hanjiangkou Reservoir. And water from upstream is used for ecological demand. With the promotion of the national strategy for Beijing-Tianjin-Hebei coordinated development, TBNA is entering into a rapid developing period, which will put greater pressure on the already strained water resources, water environment and water ecology in this region. Therefore, it is urgent to find an effective way to break through the constraint of water resources.

In TBNA, there is a big amount of micro-polluted surface water which mainly consist of surface water from upstream and local storm water (Gao and Cui,2007). It can cause disaster, but on the other hand it is also good resource. Compared with the production of reused water and desalination of sea water, micro-polluted surface water treatment can achieve a better environmental and social benefit with lower cost. Therefore, strengthen the utilization of micro-polluted water can play an important role in alleviation the water shortage and promote the sustainable development in TBNA.

However, there are some challenges exiting which include:

① Unclear definition and strategic position of micro-polluted surface water in TBNA

There is no clear definition and strategic position of micro-polluted surface water in TBNA and even in China. Thus, a big amount of this kind of water is discharged into sea without any utilization.

② Micro-polluted surface water is not included into regional water resource planning in TBNA

According to the Planning of TBNA, in 2020, the diverted water will still play an import role, however, the utilization rate of local surface water will become lower (Gao, Wang, et al., 2010). For surface water from upstream, it is not even included in the local planning.

③ Uneven distribution of water resource in TBNA

On one hand, flood is always a disaster in TBNA. So, lots of flood water is discharged into Bohai Sea every year (Ma, 2007); on the other hand, because of water shortage in TBNA, a big amount of diverted water is need for local living and production.
Therefore, we propose the following suggestions:

① Make clear the definition and strategic position of micro-polluted surface water;

② Promote utilization of micro-polluted surface water by strengthening legislation;

③ Include the micro-polluted surface water into the TBNA Water Resource utilization Plan and adopt dual water supply;

④ Connect the water system (rivers-reservoirs-wetlands) to increase the storage and utilization of micro-polluted surface water;

⑤ Overall planning flood control and ecological water supplement;

⑥ Encourage multi-utilization of micro-polluted surface water in TBNA, with priority to ecological use;

⑦ Strengthen information disclosure and improve public awareness;

Key words: micro-polluted surface water; TBNA; water resource

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PU:REST—A beer brewed with purified sewage water

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Abstract

In May of 2018, PU:REST, Sweden's first beer brewed with recycled water was launched in Sweden. This project is a collaboration between IVL Swedish Environmental Research Institute, New Carnegie Brewery and Carlsberg Sweden. The water used in the beer comes from IVL's unique pilot and demonstration facility Hammarby Sjöstadsverk, where the water has passed through a chain of purification stages (Fig. 1). After thorough lab testing, the water was delivered to New Carnegie Brewery and the brewing team took over.

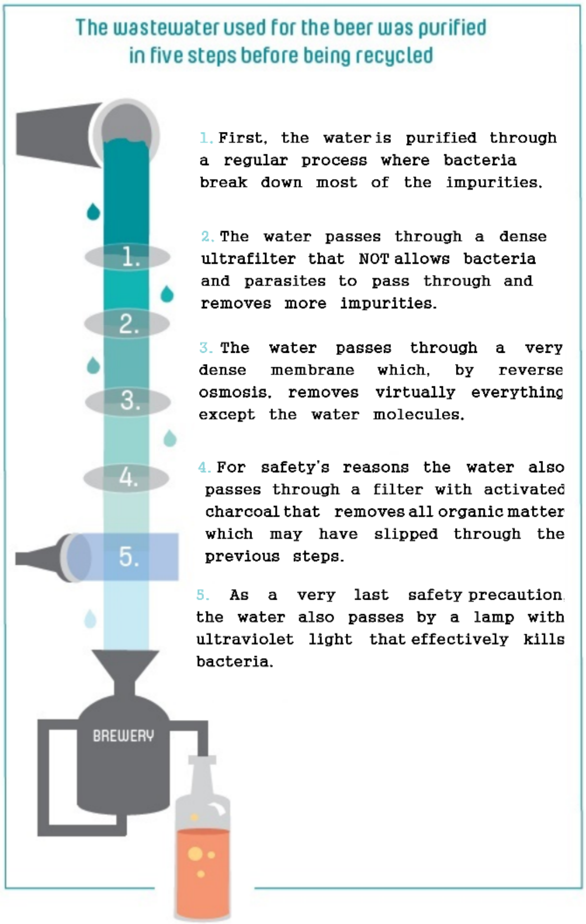

Fig. 1 The treatment process of the wastewater (IVL, 2018)

The main purpose of the project is to highlight sustainable water management and raise awareness of the global water issues and the value of clean water. In a world threatened by water shortage, IVL wants to show that we already have technologies to recycle wastewater into drinking water that is as clean as normal tap water. And these technologies can work in the cold area, e.g. Scandinavia and north part of China.

The resulting has been proved to be a creative success, raising awareness about the value of safe and demonstrate that wastewater can be made drinkable. IVL and partners have won a prestigious award for Best Business PR Campaign from SPINN and international interest from Business Insider, Bloomberg and Forbes magazine. In 2019, IVL also received the Global Energy Award for the PU:REST project.

Fig. 2 PU:REST—a beer made with purified sewage water (Huen, 2018)

Keywords: recycled water; sustainable water management; awareness raising

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Decentralized sanitary options for cold climate

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Abstract

The current sewer systems in the high north mainly consist of a collection system followed by direct discharge of untreated sewage. The cost of building sewer collection and transportation systems in the north can become very high, especially in areas of permafrost. Decentralized systems may be interesting both from a cost and treatment perspective, but many current decentralized solutions are primitive and contribute to health problems. The population density in the high north is low and when discharging wastewater to the sea it can be argued that dilution may solve the problem. This may be true for nutrients (nitrogen and phosphorus), but high loads of organic matter (BOD) and suspended solids (TSS) can cause local pollution of bays and coastal areas. Organic micropollutants as found in pharmaceuticals and personal care products (PPCP´s) are shown to accumulate in the food chain and have negative effects on wildlife, especially in the north. The organic micropollutants are a global problem, but they persist longer in the cold northern ecosystems of low diversity. Thus, the design of the treatment solutions may differ and more attention should be devoted to removal of organic micropollutants than in warmer regions. This paper explores the challenges of designing appropriate decentralized wastewater handling systems in the high north from an environmental, health and cost perspective and gives an overview of potential decentralized treatment systems. Solutions using source separation are especially interesting since they provide a cost-efficient way to handle and recycle pollutants and also give basis for local energy and food production, thus, generating circular economy.

Keywords: Decentralized systems; cold climate; circular economy.

Design consideration of urine reactor from UDDT at cold climate

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Abstract: Human urine that contains sufficient common nutrients (i.e. N, P, and K) is addressed as a good source of fertilizer. However, it may cause several severe environmental problems, especially water contamination while it is untreated and discharged to the water body. Recently, treatment of human urine is taking much attention. Amongst the treatment processes Urine-Diverting Dry Toilet (UDDT) has shown its effectiveness on on-site separation of the urine and feces as well as water saving and it is widely applied in the tropical regions. In contrast, the application of UDDT in the cold climate is still a challenge due to the lack of investigation on the effects of the low temperature on maintaining the urine nutrient values. This study therefore suggests possible design for the urine reactor in order to maintain the nutrients and to reduce the odor from the urine. In this research 3 diffferent designs of reactors were compared: anaerobic and aerobic conditions, addition of Effective Microorganisms(EM). This lab scale experiments were carried out under the 3 different temperatures: 20 ~ 25 ˚C , 10 ~ 20 ˚C and 0 ~ 10˚C. The change in urine pH, temperature, and the concentration of NH_3, NH_4, NO3 during winter is observed to evaluate the efficacy of the treatment process. Based on the results, an appropriate UDDT design can be suggested for cold climate, mainly focusing on water saving for urine treatment.

Keywords: Cold Climate, UDDT, Urine Treatment

Vermi-Composting for Treatment of Human Feces From Urine Diverting Dry Toilet (UDDT) in Cold Climate

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Human feces have been becoming a common issue over the world, even in the cold regions. Similar to dry toilet, Urine Diverting Dry Toilet (UDDT) is adopted as a water saving sanitation solution; and in addition, UDDT separately collects the urine and feces for further treatment. In this perspective, UDDT is suggested as a proper sanitation solution for the regions with the lack of access to the water supply and wastewater treatment. Due to the activation of the pathogen and parasite, and the presence of the high water content as well as strong odor, the feces must be treated for its reuse. Vermicomposting that is a method to treat human feces with earthworms is known as a successful Nature-Based Solution (NBS) in tropical and developing countries. In contrast, the approaching of vermicomposting is still facing to many challenges in the cold weather, i.e. technical design and social acceptance. Therefore, this research is focusing on the possible application of vermicomposting in the cold regions; aiming at human feces treatment for the households and public buildings. Specifically, the treatability of vermicomposting and the behavior of the earthworm are observed under various temperatures (c.a. 0-10^{o}C, 10-20^{o}C, and 20-25^{o}C). The results show that the room temperature (c.a. 20-25^{o}C) led to obtain better organic matter degradation and greater biomass of the worms. It was found that the heat generated during this process played the major role on the growth of the earthworms. The results from this research is fundamental to propose a technical design of vermicomposting process, allowing it to be a reliable tool for the human feces treatment in the cold regions.

KEYWORDS
Urine Diverting Dry Toilets (UDDT), Nature-Based Solution (NBS), Vermicomposting, Human Feces

Source-Separation and Resource Recycling - For Improved Resource Management and Sustainable Wastewater Treatment in Cold Climate

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Abstract

Wastewater is typically considered as a societal, economical and environmental challenge. The challenge is even more complicated in the extreme arctic climate, where in particular the photoperiod and temperature influence the biogeochemical treatment processes. Low temperatures in microbial sewage treatment processes not only affect microbial activity, but also strongly influence adsorption and sedimentation processes, the compositions of microbial film populations, and the total oxygen transfer efficiencies in biological aerated filters (Xu et al., 2014). The traditional wastewater treatment system requires, therefore, longer solid retention time (SRT) and thus increased reactor volume. These challenges may be addressed by considering wastewater as a resource, minimizing the amount of wastewater to be generated and treated, and by implementing carefully designed and integrated treatment and resource recovery systems. Wastewater contain energy, nutrients and water as renewable and recoverable resources. Resource recovery is more efficient when the wastewater stream from the toilet (blackwater) is collected separately in a low flush or vacuum system and is treated separately. Use of vacuum or low flush toilets results in significant volume reduction (up to 90% of the toilet water consumption).

This study demonstrates the development of technical solutions for the treatment of source-separated domestic wastewater streams (blackwater (BW) and greywater (GW)), as well as studies of processes related to the recovery of resources from treated black- and greywater. The possibility of local resource utilization through biogas production and the production of green biomass based nutrient recovery from wastewater was assessed. Most nutrients in domestic waste (water) originate from urine and faeces. Separate collection of BW from the rest of household wastewater streams resulted in a 64%, 61%, 75%, 85 and 88% reductions for COD, BOD, TSS, N and P, respectively (Moges, et al., 2017). Moreover, using vacuum toilet, a more concentrated BW in a small volume is produced. This blackwater is a feasible feedstock for direct treatment in anaerobic reactor systems (Elmitwalli, T.A. 2006; Todt, D, 2015). With compacted anaerobic technology, treatment of source-separated blackwater resulted up to 88% removal of the COD load with up to 70% of the COD being converted into CH_4 (Moges et al., 2018). Subsequent processing of the anaerobic effluent via robust post-polishing treatment and disinfection step produced sanitized, colourless and odour free liquid fertilizer with >80% of N and > 85% P recovery (Eshetu M.E., et al., 2018) as multi-nutrient solution.

The nutrient solution, rich in NPK, can be used for local agricultural production (such as hydroponic vegetable and animal feed production). Nutrient harvesting from blackwater or urine through microalgae biomass production has shown as emerging nutrient recovery technology by converting the N and P into biomass (Tuantet, K. et al. 2014, Fernandes, et al., 2017, Melesse, E.M, 2019). This implies that N and P can be stored in the form of microalgae biomass and the effluent quality from microalgae reactor meets the discharge permit limit. At the same time, separate treatment of greywater using multi-barrier treatment system (Moges, et al., 2017) can provide water as alternative source for non-potable uses. Hence, the system contributes to water saving and reuse which eventually alleviate the stress caused by increasing

demand for water. Moreover, energy and nutrient recovery from blackwater, which in combination with efficient water reuse, is the way to achieve a sustainable means of closing the resource loop while protecting the environment and public health. Figure 1 demonstrates the treatment chain and values of domestic wastewater as a source of water, nutrients and energy. This approach could be adapted in cold climate for improved resource management and sustainable wastewater treatment.

Keywords: resource recovery; source-separation; wastewater treatment.

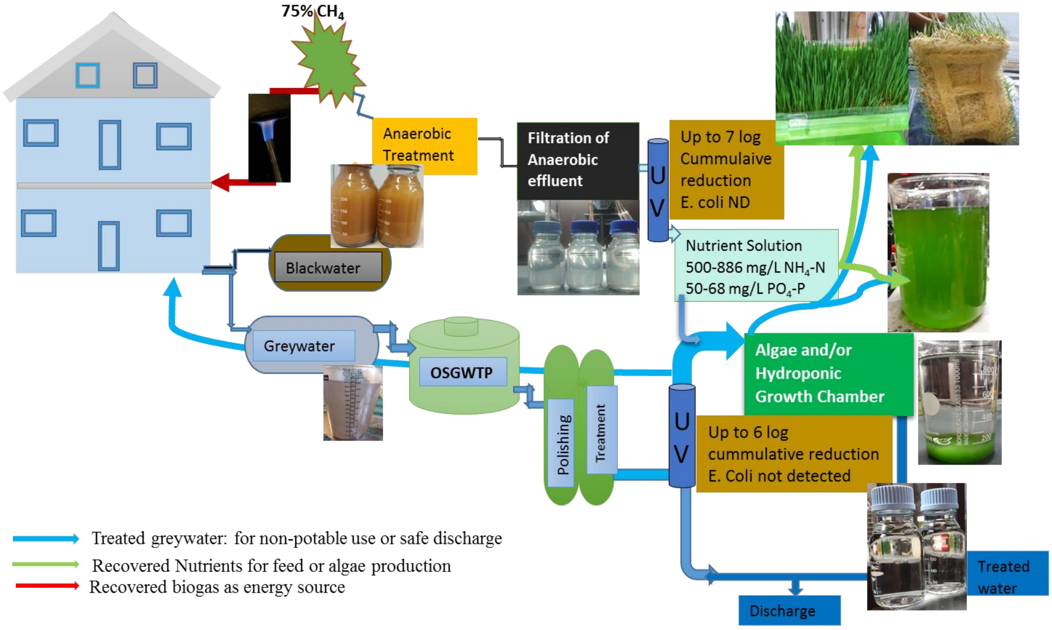

Figure 1. Domestic wastewater as a source for water, nutrients and energy (Melesse, E.M, 2019)

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PRODUCED WATER MANAGEMENT IN COLD CLIMATES

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EXTENDED ABSTRACT

Produced water (PW) is a by-product from production of oil and gas. The sources of produced water are mixtures of free formation water, condensed water and injection water during oil production. Metals and a varying amount of chemicals added during drilling and production processes makes PW hazardous. Quantities of PW from petroleum activities increase with age of producing fields, Figure 1, as well as with enhanced oil recovery technologies using water for injection. The negative environmental impacts of PW is minimized by implementing best available technologies (BAT) for separation of hydrocarbons.

Due to content of hazardous components, PW should be treated prior to discharge or reuse. Minimizing produced water close to the production source is a priority. Produced water re-injection (PWRI) is considered most environmentally friendly in dealing with such oily wastewater. Re-injection of PW into producing reservoirs simultaneously act as pressure support. Research shows that PW with modified ionic composition, smart water, also improve oil recovery, specifically increasing oil recovery from carbonate reservoirs. The overall process, however, is of high complexity and requires efficient pre-treatment. An alternative strategy for handling PW is disposal of untreated produced water into none producing aquifers (Figure 1).

The main requirement for reuse of PW as smart water for enhanced oil recovery (EOR) is defined with a specific concentration of determining divalent ions, especially sulfate, and reduced concentrations of monovalent ions. Proper methods for adjusting ionic composition prior to re-injection are crucial due to added cost and increased system complexity. Membrane separation is a most appropriate option to achieve desired ionic compositions of treated brines. The *novelty* of the research resides in combining the experience of PWRI for reservoir pressure maintenance with nanofiltration to generate smart water from PW.

The composition and characteristics of PW are strongly dependent on the origin of the water, oil quality and upstream processing. PW contains dissolved gasses, dissolved minerals,

dissolved organics including hydrocarbons, suspended oil or oil droplets, sand and drill cuttings as well as various production chemicals. The amount and composition of PW vary from one field to the other and during the lifetime of a field. Salinity of PW varies from 100 mg/L to 400,000 mg/L, compared with 35,000 mg/L for normal seawater. Table 1 presents PW compositions from different fields on the Norwegian Continental Shelf. Salinity varies significantly between fields. Njord, for example, has almost twice the salinity of normal seawater. Levels of barium and calcium, candidates for scale formation, vary. However, Njord and Gyda fields are significantly higher than other fields.

Enhanced oil recovery (EOR) by smart water injection in carbonates occur through wettability alteration. During this process, wettability alteration towards a more water-wet state takes place resulting in increased capillary forces, which stimulate spontaneous imbibition (Austad, 2013). The smart water brine composition and salinity are of high importance during the wetting process. It has been found out by many researchers (Austad, 2013; Strand, Høgnesen, & Austad, 2006) that wettability alteration is performed by ions such as Ca^{2+}, Mg^{2+}, and SO_4^{2-}. All these ions are present in seawater though sometimes a trace of SO_4^{2-} is present in PW as shown in Table 1. Smart water production from seawater has many advantages over other EOR methods such as no expensive chemicals added; seawater is easily available on an offshore platform and similarly reduce freshwater consumption.

It is desirable to re-inject PW after modifying its ionic composition as smart water for wettability alteration (Puntervold & Austad, 2007). PWRI is similarly desirable from an environmental and economic viewpoint since it decreases the quantity of treated PW discharged to sea and possibly reuse some of the added chemicals.

