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Udvikling af decentrale systemer for sikker genanvendelse af renset spildevand i landdistrikter og forstæder til storbyer i Kina

Titel:

Udvikling af decentrale systemer for sikker genanvendelse af renset spildevand i landdistrikter og forstæder til storbyer i Kina

Development of decentralized systems for safe reuse of cleaned wastewater in rural and suburban districts of China

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Forord

Denne rapport er udarbejdet på baggrund af projektet ” Udvikling af decentrale systemer for sikker genanvendelse af renset spildevand i landdistrikter og forstæder til storbyer i Kina”, der er gennemført i regi af Miljøstyrelsens/Naturstyrelsens tilskudsordning for Miljøeffektiv Teknologi 2010.

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Sammenfatning

Miljøstyrelsen giver tilskud til teknisk udvikling af miljøteknologiske løsninger, og har et specielt program, der giver mulighed for, at denne udvikling kan foregå i udlandet. Dette projekt som har titlen "Udvikling af decentrale systemer for sikker genanvendelse af renset spildevand i landdistrikter og forstæder til storbyer i Kina" er støttet af dette program, og støtten sigter mod at give Danske virksomheder finansiel støtte til udvikling og test af renseteknologiske løsninger i udviklingslande som Kina.

Formålet med dette projekt er at udvikle små renseanlægsløsninger til genanvendelse af renset spildevand til brug i områder med mangelfuld kloakering, hvilket typisk omfatter forstæder til storbyer og stort set alle landdistrikter i Kina. Renseløsningerne designes som ubemandede installationer som kan rense spildevandet for fjernelse af næringssalte og organisk stof, og renseanlæggene er designet til at tilbageholde slam, som dannes i forbindelse med renseprocessen i længere perioder.

Projektets mål er at udvikle et rensningskoncept til vandgenbrug som tilkobles den biologiske renseproces med en indbygget alarmeringsfunktion som aktiveres hvis essentielle funktioner fejler i renseinstallationen. Teknologien udvikles af de to danske firmaer Biokube A/S (producent af minirenseanlæg) og Skjølstrup & Grønborg ApS. (producent af UV systemer). Teknologien der skal udvikles og afprøves består af en filtreringsløsning med tilkoblet UV som både skal være simpel og let at benytte og den skal miljøvenlig i sin funktion.

Efter projektet var bevilget blev en indledende projektfase igangsat med henblik på at finde denne rette placering for projektets udførelse i Kina. Der var i den forbindelse en række krav som måtte opfyldes for at sikre et succesfuldt projektforløb: Råspildevand skulle være tilgængeligt ligesom det skulle være muligt at udlede det rensede spildevand til en recipient. Slam dannet fra den biologiske proces skulle kunne bortledes regelmæssigt, strømtilførsel tilgængelig og installationen skulle være nogenlunde sikret mod tyveri. Derudover skulle der være professionelt personale som kunne inspicere installationen løbende og udtage vandprøver til godkendt laboratorium. Det var desuden væsentligt for de danske projektpartnere at den medvirkende lokale partner i Kina ville være ægte interesseret i projektet og dets udvikling og medvirke aktivt i dets udførelse samt formidlingen af projektet.

Alle disse kriterier blev opfyldt hos den lokale spildevands planlægningsmyndighed i byen Suzhou – en mindre by med 3 mill. indbyggere beliggende 100 km vest for Shanghai. Testplatformen blev etableret ved Suzhou Sewage Administration´s (SSA) kontor – et kontor som til daglig deltager i planlægningsopgaver og rådgivning for lokalregeringen i Suzhou. SSA var interesseret i at afprøve nye teknologiske løsninger til spildevandsgenbrug som også kunne fungerer decentralt, idet Suzhou har mange spildevandspunktkilder til følsomme recipienter som ikke bliver renset (f.eks. mange offentlige toiletter som leder spildevand direkte ud i nettet af kanaler som løber igennem byen). Derudover har Suzhou et relativt stort landdistrikt hvor der er et stort behov for decentrale spildevandsrenseløsninger. Selve testplatformen var ideel idet anlægget kunne placeres ved en pumpestation beliggende tæt på SSA´s kontor med overvågning døgnet rundt. Spildevandet kunne derfor opsamles og udledes samme sted og slam kunne periodevist pumpes til pumpestationen. Derudover var det relativt let for DHI´s kinesiske ansatte i Shanghai at transportere sig til projektområdet i Suzhou.

Forsøgsopstillingen blev etableret i november 2011 hvor installationen blev vådtestet og i gangsat. Indkøringen af den biologiske renseproces blev forholdsvis langvarig på grund af vinteren da det tager tid for de nitrificerende bakterier at opbygge en biofilm. I februar 2012 kunne selve moniteringen og forsøgsaktiviteterne påbegyndes frem til den næste vinter således at der næsten var et års eksperimenterende arbejde til rådighed.

Det tekniske udviklingsforløb foregik indledningsvist i Danmark hvor konceptet samt ideerne bag teknologiudviklingen blev modnet og komponenter bestilt. Visse komponenter (f.eks. hele filtreringssystemet) blev fundet hos kinesiske leverandører og indbygget i den samlede løsning sammen med en Biokube Mars 3000 renseenhed. Konceptet til rensning af biologisk behandlet spildevand bestod i at lade det biologisk rensede spildevand passere en holdetank på 800 liter som så hele tiden indeholdt "friskt" renset spildevand hvilket modvirkede lugtgener og bakteriel genvækstsdannelse. Desinfektionssystemet (10 µm posefiltreringsenhed sammenbygget med UV rør i et stykke sammensvejst plast) var således nedsænket i holdetanken som kunne opstartes med en mindre PLC styringsenhed, som bl.a. kontrollerede opvarmningen af UV rørene og pumpen som skulle trykke vand igennem systemet. Filosofien bag systemet var at producere bakteriefrit vand med pumpetryk således at det desinficerede vand dels ikke skulle opmagasineres (med risiko for genvækst af uønskede mikroorganismer) og således at vandet kunne transporteres til den kilde hvor det skulle genanvendes. Ulempen ved denne metodik er, at der kun er en vis mængde vand til rådighed til vandgenbrug – denne vandmængde kan dog styres i forhold til dimensionen af holdetanken som desinfektionssystemet er nedsænket i.

Biokube Mars 3000 systemet består af en aerob biofilmproces designet til COD fjernelse og nitrifikation. Normalt kan næsten fuld denitrifikation (nitratfjernelse) og fosforfjernelse også foretages i processen men disse processer kunne ikke drives optimalt i dette set up da bundfældningstanken var for lille og kemikalierne til fosforfældningsprocessen kunne ikke medsendes sammen med forsøgsopstillingen. Biokube Mars 3000 systemet benyttes normalt til rensning af spildevand fra større bebyggelser som f.eks. hoteller der ikke er koblet til offentlig kloak. Kapaciteten af et Mars 3000 modul er normalt 40 person ækvivalenter, svarende til en normal spildevandsproduktion fra 40 personer.

I løbet af forsøgskampagnen i Suzhou blev det vist, at den biologiske proces er meget effektiv til fjernelse af organisk stof, idet fjernelsesgraden af henholdsvis COD og BOD var over 90% og 95%. Total COD koncentrationen blev vedvarende renset til en koncentration omkring 35 mg COD/l og BOD_5 var typisk under 5 mg BOD_5/l i afløbet fra Biokube systemet. Specielle undersøgelser viste at systemet rent faktisk havde en langt højere kapacitet end den maksimum belastning, som systemet kunne nå igennem forsøgsperioden. Således blev de maksimale specifikke omsætningsrater målt til 40-50 g COD/m^2 (biofilm medie)/d og på den baggrund blev vurderet at systemet kunne belastes med op til 9,5 kg COD/d samtidig med at rensekravet til den kinesiske klasse 1A for spildevandsudledning til recipient blev overholdt (50 mg Total COD/l). Den maksimale COD belastning som blev opnået igennem forsøgskampagnen var typisk kun 1-5 kg COD/l med enkelte maksimumbelastninger op til 8,8 kg COD/l.

Fjernelsen af ammonium blev undersøgt under ekstremt varme og kolde temperaturer. Analyser viste, at størstedelen af ammonium typisk blev fjernet i første kammer i Biokube anlægget (Mars 3000 indeholdt 4 kamre i alt) hvor også den højeste organiske stoffjernelsesaktivitet foregik. Dette var ret overraskende idet Biokube systemer – og nitrificerende biofilm processer generelt – designes som to trins processer (eller flere) hvor heterotrof organisk stoffjernelse foregår i første trin og autotrof ammonium fjernelse (nitrifikation) foregår i andet trin af processen. I denne undersøgelse blev de højeste nitrifikationsrater konkret målt til 1,75 g NH_4-N/m^2 (biofilm medie)/d ved 25°C, men den nitrificerende kapacitet (ammonium mindre end 1 mg NH_4-N/l) kunne opretholdes indtil temperaturen faldt til under 5°C med nitrifikationsrater op til 1,2 g NH_4-N/m^2 (biofilm medie)/d.

Total kvælstoffjernelse blev delvist opnået ved denitrifikation i bundfældningstanken med en gennemsnitlig kvælstofreduktion på 50%. Kvælstofreduktionen blev opnået ved at recirkulere nitratholdigt vand fra sidste rensetrin i Biokuben tilbage til bundfældningstanken hvor den akkumulerede slammængde i bundfældningstanken fungerede som en biologisk aktiv proces. Denitrifikationsprocessen var i denne sammenhæng særdeles nyttig, idet de anoxiske forhold forhindrede svovlbrintedannelse i tanken.

Derudover blev en del af det indkomne organiske stof fra spildevandstilledningen omsat uden brug af ilt til processen.

Fosforfjernelse kunne som nævnt ikke testes effektivt idet de kemikalier som benyttes til fældningsprocessen i Biokube systemet (PAX, polyaluminium klorid) dels ikke kunne fremsendes og dels ikke fremskaffes på det kinesiske marked i passende kvantum. Fosforfjernelse blev dog registreret som følge af den biologiske aktivitet hvilket resulterede i et fald i fosforkoncentrationen fra 3,5 mg TP/l til 2,5 mg TP/l. Da kravene til fosforudledning i Kina typisk er relative strenge (TP < 1 mg/l, Klasse 1A) nødvendiggør det en signifikant tilledning af fældningskemikalie i kombination med en tilstrækkelig stor bundfældningstank og meget lav udledning af suspenderet stof (som også indeholder fosfor).

Biokube systemet blev drevet ved et maksimalt flow op til 12,5 m^3/d. Højere flow kunne ikke opnås i det givne system på grund af hydrauliske begrænsninger igennem kamrene. Det blev imidlertid estimeret at systemet med den givne tilledningskoncentration kunne have behandlet 15-20 m^3/d hvis det havde været muligt at presse denne vandmængde igennem anlægget. Det høje flow blev bibeholdt indtil sidst i forsøgskampagnen hvor vandets temperatur faldt til 4°C. Ved denne temperatur sås de første tegn på en faldende nitrifikationsaktivitet med stigende indhold af ammonium i afløbet fra Biokube systemet.

Det udviklede UV og filtreringssystem fungerede perfekt med komplet fjernelse af Fækalkoliforme bakterier indtil en af UV ballasterne fik en defekt, som viste sig umulig at få repareret (april 2012). Det blev forsøgt at by-passe det defekte UV rør ved at flytte prøvetagningspunktet efter filtrering/UV, men det viste sig umuligt at undgå kontaminering fra den defekte del af anlægget. Posefiltreringssystemet fungerede hensigtsmæssigt og det blev ved en lejlighed succesfuldt forsøgt at lade det tilstoppe for at konstatere at anlægget responderede efter hensigten (dvs. vandet blev tilbageført til opmagasineringstanken via aktivering af en pressostat ventil). Da posefiltre kun kan tilbageholde en vis mængde partikulært materiale er det vigtigt at skifte poserne inden tilstopning forekommer, da vandstrømmen ud af anlægget ellers afbrydes. Kombinationen af posefiltre og UV synes hensigtsmæssig for eliminering af bakterier og er især hensigtsmæssig for yderligere polering og hygiejnisering af biologisk behandlet spildevand, idet vandet er klart og fri for synlige partikler og da det samtidig tappes kort tid efter at det har passeret den biologiske renseproces opstår der ingen ubehagelige lugtgener som følge af genvækst i holdetanken. Gennem den forsøgsperiode hvor anlægget fungerede efter hensigten kunne alle kinesiske standarder for genbrug af spildevand imødekommes i forhold til kravet til Fækalkoliforme bakterier(GB18918-2002, udledning fra renseanlæg til recipient, GB/T18920-2002, genbrug af spildevandvand til vanding, bilvask mv, GB20922-2007, genbrug af spildevand til landbrugsvandingsformål)

Igennem projektforløbet opstod der flere uheld som enten var fatale for forsøgene eller som kunne oprettes ved konstruktionsændringer undervejs i projektet. Tidligt i forsøgskampagnen opstod der problemer med den flyder, som kontrollerede indpumpningen af spildevand til systemet, hvilket resulterede i flere tilfælde af oversvømmelse i hele området. Fejlen opstod som følge af en fejlkonstruktion af en ny type flyder som blev afprøvet i installationen og da denne blev udskiftet sammen med et nyudviklet alarmeringssystem blev disse uheldige episoder fremover undgået. En anden begivenhed indtrådte i sommeren 2012 hvor vandtemperaturen nåede 32°C i anlægget. Ved et uheld blev bundfældningstanken ikke tømt, og da tanken (som var underdimensioneret til 20% af den størrelse som den burde have) hurtigt fyldtes med slam resulterede det i en formodet svovlbrinte dannelse som resulterede i en næsten fuldstændig hæmning af nitrifikationsprocessen. Episoden viste sig imidlertid at være nyttig i formidlingssammenhæng idet vigtigheden af slamtømning kunne demonstreres og rapporteres. Normalt designes bundfældningstanken så slamtømning bør foregå hver 6-12 måned – i denne forsøgskampagne var det nødvendigt at tømme slamtanken så hyppigt som hver 3-4 uge.

Et simpelt overvågnings- og alarmeringssystem blev udviklet og installeret i juni 2012 til overvågning af oversvømmelse og afbrydelse i elforsyning. Systemet blev udviklet som et SMS-baseret system som både kunne sende SMS'er til danske og kinesiske mobiltelefoner. Systemet sendte senere mange SMS'er med advarsler om manglende el som dog oftest blev vurderet at være meget korte og således uden betydning for systemets performance. Alarmeringssystemet vurderes at være meget værdifuldt for decentrale renseinstallationer, da det kan sættes op til at reagere på kritiske fejl i strømforsyningen og strømforbrug fra diverse simple komponenter som tryksensorer, flydere mv. og kan på den måde installeres relativt simpelt og billigt.

Driftsforbrug blev dels opgjort på baggrund af de opnåede driftserfaringer og dels på baggrund af oplysninger fra producenter af udstyr. De direkte forbrugsomkostninger relateret drift af et biologisk minirenseanlæg blev således identificeret til slamproduktion, elforbrug og forbrug af fældningskemikalier. Slamproduktionen estimeres til 5-10 liter slam/m^3 behandlet spildevand (1.5% TS i slam), strømforbrug til Biokube renseanlæg estimeres til 0.8-1.1 kWh/m^3 behandlet spildevand (pumper og beluftning) mens fældningskemikalieforbrug til fosforfjernelse estimeres til 0.4 liter PAX/ m^3 behandlet spildevand (TP< 1.0 mg TP/l). Forbrugsudgiften til drift af desinfektionssystemet blev estimeret til forbrug af filterposer og strøm til drift af UV anlæg og udpumpning af vand. Det estimeres at der i en type filterpose kan gennempumpes ca. 500 m^3 spildevand/pose (som tilbageholder 2.5 kg suspenderet stof og koster 13.6€ stykket) hvilket giver en filtreringsudgift på 0.027€/m^3 filtreret spildevand (0.2 DKK/m^3 filtreret spildevand). Forbruget af strøm til drift af UV inkl. pumpning (til 4 bars tryk) estimeres til 0.21 kWh/m^3 behandlet spildevand. Omkostningsberegningerne viser, at det er økonomisk og teknisk muligt at genbruge renset spildevand på en miljømæssig forsvarlig måde ved brug af teknisk udstyr i stedet for klor (som er den foretrukne desinfektionsmetode i Kina) og at omkostningerne til opgraderingen af spildevand til genbrug i Kina er forholdsvis begrænset, dvs. 10-20% af de samlede rensningsomkostninger.

Projektet er blevet formidlet dels ved denne afrapportering og dels ved afholdelse af et teknisk seminar som blev afholdt i Suzhou i Kina. Arrangementet tiltrak 20 deltagere fra kinesiske institutioner og firmaer hvor hovedparten af resultaterne blev præsenteret og diskuteret blandt deltagerne. Projektets resultater blev desuden accepteret som artikel til offentliggørelse i det internationale tidsskrift International Water Association og vil blive præsenteret af DHI på den næstkommende IWA konference, som afholdes 28.-30. oktober 2013 i den nordkinesiske by Harbin (11^{th} IWA Conference on Small Water and Wastewater Systems and Sludge Management).

执行概述

丹麦环保局资助环保技术的发展并有特定程序帮助在国外的技术研发。该程序支持“分散式污水处理回用系统在中国农村和郊区的开发应用”，项目的目的是给予丹麦企业资金支持使其在发展中国家（如中国）开发和测试丹麦环保技术。

该项目旨在为那些难以收集污水并输送到污水厂的中国郊区和农村地区，研发小规模的中水回用污水处理设施。该污水处理设施的优势为无人定点值守，可有效去除营养物和有机物，且产泥量少。

该项目将研发带有故障自动报警功能的，独立的污水回用处理设施。该技术源于丹麦Biokube A / S（污水处理厂生产商）和Ultra Aqua Aps（UV系统生产商）。升级的污水处理技术包括简单易用的过滤和紫外消毒系统。

项目启动后，初期的主要任务是找到合适的项目地点。另外需满足几个基础条件：污水进水/排放和污泥处置、设备保护、供电以及专业人员采集和分析水样。此外，当地合作伙伴对设备和研发的宣传及未来业务发展的兴趣也相当重要。

全部测试条件都满足苏州（上海附近的一个城市）当地标准。测试和技术开发现场设在苏州排水管理处。作为该项目当地的合作伙伴，他们对城市和郊区分散式污水处技术很感兴趣。项目现场位于一座污水泵站附近，位置非常理想，设备进出水及污泥处置都很方便。从项目现场到苏州排水管理处办公区非常近，方便日常监管和取样。此外，从DHI中国的上海办公室到现场也非常便捷。

测试设备于2011年11月安装并运行。由于冬季温度低，生物培养驯化期比较长，直到2012年2月该项目才正式开始，运行一年后，项目结束。

系统技术开发的一部分来自丹麦，它包括一个附加的消毒系统，可以和Biokube Mars 3000 标准反应器连接。污水先经过初沉和生化处理，然后再经过一个小型消毒池（800升）。消毒池包括袋滤和紫外消毒单元。该系统由一个小型PLC系统控制，启动输送泵前，紫外消毒系统需要预热。该系统的理念是消毒过的水不应该被长期保存，但是可以根据需求量来消毒。消毒系统的能力由消毒池的容积和泵的流量决定。

Biokube Mars 3000是去除COD和氨氮的耗氧生物过滤系统。通常，可以进行完全反硝化和除磷，但测试设备的尺寸限制了这方面的功能。Biokube Mars 3000 系统适用于没有排水管网的较大的家庭、宾馆或其他设施。其处理能力为40PE（人口当量，相当于40人产生的废水）。

测试期间，有机物几乎100%完全去除，COD和BOD_5的去除率分别为90%和95%。出水COD和BOD_5的浓度分别低于35 mg COD/l 和 5 mg BOD_5/l。专门研究发现，有机物去除能力远远高于测试负荷。最大去除率达到40-50 g COD/m^2 滤膜面积/d。据估计，该系统达到一级A排放标准的最大负荷为9.5 kg COD/d。该项目测试期间的COD负荷只有 1 – 5 kg COD/d，最大负荷为8.8 kg COD/d。

此外对极热和极冷条件下，氨氮的去除率做了研究。分析结果显示，Biokube系统第一隔间中异养活动非常高（COD去除），发生几乎完全硝化反应。对于生物膜硝化进程，Biokube通常设计为2步（或多步）过程，异养活动和COD去除在第一步，硝化反应在第二步。研究发现，在25°C，异养区实现完全硝化，达到1.75 g NH4-N/m^2 滤膜面积/d。在温度降到5 °C以下，氨氮负荷在150 -- 350 g NH_4-N/d时，仍然能实现完全硝化，最大去除率为1.2 g NH4-N/m^2 滤膜面积/d (NH_4-N < 1 mg NH_4-N/l)。

测试期间通过反硝化，总氮的去除率达到50%。总氮的去除是通过回流高浓度硝酸盐废水到初沉池实现的。初沉池即是污泥存储池也有沉淀去除颗粒有机物的功能。反硝化过程对于防止在初沉池中形成厌氧条件，生成H_2S有很大作用。此外，硝酸盐可以减少部分有机物进而降低耗氧过程COD负荷。

由于没有得到化学药剂三氯化铝（PAX），因此没有测试磷的去除。但是第一部的异养活动去除了部分磷，总磷浓度从3.5 mg TP/l降到2.5 mg TP/l。

Biokube系统的最大运行负荷为12.5 m^3/d。由于设计所限，不能到达更高负荷。相对于丹麦的生活污水，中国的生活污水浓度较低，因此可以通过提高泵的能力使该系统处理能力达到15-20 m^3/d。测试结果反映，在最大流量12.5 m^3/d时，最低温度（4°C）对硝化反应影响很小。

紫外消毒和过滤系统在其中的一个紫外控制器损坏之前（2012年4月）能够彻底去除粪大肠杆菌。一个解决方案是从仍然正常运作的一个紫外管中取样，但是它不能阻止粪大肠杆菌出现在消毒系统的出口。过滤系统堵塞过一次，但新的滤袋已安装。滤袋堵塞前只能拦截一定数量的颗粒，另外需要施加一定的水压以抵消堵塞阻力。滤袋和紫外消毒系统的结合非常适合去除影响水质的粪大肠杆菌及水中颗粒，以达到回用标准。在系统测试期间，粪大肠杆菌检测结果满足中国城市中水回用排放标准（GB18918-2002《城镇污水处理厂污染物排放标准》、GB/T18920-2002《城市污水再生利用-城市杂用水水质》、GB20922-2007 《城市污水再利用农田灌溉用水水质》）。

在项目实施过程中，出现了几个意外事件。项目初期，进水泵浮子控制器出现故障，持续进水导致污水外溢。后来更换新的浮子控制器并开发了水位移动报警系统。另一个事件是在2012年夏天，当时气温32°C，没有及时清空误选的较小的初沉池中产生的污泥，

可能由于进水中含有H_2S导致硝化系统几乎完全崩溃。从中得到的教训是初沉池需定期清空，通常6-12月清空一次（该项目需要3-4周清空一次）。

2012年6月项目安装了一个简单的报警系统用于防止溢流和系统断电。一旦意外发生，报警系统可以发送短信到中国和丹麦的手机，此后大量断电报警短信被发送（这种瞬间断电不影响系统运行）。此报警系统非常适合分散式设备，可以监控鼓风机、水泵、电源、UV和压力阀，并通过短信报警。

运行成本部分基于实验，部分依靠生产商提供的经验数据。污水生化处理的运行成本包括污泥处理、电耗和化学药剂，据估计处理每立方米污水产生5-10升污泥（1.5%TS）、消耗0.8-1.1kWh和0.4升三氯化铝试剂（出水达到一级A GB18918-2002）。消毒系统运行成本包括滤袋费用和紫外消毒系统的电耗。每个滤袋可以过滤500 m^3污水（相当于0.027€/m^3）。紫外消毒电耗约为0.21 kWh/m^3。这些成本表明，中水回用在经济和技术上是可行的。升级为中水回用的成本只占污水处理总费用的10-20%。

该项目的实施方和中国的合作伙伴就项目推广在苏州举办了一个研讨会（共20人出席），并发布了报告。研讨会非常成功，会上展示了大量的项目成果，并组织参观了项目现场。最后，该项目的结果（现已被接受发表）已提交将于2013年10月28-30日在中国北方城市哈尔滨举行的国际IWA会议（第11届国际IWA会议--小型水和污水系统及污泥管理）。

Executive summary

The Danish Environmental Protection Agency is funding technical development of environmental technology and has a special program where the technical development can take place abroad. This project ”Development of decentralized systems for safe reuse of cleaned wastewater in rural and suburban districts of China” is supported under this program and the funding aims at giving Danish Enterprises financial support to develop and test Danish environmental technology in development countries like China.

The purpose of this project is to develop small scale wastewater treatment plants for water reuse to be used in suburban and rural areas in China where the sever system does not collect wastewater to central wastewater treatment plants. These wastewater treatment installations are designed as unmanned units that can perform wastewater treatment for complete removal of nutrients and organic matter and they can detain the sludge produced for longer periods.

The project goal is to develop a concept of wastewater reuse as a stand-alone treatment installation with an alarm function that can be triggered if the installation somehow should fail. The technology is produced by the two Danish companies Biokube A/S (producer of wastewater treatment plants) and Ultra Aqua Aps. (producer of UV systems). The technology for upgrading of the cleaned wastewater involves filtration and UV treatment in a way that is still simple and easy to operate.

When the project was granted, the initial phase of the project focused on finding the right location for carrying out the project. There were several logistic criteria that had to be met: wastewater intake/outlet and sludge discharge had to be possible, the installation had to be protected, power had to be available and supervision, water sampling and analysis had to be done by authorized staff. It was also important that the local partner would take interest in the experiment and development for dissemination purpose and possible business development.

All criteria were met at the location which DHI found in Suzhou, a small city located near Shanghai. The site for testing and developing the technology was performed at the agency of Suzhou Sewage Administration who advises the local government in Suzhou in relation to choice of technology and planning of wastewater collection and treatment. The local partner, Suzhou Sewage Administration, found the technology interesting as a decentralized solution for urban as well as suburban areas. The experimental platform in Suzhou was ideal because it was located next to a pumping station where wastewater could be pumped up and discharged again. Sludge could be dumped in the pumping station as well. Since the test site was near the office building of Suzhou Sewage Administration it was easy to make daily inspection and sampling from the installation. Furthermore it was fairly easy for DHI to get access to the location.

The equipment was installed in November 2011 and put into operation. The running-in period of the biological process was long due to the winter season and lasted until February 2012 where the actual development program started. Experiments with the equipment were then conducted for almost one year after which the practical part of the project ended.

