TS7-1

Restoration of Loch Leven: sustaining ecosystem services

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Keywords: Lake restoration; phosphorus; pesticides; BMPs; diffuse pollution; ecosystem services

ABSTRACT

The pollution and restoration history of Loch Leven has been variously described in earlier papers. The nature and basis of the controls implemented during the recovery period included work with a textile mill, and determining appropriate best practice discharge standards for the municipal sewage effluents. The regulatory effort included enforcement actions with various polluters in the catchment to raise awareness of the requirements for better quality in the tributary watercourses and hence the loch (lake). From the mid 1990s, awareness of the nature and importance of diffuse sources of pollution increased and a series of initiatives with local farmers, agricultural advisors and the River Purification Board (later SEPA) led to the establishment of a suite of diffuse pollution controls. Creativity in finding means to fund measures such as buffer strips and reduced nutrient additions was a feature of effective work during that period. Whilst an EQS approach to discharge standards to a tributary watercourse was taken, setting standards for discharges into the loch was more challenging, and a best practice approach was adopted. That was extended to measures to manage diffuse sources too. The experiences at Loch Leven subsequently informed the development of diffuse pollution regulations and strategy in Scotland.

1. INTRODUCTION

Loch Leven is the largest lowland lake (loch) in Scotland (13.3km^2) and is relatively shallow (mean depth 3.9m) with a large surface area in relation to its catchment[1]. Historically, water quality was good at the turn of the 20th century, but deteriorated as industrial development and increases in the size of the villages and town in the catchment, resulted in phosphate rich effluents draining into the loch. A condition of hyper-eutrophication developed, with varying periods of improvement followed by slippage in quality. The catchment of the loch is mainly mixed agricultural, with some forestry in the hills. Diffuse sources of nutrients became increasingly important as restoration efforts focused on the effluent discharges were successful, leaving diffuse pollution as the principal challenge.

Social and economic activities provided by the loch have included:

- Drainage and effluent disposal
- Nature conservation
- Angling (trout)
- Bird-watching (an RSPB reserve adjacent)
- Informal recreation (walking and cycling)
- Hydropower generation (downstream industries)
- Local economic benefits (tourism)

Ecosystem services (provisioning, regulating, supporting services and cultural) have been discussed in relation to Loch Leven by May and Spears[1], exploring the inter-related impacts of various factors and actions, including unintended consequences. The years of deteriorating water quality adversely affected the above in varying ways; perhaps primarily by establishing a public image of the loch as being badly polluted with health risks from toxic algal blooms and decomposing scum along the beaches. The realities were somewhat different, but the negative messages were consistently stated.

2. POLLUTION CONTROL ACTIONS

2.1 Pollution abatement strategy

There were 3 steps in the strategic approach to achieving reductions in pollution in Loch Leven:

a) Review existing discharge permits and use published environmental quality objectives for specified pollutants in effluents discharging to the tributary watercourses of the loch

b) Adoption of a pragmatic best practice approach to P-removal at municipal sewage treatment works (STWs), and to the control of diffuse pollution sources across the landscape.

c) Support continuing monitoring of the loch and seek evidence of consequential improvements; that required development of strategic water quality goals for the loch.

2.2 Pollution abatement at major point sources

The first step was to seek compliance with the discharge limit for P which had been agreed some years earlier at the textile mill in Kinross, and to begin a review of the permit to also cover moth-proofing chemicals and toxic metals. Enforcement action was taken, followed by a strategic decision at the mill in relation to P use, which since 1987 has made the mill typically no more relevant to P issues in the loch than any other business. Subsequently, new discharge limits were agreed which precluded use of moth-proofers, and protected the S. Queich (and hence the loch too) from pollution from toxic metals. The review also reduced the permit P limit to 2 mg/l, consistent with new limits being agreed for the remaining discharges by then[2]. Prior to the actions at the mill, that P load had been estimated at 30.6% of the external load of total P into the loch[3].

In parallel with the work at the Mill post 1985, the effluent discharges from STWs in the catchment were re-appraised. The principal discharge was from Kinross North STW; a relatively new works designed to remove as much P as was possible by conventional treatment with enhanced sedimentation. Wedge wire screens in the final clarifier polished the effluent to a high standard (limits were for BOD, ammonia and total suspended solids; indirect benefits for P-removal). A 2,000 population septic tank input from South Kinross was draining directly into Loch Leven in 1985; transferring that input for treatment to Kinross North was a priority and achieved as the first stage of STW progress (agreed for some years prior to the review post 1985, and already in the capital programme of the water utility (Tayside Regional Council, then East of Scotland Water, later part of Scottish Water). That action addressed a TP load of 6.7% of the total external TP budget in the 1985 study (Bailey Watts *et al* 1987). Two other sewage discharges comprised the rest of the major point source inputs: Kinnesswood - a village on the east side of the loch; and Milnathort, the second largest village in the catchment and served by an old combined sewer network and an old treatment works. A new works was completed for Milnathort, designed with P-stripping, in 1995[4], and Kinnesswood was pumped to the neighbouring village which was just outside the loch catchment (discharging to the Leven Valley Sewer) [1]. The standards for TP in the sewage discharges (2mg/L) were determined by participating in a European workshop on appropriate best practice discharge standards for municipal sewage effluents. The regulatory effort included enforcement actions with various polluters in the catchment to raise awareness of the requirements for better quality in the tributary watercourses and hence the loch. That work included a focus on combined sewer overflows and pumping station discharges too.

2.3 Managing diffuse pollution

From the mid 1990s, awareness of the nature and importance of diffuse sources of pollution increased and a series of initiatives with local farmers, agricultural advisors and the River Purification Board (superseded by SEPA) led to the establishment of a suite of diffuse pollution controls[5]. A national 'Buffer Strips Initiative' was launched by the partnership, and Loch Leven tributaries became part of that. Creativity in finding means to fund measures such as buffer strips and reduced nutrient additions was a feature of effective work during that period. Evidence of the efficacy of those measures was published in 2006[4]. Nutrient budgets were important and popular with farmers.

2.3 The impact of 'Scum Saturday', 1992

13th June 1992, became known locally as 'scum Saturday' when an algal bloom at Loch Leven coincided with a major nature reserve open day and attracted a lot of media attention. A combination of anglers and locals formed an action group. The statutory bodies involved, together with the loch owner and the principal scientific research organisation at that time working on the loch (now CEH), responded by forming a Loch Leven Area Management Advisory Group (LLAMAG) in 1992. Of several options identified, the principal options were P-stripping (£2M) and diversion of the town effluents around the loch into the Leven Valley sewer (£3.2M). There can be little doubt that the crisis accelerated agreement on the implementation of P-stripping at public STWs (Kinross was the first town in Scotland to have this retrofitted).

3. SUSTAINING ECOSYSTEM SERVICES

The improvements in water quality began to restore the reputation of the loch. A walking/cycling trail around the loch was completed and attracts many visitors and locals. Numbers of visitors to the RSPB bird reserve have increased from 40,000 p.a. to 70,000. The Mill has allowed access through their property for the trail and re-opened a shop and café. Two additional café/restaurant developments have grown significantly too. The Mill has strengthened its position in international markets and has had a positive environmental impact on suppliers as well. Biodiversity has greatly recovered in the loch. Conversely, the native trout fishery[1] has been greatly reduced in size, as a business decision by new managers of the estate.

4. DISCUSSION

The intervention of a crisis into the abatement decision-making process had consequences. The urgency cut-short consideration of long term benefits of diversion, with its advantage of total reduction and allowance for population increases and growth in influent loads. Often limited or false information was seized upon in the press. The main beneficial consequences were the acceleration of actions to reduce the sewage P-load, and to support for diffuse pollution partnerships with farmers and their advisors[4]. Efforts to persuade local authority planners to target sewered areas for development instead of piecemeal development in the rural areas largely failed. The belief that treatment technology should prevent a problem, ignores widespread professional experience of small private treatment systems. For the main water utility STWs, the discharges are well within limits; should their concentrations be allowed to rise? Should there be an upper limit to growth of the settlements? Abatement success brings new challenges too; tourist facilities need to consider P losses more effectively.

5. CONCLUSIONS

A mixture of approaches needs to be used for pollution prevention and control, and these have been well demonstrated in Loch Leven:

1. Environmental goals need to be simple and clear
2. Cessation of a discharge in perpetuity is better than investment to achieve a percentage reduction by a treatment process.
3. Setting discharge limits based on published environmental quality standards for tributary rivers and streams, rather than allowing piped effluents into the lake, provided better control of pollution for the lake than setting limits based on debatable in lake mixing zones and dilution concepts (c.f. coastal water discharge practices).
4. For industry, environmental improvements are consistent with business efficiency and cleaner technology.
5. Many pollution incidents are avoidable; fair and reasonable enforcement actions are often needed to underline the importance of environmental protection in a community or catchment.
6. Good will from local business sectors, the public, and the water utility and local council, can accelerate progress beyond the scope of regulatory actions. Catchment management plans are one mechanism to achieve that.
7. People in a lake catchment respond well to a campaign or initiative, since they identify with their local rivers and lakes. That is especially important for diffuse pollution control, which relies on widespread uptake of best practices.
8. The sewered catchments of Milnathort and Kinross, drain to modern STWs with P-removal; those areas are therefore preferable for development to areas outside those sewered areas, when allowing development in the lake catchment.
9. Drainage from Kinnesswood and Scotlandwell is pumped into the Leven Valley Sewer, discharging after treatment into the Firth of Forth. That is therefore the least impact area for development, as long as it is connected to the sewer.
10. Success brings new challenges; tourism.

REFERENCES

[1] L. May and B.M. Spears: Loch Leven: 40 years of Scientific Research. Developments in Hydrobiology 218, Springer, 2012.

[2] BJ D'Arcy (1991) Legislation and the control of dye-house pollution, Journal of the Society of Dyers and Colourists, 107: 387-389

[3] AE Bailey-Watts, R Sargent, A Karika, M Smith *Loch Leven phosphorus loading.* Report to Department of Agriculture and Fiheries for Scotland, Nature Conservancy Council, Scottish Development Department, and Tayside regional council. Institute of terrestrial Ecology, Edinburgh

[4] BJ D'Arcy, May L, Long J, Fozzard IR, Greig S and Brachet A. The restoration of Loch Leven, Scotland, *Water Science Technology*, 53: 183-191 (2006).

[5] BJ D'Arcy, CA Frost: The role of best management practices, *Science of the Total Environment*, Vol. 3, pp. 412-415, 2002

TS7-2

A perspective on water environment management in Japanese lakes

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Keywords: environmental water quality standards, COD_{Mn}, bottom dissolved oxygen, climate change

ABSTRACT

The management of water environment in Japanese lakes and reservoirs started in 1970's by the environmental water quality standards (EWQS) such as COD_{Mn} to prevent serious problems in water uses caused by organic pollution. Effluent regulations were also started by the Water Pollution Prevention Act to satisfy with the standard. However, percent compliance of the EWQS on COD_{Mn} did not improve and various problems associated with eutrophication were reported. Additional EWQS and related effluent regulations both for nitrogen and phosphorus started in 1982 to cope with eutrophication. Also, the Law Concerning Special Measures for Conservation of Lake Water Quality (1984) was enacted to control non-point sources, to regulate total loading of pollutants and to protect lakeshore ecotone vegetation. However, only a half of lakes and reservoirs could satisfy with the EWQS even in 50 years. Also, COD_{Mn} increased in some lakes irrespective of the reduction of loadings. The new EWQS on benthic dissolved oxygen concentration and littoral zone Secchi Disk transparency were enacted as new targets of comprehensive water environment management. Also, adaption to climate change is a new challenge in Japanese lakes and reservoirs.

1. ENVIRONMENTAL WATER QUALITY STANDARD FOR LAKES AND RESERVOIRS

Japanese management for water environment started by the adoption of the environmental water quality standards (EWQS) in 1970s. EWQS define desirable quality of environmental water necessary and sufficient for various water uses based on the Basic Law for Environment and are administrative targets and criteria for promotion of comprehensive measures to cope with water pollution.

Table 1 shows one of EWQS for lakes and reservoirs to conserve living environment, i.e. to protect all the water uses for daily human life and the living environment for aquatic plants and animals closely related to human life[1]. The following are examples of definitions of the water uses in the table on drinking water supply:

>class 1 – can be treated by simple purification process such as filtration

>class 2 – can be treated by conventional purification processes such as coagulation, sedimentation and filtration

>class 3 – can be treated by advanced water purification processes with pretreatment.

In the EWQS, the most important parameter to be achieved has been COD_{Mn} to cope with organic pollution.

2. EFFLUENT STANDARDS

Regulations of wastewater discharge into public water bodies from the specified facilities started by the Water Pollution Prevention Act to satisfy with the EWQS[2].

Table 1 EWQS for Lakes and Reservoirs (mg l^{-1}, volumes > 10 x 10^6 m^3)

category	water use	pH	COD_{Mn}	SS	DO
AA	water supply class 1, fishery class 1, conservation of natural environment, and uses A-C	6.5-8.5	1	1	7.5
A	water supply class 2 and 3, fishery class 2, bathing, and uses B-C	6.5-8.5	3	5	7.5
B	fishery class 3, industrial water class 1, irrigation water, and use C	6.5-8.5	5	15	5.0
C	industrial water class 2, conservation of environment	6.0-8.5	8	No floating matters	2.0

The effluent standards are uniform and national minimum criteria on effluent quality being applied for facilities with daily discharge more than 50 m^3. Local, i.e. prefectural governments, therefore, can enact more rigorous standards than the national standards by local ordinance if the national standards are not enough to satisfy with the EWQS for local waters.

3. WATER QUALITY IMPROVEMENT

The comprehensive efforts to control wastewater discharges resulted in the improvement of water quality. As shown in Fig.1, water quality in rivers improved and percent compliance on BOD significantly increased from ca. 50% in 1970s to more than 95 % in recent years[3]. However, those for lake and reservoirs on COD are not satisfactory. They remain between 40 % and 60% showing little improvement irrespective of the similar regulation for wastewater discharge.

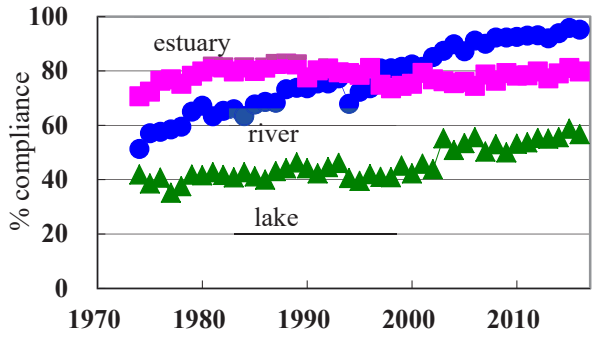

Fig. 1 Percent compliance for EWQS

4. EUTROPHCATION CONTROL

The fact that little improvement both in lakes and estuaries suggested that internal production of COD, i.e. organic production in receiving water by primary production of phytoplankton, is responsible for the non-compliance of EWQS in COD. Also, typical phenomena in eutrophication such as water bloom formation by cyanobacteria and sand-filter clogging in drinking water treatment plant have been reported. Nutrient control, therefore, is necessary in addition to organic pollutants. Additional EWQS and effluent regulations both for nitrogen and phosphorus started in 1982 to cope with eutrophication as shown in Table 2.

Fig. 2 shows percent compliance for EWQS on T-N and T-P in lakes and reservoirs. They are less than 20 % for lakes where EWQS on T-N are applied. Other lakes with T-P and both T-N + T-P are applied are also low and show little improvement irrespective of nitrogen and phosphorus regulation for wastewater discharge.

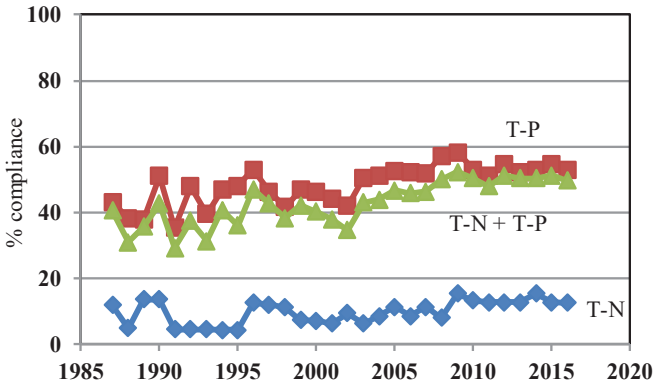

Fig. 2 Percent compliance for EWQS on T-N and T-P

In addition to the effluent regulations, the Law Concerning Special Measures for Conservation of Lake Water Quality (1984) was enacted to control non-point sources, to regulate total loading of pollutants and to protect lakeshore ecotone vegetation. However, only a half of lakes and reservoirs could satisfy with the EWQS on COD even in 50 years. Also, COD_{Mn} increased in some lakes irrespective of the reduction of both organic and nutrient loadings.

Table 2 EWQS on nitrogen and phosphorus for Lakes and Reservoirs (mg l^{-1})

category	water use	T-N	T-P
I	Conservation of natural environment, and uses listed in II-V	0.1	0.005
II	Water supply classes 1, 2, 3 ((except for special types), fishery class 1, bathing, and uses listed in III-V	0.2	0.01
III	Water supply class 3 (special types), and uses listed in IV-V	0.4	0.03
IV	Fishery class 2, and uses listed in V	0.6	0.05
V	Fishery class 3, industrial water supply, irrigation, conservation of living environment	1.0	0.1

Table 3 EWQS on benthic dissolved oxygen (DO) concentration (mg l^{-1})

category	designated use	DO
Habitat 1	・Area to protect and restore habitats for adult species sensitive for low DO ・Area to protect and restore habitats for species sensitive for low DO in reproductive stages	4.0
Habitat 2	・Area to protect and restore habitats for most adult species except for sensitive species for low DO ・Area to protect and restore habitats for most species in reproductive stages except for sensitive for low DO in reproductive stages	3.0
Habitat 3	・Area to protect and restore habitats for adult species tolerant for low DO ・Area to protect and restore habitats for species tolerant for low DO in reproductive stages ・ Area for the survival of most tolerant benthic organisms	2.0

5. EWQS ON BENTHIC DISSOLVED OXYGEN AND TRANSPARENCY

The comprehensive efforts for more than 50 years to restore lake water environment, however, cannot satisfy with the EWQS, i.e. lake environment is not satisfactory. Fishery production remains low compared to 1960s and has not recovered yet. Also, wide and frequent anoxia in lake bottom have been reported. Many circles claim that the current EWQS was good to remediate serious water pollution in 1970s, whereas they might not be appropriate as targets of the current management of lake water environment.

The Japanese government started to reconsider the current EWQS and proposed new EWQS for the better management of water environment. The new EWQS have two parameters on water quality, i.e. dissolved oxygen concentration (DO) at the bottom to secure survival and reproduction of aquatic organisms (Table 3) and littoral zone Secchi Disk transparency (SD) as local criteria for the conservation and restoration of submerged vegetation and recreation.

Designation of water area types for benthic DO in lakes will be discussed based on expected fish species for conservation. Different from COD, T-N and T-P where the same parameters were applied for effluent regulation, DO standard may require effluent regulations on organics and/or nutrients depending on local conditions.

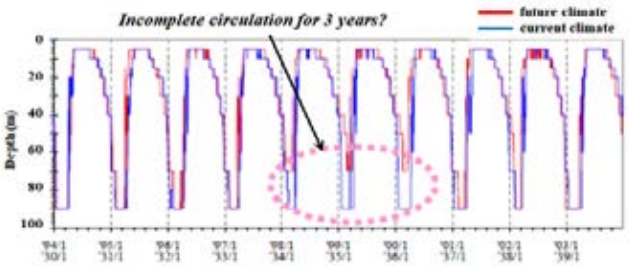

Fig. 3 Predicted incomplete circulation in the Lake Biwa

6. CLIMATE CAHNGE: ADAPTAION IN LAKES

It is well known that global surface temperature will increase several degrees and current climate will be changed in near future. Although various measures have been proposed and carried out to prevent the change, it is well known that the increase and change will be inevitable.

In addition to these mitigation, i.e. decrease in greenhouse gases emission, therefore, measures for adaptation has been studied in three Japanese lakes[4].

Changes in water temperature and precipitation were not significant in the Lake Biwa even in the most pessimistic scenario, RCP 8.5. However, depths of overturn in autumn were predicted to decrease in some years and area of DO deficit in the bottom increased by a climate model as shown in Fig. 3. This may damage benthic fish population.

However, another climate model did not show any reduction of overturn depth. The more intensive studies are required to evaluate effects of climate change on lake ecosystem and efficient measures for adaptation.

REFERENCES

[1] Ministry of the Environment, Government of Japan: Environmental Quality Standards for Water Pollution, http://www.env.go.jp/en/water/wq/wp.pdf

[2] Ministry of the Environment, Government of Japan: National Effluent Standards, http://www.env.go.jp/en/water/wq/nes.html.

[3] Ministry of the Environment, Government of Japan: Results of the FY 2016 Water Quality Survey of Public Water Areas (in Japanese), http://www.env.go.jp/water/suiiki/index.html

[4] Ministry of the Environment, Government of Japan: Report for studies on effects of climate change on lake ecosystem and adaptation (in Japanese), 2018.