However, PW contains Ba^{2+} and Sr^{2+} that initiates scaling in contact with seawater containing SO_4^{2-}. This results in production loss and increased maintenance cost. Thus, the scaling ions are removed prior to PWRI.

Membrane technology has been widely used for reclamation of industrial wastewater due to reduced availability of freshwater. The oil and gas industries produce large amount of wastewater. Membrane technology provides an important tool in reusing and recovering oily PW, and recycling components present in PW.

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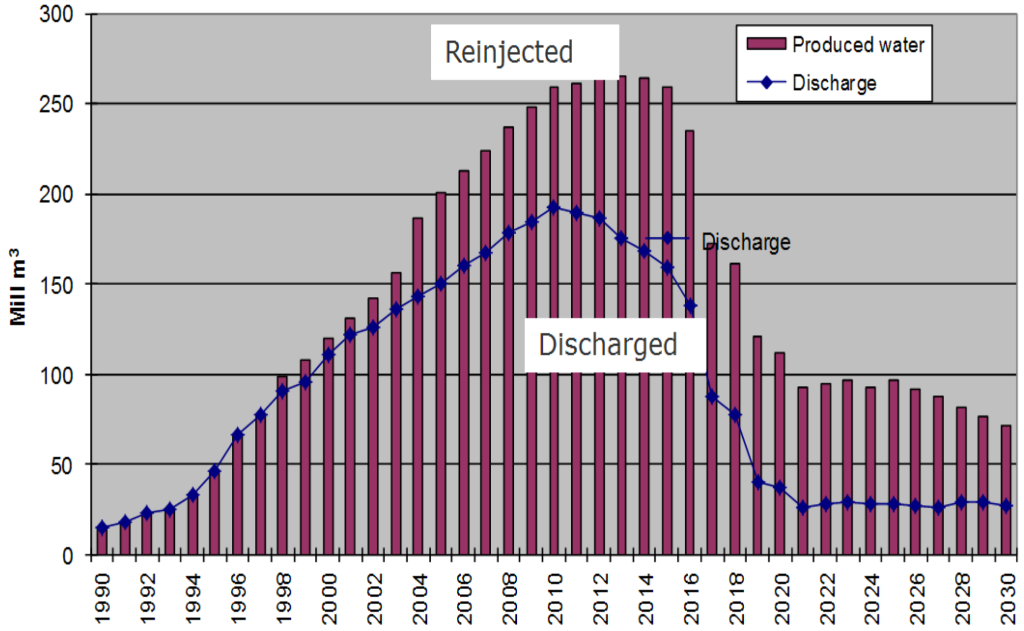

Figure 1. Produced Water Production and Discharge from Norwegian Continental Shelf

Table 1. Produced water compositions from the Norwegian Continental Shelf

Ion (mg/L)	Ormen Lange*	Oseberg	Njord	Gyda	Utsira aquifer**	Sea water
Na^+	4428	12500	19000	65340	10100	11150
K^+	90	335	747	5640	262	420
Ca^{2+}	220	978	4050	30185	494	435
Mg^{2+}	31	135	392	2325	714	1410
Ba^{2+}	19	134	765	485	6.7	0.1
Sr^{2+}	12	157	891	1085	12.1	6.6
Fe	0.6	0.1	23	-	5.7	0
Cl^-	6804	21900	41400	167400	18500	20310
SO_4^{2-}	7.9	5	15	-	2	2800
HCP_3^-	1008	633	230	76	1110	150
Organic acids	640	120	360	-	-	-
Salinity (TDS)	12650	36800	67513	272536	30100	36675

Oil spills under ice: Kinetics of oil spreading as a function of ice cover characteristics

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Abstract

Installed in 1953, Enbridge's oil pipeline "Line 5" transports 540,000 barrels per day of light crude oil and natural gas liquids beneath the Straits of Mackinac. American portions of Line 5 start in Superior, Wisconsin and across Michigan's Upper Peninsula, then across the lakebed in the Straits of Mackinaw before terminating in Sarnia, Ontario. Recent events have raised concerns about Line 5's safety and potential for spill potential in ice-covered conditions.

An ice cover may restrict the spread of oil by shielding the released crude from wind transport and partly immobilizing the spill. Absent turbulent conditions (<0.2 m/s), crude constituents should rise to the ice-water interface and pool at the ice's underside, with laboratory and field observations indicating that oil will coalesce, form a slick, and spread while resting on the ice-water interface. As a result, the morphology of the ice-water interface is of critical importance to the potential spread of oil.

In this study (Bessette et al., 2019; Gunn et al., 2019a; Gunn et al., 2019b), we simulate oil spills under ice in laboratory experiments with a water tank (Figure 1). Experimental variables include oil release rate and the nature of the ice cap (crushed ice vs integral ice cap). The working hypothesis is that the morphology of the oil plume follows the fractal scaling law and can be predicted based on the fractal dimension, D_f (Figure 2). Current work focuses on establishing a relationship between the structure of the ice-water interface, oil properties and morphology of the plume. The ultimate goal of the project is to develop a set of recommendations for under-ice oil spill remediation policy and best practices.

Keywords: oil spills, pipeline, Enbridge Line 5, ice

Acknowledgements

This material is based upon work supported in part by the Institute for Public Policy and Social Research (Michigan State University) through its Michigan Applied Public Policy Research program and the U.S. National Science Foundation Partnerships for International Research and Education program under Grant IIA-1243433. We also acknowledge financial support of V. T. Marinelli by the MSU Honors College Professorial Assistants program.

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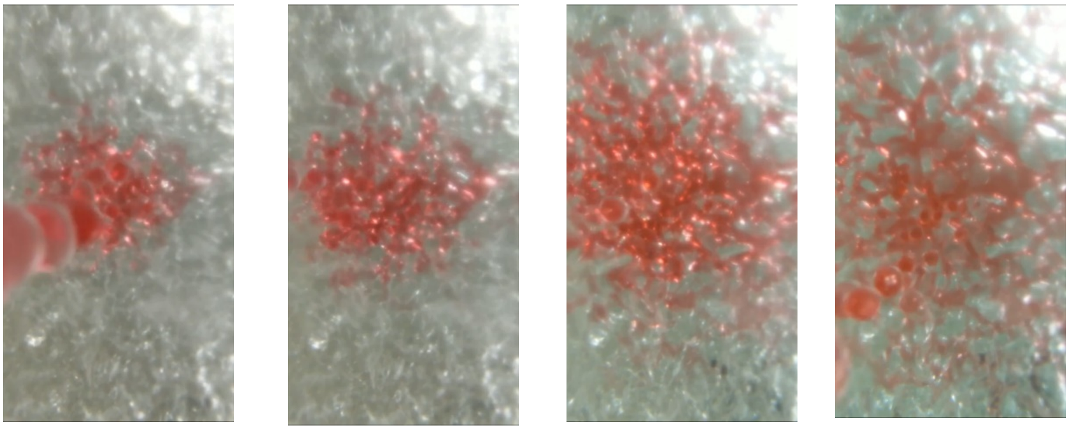

Figure 1. Evolution of an oil plume under crushed ice. Time stamps for the photos (from left to right) are 42 s, 60 s, 140 s, 200 s.

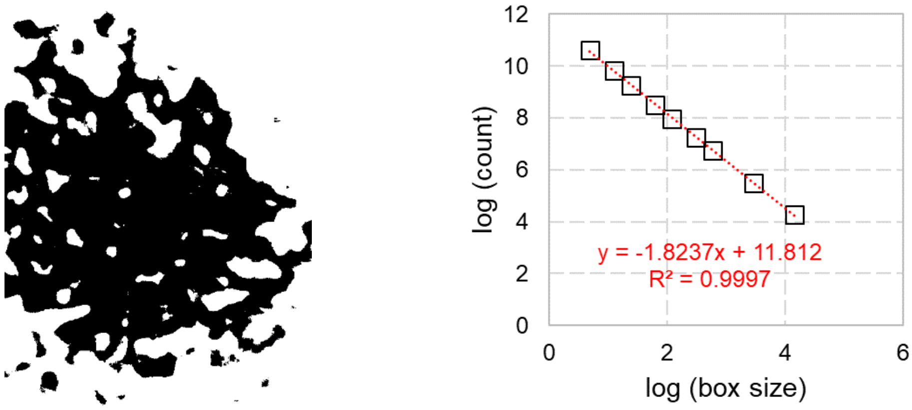

Figure 2. Left: Binary image of an oil plume under crushed ice. Right: Illustration of fractal scaling as a metric of oil spill morphology; fractal dimension D_f = 1.82 ± 0.03 was computed using the box count method applied to the binary image shown on the left.

Challenges in chemical cleaning of ultrafiltration membranes at low temperatures

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Abstract

The retention of organic matter by UF membrane is one of the widely discussed membrane applications that remains relevant due to the fouling – a decrease in the membrane efficiency with filtration time. The fouling is classified into reversible and irreversible when the former is easily removed without the use of chemicals. The irreversible fouling can be restored by efficient chemical cleaning that is often performed with standard protocols with constant concentrations of cleaning agents (Shi *et al*., 2014). Field *et al.* (2008) suggested to divide the cleaning agents into three broad categories of strong bases such as NaOH, strong acids such as HNO_3, and strong oxidising agents such as NaOCl. The goal is to restore the initial flux, typically by a shocking cleaning with higher than optimal cleaning doses (Arkhangelsky *et al*., 2015; Levitsky *et al*., 2016). The adverse effect of the approach is the changes in hydrophilicity, pore size, and surface charge, of fouled polymer membranes (Levitsky *et al*., 2011). Temperatures of filtration and cleaning is one of the less addressed parameters that affect the fouling, the chemical cleaning, and the integrity of polymer UF membranes.

The experiments were performed with pristine 300 kDa polyethersulfone (PES) membranes fouled for one hour with a mixture of organics that contained proteins, fats, carbohydrates, and organic acids. The fouled membranes were cleaned separately by water, nitric acid, caustic soda and liquid bleach. Both filtration and cleaning stages were performed at 5, 10, 20, 30, 40 and 50 °C. The degree of fouling and the efficiency of cleaning were evaluated by flux profiles, zeta potential, contact angle, atomic force microscopy AFM, scanning electron microscopy SEM, and attenuated total reflection - Fourier-transform infrared spectroscopy ATR-FTIR.

Figure 1 presents changes in transmembrane flux of a 300 kDa PES membrane periodically cleaned with HNO_3 and NaOH. A typical filtration experiment was a sequence of six cycles. Each cycle includes 1 h fouling, 5 min chemical cleaning, and 5 min deionized water rinse. The fouling stage was conducted with 0.6 g/l Similac 1 baby formula that contained 65 mg/l total proteins, 158 mg/l fat and 348 mg/l carbohydrates. The cleaning was performed with 10 mg/l HNO_3 or NaOH at 5, 10 and 20 °C.

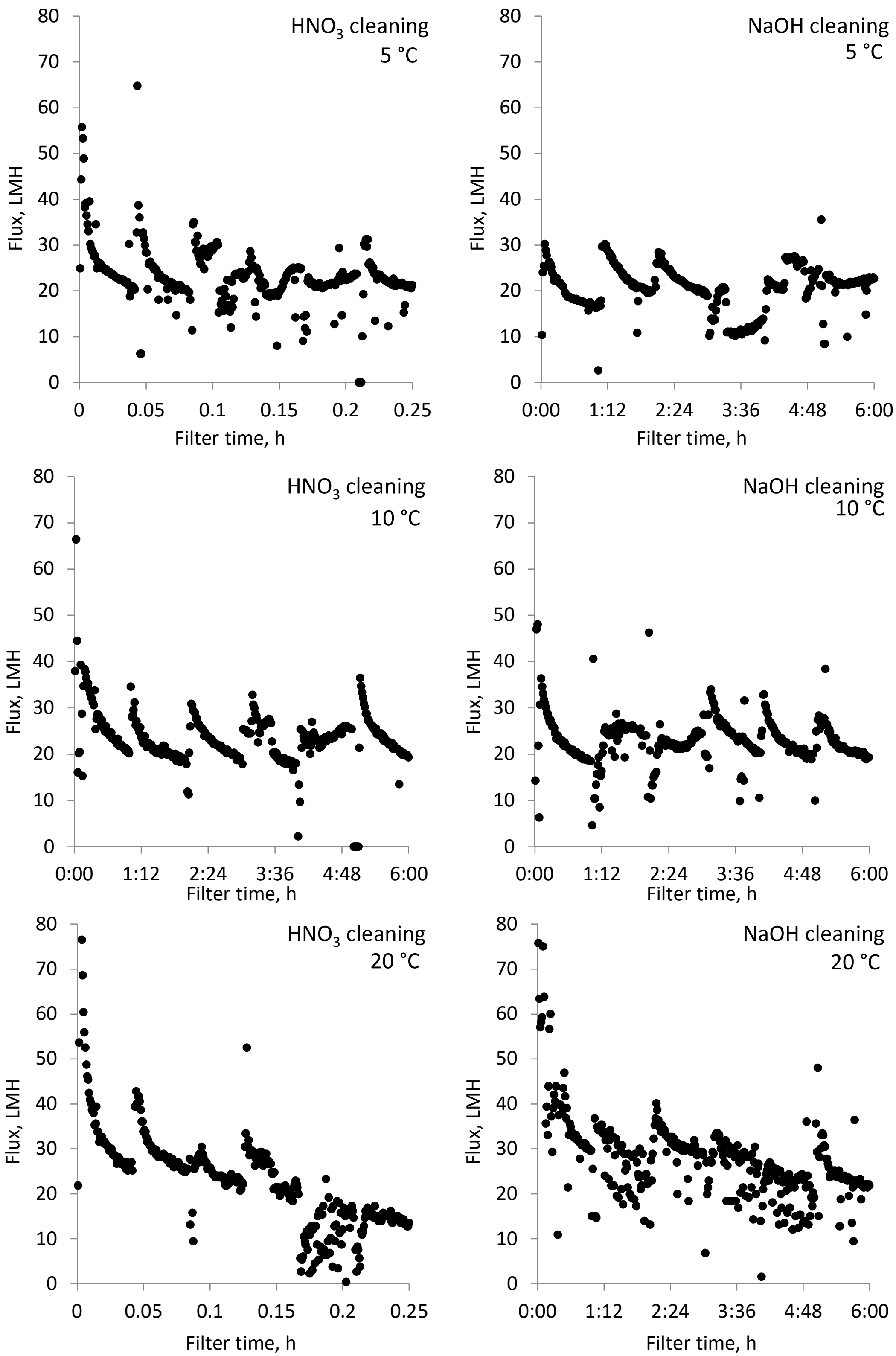

Figure 1. Evolution of flux as a function of filtration time through PES-300. The fouling with 0.6 g/l Similac 1 baby formula, the cleaning with 10 mg/l HNO_3 (left) and NaOH (right) at 5 (top), 10 (middle), and 20 (bottom) °C.

All plots showed a significant drop of transmembrane flux, from 70 to less than 30 litre/m^2-h (LMH), during the fouling of pristine membrane. As well, the first cleaning successfully lifted the flux to 40-50 LMH domain for all three temperatures. From here, the flux gradually decreased towards 30 LMH at the end of the second filtration period. The fouling at low temperatures was less severe, and the cleaning at low temperatures was more successful than at ambient conditions. The pattern was consistent and observed for both cleaning protocols. Previous studies reported more severe fouling at low temperatures (Alresheedi and Basu, 2019).

The observed behaviour was investigated further with AFM that shows a spatial distribution of fouling layer at the membrane surface, as a function of fouling temperature (Figure 2).

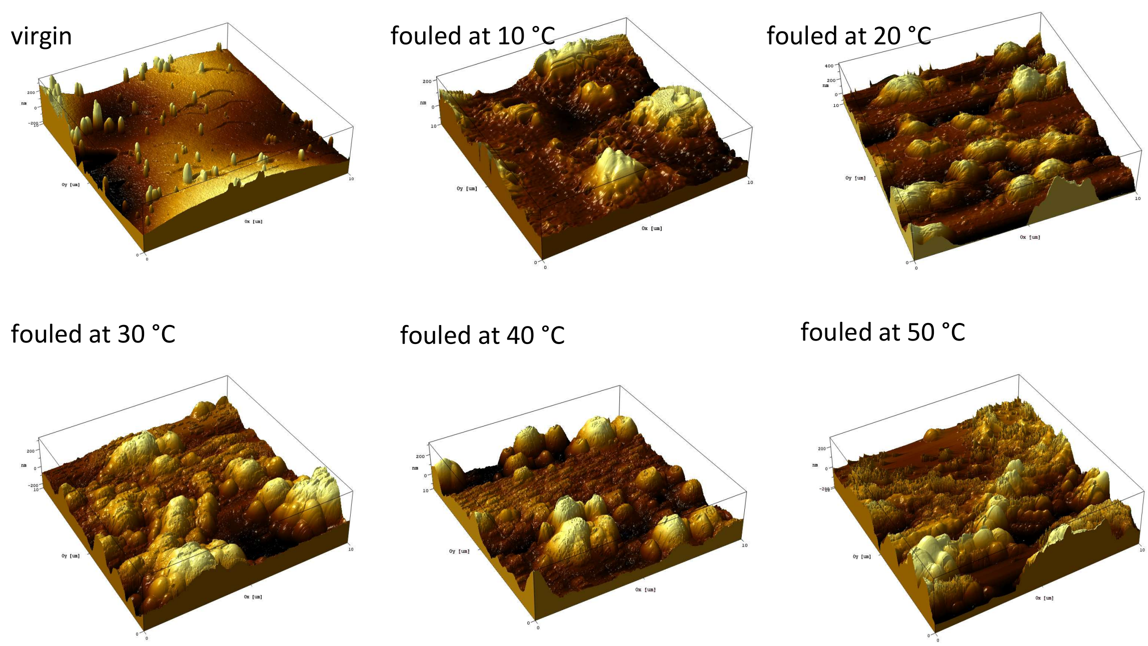

Figure 2. AFM of pristine (top left) and fouled with 0.6 g/l Similac 1 baby formula PES-300 membrane. The fouling was performed at 10 (top middle), 20 (top right), 30 (bottom left), 40 (bottom middle), and 50 (bottom right) °C.