The technical development of the system was partly prepared from Denmark and it consisted of an add-on disinfection system that could be connected to a standard Biokube Mars 3000 reactor. The idea was to clean the wastewater the normal way with pre-sedimentation and biological wastewater treatment and then pass the cleaned wastewater through a small disinfection tank (800 liter). The disinfection unit consisted partly of a bagfilter unit and partly of a UV system installed in the disinfection tank. The system was controlled by a small PLC system as the UV had to warm up before the pump could be started. The philosophy of the system was that disinfected water should not be stored for longer periods but should be produced when there was a need for it. The capacity of the disinfection system was determined by the size of the disinfection tank and the flow of the pump.

The Biokube Mars 3000 reactor was an aerobic biofilter system designed for COD and ammonia removal. Normally, almost full denitrification and phosphor removal can be obtained but limitations of the equipment size prevented this to be tested in an optimal way. The Mars 3000 system is normally used for large household treatment or installed at hotels or other facilities located far from the sewer network. The capacity of such a system is 40 PE (Person Equivalent, equal to wastewater generated from 40 people).

During the experimental campaign organic matter has been almost completely removed in the biological process with removal efficiencies of 90% and 95% for COD and BOD_5 respectively. During most of the period COD effluent concentration was below 35 mg COD/l and BOD_5 below 5 mg BOD_5/l. Special investigations revealed that the capacity for removal of organic matter is much higher than the load observed during the campaign. The maximum specific removal rate was measured to 40-50 g COD/m^2 filter area/d and it is estimated that the maximum load to be treated by this system and still meeting the Chinese Class 1A standard for wastewater treatment plant discharge is 9.5 kg COD/d. The COD load achieved during the experimental campaign was only 1 – 5 kg COD/d with peak loads up to 8.8 kg COD/d.

The removal efficiency of ammonia by nitrification was studied under extremely warm and cold conditions. Analysis showed that almost complete nitrification could be obtained in the first chambers of the Biokube where the highest heterotrophic activity took place (COD removal). This came as a surprise since Biokube systems – and biofilm nitrification processes in general - are normally designed as two-step processes (or more) with heterotrophic activity and COD removal in the first step and nitrification in the second step. In this investigation full nitrification was achieved in the heterotrophic zone with removal rates determined to 1.75 g NH4-N/m^2 filter area/d at 25°C. Full nitrifying capacity could be achieved until the temperature dropped below 5 °C with ammonia loads ranging from 150 to 350 g NH_4-N/d and maximum removal rates of 1.2 g NH4-N/m^2 filter area/d (NH_4-N < 1 mg NH_4-N/l).

Total nitrogen removal was partly achieved by denitrification with an average of 50% TN reduction during the experimental campaign. The total nitrogen removal was achieved as a result of recirculating nitrate-rich wastewater produced in the Biokube back to the pre-sedimentation tank that functioned partly as a sludge storing tank and partly as a sedimentation process for removal of particulate organic matter. The denitrification process was very useful for the process since nitrate prevented anaerobic conditions in the pre-sedimentation tank which could lead to H_2S formation. Furthermore, nitrate reduced part of the organic matter leading to a reduced COD load to the aerobic process.

Phosphorous removal could not be tested in this campaign since the chemicals needed for the precipitation process (PAX, Aluminium chloride) could not be obtained. Phosphorous removal was however observed as a result of the heterotrophic activity, which led to a reduction of the total phosphorous concentration from 3.5 mg TP/l to 2.5 mg TP/l.

The Biokube system was operated with a maximum flow of up to 12.5 m^3/d. Higher hydraulic loads could not be obtained in this system due to hydraulic limitations of the design. It is estimated that the process could have handled 15-20 m^3/d if it was possible to pump such an amount of wastewater through the system, because the wastewater was fairly thin in concentration as compared to typical Danish domestic wastewater. At the end of the experimental campaign it was noted that extremely cold water (4°C) affected the nitrification process slightly while the flow was kept at its highest level, 12.5 m^3/d.

The UV and filtration system has worked perfectly with complete removal of Faecal Coliform bacteria (FC) until one of the UV controllers failed to work in April 2012. A solution by taking water samples from the

UV tube that was still working was tested but it turned out to be impossible to prevent FC from passing to the outlet of the disinfection process. The filter system clogged once, and a replacement filter was installed. Since bag filters can only hold a certain amount of suspended solids before they clog, attention needs to be paid to the water pressure in this system which indicates clogging build-up in the bag filter. The combination of bag filters and UV treatment is suitable for removing Faecal Coliform bacteria with a perfect polishing effect on the water quality which makes it useful for reuse and aesthetic purposes since the water is clear and without particles. During the working period of the system, Chinese Discharge Standards for urban water reuse (GB18918-2002, discharge from wastewater treatment plants, GB/T18920-2002, reuse of urban recycling water, GB20922-2007, reuse of urban recycling water for farmland irrigation) could be met for FC.

There were several other accidents during the project period. Early in the experimental campaign problems with a floater controlling the inlet pump resulted in flooding of the whole test site with raw wastewater. This happened several times until a new floater device was installed and a new mobile based alarm and warning system was developed which could detect high level of wastewater in the system. Another incident happened during the summer 2012 when the water temperature passed 32°C. By mistake, the small pre-sedimentation tank, which also contains sludge produced from the process, was not emptied which resulted in an almost complete loss of nitrification – probably because of H_2S built-up in the incoming wastewater. This accident emphasized the importance of removing sludge from the pre-sedimentation tank on a regular basis – which normally is 6-12 month (in this case it had to be emptied every 3-4 weeks).

A simple alarm system was installed in June 2012 which could detect overflow and power failure in the complete system. The alarm system was designed in a way that SMS messages were sent to both Chinese and Danish mobile phones and later, many SMS messages were sent out warning about loss of power to the system (these power cuts were short though and did not affect the performance of the system and the experiments that took place). The alarm system is suitable for decentralized installations and can be set up to detect signals from blowers, pumps, power, UV and pressure valves and give warning by SMS if any errors occur.

The consumption costs of operation were determined, based partly on experimental findings and partly on experience given by the producers of the technology. The consumption cost of operation for biological wastewater treatment consists of sludge removal and deposition, electrical costs and costs of precipitation chemicals and were estimated to: 5-10 liter sludge (1.5% TS)/m^3 wastewater treated, 0.8-1.1 kWh/m^3 wastewater treated and 0.4 liter PAX/m^3 wastewater treated (meeting GB18918-2002 Class 1A). Consumption costs of running a disinfection system partly consisted of consumption of filterbags and power consumption of running a UV system. The consumption of filterbags was estimated based to 500 m^3 wastewater/filterbag (equivalent to 0.027€/m^3 wastewater treated) and UV treatment incl. pumping (4 bar) consumed 0.21 kWh/m^3 wastewater treated. These costs show that water reuse is economically and technically feasible to use technology instead of chemicals to disinfect wastewater and the prices of upgrading wastewater to be reused only constitutes 10-20% of the total cost of wastewater treatment.

The project was disseminated partly by reporting, partly by hosting a seminar for the project participants and Chinese stakeholders at a hotel in Suzhou (20 participants showed up). The seminar was very successful because the participants could be presented to most of the project results and see the actual installation, which was located nearby the seminar location. Finally, the project result was also submitted to an international IWA conference (and has now been accepted for publication) which will take place in the North Chinese city Harbin, 28-30th October 2013 (11th IWA Conference on Small Water and Wastewater Systems and Sludge Management).

1 Introduction

In spite of rapid migration to urbanized areas more than half of the Chinese population still populates 20,000 small towns and 570,000 villages outside the intensified urbanized areas of China (Zhao 2010). So far, with respect to wastewater treatment emphasis has been put on collecting and treating wastewater in the 200 major cities of China, which is reasonable considering the population densities and economic development in these areas. Today the largest cities in China have nearly 100% wastewater collection and treatment while wastewater collection and treatment in the rural areas of China is almost non-existing.

Even though the majority of wastewater is generated in the large cities, 50% of the COD discharge and 60% of the total nitrogen discharge are however still produced in the towns and villages of China. According to Li (2010) and MOHURD (2007, 2008), 96% of the wastewater in these areas is not collected and the remaining 4% is treated in simple septic tank systems. In the less developed western area of China wastewater collection and treatment is nearly zero. (Zhao 2010) stated that only 3% of villages and 12% of towns have simple wastewater treatment. This is due primarily to a lower GDP in the rural areas and little focus from the local governments to handle this environmental challenge in rural areas. The result is that surface water quality is poor and surface water resource becomes unaesthetic and unsuitable as drinking water supply for the nearby communities. So what happens to this huge amount of wastewater being discharged in the rural areas? In many cases wastewater is discharged to small creeks, ponds or directly in the backyard of the residential areas causing unaesthetic sanitary problems in the local environment.

More focus is now being addressed to this issue from the central government of China and it must be expected that large funding will be given to the less wealthy provinces of China – at least to the most populated towns and villages. The techniques used for decentralized treatment are expected to be different from the centralized wastewater treatment plants in the cities. Zhao (2010) indicates that septic tanks, anaerobic treatment facilities and wetlands are the preferred techniques as they are fairly cheap in operation, but small aerobic wastewater treatment plants become more and more interesting because they are efficient and reliable in operation and the components for these solutions can be mass-produced at reasonably low prices in China. This shift in paradigm follows the technological trend in China – the country becomes more technologically developed and today China can better afford to invest in more efficient technology.

This project aims at developing and testing a genuine decentralized wastewater treatment and reuse concept that can be operated even in the most remote regions. The concept could be relevant for the Chinese market because it is modular and it can be mass-produced in factories.

2 Objective

In this project the overall objective is to develop and test a new type of decentralized wastewater treatment system based on aerated biofilm technology where the cleaned wastewater can be recycled for different purposes of domestic reuse. The development of the concept and technology will be started in Denmark and continued in China where the actual test program is going to take place. In details, the objective of this project is to:

1. Introduce small-scale and high efficient wastewater treatment plants for decentralized wastewater treatment as an alternative to constructed wetland and other low-tech technologies with much smaller footprint, controlled processes and flexible operation for the Chinese marked.
2. Demonstrate that small ”un-manned” wastewater treatment plants can be operated in remote areas serviced by a small organization of staff. This can result in a large number of WWTP in operations – with a central management supervising the operation of the plants.
3. Develop a system for safe reuse of treated wastewater making water a resource instead of a waste problem. The system should meet the Chinese Discharge Standards for different purposes of wastewater reuse.
4. Develop a simple alarm system that can send signals to mobile phones if problems occur with the installation and operation.
5. Verify the economics (operation and construction costs) of small scale wastewater treatment plant installations as compared to conditions in China.

Disseminate the value of Danish environmental technology and benefits to the Chinese market.

3 Biokube wastewater treatment systems

The Danish company Biokube A/S produces small scale modular wastewater treatment plant units that can typically be loaded with wastewater in the range of 0.75 m^3/d – 150 m^3/d each. Modules can then be combined to much bigger systems.

About 10 years ago, Biokube started up producing small wastewater treatment plants for household wastewater treatment in places with no connection to central sewer systems. The smallest series of wastewater treatment installations (5 – 60 PE) was developed as drum-like pre-fabricated units (Figure 3.1) that can perform biological wastewater treatment, chemical wastewater treatment and sedimentation in one unit. Pre-sedimentation of raw wastewater occurs in an external tank which also contains sludge generated from the wastewater treatment process. The pre-sedimentation tank is normally big enough to hold sludge production from 6 – 12 months of operation.

Figure 3.1 Biokube's smallest series of wastewater treatment plants for decentralized household and small enterprise wastewater treatment

The increased demand for decentralized solutions for wastewater treatment has resulted in development of treatment systems for much larger capacities, but basically built on the same concept. One solution consists of mobile designed wastewater treatment installations (installation in 20” or 40” containers, Figure 3.2) that can be easily commissioned and decommissioned on a temporary basis. Such systems would of course be relatively expensive as compared to a permanent installation, but sometimes a genuine mobile wastewater treatment installation is needed for e.g. army activities, road construction or mining in remote areas.

For more permanent installations, Biokube has developed a modular concept that is based on large units of biofilter media, which can be fitted into tanks (typically concrete tanks), see Figure 3.3 and Figure 3.4. This system is called Jupiter systems and each unit can typically treat 75 m3/d. When combined, the system can be upscaled to treat much larger quantities as shown in Figure 3.3.

Figure 3.2 Wastewater treatment plant installation in containers (Uranus systems)

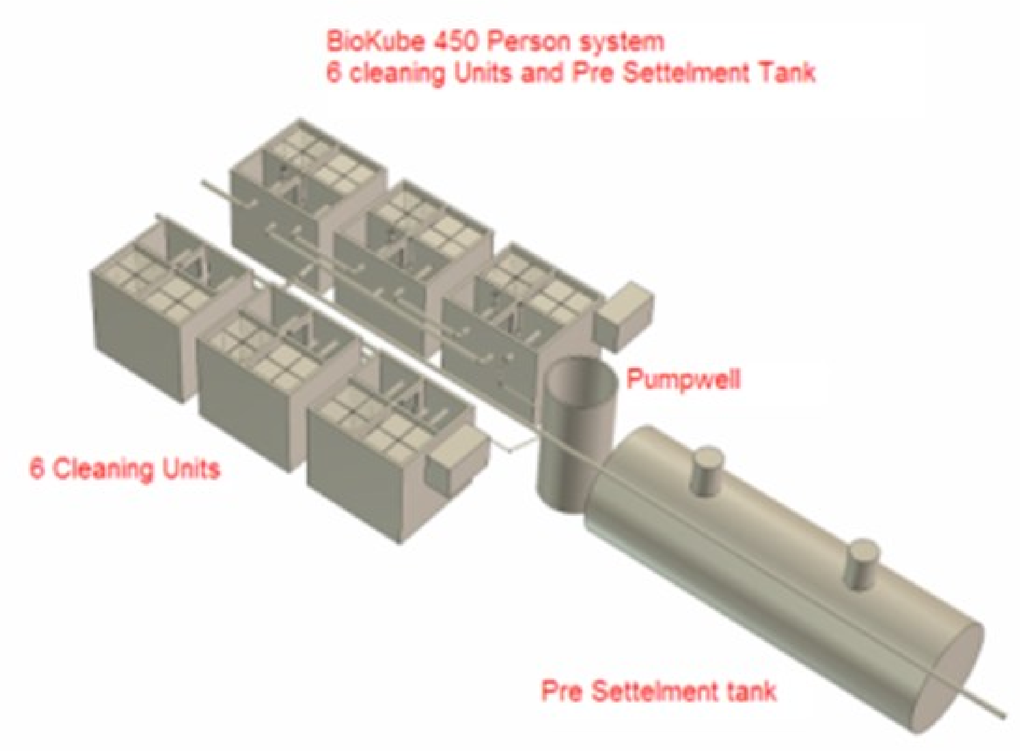

Figure 3.3 Module based wastewater treatment installation designed for small enterprises or communities (Jupiter systems, module capacity: 75 m3/d)

Figure 3.4 Installation of a Biokube wastewater treatment plant. Installation of the biological part of the wastewater treatment plant and pre-sedimentation typically takes one day after the concrete tanks have been prepared

Recently Biokube has designed even larger systems (called Saturn systems) that typically treat up to 150 m^3/d for each module (BOD < 25 mg/l). These installations are characterized by having a very small footprint for outdoor installations (about 4 m^2) since each unit is about 5 meter high, see Figure 3.5.

Figure 3.5 Large-scale pre-fabricated WWTP units from Biokube (Saturn systems, module capacity: 150 m3/d)

For more compact wastewater treatment up to 3000 m^3/d the preferred solution would normally be an integrated WWTP solution where buffer tank, screening and filtration, biological treatment and sludge dewatering is built into one permanent unit, e.g. as illustrated in Figure 3.6.

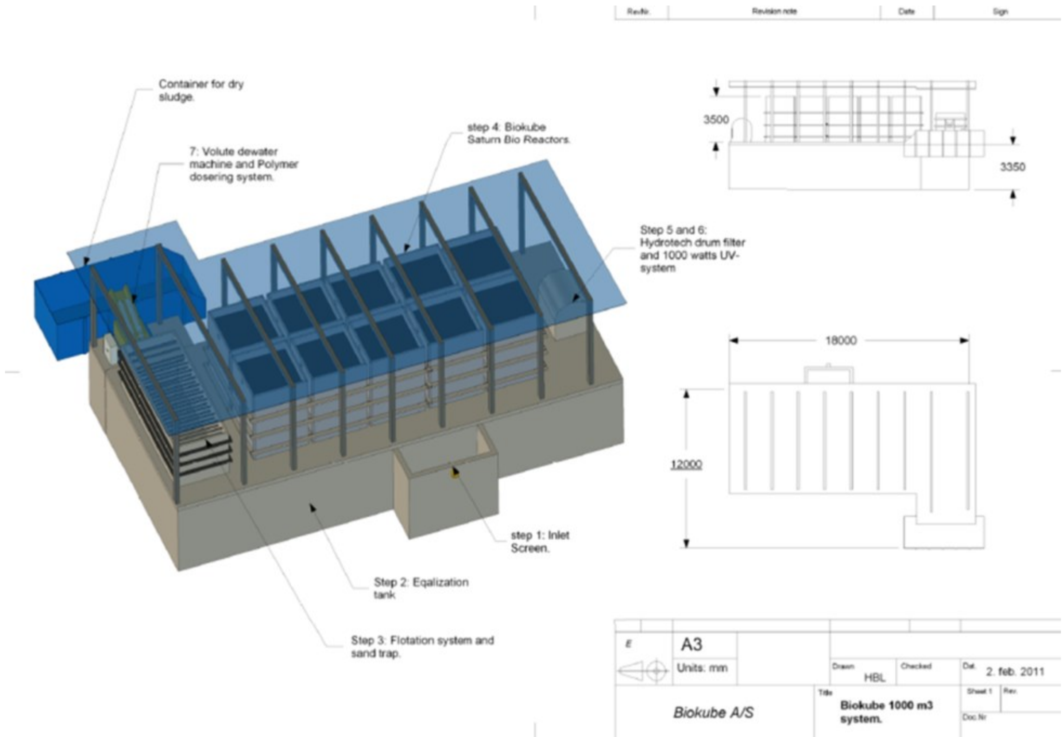

Figure 3.6 Compact wastewater treatment facility for treatment of large amounts of wastewater (1000 m^3/d), which can be achieved by a combination of flotation, biofilters and mechanical filtration. Illustration of a treatment plant installed in Kuwait which is equipped with a simple roof that provides shade to help reducing the temperature of the equipment.

4 Eksperimental development

The purpose of this project was to develop a system that enables reuse of treated wastewater for different purposes. In order to meet Discharge Standards for reuse of wastewater it is necessary to remove most of the Faecal Coliform bacteria and Nematode eggs, which requires a special treatment system that can filter the wastewater and kill the bacteria. Normally, the Biokube system would be able to meet most of the parameters in Discharge Standards for wastewater treatment but for special reuse purposes it is necessary to add another type of treatment system that can remove microbial activity.

It was decided to develop the system based on a normal biological Biokube reactor followed by a separate disinfection system. Since the installations had to be tested in China, it was decided to build a suitable sized installation that could be transported to China by a single container shipment. The disinfection system was developed as a buffer tank with a filtration system followed by UV-radiation. In the following, each part of the system is described more in detail.

4.1 The experimental platform

After the project grant had been given by the Danish EPA the task was to find a suitable place in China where the project could be carried out. It was important to find a location with access to real raw wastewater and where discharge of cleaned wastewater and produced sludge could easily take place. Furthermore, it was necessary to have at least weekly supervision of the facility and the possibility of having wastewater analyzed at a nearby laboratory. Therefore the installation had to be located in a city nearby Shanghai from where DHI could supervise the project. The most suitable place was found in Suzhou, 90 km west of Shanghai (25 min drive in train). Suzhou Sewage Administration – a planning institution for the local government in Suzhou - was interested in testing this solution and had all the required needs for the project: Electricity, a protected ground, a wastewater pumping station with continued running wastewater and local staff nearby the facility to help with supervision, sampling and laboratory analysis.

Figure 4.1 Project platform in Suzhou, west of Shanghai (25 min train trip between Suzhou and Shanghai)

Figure 4.2 Project site at Suzhou Sewage Administration, March 2011

Figure 4.3 Installation of equipment in Suzhou, November 2011

4.2 The biological system

Wastewater has to be treated in a biological system with sedimentation and sludge removal before it can be upgraded for reuse. The biological treatment carried out for this project was conducted in a Mars 3000 system (Figure 4.4, Figure 4.5). This system consists of 4 individual aerated chambers, each equipped with 0.44 m^3 biofilm carrier material (Figure 4.6) on which the biomass is attached. Between the biofilter chambers sedimentation zones enables settling of produced sludge with timer controlled pumping back into a pre-sedimentation tank. The biological process is self-cleaned due to the efficient aeration and the biofilm media does not need to be replaced from the Biokube system at any time.

The Biokube Mars 3000 is designed to treat wastewater in the range of 2.5 – 9 m^3/d which equivalents to 16 – 60 PE (Danish wastewater composition), depending on the efficiency of the process. If full nitrification (ammonia < 5 mg NH_4-N/l) and complete BOD removal (BOD_5 < 10 mg/l) must be achieved, the system can only be loaded with wastewater equivalent to pollution from 16 persons (960 g BOD/d or 2.5 m^3/d). If the system only needs to remove organic matter, the wastewater load can be increased almost 4 times to 3,600 g BOD/d or 9 m^3/d. Such a high capacity will require a pre-sedimentation tank of at least 15 m^3. For this project it was only possible to provide the installation with a 3 m^3 sedimentation tank – it was assumed that the sedimentation tank could be emptied more frequently for sludge than the regular intervals (every 3-4 weeks instead of 6-12 month which is the regular interval for sludge removal).

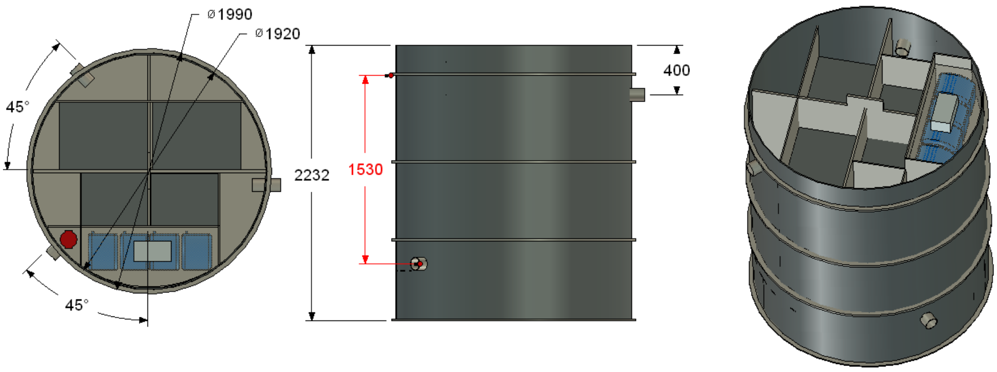

Figure 4.4 Illustration of the Biokube Mars 3000 reactor. Measurements are in mm.

Figure 4.5 Installation of a Biokube Mars 3000 in the ground (photo taken of an installation in Denmark similar to the experimental setup in China)

Figure 4.6 Biofilter media used in the Biokube system (Bioblok produced by Exponet A/S)

4.3 The desinfektion system

In order to discharge as little particulate matter as possible from the biological system, Biokube began to develop a “passive” filtration system that enables detainment of particulate matter in the Biokube before the water leaves the Biokube. The system is unique in the way that it does in fact not make any filtration; it just prevents particulate matter from leaving the settling zone leading to a smaller discharge of suspended solids. The pre-filtration system is illustrated in Figure 4.7 and Figure 4.8

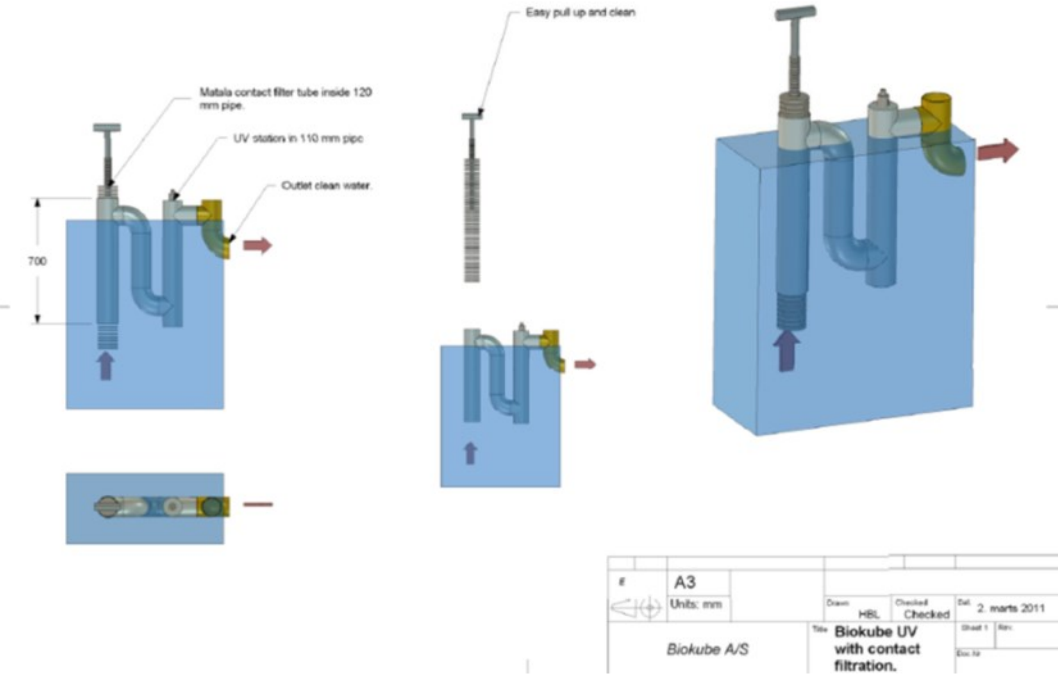

Figure 4.7 Pre-filtration system for removing particulate matter in the final settling zone of the Biokube

The filter unit consists of a cylinder shaped mat with plastic threads in a very porous structure. Floating particles will then sorb to the surface of the mat which gradually will accumulate sludge. After longer periods the filter unit needs to be replaced, which can be done at regular service intervals, e.g. when the pre-sedimentation tank needs to be emptied from sludge or when pumps and blowers need to be inspected.