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水道原水として見た霞ヶ浦の水質について

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キーワード:浄水・排水処理技術

抄録

霞ヶ浦は茨城県企業局にとって重要な水道水源であるが，有機物やかび臭物質が他の水源に比べて高い傾向にあり，浄水処理をする上ではこれらの物質の低減化を図ることが大きな課題となっている。そこで，当企業局が実施してきた霞ヶ浦水源調査に係る，過去 22 年間のデータを 4 つのフェーズに分けて解析した結果，溶解性有機物は各フェーズで夏期に高くなり，フェーズが進むにつれて値が低くなる傾向であることがわかった。また，霞ヶ浦におけるかび臭物質は冬期から春期にかけて高濃度に発生するという特有の傾向が見られるとともに，ジェオスミンと濁度に正の相関があることが明らかとなり，かび臭物質の発生を予測できることが示唆された。全体的な傾向としては近年，最悪なフェーズから改善の傾向が見られるが，有機物やかび臭物質は他の水源より依然として高い傾向にあるため，今後も霞ヶ浦水源調査を継続し，霞ヶ浦の水質について注視していく考えである。

1.　はじめに

茨城県企業局は，全 10 浄水場で用水供給事業を行っており，2016 年4月から2017 年3月までの給水実績は約 1.3 億㎥となっている。この全 10 浄水場のうち6浄水場が霞ヶ浦を取水源としており，当局にとって霞ヶ浦は貴重な水源である。

一方，我が国の水道用水は，水道法において塩素消毒が義務付けられているが，その塩素が有機物と反応することにより，発癌性が疑われるトリハロメタンを生成する[1]。このため，トリハロメタンを生成する有機物を如何に低減するかが，水道事業体において大きな課題の一つであるが，霞ヶ浦湖水中の有機物は，河川等に比べ高い傾向にある。

また，水道原水中には藻類が多種存在するが，環境因子等の条件によって特定の藻類種がかび臭物質（ジェオスミン及び 2-メチルイソボルネオール（以下，「2-MIB」という）を産生する[2]。このかび臭物質の閾値は 5ng/L[3]と言われており，極微量でも水道用水中に含まれると苦情の原因となるため，この物質の低減がもう一つの大きな課題であるが，霞ヶ浦においては，このかび臭物質濃度も，他の水源に比べ高い傾向にある。

当局では 1965 年から霞ヶ浦の水質調査を行っているが，この様な背景を踏まえ，電子データとして整理可能であった 1995～2016 年の調査結果について解析を行ったところ，幾つか知見が得られたので報告する。

2.　霞ヶ浦水源調査概要

(1) 調査地点

霞ヶ浦水源調査は図 1 のとおり全 14 地点で実施しているが，当局が管理する浄水場のうち，日最大給水量が最も多い霞ヶ浦浄水場が取水している西浦の木原取水塔の水質調査結果について整理したものを報告する。なお，調査は 1 回/月の頻度で行った。

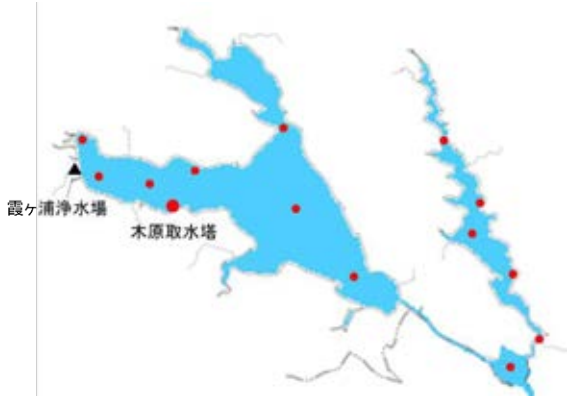

図 1 霞ヶ浦水源調査地点

(2) 調査項目

水温，水深，透明度，濁度，色度，過マンガン酸カリウム消費量，pH 値，電気伝導率，溶存酸素，浮遊物質，COD，溶解性 COD，アンモニア態窒素，亜硝酸態窒素，硝酸態窒素，総窒素，総りん，溶存りん，塩化物イオン，臭化物イオン，総アルカリ度，蒸発残留物，総硬度，総鉄，溶存鉄，総マンガン，溶存マンガン，溶性ケイ酸，クロロフィル a，TOC，DOC，2-MIB，ジェオスミン，E260，アルミニウム，溶存ア

ルミニウム，放線菌，藻類，ミクロキスチン-LR，トリハロメタン生成能

3. 解析方法

霞ヶ浦においては利水上の観点から，4月から 10 月中旬までは上限水位を Y.P.＋1.10m，11 月中旬から2月末までの期間は Y.P.＋1.30m として水位管理を行っていた。しかし，周辺環境への影響等を考慮し，2000 年 10 月からは全期間，上限水位を Y.P.＋1.10m で，2004 年 10 月からは，2月に Y.P.＋1.30m を確保し，それ以外の期間は Y.P.＋1.10m で管理するとの方針変更があった。また，西浦においては，富栄養化対策の一環として 1975 年から 2013 年4月まで底泥の浚渫工事を行ってきた[4]。

これらのことを鑑み，次のとおり4つのフェーズに分け，データ解析を行った。

フェーズ1：1996 年4月～2000 年 10 月

フェーズ2：2000 年 11 月～2004 年 10 月

フェーズ3：2004 年 11 月～2013 年4月

フェーズ4：2013 年5月～2017 年3月

4. 結果と考察

(1) 濁度の状況

各フェーズにおける濁度の経月変化を図 2 に示す。

濁度はフェーズ1・2に比べ，フェーズ3・4の方が低い傾向が見られており，水位管理による影響が示唆された。

更に濁度は，浚渫工事を終了したフェーズ4の方が，フェーズ3より低い値を示していることから，浚渫工事による影響が示唆された。

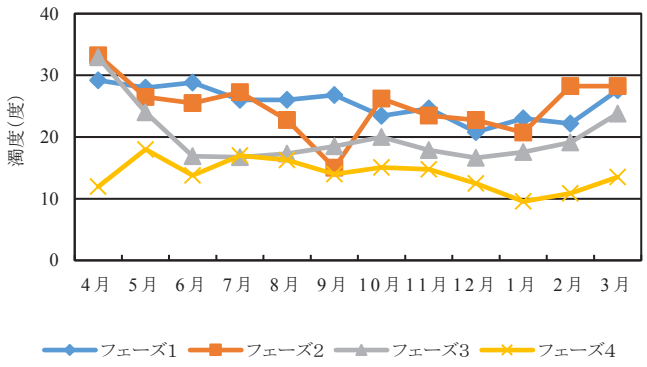

図 2 濁度経月変化

(2) 溶解性有機物及び臭化物イオンの状況

各フェーズにおける溶解性有機物の経月変化を図 3 に，臭化物イオンの経月変化を図 4 に示す。

溶解性有機物については，フェーズ1からフェーズが進むに従い，値が低くなる傾向が見られた。また，各フェーズとも夏期に高くなる傾向が見られ，フェーズ3・4については，9月に最大値を示した。

トリハロメタンは塩素と溶解性有機物（フミン酸等）の濃度，温度，臭化物イオン濃度等に依存して増加する[5]。霞ヶ浦の有機物や臭化物イオン濃度（2017 年平均値で TOC4.0mg/L，臭化物イオン 0.14mg/L）は，霞ヶ浦流入河川である利根川を取水源とする利根川浄水場原水（前述と同様に 1.8mg/L，0.04mg/L）よりも高い濃度である。また，図 3 のとおり夏期に溶解性有機物の濃度が高くなることから，トリハロメタンの低減化を図る上で，より困難な状況となっている。

この様に，霞ヶ浦を取水源とする浄水場においては，トリハロメタンの生成が非常に懸念されるが，当局は粒状活性炭処理を行っており，霞ヶ浦浄水場の浄水中のトリハロメタン濃度は 2017 年の平均値で 0.018mg/L と，基準値の5分の1以下に処理し，給水している。

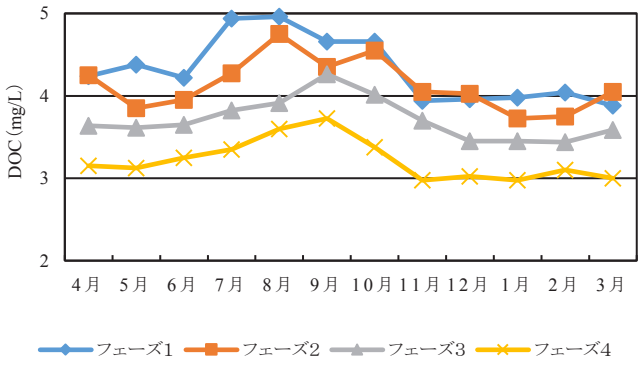

図 3 溶解性有機物経月変化

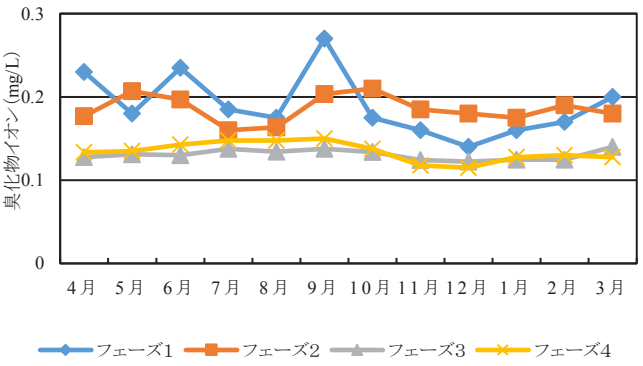

図 4 臭化物イオン経月変化

(3) かび臭物質の状況

各フェーズにおける 2-MIB の経月変化を図 5 に，ジェオスミンの経月変化を図 6 に示す。

他県の湖沼等においては夏期にかび臭物質が発生する事例が多いが，図 5 及び 6 のとおり霞ヶ浦においては，冬期から春期にかけて発生する傾向にあり，霞ヶ浦における特徴的な傾向である。しかし，フェーズ3のよう

に，夏期に発生する場合もある。また，2-MIB 及びジェオスミンとも，フェーズ2が最も低く，フェーズ3が最も高い値を示した。

このかび臭物質に対しても主に粒状活性炭処理により処理しており，霞ヶ浦浄水場浄水中のかび臭物質濃度は 2017 年の平均値で 2-MIB，ジェオスミンともに 1ng/L 未満で給水している。

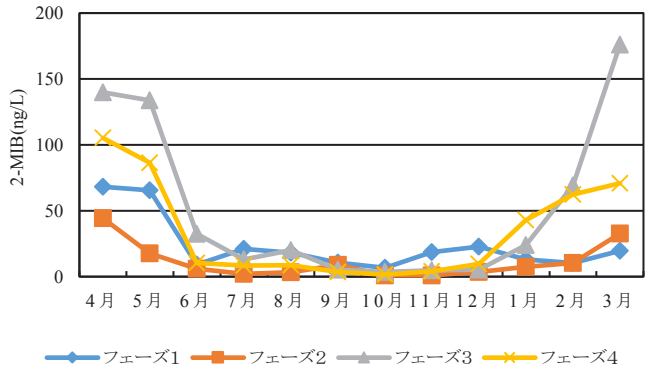

図 5 2-MIB 経月変化

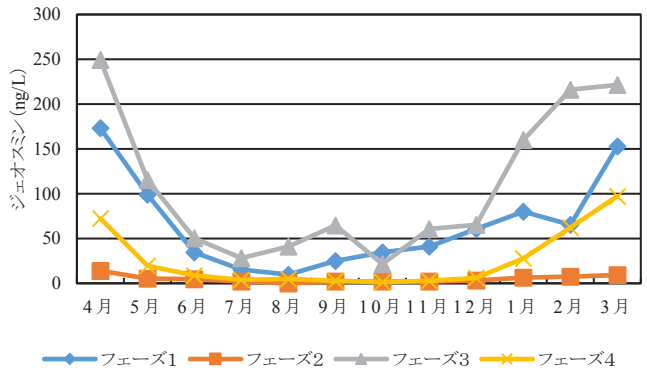

図 6 ジェオスミン経月変化

(4) かび臭物質の発生予測

かび臭物質の発生時期は年によって異なり，また過去には 1,000ng/L を超える極めて高い濃度で発生した事例もある。前述のとおりかび臭物質は，主に粒状活性炭処理により行っているが，粒状活性炭は使用期間の進展に伴い，吸着性能が低下する。このため，劣化状況やトリハロメタンの生成状況，かび臭物質発生時期等を考慮の上，再生を行っている。しかし，粒状活性炭の再生には一定期間が必要であることから，突発的にかび臭物質が高濃度に発生した場合は，その対応が遅れることも予想される。

このため，どの様な状況の時に，かび臭物質が発生するか解析を行ったところ，フェーズ4において図 7 のとおり，ジェオスミン最大濃度と濁度最大値との間に，一定の相関関係が見られた。また，風速と濁度最大値との間にも正の相関が見られるとともに，西風よりも東風の方が，濁度が上昇しやすいことが明らかとなった。

以上のことから，東風が強く吹くと底泥の巻き上がり等によって濁度が上昇し，それに伴いジェオスミンの濃度が高くなると予想される。

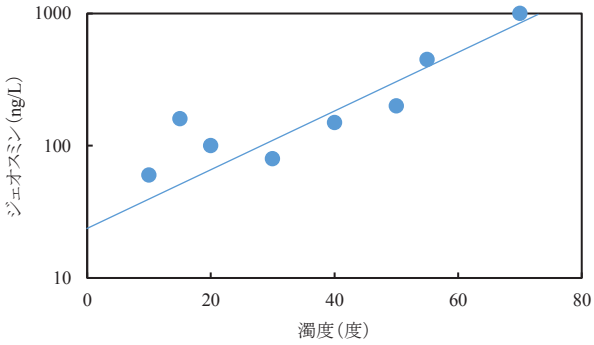

図 7 ジェオスミンと濁度の関係

5. 結論

以上のとおり，霞ヶ浦水源調査結果を各フェーズに分け整理すると，浄水処理における大きな課題であるトリハロメタンの生成要因である溶解性有機物質や，かび臭物質の濃度は，最悪なフェーズより改善していると示唆されるが，依然として他の水源に比べて高い傾向にあるため，今後も霞ヶ浦水源調査を継続していく考えである。

また，これらの物質に対し，当局は粒状活性炭処理によって低減化し，対応を図っているが，消費者ニーズの高まり等により，その再生費用は年々増加傾向にあるとともに，突発的な高濃度のかび臭物質の発生も懸念される。

この様な課題に対し，より効率的に対処するため，霞ヶ浦浄水場において現在，帯磁性イオン交換樹脂及び促進酸化処理を組み合わせた浄水処理の実証実験を行っているところである。この実証実験の成果等については，本会議の分科会で報告していることから，そちらについても参照されたい。

引用文献

[1] Krasner S. W. *et al.*: Occurrence of a new generation of disinfection byproducts, Environment Science and Technology, Vol. 40, pp.7175-7185, 2006.

[2] 日本水道協会: 生物起因の異臭味水対策の指針, pp.4-27,1999

[3] 眞柄泰基: 水道水質辞典-増補版-, pp. 63, 2005.

[4] 水資源機構: 平成 28 年度 霞ヶ浦開発事業定期報告書-概要版-, 2016.

[5] 国立保健医療科学院: WHO 飲料水水質ガイドライン第 4 版, pp. 435, 2012.

O7-2

凝集磁気分離型水処理装置を採用した霞ヶ浦直接浄化実証施設

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キーワード:湖内浄化対策, 浄水・排水処理技術

抄録

霞ヶ浦直接浄化実証施設は, 霞ヶ浦湖水を汲み上げ, 水中の浮遊物質(SS)およびりんを除去する事を目的とした実証施設である。実証施設の主要装置として採用された凝集磁気分離型水処理装置は,「凝集」と「磁気による固液分離技術」を組合せる事で, 処理時間が従来方式の約 1/30 である約 2 分 40 秒という非常に短い時間の中で効率的に水中の SS およびりんを除去することが可能な水処理装置である。実証施設は処理能力 10,000m^3/日であり, 閉鎖性水域である土浦港内の湖水を取水後, 実証施設へ送水し, 水中の SS およびりんを除去し, 処理水を再び土浦港に放流する施設である。処理水目標値は SS:5 mg/L 以下, T-P:0.03 mg/L 以下である。2013 年度～2017 年度にかけて実証運転を実施し, 全期間を通じて SS およびりんの処理目標を概ね達成することが出来たので報告する。

1. はじめに

霞ヶ浦では, これまで 7 期にわたり「湖沼水質保全計画」[1]に基づいて, 湖に流入する汚濁負荷の削減対策など, 総合的かつ計画的に対策を実施しており, さらなる湖水の水質改善を目指している。

このような背景より, 茨城県は霞ヶ浦の湖水を汲み上げ, 水中の浮遊物質(SS)および植物プランクトン増殖の一因であるりんを除去する「霞ヶ浦直接浄化実証施設」の導入を決定した。霞ヶ浦直接浄化実証施設(以降実証施設)とは茨城県が 2012 年度にプロポーザルとして公募した浄化実証施設であり, 2013 年度～2018 年度にかけて実証運転を行っている。

今回, 実証施設の主要装置として採用された「凝集磁気分離型水処理装置」は, 限られた設置面積の中で効率的に水中の SS およびりんを除去することが可能な水処理装置である。

2013 年度～2017 年度の実証運転にて SS およびりんの処理目標を概ね達成することが出来たので報告する。

2. 凝集磁気分離型水処理装置の概要

凝集磁気分離技術は,「凝集」と「磁気による固液分離」技術を組合せたコンパクトな水処理技術であり, その概要を図 1 に示す。

原水に無機凝集剤と磁性粉を添加し, 水中の SS および固形性りんを取込んで磁性粉を核としたマイクロフロックを生成させる。その後高分子凝集剤を添加しフロックを成長させる。成長したフロックは磁性を有しており, 後段の磁石により水中から吸着・分離される事で処理水を得る。

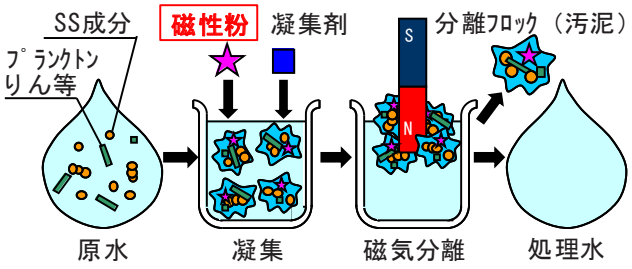

図1　凝集磁気分離技術の概要

この処理方式は固液分離のための沈殿操作が不要となり, 処理時間を従来の 1/30 に短縮できる。また磁石によって吸着・分離された汚泥は濃度 3～4%と, 通常の凝集沈殿方式で発生する汚泥濃度よりも高く, 直接脱水することができ, 汚泥濃縮槽が不要となる。凝集磁気分離型水処理装置の概要を図2に示す。

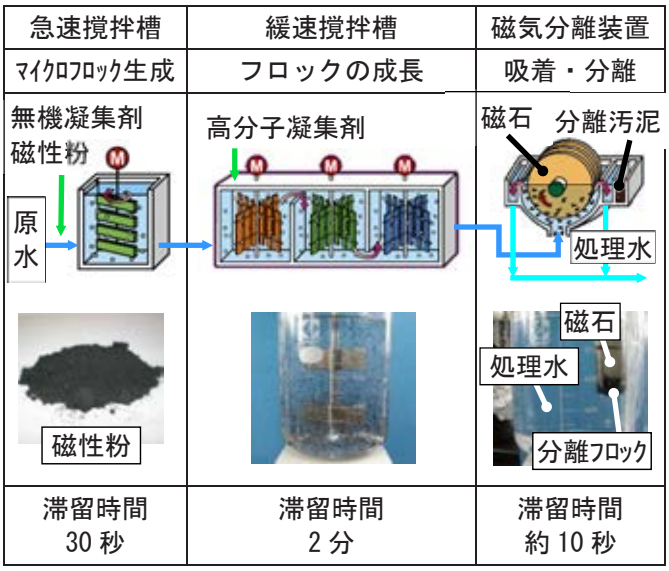

図2　凝集磁気分離型水処理装置の概要

3. 実証運転の方法

運転は，霞ヶ浦の中でも植物プランクトンが堆積しやすい閉鎖性水域である土浦港内の湖水を取水後，実証施設へ送水し，水中の SS およびりんを除去し，処理水を再び土浦港に放流した。施設設置場所状況を図3に示す。

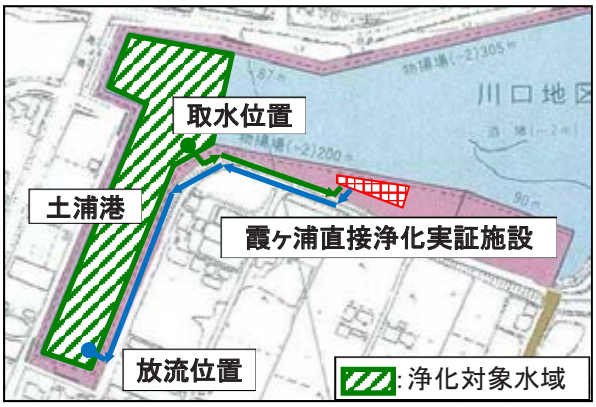

図3 施設設置場所状況

処理水量は最大 10,000m^3/日とし，処理性能評価は水処理装置の入口および出口の SS およびりんの水質によって行った。サンプリングは運転開始後概ね10日間隔で実施し，各年度合計 12～13 回実施した。実証施設の運転条件を表1に示す。