The virgin membrane has a smoothest surface as expected, and fouled membranes present a rougher surface. The higher roughness is evident through bigger difference between bright and dark surface regions that indicated the highest membrane surface points and membrane pores. Although all fouled membranes display rough surface, the membrane fouled at higher temperatures display a more uniform spread of foulants on the membrane surface. A number of contact points between organic foulants and the membrane surface is higher, the fouling layer is more uniform, the resistance to the flow is higher, and the ability to retain the initial flux with application of acids or bases is limited. Only strong oxidants will be able to partially destroy the foulants and restore the initial flux (Arkhangelsky *et al.*, 2015; Levitsky *et al.*, 2016). The fouling at low temperatures places big chunks of foulants on the membrane surface. The number of contact points between the foulants and the membrane surface is smaller, the fouling layer is irregular, the resistance to the membrane flow is local, and the initial flux can be restored relatively easy with mild cleaning regimes.

Filtration at low temperatures brings high fluxes and less organic membrane fouling. Sensible changes in foulant size and solubility suggest a colloidal rather than organic type of fouling. Chemical cleaning of polymer UF membranes fouled at low temperatures using generic protocols increases the membrane vulnerability to structural changes. Cleaning with low doses of cleaning agents becomes comparably efficient to a physical cleaning such as back or surface washing. The obtained results and observed trends are important for a filtration of preserved dairy products with polymer UF membranes, and for a removal of organic matter by polymer UF membranes at cold climates.

Keywords: HNO_3; NaOH; NaOCl

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The effect of temperature on the biosorption of dyes from wastewater

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Keywords: temperature, dyes wastewater; biosorption

Abstract

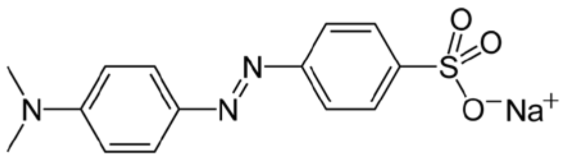
Any kind climate is first of all a result of the average temperature of all seasons, therefore determining the effect of temperature on the biosorption of dyes is very important, particularly because the dyeing process is usually carried out at high temperatures, which leads to the formation of hot textile sewage. Dyes use to appear in the outflow from the treatment plant, because the effectiveness of their immobilization is often unsatisfactory. In the treatment of dye wastewater, adsorption methods are often employed. In many contemporary works related to the natural environment, a great potential of biosorption is indicated (Ghaly et al. 2014). Initial own studies of gentian violet biosorption on live *Lemma minor* showed a much higher sorption capacity of this live biosorbent (regarding a dry mass), compared to granulated activated carbon. Biosorption, as remediation technology in water purification, can be defined as a total sorption process, i.e. adsorption and absorption of contaminants on a living or dead biosorbent. This phenomenon is accompanied by bioaccumulation and metabolism of some pollutants in the organism of the living biosorbent (Goblick et al. 2011). At the biosorption defined in this way immobilization of dyes occurs both in the area of surface phenomena (Smoczyński et al. 2019) and bioaccumulation, not excluding their metabolism in the "living" biosorbent. In practice, often use a variety of materials-biosorbents such as: fungi, yeast, molds, aerobic and anaerobic bacteria, algae and other algae, leaves, shells and shells, eg nuts, almonds or rice, wood, sawdust, various plants, agricultural waste or, e.g., seafood.

Determining the effect of temperature on the biosorption of dyes is very important, because the dyeing process is usually carried out at high temperatures, which leads to the formation of hot textile sewage. The influence of temperature on the speed of chemical reaction in the simplest way is determined by the empirical rule of van't Hoff's rule. According to this rule, an increase in T of 10 ° causes a 2-4 fold increase in the reaction rate; an increase in T from 20 ° C to 100 ° C ($\Delta T = 80$ °) can shorten the duration of the reaction, e.g. from 1 hour to 1 minute. In general, the reaction rate is measured experimentally at several temperatures (minimum at two different T), after which the linear dependence of the Arrhenius equation is analyzed: $\ln k = f(1/T)$ (where k is the rate constant) and finally determines the activation energy E characterizing the course of a given reaction. From the point of view of chemical statics and technology, the influence of temperature on the equilibrium constant of reaction is often important. For this purpose, heat of reaction Q should be determined at several temperatures (minimum at two different T) and, eg from the equation of the isobare Vant't Hoff, determine the relationship: $\ln K = f(1/T)$ (where K - constant equilibrium).

In such a natural and logical context, the question may arise whether biosorption processes will occur sufficiently efficiently in regions of the world characterized by a cold climate, i.e. in North China, for example. In order to, even partially, answer the question formulated in this way, a review and analysis of a fairly obvious database on the influence of temperature on the biosorption processes of dyes from aqueous solutions and wastewater was made. Hence the 36 scientific papers on the influence of temperature (T) on biosorption (Bios) of various dyes from aqueous solutions and wastewater were reviewed. The authors of 16 papers clearly state the positive influence of T on Bios, generally indicating the chemical nature

of this process. At the same time, the authors of the next 10 publications confirm the positive effect of T on Bios, with an initial T-rise from approx. 20° C to approx. 30-40° C, while at higher T, they indicate a decrease in Bios efficiency. It is in this group of works that record results in the form of even 3-4 times increase in Bio with an increase in T of 10 - 20° C. The authors of the next 10 works clearly state the negative impact of T on Bio. They generally point to the physical nature of this process, however indicating its limit, only up to a 15-50 % decrease of Bios with an increase in T. In this way, in general, it can be concluded that the increase in temperature in the lower range, eg from about 20 to about 30° C, in most cases positively affects the biosorption of dyes from aqueous solutions and/or wastewater, while the overall increase in T rather positively affects the efficiency of the process. It can be cautiously suggested that the not too large increase of T favourably affects the biosorption of the red and reactive dyes.

The colour of the dye is strictly dependent on its structure, and in particular on the type of chromophore group (groups) in its molecule.



auxochrome -NH_2 chromophore -N=N- hypsochrome -SO_3Na

Figure 1. Structure of methyl orange (salt).

In fig. 1 a structure of the common-known methyl orange (MO) is presented. As every dye the MO contains chromophoric, auxochromic and hypsochromic groups, and because of -SO_3Na group the MO might be considered as salt: anion = …-O^- and cation = Na^+.

In turn, the structure of the dye molecule determines its shape and size, and thus a better or worse fit to the so-called active centres on the surface of the bio sorbent. It is difficult to over-generalize these issues, however, based on the data collected and considered, an attempt was made to analyze the effect of temperature on the biosorption process depending on the type of biosorbed dye. Most data, as many as 16, were collected on the subject of blue and violet dyes. In this database 9 times positive (+) T effect on Bios was found, 5 times negative (-) T on Bios and 2 times a positive first, and at higher T negative (+/-) T on Bios. In the group of red dyes, 4 times was +/-, 3 times was +, 1 time was - and 1 time was no effect. For reactive dyes 5 was +, 2 was - and 1 was +/-. In the group of acid dyes, 4 times was +/-, 1 was +, 1 was - and 1 was no effect. Summing up the analysis of the effect of T on Bios depending on the type of biosorbate, one may cautiously suggest that the not too large increase in T (eg about 10° C) favourably affects (+: -) the biosorption of the following types of dyes: red 7:1, reactive 6:2 and blue 11:5.

In this way, in general, it can be concluded, that the increase in temperature in the lower range, eg from about 20° to about 30° C, in most cases positively affects the biosorbing of dyes, while the overall increase in T positively affects the efficiency of the biosorption process.

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Study on immobilization/stabilization of Heavy Metals Contaminated Sediments in North China

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Abstract

With the increasing waste discharges by anthropogenic activities, such as mining, metal smelting, manufacturing, fertilizer and pesticide use, a large number of sediments in rivers and lakes have been contaminated severely by heavy metal, which has become a major environmental concern (Sekulić *et al.* 2018; Li *et al.* 2019). In addition, use of de-icing anti-skid agents in cold climate areas will also cause heavy metal pollution in cities (Blecken *et al.* 2011; Monrabal-Martinez *et al.* 2018). Sediment probably acts as a source of contaminants, and causes the deterioration of water quality (Feng et al. 2019; Moore et al. 2019). Compared with conventional technologies for polluted sediment remediation, less affected by temperature, immobilization technology could reduce solubility, mobility and bioavailability of heavy metals, lowering the risk of heavy metals exposure by precipitation or sorption (Khan *et al.* 2015; Yi *et al.* 2017). Low temperatures may have practically no influence on filtration of metals associated with solid particles and the metal adsorption in the filter media (Blecken *et al.* 2011).

Therefore, we have studied the heavy metal adsorption performance and the immobilization/stabilization ability of some adsorbents, such as the Modified clinoptilolite, Citric Acid-Modified Clam Shells, $Ca(H_2PO_4)_2$, $CaCO_3$, and HAP.

The objective of this research was to investigate the performance of using calcium dihydrogen phosphate ($Ca(H_2PO_4)_2$), $CaCO_3$, and hydroxyapatite (HAP) as immobilization materials to remediate Zn, Mn, Pb and Cd contaminated sediment in contaminated river in Jinan City, north China. The remediation performance of immobilization materials was also studied by toxicity characteristic leaching procedure (TCLP).

$Ca(H_2PO_4)_2$, $CaCO_3$, and HAP were mixed with the sediment sample with 1%, 5% and 10% (mass ratio of immobilization materials/sediment), respectively. Then the water (the mass ratios of water/sample were 10:1) was added to the sediments,

followed by stirring once a day for 7 days and keeping stationary for 7 days. The immobilization effect of heavy metal in the sediments was evaluated by toxicity characteristic leaching procedure (TCLP) and Community Bureau of Reference (BCR) sequential extraction procedure (Zhang et al. 2019).

Table 1 shows the leaching amount of heavy metals under different dosages of immobilization materials. The leaching amount of heavy metals decreased significantly after the application of immobilization materials. When the dosage of immobilization materials is 5%, the leaching amount of heavy metals in different immobilization materials has obvious difference. Especially at 10%, the immobilization effect of HAP on Zn, Mn and Cd were obviously better than that of other immobilization materials, and the leaching amount decreased by 76.79%, 26.34% and 84.55%, respectively. And the Pb immobilization effect by $Ca(H_2PO_4)_2$ is better than that of other immobilization materials, and the leaching amount decreased by 81.90%.

Table 1 Leaching amount of heavy metals

Immobilization materials	Dosage	Zn ($mg \cdot kg^{-1}$)	Mn ($mg \cdot kg^{-1}$)	Pb ($mg \cdot kg^{-1}$)	Cd ($mg \cdot kg^{-1}$)
Control		948	224	2.1	0.11
$Ca(H_2PO_4)_2$	1%	709	220	1.22	0.072
	5%	505	202	0.77	0.043
	10%	340	185	0.38	0.021
$CaCO_3$	1%	780	210	1.8	0.072
	5%	380	190	1.4	0.041
	10%	325	170	0.75	0.022
HAP	1%	774	208	1.3	0.067
	5%	325	187	0.8	0.038
	10%	220	165	0.4	0.017

In summary, for immobilizing Zn, Mn, Pb and Cd contaminated sediment, HAP has better effect than $Ca(H_2PO_4)_2$, and $CaCO_3$, the change of heavy metals speciation after the immobilization would be discussed in the further research.

Key words: Immobilization materials; immobilization; heavy metals

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Contaminants of emerging concern (CECs) in background and effluent waters from Northern Europe and the Arctic

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Abstract

During the past decade, the development and application of new, highly sensitive trace analytical instruments and methods have resulted in the identification of a large number of organic contaminants of emerging concern (CEC) in Northern and Arctic environments (Donaldson et al. 2010; Riget et al. 2016; Routti et al. 2019). The recently published Arctic Monitoring and Assessment Programme (AMAP) assessment on CECs is a comprehensive testimony of the wide array of contaminants currently investigated in the Arctic environment(AMAP 2017). During the past decade, the list of priority CECs considered as relevant for Arctic pollution assessment was expanded into new flame retardants (i.e. organophosphorous flame retardants (OPFRs)), personal care products (e.g. synthetic musks and cyclic siloxanes), pharmaceuticals, surfactants, food stabilising chemicals and many more. Moreover, the recent assessments and scientific reports on CECs in the North revealed a surprising complexity of sources, distribution processes and transformation pathways(Carlsson et al. 2018; Daley et al. 2014; Heidam et al. 2004). By collating existing research and monitoring results, a comprehensive assessment will be presented where scientific understanding of the sources profiles and environmental fate of anthropogenic contaminants will be combined. Knowledge gaps and recommendations for future research priorities will be presented. Future investigations on sources, distribution pathways, as well as potential effects on humans and wildlife will be an integrated part in these assessment strategies. Our presentation will illustrate the application of new research results in regional screening and monitoring activities with several relevant examples(Kallenborn et al. 2018; Kärrman et al. 2019; Skaar et al. 2019). The transport and distribution pathways of cyclic siloxanes, novel flame retardants as well as documented local contamination issues on pharmaceutical residues in the Northern and Arctic decentralised communities will be presented and discussed. The challenges of thorough quality control and method validation for screening and monitoring CECs and its importance for the proper interpretation of research and monitoring results will be elucidated in the presentation. In addition, the final implementation in regional and even global regulatory frameworks will be discussed and elucidated. The close interdisciplinary linkage between environmental chemistry, toxicology, fate modelling and monitoring, environmental assessment and regulation is considered as mandatory for sustainable environmental regulations in the Arctic environment. This is especially true in a time of potential conflicts between environmental concerns and other important economic and strategic interests in the region.

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Distribution of Antibiotic Resistance Genes (ARGs) and Antibiotic Resistant Bacteria (ARBs) in Wastewater Treatment Plant

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Abstract: The distribution of antibiotic resistance genes (ARGs) and antibiotic resistance bacteria (ARBs) in different process in a traditional wastewater treatment plants (WWTP) were investigated in this study. The results showed that the content of ARGs in the influent was above 10^8 copied/L expect for ermA and ermC. In all treatment process, the removal efficiency of biological treatment process was the highest with the removal rate of over 96%, followed by disinfection with the removal rate of over 90%. The reduction of ARGs by the primary settling tank and the coagulation/filtration process is not ideal. After treated, the content of ARGs in the effluent was over 10^4 copies/L with the exception of ermA and ermC. The influent of the WWTP contained ARBs of 10^7~10^8 cfu/L. The overall treatment efficiency of the four kinds of ARBs could reach to over 99.9%.
Keywords: antibiotic resistance genes; antibiotic resistance bacteria; distribution, wastewater treatment plant

The abuse of antibiotics leads to the enrichment of antibiotic resistance genes (ARGs) and antibiotic resistance bacteria (ARBs) in wastewater. The treatment efficiency of ARGs and ARBs by the wastewater treatment process in wastewater treatment plant (WWTP) determined the content of ARGs and ARBs in the treated water and whether the treated water will have negative impact to the aquatic ecosystem of the receiving water. In this paper, the distribution of ARGs and ARBs in a domestic WWTP was studied. The biological treatment process of this WWTP is MSBR, the coagulation/filtration process is used for tertiary treatment, and NaClO is used to disinfect the treated water before discharge.

In this research, the distribution of 20 kinds of ARGs in different treatment process were investigated, the results were shown in Figure 1.1.

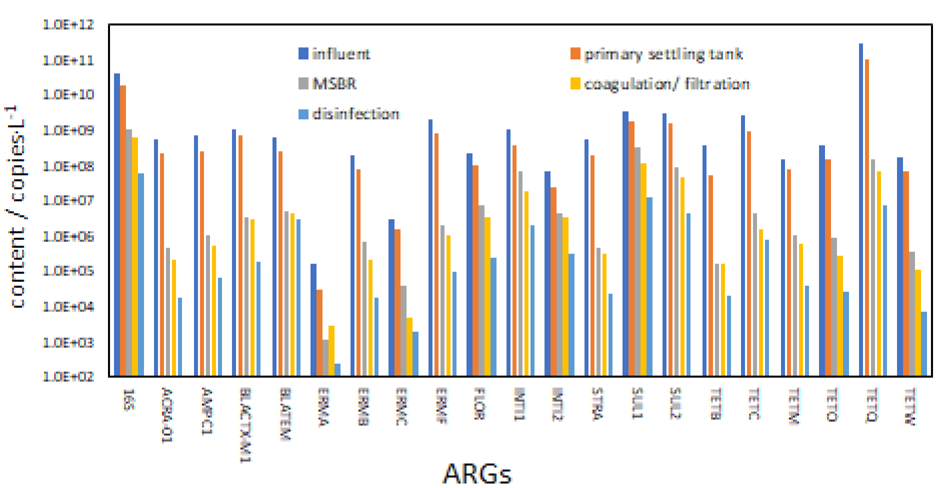

Figure 1.1 Content of ARGs in treated water by different treatment process

The content of ARGs in the influent was over 10^8 copied/L with the exception of ermA, ermC and intl2. The content of tetQ in the influent is the highest among the detected ARGs with the copies of 3.03×10^{11} per liter, followed by sul1, sul2, ermF and tetC. The content of ermA is the lowest in the influent. The current treatment process of this WWTP can reduce the ARGs efficiently. The reduction rate of all of these ARGs can reach to over 99%. In these treatment process, the removal ability of the biological treatment process and disinfection is the high with the removal rate of 96% and 90%, while the reduction by primary settling tank and coagulation/filtration is only 40%~65%. After treated, the content of ARGs in the effluent was over 10^4 copies/L with the exception of ermA and ermC.

The distribution of ARBs in different treatment process is shown in Figure 1.2. ARBs content in influent range from 1.0×10^7~3.33×10^7 cfu/L. Biological treatment process and disinfection have better removal effect on ARBs. But primary settling and coagulation/filtration process have relatively low ARBs removal efficiency. However, the overall reduction of four kinds of ARBs in this plant can reach to 3 log.