Figure 4.8 Pre-filtration unit installed in a Biokube Mars 3000 for extra fine purification of the wastewater

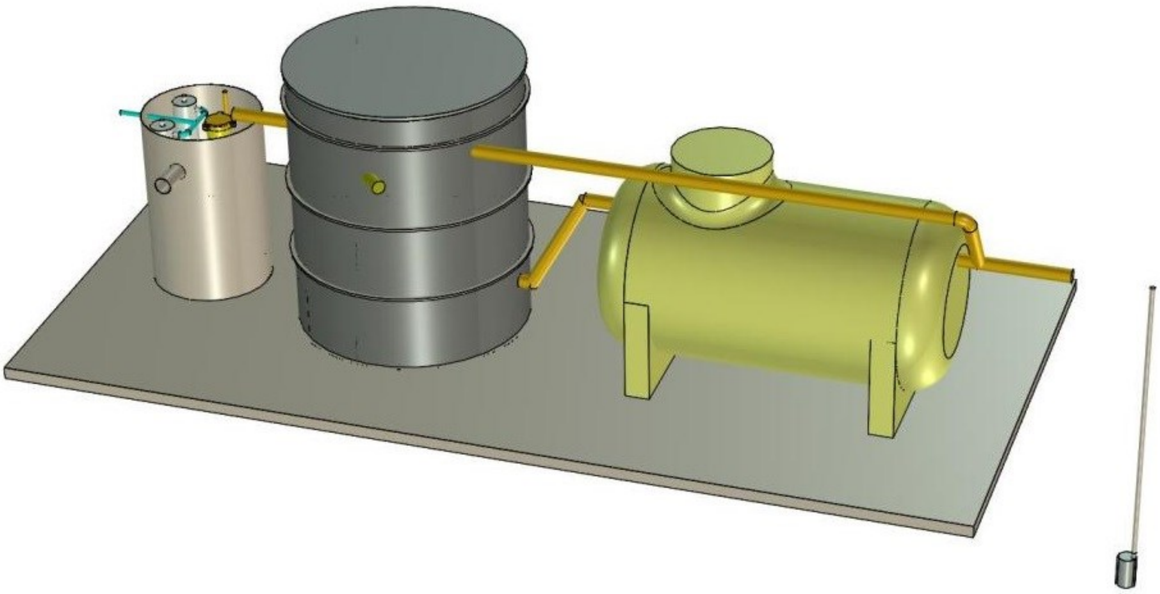

Figure 4.9 Experimental setup in Suzhou, China for normal wastewater treatment and disinfection

In China disinfection is normally done by adding chlorine to the treated wastewater, but chlorine is not environmentally friendly. For this project it was therefore decided to develop a UV and filtration system, which disinfects wastewater in a way which is completely harmless to the environment. Furthermore, the filtration process will polish the cleaned wastewater to such an extent that only very little suspended matter is left in the water to be reused (expected to be below 5 mg SS/l).

The disinfection system was developed in an individual tank (the "disinfection tank"), which the biologically treated wastewater passes through leading to a constant wash-out of treated wastewater (this was to avoid unaesthetic still water in the disinfection tank; the cleaned wastewater is now constantly "fresh"). The disinfection tank then acts as a reservoir for water to be reused – in this case it contains approximately 800 liters, which can be immediately pumped out of the disinfection system when needed for reuse. The size of the holding tank should be designed according to the purpose of reuse (quantities of water needed in short periods of time). This design is in contradiction to the normal approach of storing cleaned and disinfected wastewater in a storage tank, which often is complicated due to regrowth of microorganisms after long periods of water storage.

The filtration solution was probably the most critical part to make because the filter had to be efficient and robust but yet simple in its construction and it should be easy to clean or replace. The best solution was found to be a bag filter solution – a filter that can contain a certain amount of particles after which the filter clogs (the water is then by-passed back into the buffer tank). This solution is also relatively cheap to construct which is of course important for small installations.

Figure 4.10 Bag filter unit (10 μm used for the project)

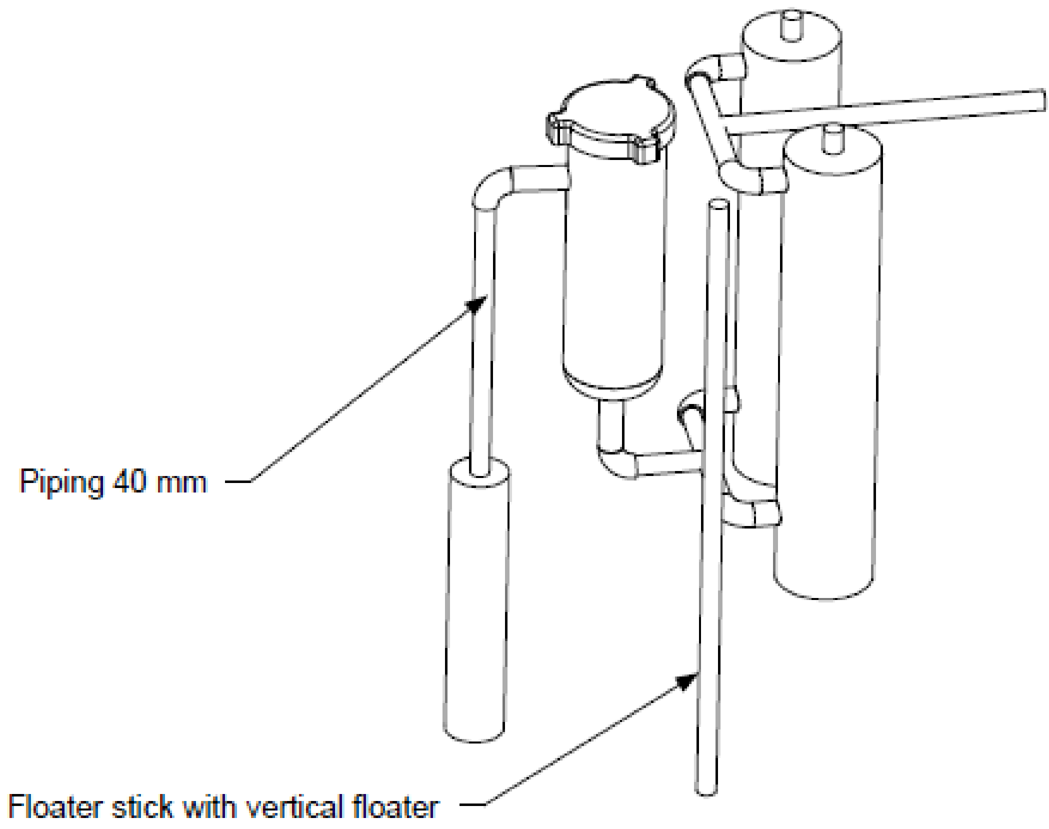

Figure 4.11 Illustration of the combined filtration and UV system developed for the project

The bag filter house was built into a complete unit with the pump and UV tubes. A pressure sensitive valve was also installed in order to measure if the pressure exceeded the maximum pressure of the bag filter (6 bar). In that case the water would be released through a valve and let back into the holding tank. When the system is activated, the UV tubes first warm up for 90 sec after which a pump (4.5 m^3/h) starts pumping the cleaned wastewater through the filter and UV tubes. The idea is that the system is turned on when water is needed for reuse and the holding tank contains a certain amount of water that can be pumped through the disinfection system.

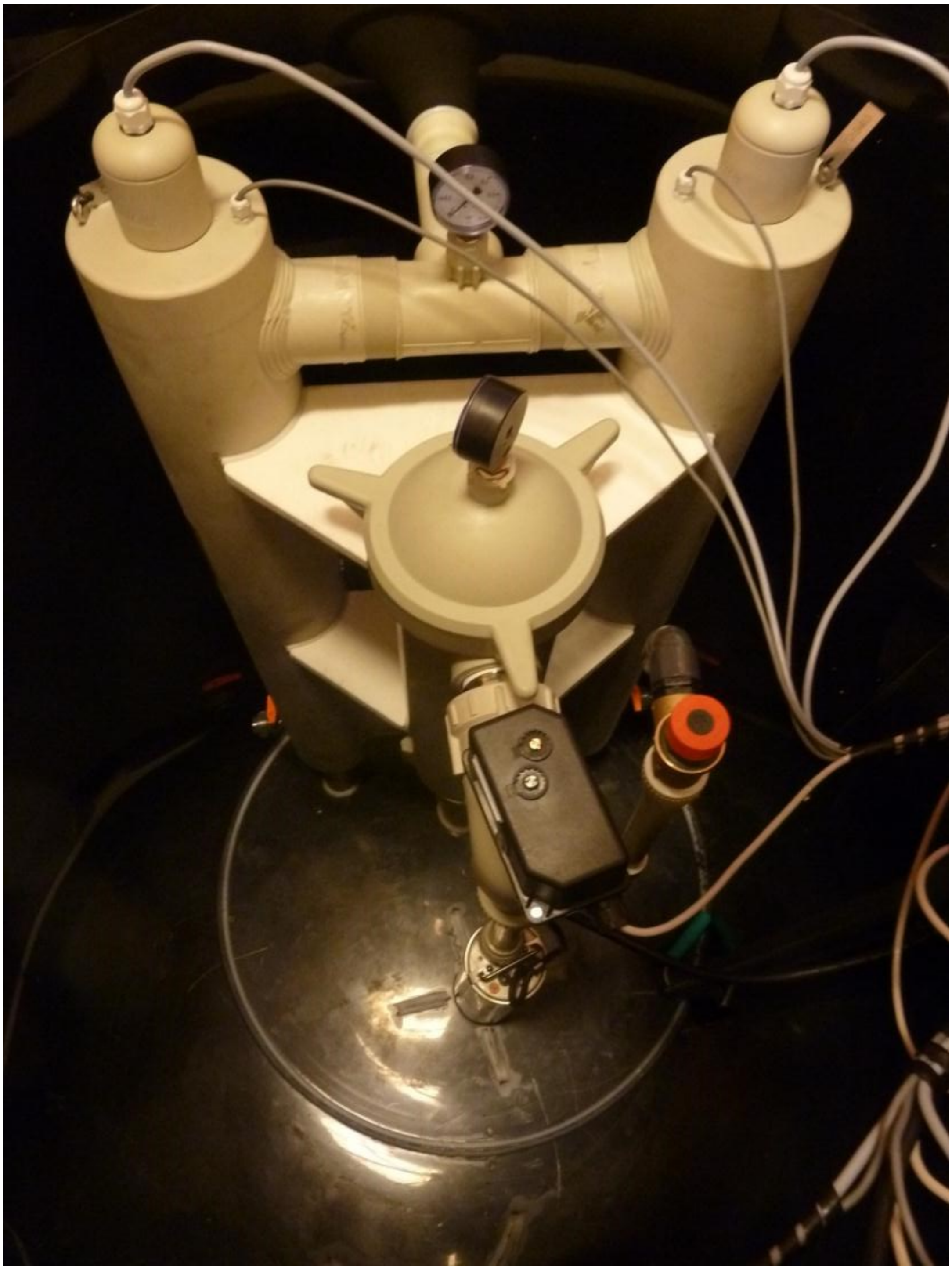

Figure 4.12 Disinfection system (pump, pressure valve, bag filter unit and UV tubes) installed in the buffer tank

Figure 4.13 Disinfection tank in use just after start-up of the installation in Suzhou, China (November 2011)

Figure 4.14 Disinfection tank in operation in Suzhou (June 2012)

The UV system consisted of two 220W UV lamps able to treat up to 40 m^3/h. The operation time of the UV lamps was 16,000 hours (approximately 2 years of constant operation). The expected UV dose by the end of the lifetime of the UV lamps would be 25 mJ/cm^2, which should be enough to eliminate faecal coliforms efficiently (UV transmission 70%). The cost of using UV lamps to disinfect wastewater consequently seems to be very low (0.004 €/m^3 wastewater treated), if the UV system can handle this amount of wastewater efficiently.

As a spin-off from this project, Biokube installed a disinfection system in Oman which was similar to the setup in Suzhou. The system in Oman was designed to reuse cleaned and disinfected wastewater for road cleaning, but the UV treatment could not remove Nemathode eggs efficiently since these organisms require a very high UV dose to be killed. After installation of a bag-filter solution (Feature-Tec Ecoclean, 10 μm filterbag) the eggs were efficiently removed (detained in the filter) and the Discharge Standards met.

Figure 4.15 Biokube disinfection system installed after a traditional Biokube wastewater treatment installation in Oman. The disinfection system was equipped with a 10 μm bagfilter and UV (130 m3/d).

4.4 The alarm system

As part of the project Biokube developed a new type of alarm system that could send out warnings to mobile phones as SMS-based text messages. The system was developed and installed in June 2012 after a series of overflow incidents had happened in Suzhou (defective floater device).

The system was designed so that it could warn about five types of errors:

1. Blower pressure failure
2. Blower filter failure
3. Overflow
4. UV failure

General power failure Table 4.1 shows how the alarm system functions and what kind of sensors can be used to trigger the alarm.

Table 4.1 Alarm system for Biokube WWTP with UV installations

Error type	Description	Error sensor	Error message text on SMS
Blower pressure failure	If pressure over the blowers is too low (e.g. if air tubes are disconnected or if the blowers fail completely), a pressure valve can send a signal to the alarm unit.	Pressostat sensors	System xx Blower failure.
Blower filter failure	If the airfilter before the blower are clogged (e.g. because of dust), the blower cannot get enough air (just like a normal clogged vacuum cleaner). A vacuum sensor can detect if the vacuum too high.	Vacuum sensors	System xx airfilter clocced.
High water level	High level of water in pump well.	Floater switches	System xx high water level in pump well.
UV failure	If the UV system fails (balaster system error) because of e.g. a broken UV lamp, an alarm message is sent	UV balaster alarm output	System nr. xx UV system down.
Power failure	If an electric power failure occurs, a battery back-up function will start up and send a message that there is no electricity to the system. The backup battery is always fully charged by the normal electric supply.	Power failure sensor with back-up battery function in alarm unit	System nr. xx main power falure.

In Suzhou, the alarm system was only installed for two types of errors: Power failure and overflow. It was installed with a Danish SIM card which enabled it to send messages to both Chinese and Danish mobile phones. The system was tested and several warnings were actually sent in the remaining period of the project – only addressing short power failures at the test site. The alarm system is illustrated in Figure 4.16.

Figure 4.16 Alarm system installed in the Biokube system in Suzhou (June 2012)

Later on, the alarm system proved that warnings could be sent in case of power failure. However, it was then experienced that it is not enough to have a “power off” warning. Since it was found later that short local power failures happen very often in Suzhou, it is also necessary to have a “power on” message (which is then linked to the power off message with a certain ID number).

5 Chinese Discharge Standards

Chinese discharge standards for wastewater discharge can be categorized into discharge standards for wastewater treatment plants and discharge standards for several purposes of reuse. In case wastewater is being treated from a wastewater treatment plant, the discharge must meet GB18918-2002. This standard is categorized into several sub standards, depending on the sensitivity of the recipient. In case the cleaned wastewater is to be reused, it may be relevant to consider several other standards, depending on the reuse type and purpose. It is not completely clear if it is the reuse standard or the WWTP standard that is decisive for a given parameter in case of a conflict between the standard values, but it would be normal to assume that the discharge should meet the standard relevant for the recipient to which it is discharging[1].

5.1 Chinese Discharge Standards for wastewater treatment plants (GB18918-2002)

The Chinese Discharge Standards for wastewater treatment, GB18918-2002 (

[1] E.g. the COD discharge standard for wastewater treatment plant scan be as low as 50 mg COD/l (1st Class A, GB18918-2002) for discharge to a given recipient but if this wastewater were to be reused for farmland irrigation instead (Fiber crops, GB20922—2007) the standard value is 200 mg COD/l.

Table 5.1), Class 1A and 1B, are usually the most relevant standards to consider in China since these standards would normally be enforced for wastewater discharge into the river network. These standards are quite stringent with respect to removal of organic matter (COD, BOD), phosphorous removal and Faecal Coliform bacteria elimination. Ammonia removal does not seem to be so stringent and the standards have even lower restrictions when the water temperature is below 12°C. Removal of bacteria requires addition of significant amounts of chlorine (which is the preferred method used in China because it is efficient, easy to use and cheap). Chlorine is, however, an environmentally unfriendly substance that can create toxic residual products in the environment. In Suzhou most of the central wastewater treatment plants have to meet Class 1A, whereas decentralized wastewater treatment in sub urban and rural areas often has to meet Class 1B.

Table 5.1 GB18918-2002 – Chinese Discharge Standards for wastewater treatment plants

No.	Parameter	1st class standard		2nd class	3rd class
		A	B		
1	CODcr	50	60	100	120
2	BOD5	10	20	30	60
3	SS	10	20	30	50
4	Animal-plant oil	1	3	5	20
5	Petroleum	1	3	5	15
6	Anionic surfactant	0,5	1	2	5
7	TN	15	20	-	-
8	NH4-N	5(8)	8(15)	25(30)	-
9	TP	0,5	1	3	5
10	Chroma	30	30	40	50
11	pH	6 – 9			
12	Faecal Coliforms (FC/l)	1,000	10,000	10,000	-

Unit: mg/L
Note: The value outside the bracket is the control value when water temperature is higher than 12 °C, inside the bracket is the control value when water temperature is less than or equal to 12 °C.

5.2 Chinese Standards for reuse of urban recycling water —Water quality standard for urban miscellaneous water consumption (GB/T18920-2002)

For reuse of wastewater it is relevant to consider several discharge standards. The standard GB/T 18920-2002 (

Table 5.2) is relevant for urban recycling of water to be used for miscellaneous water consumption (toilet flushing, road cleaning, garden watering, vehicle washing and in connection with construction works). This standard is particularly restrictive for BOD, TDS (it can be a big problem if TDS content is high in the local water supply) and for Faecal Coliform bacteria. If water is to be used for these purposes, a very efficient disinfection system needs to be installed, and even if chlorine is to be used, it requires a certain holding time after addition since the contact time should be more than 30 min. When the water is released, the chlorine level should be below 0.2 mg Cl/l.

Table 5.2 GB/T18920-2002 – Chinese Standards for reuse of urban recycling water

No.	Item	Toilet flush-ing	Road cleaning, firefighting	Urban greening	Vehicles washing	Con-struc-tion
1	Chroma ≤	30				
2	Smell	no unpleasant smell				
3	pH	6-9				
4	Total dissolved solid ≤	1500	1500	1000	1000	
5	Turbidity (NTU) ≤	5	10	10	5	20
6	BOD5 ≤	10	15	20	10	15
7	NH4-N ≤	10	10	20	10	20
8	Anionic surfactant ≤	1	1	1	0,5	1
9	Fe ≤	0,3			0,3	
10	Mn ≤	0,1			0,1	
11	DO ≧	1				
12	Chlorine	contact time in 30min ≧1, the end of the pipe network ≧ 0.2				
13	Faecal coliforms(FC/L) ≤	3				
Unit: mg/L						

Apparently, the Chinese discharge standards for reuse of urban recycling water consider chlorine as the only disinfection method. It is not clear if it is possible to use more environmentally friendly methods like filtration combined with UV radiation to meet the discharge standards in question.

5.3 Chinese Standard for reuse of urban recycling water for farmland irrigation (GB20922—2007)

In relation to reuse of wastewater for farm land irrigation, the Standard GB20922 – 2007 applies for urban recycling water (

Table 5.3). This standard is not very strict with respect to treatment of nutrient and organic matter, and it allows a significant concentration of Faecal Coliform bacteria. Compared with WHO guidelines for safe use of wastewater, excreta and greywater (WHO, 2006) the Chinese standards for urban recycling water are quite comparable with respect to microbial hazards but much less strict with respect to toxic chemicals, as it does not cover the wide variety of chemicals set by WHO and also it does not take into account the accumulated effect of concentration buily-up in soil.

Table 5.3 GB20922—2007 – Chinese Standard for reuse of urban recycling water for farmland irrigation

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">Parameter</th><th colspan="4">Type of irrigation crops</th></tr>
<tr><th>Fiber crops</th><th>Dry grain</th><th>Wet grain</th><th>Open-air vegetables</th></tr>
<tr><td>1</td><td>BOD5</td><td>100</td><td>80</td><td>60</td><td>40</td></tr>
<tr><td>2</td><td>CODcr</td><td>200</td><td>180</td><td>150</td><td>100</td></tr>
<tr><td>3</td><td>SS</td><td>100</td><td>90</td><td>80</td><td>60</td></tr>
<tr><td>4</td><td>DO≧</td><td colspan="2"></td><td colspan="2">0,5</td></tr>
<tr><td>5</td><td>pH</td><td colspan="4">5.5-8.5</td></tr>
<tr><td>6</td><td>TDS</td><td colspan="3">no alkaline land 1,000,
alkaline land 2,000</td><td></td></tr>
<tr><td>7</td><td>Chloride</td><td colspan="4">350</td></tr>
<tr><td>8</td><td>Sulfide</td><td colspan="4">1</td></tr>
<tr><td>9</td><td>Chlorine</td><td colspan="2">1,5</td><td colspan="2">1</td></tr>
<tr><td>10</td><td>oil</td><td colspan="2">10</td><td>5</td><td>1</td></tr>
<tr><td>11</td><td>Volatile hydroxybenzene</td><td colspan="4">1</td></tr>
<tr><td>12</td><td>Anionic surfactant</td><td colspan="2">8</td><td colspan="2">5</td></tr>
<tr><td>13</td><td>Hg</td><td colspan="4">0.001</td></tr>
<tr><td>14</td><td>Cd</td><td colspan="4">0.01</td></tr>
<tr><td>15</td><td>As</td><td colspan="2">0.1</td><td colspan="2">0.05</td></tr>
<tr><td>16</td><td>Cr (sexavalence)</td><td colspan="4">0.1</td></tr>
<tr><td>17</td><td>Pb</td><td colspan="4">0.2</td></tr>
<tr><td>18</td><td>Faecal Coliforms(/L)</td><td colspan="3">40,000</td><td>20,000</td></tr>
<tr><td>19</td><td>Roundworms' eggs (/L)</td><td colspan="4">2</td></tr>
<tr><td colspan="6">Unit: mg/L</td></tr>
</table>

6 Experimental results

The experimental results were obtained during an experimental campaign that took place in the period from November 2011 to February 2013. While the pre-development was made in Denmark, the experimental platform and final development was carried out in Suzhou, China. Our partner in China was Suzhou Sewage Administration – a local government planning bureau who is responsible for selection of solutions for wastewater treatment in urban and rural areas of Suzhou. An ideal location to carry out the project was found only a few hundred meters from Suzhou Sewage Administration office building which was very convenient for the staff in charge of the experiments.

6.1 Sampling and analysis

The sampling from the Biokube system is conducted at 4 locations: 1) deep inlet pump well before the pre-sedimentation tank (Inlet Biokube system), 2) Biokube reactor, 3) outlet Biokube reactor and 4) outlet disinfection tank (outlet after filtration and UV), see Figure 6.1.

The sampling from the inlet (1) has to be done before the settling tank (1) because the water in the settling tank is being diluted by return sludge pumping and recirculation from the Biokube reactor. This means that the inlet samples will have some variation, depending of the composition of the wastewater passing by the sampling point (see Figure 6.2).

Sampling from the Biokube reactor (sampling point 2) was only taking place a few times. During a special investigation, samples were taken directly from the Biokube aeration zone chambers (see Figure 6.3) to investigate the removal efficiency of each aeration chamber.

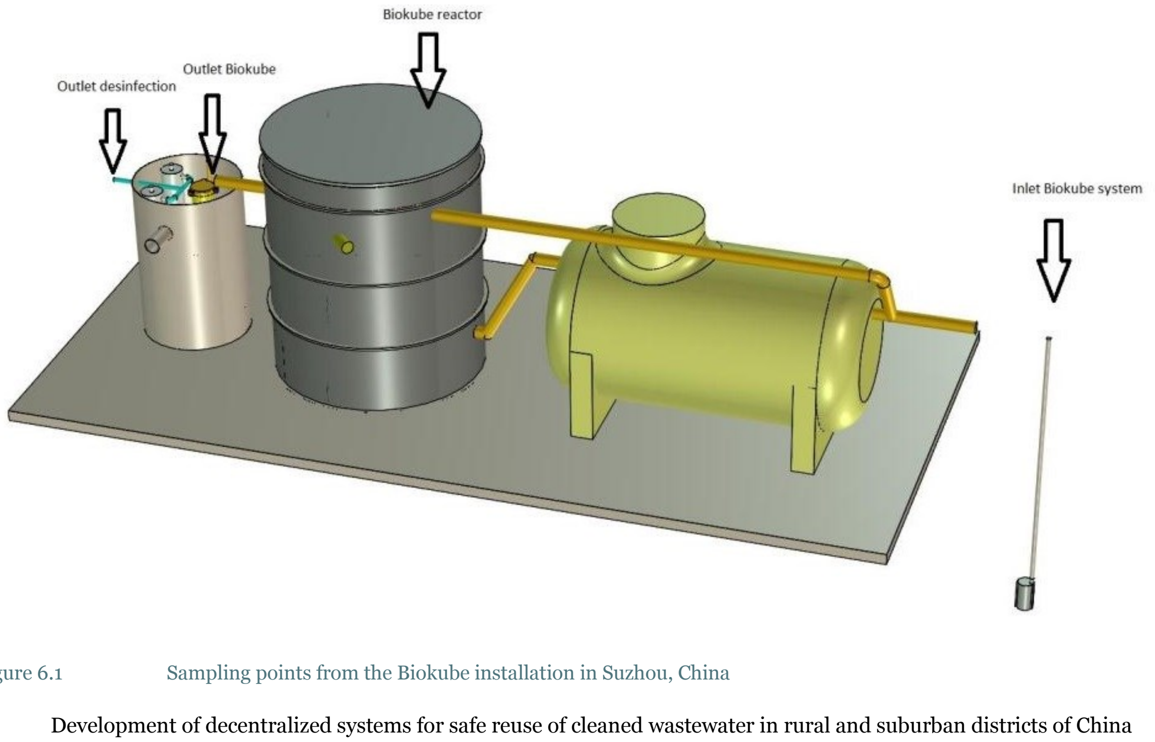

Figure 6.1 Sampling points from the Biokube installation in Suzhou, China

Figure 6.2 Sampling from the inlet canal

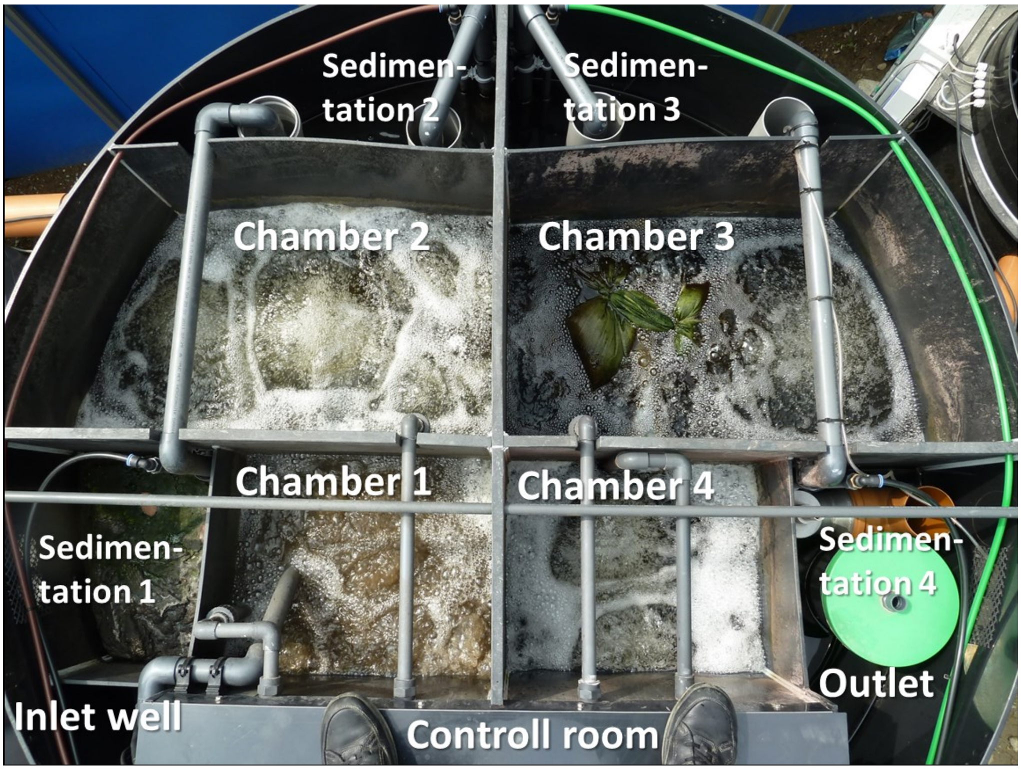

Figure 6.3 Sampling from the Biokube reactor (Chamber 1-4)

The sampling from the outlet of the Biokube reactor was taken in the disinfection tank where cleaned wastewater was pumped discontinuously into the tank every 15 minutes (see Figure 6.4). The sampling from the disinfection system (after filtering and UV treatment) was taken from a special tube through which disinfected wastewater was pumped (see Figure 6.5). These samples could only be taken when the disinfection system control was activated.