表1 実証施設 運転条件

項目	仕　様
処理方式	凝集磁気分離方式
対象原水	霞ヶ浦土浦港内湖水
処理能力	最大 10,000m^3／日
装置内滞留時間	約 2 分 40 秒（全体処理時間）
処理水目標値	SS　：　5 mg/L 以下 T-P　：　0.03 mg/L 以下

各薬品の注入率については以下のとおりである。

無機凝集剤は原水 SS 濃度および原水 pH 値によって 3～6 mg-Al/L の範囲で注入率を設定した。

磁性粉は，運転開始初期の 2013 年度～2014 年度は設計標準注入率で固定注入とした。一方，2015 年度～2017 年度は磁性粉注入率低減を目的とし，分離汚泥の一部を水処理装置内で回収・循環し，再利用磁性粉として急速撹拌槽に再添加した。この時の新品の磁性粉注入率は設計標準値から再利用分を差引いた値とした。（磁性粉再利用率約 30%）

高分子凝集剤は 0.6～0.7 mg/L を標準とした。

なお発生した汚泥については後段の脱水機で脱水後場外搬出とし，脱水脱離液については水処理装置急速撹拌槽に返送し再処理するクローズドシステムとしている。

4. 結果

(1) SS 処理性能

原水および処理水の SS 濃度の推移を図4に示す。2013 年度は実証施設の建設に伴い運転は 11 月～3 月の冬季に行った。原水 SS 濃度は 7.0～13.2 mg/L と比較的低濃度に対し，処理水 SS 濃度は 2.2～5.3 mg/L と概ね目標値を満足した。

ただし 12 月から 1 月にかけては原水水温が 6～8℃，原水 SS 濃度が 7.0～9.0 mg/L 程度と低水温・低 SS 濃度となり，凝集に不向きな条件となった。そこで凝集核確保のため磁性粉注入率及び，高分子凝集剤注入率を各々増加させたが，凝集反応の安定性を確保する事が難しく，処理水量を 5,000m^3/日とし，滞留時間を 2 倍とする事で処理性能を確保した。

2014 年度～2017 年度は SS，りん濃度共に年間で最も高くなる 6 月～9 月の夏季に運転を行った。原水 SS 濃度 5.0～30 mg/L に対し，処理水 SS 濃度は 1.3～5.6 mg/L と概ね目標値を満足した。特に 2015 年度～2017 年度に実施した磁性粉の循環再利用運転においても，安定した処理性能を得る事ができた。

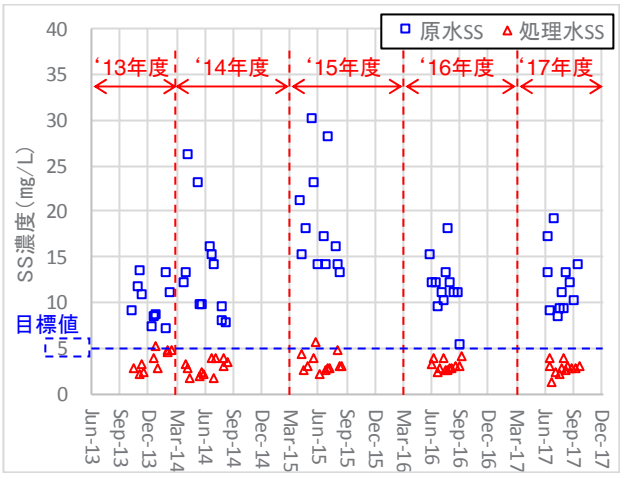

図4 SS 濃度推移

(2) りん処理性能

原水および処理水の T-P 濃度の推移を図5に，PO_4-P 濃度の推移を図6に示す。2013 年度の冬季運転では，原水 T-P 濃度 0.037～0.1 mg/L に対し，処理水 T-P 濃度は 0.002～0.041 mg/L と概ね目標値を満足した。また溶解性のりんである PO_4-P 濃度は，原水で 0.003～0.016 mg/L と非常に低濃度であり常時目標値以下であった。

2014 年度～2017 年度の夏季運転では，原水 T-P 濃度 0.048～0.22 mg/L に対し，処理水 T-P 濃度は 0.003～0.061 mg/L と，原水濃度上昇に伴い一時的な処理水 T-P 濃度上昇はあったが，概ね目標値を満足した。一方で原水 PO_4-P 濃度 0.003～0.11 mg/L に対し，処理水 PO_4-

P 濃度は 0.003～0.027 mg/L となり，溶解性のりんについても処理できることが解った。

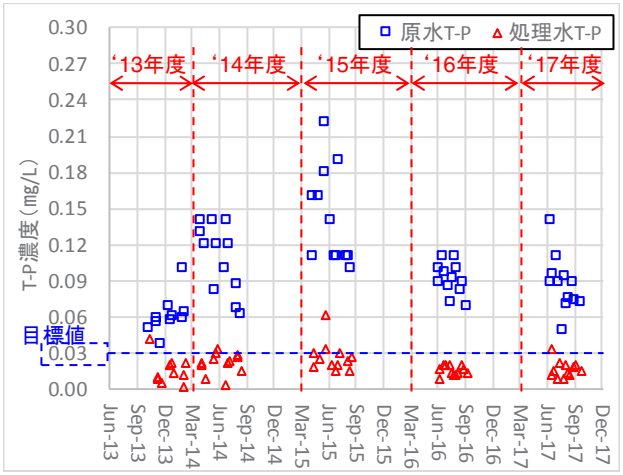

図５　T-P 濃度推移

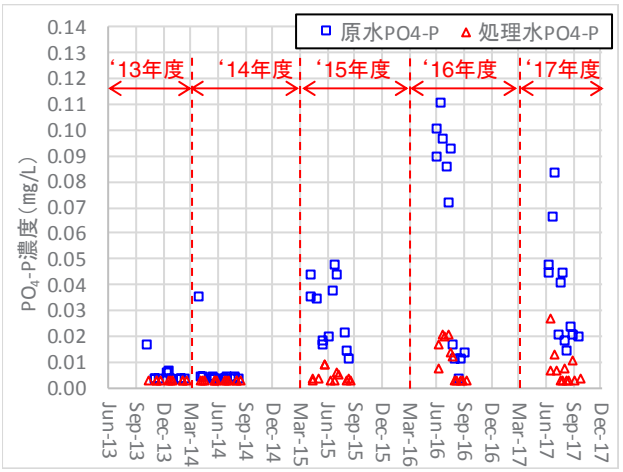

図６　PO_4-P 濃度推移

5.　考察

(1)SS 処理性能と無機凝集剤注入率について

凝集剤注入率の評価として，凝集剤のアルミニウム添加量と原水 SS 濃度の比（AL/SS 比）および処理後 pH 値に着目した。各々の関係を表2に示す。

表２　原水 SS 濃度に対する AL/SS 比，処理後 pH 値

原水 SS 濃度	10 mg/L 前後	20 mg/L 前後	30 mg/L 前後
AL/SS 比	0.3～0.35	0.17～0.2	0.13～0.17
処理後 pH	6.8～7.2	6.8～7.2	6.8～7.2

原水 SS 濃度上昇に伴い AL/SS 比は小さくなっており，相対的なアルミニウム添加量が少なくても良好な処理水を得ることが解った。処理後 pH 値については中性付近が最適であった。土浦港は夏季に原水 pH 値が著しく上昇する傾向がある。よって凝集剤注入率の管理指標は，表3に示す AL/SS 比を基本とし，処理後 pH 値により注入率を調整する事で安定した処理性能を得ることが出来ると考えられた。

(2)りん処理性能と無機凝集剤注入率について

りん処理性能については，原水りんの形態によって処理過程が異なる事が解った。2013 年度～2014 年度では原水りんのほとんどが SS 性のりんであり，SS を除去することでりんも除去されていたと考えられるため AL/SS 比による注入率管理が適用できると考えられる。

一方 2015 年度～2017 年度は原水りんの内，溶解性のりんである PO_4-P の割合が平均で 40%程度であり，2016 年度においては PO_4-P の割合が最大 90%以上であったが，安定して処理水 T-P 濃度 0.03 mg/L 以下で運転継続可能であった。溶解性のりんに対する処理性能として，この期間における凝集剤のアルミニウム添加量と原水 T-P 濃度のモル比（AL/P モル比）に着目し評価した。安定運転時の原水 T-P 濃度に対する AL/ P モル比の結果を表3に示す。

表３　原水 T-P 濃度に対する AL/P モル比の結果

原水 T-P 濃度	(2015 年度) 0.1～0.22	(2016 年度) 0.08～0.11	(2017 年度) 0.05～0.14
AL/P モル比	25～52	31～44	20～34

実証運転における凝集剤注入率は原水 SS 濃度および処理後 pH 値から決定していたため，表3に示す AL/P モル比は結果値であるが，処理目標 T-P 濃度 0.03 mg/L という極低濃度域において，溶解性のりんについても安定して処理するためには比較的高い AL/P モル比での凝集剤注入が必要であると考えられる。

(3)磁性粉の循環再利用運転について

2015 年度～2017 年度に実施した，磁性粉の循環再利用運転では安定した処理性能を得る事が出来た。新規磁性粉注入率を 30%低減しても，今回の原水では処理可能であった。

6.　結論

今回設置した「凝集磁気分離型水処理装置」は，処理時間約 2 分 40 秒という非常に短い時間の中で，SS およびりんの処理目標を全期間を通じて概ね達成することが出来た。また，磁性粉の循環再利用運転を実施し，新規磁性粉の注入率を 30%低減することが出来た。

本施設の設置及び運転管理は，茨城県の「霞ヶ浦直接浄化対策検証事業」に基づき，茨城県から株式会社日立製作所への発注・委託により行われたものである。

引用文献

[1]　茨城県・栃木県・千葉県: 霞ヶ浦に係る湖沼水質保全計画(第 7 期)，平成 29 年 3 月.

O7-3

Value-chain analysis - An assessment approach to estimate Lake Nasser fisheries performance

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Keywords: Fisheries, Lake Nasser, value chain, tilapia and pebbly fish

ABSTRACT

Although, the fishery in Lake Nasser has existed for more than 40 years, the economic and financial performance of its fisheries-based businesses not well understood. The current study aimed to improve understanding of fisheries value chain performance in Lake Nasser. Individual interviews and focus group discussions with fishers, traders, and processors were used to collect quantitative and qualitative information about financial performance, employment creation and critical factors impacting performance of each node throughout the chain. Tilapias account for 75%, while pebbly fish and tigerfish account for 13% of capture. Fish processing is an important subsector as some fish species (mainly tigerfish and pebbly fish) are only consumed after going through a salting process. Fishers obtained a relatively low percentage (49%) of the final consumer price. Average catch per fisher per day was 20 kg and average total cost in the three fishing harbours was EGP 5210/t. One hundred tons of fish caught and sold provides an average 29.99 Full-Time equivalent jobs (FTE). The current study suggests that the fishery is under pressure from overfishing. Critical factors facing the fisheries sector and impacting profitability are numerous. This value chain study improve our understanding of the performance of fisheries sector in Lake Nasser and identified limiting factors and action needed to support fisheries development in the Lake.

1. INTRODUCTION

Lake Nasser is an important source of fish for the Egyptian markets. Lake Nasser has a diverse fishery with 52 fish species belonging to 15 families [1]. During recent decades, the lake's ecosystem has undergone change and species diversity has declined [2, 3]. Tilapias, comprise 75% of the total catch by weight and are sold as fresh fish, while pebbly fish (*Alestes* spp.) and tigerfish (*Hydrocynus* spp.) are also important and are used as raw material to produce a traditional salted fish product. Other fish species in the catch are Nile perch, squeaker catfish, sharptooth catfish, Bagrus catfish and Nile carp. The statistics indicate that fish catches declined in the last 5 years mainly due to reduced tilapia and Nile perch catches [4]. Value chain analysis (VCA) has become increasingly prominent as a form of analysis in the fisheries and aquaculture sectors [5 - 7]. The particular aims of this study were to: Map the fisheries value chain and the flow of products through the chain; identify the various actors, their functions, and existing linkages across the chain; conduct a preliminary analysis of the input-output structure and the distribution of margins, return on investment and job creation along the chain; identify the problems and opportunities facing different actors in the fisheries value chain.

2. METHOD

The work for this study consisted of three main stages: planning, data collection and data entry. Three main target groups were identified in this study: fishers, traders (intermediaries, wholesalers, and retailers) and fish processors. Three questionnaires designed to be used in the study (one for fishers, one for processors, of both fresh and salted fish, and one for the postharvest subsector; i.e. intermediaries, wholesalers and retailers). The questionnaires tested and revised and simplified wording for the interviewees.

Fishers were selected on a stratified random basis in the three fish landing sites (Aswan, Garf Hussein and Abu Simbel). Fish processors are based in Aswan and the sample selected randomly from a list of fish processors. While, fish traders were selected to represent different trading activities (intermediaries, wholesalers, and retailers). The number of interviewees for each category considered in this study are as follows; fishers 162; processors 22 (fresh and salted processors); and traders 23 (intermediaries, wholesalers and retailers). A total of 207 respondents (fishers 162, processors 22, and traders 23) were interviewed. Data collected allowed the estimation of a number of key indicators for each link in the value chain.

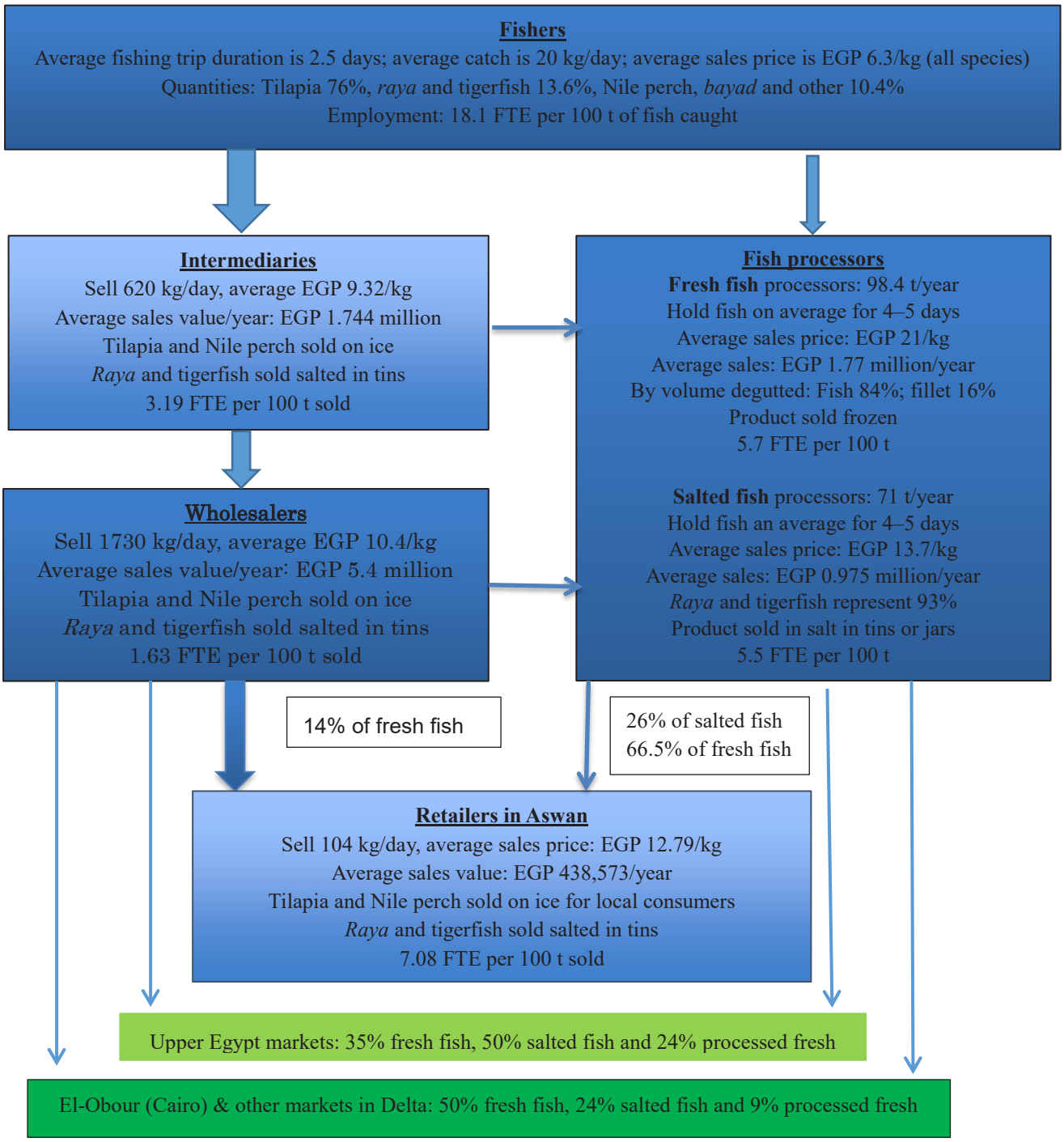
The data collected allowed for the construction of costs and earnings models for each respondent across the chain. The data collected on employment was converted into Full-Time Equivalent (FTE) jobs. FTEs were estimated based on 1 FTE being the equivalent of 300 days per year in fishing and processing sub-sectors, and 330 days FTE in the trading sub-sector as described by Macfadyen et al. [6].

3. RESULTS AND DISCUSSION

4.1. Lake Nasser fisheries value chain mapping

Results of the value chain mapping and analysis revealed that the average catch per fisher per day was 20 kg and average sales price is EGP 6.3/kg, Fishers obtained a relatively low percentage (49%) of the final consumer price, due to the long supply chain compared to aquaculture value chain [6]. Tilapias represent 76% of catch and pebbly fish and tigerfish represent 13.6%. Intermediaries play an important role in collecting catches from fishers in their fishing camps and selling on to wholesalers at landing sites or in the market. Fish processing is an important subsector of the fisheries value chain in Lake Nasser. Fresh fish processing generates 5.7 FTE/100t processed, while salted fish processing generated 5.5 FTE/100t processed. Also, fresh fish processing led to higher value added (EGP 3652/t) than salted fish processing (EGP 2507/t). Salted fish (*muluha*) is a product that is unique to Upper Egypt and comes mainly from Lake Nasser. *Muluha* is made from tigerfish (*Hydrocynus* spp.), pebbly fish (*Alestes* spp.), Nile carp (*Labeo* spp.) and other species that cannot be sold as fresh fish.

Figure 1. Schematic chart for Lake Nasser fisheries value chain.



4.5. Data summary

Changes in the average product price across the value chain indicate the average sales price for each link in the value chain (i.e. the basket price) (Table 1). The data indicates that fishers receive just below 50% of the final retail price.

Table 1 Gross output values (average prices) for the Lake Nasser fisheries value chain

Subsector	Price EGP/kg	% of Retail prices
Fishers	6.29	49
Intermediaries	9.32	73
Wholesalers	10.40	81
Retailers	12.79	100

4.6. Job creation in fisheries value chain

This study found that the fishing subsector resulted in total employment of 30 jobs (FTE) per 100 t of fish caught in Lake Nasser (Table 2). The highest employment level was in fishing followed by retailing, and intermediaries and wholesaling. More than 90% of fishers working in Lake Nasser are from Upper Egypt governorates. Meanwhile, 50% of wholesalers and 65% of retailers are also from outside Aswan. This indicates that the fisheries sector is an important source of job creation not just for Aswan but also for other governorates, including those of Upper Egypt. The current study found that most work was full time (>79%) indicating that fish businesses generate a good level of income across all subsectors. Furthermore, in fish retailing and wholesaling, almost all employment was full time (97% and 95% respectively). Youth (30 years old) represented 49–59% of total FTE indicating that working in the fisheries value chain is an acceptable option for young men.

Table 2 Employment creation in the Lake Nasser fisheries value chain

Employment	Fishers	Inter[1]	Ws[2]	Re[3]	Total
Jobs (FTE)/100 t sold	18.1	3.19	1.63	7.08	29.99
% across the chain	60	11	5	24	100
Full-time (% of FTE)	79	78	95	97	
Youth (% less than 30 years old)	57	53	59	49	
Source of labor					
Aswan %	9	47	50	35	
Other governorates %	91	53	50	65	

[1]Intermediators; [2]Wholesalers; [3]Retailers

4.7. Analysis of critical factors limiting fisheries development

Focus group discussions (FGD) resulted in identification of a series of challenges categorized into; livelihood challenges; inputs availability challenges; operation challenges include; post-harvest and marketing challenges.

4.8. Recommended actions to improve fisheries value chain performance

Suggested recommendations are based on the critical issues identified during the FGD and issues raised by fishers during interviewing.

- Establish new service organizations to provide inputs.
- Capacity building on recent fishing methods, improved handling and fish processing technologies.
- Facilitate affording operations inputs (food, fuel and ice).
- Ensure enforcement of security on and around the lake
- Adopt community-based fisheries management approach
- Improve living standards in the fishing camps in the lake and provide health service and social insurance service.
- Local authority should support establishing fish auctions in both Aswan and Abu Simbel to regulate fish prices.