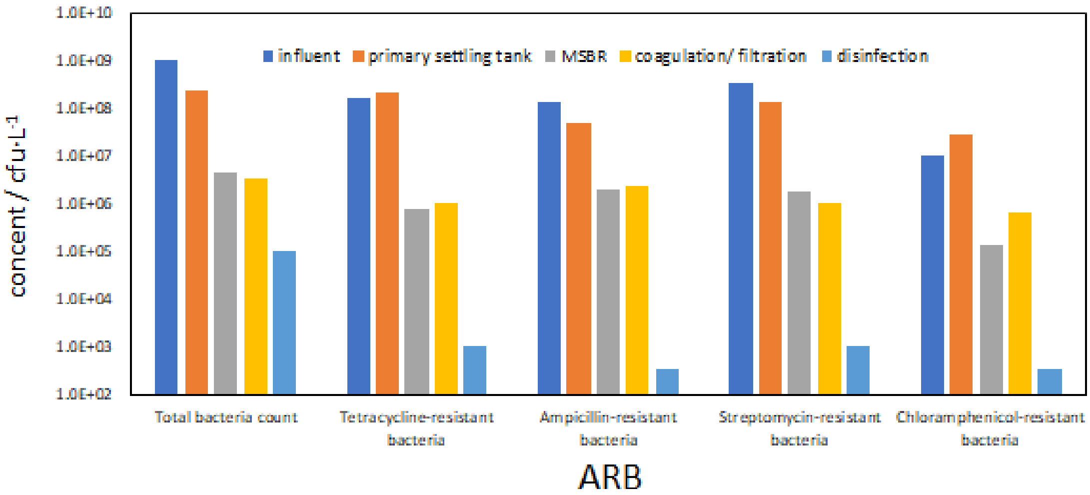

Figure 1.2 Content of four kinds of ARBs in treated water by different treatment process

The proportion of bacteria resistant to tetracycline, ampicillin, streptomycin and chloramphenicol changes during the treatment. In the influent, ARBs accounts for 13.8~32.3% of the total bacteria. After treated by primary settling tank, 21.7% bacteria can resistant to chloramphenicol, almost all bacteria can resistant to tetracycline, the proportion of bacteria resistant to ampicillin and streptomycin lies in these two figures. Biological treatment process can significantly reduce bacteria number, but the bacteria still have strong tetracycline resistance. Disinfection can significantly kill the resistance bacteria, the proportion of bacteria resistant to four kinds of antibiotics decreased to 0.32%~0.96% of the overall bacteria.

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A potential adsorbent ZIF-67 decorated with nanosheets for the removal of antibiotics, Cr (VI) ions and organic dyes

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Abstract

In this study, an eco-friendly and low-cost hollow metal organic framework with layered double hydroxides are prepared for waste water treatment via simple approach at room temperature. The prepared material exhibits high adsorption capacity because of its synergistic effect towards chromate Cr (VI) ions, antibiotic and organic azo dyes (methyl orange). Various batch experiments were performed to examine the influence of pH, temperature, concentration, and time. The activity of adsorbent at various temperatures including cold climatic conditions is also reported in the study. Adsorption capacities could be mostly achieved in the beginning of the reaction. The adsorption kinetics data matched well with pseudo second order model. The results indicate that prepared material is a promising applicant for the efficient adsorption of heavy metal ions, antibiotics and azo dyes from polluted water.

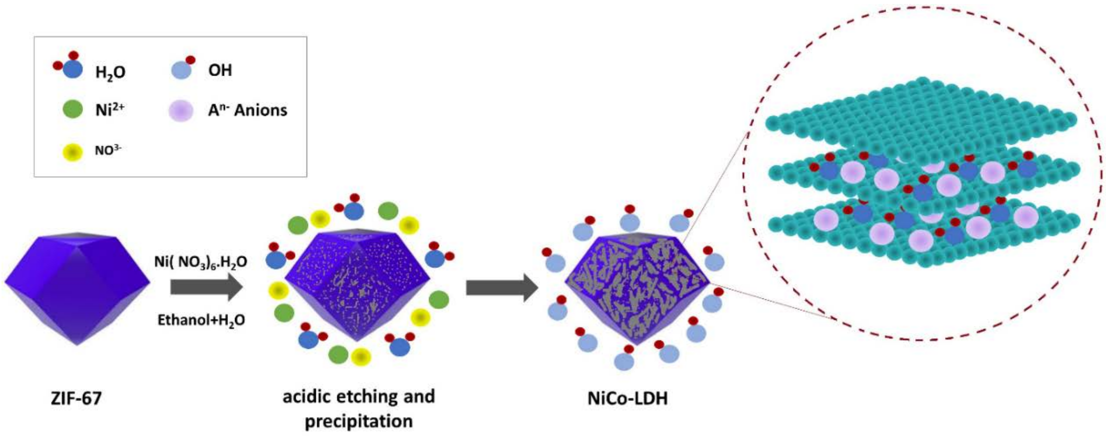

Figure 1 Schematic diagram for NiCo-LDH formation

Keywords: ZIF-67, adsorption, Chromate Cr (VI) ions, antibiotics, methyl orange.

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An innovative method for improving cold-resistant of activated sludge by composite ferric in the biomass

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Abstract

Ferric (Fe3+/Fe2+) plays an essential role in biochemical reaction, since ferric compounds are either the electron acceptors or intermediate electron transfer hub. This study is based on the hypothesis that a certain amount of Ferric Hydroxide (Fe(OH)3) addition will increase the biochemical reaction activity of microorganisms. Series of tests were carried out to verify the nitrogen removal and microbial community of the activated sludge composited with ferric. When the ferric salt dosage is within 3.4 -17.0 mg Fe /L, the nitrification efficiency was found rising with the increase of ferric composited with activated sludge. In the long term culture, highest nitrogen removal efficiencyPlease ensure that all figures are clearly labelled and easily readable in black-and-white printing.

Nitrification at low temperature is a challenge issue for biological wastewater treatment. Wang et al (2003) reported that nitrification could be enhanced by ferrous ion with the concentration of 5-20 mg Fe/L. The nature of wastewater biological treatment is a series of enzymatic redox reactions conducted by microorganisms. A new method was developed to improve cold-resistance ability and enhance nitrogen removal, namely composite ferric enzymatic activated sludge (CFEAS). The effects of ferric ion on ammonium removal and microbial metabolism were investigated.

Two pilot biological nitrogen removal (BNR) systems were set up in parallel (Figure 1). Both systems are the pre-denitrification activated sludge systems. Each of the BNR reactor has four chambers, two anoxic chambers for denitrification and two aerobic chambers for nitrification and other organic matters removal. The activated sludge in one of the BNR reactor was composited with Fe(OH)3, and the ferric composition was maintained as 5 g Fe/(100 g MLSS) by continuously ferric dosing to the aerobic chamber. The inlet wastewater was obtained from the outlet of the primary settlers at Licunhe WWTP, Qingdao, China.

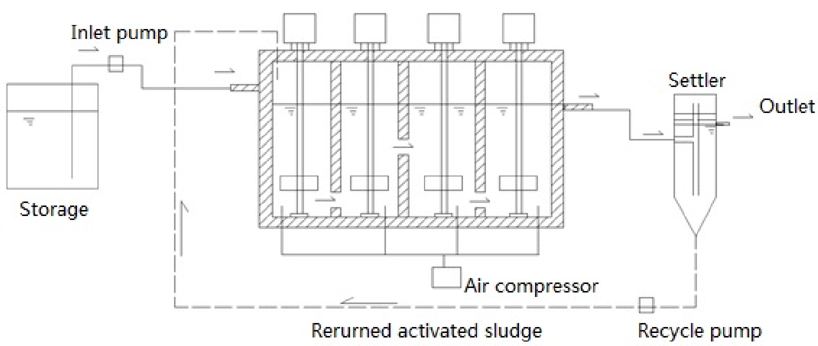

Figure 1 The diagram of the pilot biological nitrogen removal systems.

The nitrification performance of these pilot systems were observed over two years. Ammonium removal ratio of the composite ferric enzymatic activated sludge system (CFEAS) and the conventional activated sludge (CAS). Benefit of ferric dosing was also found in medium and warm temperature condition, but the improvement in nitrification is not as significant as that in cold condition. As shown in Figure 2, the ammonium removal ratio below 12 ℃ of the microbial in the CFEAS system are significantly higher than that in the CAS system. In Figure 2a, the trend line slope below 12 ℃ is 5.3541 while it is 13.669 in Figure 2b for the CAS system, which indicated that the CFEAS nitrification is less affected by low temperature. Therefore, composite ferric activated sludge was found with high cold-resistance ability. Relevant technology can be developed to improve the nitrogen removal efficiency of activated sludge system based on this finding.

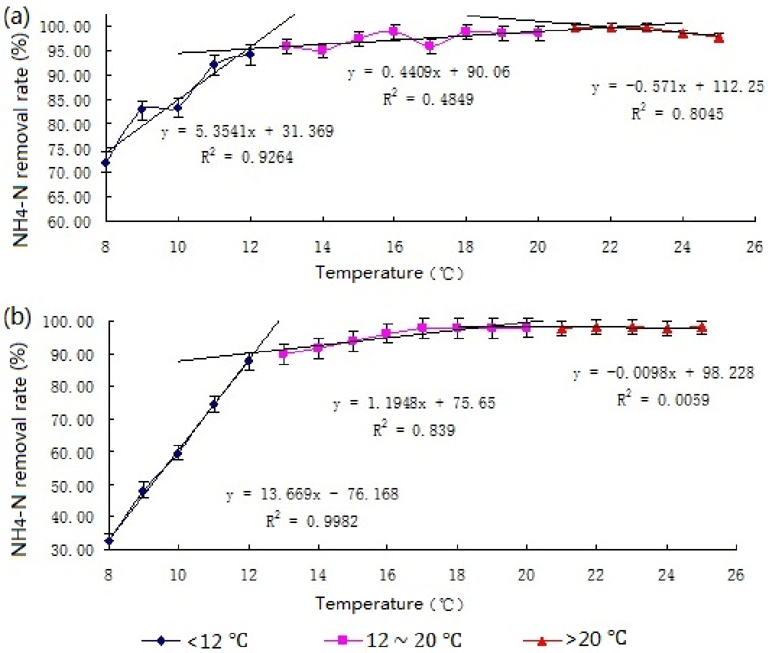

Figure 2 Ammonium removal ratio of the CFEAS and CAS under different temperature conditions.

To further investigate the effect of ferric on the cold-resistance ability of nitrifying bacteria, pure culture of ammonium oxidation bacteria (AOB) and nitrite oxidation bacteria (NOB) were carried out in the culture medium with different Ferric dosage. The bacteria species used in this study are ATCC25196 (AOB) and ATCC14123 (NOB).

Activated sludge composites with ferric hydroxide was found higher ammonium removal efficiency than the conventional activated sludge, especially in cold condition. A novel method namely composite ferric enzymatic activated sludge (CFEAS) was proposed to enhance the nitrification ability of activated sludge under low temperature condition.

Keywords: activated sludge; cold-resistant, activated sludge, AOB, NOB, nitrification

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Enhanced Biological Phosphorus Removal (EBPR) in cold and diluted wastewater

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Abstract

Temperature is one of the most important environmental factors influencing microbial functions in biological wastewater treatment processes (WWTP). Low wastewater temperature (1- 15 °C) affects the physiological characteristics, growth rate and activity of microorganisms, microbial community structure and sludge settleability, which can lead to deterioration of process performance (Zhou et al., 2018). Furthermore, an additional challenge for the WWTP is the presence of diluted wastewaters, including low organic content (such as volatile fatty acids, VFA), caused by infiltration and inflow of stormwater, particularly after periods of rain and snowmelt. The Enhanced Biological Phosphorus Removal (EBPR) process is particularly vulnerable to these conditions, since one of the keys to efficient (EBPR) performance lies in the presence of adequate VFA. For low organic content (weak) wastewater, external VFA addition, such as acetate or fermented primary sludge supernatant (FPSS) rich in VFA, has often become necessary to sufficiently stimulating phosphorous removal to meet the increasingly stringent effluent phosphorus limits (Yuan et al., 2010). On the other hand, it has been reported that biofilms have the potential to decrease the temperature sensitivity of embedded bacteria (Zhou et al., 2018). Combining the EBPR process with Moving Bed Biofilm Reactors (MBBR) may therefore be an interesting configuration for diluted and low temperature waste waters. However, more fundamental knowledge is needed to understand the combined effect of dilution and low temperatures on the Polyphosphate-accumulating organisms (PAOs) present in the MBBR configuration.

In this research, a pilot based on continuous MBBR with EBPR as described by Saltnes et al. (2017) was used, with a total volume of 1 m^3. This was fed with only fresh raw domestic wastewater from Trondheim, Norway. K1 (AnoxKaldnes TM) carriers were used, with a 60% filling degree. The total hydraulic retention time (HRT) of the pilot was 6 hours. In order to evaluate process and pilot performance, effects of dilution, temperature and the addition of FPSS as additional carbon source, a series of batch experiments with P-release and P-uptake were performed using carriers from the pilot. Examples of the results are shown in Figure 1.

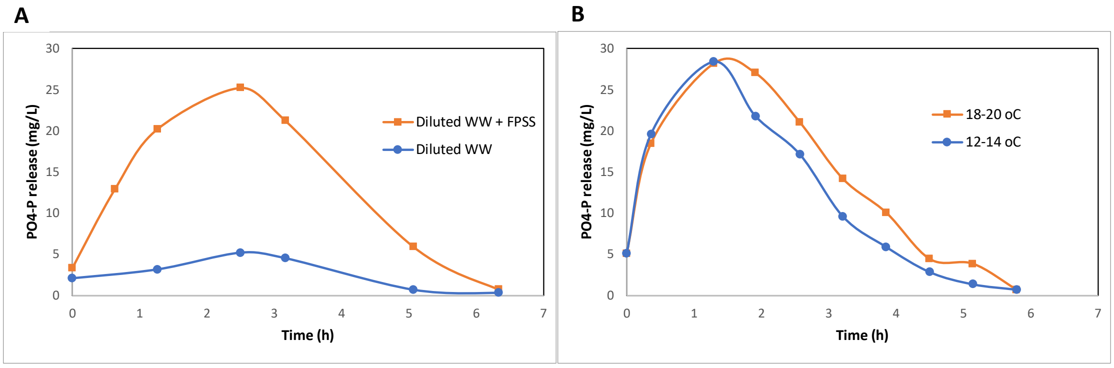

Figure 1. Example of the effect of FPSS addition to diluted wastewater at 12-14 °C (A) and the effect of temperature on P-release and P uptake kinetics.

The results show that good removal of phosphorus was achieved under cold conditions (12-14°C), Figure 1A and B. Around 90 % of P-removal was achieved without dosing FPSS to the diluted wastewater (Figure 1A), and the removal was higher than when dosing FPSS. Furthermore, the low temperature did not impact the overall P-removal, and it had a slight positive impact on the P-uptake rate.

The results showed that the PAO (Bio-P bacteria) does not necessarily depend on VFA, and that it is possible to obtain good phosphorus removal under diluted conditions and at low temperatures (12-14°C). The results indicate that a sufficiently long period is needed for selection of microbial communities thriving under these conditions in order to obtain good P-removal. This has been documented by microbial community analyses. The use of a biofilm process seems to enhance this selection. This makes the continuous MBBR-EBPR process an interesting P-removal alternative for cold and diluted wastewater.

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Rapid formation of aerobic granular sludge for simultaneous removal of organics, nitrogen, and phosphorus at low temperature

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Abstract

Aerobic granular sludge (AGS) is one of novel and promising wastewater treatment methods due to its characteristics of good settling property, high biological activity, strong capacity of withstanding shock loading as well as resistance to inhibitory and toxic compounds compared with traditional activated sludge process (Sarma et al., 2017). It is widely acknowledged that sludge granulation is a complex physicochemical and biological process. Temperature is found to be of great importance to sludge granulation since it has great influence on metabolism of extracellular polymeric substances (EPS), relative enzymes and many other characteristics of organic cells, resulting in the changes of settling velocity of sludge with the decrease of temperature (Winkler et al., 2012). In mid or high latitude areas, temperatures of sewage are always relatively low, which retards the self-immobilized process of sludge. In this work, a sequencing batch airlift reactor (SBAR) was used for rapid aerobic granulation at low temperature. The properties and pollutants removal ability of sludge during formation of granules were evaluated. After sludge was fully transformed into granules, the effect of aeration rate, temperature and organic loading rate on reduction of pollutants was evaluated.

The internal loop airlift reactor with working volume of 17 L was used. The inner riser was 80 mm in diameter and 1300 mm in height. The outer down-comer was 120 mm in diameter and 1600 mm in height. The SBAR was operated at gradually decreased settling time with volume exchange ratio of 50%. The operating cycle was 6 h with 30 min of initial settling time. During the start-up period of the reactor, the temperature of water was controlled at 12±2 °C and dissolved oxygen concentration (DO) in aeration time was maintained at 6.5±0.5 mg L^{-1}. The organic loading rates were set to stabilize at 0.6 g COD L^{-1} d^{-1}. To investigate ability of reactor to remove pollutants after granulation, temperature, DO, and organic loading rates varied from 12.0 to 18.0 °C, 4.0 to 7.0 mg L^{-1}, 0.6 to 4.0 g COD L^{-1} d^{-1}, respectively.

Part of sludge assembled and became floc-like aggregates within the first 2 days and the sludge was transformed into granules with clear boundaries and compact structures on day 10, indicating that the advantage of the structure and existence of Ca^{2+} in influent contributed to sludge granulation even at low temperature. SVI gradually decreased when partial sludge was transformed into particles in the first 2 days and a notable drop could be seen after 10 days of operation (Fig. 1a). Correspondingly, the content of protein (PN) remarkably increased with the granulation of sludge. The content of PN increased to 443.2 mg $gMLSS^{-1}$ and PN/PS was over 3.7 after 10 days of operation. The interactions among EPS, microbial cells and ions promoted cell aggregation and EPS was able to alter the charges and many other properties of microbial surface, which helped the granulation process of activated sludge.