Figure 6.4 Sampling from Biokube outlet

Figure 6.5 Sampling from outlet disinfection system when it was activated

Figure 6.6 Raw and cleaned wastewater before and after the Biokube system

Wastewater samples were taken from the Biokube system with different frequency depending on the period of experiment. In the running-in period from October 2011 to February 2012 no samples were taken (in order to reduce the total amount of samples). From February 2012 to May 2012 samples were taken every two weeks. From May 2012 the sampling was carried out every week, including also scenario campaigns for different purposes.

Table 6.1 Parameters measured in the Biokube system

Parameter	Inlet (before pre-settling tank)	Biokube chambers (1, 2, 3, 4)	Outlet (inlet to disinfection tank)	Outlet disinfection (after filtration and UV)
COD_{cr}	X	X	X	X
BOD_5	X		X	X
TN	X		X	X
TP	X		X	X
NH_4-N	X	X	X	X
NO_3-N	X		X	X
SS	X		X	X
pH	X		X	X
Faecal Coliform				X
Temperature		X		
O_2		X		

The Biokube reactor is a 100% aerobic system and as such it can remove organic matter and ammonia. Since the Biokube system is designed to remove organic matter (CODcr, BOD_5), suspended solids (SS), ammonia (NH_4-N), and phosphorous (TP), these parameters are of course included. However, the Biokube system will also remove a significant amount of nitrate – partly as a result of the recirculation to the settling tank and partly as a result of simultaneous denitrification in the deep part of the biofilm in chamber 1 and 2. Consequently, total nitrogen (TN) and nitrate (NO_3-N) are also included as monitoring parameters in the analysis campaign. It should be noted that this Biokube installation is not designed for TN removal, and if TN removal is required to a specific level, the system should be designed for this, including a dedicated denitrification process. The Biokube reactor can also perform phosphorous precipitation (with appropriate amount of dosing chemicals), which makes it relevant to measure total phosphorous (TP) as well. For evaluating the effect of the disinfection process, Faecal Coliform bacteria (FC) is being measured after the disinfection process which includes 10 μm filtration and UV treatment. Other relevant parameters for the biological process like temperature, oxygen concentration and pH were also measured with online instrumentation.

6.2 Operation stability during experimental campaign

During the experimental campaign, the Biokube system was operational for 15 months (including the running-in period from October 2011 to February 2012). Quite early in the project (during the running-in period) the floater in the Biokube pump well began to fail. The floater design was new and never tested before (not standard in the Biokube systems) and it turned out that sludge could block the floater resulting in malfunction of the inlet pump control. On several occasions the test facility was floated with wastewater and the floater had to be cleaned. In fact, this incident did not disturb the operation of the Biokube and the disinfection system, but it did show the necessity of an alarm system. A new floater type and the alarm system were installed in June 2012 after which no flooding incidents happened again.

Figure 6.7 A defective floater device resulted in wastewater flooding at the test facility at several occasions in the beginning of the campaign. A new floater device and an overflow alarm system prevented further flooding incidents.

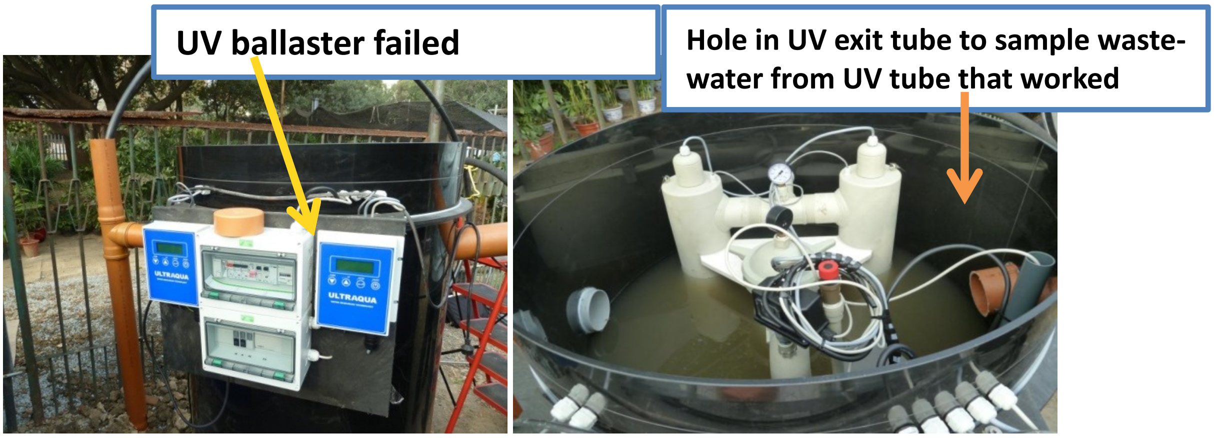

Figure 6.8 Relatively early in the experimental campaign one of the ballasters controlling the UV system failed.

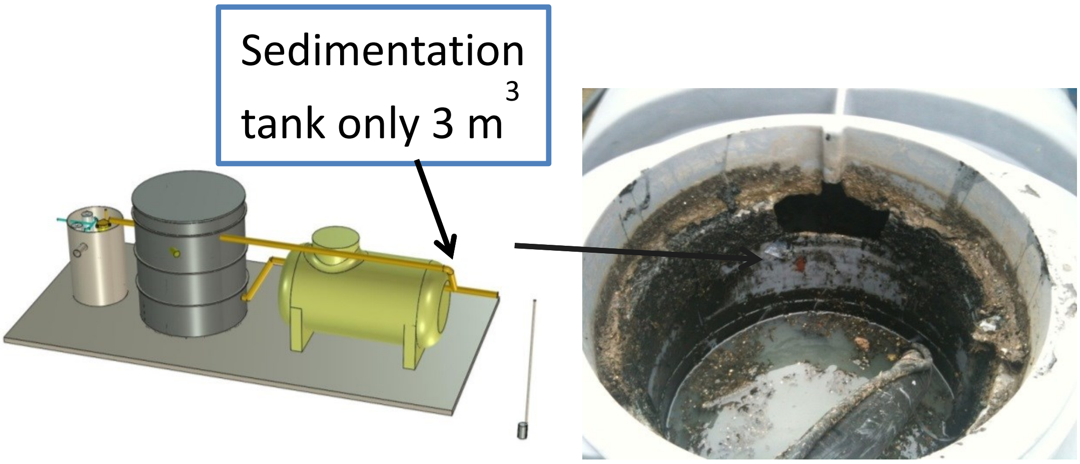

Figure 6.9 At one occasion the pre-sedimentation tank was running full of sludge which resulted in deterioration of the biological performance of the Biokube reactor

6.3 Experimental results

6.3.1 Flow and temperature

The flow could be varied by changing the inlet pump timer control. Typically, wastewater was pumped into the Biokube with 15 min interval in periods of 1-2 minutes. Normally, the Biokube Mars 3000 system is designed to treat 5-9 m^3/d depending on the wastewater composition and the demand for nitrification, but during the experiment the flow was increased to its maximum 12.5 m^3/d (the maximum hydraulic capacity of the Biokube Mars 3000 system).

I the beginning of this campaign the flow was kept low (3.5 m^3/d) in the period from October 2011 – February 2012 so that the Biokube system could be inoculated. After the first sampling took place in February 2012, the flow was gradually increased. Most of the time, when the Biokube system was operating well, the flow could be maintained at its highest possible level (12.5 m^3/d) – even when the temperature dropped dramatically. The flow was measured by the “bucket method” measuring the time to fill a bucket with a known volume.

In the beginning the temperature was quite low, around 8 °C. Maximum temperatures were observed during the summer (July), where the temperature for a period of one month climbed to 30-31°C. By the end of 2012 the lowest registered temperature was 4°C. The temperature was measured with the oxygen probe, but in the period from August to December 2012 the temperature was not measured directly but estimated from other WWTPs nearby, as the oxygen meter used for the experiment was defective.

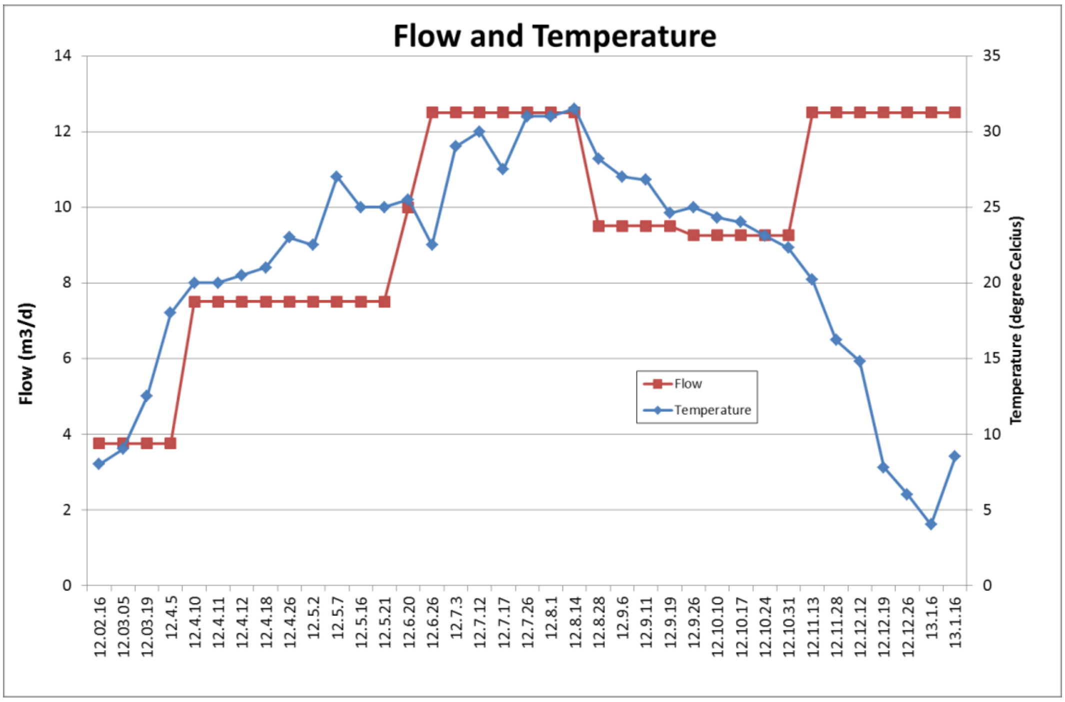

Figure 6.10 Flow and water temperature during the experimental campaign

6.3.2 Organic matter (COD-total and BOD5)

6.3.2.1 COD-total

The COD-total concentration level in raw wastewater is known to be fairly low in China as compared with Danish domestic wastewater. As it can be seen in Figure 6.11, the COD concentration in raw wastewater varies typically from 150 to 400 mg COD-total/l (COD_{cr}) with a higher concentration in the first half of the experimental campaign. Throughout the entire campaign, the effluent concentration is quite low and below Class 1A (50 mg COD_{cr}/l) standard, except on one occasion where organic matter was high in the outlet, presumably because the pre-sedimentation tank (sludge tank) was not emptied timely.

As a result of the low COD inlet concentration, the COD load to the Biokube system is also low (Figure 6.12) even though the flow was increased to the maximum possible level (12.5 m^3/d), except during the summer period where the wastewater was more concentrated. However, the load recommended by Biokube A/S (2 kg COD/d with full nitrification) is exceeded during most of the period as a consequence of the high load, but the load is by far lower than the maximal organic removal capacity of the Biokube (8 kg COD/d) without nitrification. The removal efficiency is typically 90%, but in the period from August to September 2012 the removal efficiency dropped because of a very low COD concentration in the inlet wastewater.

The surface specific removal rates (Figure 6.13) calculated for the biofilter media are fairly moderate (5-15 g COD/m^2 filter area/d with peaks around 12-30 g COD/m^2 filter area/d) when the complete area of the biofilm media of the Biokube is included in the calculation. Howver, this method of calculation is not reasonable because the removal rate activity in the first chambers of the Biokube would normally be much higher.

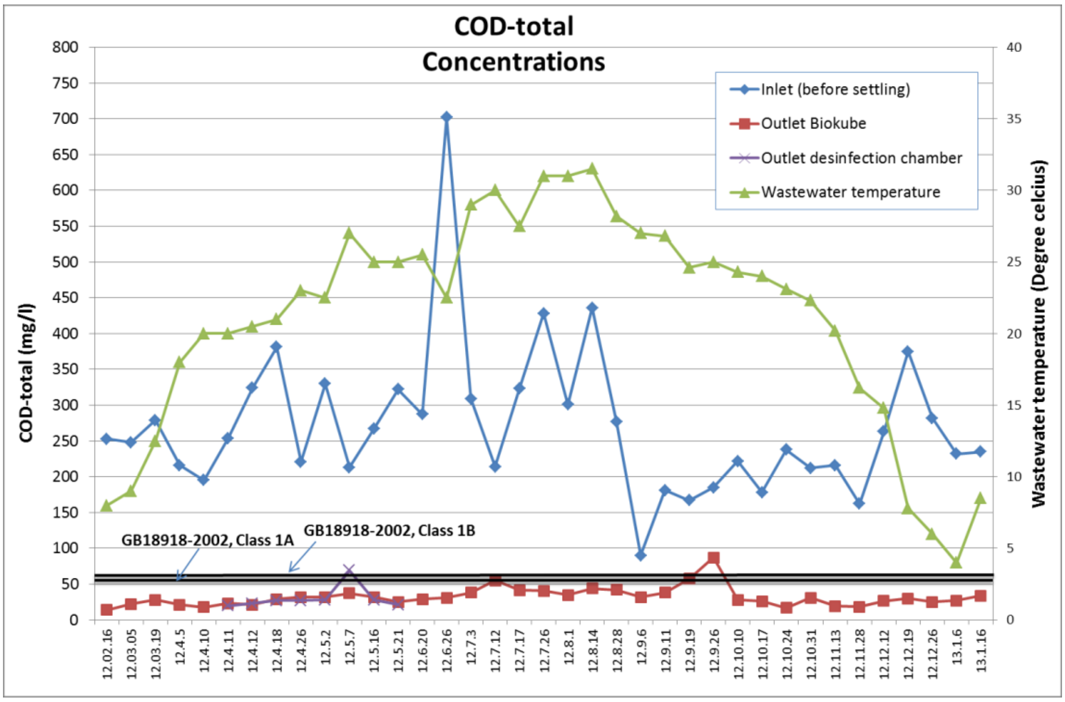

Figure 6.11 COD-total concentrations in and out of Biokube system

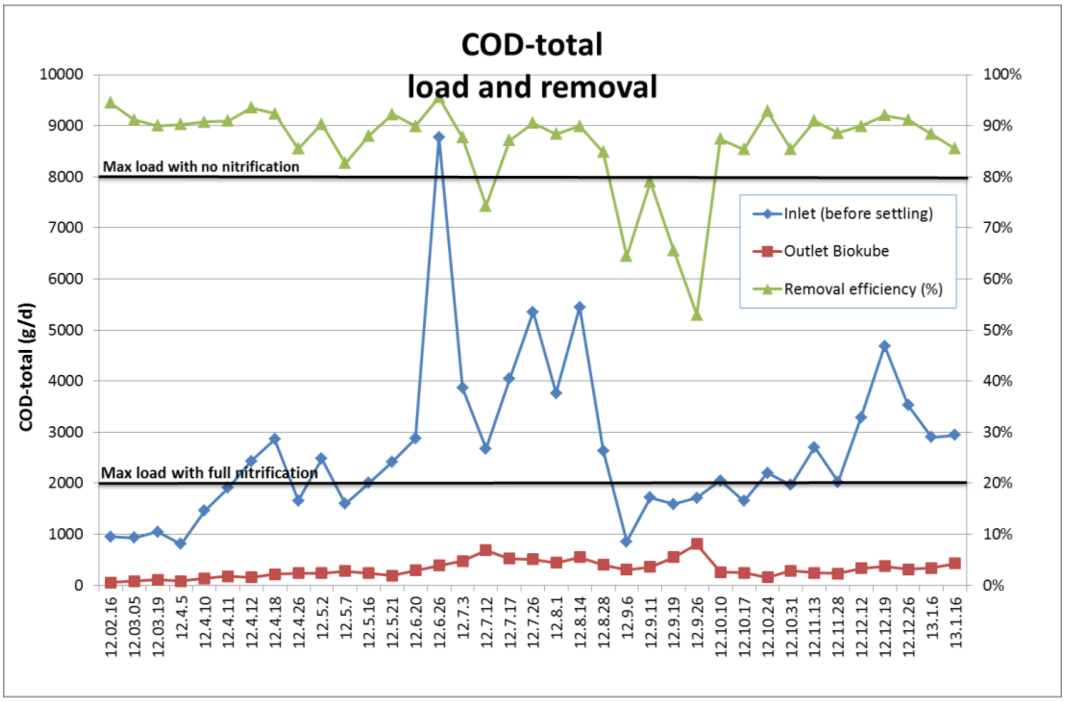

Figure 6.12 COD-total load into the Biokube system and discharge to recipient

A special investigation was carried out in April 2012 to find out if the air in Chamber 1 could be switched on and off while still maintaining efficient process stability. During the investigation the air supply was turned off and on automatically by the system in intervals of 5 minutes with the following sequence:

- Scenario 1: 5 minutes air, 0 minute no air (100% air in chamber 1)
- Scenario 2: 4 minutes air, 1 minute no air (80% air in chamber 1)
- Scenario 3: 2½ minutes air, 2½ minute no air (50% air in chamber 1)
- Scenario 4: 1 minutes air, 4 minute no air (20% air in chamber 1)
- Scenario 5: 0 minutes air, 5 minute no air (0% air in chamber 1)

The analysis investigated the removal rate activity in each of the four individual chambers of the Biokube by measuring the COD and ammonia concentration in each chamber after steady-state was obtained. The investigation showed that the removal rate was high in the first chamber of the Biokube - around 45-50 g COD/m² filter area/d (equivalent to 4.5-5 kg COD/m³ reactor volume/d). This high removal rate activity was only possible because the COD was not removed completely (75 mg COD/l in chamber 1) and the oxygen concentration in the chambers was fairly high (7.8 mg O_2/l) and with temperatures around 25°C. In the second chamber COD was removed almost completely with a much lower removal rate activity around 7-10 g COD/m² filter area/d (due to the low COD concentration obtained in the chamber). The chamber analysis test demonstrated that organic matter was almost completely removed in chamber 1 and residual degradable COD was removed in chamber 2 of the Biokube reactor. In chamber 3 and 4 (which contained 60% of the biofilter support media) there was no COD removal activity, which indicates that the Biokube had much more removal capacity available than it was possible to load to the system. COD concentrations could be treated down to 25-30 mg COD/l in the effluent of the Biokube system (residual inert COD). The removal rate activity was gradually affected by the lower oxygen concentration level and reduced mixing as a consequence of the sequenced aeration.

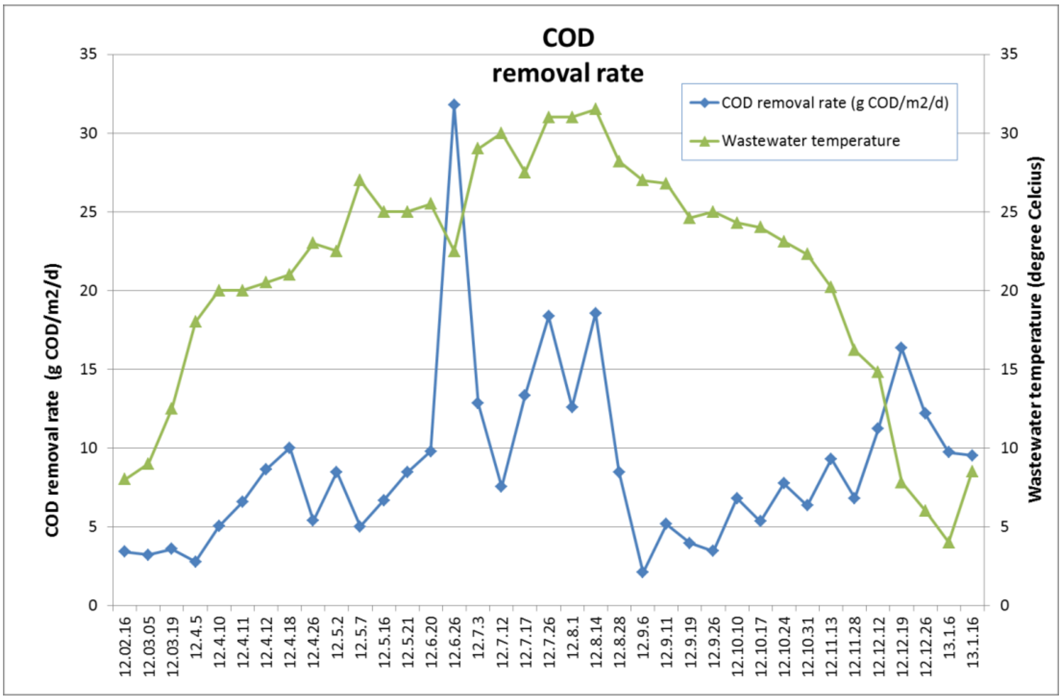

Figure 6.13 COD-total surface specific removal rate as an average in all 4 chambers

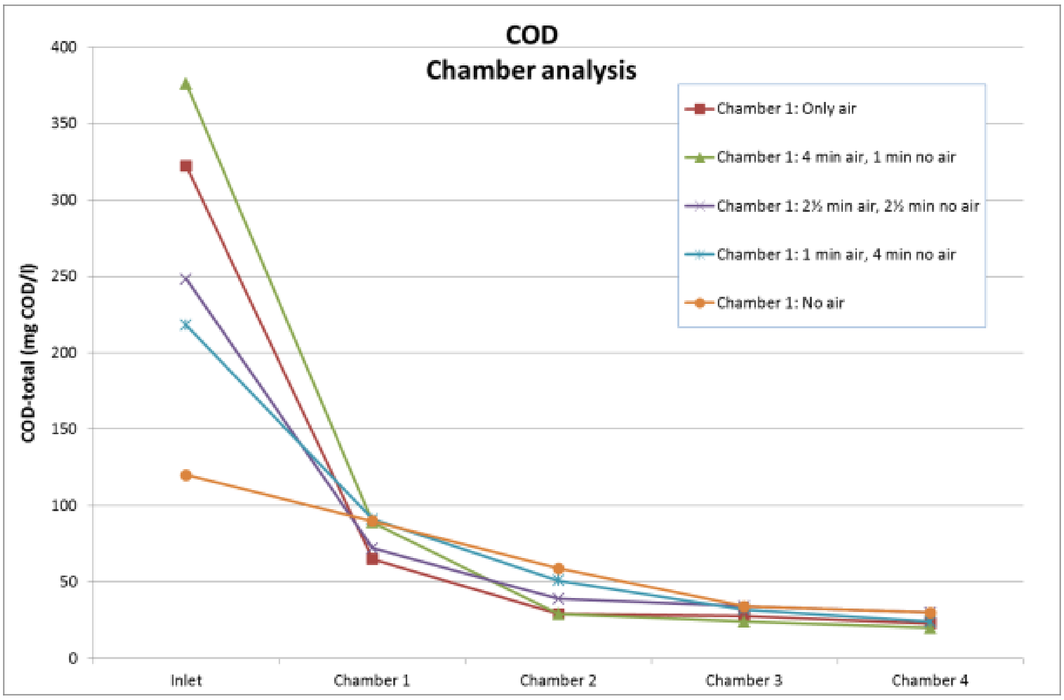

Figure 6.14 Chamber analysis of specific surface removal rate of COD-total in individual chambers of the Biokube Mars 3000. Concentration of COD (mg COD/l).