4. CONCLUSION

The Lake Nasser fishery is an important source of food and job creation in Aswan and Upper Egypt. The fisheries sector contributes significantly to direct job creation, including for youth. No women were employed in the fishers or fish processing sectors in Aswan.

REFERENCES

[1] VAN ZWIETEN, P. A. M., et al. *Review of tropical reservoirs and their fisheries: The cases of Lake Nasser, Lake Volta and Indo-Gangetic Basin reservoir*. No 557. Food and Agriculture Organization of the United Nations, 2011..

[2] Béné, C.; B. Bandi and F. Durville. Liberalization reform, 'neo‐centralism' and black market: The political diseconomy of Lake Nasser fishery development. Water Alternatives, 1(2): 219‐235, 2008

[3] Halls, A.S., O.A. Habib, A. Nasr-Allah and M. Dickson: Lake Nasser fisheries: Literature review and situation analysis. Penang, Malaysia: WorldFish. Program Report: 42, 2015

[4] GAFRD: Fish Statistics Yearbook. General Authority for Fishery Resources Development, Ministry of Agriculture and Land Reclamation, Egypt, 2015.

[5] Veliu, A., N. Gessese, C. Ragasa and C. Okali: Gender Analysis of Aquaculture Value Chain in Northeast Vietnam and Nigeria. Agriculture and Rural Development. The World Bank Discussion Paper 44, 2009

[6] Macfadyen, G., A. Nasr Allah, D. Kenawy, F. Mohamed, H. Hebicha, A. Diab, S. Hussein, R. Abouzied, and G. El-Naggar: Value-Chain Analysis – an assessment methodology to estimate Egyptian aquaculture sector performance, and to identify critical issues and actions for improvements in sector performance. Aquaculture, 362–363: 18–27, 2012

[7] Anane-Taabeah, G., W. Quagrainie and S. Amisah: Assessment of farmed tilapia value chain in Ghana. Aquacult. Int., 24(4), 903-919, 2016.

O7-4

水草の持続的利活用を通した湖沼生態系の保全

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キーワード:水草, 持続的利用, 里湖循環型社会, メタン発酵, 微細藻類培養

抄録

近年, 世界中の多くの閉鎖性水域において, 水生植物(以下, 水草)の異常繁茂が様々な環境問題を引き起こしている。一方で, 水草は水質を浄化し湖沿岸に生息する生物に産卵・育成場所を提供する湖沼生態系になくてはならない存在と認識されている。実は, 1950 年以前には水草(主に沈水植物)は農地に施用する肥料として利用されており, 「循環型」の社会構造を形成していたと考えられている。今日, 便利で安価な化学肥料が利用されるようになり, 水草は全く利用されなくなった。これらのことは, 水草の効果的な利活用方法を開発することが, 異常繁茂した水草に関する問題を解決する最も良い方法であることを暗示している。ここでは, 水草をメタン発酵してエネルギー変換し, 発酵液分残渣を使って微細藻類を培養し利益還元することで刈り取られた水草を有効活用する取り組みについて紹介する。

1. はじめに

近年，水草の大量繁茂による環境問題が世界各地で報告されるようになっており[1-5]，日本国内でも社会問題となって久しい[6-7]。例えば，琵琶湖南湖では，沈水植物が湖面の 90%以上を覆うまでに至っており，複合的な環境問題を引き起こしている[8]。

一方で, 水草は元来, 水質浄化あるいは魚類の産卵場所や仔稚魚の生育場所として機能しているため[9], 適度に存在することで水域生態系を健全に保つことに貢献している。日本では僅か 60 年程前まで，水草は農地施用の肥料として刈り取られ利用されていたことが分かっている[10]。琵琶湖においても 1930～1938 年の滋賀県統計全書によれば，藻類の販売量は 2～3 万トンと記されている[10]。もしかするとこのように定期的に刈り取られることによって，過去において水草は適度な現存量に保たれていた可能性がある。水草は肥料として農地に施用され, 農作物として人間社会へ還元されることによって,「里湖循環型社会」と呼べるリサイクルシステムが形成されていたと考えることができる[10]。

今日，安価で便利な化学肥料の台頭により水草を肥料として利用することはまったくない。琵琶湖などで異常繁茂する水草に関連した問題とは, 即ち, 水草が利用されなくなったことで生じているのかもしれない。今日的な利活用の方法さえ見出すことができれば，過去に行われていたような水草の循環利用が可能となり, 水草問題も解決し, ひいては水域生態系の保全に役立つものと期待できる。

現在, 琵琶湖では水草は, 主にマンガンと呼ばれる道具を用いて，根こそぎ除去される[8]。しかし，これは水草の生態学的役割や水草除去に伴う環境への影響をまったく考慮していない。水草の刈り取り方法, および適正な現存量を策定することは，これを管理する上で極めて重要な知見を提供する。

我々は，2014 年～2016 年の 3 年間，環境省の環境研究総合推進費の助成を受け，琵琶湖環境を保全するために，過剰繁茂した水草類の持続可能な管理基準を策定し，加えて除去した水草バイオマスを有効利用する基盤技術を確立するための研究を行った。ここでは，メタン発酵と微細藻類培養による水草バイオマスを利用した現代版里湖循環型社会を実現するための研究および技術開発の概要について紹介する。なお，本発表の内容はすでに環境技術[11]に掲載された内容を含む。

2. 持続可能な水草刈り取り量および刈り取り方法

水草を持続的に利活用するためには，適正な刈り取り量を推定する必要がある。滋賀県が 2002 年から継続して行っている水草バイオマス調査によると，水草群集としての成長期は 5～9 月であり，9 月の現存量は湿重量でおよそ 10 万トンと見積もられている[12]。これは，月当たりにして湿重量で 2 万トンずつ増加している計算になる。

2015 年に行われた琵琶湖南湖での調査によると，湖底直上での溶存酸素量が，魚介類の成長・生理活性が低下するレベル（4.3 ml/L 以下）まで減少した地点は全調査地点の 8%を占めた[13]。これらの地点は水草の水柱当たり占有率が 60%を上回るところと良く一致していた。一方，水草に付着する微小動物の種数は，水草占有率が 30%を下回ると急激に減少傾向を示した。このことは，湖底直上の溶存酸素量と水草に関連する生物の多様度を指標にすることで適正な水草量を推定できることを暗示する。

今日，琵琶湖での水草除去は，刈り取り船を用いた表層刈り取りとマンガンを用いた根こそぎ除去がおこなわれている。しかし，これら刈り取り方法の違いが湖沼生態系に及ぼす影響については，これまであまり検討されてこなかった。我々の研究では，湖底堆積物中の化学物質の鉛直分布より，湖底堆積物表層の短期的な攪乱は，ある種の化学物質が湖底から溶出する可能性を示唆した。一方で，刈り取りによる長期的な有機物堆積量の減少は，これら化学物質の溶出を抑制する効果があることを示した。これらの結果は，水質・底質を保全するには水草の除去がある程度有効だが，根こそぎ刈り取るのではなく，表層のみ刈り取る方法がより適切であることを示す。

3. 刈り取った水草の有効活用方法

琵琶湖における水草の有効活用については，これまでにバイオエタノールや堆肥化など様々な試みがなされてきたが，有効な解決手段は見出されてこなかった。我々は，メタン発酵によって水草バイオマスを処理し，効率的にメタンガスに変換することでエネルギー転換し，廃液として生成される発酵液分残渣（消化液）を用いた微細藻類培養を行うための研究開発を行った。

水草は種によってリグニン含量が異なり，そしてこれに伴ってメタン生成量の変動することが分かった。従って，メタン発酵の前処理としてアルカリ加熱処理が必要であることを明らかにした。また，微細藻類培養において Mg が不足していることを見出し，消化液の pH を下げることでこれを解消できることも分かった。これらの実験結果を踏まえてベンチスケールでの実験を実施し，60%以上のメタン変換率と水草 1kg 当たりクロレラ 6-8g 乾重量の生産を達成することができた。

4. 引用文献

1) Abbasi, S. A., P. C. Nipaney and G. D. Schaumberg: Bioenergy potential of eight common aquatic weeds, Biological Wastes, Vol. 34, pp.359–366, 1990.
2) Food and agriculture organization of the United Nations: Management of problematic aquatic weeds in Africa-FAO efforts and achievements during the period 1991-2001, 2002.
3) O'Sullivan, C., B. Rounsefell, A. Grinham, W. Clarke and J. Udy: Anaerobic digestion of harvested aquatic weeds: water hyacinth (*Eichhornia crassipes*), cabomba (*Cabomba caroliniana*) and salvinia (*Salvinia molesta*), Ecological Engineering, Vol. 36, pp.1459–1468, 2010.
4) Santos M, L. Anderson and S. Ustin: Effects of invasive species on plant communities: an example using submersed aquatic plants at the regional scale, Biological Invasions, Vol. 13, pp.443–457, 2011.
5) A. Hussner: Alien aquatic plant species in European countries, Weed Research, Vol. 52, pp.297–306, 2012.
6) 芳賀裕樹，石川可奈子: 2007 年夏の琵琶湖南湖における沈水植物の現存量分布および 2002 年との比較，陸水学雑誌, Vol. 72, pp. 81-88, 2011.
7) Hamabata, E., S. Sugimura and K. Ishikawa: 7.2.3 The explosive development and control of aquatic weeds, Kawanabe, H., M. Nishino and M. Maehata (eds.) Lake Biwa: Interactions between Nature and People, pp.469–472, 2012.
8) 川崎竹志: 琵琶湖の水草の順応的管理と有効利用への挑戦，環境技術, Vol. 44, pp.500-505, 2015.
9) 芳賀裕樹: 琵琶湖南湖の沈水植物の長期変遷と近年の繁茂について，環境技術, Vol. 44, p.482-487, 2015.
10) 平塚純一，山室真澄，石飛裕: 里湖木採り物語, 50 年前の水面下の世界, 141p., 2006.
11) 伴修平，戸田龍樹，石川可奈子，高津文人: 水草

バイオマスの持続的利用を通した里湖循環型社会の可能性，環境技術，Vol. 45, pp. 478-483, 2016.
12)芳賀裕樹，石川可奈子: 2012 年夏の琵琶湖南湖の沈水植物の現存量分布ならびに 2002, 2007 年との比較，陸水学雑誌, Vol. 75, pp.107-111, 2014.
13)石川可奈子，岡本高弘: 水草繁茂と琵琶湖南湖の水質，環境技術, Vol. 44, pp. 488-493, 2015.

O7-5

Assessment of Ecosystem Services of Water Reservoirs/HPP dams in the Kura-Araz Basin

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Keywords: sustainable ecosystem management, targeted scenario approach, irrigation, flood management

ABSTRACT

This study focuses on freshwater ecosystem services that support hydropower plants (HPP)/dams development in the Kura-Aras River Basin in Azerbaijan. The study assesses the HPP/dams sector, and reviews additional sectors including nature-based tourism, irrigated agriculture, and drinkable water supply. In addition, the study briefly discusses the role and value of ES that help to mitigate natural hazards related to poor ecosystems management.

The study used a basic Targeted Scenario Analysis (TSA) approach. The TSA assesses current "business as usual (BAU)" ecosystems management practices and its current value of ecosystems services under BAU. It uses sector output indicators and compares with potential "sustainable ecosystems management (SEM)" outputs to assess losses and potential gains (or losses) of shifting from BAU to SEM. The BAU approach is characterized by a focus on short-term gains (e.g., < 10 years), externalization of impacts and their costs, and little or no recognition of the economic value of ES, which are typically depleted or degraded. Under SEM, the focus is on long-term gains (> 10 years); also under SEM, the costs of impacts are internalized. Ecosystem services are maintained, thus generating potential for a long-term flow of ecosystem goods and services that can enter into decision making. SEM practices tend to support ecosystem sustainability as a practical and cost-effective way to realize long-run profits.

1. INTRODUCTION

The hydropower dams/ reservoir in Azerbaijan provide a preferred cultural, regulatory, and provisioning ecosystem services [1]. The study aims at: 1) Demonstrate the value of contribution of biodiversity and ecosystem services to hydropower/dams development in the Kura-Aras River Basin; 2) Support the introduction a Sustainable Dams Assessment and Planning Methodology; and, 3) Mobilize key stakeholders, secure their support and launch the Caucasus Sustainable Dam Initiative [9].

The study stresses that joint-effort of key stakeholders at the river-basin-scale can support sustainable ecosystems management to ensure that the benefits of the hydropower sector, both financial and economic are secured for the long-term.

The study assesses the HPP/dams sector, and reviews additional sectors including nature-based tourism, irrigated agriculture, and drinkable water supply. In addition, the study briefly discusses the role and value of ecosystem services that help to mitigate natural hazards related to poor ecosystems management.

2. METHOD

The study used a basic Targeted Scenario Analysis (TSA) approach. The TSA assesses current "business as usual (BAU)" ecosystems management practices and its current value of ecosystems services under BAU. It uses sector output indicators and compares with potential "sustainable ecosystems management (SEM)" outputs to assess losses and potential gains (or losses) of shifting from BAU to SEM. The BAU approach is characterized by a focus on short-term gains (e.g., < 10 years), externalization of impacts and their costs, and little or no recognition of the economic value of ES, which are typically depleted or degraded. Under SEM, the focus is on long-term gains (> 10 years); also under SEM, the costs of impacts are internalized. Ecosystem services are maintained, thus generating potential for a long-term flow of ecosystem goods and services that can enter into decision making [4]. SEM practices tend to support ecosystem sustainability as a practical and cost-effective way to realize long-run profits.

It is expected that the TSA approach will serve multiple purposes:

1.Analyze the HPP/dams sector and determine the potential economic gains or losses of undertaking productive activities by comparing "poor" with "sound" environmental management practices.

2.Inform policy makers and businesses about the economic risks and opportunities of undertaking productive activities that impact ecosystem services.
3.Assist government officials and the private sector to incorporate ecosystems' management policy into economic planning, corporate business plans, and investment policies at sectoral level.
4.Provide economic (and social) arguments to mobilize political will to increase financial support to improve fresh water and forestry ecosystems management [2].

3. RESULTS

During 2005-2009 large investments were made in HPP sector, including new and advanced generators installed in several HPP. Contribution of these new generators rapidly increased electricity production, however, over the last two years a considerable reduction of the electricity produced is noticeable. However, during this period, little or nothing was invested in watershed management (the water factory). This is typical BAU scenario; it may include deforestation, intense silting, and poor dam management. Despite the increasing trend for this period, total amount of investments is rather low [6]. Under BAU, investment in infrastructure and equipment is high; Economic losses in electricity production for the period of 2003-2012. Actual production of HPPs in Azerbaijan is much lower than the installed capacities of all HPP. E.g. the Mingechaur HPP the installed capacity is 402 Mw, while actual production in 2012 was only 159 Mw. This difference may be explained by the impact of various factors. One and very simple explanation is related to the effective dam management. This large difference between installed capacity and actual production is considered as an indicator that HP dam management in Azerbaijan is under BAU.

A total economic loss 2003-2012 under BAU makes nearly 4.5 billion USD (for 2000-2012 it makes 6.4 billion USD), which is considerably higher than market value of produced electricity for that period. The optimal annual level of productivity assumed under SEM is nearly 2000 kWh per year, while under BAU we observe sharp fluctuation of productivity.

Comparison of total actual productions and total installed capacity of HPP and Economic loss from reduced HP generation sector 2003-2012 under BAU

The current BAU situation contributes to create conflict amongst stakeholders; i.e. reduced electricity production, less water available for irrigation leads to a decrease in agricultural output, and inadequate flood management that leads to flooding in downstream regions. For instance, the Mingechaur dam and reservoir has a purpose of hydropower generation, irrigation, and flood management. So, at least three stakeholders have an interest on management of the dam and reservoir.

Well-managed reservoirs should be operated to be able to storage water during high flows [5]. However, state owned HPP/Dams operators are interested in maintaining energy flow and little is invested in maintenance on dams. For example, during the high flow seasons, Mingechaur Reservoir serves as a flood prevention depository, reducing the risk of floods. However, in 2010, before high flow season, Mingechaur reservoir was not emptied to prevent reduction in electricity generation. Thus, during the high flow the reservoir did not function as a depository and it resulted in floods and inundation of 50 ha of irrigated lands, and destruction of homes. By the end of 2013, Azerbaijani hydro power plants decreased electricity generation by almost 75%. This is a strong case for promoting a shift from BAU to SEM.

Simultaneously, the government reported that the hydropower plant crisis in Azerbaijan started in the end of 2012 and continued in 2013. According to the information, power generation at HPPs for January-October 2013 reached only $1.209 \bullet 10^6$KW/h that is by 24.5% below that for the 2012 same term[1]. According to estimations, this makes additional economic loss equal to USD 184,292.000 only in 2011-2012. Estimated total economic loss in hydropower sector over the period of 2002-2012 is nearly USD 4.5 billion.

Poor dam and watershed management started to cause big floods since 1993. Recently, floods in the target region affect lives of 200,000-250,000 people on average per year. E.g. in May 2010, more than 240,000 people were affected, with tens of thousands of homes flooded or destroyed and 50,000 hectares of farmland inundated. The damage was estimated at $591 million. The main reason for this flood damage was a combination of poor upper basin management and dam management (flow regulation).

In 2010, the GoA increased its state budget up to USD 425 million to eliminate consequences of flooding. In 2013 USD 180 million has been spent to reduce consequences of floods. In 2014, the projected costs will be nearly USD 185 million. Total spending over the last four years slightly exceeds USD 1 billion. The Figure 12 shows the annual costs for elimination floods. The high cost of the 2010 flood is linked to BAU. This cost could be reduced by shifting to SEM management; for instance, only USD 20

million annually. The data to support this estimation was provided by the government.

4. DISCUSSION

BAU practices in fresh water ecosystem management have a high cost to the economy of Azerbaijan. Part of this high cost can be avoided by shifting to low cost SEM practices. Despite the availability of several laws and regulations governing the administration and management of HPP and Dams in Azerbaijan, enforcement is weak. The legal framework is also incomplete, there are no means for law enforcement, and no measurable indicators or means to collect and evaluate it. Therefore no results of evaluation are fed into policy making or to improve HPP/Dams management.

5. CONCLUSION

Because of different priorities, poorly planned BAU management generates conflict amongst fresh water ecosystems' stakeholders [3].

The current environmental impact assessments of HPP/Dam projects (small and large) neglect to assess the potential impact of current ecosystems management practices in the upper river basin. This in turn will have a negative impact on HPP/Dams performance that may result in additional negative externalities affecting other sectors such irrigated agriculture, tourism, fisheries, and drinkable water supply. The aggregated cost of these negative externalities often surpasses the current benefits deriving from the HPP/Dams sector.

Because improving ecosystem management in the upper watershed requires the participation of multiple sectors, e.g., HPP/dams, agriculture, forestry, fisheries, tourism, water supply, a comprehensive package of interacting policy reform measures is needed, both at national and at regional level. This is defined as a "policymix" package that is indispensable to introduce sustainable HPP/Dams development in the Southern Caucasus [10].

The lack of information and data limited the scope of this study; therefore, further research is needed, and it may include developing of primary data baselines. However, basic scenarios (BAU/SEM) were constructed where possible to inform policy makers and businesses about the economic risks and opportunities of undertaking productive activities that impact ecosystem services.

It is evident that BAU scenario causes huge economic losses in all sectors, reducing long-term gains. In contrast, the SEM could help to gradually increase ecosystem values and related benefits. For illustration purposes, a rough aggregate of the economic losses in various sectors under BAU and shows how costly BAU management can be, USD 18,6 billion. It also shows how economic losses may continue to increase, unless SEM management is provided.

REFERENCES

[1] TEEB Foundations, 2010. In: Kumar,P.(Ed.),TheEconomics of Ecosystems and Biodiversity: Ecological and EconomicFoundations. Earthscan, London, Washington.

[2] Costanza, R., d'Arge, R., De Groot, R.S., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruel, J., Raskin, R.G., Sutton, P., Van den Belt, M., 1997. The value of the world's ecosystem service and natural capital. Nature 387, 253–260.

[3] Daily, G. (ed.) Nature's Services: Societal Dependence on Natural Ecosystems (Island, Washington DC, 1997).

[4] Millennium Ecosystem Assessment (MA), 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington DC.

[5] Gleick P. H., Singh A., Shi H. 2001. Emerging Threats to the World's Freshwater Resources. A Report of the Pacific Institute for Studies in Development, Environment, and Security, Oakland, California.

[6] Small hydropower potential in Azerbaijan, 2009.United Nations Development Program Final Report, Baku, Azerbaijan

[7] Scandizzo, P.L., and R. Abbasov. 2012. The value of water in the Greater Baku Area: an integrated water management study, Internal report, The World Bank.