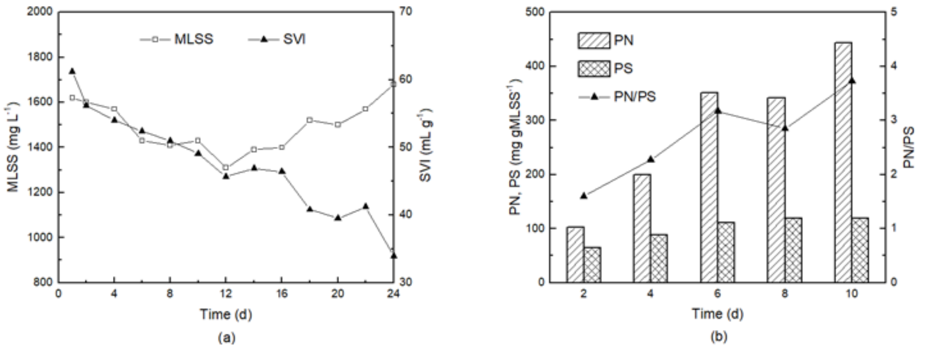

Figure 1 Variations of settling properties and EPS secretion of sludge.

As with pollutant removal during granulation, COD, NH_4^+-N, TN and TP removal efficiencies in the first 4 days were relatively low and unstable while the reduction rates increased in the next few days with the effluent COD concentrations below 50 mg L^{-1}. The removal efficiencies of TN and TP could be over 70% and 55%, respectively. The removal efficiencies of COD and NH_4^+-N were almost invariable when the temperature ranged from 12 to 18 °C, while TP reduction rates increased moderately (Table 1). The degradation rate of TP slightly dropped along with the decrease of DO values while TN concentrations in effluents were modestly increased.

Table 1 Average removal efficiency of pollutants under different temperature and DO.

Stage	Temperature (°C)	DO (mg L^{-1})	Average removal efficiency (%)			
			COD	NH_4^+-N	TN	TP
1	12	6.0~7.0	90.7	92.2	73.8	78.6
2	15	6.0~7.0	92.8	93.0	75.5	85.0
3	18	6.0~7.0	94.9	90.9	75.6	90.3
4	18	5.0~6.0	93.5	92.7	78.5	86.1
5	18	4.0~5.0	92.4	92.0	82.1	62.5

The effect of influent organic loading on the performance of the reactor in COD removal was also investigated. The results revealed that the removal performance of COD was not remarkably affected by the increase of inlet concentrations when organic loading rates varied from 0.6 to 3.0 kg COD m^{-3} d^{-1} and outlet COD concentration was below 30 mg L^{-1} in most cycles of operation. The layered structure as well as high biomass concentration of aerobic granules contributed to the removal of organic matters, nitrogen and phosphorus at low temperature, and the rapid granulation as well as good removal performance of pollutants by the system might provide an alternate for wastewater treatment in cold region.

Keywords: aerobic granular sludge; low temperature; pollutant removal

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Impact of temperature history on anammox process performance and ladderane lipid composition

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Abstract: Enabling partial nitritation-anammox process in the colder mainstream of municipal wastewater will substantially reduce the costs for nitrogen removal at WWTP. However, to reach suitable nitrogen loading rates, anammox microorganisms must be adapted to 10-15 °C, which remains a challenge in engineered systems. In this study, 5 psychrophilic and 9 mesophilic anammox cultures representative for the types of PN/A biomasses used in practice have been tested for (a) activities at 10-30 °C in batch assays, (b) the composition of ladderane membrane lipids, and (c) dominant anammox populations. The cultivation under psychrophilic conditions for 8 months to 5 years did not necessarily elevate absolute activity, but certainly improved their relative activity at 10-15 °C, so that their activation energy became consistent at 10-30 °C. The marine enrichment of "*Ca.* Scalindua" was the most active culture at 10-20 °C, harbouring outstanding potential for the treatment of cold streams.

Keywords: anaerobic ammonium oxidation; low temperatures; ladderane phospholipids

Currently, the main challenge in main-stream anammox research is its implementation to colder conditions, one of the main bottlenecks being the low activity of anammox bacteria at low temperatures [1]. Specifically, anammox cultures activity as a function of temperature has yet to be reported in sufficient detail [2]. And, one of the hypothetical mechanisms responsible for anammox adaptation to cold stress is the altered composition of ladderane phospholipids, however, this has been investigated only by a single study [3].

In this study, we assess the effect of temperature (10, 15, 20, 25, 30 °C) on the activity of 14 anammox cultures ranging from those representative of full-scale reactors to simple enrichments (Fig. 1.1). Dominant anammox populations were determined by 16S rRNA gene amplicon sequencing (MiSeq). Qualitative analysis of ladderane phospholipids was done by U-HPLC–HRMS/MS.

We rebut the dogma that anammox cultures are exceedingly susceptible at less than 15 °C. Instead, we show the singular effect of temperature on all but one psychrophilic anammox culture (Ea = activation energy, empirical coefficient = 85±49 $kJ.mol^{-1}$, median±standard deviation, for 10-30 °C, Fig. 1.2 A). For mesophilic anammox, we detected a wide spectrum of activation energies (160±95 $kJ.mol^{-1}$, Fig. 1.2 A) between 10 and 15 °C. Thus, when modelling the activity of mesophilic anammox culture under low temperature, the temperature coefficient should be determined experimentally.

We report an exceptionally beneficial performance of a cold-adapted marine "Ca. Scalindua" enrichment (Fig. 1.1), highlighting its potential for nitrogen removal from cold and more saline streams, which is crucial when choosing most appropriate inoculum and reactor set-up.

"*Ca*. Brocadia" in this study reduce the length of [5]-ladderane esters distinctly from "Ca. Scalindua" in Rattray et al. [3], the latter synthesizing much more C18 compared to C20 [5]-ladderane esters at temperatures <20 °C. "*Ca*. Brocadia" also adapt to low temperatures by altering the structure of their non-ladderane alkyl moieties.

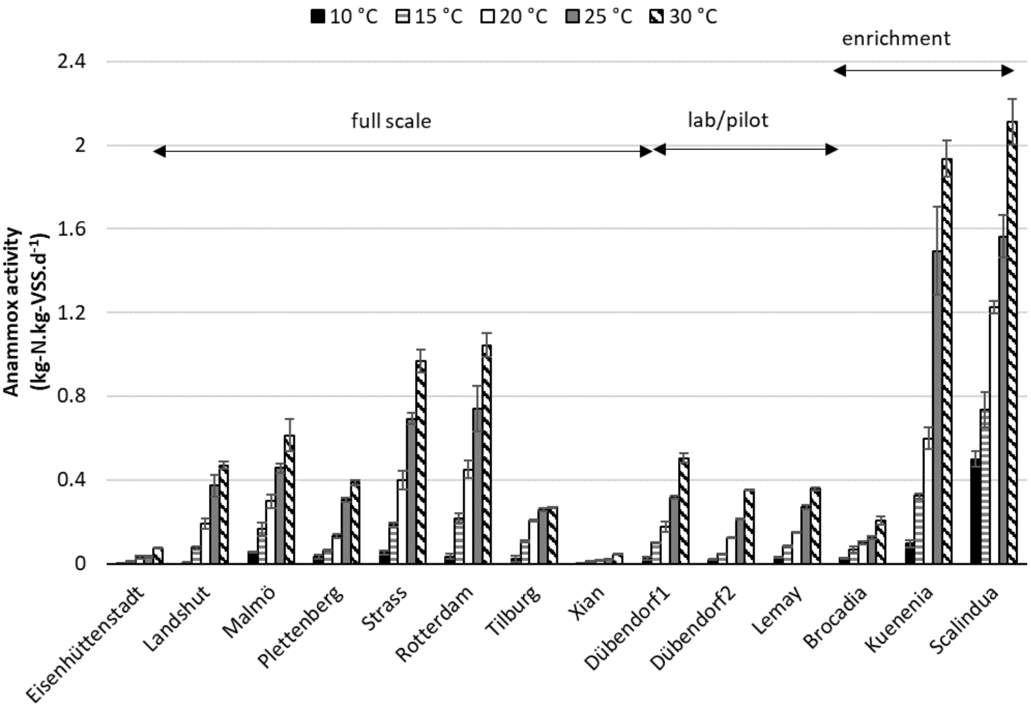

Figure 1.1 Effect of temperature on specific anammox activity of multiple anammox cultures. "Ca. Scalindua" had the highest activity at 10-20 °C of all cultures.

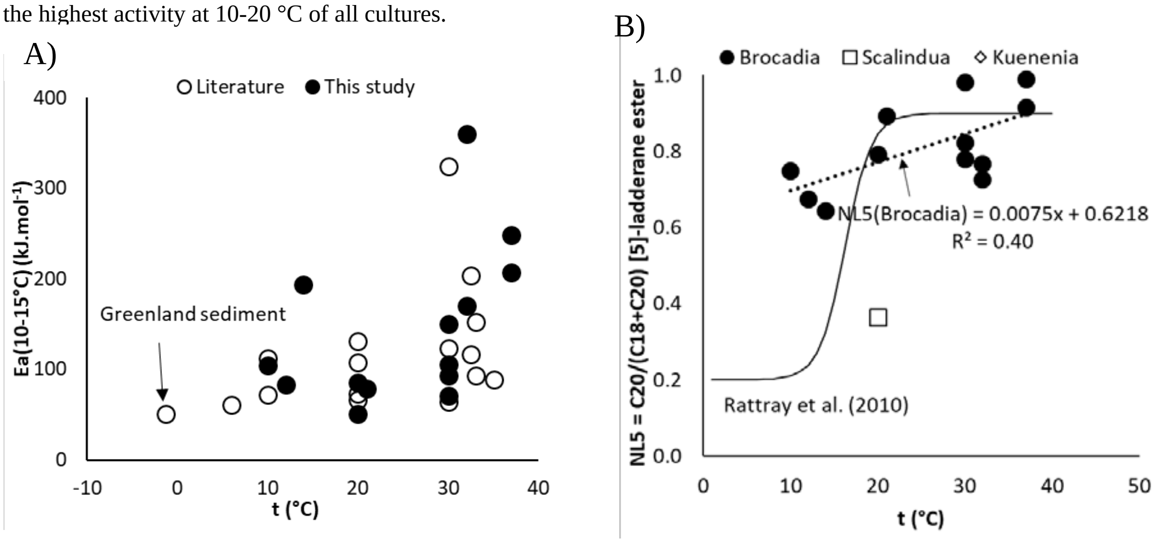

Figure 1.2 Activation energy (Ea) at 10-15 °C of mesophilic (30-37 °C) anammox biomasses was in the range of 64-360 kJ.mol^{-1}, whereas the cultures operated at low temperatures had substantially lower Ea.

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THP Advanced Anaerobic Digestion for Compact and Efficient Biosolids Management in Cold Climates

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Abstract

In cold climates, outdoor wastewater treatment plants (WWTP) are challenged by weather conditions. Therefore, it is preferred to move facilities indoors, in e.g. rock caverns or tunnels underground. Sludge treatment for biosolids management in cold climates has been a great challenge in expensive space requirement and potentially unstable operation in winter time. Process intensification to achieve compact installation and operational stability are called for to ensure efficient biosolids management. In this paper, Thermal Hydrolysis Process (THP) to enhance Anaerobic Digestion (AD) for sewage sludge treatment is discussed in terms of compactness index and operational stability. Two cases using CambiTHP in Norway and China are described. With long term operational data in small to large scale projects, CambiTHP AD is a proven solution for compact and efficient biosolids management in cold climates.

Keywords: Thermal Hydrolysis Process; Anaerobic Digestion; Compactness; Operational Stability; Biosolids Management

Introduction

There are many Thermal Hydrolysis Process (THP) plants in operation in cold climates. Out of more than 50 delivered CambiTHP plants, 9 plants are in Nordic countries and 5 plants are in Northern China (Beijing). In cold climates, outdoor wastewater treatment plants (WWTP) are challenged by weather conditions. Therefore, it is preferred to move facilities indoors, in e.g. rock caverns or tunnels underground. This assures favourable working conditions for operators and equipment and a stable temperature for biological treatment processes. However, excavation of rock caverns is often expensive. Further, land application of biosolids is only possible during a short period of the year, making storing of biosolids through the long winter a necessity. Therefore, technologies that enable process intensification in compact installation or reduction of the amount of biosolids are advantageous. THP is one such technology that reduces the amount of biosolids, while also reducing the needed digestion volume and thereby the overall plant footprint.

In THP sewage sludge is cooked with steam at high temperature and pressure (165°C and 6 barg) (Barber, 2016). The high temperature disintegrates sludge particles, destroys microbial cells and reduces the molecular weight of organic compounds including Extracellular Polymeric Substances (EPS). The treatment results in a thermally hydrolysed sewage sludge that is free from pathogens, readily available for anaerobic digestion (AD), and has a lower viscosity compared to the raw sludge.

The combination of a lower viscosity and a more readily available sludge for biodegradation reduces required digester volume and footprint significantly. The lower viscosity allows for feeding the digesters with a high dry solids (DS) concentration up to 12%, while the enhanced biodegradability reduces the design hydraulic retention time (HRT) to 15 days. Together, these amount to a design digester volume that is about 1/3 of a typical conventional case (see Table 1 below), while at the same time leads to a higher Volatile Solids Reduction (VSR) and specific biogas production.

Furthermore, the reduced viscosity and destruction of EPS enhance sludge dewaterability and a higher DS in the final cake after digestion is achieved. Since this is combined with a higher VSR, the final cake tonnage is significantly less for the THP case compared to conventional digestion. This final cake is pathogen free and complies with US EPA Class A criteria for biosolids land application. The final product is therefore a superior bio-fertilizer enabling recirculation of valuable nutrients back to the soil. The above comparative analysis can be summarized in Table 1 below.

Table 1. Comparison of CambiTHP AD with conventional AD

Parameters	**Conventional AD**	**CambiTHP AD**	**Difference**
AD Feed DS%	3-6%	8-12%	Up to three times
Design HRT in AD	20-30 days	15 days	Saving by up to 50%
Total digester volume	100X	30X	Saving up to 70%
VS Reduction	30-50%	50-65%	Improve by up to 60%
Final cake DS%	20-30%	30-40%	Improve by up to 10%DS
Cake tonnage	100X	50X	Reduce by up to 50%
Biogas production	100X	130-150X	Improve by up to 50%

In conventional digestion, sludge should be heated for the digester temperature to reach mesophilic conditions (38-41°C). Given the low DS of the feed, the volume of sludge is relatively large. In cold climates, the heating requirement is even higher.

CambiTHP is an energy efficient process that recovers the heat from the hydrolysed sludge to pre-heat the THP feed. By combining THP with combined heat and power (CHP), all or main part of the required heat for THP is provided by the exhaust heat from the CHP engines. Depending on site specific conditions, as well as factors such as electric efficiency of the CHP, small amount of biogas or another auxiliary fuel might be required for the thermal hydrolysis treatment. Nevertheless, increased biogas production is larger than this potential additional energy need, and hence, in comparison with conventional AD, net biogas production is higher with CambiTHP AD.

HIAS in Norway and Gaobeidian in China

HIAS IKS:

HIAS IKS is an inter-community company which owns a plant for water and wastewater treatment and service delivery for four communities: Hamar, Løten, Ringsaker, and Stange in the middle of Norway. The four communities are located around Norway's biggest lake Mjøsa. In order to protect Mjøsa, HIAS built a WWTP plant in 1980s. The wastewater treatment load is on average 25000 m^3/d, with dry and max flows being 15000 m^3/d and 70000 m^3/d, respectively. Average sludge production is 4000 tDS/a (ca. 11 tDS/d) and design capacity for sludge treatment is 7200 tDS/a (20 tDS/d). The overall area for all treatment facilities is 32500 m^2, while the sludge treatment occupies 3500 m^2. The wastewater treatment consists of primary settling, activated sludge process for COD and partial N removal and chemical P removal with clarification. Currently, the plant is gradually being converted to bio-P removal using an innovative MBBR process. The sludge treatment consists of CambiTHP pre-treatment, anaerobic digestion, and Bucher hydraulic filter press for dewatering. The biosolids after digestion is used as soil conditioners in the farms of surrounding area. The HIAS was the first full scale THP plant, which has been in operation since 1995. The upgrading of THP to newest version is under the way.

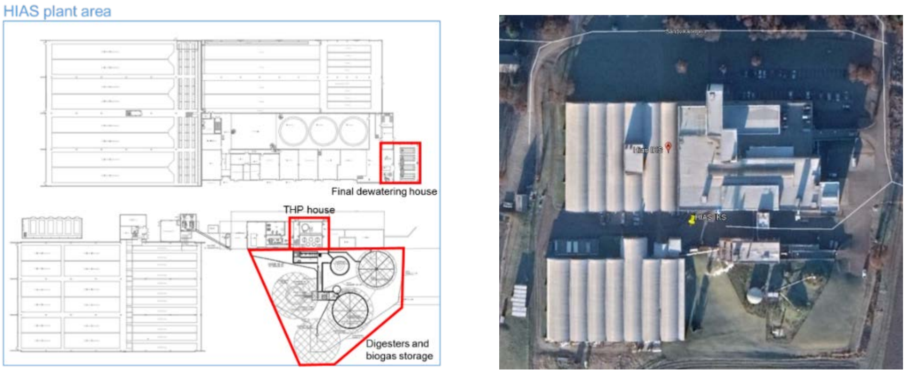

Fig. 1. Left: HIAS plant area. Sludge treatment facilities include THP house, underground digesters, biogas storage, and final dewatering house, marked in red. Right: Google Earth Pro Plot of the plant.

Gaobeidian:

Gaobeidian plant is the biggest WWTP in Beijing, treating 1 million m^3/d wastewater from part of the Beijing downtown area. The sludge treatment had been conventional mesophilic digestion until 2016, when CambiTHP was installed to upgrade and increase the capacity of the sludge treatment facility. The original digesters were built in two phases with 16 digesters in total 140 000 m^3 (8750 m^3 each) treating around 180 tDS/d. Due to the stringent effluent standard, and import of some sludge from other plants nearby, total design sludge capacity needed to be increased to 272 tDS/d. Despite the increased sludge load (by approx. 40%), installing CambiTHP in 2016 reduced the number of required digesters to 8 units. Therefore, 8 digesters were demolished which freed space for both THP system and reject water treatment by de-ammonification as required due to stringent effluent standard. Fig. 2 and Fig. 3 show the changes in layout before and after upgrading. Gaobeidian is one of the five plants treating the total of 1200 tDS/d sewage sludge in Beijing downtown area with around 20 million population. The other four plants are also equipped with CambiTHP pre-treatment and are in operation. Gaobeidian plant occupies 668000 m^2 area, while the sludge treatment takes a space of 113000 m^2.