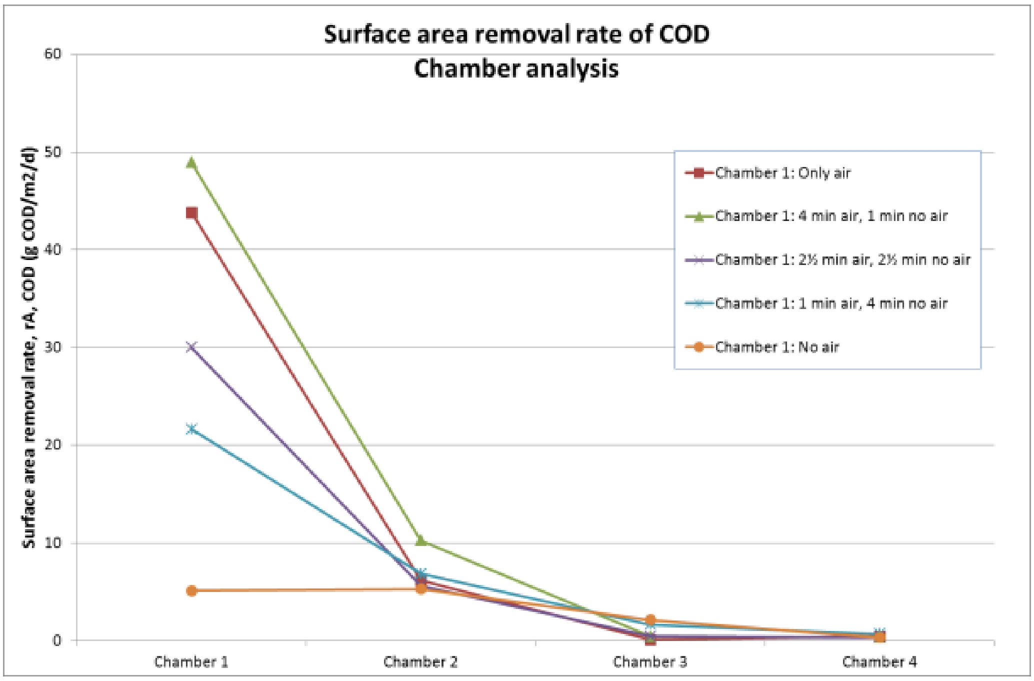

Figure 6.15 Chamber analysis of specific surface removal rate of COD-total in individual chambers of the Biokube Mars 3000. COD removal rate activity (g COD/m2 filter area/d).

6.3.2.2 BOD5

BOD_5 was measured in order to evaluate the removal of biodegradable organic matter. The COD/BOD_5 ratio of the incoming wastewater was fairly high, 2.7 which indicated a rather large amount of non-degradable organic matter contained in the wastewater. The inlet and outlet concentrations of BOD_5 are illustrated in Figure 6.16 and as it appears, during most of the period BOD_5 is treated to a concentration below 10 mg BOD_5/l in spite of significant load variations of BOD_5. During the summer of 2012 the BOD_5 concentration level increased to approximately 20 mg BOD_5/l in the outlet, presumably because of inhibition caused by H_2S production in the pre-settling tank (as described in chapter 6.2).

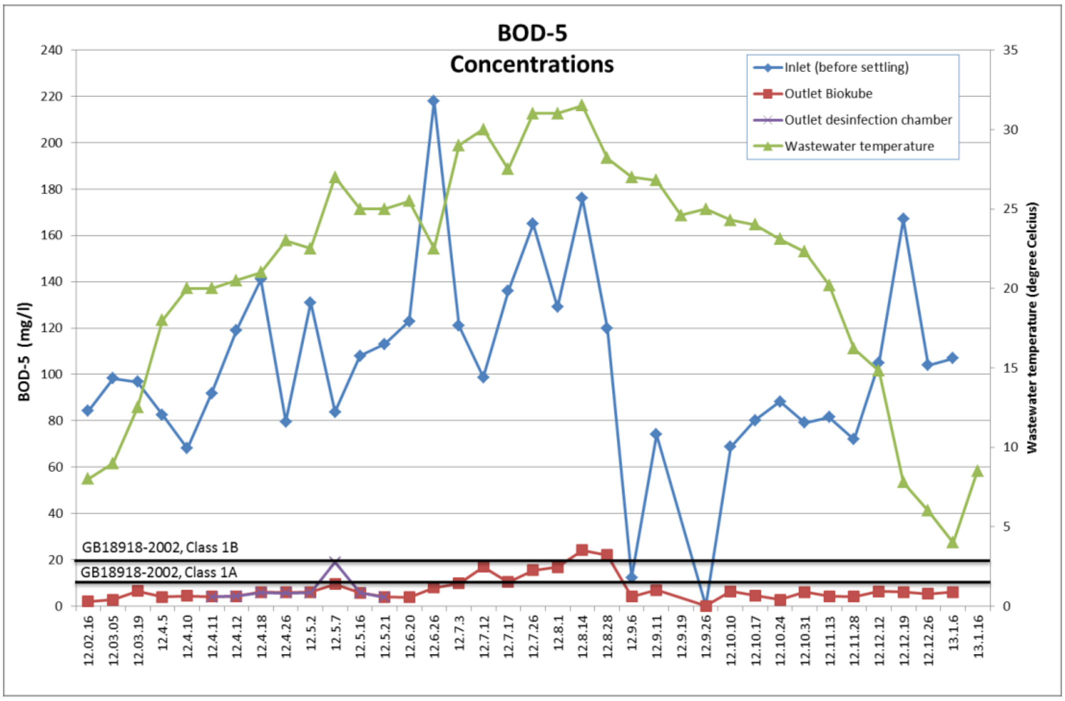

Figure 6.16 BOD5 inlet and outlet concentrations during the experimental campaign

As for COD the load of BOD_5 is far below the maximum capacity as if no nitrification is taking place (Figure 6.17), but the load seems to exceed the biological capacity in periods when full nitrification is occurring at the same time (just as for COD). The removal efficiency of BOD_5 is high – around 95% – except in the summer period when the process was inhibited by the full pre-settling tank.

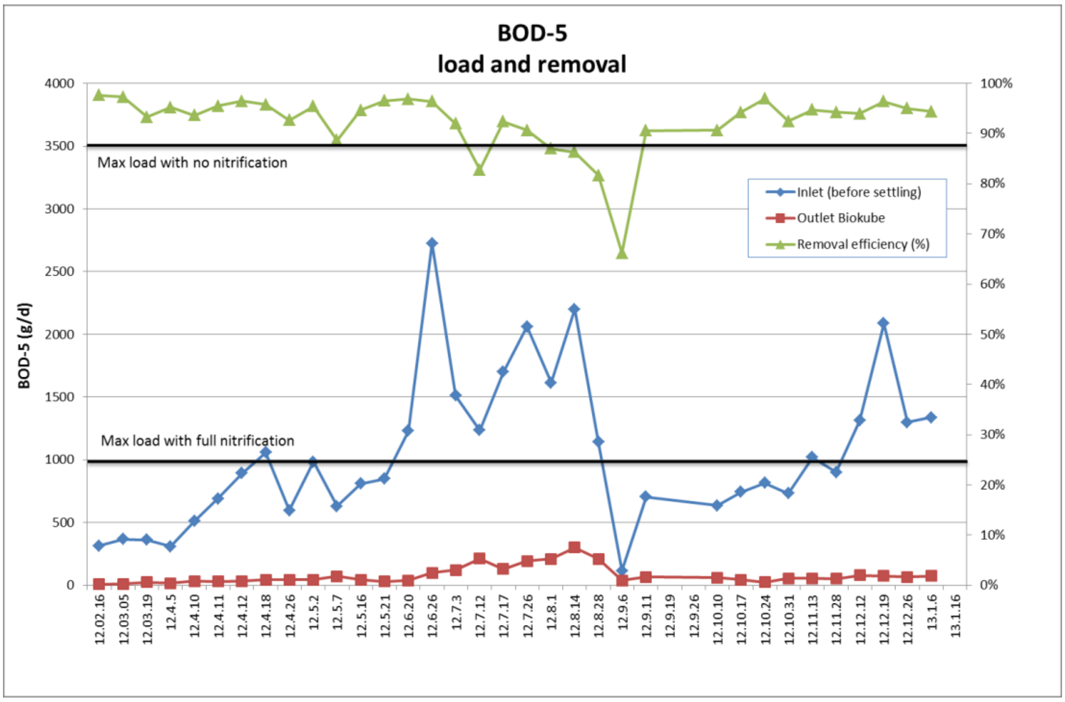

Figure 6.17 BOD5 load and removal efficiency during the experimental campaign

6.3.3 Nitrification

After the installation and start-up of the Biokube system in October 2011 the inoculation of the Bioblok biofilter media began. Normally it takes 2-4 weeks to obtain full nitrification, but it was decided to run the Biokube with low flow during the whole winter period 2001-2012 because of very low water temperatures. The sampling and analysis started in February 2012 and it was clear that full nitrification occurred even with temperatures below 10°C. In Figure 6.18 it appears that inlet concentrations of ammonia vary between 17 and 40 mg NH_4-N/l – with an average of 27 mg NH_4-N/l. The outlet concentrations are typically low – around 1 mg NH_4-N/l with a removal efficiency of more than 95%.

However, during the summer of 2012 with extreme water temperatures the pre-sedimentation tank was accidentally not emptied which led to a very significant inhibition of the nitrification process. It is believed that either high temperatures (which could have been higher than measured), sludge release or high H_2S built-up in the pre-sedimentation tank could have caused this inhibition, because of the extreme heat, low nitrate recirculation and very high concentration of sludge in the tank. Sulphide concentrations higher than 0.5 mg HS^-/l are known to inhibit nitrification processes in biofilters significantly (Æsøy *et al.*, 1998).

At the end of the test period (December 2012), the wastewater temperature dropped to an unusually low concentration level below 5 °C, which gave an ideal situation for testing the temperature limit of the nitrification process. In addition, it was decided to keep the inlet flow to the maximum possible level – 12.5 m^3/d – in order to identify the limits of the process. It became clear that temperatures below 5 °C start reducing nitrification with maximum flow obtained (Figure 6.18). As it can be seen in Figure 6.19 the maximum load of ammonia seems to be 0.4-0.45 kg NH_4/d (at 5 °C) equivalent to 0.2-0.25 kg NH_4/m^3 (reactor volume)/d.

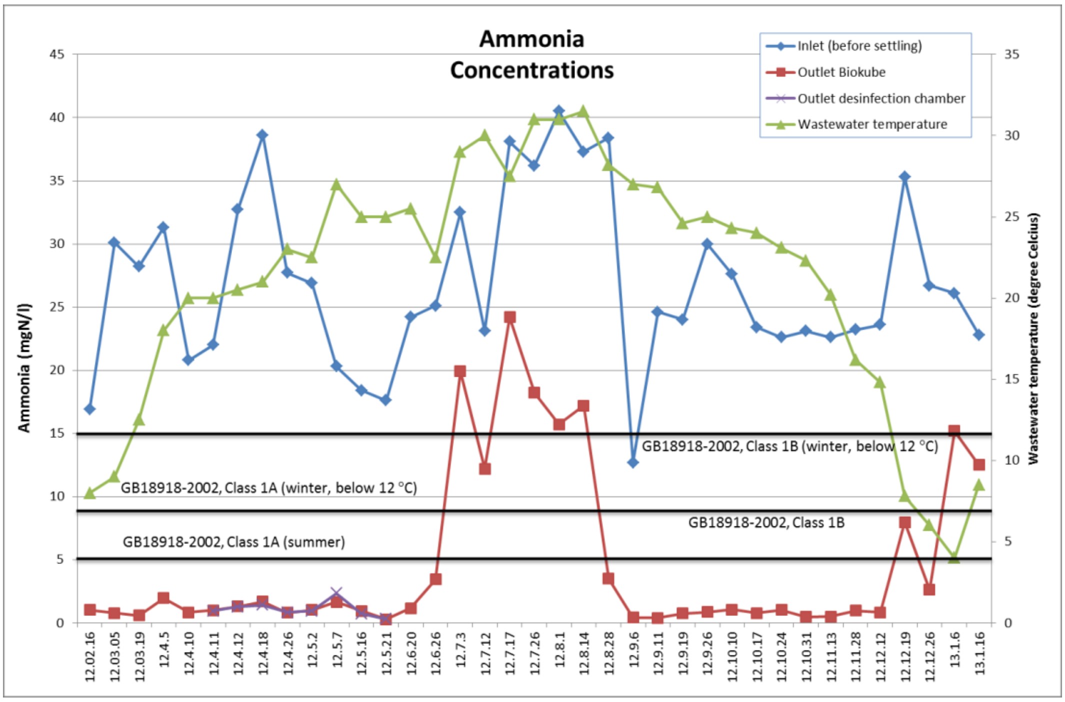

Figure 6.18 Ammonia concentrations in and out of Biokube system

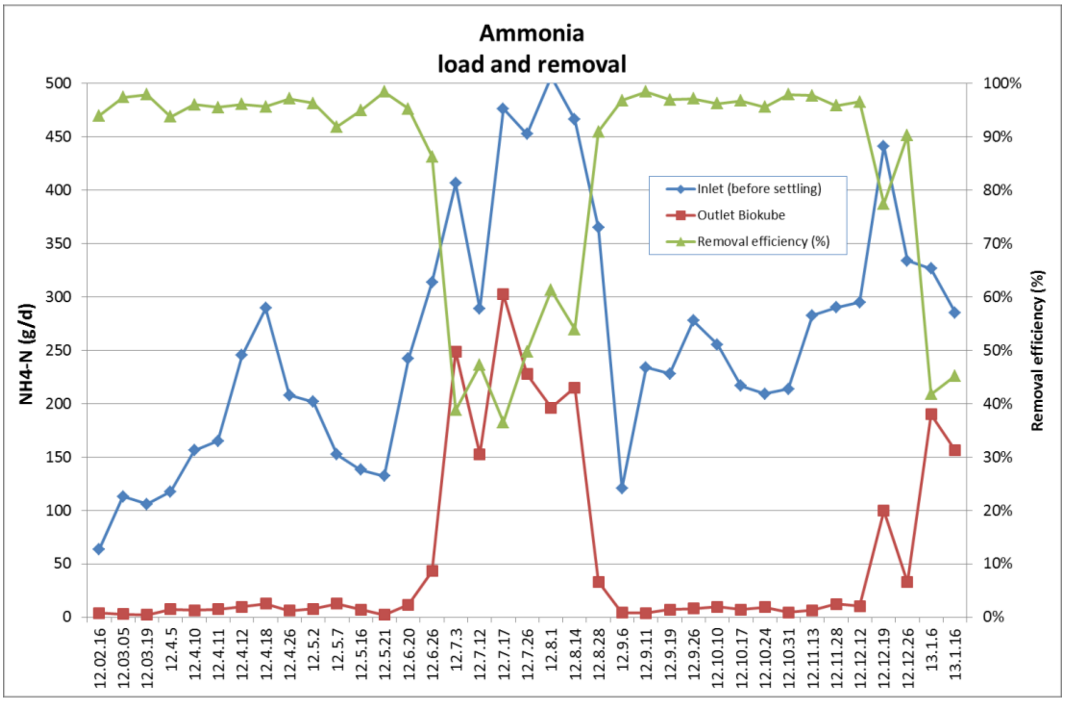

Figure 6.19 Ammonia load into the Biokube system and discharge to recipient

In Figure 6.20 the average surface specific ammonia removal rate has been calculated. The overall maximum removal rates observed was 1.2 g NH_4-N/m² filter area/d even at temperatures around 6-8 °C. These removal rates are comparable with traditional biofilters like trickling filters, RBC and submerged biofilters, but it must be kept in mind that all biofilm surfaces (chamber 1-4) have been included in the calculations. Normally it is not expected that nitrification will occur in chamber 1 and only to some extend in chamber 2.

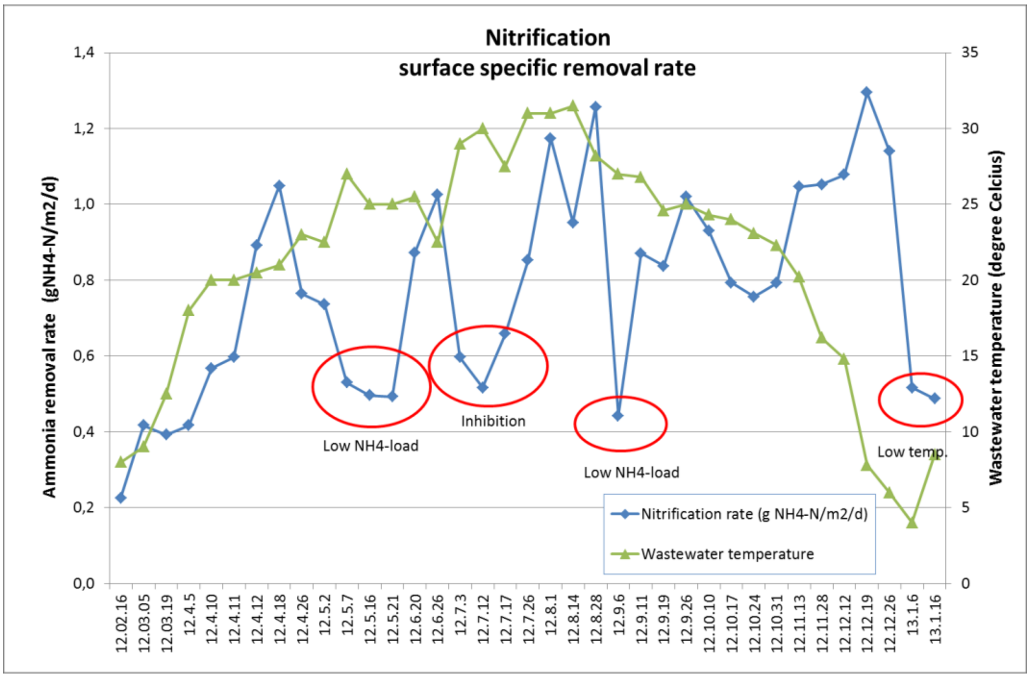

Figure 6.20 Surface specific removal rate as an average in all 4 chambers

In order to verify the performance of processes in the individual chambers, samples of ammonia were taken over a 5 day investigation campaign (the Special Investigation described in chapter 6.3.2.1). The purpose of this monitoring campaign was actually to test if denitrification could be enhanced by partial aeration of chamber 1, but the budget did not allow additional analysis of the wastewater samples. The highest priority was to analyze if the COD and ammonia removal would be affected by sequential aeration of chamber 1. The experiments took place in middle of April 2012 when the wastewater temperature was rising to 25 °C. Temperatures at this level and higher are normal during most of the year in Suzhou. The test (which is described in more details in 6.3.2.1) verified that most of the ammonia is actually removed in chamber 1 and 2, where the highest heterotrophic activity also takes place. This was a surprise since the Biokube Mars 3000 is designed to remove COD and BOD primarily in chamber 1 and 2 and ammonia in chamber 3 and 4.

The result of the test showed that the highest removal rates were observed in chamber 1 with full or partial air supply. However, since most of the COD was also removed here, part of the ammonia was actually removed by the sludge production from the COD removal. The COD was reduced to 60-80 mg COD/l in chamber 1 and assuming that the COD/BOD_5 ratio is 3, then the BOD_5 concentration would be reduced to 20-25 mg BOD_5/l – and still inhibiting the nitrification process significantly. The ammonia concentration typically drops with 20 mg NH_4-N/l from chamber 1 to chamber 2, except when no air is supplied to chamber 1 (almost no ammonia removal). The ammonia removal rate reflects this – the surface specific removal rate is determined to approximately 2.5 g NH_4-N/m^2 filter area/d, except in the phase with full air where the ammonia removal was significantly lower (probably because the inlet concentration was very low that day at the time when the sampling took place). The high ammonia removal rate in chamber 1 can be explained partly by the high COD removal rate (aerobic degradation of organic matter requires 6% ammonia nitrogen). Taking this into account, it is estimated that 60% of the ammonia removal is caused by nitrification, leading to a simultaneous nitrification in chamber 1 of 1.5 g NH_4-N/m^2 filter area/d, which is very high considering the high heterotrophic activity in the tank. Chamber 2 apparently performs just as much nitrification with nitrification rates in the same order, around 1.5 – 2.0 g NH_4-N/m^2 filter area/d, even though the ammonia concentration in chamber 2 is very low, around 2 mg NH_4-N/l (chamber 2 is probably already ammonia process limited). In chamber 3 and 4 almost no nitrification takes place since all the ammonia is being removed in chamber 1 and 2.

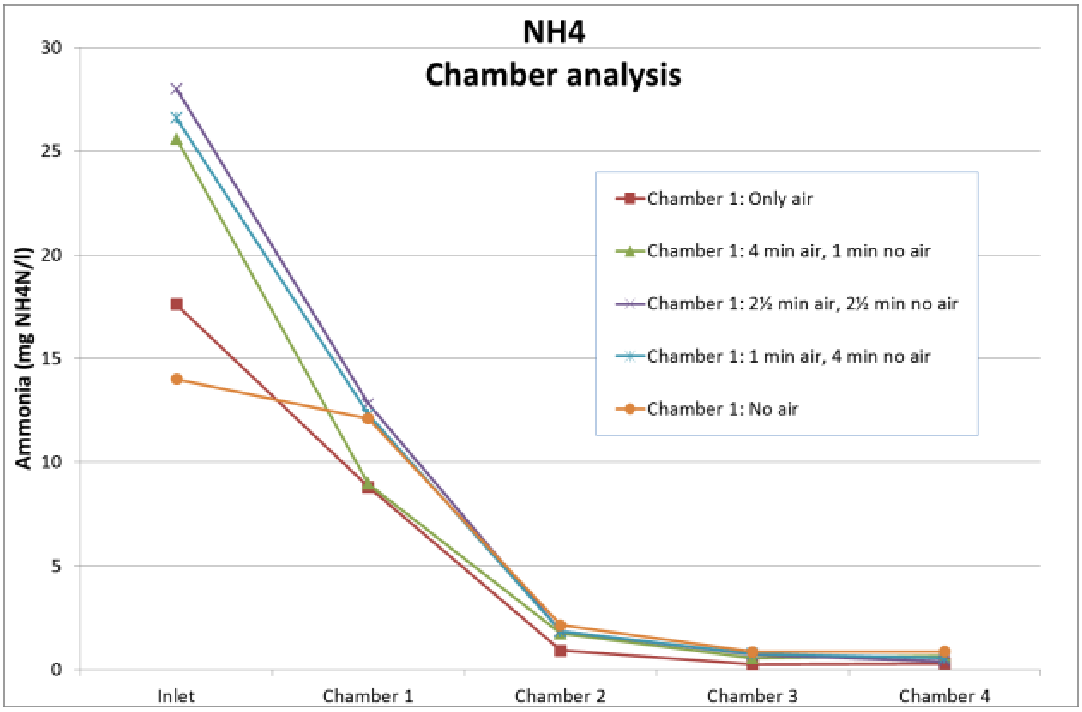

Figure 6.21 Chamber analysis of specific surface removal rate of ammonia in individual chambers of the Biokube 3000 reactor. Ammonia concentrations in chambers

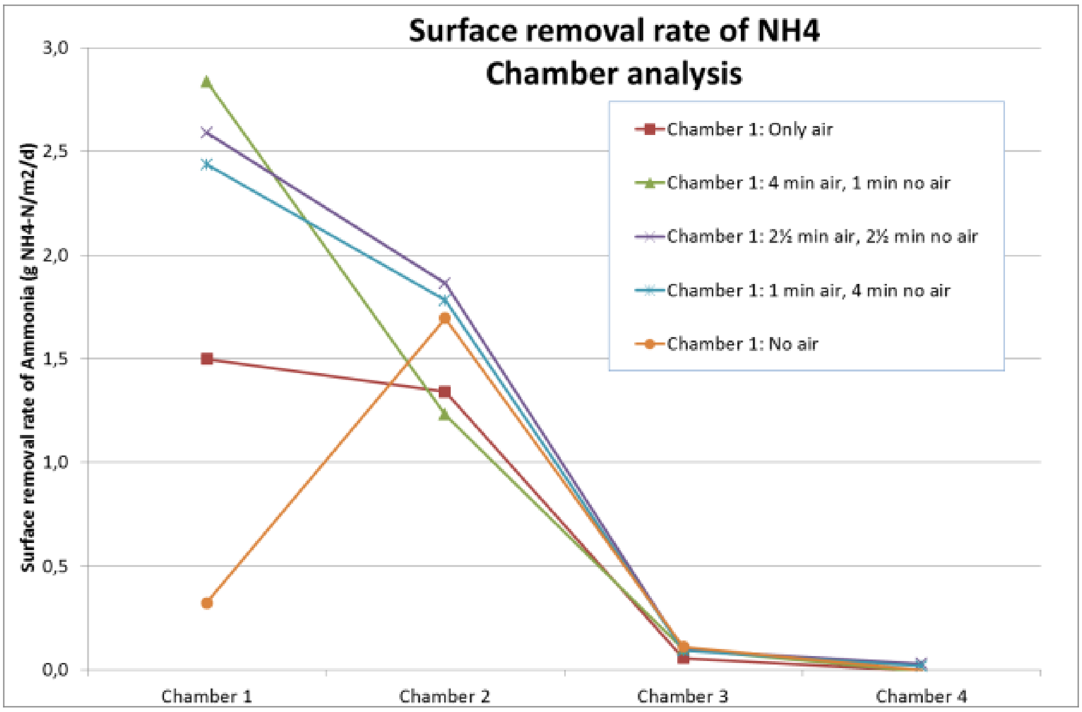

Figure 6.22 Chamber analysis of specific surface removal rate of ammonia in individual chambers of the Biokube 3000 reactor. Ammonia surface specific removal rates in chambers

The findings in the chamber analysis are very important and significant for the design of Biokube systems. It seems that the way the biofilm is controlled/aerated makes it possible to achieve both maximum COD removal and nitrification activity, which should only be possible if the oxygen concentration can penetrate deep enough into the biofilm and liquid film diffusion is negligible. A basic rule says that when the $BOD_5/O_2>5$ in the bulk water of the biofilm, the nitrification is completely inhibited (Henze *et al*, 2000). During this campaign the oxygen concentration in chamber 1 was measured to 7-9 mg O_2/l. BOD_5 was not measured, but based on the COD concentration level in chamber 1 (60-80 mg COD/l) it is assumed that the BOD_5-concentration must have been 20-30 mg BOD_5/l, which gives BOD_5/O_2 =3-3.5. In chamber 2 almost all COD is removed which means that this chamber has ideal conditions for obtaining full nitrification.

The results therefore concludes that a Biokube 3000 can be loaded with 0.25 kg NH_4-N/d at winter and 0.4 kg NH_4-N/d at summer time and still meet Class 1A standard for wastewater discharge. It is not clear how much a load increase of organic matter would affect the nitrification in the first chambers, but apparently there was plenty of nitrification capacity in chamber 3 and 4 (where 60% of the biofilter media was located) to absorb additional loads of ammonia.