[8] Water Cadastre of Azerbaijan (2010) Hydrological annual. Hydromet, Baku

[9] UNEP (United Nations Environment Programme) (ed.) (2009): Integrated Policy Making for Sustainable Development: A Reference Manual. Geneva. [URL]: www.unep.ch/etb/publications/IPSD%20manual/ UNEP%20IPSD%20final.pdf

[10] UNEP (United Nations Environment Programme) (ed.) (2009a): Overview of the environmental assessment landscape at the global and regional levels. UNEP/GC.25/INF/12. Nairobi. [URL]: www.unep.org/gc/ gcss-x/download.asp?ID=1012

O7-6

Climate change impact assessment on ecosystem services of West Lake, Hanoi capital and suggestion a system of mitigation and adaptation measures

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Keywords: climate change, ecosystem services, West Lake, mitigation, adaptation, Hanoi capital.

ABSTRACT

West Lake is the freshwater lake in the Red River Delta in Vietnam, located in Hanoi capital. The lake is one of the few natural freshwater largest lake in the country. West Lake is listed as one of the lakes to be preserved in the world. Due to this such important role of lake, this research has analyzed current status of natural and socio-economic conditions of the West Lake, Hanoi capital and surrounding areas. From there, assess the ecosystem services that the West Lake ecosystem brings. There are four ecosystem services groups of West Lake: provisioning services, regulating services, supporting services and cultural services, in which the group of cultural services is crucial. By analyzing climate change scenarios of Vietnam in general, climate change scenarios of Hanoi capital in particular to assess the impacts of climate change on each group of ecosystem services of West Lake. From that point of view, proposals will be made to mitigate and adapt to climate change impacts for conservation and sustainable development of lake ecosystem services. A system of mitigation and adaptation actions has been proposed to restore West Lake as natural wetland as previous time for strengthening the resilience of West Lake to climate change.

1. INTRODUCTION

Analyzing the impact of climate change on ecosystems in Viet Nam is a country-wide requirement and based on these results of this analysis to propose mitigation and adaptation measures with climate change.

West Lake is the largest lake in the Red River Delta. The lake has an area of about 527ha, average depth of 1.5m, capacity of lake $7.5x10^6$m3. Lake is one of the few natural freshwater largest lake in the country. West Lake is listed as one of the lakes to be preserved in the world. Besides, ecosystem services of West Lake play an important role for Hanoi capital.

2. METHOD

This research uses method of document synthesis and methods which authors used for the previous researches listed in references.

3. RESULTS AND DISCUSSION

3.1. Current status of water quality, environment and aquatic biodiversity of West Lake

There are so many surveys on water quality, environment and aquatic biodiversity of West Lake since 1960. The most recent and more in details is the report of Institute of Ecology and Biological resources (IEBR) in 2012:

- ***Water quality***: all the water quality parameters are in the limit of tolerant of National Technical Regulation on surface water quality of QCVN 08-MT 2015 BTNMT with category B1 i.e. for living aquatic organisms but not so good in comparison with the past time (1960).

- ***Water and sediment layer depth***: after a half century, the water layer depth is shallower around 0.5m (in 1961 the deepest point is 3.5m and 2.5m in 2012. The sediment depth is more deeper, around 1m.

- ***Heavy metals of water, sediment layers and in living organisms***: there are so many heavy metals in presence of water and sediment layers such as: arsenic, cadmium, chromium, copper, iron, lead, zinc… The above heavy metals are also in presence (contamination) on aquatic plant species and commercial animal species such as fishes, shrimps, molluscs…

- ***Aquatic biodiversity***: is originally very diverse (1961) but rather poor now. There are many exotic (alien) species, cultured species (for fish species). No aquatic plant species. For other species such as shrimps, crabs, clams, snails…are decrease in species number and in stock (biomass).

3.2. Climate change in Vietnam in general and in Hanoi capital in particular

The ministry of Natural resources and Environment has deliberated two scenarios for global climate change 2009 and 2016. The followings are some data of Hanoi capital in the recent scenario 2016:

Annual average temperature: The change in mean annual temperature (^oC) over the baseline period (1986-

2005) (The value in parentheses is the variation around the mean value for the lower bound 10% and the upper bound 90%):

- RCP4.5 scenario: 2016-2035: 0,6 (0,2÷1,1); 2046-2065: 1,7 (1,2÷2,5); 2080-2099: 2,4 (1,6÷3,4);
- RCP8.5 scenario: 2016-2035: 1,1 (0,6÷1,6); 2046-2065: 2,2 (1,4÷3,4); 2080-2099: 3,9 (3,0÷5,7);

Annual average precipitation: The change in mean annual precipitation (%) over the baseline period (1986-2005) (The value in parentheses is the variation around the mean value for the lower bound 20% and the upper bound 80%):

- RCP4.5 scenario: 2016-2035: 12,6 (3,1÷22,9); 2046-2065: 17,0 (10,8÷23,8); 2080-2099: 24,0 (14,3÷35,3);
- RCP8.5 scenario: 2016-2035: 9,9 (2,7÷17,0); 2046-2065: 17,8 (9,8÷25,9); 2080-2099: 29,8 (18,0÷40,9);

Extreme weather phenomena in Hanoi: It can be said that with the people of Hanoi, the phrase climate change is no longer strange, because the unusual evolution of the weather in recent years has had a great impact on the life and environment in the capital. The issue for Hanoi is the response to climate change and extreme weather, such as colder winters, hotter summers, drier seasons and more rainy seasons. There are six rivers and dozens of natural lakes in Hanoi, which have suffered from climate change, such as erosion, lower water levels in recent years.

3.3. Ecological services of West Lake and climate change impacts

3.3.1. Provisioning services

Food supply (aquaculture, vegetables and fruits); Water supply (for irrigation and domestic use). Every year, West Lake is put into raising from 2.2 to 2.5 million, equivalent to about 5 tons of fingerling. Estimated, the yield of fish is supplied to Hanoi market over 400 tons per year. Genetic resources includes the genes and genetic information used for animal and plant breeding and biotechnology. Flora and fauna in the West Lake is very diverse and abundant. Therefore, this is the place to store biological genetic resources with many rare genes. Under extreme heat conditions at certain times of the year, surface water is heated up and the absorption of oxygen into the water is reduced. When surface water oxygen levels decrease, some of the surface water species are affected. In addition, warm waters, oxygen-deficient and excess CO_2 are favorable for algal blooms. After the algae blooms, the water will be contaminated by dead aquatic organisms, along with decaying algae causing odors, pollution in the lake area, affecting the air environment as well as lake water quality. Highly polluted species will overwhelm low-polluted species. Increasing temperatures during intense summer heat, or longer deep cold in winter can affect the organisms inside the lake as well as on the lake shore. Some species that do not suffer from prolonged colds can die and cannot be recovered without protection, such as the Bach Diep lotus species in lake. In addition, invasive alien species will rapidly overwhelm the native species.

3.3.2. Regulating services

Climate control (air conditioning, micro-climate of the city); Hydrological regulation (under groundwater collection and exchange); Pollution control (receiving and keeping of sediment, solubilizing nutrients and pollutants, waste). Disaster control (flood control). In the context of climate change, storms with high intensity, heavy rainfall in short time, change in precipitation intensity and frequency, increase flooding in the lake and surrounding areas. Floods associated with rainwater combined with domestic effluent spills from the sewage system, along the lake can be turned into the disease outbreaks associated with stagnant water environment, pollution. In addition, when rainwater runs over sewers with high concentrations of inorganic substances, organic matter can cause eutrophication in the lake and can cause odors. This phenomenon not only affects the organisms in the lake but also affects the people living around as well as visitors. Besides, due to the increased rainfall, however, not frequent, therefore, it will cause sometimes floods, sometimes drought and the erosion and sediment will be increased, the life expectancy of the lake will decrease as the depth of the lake will be shallow gradually with faster speed.

3.3.3. Cultural services

Spiritual values (belief and trust of the people); Landscape value, entertainment (opportunities for tourism and leisure activities, sightseeing); Educational value (opportunities for education, formal and extracurricular training). Due to the harsh climate, unusually hot sunshine, high temperatures in summer and winter, people often prefer to live around the lake. Land price in the West Lake (Tay Ho district) is the most expensive of Hanoi. Human activities have encroached, separating the lakes into areas that serve different purposes: restaurants, hotels, houses.., water surface area is shrinking. Crowded population will cause pollution from the discharge of the basin due to tourism activities on the lake, including solid waste. Many construction works are not suitable to lose the beauty of West Lake. Urbanization process of rapid development, especially in the northern, northeastern together with the population density is on the development. This process reduces the risk of rapid area "green" of the natural ecosystems in the basin.

3.3.4. Supporting services

Support biodiversity (habitats of species); Nutrition cycle support (take / hold and nutrient handling). Supporting services are those that are necessary for the production of all other ecosystem services. Extreme weather makes rare species listed in the Vietnam Red Data Book. Described species and new species (possibly endemic) will disappear. Southern species will dominate the northern species. Gradually, primary production, atmospheric oxygen production, soil formation and retention, nutrient cycling, and primary production will be reduced.

3.4. Suggestion a system of mitigation and adaptation measures of climate change impacts on ecosystem services of West Lake

Climate change will put negative impacts on ecosystem services of West Lake. The issue is: should preserve/restore the natural biodiversity of the West Lake, as wetland. The best way, in view of this research is: to conserve the maximum biodiversity, minimize and adapt to climate change while limiting human activities affecting the natural biodiversity/ecosystem of West Lake. Here are the proposed actions in this direction:

- Making a system of floating treatment wetlands and near coast wetlands.
- Removing the toxic microalgae.
- Destroying/catching the invasive aquatic species.
- Reconstructing 3 islands in the centre of the lake as formerly.
- Making the lotus plantation and submerged aquatic plants as formerly.
- Better bio-manipulation of lake.
- Integrating lake and water management.
- Enhancing the community participation.
- Adaptation with climate change by construction. The canal connecting with Red river – sustainable biodiversity development.

4. CONCLUSION

West Lake is one of the most famous natural lakes in Vietnam, so the locations around West Lake always attracts a large number of visitors. West Lake has high level of biodiversity and there are four ecosystem services groups in which the group of cultural services is crucial. Climate change affecting the ecosystem services of West Lake has made them degradation. If combined with the inadequate economic, social and cultural activities of human, the ecosystem services that West Lake supports is likely to be at risk and destroyed by the end of the 21st century. To better preserve ecosystem services of the West Lake, a set of actions has been proposed and should be implemented.

REFERENCES

[1] Do Kim Anh: Predict the fluctuation of some groups of organisms in West Lake, Hanoi. Master thesis of Science, Hanoi University of Science, 2007.

[2] Department of Environmental Protection, Association for Nature and Environment Protection: Workshop on Biodiversity Conservation in Truong Son Range, Hue city, 2008.

[3] Decision on Approval of the National Green Growth Strategy of the Prime Minister. No: 1393/QĐ-TTg September 25, 2012.

[4] Truong Quang Hoc, Vu Hoan, Tran Hong Thai: Thinking about climate change factors integrated into the planning project of Hanoi Capital to 2030 and 2050 vision. Conference on Science and Technology for response and adaptation to climate change – Issues of Hanoi, November, 2010.

[5] Institute of Ecology and Biological Resources: Implementation of the project on surveying and assessing the current status of water pollution, ecosystem of West Lake; to propose solutions to minimize pollution and rationally exploit West Lake, 2012.

[6] Ministry of Science and Technology, Institute of Science and Technology Vietnam: Vietnam Red Data Book. Hanoi Natural Science and Technology Publishing House, 2007.

[7]. Ministry of Natural Resources and Environment: Conference of Biodiversity and Climate change. Hanoi, 22-23 May, 2007.

[8] Ministry of Natural Resources and Environment: State standards of Vietnam on environment. QCVN 03: 2008/BTNMT; QCVN 08:2008/BTNMT; QCVN 08-MT: 2015/BTNMT, 2008.

[9]. Ministry of Natural Resources and Environment: Scenario of Climate change and sea level rise of Vietnam. Vietnam Natural Resources and Environment Publishing House, 2016.

[10] People's Committee of Hanoi, Department of Natural Resources and Environment: Demonstrate the outline of the task of developing an action plan to respond to climate change in Hanoi, 2011.

[11] Hoang Van Thang, Bui Ha Ly: The functions and services of the West Lake ecosystem in the context of climate change. Environmental Journal No.10, 2016.

[12]. Mai Dinh Yen: West Lake in "Lakes of the World". ILEC Publications, Japan, 1994.

[13]. Mai Dinh Yen: Four important natural freshwater lakes of Vietnam and the protection of their biodiversity. International Symposium at Japan, 1995.

[14] Mai Dinh Yen: Overview of surveys and research on the biodiversity of the West Lake, Hanoi. Scientific Conference of Vietnam National University, Hanoi, 2000.

[15] Mai Dinh Yen, Doan Huong Mai: Preliminary analysis of the impact of climate change on the West Lake ecosystem and propose direction of response. Workshop to conserve, develop and promote the value of West Lake as National famous landscape, 2014.

O7-7

Which of zebrafish or Japanese medaka is suitable for the WET test for the evaluation of sewage effluent?

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Keywords: Whole Effluent Toxicity (WET), Zebrafish (*Danio rerio*), Japanese medaka (*Oryzias latipes*), Sewage treated water

ABSTRACT

To establish the whole effluent toxicity (WET) test specific to evaluation of sewage effluent, we examined the sensitivities of Zebrafish (*Danio rerio*) and Japanese medaka (*Oryzias latipes*). In the test of sensitivities to three chemicals (nickel chloride, ammonium chloride, and sodium hypochlorite), differences of NOEC values by these two fishes were the extents of 0.5-2 fold. These results showed that the sensitivities to chemicals were similar in *D. rerio* and *O. latipes*. In the WET test for the sewage effluent, NOEC values of the influent were the same (40%) as *D. rerio* and *O. latipes*. The NOEC value was over 80% in the test of second effluent using *D. rerio.* On the other hand, the NOEC value of secondary effluent could not be obtained from the test by *O. latipes*, because surface of eggs allowed microorganisms to grow in water samples diluted in 20 and 40%. From these reasons, we suggest that *D. rerio* is recommended to be used to evaluate wastewater in the WET assay.

1. INTRODUCTION

The whole effluent toxicity (WET) test is useful to evaluate effluents from the two points of view; firstly, the WET test can evaluate chemical toxicities including unknown compounds, while conventional methods using chemical analysis are restricted to detect known chemicals. Another is that WET test can evaluate multiple-chemical effects by using biological responses. In the late 20th century, the U.S. EPA has started WET test to monitor effluents, and the method has been followed by many other countries including Canada and Germany to protect environments from pollutions. Recently, Japanese government is considering the application of WET test for environmental conservation [1]. The WET test is suitable for evaluating wastewater because various kinds of pollutants are discharged into sewage treatments from many sites such as residential and industrial areas.

Zebrafish (*Danio rerio*) and Japanese medaka (*Oryzias latipes*) are recommended to evaluate water samples in WET test [1]. In acute toxicities, *D. rerio* have similar sensitivities to *O. latipes* [2]. However, there are few reports on comparisons of chemihal-sensitivities between *D. rerio* and *O. latipes* in subchronic toxicity test used in WET test. Because WET test using fishes takes a lot of time and labor, more convenient methods are needed to promote WET test for evaluation of sewage treated water.

Here, we examined sensitivities of three chemicals (nickel chloride, ammonium chloride, and sodium hypochlorite) using *D. rerio* and *O. latipes* firstly. To establish the WET test method specific for evaluation of sewage treated water, secondly, influent and secondary effluent water were examined using *D. rerio* and *O. latipes.*

2. METHOD

D. rerio and *O. latipes* were obtained from the National Institute for Environmental Studies in Japan (NIES).

For chemical test, nickel chloride (3.75, 7.5, 15, 30 mg/L), ammonium chloride (12.5, 25, 50, 100, 200 mg/L), and sodium hypochlorite (chloride concentration; 0.03, 0.06, 0.125, 0.25, 0.5, 1.0 mg/L) were used in this experiment. We examined the water quality base on the WET test [1]. In each beaker, 10 eggs and 50 ml test solution were added, and incubated for 8 (*D. rerio*) and 13 (*O. latipes*) days, respectively (Experiments were carried out until 5 days after hatching). Four replicates were performed for each treatment and control. Hatch of eggs and viability rate of larval fish were documented every day. All the beakers were stored in an incubator at 26±1°C (*D. rerio*) and 24 ±1°C (*O. latipes*), respectively. Exchanging water was performed every other day.

Wastewater samples (influent and secondary effluent) were obtained from a waste water treatment plant employing conventional activated sludge process in November 2017. The water samples were filtered with 60 μm mesh and stored at a dark cold place (4°C). Secondary effluent was used after treatment with chlorine (2.5 mg/L) for 30 min to simulate final effluent. Eggs of *D. rerio* and *O. latipes* were exposed to each diluted wastewater (0% (control), 10%, 20%, 40%, and 80%). Dechlorinated water was used to dilute water samples and control.

Experimental conditions were the same as the above method.

Statistical analysis was performed using the statistical package R [3]. The homoscedasticity of viability and hatching rate were examined by Bartlett test ($p<0.05$). Statistically significances were evaluated using Dunnett test ($p<0.05$), because of the rejection of homoscedasticity in the all tests. The highest concentration with no differences between a samples and control was determined as the No Observed Effect Concentration (NOEC).

3. RESULTS and DISCUSSION

Comparisons of sensitivities for three chemicals (nickel chloride, ammonium chloride, and sodium hypochlorite) between *D. rerio* and *O. latipes* were examined based on hatching and survival rate. As shown in Table 1, NOEC values calculated from survival rates were lower than those of hatching rates both in *D. rerio* and *O. latipes*. These results suggest that egg has more chemical tolerance than larval fish. Differences of NOEC values by two fish-species were the extents of 0.5-2 fold, though NOEC value were different among chemical types in these fishes (Table 1). These results suggest that sensitivities to chemicals were similar in *D. rerio* and *O. latipes*.

Table 1 Comparison of NOEC values for three chemicals derived from *D. rerio* and *O. latipes*

Chemical	NOEC from hatching	NOEC from viability
	D. rerio / *O. latipes*	*D. rerio* / *O. latipes*
Nickel chloride	30 mg/L> / >30 mg/L	15 mg/L / 7.5 mg/L
Ammonium chloride	100 mg/L />200 mg/L	25 mg/L / 12.5 mg/L
Sodium hypochlorite*	1.0 mg/L> / 0.5mg/L	0.5 mg/L / 0.5 mg/L

* Total chlorine concentration

Interestingly, characteristics of chemical sensitivities were observed in hatching times of *D. rerio* and *O. latipes*. Delay in hatching was observed in *D. rerio* treated with nickel chloride, which was not observed in *O. latipes*. Acceleration in hatching was observed both in *D. rerio* and *O. latipes* treated with sodium hypochlorite. These results may suggest that hatching time is important factor to judge water quality in addition to conventional criteria including hatching and survival rate.

Water samples of influent and secondary effluent (addition of chlorine 2.5 mg/L) taken from a wastewater treatment plant were evaluated by the WET test using *D. rerio* and *O. latipes* (Fig. 1). Both NOEC values of the influent were the same (40%) between *D. rerio* and *O. latipes*. The NOEC value of secondary effluent was over 80% derived by the test of *D. rerio*. On the other hand, it was difficult to obtain the NOEC value of secondly effluent from the test of *O. latipes* because treatment with 20 and 40% diluted secondary effluent resulted in annihilated eggs, though 80% diluted secondary effluent was not effect on them. These results may be due to the differences in the hatching time between *D. rerio* (8-9 days) and *O. latipes* (13-14 days). Low concentrations of chlorine may be a reason of microorganism growth on egg membrane, though further studies are needed to appear these phenomenon.

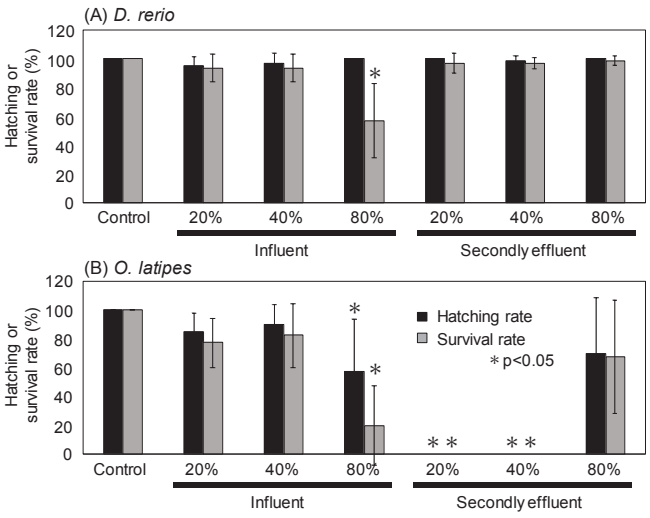

Fig. 1 Evaluation of wastewater samples (influent and secondary effluent) using *D. rerio* and *O. latipes*

4. CONCLUSION

Our study demonstrated that sensitivities of *D. rerio* exposed to chemicals are similar to those of *O. latipes*. Egg haching of *D. rerio* was more stable than that of *O. latipes* both of the cases in the treatments with standard chemicals and actual wastewater. From these reasons, *D. rerio* is recommended to be used to evaluate wastewater in the WET assay.

REFERENCES

[1] National Institute for Environmental Studies and Ministry of the Environment, Japan: Examination method for effluent using biological response (draft), 2013,

[2] T Nishida, K Kadota and A Nakamura, Comparison and validation of fish bioassays for effluent toxicity testing. Jpn. J. Environ. Toxicol., Vol.13, pp.27- 35, 2010.