Fig. 2. Gaobeidian – original sludge treatment facilities (with 16 digesters until 2016)

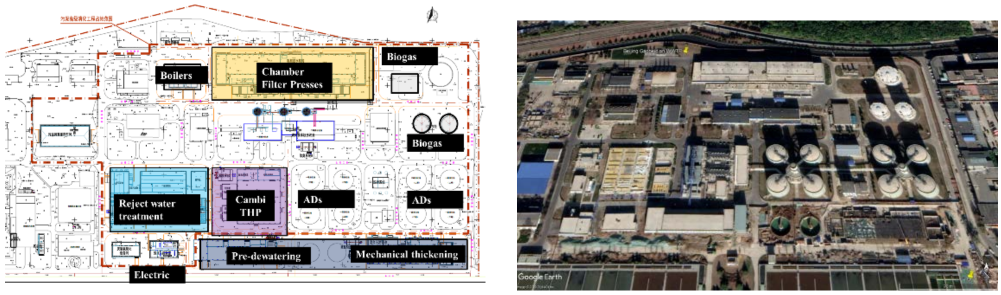

Fig. 3. Gaobeidian –CambiTHP AD since 2017 (left - layout; right – Google Earth Pro Plot)

Compactness Index

Expansion of WWTPs and technology selection in urban areas are often driven by space constraints. In order to evaluate the space needed, a Compactness Index is defined here as area or volume requirement per ton dry solids treated (m^2/tDS or m^3/tDS), abbreviated as CAI and CVI, respectively. This parameter can be used to compare various processes and entire plants.

Taking anaerobic digestion in general as an example, when a design feed DS% and hydraulic retention time (HRT as days) are set, the Compactness Index can be described as

Compactness Volume Index (CVI) (m^3/tDS)
*= X (ton DS/day) /DS% *HRT /X (ton DS/day)*
= HRT/DS%.

For a traditional digestion, DS% of the digester feed is between 3-6%, while HRT is between 20-25 days. So, the Compactness Volume Index (CVI) is 333-833 m^3/tDS. For a Cambi THP enhanced digestion, feed DS% is 8-12% while design HRT is 15 days, then Compactness Volume Index (CVI) is 125-187 m^3/tDS.

When the digester volume (2600 m^3) in HIAS is used to calculate the compactness, the compactness CVI is 2600/20=130 m^3/tDS. When the digester volume (of 8 digesters) of 70000 m^3 in Gaobeidian is used to calculate, the compactness CVI is 70000/272=257 m^3/tDS. To compare CVI in both plants, there is a potential for Gaobeidian to expand capacity further with existing digester volume, by increasing the feeding DS% and shorter HRT as well.

The compactness can also be described as area occupied per treatment capacity, as *Compactness Area Index (CAI): m^2/tDS*. A real project considers many factors, including not only the main processes, but also the ancillary equipment, so that the overall space can be compared in terms of CAI (m^2/tDS).

In order to evaluate the real space used for sludge treatment in each plant, the Google Earth Pro was used to measure the area for sludge treatment in HIAS plant in Norway and Gaobeidian plant in Beijing, China.

Based on Google Earth Pro, the CAI for HIAS sludge treatment is 3500/20=175 m^2/tDS. The CambiTHP takes 130 m^2, so the CAI in HIAS for THP is 130/20=6.5 m^2/tDS. It is noted that the operational data shows the sludge production is 4000 tDS/a, lower than design capacity of 7200 tDS/a. Comparatively, the CAI for sludge treatment in Gaobeidian is 415 m^2/tDS. It is noted that Gaobeidian has included a de-ammonification process for treating reject water, contributing to a larger footprint. CambiTHP system takes 1600 m^2, so the CAI is 1600/272=5.88 m^2/tDS. The operational data shows that the sludge treatment is peak 269 tDS/d with average 202 tDS/d. Gaobeidian imports some amount sludge from other plants. A summary of Compactness Index for comparison is shown in Table 2.

Table 2. The CVI (m^3/tDS) and CAI (m^2/tDS) for HIAS and Gaobeidian

Plants and Conditions	CVI for AD	CAI for Sludge treatment	CAI for THP	Notes
Conventional AD in Gaobeidian	778	628	NA	
CambiTHP AD in Gaobeidian	257	415	5.88	De-ammonification is included additionally
HIAS	130	175	6.5	Compact area design

Performance and Operational Stability

An advanced digestion system consists of various processes and components, so stable and robust processes contribute to overall performance in throughput capacity and digestion efficiency. In the following we analyse and discuss the operational data from both plants (2015 data from HIAS and 2018 data from Gaobeidian) in terms of digestion performance and operational stability.

HIAS:

The operational data from HIAS for 2015 was analysed. An average daily sludge treatment amounted to 11 tDS/d, although the design capacity was 20 tDS/d as it was the first CambiTHP plant. Fig. 4 shows the average biogas production and sludge treated per month at HIAS. Average specific biogas production per tDS and tVS are calculated as 421 m^3/tDS and 527 m^3/tVS, respectively.

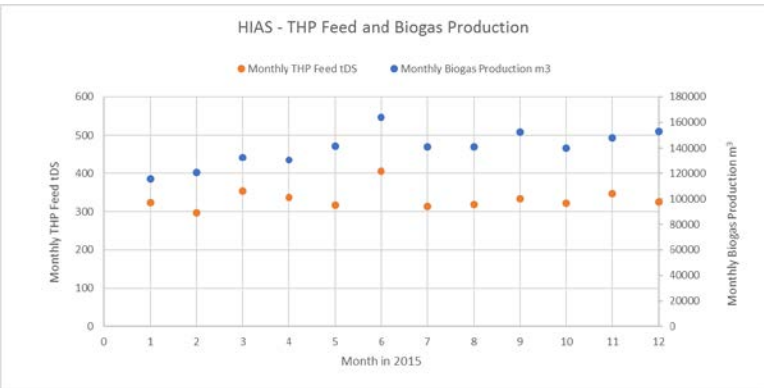

Fig. 4. HIAS – THP Feed and Biogas Production calculated in each month

Gaobeidian:

The THP has the nominal capacity to treat up to 320 tDS/d at 16.5% DS with all 4 lines of THP, while the sludge amount fed to THP and AD was in average 202 tDS/d in 2018. Some data points show that the sludge feed to THP was less than 150 tDS/d, this is due to less sludge being produced or the pre-dewatered sludge having a lower DS% (down 12-14%DS) than design THP feed of 16.5%DS. THP feed DS% and throughput in tDS/d is presented in Fig. 5. At times, the THP was fed with sludge as high as 20% DS and throughput as high as 300 tDS/d, without any operational issue in THP and AD. The 30 day's moving average line depicts the capacity.

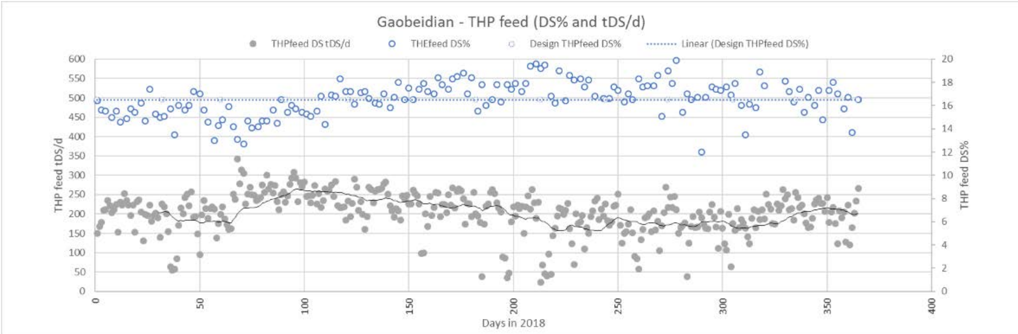

Fig. 5. Gaobeidian – THP feed (DS% and tDS/d) in 2018

The temperature in the AD was very stable at around 40 ºC. Stable temperature is thought to be critical for optimal microbial performance in AD. The AD feed DS% varied gradually from 6% to 10%, where 8.5% was the design DS%. The AD operation has been gradually improved through 2018 (Fig. 6).

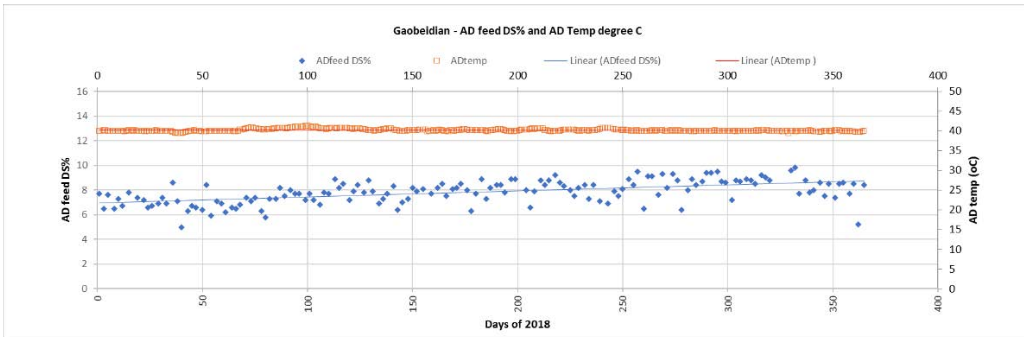

Fig. 6. AD Feed DS% and Temp (ºC) in 2018

The stability in AD can also be described by the VFA/Alk ratio and VFA as shown in Fig. 7 below. The VFA/Alk was very stable, well below 0.1, showing no accumulation of intermediate products such as VFAs.

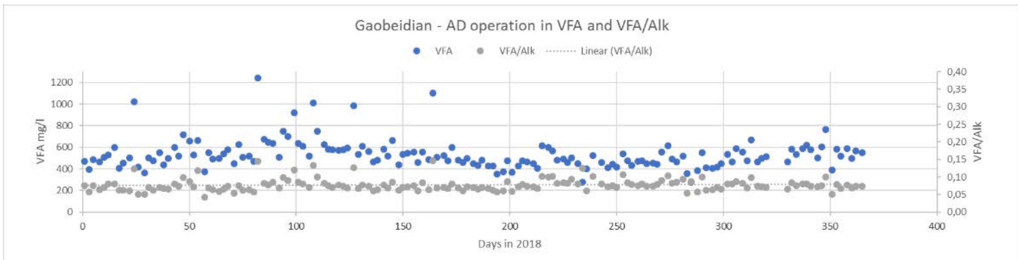

Fig. 7. VFA and VFA/Alk in AD in 2018

The biogas production varied with digester loading. A specific biogas production (m^3/tDS and m^3/tVS) explains how much biogas produced and how stable is digestion operation. Fig. 8 shows that the specific biogas production is averaged to around 375

m^3/tDS and calculated to 587 m^3/tVS with average VS% in sludge feed as 63%. Total biogas production in 2018 amounts to 27 322 612 m^3/a for treating 73738 tDS/a. The biogas contains 65% CH_4, so the total bio-methane production in 2018 amounts to 17 759 698 m^3/a.

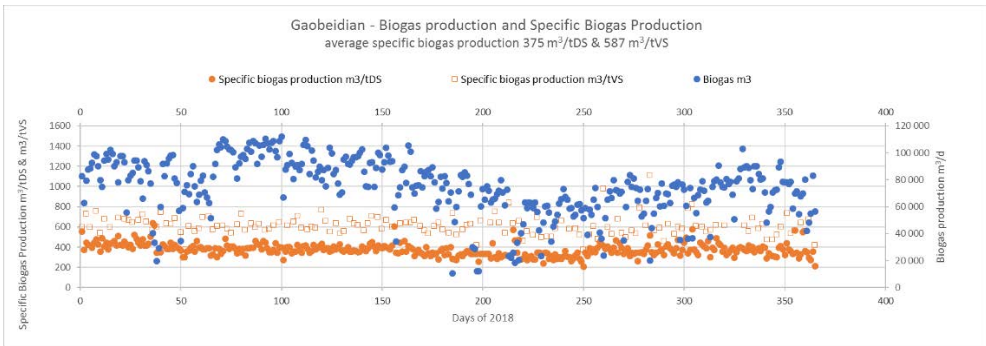

Fig. 8. Biogas production and specific biogas production in 2018

When comparing the specific biogas yield of the two plants in Table 3, we observe that with respect to tDS number, HIAS has a higher specific biogas yield, while on the basis of tVS Gaobeidian has the best performance. The first can be explained by the ash content in feed sludge at Gaobeidian being much higher than at HIAS. The latter however, must be explained by the properties of the feed sludge (i.e. COD/VS content), the performance of the digesters, or quality of gas volume measurements, etc.

Table 3. Comparison of specific biogas production at Gaobeidian and HIAS

Plant	Specific biogas production (m^3/tDS)	Specific biogas production (m^3/tVS)
Gaobeidian	375	587
HIAS	421	527

When investigating more closely the impact of sludge VS% on specific biogas production by plotting data from both Gaobeidian and HIAS together in Fig. 9, it becomes clear that Gaobeidian performs as good as HIAS when treating sludge with 70% VS although HIAS is treating sludge at 80% VS. Hence, this further supports that some other conditions are different between the two plants.

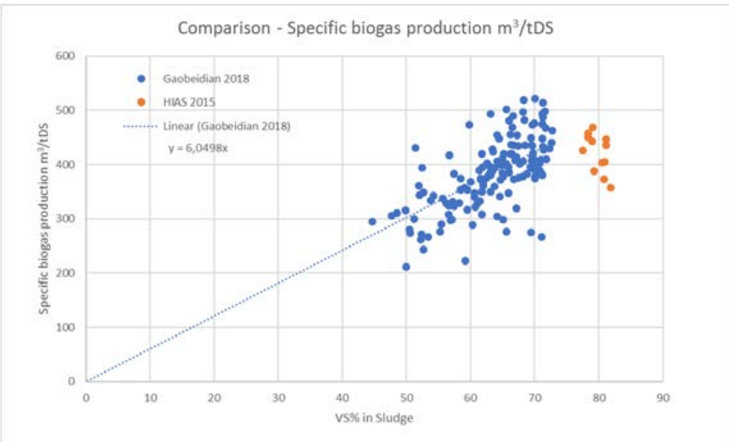

Fig. 9. Comparison of specific biogas production in Gaobeidian 2018 and HIAS 2015

Conclusions

Long term operation of CambiTHP AD at HIAS since 1995 and a large-scale project Gaobeidian since 2017 have demonstrated the compactness (with CVI and CAI index) and high efficiency in biogas production and high operational stability in digestion (in AD Temperature, VFA/Alk, etc.). The compactness and operational stability are extremely important for efficient biosolids management in cold climates, therefore THP for enhancing digestion is one of key factors that ensure successful biosolids management.

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Acknowledgement

HIAS IKS and Beijing Drainage Group are highly appreciated for the close cooperation with Cambi and support with essential operational data for analysis.

Looking into lipolytic potential of psychrophiles to develop anaerobic digestion in domestic wastewater treatment

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Abstract

Generating energy while treating wastes has made anaerobic digestion (AD) a competitive technology in the domestic wastewater treatment sector. However, not every climate can benefit the AD as its key players, microbial community, respond differently to the environmental factors like temperature, pH, salinity etc. At cold temperatures, psychrophiles fail to degrade lipids as much as they do the carbohydrates and proteins [1]. Yet, about 30-40 % of the total chemical oxygen demand of municipal wastewater is lipid [2], which makes it essential to evaluate the lipolytic potential of psychrophiles before developing the AD technology in cold climates. Microbes tend to produce a matrix of extracellular polymeric substances (EPS), which benefits them in many ways. The EPS is like a cloud space that bio-users of this network share their hydrolysing enzymes to degrade biopolymers (i.e. carbohydrates, proteins, lipids, etc.) and uptake the hydrolysed products as food. However, not all of the users pay their share and cheater organisms would benefit the public good as well. This might prevent the effective growth of producers or at the worst scenario alter the ultimate biological goal of the community. From another perspective, microbes might not find it economical to invest their available energy on producing hydrolysing enzymes at a specific environmental condition. At cold temperature, microbes have different strategy to adapt themselves and survive. In terms of poor lipid degradation, the first step to consider is to find out whether the cold-adapted microorganisms are capable of producing lipase genes and see if they exist extracellularly in the EPS. If the most abundant microbes were not lipolytic and their genes did not exist in the EPS, we will know that the community do not have the potential of lipid degradation. However, if this potential exist we can start to search for the barriers inside and outside of the cell for lipase expression and activation.

We developed eight cold-adapted anaerobic membrane bioreactors (An-MBRs) seeded with psychrophiles collected from the sediment of Lake Geneva and soils of Svalbard, in the high Arctic at various sampling points. The working temperature of the reactors were 4 and 15 ℃ and we fed them with the UV-treated/non-treated primary settled influent (Tudhoe Mill, County Durham, UK). Using Shotgun metagenomics and different bioinformatics tools, we co-assembled the reads into contigs (MEGAHIT) and annotated them (PROKKA). In order to find all lipase genes, we searched for the lipases with the enzyme commission number of 3.1.1.3. Moreover, using a binning tool (MetaBat2) we formed metagenome-assembled genomes (MAGs) to assign the genome to taxa using taxonomic classification tools like GTDB tool.

Out of 31,570,310 annotated proteins, we identified about a thousand lipase genes with different classes in overall. Further binning on the contigs showed that only 95 bins out of 1500 had good quality (genome completeness of more than 90 % and contamination less than 10 %.). However, not all of these good bins were lipolytic (about 42). The total number of lipases obtained from the good bins dropped to 88 with the average length of 379 aa. Most identified lipases had the right E.C. number though some were putative, which do not provide any certainty in terms of true lipase activity.