6.3.4 Denitrification and total nitrogen removal

The Biokube system was not designed for total nitrogen removal and denitrification, but it was expected that a certain amount of nitrate would be removed since the recirculation and sludge pumping returns nitrate-rich wastewater from the chambers to the pre-settling tank. The pre-settling tank holds a lot of sludge and receives degradable organic matter with little oxygen from the incoming water which will result in denitrification if nitrate is then added. Another purpose of the recirculation is to reduce sulphide production in the pre-settling tank in order to prevent bad smelling and inhibition of the nitrification process. The denitrification process in the pre-settling tank is probably not optimal because no stirring is supplied and every time the pre-settling tank is emptied, the sludge that can perform denitrification is removed and needs to build up again gradually. The recirculation flow is determining how much nitrate can be removed, since recirculation in fact just dilutes the nitrate-rich wastewater in the system. In the Biokube Mars 3000 the recirculation is calculated based on the timer settings of the different pumps installed. The net hydraulic flow through the Biokube system and the recirculation can be calculated as follow:

Q = ((1,9l/s * X * C1) - (0,78l/s * Y * C2)) - (0,78l/s * Z * 3 * C3)

The turquoise part is inflow.
The green part is recirculation from chamber 4
The yellow part is return sludge from chamber 1, 2 and 3

X = running time for inlet pump (seconds).
Y =running time for the mammuth pump in chamber 4 (seconds).
Z =running time for the three mammuth pumps in chamber 1, 2 and 3 (seconds).
C1 = number of cycles per 24 hours for pumping in wastewater (96 when the frequency of pumping is 15 min).
C2 = number of cycles per 24 hours for recirculation pumping from chamber 4 (96 when the frequency of pumping is 15 min).
C3= number of cycles per 24 hours for return sludge pumping of chamber 1, 2 and 3 (1 when the frequency of pumping is 24 hours).

So for the following setting:

Inlet pump (X): 90 sec/15 min.
Valve 1 (Z): 100 sec/24 hours.
Valve 2 (Y): 60 sec/15 min.

The net flow is then: (1.9 * 90 * 96) – (0.78 * 60 * 96) – (0.78 * 100 * 3 * 1) = 11,689 l/d.
The recirculation flow is then: (0.78 * 60 * 96) – (0.78 * 100 * 3 * 1) = 4,727 l/d.

So basically the return flow back to the pre-settling tank is about 40% which theoretically means that less than one third of the nitrate produced can be removed if all nitrate returned to the pre-settling tank is removed and no denitrification takes place in the aerated chambers.

In Figure 6.23 the nitrate concentration in and out of the Biokube system is plottet and as it appears, a significant amount of nitrate is discharged from the Biokube.

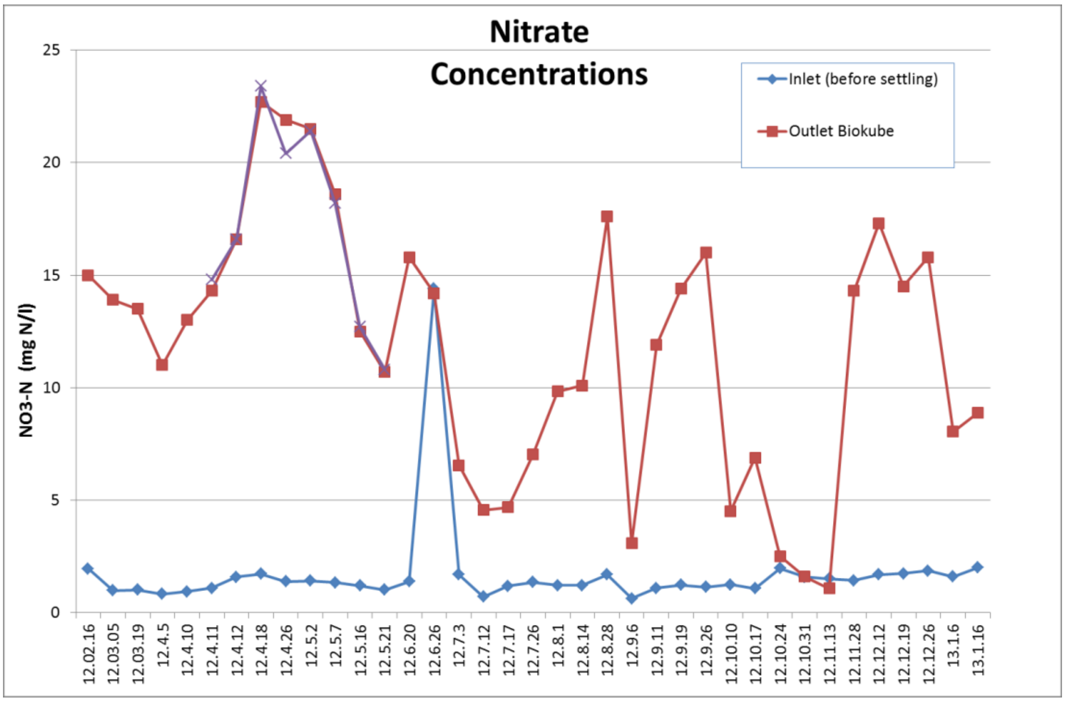

Figure 6.23 Nitrate concentration, inlet and outlet of the Biokube system

When the total nitrogen is plotted (Figure 6.24) it appears that approximately half of the nitrogen is removed completely – mainly by denitrification.

The nitrogen cycle is however a bit complicated since part of the incoming total nitrogen is organic, and part of this will be hydrolyzed into ammonia. Ammonia will then be taken up partly by the heterotrophic growth and built into the sludge (which can then again be hydrolyzed back into ammonia), but the main part of the generated ammonia is nitrified into nitrate. The net result shown in Figure 6.24 represents the nitrogen contained in the system (as sludge) and the nitrogen completely removed by the process (by denitrification).

The total nitrogen discharge seems to meet the Class 1A standard in shorter periods and the Class 1B standard for more than half of the experimental period. But it must be considered that the nitrogen removal is not optimized in any way except by the relatively small recirculation flow returned to the pre-settling tank. If more nitrogen should be removed, it would require a higher recirculation flow and a more dedicated arrangement in the pre-settling tank , e.g. stirring, sectioning of the pre-settling tank and containment of a certain amount of sludge to make sure that there will always be a minimum amount of biological sludge that can perform denitrification. Introduction of such an arrangement would not only remove more nitrate/nitogen – it would also remove COD that does not have to be removed aerobically in the Biokube system.

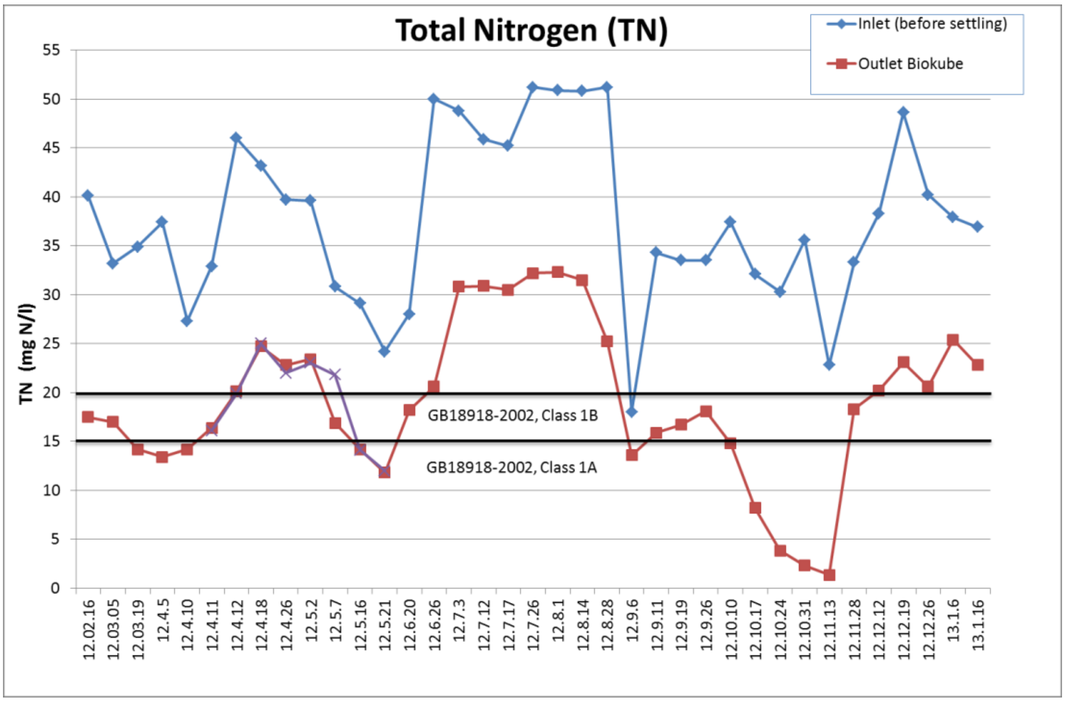

Figure 6.24 Total nitrogen concentration, inlet and outlet of the Biokube system compared with Class1A and Class 1B standard for wastewater discharge in China

6.3.5 Oxygen

Oxygen is supplied in all four aeration chambers with individual blowers. In Figure 6.25 it appears that the O_2 level gradually decreases as the water temperature gradually increases as a consequence of a decrease in O_2 saturation in the water. It can also be seen that O_2 is lowest in chamber 1, where the highest aerobic activity takes place, and is then gradually increasing in chamber 2, 3 and 4. Because of a defective oxygen meter the O_2 level was not measured after mid-August.

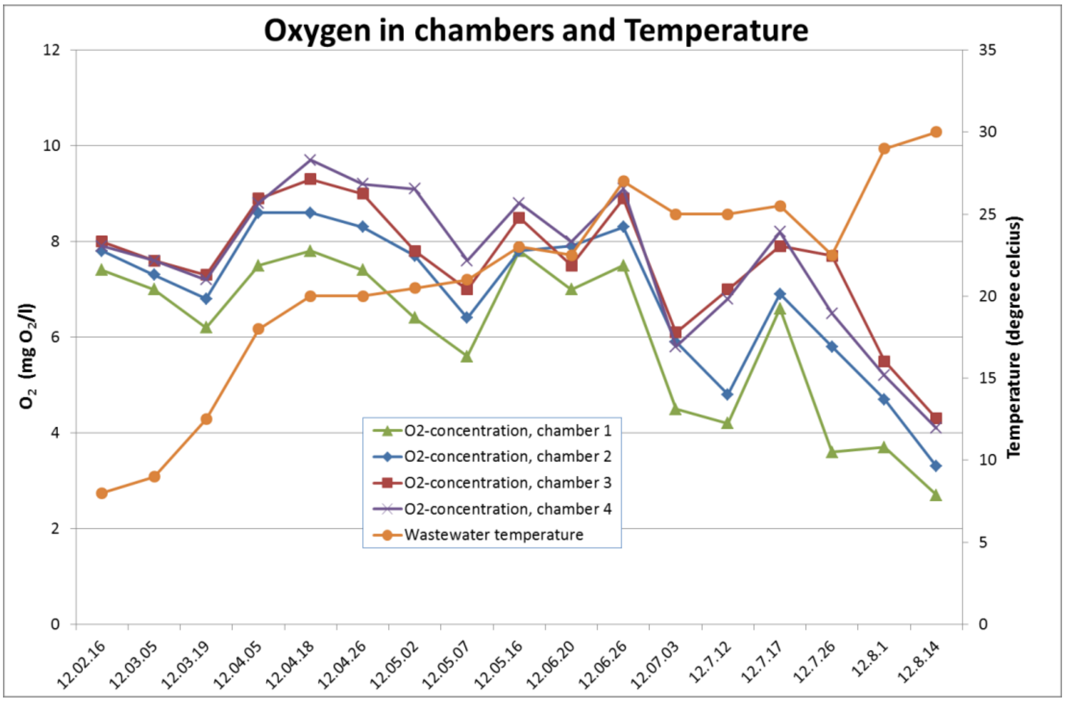

Figure 6.25 Oxygen concentration measured in the four chambers of the Biokube reactor

It is important to know which substance is controlling the reaction rate in order to understand and optimize the process conditions for the biological biofilter process and it is important to recognize that it is the concentration level of the controlling substance in the water that controls the reaction rate. It must be assumed that oxygen is limiting the process rate only in chamber 1 for aerobic heterotrophic activity and nitrification, but only one analysis campaign supports this theory. As for the air supply in chamber 2, 3 and 4 it seems that plenty of oxygen is supplied leading to an O_2 concentration level higher than 8 mg O_2/l, dropping to 4 mg O_2/l during the warmest period of the campaign. It is uncertain whether it was a malfunction of the O_2 meter that led to the measurements of very low oxygen concentration in August 2012, as these measurements seem to be too low in the chambers in spite of the high water temperatures.

Interestingly, the measurement of oxygen in chambers and the special chamber analysis campaign clearly show that too much oxygen is supplied for the process in periods when the load of organics does not reach its maximum capacity. The situation is however that oxygen is used for both aeration, slugging off biofilm and water mixing in the chambers so if oxygen supply is reduced – e.g. by alternating the air supply – it might affect the process stability. Air supply is however an expensive way of mixing so there might be other ways to introduce turbulence – e.g. by pumps or mixers in order to save more energy. In small systems it is necessary to keep the technology as simple as possible, which justifies the use of aeration for multiple functions in the biological process.

6.3.6 Suspended solids

Suspended solids (SS) are measured in the inlet canal before the pre-sedimentation tank and after the last sedimentation tank in the Biokube reactor. The inlet concentration seems to be very fluctuating ranging from 70 mg SS/l to more than 200 mg SS/l (Figure 6.26). The incoming wastewater is thin in concentration probably because of the combined sewer system and because of settling of particulate matter in the inlet canal in periods with low incoming flow (wastewater is then still in the canal).

In the effluent the Biokube has excellent sedimentation abilities. In most periods the Biokube can meet Class 1A standard – only during one occasion a higher level of SS is seen in the outlet, probably because the settling tank was not emptied timely which resulted in a significant sludge release to the Biokube system.

SS was also measured after the disinfection process in the first half period of the campaign. It appears that SS is almost identical before and after the 10 µm filtration. This indicates that the suspended particles are smaller than 10 µm but it does seem unlikely that such small particles can contribute so much to the particulate matter volume. Normally, larger particles contribute mostly to the suspended solids concentration even though they are much less in numbers. Therefore it's likely that the bagfilter used for filtration does not give the prober and expected filtration, but no analysis can support this.

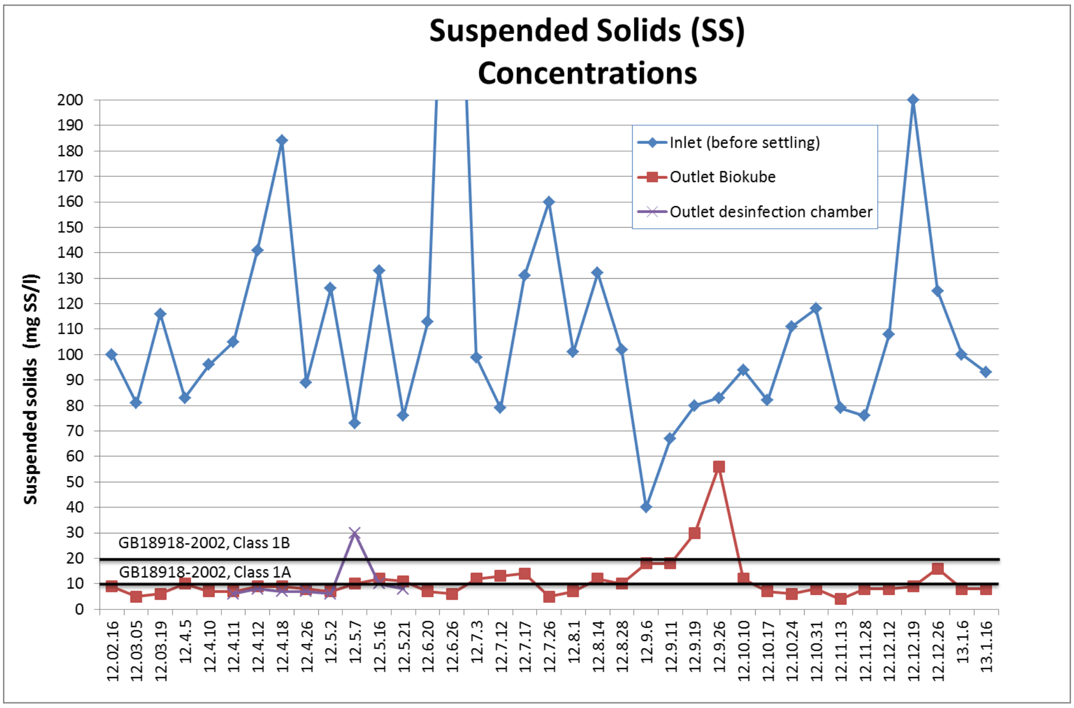

Figure 6.26 Suspended solids concentration in and out of the Biokube system (inlet is before the pre-sedimentation tank)

6.3.7 Phosphor

The Biokube system is designed to remove phosphorous by chemical precipitation. Precipitation chemicals can inhibit the nitrification in cases where the alkalinity is low (because the pH can be lowered), but Biokube uses PAX (Polyaluminium chloride) which is known to inhibit the nitrification process least. Due to complications with Chinese customs inspection and clarification it was decided not to send the chemical with the Biokube components to be tested in China. Later on, it turned out to be very expensive to send it separately from Denmark. Attempts were made to try to purchase this chemical in China but it was not possible to purchase such small amounts. Another precipitation chemical – ferrous sulfate was tested but without success. Therefore it has not been possible to test the Biokube system's ability to remove phosphor by precipitation during this campaign.

Wastewater samples were analyzed for phosphor to detect the level of phosphor concentration in the wastewater and to measure how much phosphor the Biokube system would remove solely by the biological process. As it appears in Figure 6.27, the inlet concentration of phosphor normally fluctuates between 3 and 5 mg P/l (average 3.5 mg P/l), which is considered to be quite low (but normal, however, in Chinese domestic wastewater). The outlet concentration of phosphor is lower – typically between 2 and 3.5 mg P/l (averagely 2.5 mg P/l). Assuming that the biological yield of organic matter removal is 0.35 (35% sludge produced from 100% organic matter removed) and that 1–1.5% of phosphor is built into the produced sludge, the net amount of phosphor removed from the water phase should be 0.8 – 1.25 mg P/l, which fits with the observed amount of phosphor that is actually being removed (1.0 mg P/l). Phosphor will not be removed completely from the system like nitrogen but will accumulate in the sludge storing tank (pre-settling tank) and removed when this tank is emptied.

It can be seen that additional phosphor removal is needed, if the Chinese Discharge Standards should be met.

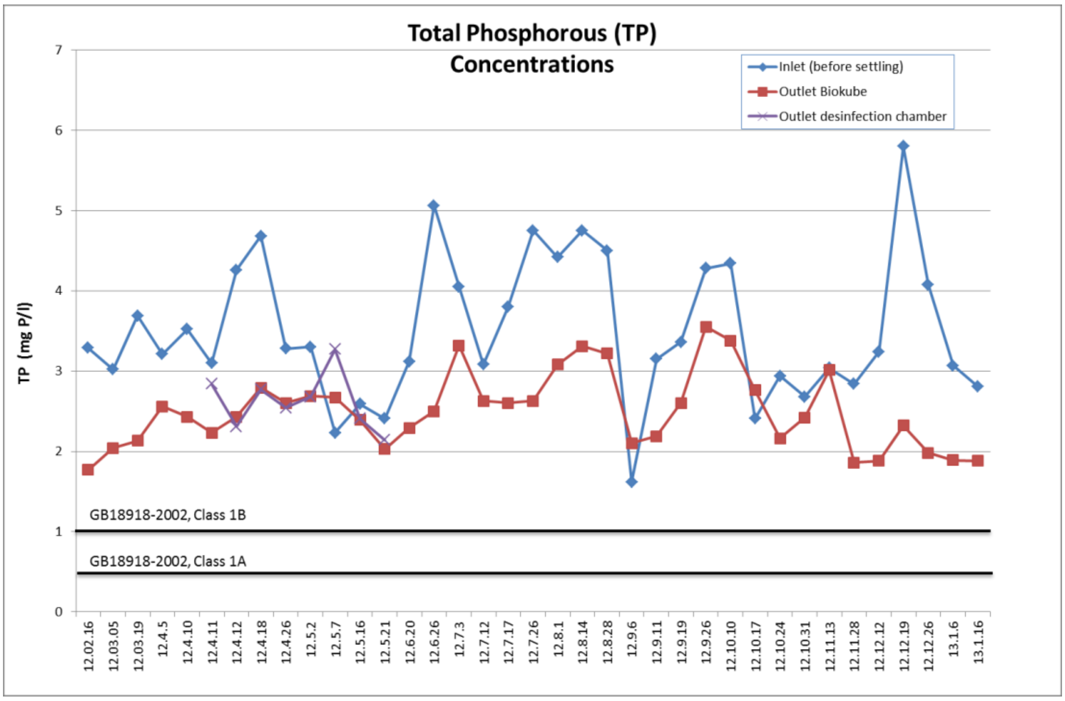

Figure 6.27 Total phosphorous concentration, inlet and outlet of the Biokube system compared with Class1A and Class 1B standard for wastewater discharge in China

6.3.8 Faecal Coliforms

The results from Fecal Coliform represent microbial results from water samples taken after the disinfection system (bag filter and UV system). In chapter 6.3.6 “Suspended solids” it was shown that there were no significant difference in SS concentration before and after 10 µm filtration. The SS concentration was typically measured to 9-10 mg SS/l, which is a normal outlet concentration of suspended solids from a Biokube system.

Measurement of FC after the UV process showed that no detectable concentration could be measured, but this was true only in the beginning of the test when everything functioned well. In April 2012 the bag filter clogged and in such a case the installation was designed to pump the wastewater back into the disinfection holding tank, which it did. However, one analysis taken before the clogging took place showed FC in the UV treated wastewater (167 FC/l), which could indicate that big particles were able pass the bag filter or that many small particles were released into the UV system. After the bag filter was replaced in April 2012, one analysis showed that no FC was present in the UV treated wastewater.

In May 2012 one of the ballasters controlling the UV system stopped working so that one of the UV tubes could not radiate the wastewater. Unfortunately, the construction was made in a way that made it impossible to bypass the UV lamp that had no power. The result is that even though half of the water was radiated, high concentrations of FC were found in the outlet of the disinfection system. Even after the sampling point was changed to a location very close to the functioning UV lamp, high FC values were still found in the outlet. Consequently, it was not possible to make experiments with the UV system.

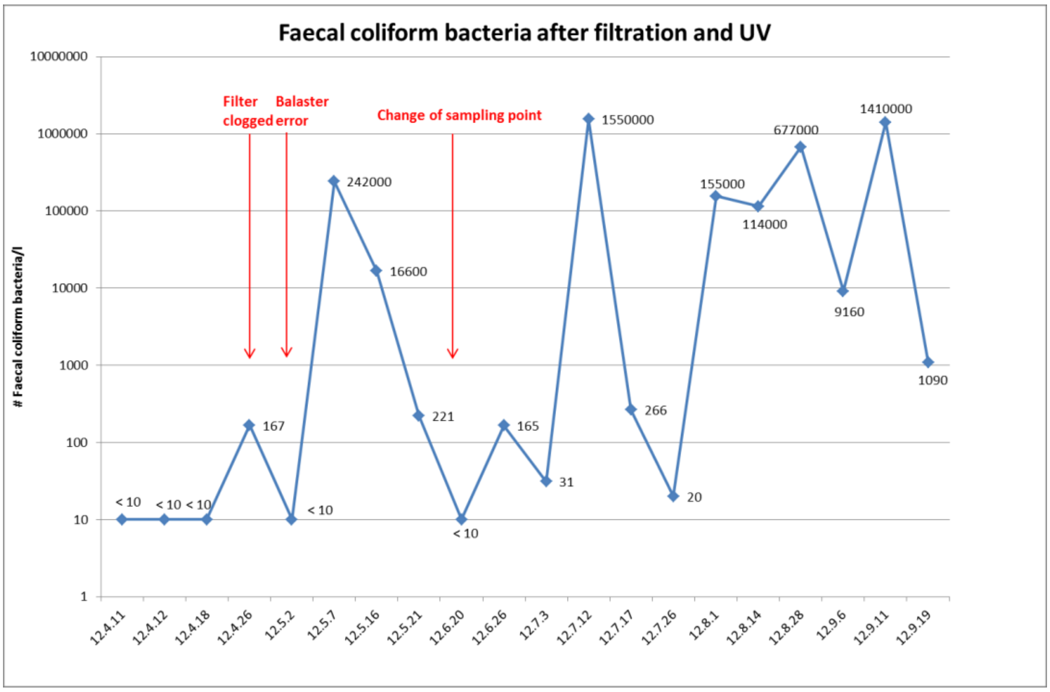

Figure 6.28 Faecal Coliform bacteria concentration measured after the UV

Fortunately 3-4 samples were made successfully in the beginning of the campaign and it could be concluded that the combination of bag filtration and UV can eliminate FC. Furthermore, it was seen that a clogged bag filter can affect the FC even after UV radiation, possibly because many small particles or fewer big particles can be released leading to a shadow effect of the FC bacteria that enables them to survive the UV light.

6.4 Expenses of operation

It is of course important to know about construction, operation and maintenance costs, since it is the efficiency and competitiveness of the technology that will decide if Danish environmental technology can be exported to growth markets like China.

For this investigation, only the direct running expenses of operation (consumption) have been calculated, since equipment and maintenance costs will be relative according to the local price of labor, materials and local production costs. Therefore, costs of equipment, maintenance, depreciation, land purchase etc. have not been included in the consumption calculations. The consumptions related to operating a biological wastewater treatment plant including disinfection have been calculated partly from experimental findings (from this project) and partly from reported consumption costs given by the producers of the technology.

6.4.1 Expenses of biological wastewater treatment

The running expenses of biological wastewater treatment consist of sludge production (to be removed), electricity consumption and chemical precipitation consumption.

6.4.1.1 Sludge production

Sludge will accumulate in the pre-sedimentation tank as a result of suspended matter settlement (from the raw wastewater) and sludge production (from the biological and chemical process). Biokube has experienced that a 100 m^3/d domestic wastewater treatment plant needs to have its pre-sedimentation tank (100 m^3) emptied once every 3 month. The tank will then be half or 2/3 full of sludge with an average dry matter content of 1.5%. The sludge production can then be calculated to 0.011 m^3 wet sludge/m^3 treated wastewater. In this experiment it is estimated that the sludge production will be 1 kg SS/d (flow 12.5 m^3/d, 300 g SS/d from raw wastewater settlement and 700 g SS/d from biological sludge production). With a sludge concentration on 1.5% in the pre-sedimentation tank, 0.067 m^3 wet sludge is produced per day equivalent to **5.4 liter wet sludge/m^3 treated wastewater.**

6.4.1.2 Power consumption

The power consumption used by a Biokube wastewater treatment system normally varies between 0.8 and 1.3 kWh/m^3 treated wastewater, depending on the discharge standards and the size of the system. In this experiment the power consumption was measured to approximately 600W equivalent to 14.4 kWh/d with a maximum flow set to 12.5 m^3/d. The experimental determined power consumption can then be calculated to **1.15 kWh/m^3 treated wastewater**. It is assumed that this number can be reduced – partly because the aeration can be reduced by sequential aeration in some of the chambers and partly because the Biokube Mars 3000 system did not utilize its full capacity due to hydraulic limitation. With an optimization of the system it is estimated that the power consumption could be reduced to **0.8-0.9 kWh/m^3 treated wastewater** and still meet the Chinese Class 1A Standard.