[3] R Core Team, The R Project for Statistical Computing, http://www.r-project.org/.

O7-8

Effects of Sediment and Water Quality on Antioxidant Response of Brackish Bivalve *Corbicula Japonica*

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Keywords: Clay/silt, *C. japonica*, Multiple regression analysis, ORAC, Salinity, Turbidity

ABSTRACT

This paper deals with field experiments conducted in actual brackish environment (Hinuma lake/river and Naka river) to investigate the effects of sediment and water quality on antioxidant capacity of *Corbicula japonica*. For sediment experiments, clams were cultivated on sediments with adjusted contents of clay/slit (3.7, 20.2 and 33.1%). For water quality experiments, clams were placed in water of totally five sites. It is observed that sediment with clay/silt content of 33.1% decreased in oxygen radical absorbance capacity (ORAC) within two weeks, while sediments with those of 3.7 and 20.2% had no changes. The results indicate that the effects of sediment with up to ~20% of clay/silt content can be neglected on ORAC assay. On the other hand, Naka river had a large variation in salinity, which was different salinity condition to Hinuma lake/river. ORAC assay showed that there were significant differences between Naka River and Hinuma River (p<0.05). To estimate the water quality parameters that affect ORAC, multiple regression analysis was carried out. The results revealed that ORAC values were affected by variations in salinity and turbidity. In particular, variations in the two parameters during the past two days determined ORAC of brackish bivalve *C. japonica*.

1. INTRODUCTION

Recently for environmental assessments, application of biomarkers is becoming an important topic in aquatic organisms as indicators of pollution effects [1]. For sustainability of ecosystem, countermeasures and technologies based assessment is required. Oxygen radical absorbance capacity (ORAC) has been widely accepted as a biomarker for the direct assessment of antioxidant capacity. The ORAC assay measures peroxyl radical–induced oxidations of a fluorescent probe through the change in its fluorescence intensity with a microplate reader. This enables rapid and simple assessment of total antioxidant capacity.

There are limited findings on the effects of sediment and water quality on antioxidant capacity of bivalves in brackish environment. Present study focuses on brackish water clam *C. japonica* [2] available in Hinuma lake/river and Naka river. The research objectives can be described as follows; (1) to investigate the effects of different sediment composition on ORAC; and (2) to find out the water quality parameter affecting on ORAC.

2. MATERIALS AND METHOD

2.1 Experimental conditions and sampling

2.1.1 Sediment experiment

Field experiment was carried out in Hinuma lake from October to December 2017. Plastic cage (35×65×30cm) of three different sediment particles of (3.7, 20.2 and 33.1%) were fixed in the site. These sediment particles were obtained by blending bottom quality of the field (experiment site) and clay sediment obtained from Naka river shown in Table 1. For each run, 50 individuals were placed, out of which 10 individuals were taken out once in every two weeks. 5 individuals were used for ORAC analysis and others for NADH analysis. Both analyses were conducted for six weeks from the start of experiment.

Fig. 1 Experimental site

Table 1. Composition of sediment for experiment

No.	Clay / silt content (%)	Ignition loss (%)
Run 1	3.7	2.8
Run 2	20.2	20.2
Run 3	33.1	10.4

2.1.2 Water quality experiment

Field experiment was conducted at the survey points A, B, C, D and E shown in Fig. 1 from October to November, 2017. Clams were placed in a basket once every two weeks on each survey points for ORAC and NADH assays. At the same time, water quality parameters such as temperature (°C), Salinity (psu), DO (mg/l), Turbidity (FTU) and chlorophyll a (µg/l) were measured every 30 minutes interval at the survey points A, C, D and E.

2.1.3 Biochemical analysis

Each soft tissue of five clams was homogenized in 20mL of buffer solution (20mM Tris-HCL, 1mM EDTA, 50mM KCl) for 1min (GLH-115, Yamato Scientific, Tokyo) and centrifuged at 10,000g for 10min at 4°C. The supernatant was subjected to total antioxidant capacity and protein assays as a sample. Total antioxidant capacity was assayed as ORAC [3] with minor modification. 30µL of sample was added to each well and mixed with 150µL of fluorescein (40nM) as a fluorescent probe and 60µL of 2,2-azobis (2-amindinopropane) dihydrochloride (AAPH) (100mM) as a source of peroxyl radicals. Fluorescence was continuously measured with a microplate reader (Infinite F200 PRO, Tecan Japan, Tokyo). Total antioxidant capacity was expressed as micromoles of trolox equivalent per milligram of protein [4]. Protein was quantified by the Bradford method [5] using a Protein Assay CBB Solution (Nacalai Tesque, Kyoto, Japan). Oxygen Radical Absorbance Capacity is given by the following equation;

$$\text{ORAC (µmol-TE/mg-Protein} = \frac{Sample\ Area}{Trolox\ Area} \times \frac{Trolox\ Concentration}{Sample\ Value} \times \frac{Dilution\ Factor}{Protein} \quad \text{eq (1)}$$

2.1.4 Statistical analysis

Water quality data at the survey points A, C, D and E were analysed by principal component analysis and cluster analysis. To understand the independent water quality variables affecting ORAC, each water quality variable; average, standard deviation, maximum, minimum and median were calculated as 1 day, 2 days and 3 days before the measurement day of ORAC respectively and then ORAC and the extracted water quality data were subjected to multi-regression analysis. Tukey's test was conducted to detect significantly different means (p<0.05).

3. RESULTS AND DISCUSSION

3.1 Sediment and ORAC in *C. japonica*

The three-different composition of sediment particle with respect to ORAC is shown in Fig. 2. Sediment particle that of 33.1 % decreased in ORAC, while those of 3.7% and 20.2% had no changes. It was revealed that the influence of bottom sediment up to ~20% of clay/silt content can be neglected in ORAC assay for *C. japonica*.

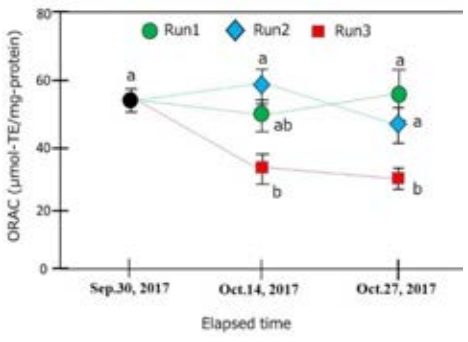

Fig. 2 Antioxidant Response to Sediment

3.2 Water quality characteristics and ORAC responses

3.2.1 Evaluation of water quality parameters

Remarkable variation in salinity at points A and C was observed as shown in Fig. 3. Also, turbidity was seen highest at points C, D and E. It rapidly increased in approximately one-week span. Chl.a, was seen highest at point E. Principle component analysis and cluster analysis demonstrated that points D and E were found to have similar characteristics and points A and C have a separate feature. In terms of salinity, the average value is almost same at points A and C. Value of turbidity at point C have greater influenced than point A. Also, the value of standard deviation shows that points A and C have high salinity variation compared to the points D and E. Value of Chl.a was seen higher at points D and E. This is due to the growth of phytoplankton in Hinuma lake as compared to rivers.

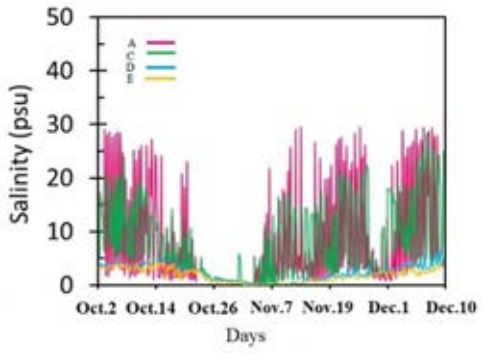

Fig. 3 Salinity variation in experiment points

3.2.2 Impacts of water quality factors on ORAC

The differences in ORAC were found in experimental sites (Fig. 4). Significant difference (p<0.05) was observed in ORAC value at points A and C in the brackish river zones where salinity variation was large. Multi-regression analysis revealed that two water quality factors salinity and turbidity were the most affective to ORAC. The highest value of R^2 was observed in 2 days (R^2 = 0.87) analysis, compared with 1 day (R^2 = 0.49) and 3 days (R^2 = 0.43) analyses. t values were highest in salinity and turbidity that suggests variable highest impact on ORAC.

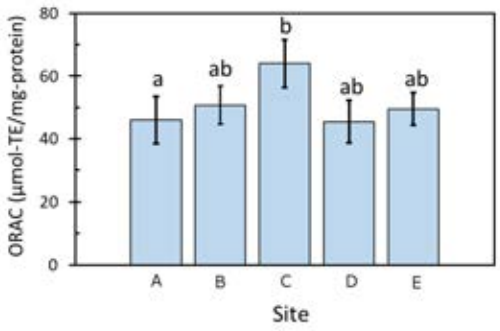

Fig. 4 Differences in ORAC in experimental sites

4. CONCLUSIONS

Clay/silt content of sediment is very important to evaluate the responses of ORAC in *C. japonica*. Also, salinity and turbidity have an influence on ORAC responses. Particularly, variations in the two parameters during the past two days determined ORAC values. We conclude that natural environmental factors should be considered in ORAC assay for *C. japonica*.

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REFERENCES

[1] Leinio¨ Sari and Lehtonen Kari K: Seasonal variability in biomarkers in the bivalves Mytilus edulisand Macoma balthicafrom the northern Baltic Sea. Comparative Biochemistry and Physiology, Part C 140, pp. 408–421, 2005.

[2] Okamoto, S., Yamaguchi, H., Koyama, H., Nakaya, M., Yoneda, C., Watabe, S: Comparison of extractive components and taste of soup from brackish water clam Corbicula japonica in different habitat waters of the Hinuma River system, Nippon Suisan Gakkaishi 78, pp. 444–453, 2012.

[3] G Cao, E Sofic, RL Prio: Antioxidant and Prooxidant Behavior of Flavonoids: Structure-Activity Relationships. Free Radic Biol Med 22(5), pp. 749-60, 1997.

[4] Furuhagen S, Liewenborg B, Breitholtz M, and Gorokhova E, Feeding Activity and Xenobiotics Modulate Oxidative Status in Daphnia magna: Implications for Ecotoxicological Testing, Environ. Sci. Technol. 48(21), pp. 12886–12892, 2014.

[5] Bradford, M. M, A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding, Analytical Biochemistry 72(1–2), pp. 248–254, 1976.

O7-9

汽水域における自然的・人為的水質要因がヤマトシジミの成長力に及ぼす影響

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キーワード：汽水性二枚貝, 成長力, 総抗酸化力, 水質汚濁, 都市下水

抄録

汽水域の自然的水質要因として浮遊物質（SS），塩分，水温，人為的水質要因として都市下水（5 倍希釈）の 4 要因各 2 水準を組み合わせた合計 16 系をヤマトシジミに実験的に与え，成長力と総抗酸化力を評価した．その結果，成長力に対しては，都市下水（5 倍希釈）の単一効果が認められた。また，塩分と都市下水の交互作用も認められた。塩分が時間変動する汽水域において，都市下水の影響が加わると，ヤマトシジミの成長力に対して複合的な影響を及ぼすことが明らかとなった．また，自然的水質要因に曝されたヤマトシジミの成長力と総抗酸化力の間には負の相関がみられた。一方，自然的水質要因に都市下水の影響が上乗せされた条件では，両者には明確な相関がみられなかった。

1. はじめに

欧州では沿岸海域の包括的な環境影響評価のために，水生生物の生体内バイオマーカーを用いた調査が行われている[1), 2)]。環境ストレスを受けた生物は，生体内に生成される過剰な活性酸素種を除去するために，抗酸化成分を合成する[3)]。この抗酸化成分は，抗酸化力の指標（ストレスバイオマーカー）として評価されている。近年では，簡便な蛍光分析に基づく ORAC（Oxygen Radical Absorbance Capacity）法を用いた研究も行われている[4), 5)]。

汽水域では，自然的水質要因と人為的水質要因が生物に対して複合的に作用していると考えられる。こうした複合作用を明らかにできると，水生生物保全に基づく水環境評価に繋げられると考えられる。また，抗酸化力等の生化学レベルの応答を生体成長等の個体レベルの応答と関係づけることができると，抗酸化応答に対する理解や解釈が可能になる。

海洋性二枚貝の成長力を評価する手法として，SFG（Scope for growth）法が提案されている[6)]。生体成長を評価するためには年月を要するが，SFG 法では数時間で成長に利用できるエネルギーを成長力として評価することができる。しかし，既存の方法[8)]では測定項目が多いことから，著者らはこれまでに炭素収支に基づく成長力評価手法を検討してきた[7)]。

そこで本研究では，筆者らが確立した炭素収支に基づく簡便なヤマトシジミの成長力評価手法を用いて，汽水域の自然的・人為的水質要因がヤマトシジミの成長力に及ぼす要因や複合作用を明らかにした。さらに，成長力と総抗酸化力などの生体内バイオマーカーとの関係を整理した。

2. 方法

2.1 炭素収支に基づく成長力評価手法

炭素収支に基づく成長力評価手法では，ヤマトシジミが摂取または排出する炭素量を測定した。**式 1** に示すように，摂餌（C）による炭素摂取量と擬糞（P），排泄（U），呼吸（R）による炭素排泄量をそれぞれ実験に基づいて算出し，その差分を成長力（SFG）として評価した（**図 1**）。 SFG>0 であれば摂取した炭素を成長に使用可能であり，SFG<0 であれば炭素を成長に使用できない環境であると判断できる。

$$SFG\ (\mu gC/individual \cdot h) = C - (P + U + R) \qquad (1)$$

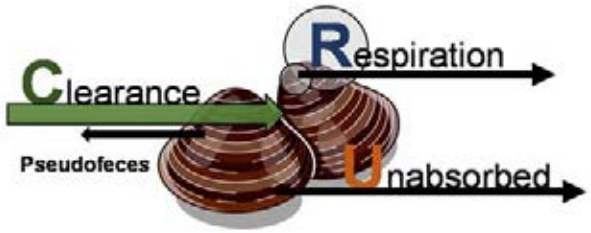

図 1 炭素収支に基づく成長力評価手法の概念図

(1) 摂餌実験

有効容積 4.5 L プラスチック製容器に，培養珪藻類 20 mg-SS/L に調整した人工海水 3 L とヤマトシジミ 30 個体を投入し，循環ポンプを用いて十分に曝気と攪拌を行った。実験中はウォーターバスの中で水温を一定にした。

事前検討により，ヤマトシジミが摂餌中に排泄する擬糞は試験水中に拡散すると，摂餌量の測定に影響を及ぼすことが明らかとなっている。そのため，擬糞の拡散を防ぐために，ヤマトシジミは開き目 50 μm のプランクトンネットに入れて実験を行った。プランクトンネット内で捕集した擬糞は採取後，超純水を加えてホモジナイズ処理し，全有機炭素（TOC）を測定した。そして，この擬糞由来の TOC をヤマトシジミの排泄量とした。ヤマトシジミを投入した時間を実験開始時刻とし，1 時間で減少した粒子態炭素（POC）量を摂餌量とした。

(2) 排泄実験

摂餌実験で使用したヤマトシジミをよく拭き，0.5 L の人工海水に投入した。実験中は水温を一定に保ち，

十分に曝気を行った。ヤマトシジミが排出する糞（POC）を排泄量とした。

前検討より，糞（POC）は 1 時間程度で溶出率が高くなり，排泄量の過小評価となることが明らかとなっている。そのため，炭素溶出率の低い 30 分毎に試験水を交換し，既存の方法と同様に 1 時間の排泄量を算出した。

(3) 呼吸実験

アルミホイルで遮光した 1L 三角フラスコにヤマトシジミを 30 個体投入後，珪藻類 20 mg-SS/L に調整し十分に酸素を溶存させた人工海水を満水まで投入し密閉した。実験中は水温を一定に保った。密閉した時刻を実験開始時刻とし，1 時間で増加した溶存無機炭素（DIC）量を呼吸による炭素排出量とした。採水した試料への CO_2 溶解を防ぐために，流動パラフィンを試料に重層した。そして，すみやかに DIC を分析した。事前の検討により，流動パラフィンを使用することによる試料の DIC は変化しないことを確認している（p>0.05）.

2.2 汽水域の自然的水質要因と都市下水に対する成長力の応答実験

室内水槽で飼育しているヤマトシジミ（殻長 : 20.5 ± 1.5 mm）90 個体を水温 20 ℃，塩分 10 psu の実験水槽に移し，室内培養している珪藻類を 1 日 1 個体あたり 1 mg-SS となるように 1 時間毎に等分量を給餌して馴致した。馴致後，汽水湖の自然的水質要因として餌源（SS），水温，塩分と人為的水質要因として都市下水（5 倍希釈）の濾水の合計 4 要因各 2 水準の組み合わせで合計 16 系の室内実験を実施した。実験条件を**表 1** に示す。各系 3 日間暴露した後，成長力と総抗酸化力（ORAC）を評価した。ORAC 分析は既報 [5]に従った。応答実験の期間は，事前の検討実験の結果に基づいて決定した。応答実験期間は馴致時と同様に，培養珪藻類を給餌した。都市下水は人工海水で 5 倍希釈した。

要因の主効果および交互作用を明らかにするために実験計画法を用いた。条件の割付には $L_{16}(2^{15})$直行表を用いた。分析にあたり，各要因のみの効果（主効果）および 2 因子間の複合作用（交互作用）をみることとし，3 因子以上の交互作用は誤差 e として扱った。

3. 結果と考察

3.1 汽水域の自然的水質要因と都市下水に対する成長力の応答

図2に汽水域の自然的水質要因と都市下水に対する炭素収支と成長力を示す。自然的水質要因に上乗せして都市下水を与えた系は，自然的水質要因のみを与えた系と比較して摂餌量がより少なくなる傾向がみられた。一方で，排泄量や呼吸量はより多くなる傾向がみられた。その結果，成長力が抑制される傾向を示した。つまり，都市下水はヤマトシジミの成長に対して負の影響を与えていることがわかった。また，餌源（SS）の給餌量が少ない系（Run9～16）は，給餌量の多い系（Run1～8）と比較して，摂餌量が少なくなり，成長力も低く見積もられる傾向がみられた。高塩分の系（Run5～8，Run13～16）の系と比較して低塩分の系（Run1～4，Run9～12）の成長力は，低く見積もられる傾向がみられた。ヤマトシジミは濾過摂食性の二枚

表 1 汽水湖の水質に対する成長力・総抗酸化力の評価実験条件

Run	Feeding (mgSS/ind.d)	Sal. (psu)	Water Temp. (℃)	W.W (DF=×5)	Run	Feeding (mgSS/ind.d)	Sal. (psu)	Water Temp. (℃)	W.W (DF=×5)
1	5	5	25	−	9	0.5	5	25	−
2	5	5	25	○	10	0.5	5	25	○
3	5	5	15	−	11	0.5	5	15	−
4	5	5	15	○	12	0.5	5	15	○
5	5	20	25	−	13	0.5	20	25	−
6	5	20	25	○	14	0.5	20	25	○
7	5	20	15	−	15	0.5	20	15	−
8	5	20	15	○	16	0.5	20	15	○

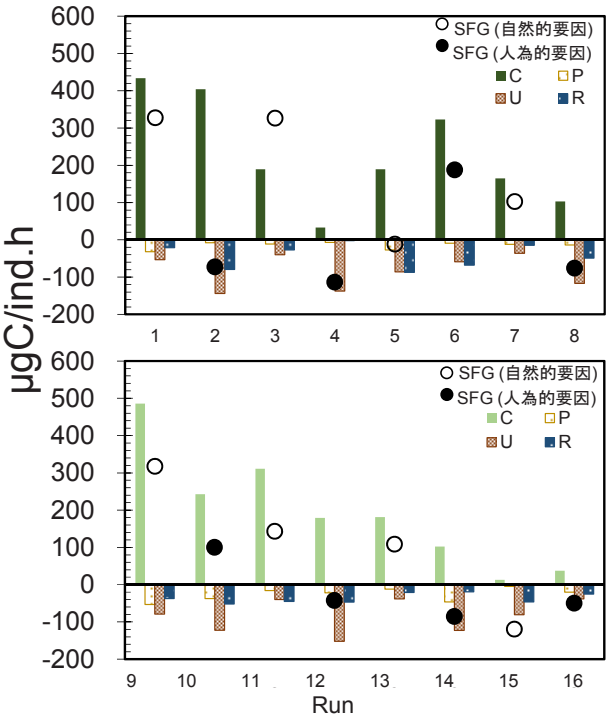

図 2 汽水域の自然的水質要因と都市下水に対する成長力の応答

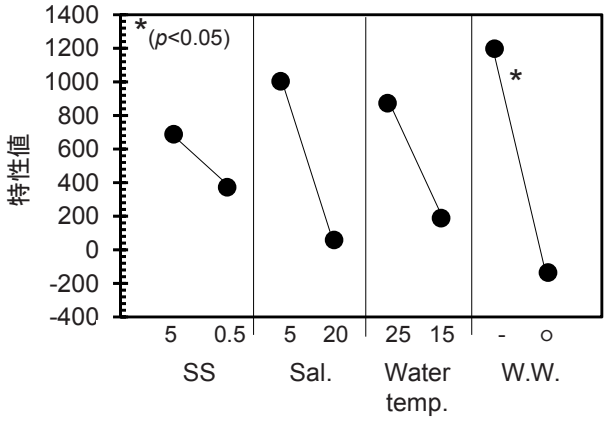

図 3 効果推定図

貝であり，開殻をともなった給水とともに，摂餌や呼吸を行う[9]。しかし，高塩分に曝されると開殻する時間が短くなる[10]。ヤマトシジミは高塩分に曝されて開殻する時間が短くなり，炭素摂取量が少なくなったと考えられる。