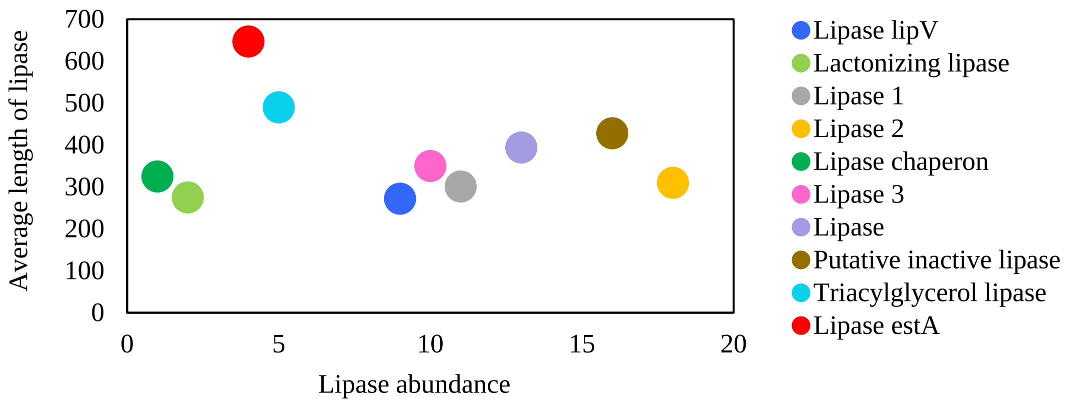

Figure 1. Lipase abundance and average length from the good quality bins (completeness>90 %, contamination<10%).

It is evident from the Figure 1 that the most abundant classes of lipases are *Lipase 2 > Putative inactive lipase > Lipase > Lipase 1> Lipase 3 > LipV* with an average length of 300 to 400 aa. Furthermore, the taxonomic classification showed that most of the bins contain novel genomes classified only at lower levels like class, order, and family. Only 15 of the bins had their classification at genus level with two at species level. These two bins contained species such as *Desulfobacter postgatei* and *Chlorobium limicola* from different phyla of *Desulfobacterota* and *Bacteroidota*. The most abundant phyla among good lipolytic bins (Figure 2) were *Actinobacteriota* > *Proteobacteria* > *Bacteroidota* > *Desulfobacterota*.

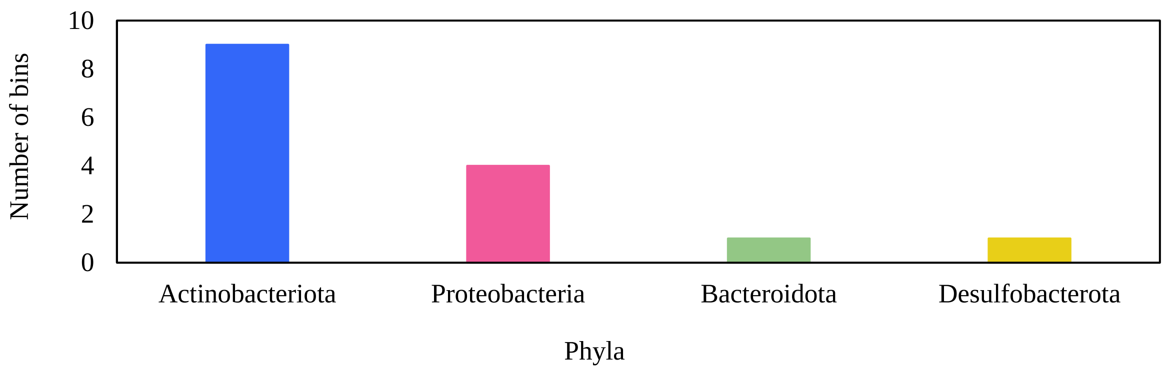

Figure 2. Taxonomic classification of good lipolytic bins at phylum level.

Although, this analysis will give us insight about the genomes exist in each bin, it is not enough to be sure who the major lipase producers are. Combining the metagenomics with the metaproteomics and considering the taxonomic abundance data will help to get closer to the answer, which is still in progress.

Keywords: Psychrophilic anaerobic digestion; Lipase; Metaproteogenomics

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Applying holistic cost benefit analysis in the water sector: Cold Climates

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Abstract: Investments in the water sector can benefit from the holistic cost benefit analysis framework (hCBA). National and regional guidelines on fiscal, socioeconomic and environmental impacts of water infrastructures underpin the qualitative and quantitative approach of current-day investment analyses[1]. The hCBA provides the framework to quantitatively valuate each of these impact parameters. However, knowledge gaps still exist in water infrastructure investment analyses; this paper attempts to expand the library of techniques beyond the limits of general infrastructure investment guidelines, specifically addressing how to valuate spatially driven challenges in water sector infrastructures. Examples of such spatial drivers are evaluated as cost-benefit factors through case studies in this paper: 1) Retarded process kinetics in wastewater treatment plants (WWTP) conditional to cold climates; 2) direct discharge to seas and lagoons where micropollutant pathogens such as pharmaceuticals and personal care products (PPCP) affect the food chain in remote coastal communities; 3) WWTP inflow variations in temperate and subpolar regions caused by seasonal dilution and temperature changes of sewage in combined sewers. Findings from these directions suggest a wider applicability of the hCBA valuation techniques than forecasted by general assessment guidelines. It further suggests the need for, and importance of, a comprehensive cost-benefit valuation library of spatial-driven factors relating to water sector infrastructures if a decision support system (DSS) is to be developed. Such DSS could in turn increase the accessibility of valuation tools such as hCBA to non-experts. Consequently, an hCBA DSS could increase the rate of which decision makers consider socioeconomic and environmental impact factors in investment stages of water sector infrastructure projects.

Keywords: Holistic cost benefit analysis, cold climates, water sector infrastructures, retarded process kinetics, WWTP, PPCP, inflow dilution

Spatially distinctive regions place spatial-driven challenges on water sector infrastructures. Some of the most infrastructure-impoverished parts of the world exist in spatially challenging regions. In this context, several cold climate communities face distinct challenges in their efforts to provide access to sanitation services.

CBA is a tool designed to account for the financial and economic desirability of a project. Although the World Bank, Asian Development Bank and the European Commission[2] have published CBA handbooks, they diverge in methodologies and insist on CBA expertise to execute the analysis. The hCBA framework looks to harmonize the generalized practices from these handbooks within the narrow scope of water supply, sanitation and wastewater management infrastructures in the water sector, and are matched with valuation techniques by the hCBA framework as follows;

Shadow prices for the labour market, willingness-to-pay (WTP) surveys for aesthetic disamenities, hedonic travel cost methods for loss of recreational value areas, quality adjusted life years (QALY) values for direct impacts on human health, and surveys for existential use values and for the loss of biodiversity, cultural and heritage sites.

[1,2] Florio, Massimo, et al. "Guide to cost-benefit analysis of investment projects”. Final Report. European Commission, Directorate General Regional Policy (2008).

hCBA also utilizes LCA tools to valuate impacts of energy consumption and CO_2/greenhouse gas (GHG) emissions[3].
This paper's assessment of three case studies help create the path of progressing the hCBA framework from being a generalistic to a comprehensive assessment tool beyond the limits of assessment guidelines, making the hCBA framework flexible for use in case-by-case decision scenarios.

The three case studies considered in this paper help developed the hCBA valuation library beyond generalized standards and initiates the process of shaping it into a comprehensive tool through growing a valuation library: 1) Cold climate cities must consider larger reactor volumes for treatment as colder temperatures cause retarded process kinetics; i.e. nitrification rates reduce by 50% for every 10°C reduction and slow down sedimentation processes etc. 2) Water infrastructures in temperate and subpolar regions must consider WWTP and transport system dimensions when floods and snow melts can rapidly dilute and increase the sewage inflow volume while reducing its temperature and affecting treatment processes. 3) Remote locations, sparse populations, hostile construction environments and the ability to directly discharge into vast sea areas and sewage lagoons are cited reasons to not invest in water sector infrastructures in the arctic north, yet expose the population to harmful pathogens and micropollutants such as PPCP through the food chain harvested from the discharge recipients. Each resulting cost benefit analysis is run through a sensitivity analysis to test for the significance of each spatial driver.

DSS with valuation libraries that address such spatially niche challenges can help convince decision makers of the benefits of investing in these communities' water sector infrastructures, despite their comparatively higher fiscal costs to warmer climate investments. There is a need to show the cost benefits of investments beyond a fiscal perspective, by assessing socioeconomic and environmental impacts in comparable units. With SDG target 6A, UN sets a favourable context to quantify holistic cost-benefits of new technologies in water sector infrastructure appraisals. Assessment tools such as hCBA can comprehensively quantify socioeconomic net beneficial water sector infrastructures against fiscal sunk costs and environmental cost-benefits to help sound projects in "…wastewater treatment, recycling and reuse technologies" [4] succeed through investment assessment processes.

The three directions reviewed in this paper provide novel valuation techniques designed beyond current boundaries set by generalized assessment guidelines to help conduct useful hCBA. The paper identifies valuation techniques for spatially-driven challenges in water sector infrastructures, and proposes the expansion of current calculation methods to make CBA's more comprehensive. Conclusively, it launches the concept of algorithm-based valuation libraries as the platform on which to build an hCBA DSS. By developing a wide-ranging valuation library, a DSS could semi-automate the valuation process and remove the dependency of costly valuation experts for each unique investment, at least at the project development stage. A hCBA DSS tool can be a useful draft-level solution to worlds that cannot access CBA experts for each water infrastructure project, if it develops a wide range of valuation libraries of spatial cost benefit factors based on the hCBA framework.

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Sustainable wastewater treatment for the Norwegian context – Use of LCA for selection of chemicals and comparison of processes

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Abstract

The UN Sustainable Development Goal (SDG) have a sub-goal for improved water quality through wastewater management (UN, 2013). Research and development are necessary to reach environmental objectives for water quality in lakes and rivers, for example as given in the EU Water Framework Directive (European Commission, 2000), as well as reduced carbon footprint, which is also a top priority objective. This is especially true for Norway as several WWTPs fail in fulfilling the Wastewater directive and require improved phosphorous removal either chemically or biologically.

In Norway and other Scandinavian countries, due to a combination of factors (Cold climate, low carbon source, need for compact phosphorous removal in order to be indoor for a warmer temperature, and lack for tradition to apply activated sludge) phosphorus is mainly removed by chemical precipitation (Ødegaard, 1992). However, lately wastewater utilities show increased attention to the consumption of chemicals and energy, and their influence on environmental efficiency overall.

Currently, to assure the paradigm-shift from waste treatment to resource recovery, many WWTPs are being upgraded by implementing technologies and strategies suitable for cold climates. As part of this process, both utilities and researchers are comparing chemical and biological treatments, or a combination of those. These treatment alternatives need to be evaluated and compared with respect to environmental and economic criteria. For chemical phosphorous precipitation, utilities need to select the most environmentally friendly and cost-effective chemicals. Furthermore, recent developments in wastewater treatment propose to enhance the carbon redirection from primary treatment units to anaerobic digestion for maximizing energy recovery. Chemically enhanced primary treatment (CEPT) shows superior efficiencies in removing suspended solids and phosphorus and is one possible solution for carbon redirection (Dong et al., 2019). However, in biological phosphorous removal the need of carbon for the phosphorous removal versus redirection of carbon to biogas production needs to be balanced.

Process alternatives for chemical treatment, including various chemicals, biological treatment and combination of those to achieve treatment standards for phosphorous and BOD, are compared. Comparisons are based on designs and operations used in cold climates, and in this paper the Norwegian context is emphasized. Holistic environmental profiles were based on life cycle assessment (LCA). Biological process included in this evaluation are enhanced biological phosphorous removal using activated sludge (EPBR AS), EBPR in moving bed bioreactor (EPBR in MBBR), high rate MBBR (HR MBBR), and EBPR in membrane bioreactor (EPBR in MBR). The sludge treatment line used for this evaluation is common to each alternative and consists of anaerobic digestion and thermal hydrolysis. GHG emitted from the wastewater treatment, the effluent and the sludge disposal are also included. The recovery of nutrient takes place through the spreading of the sludge on agricultural land. This

comparison takes into account the minimization of energy input and GHG emissions, maximization of energy production and recovery of valuable nutrients, and the fulfilment of the effluent discharge limits.

These systems have been first designed using values derived from process calculations based on Norwegian standards. All design alternatives have been evaluated for a capacity of 1000 m^3/hour and a typical Norwegian wastewater composition defined according to a survey. Furthermore, mass balances for C, N and P have been calculated to assess the resource recovery potential for the different water treatment process alternatives. The main elements of energy use in the unit processes have been included. These parameters have been used to populate the life cycle inventory of resources consumed and emissions produced in order to perform the comparative LCA.

As an example, Figure 1 displays a comparison of the different wastewater alternatives evaluated based on global warming indicator. The results clearly indicate that the chemical treatment has slightly higher global warming impact than biological. Furthermore, the results show that the selection of the type of coagulant is crucial and there is potential to reduce CO_2 eq. emissions by selecting a green chemical. One of the major CO_2 eq. emissions is associated with the effluent discharge (e.g. N_2O emissions included under the category treatment emissions) indicate the need for improved nitrogen removal. Additional outcomes of the comparison will be presented and discussed during the conference.

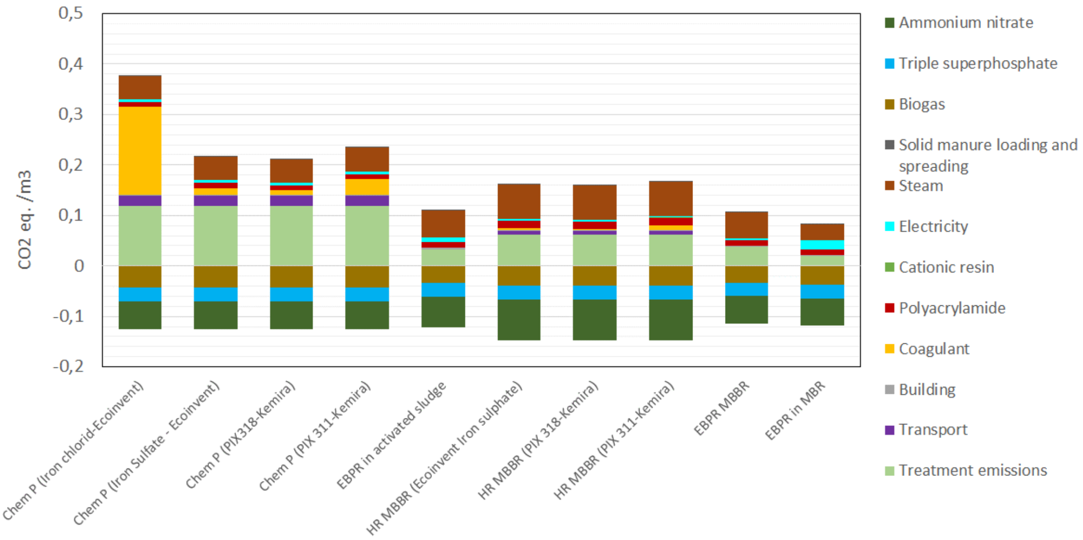

Figure 1 Comparison of evaluated alternatives based on Global warming (CO_2 eq./ m^3) including the contribution of each component associated with each treatment alternative.

Keywords: Phosphorous removal; LCA; Process comparison

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New methods of internal calibration of water quality monitoring systems in cold climate

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Quality of life in the modern world depends on access to good quality drinking water as well as on the environment. It is associated with monitoring the presence of undesirable and harmful components in it, using field water quality monitoring stations. Such installations, powered by solar or wind power, especially in cold climate, are exposed to considerable changes in temperature, which affect both the balance and the kinetics of chemical processes and the characteristics of detection systems. Due to their power consumption, effective thermostating is not possible. Every analytical method requires a calibration procedure to be carried out. The frequency of calibration is dictated by a number of factors. Introducing an autocalibration procedure into an analytical system eliminates those problems. A calibration step using a standard solution can be performed in each determination. Application of solenoid pulse micropumps into analytical flow systems created new ways of measurement calibrations. Both the sample and the reference can be injected directly into the carrier stream. It is therefore possible to carry out automatic calibration both in the form of a calibration curve and standard addition method. Particularly simple and effective autocalibration capabilities can be found in direct injection detectors (Kalinowski and Koronkiewicz 2013, 2014, 2014a, 2015, 2015a, 2016, 2017, Koronkiewicz and Kalinowski 2015, 2018, Koronkiewicz et al. 2018, Nalewajko-Sieliwoniuk et al. 2016). Because of their very low consumption of reagents and power as well as maintenance-free operation, these kinds of detectors are a great choice for terrain monitoring stations.

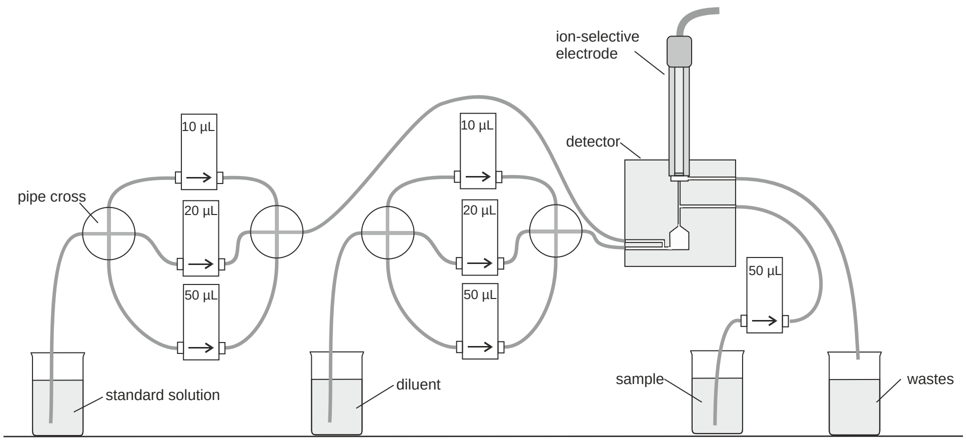

Figure 1 Schematic of the potentiometric analytical flow system with a gradient pump

Ion-selective electrodes are relatively popular in analytical chemistry. Because of their low stability and deterioration in parameters over time, they require frequent calibration. This frequent calibration is also rendered necessary because of the logarithmic relationship between the potential and the concentration. While it results in a very wide range of analyte concentration, it also worsens the accuracy of measurements. This problem can be solved through introduction of an autocalibration procedure into each analysis. It could be performed by preparation of calibration graph of the electrode as well as addition of the standard solution, which eliminates the influence of the matrix to a large degree. For that purpose, we have constructed a gradient pump comprising six pulse pumps – three for reference and three for the diluent (Fig. 1, 2).