6.4.1.3 Precipitation chemicals for phosphor removal

In this study, the efficiency and cost of phosphor precipitation was not investigated. In Denmark, most of the 2500 wastewater treatment plants are equipped with this solution and based on experience 30 liter of PAX (Poly Aluminum Chloride) is normally consumed per 150 m^3 treated wastewater (Discharge Standard in Denmark: 1.5 mg P/l). It is estimated that 50% more PAX will be needed to treat phosphor to a concentration below 1.0 mg P/l resulting in a PAX consumption on **0.4 liter PAX/m^3 treated wastewater** to reach the Chinese Class 1A Standard (1.0 mg P/l).

6.4.2 Cost of wastewater disinfection

In this study the disinfection of wastewater was carried out by a combination of filtration and UV radiation. The cost of using this type of disinfection system has been calculated based on the number of bags used, the electrical cost of using UV lamps (incl. pumping) and the cost of UV lamps.

6.4.2.1 Cost of filtration with 10 µm bag filters

This investigation indicated that filtration was necessary in order have an efficient UV treatment. The investigation showed that suspended sludge removal by bag filtration (10 µm) could not be measured by sampling of suspended matter before and after filtration. However, it is believed that suspended particles will be removed by filtration, but it is quite uncertain how much suspended matter will be detained in the bag filter. Other investigations made in recirculated aquaculture systems, where filtration is a major part of the treatment process, suggest that approximately 50% of the mass of particulate matter consists of particles smaller than 20-30 µm. If it is assumed that 50% of the suspended matter will be removed by the 10 µm bag filter, 5 g SS/m^3 will then be detained in the filter. It was not possible to get information about particle detainment from the Chinese supplier of bag filters used for this project, but another big Chinese supplier of bag filters (Feature Filtration Technology Co., LtD.) informed that they had a solution with 10 µm bag filtration (pleated filter bags), which could hold 2,500 g SS before replacement. This means that it should be possible to load 500 m^3 wastewater through each filterbag before it needs to be replaced. The cost of these bags is 13.6€/bag, which leads to a treatment cost of **0.027€/m^3 treated wastewater**.

6.4.2.2 Consumption expenses of UV treatment

The expense of running a UV installation includes electricity and replacement of the lamps. For a system with pre-filtration and UV lamps a powerful pump is also needed because the water has to be pumped through the filter bag, into the UV system and then through a hose to the end disposal. This UV system is designed for a very high flow, 40 m^3/h, and therefore the pump needs to have the necessary capacity for a maximum pressure of 5 bars. The power consumption of such a pump is estimated to 8 kW (Grundfos SP45-5 groundwater pump) and the UV installation uses 500 W, which means that the total expense for electricity will be 8,500 W for treating 40 m^3/h. The power consumption will then be 0.21 kWh/m^3 treated wastewater (16,000 hours lifetime of UV tubes).

6.4.3 Summary, expenses of operation

The running expenses of operating a biological wastewater treatment plant (Biokube Mars 3000 system) with a disinfection system that consists of bag filtration and UV lamps can be summarized as follows:

Table 6.2 Expense of operation, Biokube Mars 3000 system and disinfection system

Operation	Expense of operation	Unit	Assumptions
Sludge removal	5.4 – 11.1	liter wet sludge/m^3 treated wastewater	Sludge liquor produced from raw wastewater sedimentation and biological produced sludge. Sludge concentration in sedimentation tank: 1.5% SS
Power consumption	0.8 – 1.1	kWh/m^3 treated wastewater	Full nitrification. 12-20 m^3/d in a Biokube Mars 3000 system.
Precipitation chemicals	0.4	liter PAX/m^3 treated wastewater	Total phosphor < 1.0 mg TP/l in outlet
Bag filtration	500	m^3 wastewater/fil-terbag	Pleated filter bags, 2,500 g SS/bag. SS detainment in bag: 50%. SS concentration in wastewater to be filtered: 10 mg SS/l.
UV and pumping	0.21	kWh/m^3 treated wastewater	40 m^3/h, 16,000 hours lifetime (UV tubes) end capacity of UV: 25 mJ/cm^2, transmission: 70%,

6.5 Further development suggestions

This project has focused on developing a small-scale unmanned wastewater treatment installation that could upgrade the biologically treated wastewater to be reused according to Chinese Discharge Standards. Even though the project goal has been achieved (however not without technical problems, of course), further investigations will be needed to optimize the treatment process. In the following the most important development issues that need to be followed up are described.

6.6 Investigations of the effect of particulate removal on UV system performance

The efficiency of UV radiation on water depends on the transmission in the water and the amount and size of particles in the water. The efficiency of pre-filtration is very important for the efficiency of the UV system and there is definitely a dependency between the pore size of filtration and the UV intensity. Since filtration is much more expensive in running cost than UV treatment, it would be very relevant to determine the relation between pore size filtration and UV light intensity. If the running time of filter bags can be increased, it would mean cheaper cost of operation as well as less work with filter bag replacement even if the UV light intensity should be much larger. There is probably a maximum limit of the pore size, where the UV will not be efficient enough to kill microorganisms in the particles that pass the filter, and it is relevant to be aware of this limit in order to find the most optimal combination of size filtration and UV intensity.

6.7 Development of better denitrification in the pre-settling tank

The project has shown that denitrification can be obtained very easily in an aerobic system with a pre-sedimentation tank installed. However, it is evident that the denitrification process in this setup will be running variably depending on how much sludge is in the pre-sedimentation tank (it should normally be emptied with a certain frequency depending on the size of the tank). There seems to be a large optimization potential for increased denitrification, if the recirculation could be increased, the pre-sedimentation tank could be divided in sections and include a “denitrification section” that always has sludge stored, and if slow mixing (e.g. by arranging it with the incoming water from recirculation) could be introduced in the “denitrification section”. If denitrification could be increased, if would potentially save aeration energy in the Biokube chambers because part of the COD will be removed by denitrification. This would furthermore help to reduce the total nitrogen discharge from the Biokube system, which would be necessary in cases with stringent Total Nitrogen Discharge Standards.

6.8 Test of flow reversal in Biokube chambers

Experiments investigating the COD and ammonia removal in the different chambers of the Biokube Mars 3000 system have clearly shown that the first chambers remove most of the COD and ammonia. Furthermore, the experiments indicated that the last chambers, which were loaded with very diluted wastewater, did not develop a very robust biofilm because the substrate (COD and ammonia) would not be able to penetrate deep into the biofilm. In case of sudden loading, where higher concentrations of COD and ammonia would build up in chamber 3 and 4, there might not be biofilm capacity to remove these pollutants very efficiently. In other biofilter systems, having individual biofilter sections, flow reversal has successfully shown (Boller *et al.*, 1994) that the capacity of the last chambers can be increased, especially for improving the kinetic performance at low concentrations of ammonia (>5 mg NH_4-N/l,), if the biofilm in the last chambers can be regularly loaded with higher concentrations of COD and ammonia by changing the flow direction so that the last chamber will periodically be the first one. In cases where a Biokube system uses 3 or 4 chambers, it might be possible to increase the overall capacity of the system if such a flow reversal system could be introduced.

6.9 Sequential aeration – maintenance of biofilm control, stirring and the need for aeration

The Biokube system is developed as a very simple biofilter technology where the aeration has many functions. First of all it supplies the necessary oxygen for the process, but it also rubs off excess biofilm (very important for the biofilm performance) and it ensures mixing in the chambers which helps to transport substrate to the biofilm surface where it can then diffuse into the biofilm. However, it seems that aeration could be reduced in periods with low loading leading to much less power consumption of the Biokube system. The concept of sequenced aeration has in fact already been tested now by Biokube (denoted “Family Match”) in wastewater treatment systems with highly variable loading of wastewater (e.g. summer houses). If the concept should be developed further, stirring by short aeration bursts or some sort of periodic mixing could help to enhance the substrate removal in periods when the aeration is paused.

6.10 Alarm system - further development

The alarm system has proven to be important in situations where installations are running unmanned with no possibility of physical contact to the installation. In this project, 3 flooding incidents happened and many power cuts were experienced, which of course led to considerations of establishing some sort of simple monitoring of the system. After the flooding incidents the alarm system was developed but at the same time the floater device in the Biokube Mars 3000 system was improved, so no further flooding accidents were detected. However, the power alarm function demonstrated that many power cuts happen, even in a well-developed area like Suzhou. The alarm system should however be able to tell both when the power is cut and when it comes back as a power cut can be very short (minutes, seconds) and therefore having no effect on the Biokube operation. There are other errors that could be detected by simple sensors like power off sensors, pressure sensitive valves and floaters, but since the alarms are transmitted over the mobile phone network it could also be relevant to have a visual look at the installation, e.g. with a web cam. The complexity of the alarm system should of course be determined by the size and complexity of the wastewater treatment system.

7 Dissemination

An important part of the project was to disseminate the results of the project development and testing. Originally the idea was to set up a homepage in Chinese, but it was concluded that neither the project, nor the technology would benefit from this kind of passive dissemination and also a homepage has to be maintained, supported and further developed in the future. Instead it was decided to have a small conference/seminar with presence of possible stakeholders that could be interested in the technology. Furthermore, the results of the project have been submitted to the 11th IWA Conference on Small Water & Wastewater Systems and Sludge Management to be held in Harbin in October 2013.

7.1 DHI-Biokube seminar, Suzhou China

DHI hosted a project seminar on October 26, 2012 in Suzhou where the test took place and there were many representatives from companies and institutions from Suzhou, Shanghai and other provinces of China. The seminar was planned as a one-day seminar with project presentation and discussion at The Castle Hotel (Xucheng Dasha) located just 10 minutes' walk from the test site. After the meeting and lunch the participants went to the project site to inspect the installations and ask practical questions about the technology.

1. The seminar had the following agenda:
2. Cleaning wastewater with fixed film technology (Peter Taarnhøj, Biokube)
3. Project results and discussion (DHI)
4. Presentation of other Biokube products (Peter Taarnhøj, Biokube)
5. Suzhou Sewage Administration´s interest in decentralized wastewater treatment/Biokube, possible installations in Suzhou? (SSA)
6. Suzhou Sewage Administration´s needs and requirements (what do they require if they should use Biokube WWTP for wastewater treatment in Suzhou) (SSA)
7. What is going to happen to the Mars 3000 installation in Suzhou – hopefully we can make a plan (all)
8. Site inspection of Mars 3000 installation (all)

The following companies and institutions participated in the seminar:

Suzhou Sewage Administration, SSA. SSA who is our local project partner facilitated the experimental part of the project and was responsible for sampling and analysis of water samples. SSA is the Suzhou´s local government advisor in terms of wastewater treatment planning.

CXJH (Wastewater Treatment Construction Company in Suzhou). CXJH constructs wastewater treatment plants for the local government in Suzhou. CXJH is interested in investigating the Biokube technology further in terms of stability and running costs.

SAES (Shanghai Academy of Environmental Science). SAES is interested in investigating possible decentralized solutions for wastewater treatment in Shanghai´s suburban districts and point sources from e.g. public toilets in the city area.

Greenspace (Shanghai). Greenspace is a company with approximately 200 employees who develops ecological natural parks with water systems, including irrigation, water recycling and landscaping. Greenspace is interested in being an agent for Biokube technology in China because Biokube technology fits perfectly into Greenspace´s project types, which often involve decentralized water treatment solutions and reuse.

Hong pumps (Taiwan). Biokube uses pumps from Hong pumps and Hong pumps are interested in learning more about the Biokube technology. Possible agent in Taiwan.

DHI-China. Local project partner located in Shanghai.

DHI-Denmark (Kenneth Janning). Project Manager.

Biokube A/S (Peter Taarnhoj). Owner of Biokube A/S.

Figure 7.1 Pictures from the one-day project seminar arranged by DHI in Suzhou, October 26, 2012

7.2 Paper presentation, IWA Harbin 2013

The results obtained from the project were important in terms of performance of the technology but also in terms of demonstration of the concept in China. Most decentralized wastewater treatment solutions in China consist of constructed wetlands, activated sludge systems, and anaerobic treatment solutions but also to some extend biofilters, even though this technology seems to be rare. When the call for the 11th IWA Conference on Small Water & Wastewater Systems and Sludge Management was announced at the end of the experimental period of this project, it was decided to publish the project results in order to disseminate them the best possible way. The IWA conference is to be held on October 28-30, 2013 in Harbin and the abstract: “Small-scale biofilter systems for domestic wastewater treatment” has been submitted to be presented at the conference (see Annex A).

Figure 7.2 Announcement of the 11th IWA Conference on Small Water & Wastewater Systems and Sludge Management to be held on October 28-30, 2013 in Harbin

8 Discussion

8.1 What have we achieved

This project has demonstrated that it is possible to conduct a technical development project successfully in China. During the project period we have managed to find an ideal local partner for the project who was interested in the technology and who had technical facilities and access to a laboratory, which was needed to conduct analysis of water samples. We managed to install a fairly complicated wastewater treatment plant system and have been running it for more than one year in the middle of Suzhou city. The project has managed to show that wastewater reuse is possible in a small unmanned installation and that it is possible to meet Chinese Discharge Standards for urban water reuse. Another achievement is that we have demonstrated to the Chinese stakeholders that such a concept can work and a paper has been accepted for publication at an international conference to be held in North China (October 2013).

The technical achievement is a small scale wastewater treatment system that can reuse biologically treated wastewater in an environmentally friendly way. In China wastewater is normally disinfected by adding chlorine, but this solution does not add any environmentally unfriendly chemicals and it has even proved to be fairly cheap and simple to operate.

The technical level of development could, however, have been higher if the project had been conducted in Denmark due to extraordinary expenses like travel, shipment an customs fees and high local budget for supervisions and sampling, but the advantages are certainly clear: The project has been able to disseminate the project results much better for Chinese stakeholders by the development and demonstration of the technology IN China – the value of this in terms of possible future corporation and potential export is evident. In this way, Danish companies can be in direct contact with stakeholders and potential partners, which makes the subsequent business development phase more obvious – in fact business development was a part of the project but not funded by the project grant given by the Danish EPB. Today Biokube has a local and trusted partner (Greenspace), who is interested in selling and distributing the technology in China. Whether they will be successful depends on the future effort they will put into the business development and how much Biokube can and will support the next difficult steps in this process.

DHI has also benefitted from this project – we have learned what is required to conduct such a project abroad and how to adjust our level of ambition. There are many technical and administrative details involved in conducting such a project and there are clearly more risks when a project has to be completed with REAL equipment involved. We now know that the real risks are linked to the local organization and project partner you select – if this selection is successful, there is a big chance that the project will succeed.

8.2 Technology development in China – lessons learned

The idea of having technology developed and demonstrated abroad can help companies to show how Danish environmental technologies work on new potential export markets. It is an excellent way of exposing new technologies on new growth markets, but there are some very important practical issues that have to be addressed, which may affect the success of a project.

The local partner/platform has to be very carefully chosen – the success of the project depends very much on the local team and their idea and motivation for joining the project. The logistics have to be optimal (both in terms of transportation, facilities, and language) and the technical skills of the local team have to be sufficiently good – otherwise the budget needs to be much bigger and the project outcome much lower.

Moving the technical development to a country like China is probably more expensive than if the project had been carried out in Denmark – again, it completely depends on where the project will take place in China and how much effort the local counterpart puts in the project. We found that prices of water analysis were comparable with Danish costs and that cost of local assistance might be much cheaper on an hourly basis (cost of technical assistance in China is 4-5 times cheaper than Denmark), but many more man-hours will be charged on the project than in Denmark.

A clear disadvantage is that the project schedule will be much longer than if the project had been carried out in Denmark due to many reasons: It is more bureaucratic to run a project in China, it is complicated to follow up on technical problems and the time for getting results from e.g. water analysis is very long (in our case up to one month), which means that it is difficult to plan experiments based on results that are one month old.

The greatest value of conducting the technical development and demonstration in China is that it is possible to demonstrate how we work and what we make out of it directly on a potentially big market. It also gives us an excellent impression of the market and what kind of people and culture we have to adapt to. There is a clear risk that somebody wants to steel the idea (very common in China) and that was also the case in this project. Therefore it is important that the key technology is kept confidential, and if export or even production is going to be started up, the partner has to be trusted and a professional contract has to be signed. Furthermore, it will be an advantage if the local partner can invest in the local expenses to show that they are serious and that they have something at stake.

9 Conclusion

From the project results obtained, the following conclusions can be drawn:

- The project has shown that it is possible to conduct a technical development project in China. The project was supported with a grant from the Danish Environmental Protection Agency and was carried out by DHI (Consultant Company), Biokube A/S (producer of wastewater treatment systems) and Skjølstrup & Grønborg ApS (UV systems). During the project it became clear that trusted local support, good communication between partners, motivation and optimal logistic conditions are essential needs for obtaining successful result. It will then be possible to complete the technical part of the project.
- The project has successfully developed a new water treatment technology that enables environmentally friendly reuse of cleaned wastewater. The technology can work in a decentralized manner with little or no supervision from staff present at the installation.
- The treatment technology for reuse involves simple bag filter filtration followed by UV and the concept builds on the idea of purifying biologically cleaned wastewater when it is needed. This will eliminate the use of a holding tank for cleaned disinfected wastewater, where hygiene standard can be very problematic to maintain.
- The performance of the biological wastewater treatment plant (the Biokube Mars 3000 system) was satisfactory during extreme warm and cold periods and could treat the wastewater to meet the Chinese Class 1A standard for wastewater discharge most of the time.
- The performance of the disinfection system demonstrated that Faecal coliform bacteria could be removed below the detection limit meeting Chinese Discharge Standards for different kinds of water reuse. Early in the project, an error in one of the UV systems made it impossible to continue the experiment even though attempts were made to bypass the defected system.
- Technical accidents during the project clearly demonstrated the need for a simple alarm system, which was also developed as a part of the project. Remote operation of wastewater treatment installations cannot be done safely without some sort of indication that the basic functions of the system are in order. Today's technology enables fairly cheap and simple monitoring via the mobile phone network, which covers larger and larger areas of even remote locations.
- The consumption costs of operation were calculated for the biological treatment system and for the disinfection system The consumption cost of operation for biological wastewater treatment consists of sludge removal and deposition, electrical costs and costs of precipitation chemicals and were estimated to: 5-10 liter sludge (1.5% TS)/m^3 wastewater treated, 0.8-1.1 kWh/m^3 wastewater treated and 0.4 liter PAX/m^3 wastewater treated (meeting GB18918-2002 Class 1A). Consumption costs of running a disinfection system partly consisted of consumption of filterbags and power consumption of running a UV system. The consumption of filterbags was estimated based to 500 m^3 wastewater/filterbag (equivalent to 0.027€/m^3 wastewater treated) and UV treatment incl. pumping (4 bar) consumed 0.21 kWh/m^3 wastewater treated. These costs show that water reuse is economically and technically feasible to use technology instead of chemicals to disinfect wastewater and the prices of upgrading wastewater to be reused only constitutes 10-20% of the total cost of wastewater treatment.

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Annexes

Annex A: Paper submitted to the 11th IWA Conference on Small Water & Wastewater Systems and Sludge Management

Annex A: Paper submitted to the 11th IWA Conference on Small Water & Wastewater Systems and Sludge Mangement

Small-scale biofilter systems for decentralized wastewater treatment

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Keywords: Decentralized wastewater treatment; biofilm reactors; aerated biofilters; reuse; China; Biokube

Abstract

In many developing countries the need for decentralized wastewater treatment is greater than ever due to economic growth and rapid increase in population in areas with inadequate sewer networks. There is an evident need for different technical solutions to handle the sanitation problems arising in both urban and rural areas and biofilters are known to be very suitable and flexible for decentralized wastewater treatment due to their efficient attachment of biomass. The present study investigated the performance of municipal wastewater treatment in a small scale automated aerobic biofilter system in Suzhou, China. Results showed that efficient removal of COD and ammonia could be achieved simultaneously with maximum biofilter surface removal activity of 50 g COD/m2/d and 2.5 g NH4-N/m2/d (22°C). Nitrification was efficient down to 5°C and 55% of the generated nitrate could be removed by recirculating to the sludge holding tank. Phosphor could be removed by precipitation but was not tested. The energy consumption of the process was measured to 1.1 kWh/m3 treated wastewater but sequential aeration could reduce power consumption significantly to 0.8 kWh/m3. Bagfiltration followed by UV treatment was tested as a method for upgrading wastewater to be reused and the cost of operation was found to be reasonable.

Introduction

In many developing countries central wastewater treatment systems in both rural and urban areas are often not fully implemented mainly due to inadequate sewer collection networks. Even though population densities in major cities of development countries have been increasing dramatically in the nearby future (Kazmi and Furumai, 2005) billions of people will still face inadequate sanitation in both urbanized and rural areas (Massoud *et al*.,2009, Ho 2003). The extreme population growth in megacities will undoubtedly requires the highest sanitation priority with preferably full wastewater collection and treatment which is also the case for developed cities like Shanghai, Seoul and Tokyo (Kazmi and Furumai, 2005). Other big cities like Bangkok, New Delhi, Jakarta and Manila face the general problem of having an insufficient sewer collection system which makes the sanitation task very complicated: Constructing a sewer network in an overpopulated asphalted city with limited economic ability is nearly impossible due to the huge investments it would require. This leads to many diffuse wastewater discharges to the nearest available recipient with little or no treatment before the discharge. Septic tank solutions are very common in such situations and it is probably the best feasible alternative if sewage infiltration and sludge collection are managed well (Harada *et al.,* 2008, Wibisono *et al.,* 2003, Nowak *et al.,* 2003). However, in many cases the septic tank solution is not at all managed well with insufficient or no sludge removal resulting in a very inefficient COD removal from the septic tank process. In a Vietnamese case study Harada *et al.*, (2008) found that 89.6% of septic tanks in Hanoi had never been emptied resulting in a high pollution discharge in seepage liquor that builds up infectious pathogens in ground water and local recipients.

More stringent discharge standards and enforcement of environmental laws are evidently necessary to improve sanitation conditions in both highly populated areas and rural communities. Where decentralized wastewater treatment is needed a variety of technical solutions are available ranging from low tech stabilisation ponds and anaerobic treatment systems or constructed wetlands to more advanced and efficient biological aerated systems being the most recognized and efficient way to reduce organic matter and nutrients to low concentration levels. Many investigations have documented this variety of small-scale technical wastewater treatment options, e.g. Ho, (2003), Otterpohl *et al.*, (2003), Langergraber *et al.*, (2007) and Massoud *et al.*, (2009). The choice of technology seems to be a compromise between cost of technology, complexity of operation (O&M), space limitations, flexibility of adapting the technology and required efficiency of the treatment process (Brissaud, 2007, Park *et al.*, 2003). The tendency seems clear that richer regions in developing countries with close to two-digits GDP values now require more efficient installations to pre-treat or full-treat wastewater efficiently which will increase the demand for pre-fabricated modularized systems that are easy to install, upgrade or even move around. But it is also evident that such installations have to be affordable and service friendly which makes local production and expertise an absolute necessity.

Biofilm reactors for wastewater treatment

Small automated wastewater treatment plants based on biofilm technology (also referred as "Package plants", Daude & Stephenson, 2003a) can be used in cases with daily and weekly fluctuations in flow and composition of wastewater. Biofilters have proven to be very suitable for this purpose due to the efficient attachment of biomass, efficient handling of load variations and their ability to treat very cold wastewater without losing its nitrifying capacity (Boller *et al.* 1994, Larrea *et al.*, 2003, Daude & Stephenson 2003b, Park *et al.*, 2003). Wastewater can be treated low in nitrogen and BOD concentrations and some biofilters types offers extremely good polishing for removal of suspended solids which eliminates the need for secondary settling (Tschui *et al.*, 1994, Hansen *et al.*, 2007). In contradiction to constructed wetland installations biofilters can stand extreme variations in wastewater load with long periods of little or no incoming wastewater to the system as well as high variable inlet concentration of pollutants in wastewater. Hydraulic variations will not significantly affect the biological sludge detainment from the support media and the capacity of biofilm systems is often much higher than its daily average capacity due to its ability to develop a high and dense biomass concentration in the biofilm.

Biofilm processes also have some limitations that are essential to know. Diffusion of soluble substrate is the fundamental transport process that limits the reaction rate and even hinders important biological processes like nitrification because of overgrowth by the heterotrophs (Harremoës, P. (1978), Gönenc and Harremoës, 1990). The consequence of diffusion limitation for the biofilm process performance is typical a need for higher oxygen concentrations in the bulk water as compared with activated sludge processes (in case of aerobic processes) and sufficient mixing in order to avoid too significant liquid film diffusion near the surface of the biofilm (Janning *et al.*, 2004). Consequently, the energy consumption is typically higher as compared to e.g. activated sludge treatment but with a much higher degree of robustness and flexibility in both centralized and decentralized installation situations (Hansen *et al.*, 2007). Phosphorous removal in biofilters systems can be achieved by chemical precipitation but not as efficiently as e.g. by sandfilters and activated sludge systems (Hellström and Jonsson, 2003, Hansen et al., 2007). Biological phosphorous removal in biofilters has been achieved (Falkentoft *et al.*, 1999) but has never been commercially implemented due to the complexity of the process.

Material and Methods

Experimental setup

This study represents the test of a small-scale wastewater treatment plant based on biological aerated biofilm technology (submerged biofilters) developed to purify wastewater for reuse purpose. The treatment system is developed by Biokube A/S – a Danish manufacturer of small scale pre-fabricated WWTP modules based on biofilm technology. Modules range from capacities between 1 to 150 m^3/d and by connecting WWTP modules even higher capacities can be achieved to treat household family wastewater, wastewater from small communities and wastewater discharged from small- and medium sized enterprises (SME).

The test was conducted in China in collaboration with Suzhou Sewage Administration (SSA) who is a wastewater planning office and advisor for the Government of Suzhou in matters related to research and development of new and emerging technologies for wastewater treatment. SSA was interested in testing a decentralized compact wastewater treatment concept that could meet the Chinese wastewater discharge standard (GB18918-2002, Class 1 A) for treating public toilet point source in the city and as a solution for wastewater treatment in suburban areas with insufficient sewer system coverage and recipient discharge locations.

The biological reactor used in this test contained 4 separated biofilter chambers (serially connected) each equipped with aeration of the biofilm media (Expo-Net Bioblok). The specific surface area of the biofilm media was 100 m^2/m^3 in chamber 1 and 2 and 200 m^2/m^3 in chamber 3 and 4. Detached biofilm and suspended matter from the wastewater were then removed in separate sedimentation chambers that were located after each aeration chamber. All technical equipment (blowers, PLC, timers etc.) were located in a special, sealed dry compartment and the bottom of the reactor contained a 1.2 m^3 inlet pump well designed to equalize wastewater flow and concentration fluctuations.