以上のことから，確立した成長力の評価手法を用いると各要因やそれらの組み合わせによって成長力に違いがみられた。水質要因が成長力に及ぼす影響にはおおよその傾向がみられたが，条件の組み合わせによってその傾向とは異なる応答も確認できた。これは，水質要因を組み合わせることによる複合作用の効果であると考えられる。

3.2 水質要因が成長力に及ぼす効果と複合作用

成長力の応答値を各要因の水準毎に累積して算出する特性値に基づいて，要因がヤマトシジミの成長力に及ぼす効果の有意性を判断した。効果推定図を**図 3** に示す。成長力は 5 倍希釈した都市下水に影響を受けることが明らかとなった（p<0.05）。池田ら（2017）[11]は，10 倍希釈の都市下水に曝したヤマトシジミの細胞に損傷が起こることを明らかにしている。本実験で条件として与えた 5 倍希釈の都市下水も，ヤマトシジミに負の影響を与えていると考えられる。一方で，SS や塩分，水温の影響は受けないことがわかった（p>0.05）。

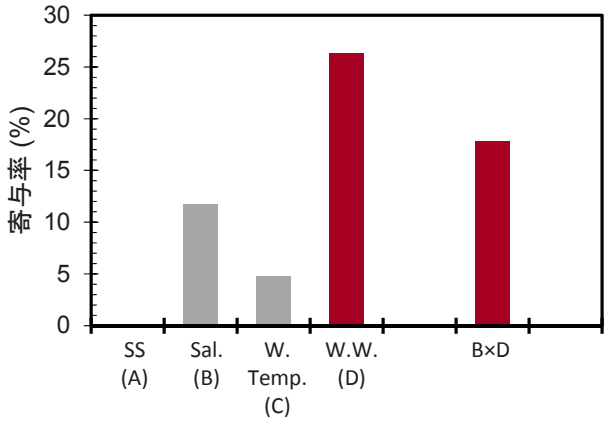

図 4　成長力に対する汽水域の自然的水質要因と都市下水の寄与率

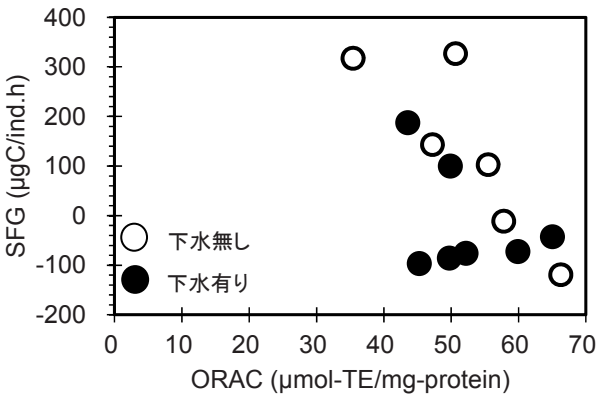

図 5　成長力と総抗酸化力の関係

また，各要因の主効果に加えて要因間の複合作用を明らかにするため，交互作用も考慮した分散分析を行った。成長力に対する効果の分散分析結果とその寄与率をそれぞれ**図 4** に示す。成長力は都市下水の主効果及び都市下水と塩分の交互作用を受けることが明らかとなった（p<0.05）。自然的水質要因の一つである塩分に主効果はないものの，都市下水に曝された場合は交互作用が発生し，塩分も成長力に影響を与える要因となることが明らかになった。

3.3 成長力と生体内バイオマーカーの関係

図 5 に SFG と総抗酸化力（ORAC）の関係を示す。ORAC が高くなると成長力は低くなる傾向を示した（p<0.05）。ここでは，成長力に寄与する都市下水の有無に着目してみる。自然的水質要因にのみ曝した系では，ORAC と SFG に強い負の相関性が得られた（p<0.01）。一方で，都市下水に曝した系では，ORAC と SFG には相関がみられなかった（p>0.05）。二枚貝はアンモニアに曝されると体内の活性酸素種の生成が促進されることが知られている[12]。より多くの活性酸素を消去するために抗酸化成分が消費されて，合成した抗酸化成分を維持することができず，ORAC 値が低くなったものと考えられる。このように，成長力と総抗酸化力の関係から ORAC の解釈が可能になると考えられる。

4. 結論

本研究では，炭素収支に基づく成長力評価手法をヤマトシジミに適用し，汽水域の水質がヤマトシジミの成長力に及ぼす影響を調べた。また，ヤマトシジミの総抗酸化力（ORAC）と成長力の関係を整理した。得られた知見を以下に示す。

1) 自然的水質要因（SS，塩分，水温）はヤマトシジミの成長力に影響しなかったが，都市下水（5 倍希釈）は影響を及ぼした。また，成長力に対して，塩分と都市下水の交互作用が確認された。
2) ヤマトシジミの成長力と総抗酸化力の間にはおおむね相関がみられた。ただし，都市下水が存在する場合については，今後さらに整理する必要がある。

参考文献 1) Gorbi *et al.* (2008) *Marine Environmental Research* 65, 34–49. 2) Hagger *et al.* (2008) *Marine Pollution Bulletin* 56, 1111–1118. 3) Regoli *et al.* (2014) *Marine Environmental Research* 93, 106–117. 4) Grajeda-Iglesias *et al.* (2014) *Food chemistry* 194, 749–757. 5) 池田ら (2016) 土木学会論文集 B2 (海岸工学) 72(2), I_1351-I_1356. 6) Widdows *et al.* (1988) *Marine Ecology* 46, 113−121. 7) 増子ら (2018) 水環境学会誌 (審査中). 8) Chandurvelan *et al.* (2012) *Aquatic Toxicology* 124−125, 114−124. 9) 片山ら (2016) 土木学会論文集 G (環境) 72(4) 61−69. 10) 石田ら (1978) 水産増殖 19(4), 167−182. 11) 池田ら (2017) 土木学会論文集 B2 (海岸工学) 73 (2), I_1219−I_1224. 12) Chetty *et al.* (1995) *Joumal of Environmental Biology* 16, 137–142.

O7-10

題名:製鋼スラグを用いた藍藻類沈降処理法の検討

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キーワード:製鋼スラグ, *Microcystis aeruginosa*, *Daphnia magna*, 酸抽出液,遊泳阻害試験

抄録

閉鎖性水域の富栄養化により引き起こされる藍藻類の大量発生(アオコ現象)は, 景観の悪化, 魚の斃死, 水道水のろ過障害による経済損失を引き起こすため, 改善が求められている. 本研究では, 製鋼スラグから抽出した成分(抽出液)によって, 藍藻類 *Microcystis aeruginosa* への沈降効果の有無を検証した. 同時に, 藍藻類への沈降効果が現れる添加量の検討も実施した. さらに, 製鋼スラグからの抽出液による水生生物への影響を確認するために, *Daphnia magna* を用いた遊泳阻害実験を実施した. 藻類沈降実験の結果, 製鋼スラグでは, 酸抽出中和液 0.8 mL を添加したときに高い沈降除去効果を得られた. *Daphnia magna* を用いた遊泳阻害実験の結果, 製鋼スラグ酸抽出中和液において影響が無いとは言えなかった. これより,製鋼スラグを用いた藍藻類の沈降処理が可能であることが提案できたが, 実用するためには毒性を弱める工夫が必要となる.

1. はじめに

閉鎖性水域の富栄養化により引き起こされる藍藻類の大量発生(アオコ現象)は, 景観の悪化, 魚の斃死, 水道水のろ過障害による経済損失を引き起こすため, 改善が求められている[1][2]. 現状のアオコ対策では, ほぼ全てが湖沼付近に施設建設が必須であり, 維持管理コストがかかることが問題点として挙げられる[3]. しかしながら, 中国の大湖で$\mathbf{Mg(OH)_2}$を散布することでアオコの沈降が報告されたことや[4], PAC(ポリ塩化アルミニウム)とカゼインを用いて, *Microcystis aeruginosa* を凝集除去できた報告[5]があることから, 閉鎖性水域に薬剤を散布する対策が有効であると考えられる. また, 鉄を用いた凝集沈殿も実施されており, ポリシリカ鉄(PSI)を用いて懸濁質を凝集させた報告がある[6]. そこで本研究では, 薬剤と比較してより安価に入手が可能であり, 既存研究より沈殿凝集に寄与する可能性がある Mg, Al, Fe を含む産業廃棄物である製鋼スラグに着目し, その中に含まれる成分により沈降除去が可能であるかを実験室にて検討することにした. また, 閉鎖性水域への散布を仮定した場合, 水生生物への影響が懸念される. そこで本研究では, 動物プランクトンである *Daphnia Magna* を用いて影響評価を行うことで, 産業廃棄物中の成分が生態系に及ぼす影響を評価した.

2. 実験方法

2.1 藻類沈降実験

まず, 製鋼スラグを用いて藻類の沈降除去が可能であるかを検証するために, 藻類沈降実験を実施した. 表 1 に示す異なる形態の製鋼スラグを, 藻類懸濁液 50ml が入っている試験管に添加することで, 沈降効果の有無を検討した. 実験条件は, 対数増殖期に該当している *Microcystis aeruginosa*(NIES-102 株)の細胞を使用した. また, 初期クロロフィル a 濃度を 1,500~2,500 μg/Lとした. 添加後 1, 2, 24 時間後の水温, pH, 藍藻類の細胞を含んでいる懸濁液(以下藻類懸濁液とする)の上澄み 10 mL におけるクロロフィル a 濃度を測定した.

表 1 添加方法

ケース1	直接添加
ケース2	水抽出産廃混液-中和後懸濁液 (以下水抽出中和液)
ケース3	酸抽出産廃混液-中和後懸濁液 (以下酸抽出中和液(A液))
ケース4	酸抽出ろ液-中和後懸濁液 (以下酸抽出中和液(B液))
ケース5	酸抽出ろ液-中和後ろ液 (以下酸抽出中和液(C液))
ケース6	酸抽出ろ液-中和後ろ過物懸濁液 (以下酸抽出中和液(D液))

次に, 藍藻類の沈降効果が確認された製鋼スラグの形態について, コスト削減を目的として, 藍藻類の沈降除去が見られる製鋼スラグの最少添加量の推定を実施した. 実験条件は, 初期クロロフィル a 濃度を 500 μg/L に統一し, 水温 25 ℃と設定した. また, 光による沈降効果のばらつきを排除するために暗条件で実験を実施した. 添加後 24, 48 時間後の水質(水温, pH, ORP, 藻類懸濁液の上澄み 10 mL におけるクロロフィル a 濃度)を測定した. 本実験において, 48 時間後の上澄み 10 mL におけるクロロフィル a 濃度が富栄養湖の基準となる 10 μg/L 以下である状態を沈降除去効果があると見なした.

2.2 *Daphnia magna* を用いた遊泳阻害実験

藍藻類の沈降除去効果が確認できた形態において，最少量と推定された前後の量を添加し，水生生物に影響を及ぼさないかを確認することを目的として実施した．実験条件は，温度を 25 ℃，照度を 2500 lux，明暗周期を 16 L/8 D とした．実験には，生後 24 時間以内の *Daphnia magna* の個体を 1 つのコニカルビーカーにつき10匹用いた．*Daphnia magna* に産業廃棄物中の成分を暴露して 0，24，48 時間後に水質(水温，pH，DO)および遊泳阻害が生じた *Daphnia magna* の個体数を測定した．

3. 実験結果と考察

まず，製鋼スラグの形態の違いによる藍藻類沈降実験の結果を表 2 に示す．

表 2 形態の違いによる藻類沈降実験結果

	ケース1	ケース2	ケース3
0.8ml	×	○	○
1.6ml	×	○	○
4.0ml	×	○	○
＼	ケース4	ケース5	ケース6
0.8ml	○	○	×
1.6ml	○	○	×
4.0ml	○	○	×

表 2 より，ケース 2~5 において，沈降効果が確認された．沈降効果が見られた理由として，産業廃棄物に含まれるカオチン(陽イオン)が抽出され，中和の過程で生じた金属水酸化物が藍藻類沈降効果に影響している可能性が考えられる．また，今後の実験結果についてはケース 3 およびケース 4 について記述する．

次に沈降が確認されたケースについて最小添加量の推定実験を実施した．製鋼スラグ酸抽出中和液(A 液)を藻類懸濁液に添加した実験結果を図 1 に示す．

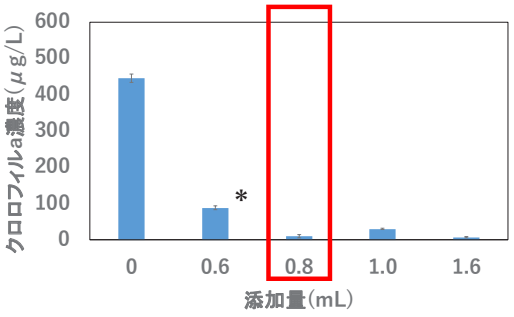

図 1 製鋼スラグ酸抽出中和液(A 液)での実験

(n=2～4, AVE.±S.E.) ＊:Dunnett 法にて 5%有意

製鋼スラグ酸抽出中和液(A 液)を添加した場合において，48 時間後のクロロフィル a 濃度が 10 μg/L 以下を達成している区間は，0.8 mL 添加した場合であった．0.8 mL 添加した場合における 48 時間後のクロロフィル a 濃度を対照区として，多重比較(Dunnett 法)を実施した．製鋼スラグ酸抽出液(A 液)を添加した区間において，0.6 mL 添加した区間と 0.8 mL 添加した区間との間で，有意水準 5%において有意な差が見られた．この結果から，本研究において，藻類の沈降除去効果が見られる製鋼スラグ酸抽出中和液(A 液)の量は，0.8 mL と推定できた．

最後に，遊泳阻害実験を製鋼スラグ酸抽出中和液(A 液)を添加し実験を実施した．添加 48 時間後の反応率(遊泳阻害率)を確認した結果，50mL のカルキ抜き水道水に対して製鋼スラグ酸抽出中和液(A 液)では，1.0 mL において 38.3%を示した．この結果を用いて probit 法を用いることで *Daphnia magna* に対しての EC50 に相当する天下量の推定を実施した．その結果，1.2mL と推定できた．

4. 結論

形態の違いによる藻類沈降実験の結果，産業廃棄物を酸抽出した場合において，高い藍藻類沈降効果が見られる結果となった．このことより，製鋼スラグから抽出したカチオンおよび中和の過程で生じた金属水酸化物が藻類の沈降に強く影響している可能性が示唆された．さらに，藍藻類が沈降した形態において，藻類の沈降除去効果が見られる最少添加量の推定を実施し製鋼スラグ酸抽出中和液(A 液)に関しては，0.8 mL と推定できた

遊泳阻害実験の結果，製鋼スラグ酸抽出中和液において，Daphnia magna に影響を及ぼしたことより，製鋼スラグ酸抽出中和液(A 液)の水生生物に対しての影響は無いとはいえない結果となった．

製鋼スラグを用いた藍藻類の沈降処理が可能であることは提案できたが，実用するためには，毒性を抑える工夫が必要となる．

引用文献

[1] 岩井重久，内田千尋 石灰による底質改善の現状と可能性(1)，環境技術，Vol.17, No.12, pp36-38, 1988

[2] 高村典子 アオコ研究におけるこれまでの取り組みと湖沼管理に向けた今後の課題，Vol.37(A), No.5, pp156-159, 2014

[3] 農林水産省 農村振興局農村環境課，農業用貯水池におけるアオコ対応参考図書，pp73, 2012

[4] 神田玲子，稲森隆平，中澤雄太，鈴木理恵，村上和仁，稲森悠平;水酸化マグネシウムを活用した環境改善手法の開発，用水と排水，Vol.56, No.3, pp52-58, 2014

[5] 有村一雄，橋本雅司，前英雄，福田哲郎，高尾典子，角野浩二，佐々木紀代美，下濃義弘; アオコ凝集剤の開発，山口県産業技術センター研究報告書，19 号，pp19-21, 2007

[6] 鈴木祥弘，丸山俊朗: 鉄塩凝集剤と乳製カゼインを用いた凝集・泡沫分離法による懸濁物除去に関する基礎的研究，水環境学会誌，Vol.24, No.5, pp317-324, 2001

O7-11

霞ヶ浦を水源とする新たな浄水処理システムの実証実験（Ⅰ）

－促進酸化処理の処理性及び運転条件の検討－

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キーワード：浄水・排水処理技術

抄録

茨城県企業局では 10 浄水場で用水供給事業を行っており，その内 6 浄水場が霞ヶ浦を取水源としている。この霞ヶ浦は，流域人口の増加や地形的要因等により，1960 年代から富栄養化が進行し，有機物濃度が高い状況で推移していることから，各浄水場においては，夏期のトリハロメタン対策と，冬期から春期に発生するかび臭物質対策が大きな課題となっている。そこで，当局では，2009 年から 2011 年にかけて民間企業との共同研究を実施した結果，帯磁性イオン交換樹脂処理及び促進酸化処理が霞ヶ浦を水源とする浄水処理に有効であると判断した。この結果を踏まえ，霞ヶ浦浄水場に，これらの処理を組み合わせた新たな浄水処理システムの実験プラントを建設し，2014 年 12 月から実証実験を行っている。今回，これまでの実験によって得られた，本処理システムにおける処理効果，特に促進酸化処理の処理性について報告する。

1. はじめに

茨城県企業局が運営する全 10 浄水場のうち 6 浄水場が霞ヶ浦を取水源としているが，富栄養化を起因とする様々な浄水処理障害が生じている。中でも冬期から春期にかけて発生する高濃度のかび臭物質（1993～2017 年における 2-メチルイソボルネオール（以下，「2-MIB」という。）の最大値 910ng/L）への対応，また塩素との反応によってトリハロメタン（以下，「THM」という。）を生成するとともに夏期に高い値となるトリハロメタン生成能（以下，「THMFP」という。）の除去が大きな課題となっている。

このような霞ヶ浦を取水源とする霞ヶ浦浄水場においては前段に生物処理，後段に粒状活性炭処理を導入して対応してきた。しかし，生物処理は維持管理費用が高額であるとともに冬期にその処理性が低下する等の課題があり，また，粒状活性炭処理も年々再生費用が増加する傾向にある。こういった課題に対応するため，当局は 2009 年から 2011 年まで民間企業との共同研究を行い，溶解性有機物（以下，「DOC」という。）の高い除去能を有する帯磁性イオン交換樹脂処理（以下，樹脂処理）と，低水温期においても高いかび臭除去能を有し，かつ臭素酸生成抑制効果を併せ持つ促進酸化処理（以下，「AOP」という。）が有効であると判断した。この結果を踏まえ，既存の凝集沈殿・砂ろ過処理に加え，樹脂処理と AOP を導入することを目的に 2014 年 12 月から実証実験を行っているところである。

2. 実験・調査方法

2.1 実験プラント運転条件等

実験プラントの処理フローは図 1 のとおりである。

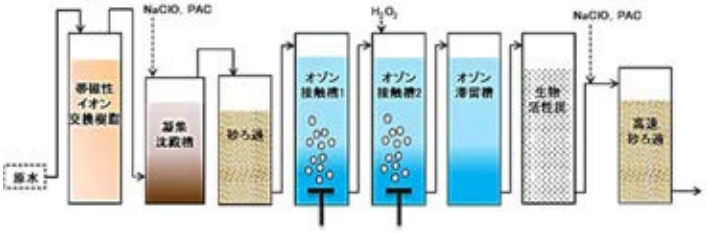

図 1　実証実験における処理フロー

帯磁性イオン交換樹脂は，イオン交換によって原水中の DOC を除去するものであり，塩水で再生し，繰り返し利用が可能である。なお樹脂は，処理水量に対する再生樹脂量の比（BVTR：Bed Volume Transfer Rate）が 10,000 となるよう引き抜き，再生，投入を行った。AOP はオゾンと過酸化水素の併用により，オゾンよりも酸化力の強いヒドロキシラジカルの生成を促進し，有機物の酸化分解力の向上を図るものである。このため，原水におけるかび臭物質濃度が高くなる冬期から春期にかけては AOP を，その他の期間はオゾン単独処理を行うこととした。AOP における過酸化水素の添加はオゾン接触槽

2（図 1）のみとした。なお，過酸化水素はオゾン注入率に対する物質量比（以下，「モル比」という。）で制御し添加しており，オゾン接触槽全体に対する過酸化水素の注入率は式 1 のとおりである。

$$H_2O_2\text{注入率}\ (\text{mg/L}) = \frac{34}{48} \times \text{モル比} \times O_3\text{注入率}\ (\text{mg/L}) \times \frac{1}{2} \quad \text{（式 1）}$$