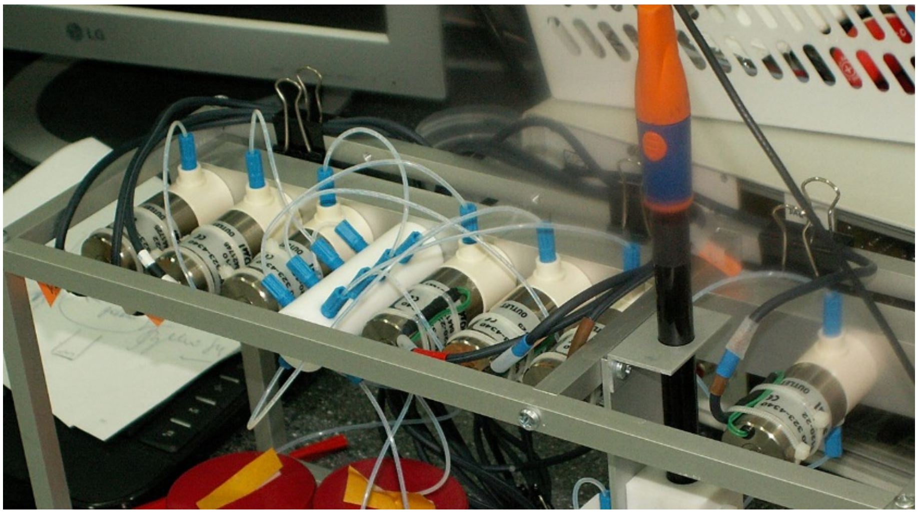

Figure 2 Photo of the analytical flow system with potentiometric detection

Reference solution and diluent are simultaneously injected into the mixing chamber. Diluted standard solutions from the mixer are injected into the potentiometric detector, followed by the sample. The system was tested with ion-selective electrodes sensitive to NO_3^- and NH_4^+ ions.

A photometric detector that would allow for double addition of a standard solution was also designed and constructed. This approach ensures short analysis time, low consumption of reagents and reduction of influence of the matrix on the results.

Keywords: Flow analysis; direct-injection detectors; ion-selective electrodes, autocalibration

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A stepwise machine learning method for managing uncertainty of wastewater treatment plants caused by snow melting in cold climate

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Abstract

The surveillance of influent variation is essential for the control of wastewater treatment plants. In cold climate area, snow melting happens frequently in cold season and affects wastewater characteristics significantly. The dilution effect of snow melting in cold season makes it impossible to compare cold season influent and warm season influent fairly. Besides, the hourly, daily and seasonal variation of influent characteristics of wastewater treatment plants (WWTPs) increased the uncertainty of the performance of WWTPs. A key step towards optimised wastewater treatment performance is handling the uncertainties of process inputs. In this study, a stepwise classification method was developed to discriminate whether the WWTP influent wastewater contains snowmelt (wet climate) or not (dry climate). This study investigated the daily, weekly and seasonal variation of WWTP influent, and provide evidence of climate effect on influent characteristics by analysing the correlation of climatic information and wastewater characteristics. The stepwise classification method developed in this study can be further applied to develop scenario-based soft sensor as well as support WWTP surveillance and control.

Influent variation was caused by the joint effect of human activities and climate conditions (Plósz, Liltved, et al., 2009). Distinguishing the wet climate influent becomes more difficult in the cold season because it is not realistic to know the amount of snowmelt or when the snow melting started (Moghadas, Gustafsson, et al., 2015). A statistical learning approach was proposed to distinguish the dry climate influent and wet climate influent. The approach has four steps:

1. Conduct the first ANOVA test to compare the raw influent data in the warm season and cold season. The results cannot indicate the real seasonal differences, because it is highly affected by climate factors.
2. Perform principal component analysis on the cold season data. The first two principal components (PC-1 and PC-2) explain 96 % of the total variability. Therefore, the scores of PC-1 and PC-2 can be used to represent the original dataset with reduced dimension.
3. Use the scores of PC-1 and PC-2 to perform hierarchical clustering. The observations (influent wastewater) are divided into two subgroups (clusters) by hierarchical clustering. Based on the features of these two clusters, one cluster is recognised as the dry climate influent, while the other cluster consists of wet climate influent.
4. Build a classification model based on PLS-DA to classify future influent, with which the previous steps can be bypassed for future classification.

The key steps of using the machine learning method to develop a discriminant tool for influent wastewater with snow melt are illustrated in Figure 1. The correlation matrix of water characteristics and climate factors is shown in Figure 2.

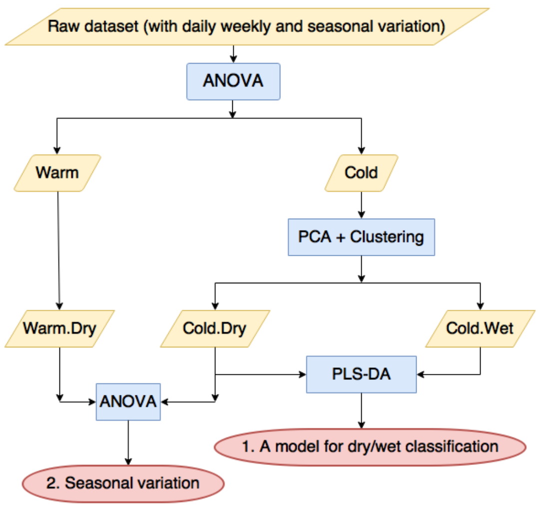
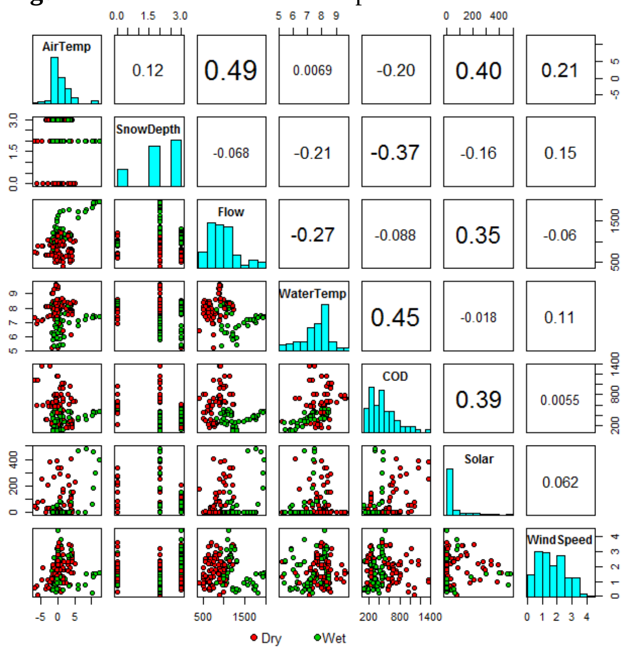


Figure 1 The stepwise method for developing a snow melt influent d

Figure 2 The correlation matrix plot of influent wastewater characteristics and climate factors



Keywords: cold climate, wastewater treatment, snow melt, machine learning

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A conductivity based soft-sensor for real-time estimation of phosphate concentration in a multi-stage Bio-P MBBR pilot plant.

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Abstract

Enhanced biological phosphorus removal (EBPR) is a treatment configuration designed for phosphorus removal from wastewater. The EBPR process consists of an anaerobic stage before the aeration stage, where a specific species of biomass called polyphosphate-accumulating organisms (PAO) is enriched. A novel configuration was developed by Saltnes, *et al.*, 2017 for achieving EBPR in a moving bed biofilm reactor (MBBR) process. The reactor performance is currently monitored using off-line laboratory analysis of PO_4-P. However, off-line monitoring implies a low data sampling frequency and a delay between sampling time and data availability.

Real-time measurement of PO_4-P concentration can result in faster detection of process abnormalities. Online monitoring can also enable the possibility of implementing control strategies. However, the high price of online phosphate analyzers often discourages their use in treatment plants. Soft-sensors are a viable alternative for expensive composition analyzers (Haimi *et al.* 2015).

Electrical conductivity (EC) can be measured using inexpensive and low-maintenance sensors. Conductivity measurements can be used to estimate nutrient concentrations in biological wastewater treatment processes (Serralta *et al.* 2004). Both mechanistic (Aguado *et al.* 2006), as well as data-driven models (Aguado *et al.* 2007), has been used to correlate conductivity measurements to PO_4-P concentrations. However, most work has been done either in a lab-scale using synthetic wastewater or in a sequential batch reactor.

This work presents the development of a conductivity based soft-sensor for real-time estimation of PO_4-P in the anaerobic stages of a multi-stage MBBR pilot plant. A grey-box model was developed by combining mechanistic elements of phosphorus release kinetics in anaerobic conditions, and statistical model correlating PO_4-P concentration with conductivity. The hybrid model is used with an extended kalman filter to estimate PO_4-P concentration in the anaerobic chambers.

Mathematical Model and Soft-sensor

The rate kinetics explaining PO_4-P release during the anaerobic phase (Nair *et al.* 2019) is adapted for a multi-stage MBBR system. The discrete state-space form of the model is presented in Eq. 1 – 6. The influent concentrations of fermentables ($S_{\mathrm{f,in}}$), volatile fatty acids ($S_{\mathrm{a,in}}$) and phosphates ($S_{\mathrm{po,in}}$) are estimated by augmenting them as state variables in the model.

$$x_{\mathrm{k+1}} = x_{\mathrm{k}} + T_{\mathrm{s}} f \tag{1}$$

$$x_{\mathrm{k}} = [S_{\mathrm{f,in}} \; S_{\mathrm{a,in}} \; S_{\mathrm{po,in}} \; S_{\mathrm{f,1}} \; S_{\mathrm{a,1}} \; S_{\mathrm{po,1}} \; S_{\mathrm{f,2}} \; S_{\mathrm{a,2}} \; S_{\mathrm{po,2}}] \tag{2}$$

$$y_{\mathrm{k}} = [C_{\mathrm{in}} \; C_1 \; C_2] \tag{3}$$

$$f_i = \begin{cases} 0 & i = 1,2,3 \\ \tau^{-1}\,(x_k(i-3) - x_k(i)) - \rho_i & i \geq 4 \end{cases} \quad (3)$$

$$\rho_i = \begin{cases} r_1 \dfrac{x_k(i)}{K_{fe} + x_k(i)} & i = 4,7 \\ r_1 \dfrac{x_k(i-1)}{K_{fe} + x_k(i-1)} - r_2 \dfrac{x_k(i)}{K_a + x_k(i)} & i = 5,8 \\ Y_{PO}\, r_2 \dfrac{x_k(i)}{K_a + x_k(i)} & i = 6,9 \end{cases} \quad (4)$$

$$y_k(i) = h(x_k(3i-1), x_k(3i))$$

T_S is the time-step, k is the discrete time index and τ is the residence time in each chamber. The kinetic parameters K_{fe}, K_a, r_1, r_2, and the stoichiometric parameter Y_{PO} are obtained from the kinetic studies. The PLS regression is used to correlate phosphate concentration with S_a and S_{po} to obtain the measurement function h**.** The EFK equation, as well as the method used for tuning the EKF parameters, is explained in (Haugen *et al.* 2014).

Preliminary Results

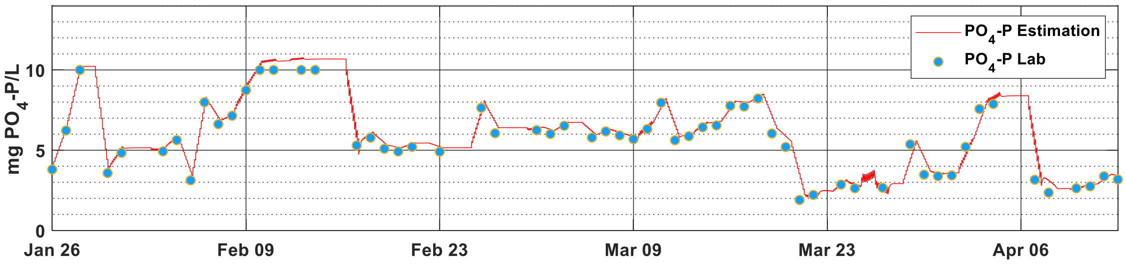

Figure 1 Validation results estimated influent PO4-P concentration versus lab measurements.

Validation tests comparing the online estimation results of influent PO_4-P concentration with the lab measurements proves the validity of the phosphate sensor.

Keywords: EBPR; extended kalman filter; MBBR; soft-sensor

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Dosage optimization of polyaluminum chloride by the application of convolutional neural network to floc images taken in a jar-test

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Abstract: Optimization of coagulation is still challenging as it is affected by several factors including pH, turbidity, and alkalinity. The jar-test is a reliable and cost-effective method; however, it requires an experienced technician and it is time-consuming to obtain accurate results. In this study, to examine the coagulation performance immediately and automatically, an alternative technology that applies a convolutional neural network to floc images taken using a video camera during the jar-test was proposed. The pictures recorded at different jar-test times were input by the six models. The validation test revealed that only the model learning initial 120 s of floc pictures achieves an accuracy of 99.6%. In addition, this model showed good performance by using a natural water sample. These results demonstrated that the developed technique could successfully judge the floc settleability until the end of the rapid mixing phase.

Keywords: convolutional neural network; artificial intelligence; floc image analysis

Although flocculation and coagulation are indispensable unit processes in drinking water treatment plants, it is still challenging to optimize these physicochemical processes because the processes are comprised of several complex reactions that change depending on the pH, coagulant dosage, and temperature[1]. In practice, the dosage optimization of the coagulant is typically carried out by a jar-test. While the jar-test is a reliable technique, it can take ~1 h for manipulation even by an experienced technician. Hence, it is extremely difficult to adjust the coagulation conditions depending on the changes in the source water condition.

Meanwhile, convolutional neural networks (CNNs) constitute an emerging technique that has been applied from a self-driving car to an accurate image recognition system[2]. CNNs can be applied in water treatment and in the recognition and assessment of the physical characteristics formed during coagulation, surpassing human capacity.

In this study, to optimize the coagulant dosage, CNN was newly applied. First, databases, including the combination of floc images and turbidity of the final supernatant, were prepared by using a video camera to record a series of jar-tests using artificial surface water, followed by categorizing them into several groups based on the turbidity of the final supernatant. Then, the floc images (input) and categories of their performance (output) of the CNN model were input into the calculation.

Six models were built based on videos with different jar-test durations. The model built using a short recording duration enabled considerably speedy judgment. The optimum recording duration was clarified based on the accuracy of the models, and the potential of CNN for controlling coagulation was finally discussed.

The prediction model was first built using the training dataset. Figure 1 plots the prediction accuracy as a function of the training step (epoch), known as the learning curve. Until 50 epochs were implemented, all of the built models reached a plateau of 100% accuracy, which indicates the prediction models were successfully built.

The level of overfitting of each model was verified by the input of the validation data. The prediction accuracy, denoted by a dashed line in Figure 1, at maximum exceeded 96% for all the models, although the value of some models fluctuated to some extent depending on the epoch number. The prediction accuracy was considerably greater than that determined by multi-layer artificial neural network or a multi-regression analysis set under the jar-test condition as input and the supernatant turbidity as the output. The highest value of 99.8% was observed for model 6 (0–100s), and the lowest value of 99.6% was observed for model 4 (0–800s). Model 6 required pictures of rapid mixing only, while model 4 was built using dataset including rapid and slow mixing pictures, which implies that learning using only rapid mixing pictures prevents overfitting. Hence, training with rapid mixing pictures only builds a more reliable model compared to training with both rapid and slow mixing pictures.

Similar to the maximum accuracy, model 6 exhibited the least amount of fluctuation for prediction accuracy. From the verification of overfitting, it can be concluded that using pictures of rapid mixing only can build robust, general, and reliable models. In other words, under the jar-test conditions employed herein, the optimum coagulation condition can already be determined by the end of rapid mixing.

From the input of the images taken at rapid mixing into model 6, the further accurate prediction of all three samples taken at different times was achieved despite the fact that the source water quality was completely different from the artificial water quality. Hence, the model built with artificial water is also applicable to actual natural water.

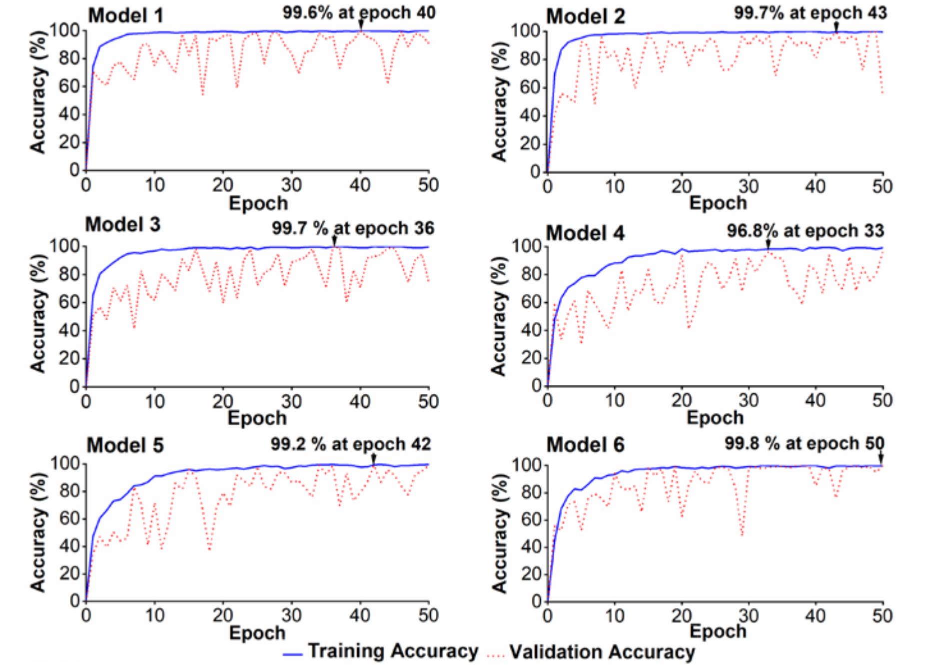

Figure 1.1 Learning curve of six models. Each model input pictures taken at different times of the jar-test: model 1 = 0–120 s, model 2 = 0–200 s, model 3 = 0–400 s, model 4 = 0–800 s, model 5 = 0–1200 s, model 6 = 0–1600 s.

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