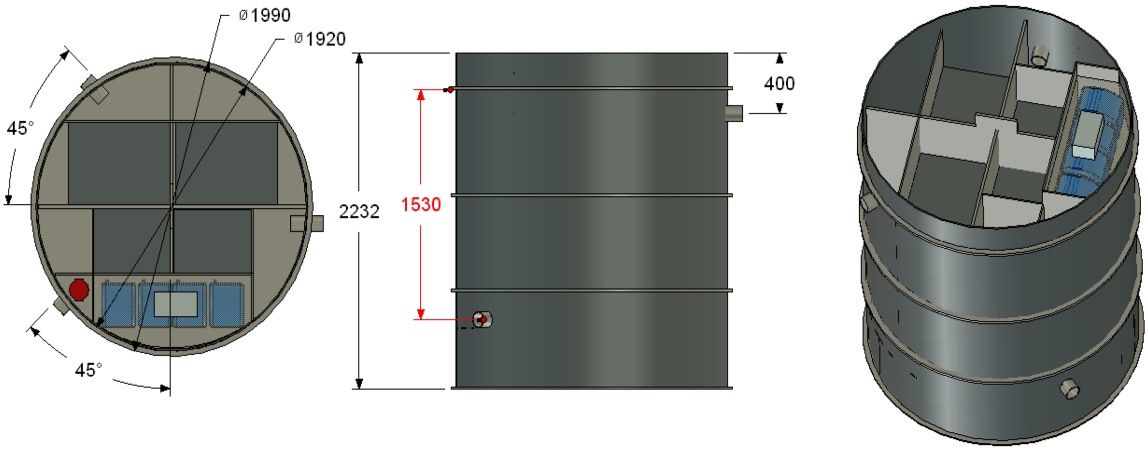

Figure 1.1 Illustration of the biological reactor (Biokube Mars 3000, capacity equals wastewater generated from 40 persons, PE).

The biological reactor (designated Biokube Mars 3000) was designed to treat wastewater from 40 PE equivalent to 2.4 kg BOD_5/d and 0.5 kg N/d in an aerobic biological system. Denitrification could be obtained partly by recirculation in the system. Phosphorous removal by chemical precipitation was feasible but was not included in this test for practical reasons. The flow through the reactor would be adjusted in the range between 0-12 m^3/d by timer control of the inlet pump. The Biokube Mars 3000 has typically been used to treat wastewater from hotel complexes, small schools and communities. It is a fully automated installation without any regular presence of staff and it functions with only one or two technical visits per year.

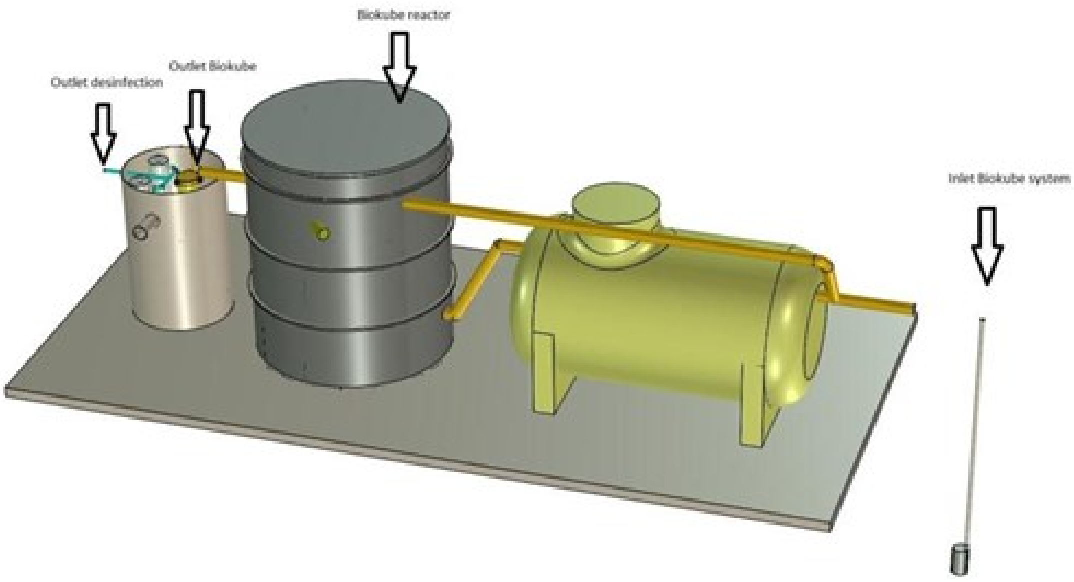

Figure 1.2 Experimental setup in Suzhou, China.

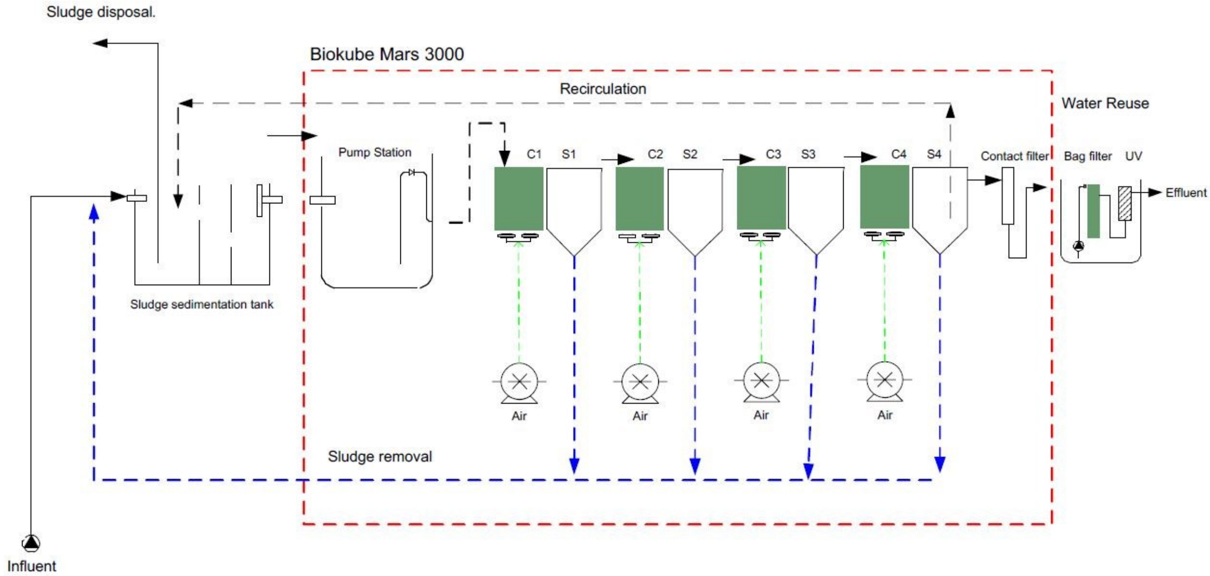

Figure 1.3 Flow diagramme through the complete Biokube system.

The experimental setup in Suzhou consisted of a 3 m^3 pre-sedimentation sludge tank, a 6 m^3 biological reactor (Biokube Mars 3000) and a 1 m^3 disinfection holding tank designed to purify biologically cleaned wastewater to be reused. Municipal wastewater from a public pump station was first pumped into the pre-sedimentation tank and was then running into the biological reactor by gravitation. Sludge was pumped out every 24 hours from the sedimentation chambers of the biological reactor and back into the pre-sedimentation tank via recirculation. All operations (pumping time, aeration, recirculation and sludge pumping) were controlled by timers in a microprocessor that could be adjusted via a Bluetooth mobile phone program on site. The purpose of the experiment was to test the robustness and performance of the Biokube installation during a one year period with low and high temperatures. Furthermore a newly developed integrated bag filtration and UV system was tested to demonstrate its efficiency to remove Faecal Coliform bacteria in order to meet Chinese Standards for urban water reuse (GB/T18920-2002) and farmland irrigation (GB20922—2007).

Measurements and analysis

The installation was commissioned in November 2011 and inoculation of the biofilm media was initiated until February 2012 after which sampling and analysis of wastewater in and out of the system began. The following parameters were all measured regularly every 1 or 2 weeks according to Chinese National Standards for water quality determination: Chemical Oxygen Demand (COD_{Cr} HJ/T399-2007), 5-day Biological Oxygen Demand (BOD_5, HJ 505-2009), total phosphorous (GB 11893-1989), total nitrogen (HJ 636-2012), nitrate (NO_3-N, HJ/T 346-2007), ammonia (NH_4-N, HJ/T 346-2007), suspended solids (SPJ/FB03-2012) and pH (CJ/T 51-2004). Temperature and oxygen concentration were measured by an online oxygen meter and Faecal Coliform bacteria were measured periodically during the testing of the water reuse system (Water quality determination of faecal coliform manifold zymotechnics and filter membrane, standard no.: HJ/T347-2007).

Results and Discussion

The experimental period was started up in February 2012 after the inoculation of the biofilter media was completed, and the wastewater flow to the system was then gradually increased until April 2012 where the system most of the time was loaded with the maximum possible flow (12.5 m^3/d). Wastewater is generally more diluted in China compared to Europe which makes the load of organic matter and nutrients lower than expected. The Biokube Mars 3000 was designed to be loaded with 2 kg COD/d (full nitrification) or 8 kg COD/d (no nitrification), but even with a maximum flow the average COD load was typically 2-3 kg COD/d. In some periods peak loads around 5-6 kg COD/d were achieved with no negative influence on the heterotrophic and autotrophic process stability. On average the removal efficiency of COD and BOD was in average 86% and 92% respectively – highest efficiency was obtained when the load was highest which indicate that the maximum removal capacity of organic matter was never reached. Most of the time the most stringent Chinese wastewater Discharge Standard (GB18918-2002, Class 1A) could be reached even when the wastewater temperature dropped below 5°C (January 2013).

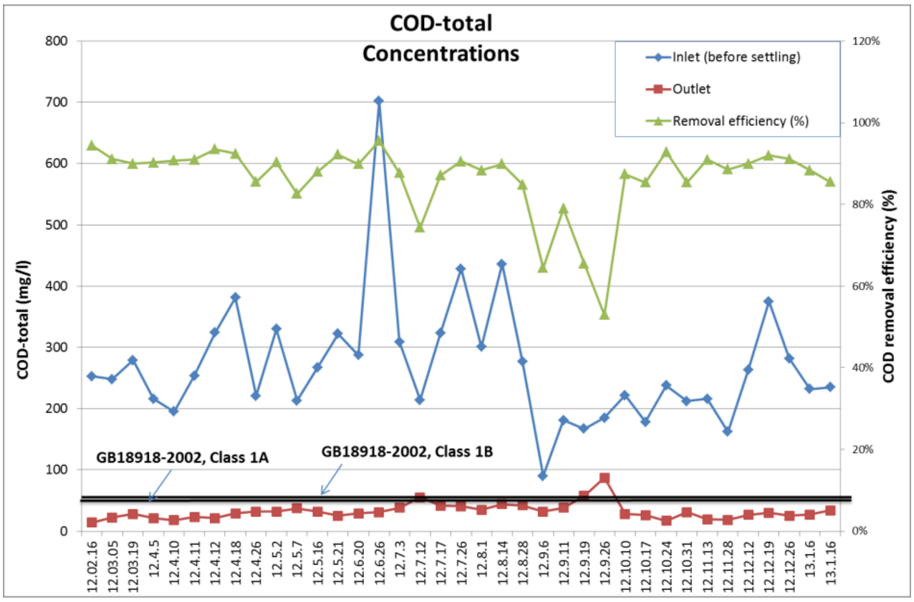

Figure 1.4 COD removal in the Biokube system.

Most of the time nitrification was very efficient with more than 95% removal efficiency and the average surface specific ammonia removal rate in the 4 chambers of the Biokube reactor was observed to 1.0-1.2 g NH_4-N/m^2/d down to 6°C. Apparently water temperatures lower than 5°C started to inhibit the nitrification process which was seen in January 2013 when the outlet ammonia concentration from the Biokube reactor reached 15 mg NH_4-N/l (figure 1.5).

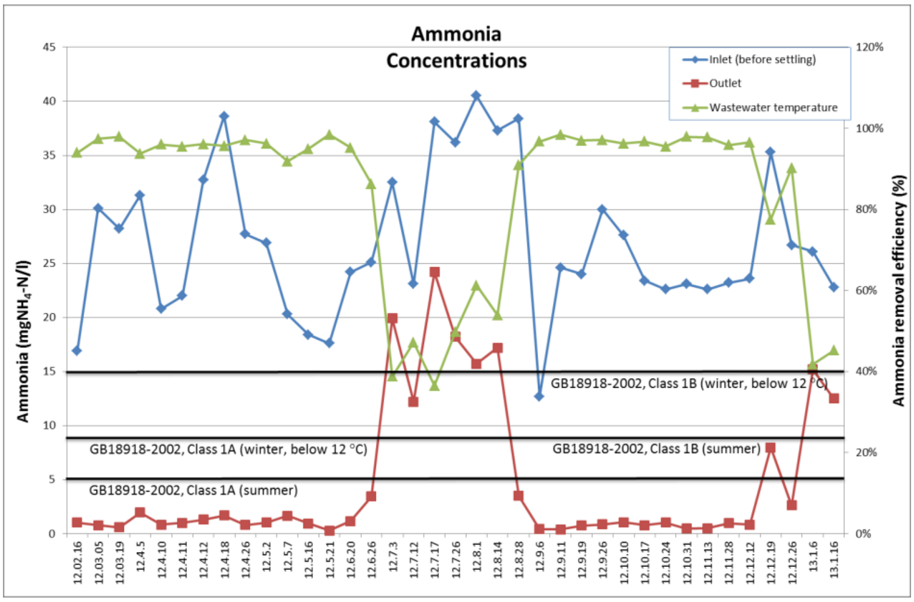

Figure 1.5 Results of ammonia removal in the Biokube system.

During the summer the pre-sedimentation tank was accidently not emptied for sludge, which presumably resulted in high sulphide formation that inhibited the nitrification process. During this period the organic load was at its highest and the wastewater temperature reached 32°C. For practical reasons the pre-sedimentation tank was much smaller during this experiment than the normal design practice consequently required much more frequent sludge removal activity. The incident clearly showed that it is important for the nitrification process stability to avoid overflow from the pre-sedimentation sludge tank and it is consequently necessary to operate the system with a sufficiently large sludge holding tank if sludge cannot be removed on a regular (weekly) basis.

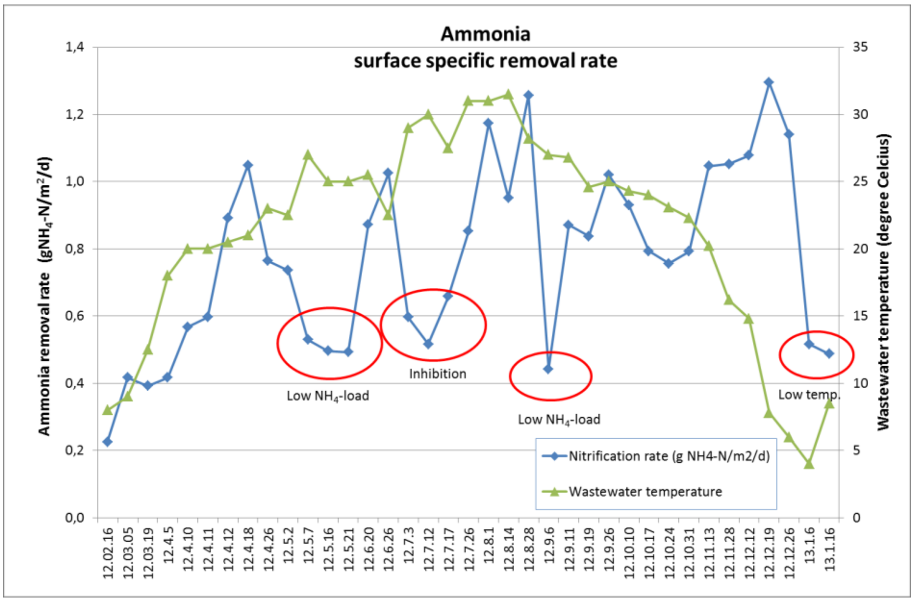

Figure 1.6 Specific ammonia removal rate and water temperature during the test period.

The total nitrogen (TN) removal by denitrification was quite significant in spite of the fact that the biological process was strictly aerobic (typically 6-8 mg O_2/l in chamber 1-4). The TN removal was achieved by the relatively small recirculation (40% of the incoming flow) that was pumped periodically from the last sedimentation zone to the pre-sedimentation tank. This recirculation not only reduced the nitrogen content, it also inhibited sulphide production in the pre-sedimentation tank and was responsible for a part of the reduction of COD which was partly removed by denitrification. Normally, a 70% total nitrogen removal can be achieved in such systems but in this case the nitrogen reduction was determined to 50-60% due to the relatively low recirculation and too small pre-sedimentation tank that was used for the experiment.

Analysis of the biological performance with sequential aeration in chamber 1

In order to test potential measures for saving energy experiments were carried out with sequential aeration in the biofilter chambers of the Biokube reactor. One investigation tested the effect of turning aeration on and off in chamber 1 for certain periods. The experiment was planned over one week where different degrees of aeration were introduced every day and the process performance (COD removal and nitrification) was then determined in each chamber the next day. The aeration was turned on and off in 5 minute cycles beginning with full aeration the first day, and then the aeration time within the 5 minute interval was changed in the following way: day 2: 1 minute pause and 4 minute air, day 3: 2½ minute pause and 2½ minute air, day 4: 4 minutes pause and 1 minute air, day 5: no air. Each day, before the aeration cycle was changed, oxygen concentration was measured in chamber 1 and samples were taken in each of the 4 chambers in order to determine the efficiency of COD removal and nitrification in each chamber. The water temperature during this investigation was measured to 22°C and the flow to the Biokube reactor was 7.5 m^3/d.

The results showed a surprisingly predominant nitrification in chamber 1 in spite of the gradually reduced air supply (figure 1.7). The total surface specific removal rate of ammonia was determined to 2.5 g NH_4-N/m^2/d, while the maximum COD removal rate in the same chamber was very high, almost 50 g COD/m^2/d. Knowing that a part of the ammonia is consumed in the heterotrophic activity, it could be estimated that 60% of the ammonia removal was removed by nitrification. The results indicate that it is possible to achieve both a high heterotrophic activity and a significant nitrification in the same biofilm. This is somehow in contradiction to other investigations that showed a rapidly declining nitrification activity when the BOD_5 concentration exceeds the level of oxygen concentration in the bulk. When the BOD_5 concentration is five times higher than the oxygen concentration, nitrification should be 100% inhibited (Gönenc and Harremoës, 1990). In this investigation, the BOD_5/O_2 ratio in the first chamber varied between 3-10 while the air was still supplied and a significant nitrification (1.5 g NH_4-N/m^2/d) was achieved even with just 20% aeration time. It is believed that a combination of good biofilm control, efficient aeration and turbulent mixing in each chamber gives almost perfect conditions for the microorganisms in the biofilm with little effect from liquid film diffusion, which is important for the nitrifying bacteria located in deeper zones of the biofilm.

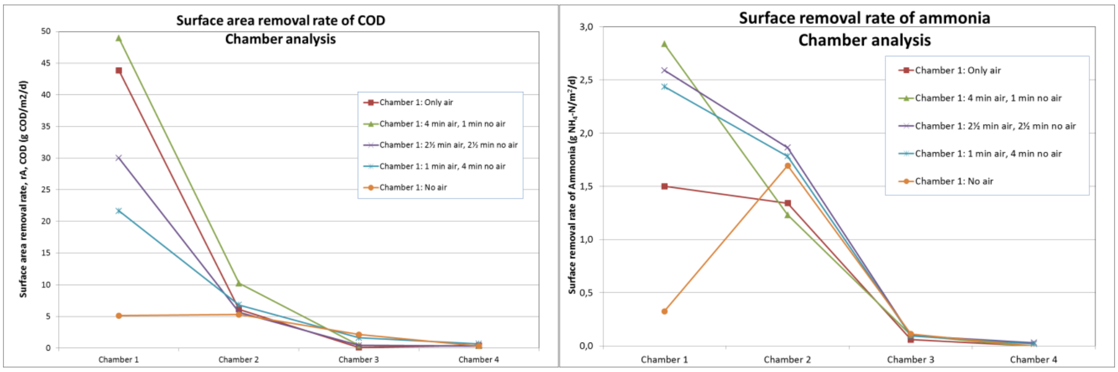

Figure 1.7 Results of COD and NH_4 removal in chambers of the Biokube reactor.

The investigation also demonstrated that in this case the first two chambers (which carried 40% of the total biofilter area) were responsible for the most significant biological activity. Apparently the process is limited by the oxygen concentration level in chamber 1 but already in chamber 2 limited by the ammonia concentration with the load applied in this case.

The study shows that the Biokube Mars 3000 system probably has a much higher nitrification capacity than expected because it is normally assumed that full nitrification will only take place in chamber 3 and 4 as a result of the competition between heterotrophs and autotrophs for oxygen.

Upgrading biologically cleaned wastewater for water reuse purpose

A part of the objective of this investigation was to develop a simple filtration and UV system that could remove Faecal Coliform bacteria (FC) from the biologically purified wastewater. Knowing that China has a very uneven distribution of water resources with water scarcity in the Northern part of China most of the year, it was relevant to investigate the technical and economic implications of upgrading the wastewater quality for reuse purpose. The most critical parameter in this aspect was the concentration of Faecal Coliform bacteria. The normal wastewater disinfection practice in China is to use chlorine but the purpose of this project was to demonstrate that a more environmentally friendly technical solution could be a feasible alternative.

The solution used consisted of a 1 m^3 reservoir tank where cleaned wastewater from the Biokube reactor constantly passed by gravitation. In this tank an integrated bag filter unit (10 μm filter) and low-pressure UV lamps were installed with a pump that could be started when water needed to be tapped for various reuse purpose (irrigation, car wash, toilet flushing, road cleaning, construction work etc.). Analysis showed that FC could be removed efficiently by the UV system but the bag filtration is essential for the efficiency of the UV radiation to ensure efficient elimination of FC.

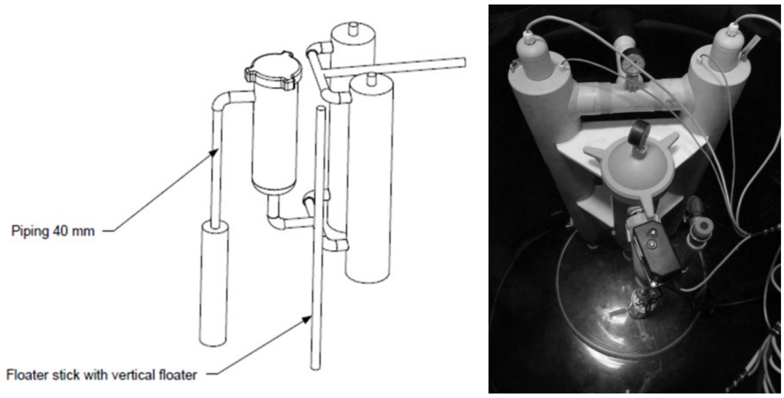

Figure 1.8 Combined bag filtration and UV treatment unit submerged in a 1 m^3 holding tank developed for FC removal of biologically cleaned wastewater.

Operational expenses for aerobic biological wastewater treatment and water reuse

In order to determine the economic implications of operating a biologically aerated biofilter with water reuse functionality, the direct expenses have been evaluated (table 1.1). The direct operational expenses for biological wastewater treatment involved sludge removal (and disposal), power consumption and eventually use of precipitation chemicals in case of phosphorous precipitation (information given by Biokube A/S). The direct costs of upgrading wastewater for reuse involved consumption of bag filters and electricity for pumping and UV.

Table 1.1 List of operational consumption expenses required for aerobic biological wastewater treatment and water reuse

Operation	Consumption	Unit	Assumptions
Sludge removal	5.4-11.1	l wet sludge/m^3 wastewater	Sludge concentration in sedimentation tank: 1.5% SS
Electric consumption	0.8-1.1	kWh/m^3 wastewater	12-20 m^3/d, full nitrification
Precipitation chemicals (phosphorous removal)	0.4	l PAX/m^3 wastewater	Total phosphor < 1.0 mg TP/l in outlet
Bag filtration	500	m^3 wastewater/filter bag	Pleated filter bags, 2,500 g SS/bag. SS detainment: 50%. SS concentration in wastewater before filtration: 10 mg SS/l
UV incl. pumping	0.21	kWh/m^3 wastewater	40 m^3/h, 16,000 hours UV lifetime. End capacity of UV: 25 mJ/cm^2 Transmission: 70%

Conclusions

Tests with small-scale pre-fabricated biofilter wastewater treatment plants show that such small installations are suitable for unmanned operation and efficient in terms of

COD removal and nitrification. Normally COD removal and nitrification process are separated as secondary and tertiary treatment process in the Biokube reactor which in practice means that the incoming wastewater will pass through several chambers with predominant heterotrophic activity in the first chambers and then autotrophic activity in the last chambers. This investigation has shown that high removal rates of both COD and ammonia can be achieved in the first biofilter chambers of the system, where the concentrations of these substrates are high due to efficient and turbulent aeration, which ensures a stable biofilm control and efficient nutrient transport to the surface of the biofilm. These findings change the understanding of the system and will lead to a change in design practice of such systems.

Construction costs are competitive compared to existing biological systems operating with aeration (activated sludge systems and biofilters), and the energy consumption is relatively low, 0.8-1.1 kWh/m^3 treated wastewater. The process is very robust to load fluctuations but regular service and sludge removal from the pre-sedimentation tank must be conducted timely, typically every 6 – 12 month depending on the scale of the system. An up scaling of this concept seems very suitable for decentralized wastewater treatment in rural and even in urban areas of China as an alternative to or in combination with constructed wetlands which is often the preferred technical solution.

Experiments with bag filtration and UV have shown that this technology is a good environmental alternative to chlorine addition if cleaned wastewater needs to be reused for various purposes, which Chinese laws allow. The estimated running cost of upgrading biologically cleaned wastewater to be reused corresponding to an additional 20% of the total running costs of biological wastewater treatment.

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Udvikling af decentrale systemer for sikker genanvendelse af renset spildevand i landdistrikter og forstæder til storbyer i Kina

Denne rapport indeholder resultaterne af projektet "Udvikling af decentrale systemer for sikker genanvendelse af renset spildevand i landdistrikter og forstæder til storbyer i Kina" gennemført i regi af Miljøstyrelsens/Naturstyrelsens tilskudsordning for Miljøeffektiv Teknologi 2010.

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