また，本実験における目標値は，表 1 の通りである。

表 1 実証実験における目標値

項目	対象処理水	目標値
2-MIB	オゾン又は AOP 処理水	1 ng/L 以下
臭素酸	BAC 処理水	0.005 mg/L 以下
THM	高速砂ろ過水	0.03 mg/L 以下
72hrTHM※	高速砂ろ過水	0.07 mg/L 以下

※高速砂ろ過水に次亜塩素酸ナトリウムを添加し，恒温槽で 72 時間静置した後の THM 濃度

2.2 かび臭物質添加実験

当該処理システムにおける高濃度かび臭物質の処理性を調査するため，冬期にかび臭物質添加実験を行った。添加実験は市販の 2-MIB 及びジェオスミン標準品を超純水に溶解し，実験プラントの凝集沈殿槽（図 1）に想定した濃度（冬期 250～2,000ng/L，夏期 10～1,000ng/L）となるように添加し，オゾン注入率（1.0～3.0mg/L）及び過酸化水素のモル比（0～10）を変化させ，かび臭物質の処理性，臭素酸の抑制効果等を調査した。なお，当該実験においては，高濃度かび臭物質による負荷を避けるため，生物活性炭（以下，BAC）処理塔以降へは通水しなかった。

2.3 給水末端を想定した 72hrTHM

給水末端を想定した 72hrTHM 調査を夏期（7~9 月）は月 2 回，他の期間は月 1 回の頻度で行った。なお，72hrTHM は，100mL ガラスびんに高速砂ろ過水を満水に採り，次亜塩素酸ナトリウムを採水から 72 時間後の残留塩素濃度が 0.2mg/L 程度となるように添加し，採水時の水温で暗所で 72 時間恒温静置し THM 濃度を測定して求めた。

3. 結果及び考察

3.1 かび臭物質添加実験

かび臭物質添加実験は前述のとおり 2-MIB 及びジェオスミンを添加して行ったが，ここではより除去性が低い 2-MIB について考察する。2-MIB 添加濃度 1,500ng/L，オゾン注入率 3.0mg/L の条件における，AOP とオゾン単独処理を比較すると，図 2 のとおり，オゾン単独処理では滞留槽で 577ng/L 残留したのに対し，AOP（モル比 5.0）では定量下限値（1ng/L）以下まで処理された。

一方，臭素酸濃度は，図 3 のとおりオゾン単独処理では 0.008mg/L 生成したのに対し，AOP では 0.003mg/L と，半分以下の生成量であった。これらのことから，オゾン単独処理と比べ，AOP の方が 2-MIB 除去能が高く，臭素酸抑制に優れることが明らかとなった。

これらの条件の他にオゾン注入率及びモル比を変化させてかび臭物質添加実験を実施した結果，冬期においては，モル比 5.0，オゾン注入率を 3.0mg/L とすることにより 2-MIB 添加濃度 2,000ng/L まで目標値を達成することが可能であった。

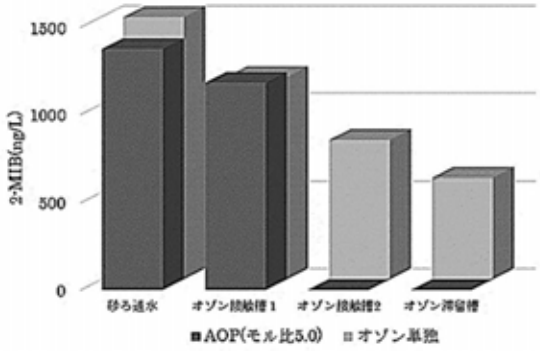

図 2 かび臭添加実験における 2-MIB 除去効果（2-MIB 添加濃度 1,500ng/L，オゾン注入率：3.0mg/L）

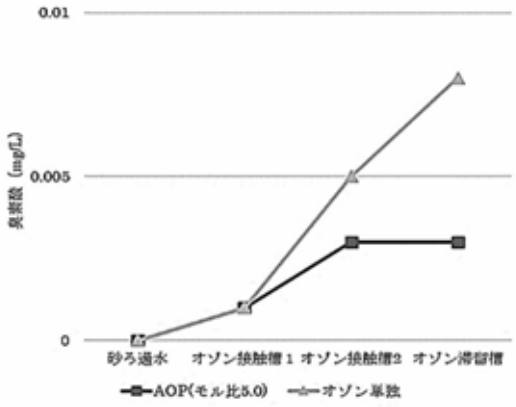

図 3 かび臭添加実験における臭素酸抑制効果（2-MIB 添加濃度 1,500ng/L，オゾン注入率：3.0mg/L）

3.2 72hrTHM 調査等結果

72hrTHM の推移を図 4 に示す。72hrTHM は水温の高い夏期（7~8 月）に高くなり，目標値（0.07mg/L）を超

過する結果となった。また，夏期の 72hrTHM は年々増加傾向にあり，2017 年 7 月には水質基準値（0.1mg/L）を超過した。

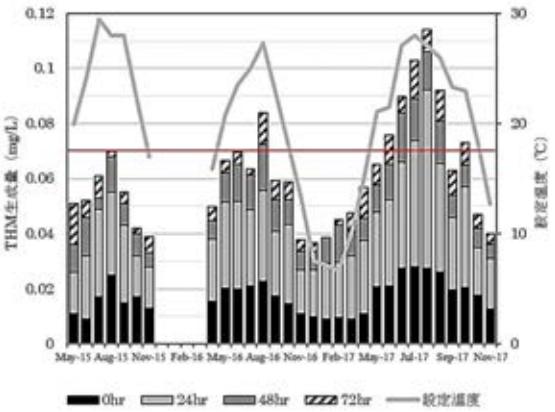

図 4　72hrTHM 調査結果

また，2017 年の夏期にオゾン単独処理と AOP における THMFP の比較結果を表 2 に示す。なお，砂ろ過水の THMFP は，0.036mg/L であった。

表 2　2017 年夏期における THMFP 調査結果

運転条件	AOP	オゾン単独
O_3 注入率(mg/L)	2.5	1.0
モル比	5	－
臭素酸濃度(mg/L)	0.003	0.003
THMFP(mg/L)	0.055	0.033

AOP 及びオゾン単独処理のいずれも臭素酸濃度は 0.003mg/L であった。夏期はオゾン単独処理を基本とするが，夏期に高濃度のかび臭物質が発生した場合は，臭素酸の抑制等の観点から AOP への切り替えが必要になると考えられる。しかし，表 2 のとおり，AOP の方が THMFP が高くなることから，この点について注意が必要である。

3.3　日常運転の結果（かび臭物質，臭素酸）

以上の実験結果を踏まえ，表 3 の運転指標を定め，かび臭物質濃度が高くなる冬期から春期の期間を AOP，その他の期間をオゾン単独処理として，連続運転した。その結果を図 5 に示す。全期間において 2-MIB 及び臭素酸の目標値を概ね達成することができていることから，AOP とオゾン単独処理を適切に切り替えて運転することで，かび臭物質の除去及び臭素酸の抑制が安定的且つ効率的に行えることが明らかとなった。

表 3　実証実験結果に基づく運転指標

かび臭濃度 (ng/L)	水温 (℃)	運転条件	O_3 注入率 (mg/L)	モル比
1,500 以上	10 未満	AOP	2.0~3.0	5~10
500~1,000			2.0~2.5	5
100~500			1.5~2.5	2.6~5
10~100			1.6~2.0	5~10
5~10	10 以上		1.5	2.6~5
1~5		O_3 単独	1.0~1.1	－

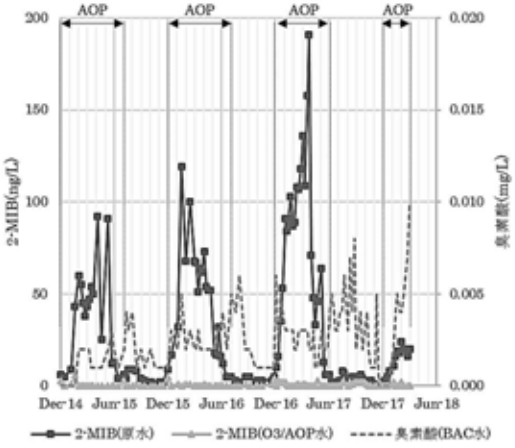

図 5　日常運転におけるかび臭及び臭素酸の推移

4. 結論

かび臭物質添加実験及び 72hrTHM 等の調査から，以下のことが明らかとなった。

(1) AOP はオゾン単独処理と比較して，かび臭物質除去及び臭素酸抑制に優れているが，処理水中の THMFP 及び 72hrTHM が高くなる傾向が見られる。

(2) 冬期においては AOP 処理により臭素酸の生成を抑制しながら最大 2,000ng/L の 2-MIB を除去することが可能である。

(3) 給水末端を想定した 72hrTHM は夏期に目標値を超過しており，さらに経年的に高くなる傾向が見られる。

AOP のかび臭物質除去及び臭素酸抑制に対する有効性は確認できたが，夏期における 72hrTHM の抑制対策が課題である。このため，今後，溶解性有機物の低減対策について検討するとともに，実運転を見据えた運転条件等について検討したいと考えている。

O7-12

霞ヶ浦を水源とする新たな浄水処理システムの実証実験（Ⅱ）

−帯磁性イオン交換樹脂の処理特性−

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キーワード:浄水・排水処理技術

抄録

茨城県企業局では10浄水場で用水供給事業を行っており，その内6浄水場が霞ヶ浦を取水源としているが，霞ヶ浦の富栄養化の進行により，各浄水場では夏期のトリハロメタン対策と冬期のかび臭物質対策が大きな課題となっている。このため，霞ヶ浦浄水場において，帯磁性イオン交換樹脂処理及び促進酸化処理による実証実験を行っているが，帯磁性イオン交換樹脂処理がトリハロメタン生成能の除去に有効であることを確認した。

1. はじめに

茨城県企業局では 10 浄水場で用水供給事業を行っており，その内6浄水場が霞ヶ浦を取水源としている。この霞ヶ浦は，流域人口の増加や地形的要因等により，1970 年頃から富栄養化が進行し，有機物濃度が高い状況で推移していることから，霞ヶ浦を取水源とする浄水場においては，夏期のトリハロメタン対策と，冬期から春期に発生するかび臭原因物質対策が大きな課題となっている。

そこで，茨城県企業局では，2009 年から 2011 年にかけて民間企業との共同研究を実施した。その結果，当局は，帯磁性イオン交換樹脂処理（以下，「樹脂処理」という。）と促進酸化処理が，霞ヶ浦を水源とする浄水処理に有効であると判断した。この結果を踏まえ，霞ヶ浦浄水場に，これらの処理を組み合わせた新たな浄水処理システムの実験プラントを建設し，2014 年 12 月から実証実験を行っているところである。今回，この実験によって得られた樹脂処理の効果について報告する。

2. 方法

実証実験の処理フローは図1のとおり，樹脂処理（124 ㎥/日）→凝集沈殿処理（80 ㎥/日）→砂ろ過処理（50 ㎥/日）→促進酸化（オゾン）処理（40 ㎥/日）→生物活性炭（以下，「BAC」という。）処理（40 ㎥/日）→高速砂ろ過処理（40 ㎥/日）となっており，本実験の目標値は表 1 のとおりとした。

樹脂処理に使用する樹脂は平均粒径 200 μm 程度の磁性を帯びたイオン交換樹脂で，溶解性有機物の選択性が優れるとともに，磁性によって集塊化するため，沈降性に優れる。なお，樹脂（110L）は，処理水量の比（BVTR：Bed Volume Transfer Rate）が 10,000 となるよう一定量引き抜いた（12L/日）。引き抜いた樹脂は，10%塩化ナトリウム水溶液で再生し，繰り返し使用した。

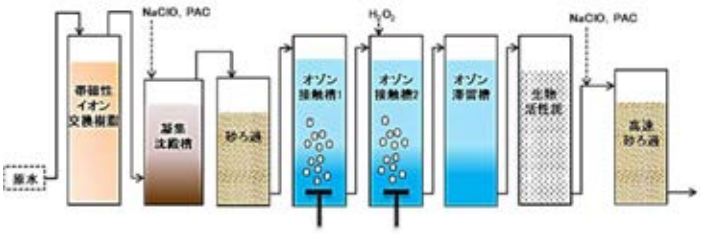

図 1　実証実験における処理フロー

表 1　実証実験目標値

項目	対象処理水	目標値
2-MIB，ジェオスミン	オゾン処理水	1ng/L 以下
臭素酸	BAC 処理水	0.005mg/L 以下
THM	高速砂ろ過水	0.03mg/L 以下
72hrTHM※	高速砂ろ過水	0.07mg.L 以下

※高速砂ろ過水に次亜塩素酸ナトリウムを添加し，恒温槽で72時間静置後の THM 濃度

3. 結果と考察

(1) 樹脂処理の処理性

図2のとおり，原水中のトリハロメタン生成能（以下，「THMFP」という。）は0.054～0.094mg/L で推移したのに対し，樹脂処理水は 0.032～0.068mg/L で推移し，除去率の平均は 30%であった。また，原水中の DOC は 2.6～3.8mg/L で推移したのに対し，樹脂処理水は 1.9～

2.8mg/L で推移し，除去率の平均は 23%であった。

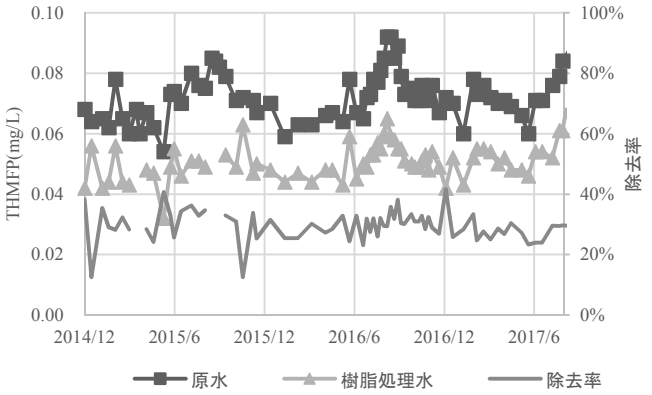

図 2　THMFP の変動

促進酸化処理及びオゾン単独処理について，それぞれ約2週間程度，樹脂処理を停止し，各処理工程における THMFP の挙動を調査した。その結果を図3に示す。原水濃度に対する各処理工程までの除去率は，どちらの処理も樹脂処理を行った方が高い傾向が見られた。このことから，樹脂処理によって BAC への流入負荷を減らすことが出来ると考えられるため，BAC の交換サイクルも長く出来ると考えられた。

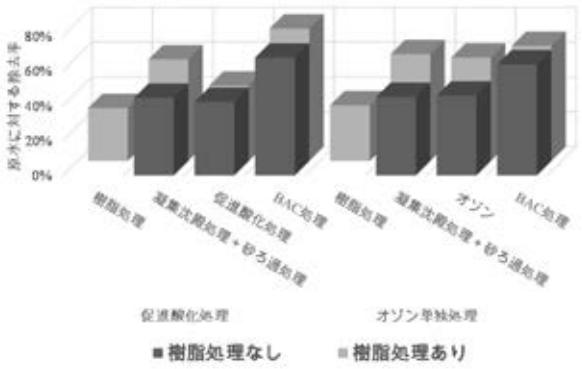

図 3　処理過程ごとの THMFP 除去率

(2) BVTR の影響

給水末端を想定したトリハロメタン生成量を調査するため，高速砂ろ過処理水に必要な次亜塩素酸ナトリウムを添加し，採水時の水温で3日間，恒温静置した際のトリハロメタン生成量（以下，「72hrTHM」という。）を調査した。その結果，夏期における 72hrTHM は，図 4 のとおり年々増加傾向を示した。オゾン処理水までの THMFP の除去率等の指標については，経年的な低下傾向は認められていないことから，BAC の THMFP の除去能が低下していると考えられた。

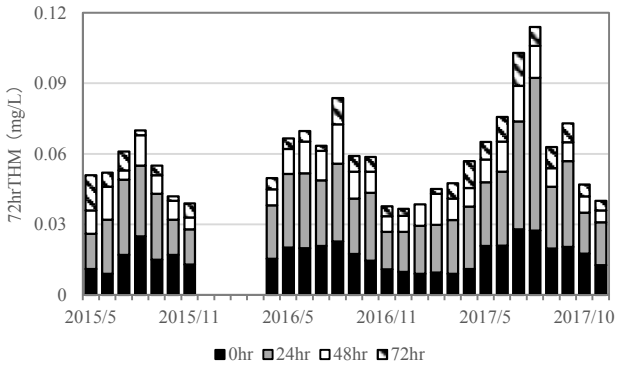

図 4　72hrTHM の変動

このため，夏期におけるトリハロメタン生成量の抑制が必要であると考え，樹脂処理における THMFP 等の除去率の向上について検討を行った。

テーブル試験によって所定の BVTR となるよう原水と樹脂を接触させ，BVTR の変化が THMFP の除去量に，どの様に影響するか調査した結果を図 5 に示す。BVTR が低くなる程，THMFP の除去量が大きくなっていることから，現状の BVTR10,000 より低い条件で運転することにより，夏期のトリハロメタン生成量の低減化が図れると考えられた。

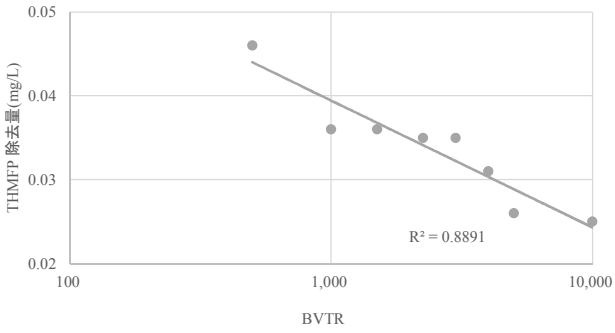

図 5　BVTR と THMFP 除去量の関係

更に，前述の樹脂接触水に対し段階的に PAC を添加し，THMFP の除去量の変化を調査した結果を図 6 に示す。なお，THMFP の除去量は，原水の THMFP から，各 PAC 処理後の THMFP を減じて算出した。全ての BVTR 条件において，PAC 注入率を増加させるに従い，THMFP の除去量が増加する傾向が見られた。これらのことから，BVTR 及び PAC 注入率を適切に設定することにより，更なる THMFP の低減化が図れることが明らかとなった。

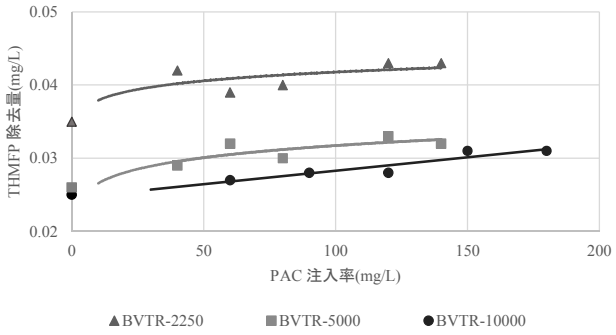

図 6　PAC 注入率と THMFP 除去量の関係

以上の結果を踏まえ，2017 年8月 28 日から 11 月 20 日の間（9月 11～28 日を除く），実証実験プラントの樹脂処理の BVTR を 2,500 に変更し，調査を行った。

BVTR の変化が 72hrTHM にどの様な影響を及ぼすか調査するため，水温が同程度となるよう考慮し，2017 年８月 21 日に BVTR10,000 で，同年９月４日に BVTR2,500 で 72hrTHM を調査した結果を図７に示す。

図のとおり，BVTR10,000 における 72hrTHM が 0.092mg/L と目標値を超過しているのに対し，BVTR2,500 では 0.063mg/L と目標値を満足した。

前述のとおり，BAC は通水開始時と比べ，溶解性有機物等の除去能の低下が見られており，BVTR10,000 の条件では BAC の使用期間は約3年と評価している。有効使用期間は，72hrTHM の濃度も考慮して評価するが，BVTR を 2,500 にすることによって 72hrTHM の低減が図れることが明らかとなったことから，BAC 使用期間をより延長することが可能であると示唆された。

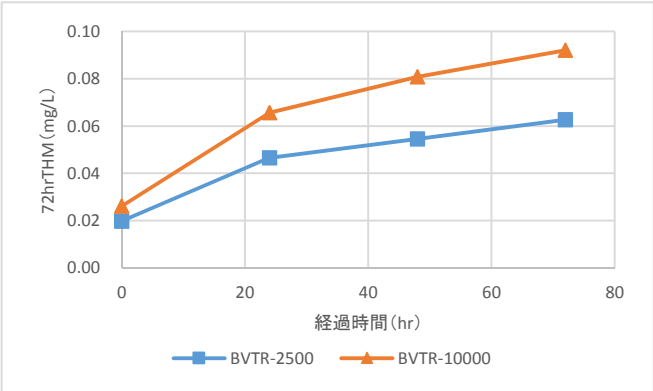

図 7　BVTR が 72hrTHM に与える影響

4. 結論

以上のことから，次のことが明らかとなった。

(1) 樹脂処理により，原水中の THMFP を平均で 30％除去出来る。

(2) 促進酸化処理，オゾン単独処理のいずれにおいても，樹脂処理を行うことにより，各処理工程での THMFP 除去率が高くなる。

(3) BVTR を低くする（再生サイクルを早くする）ことにより，樹脂処理における THMFP の除去率が向上し，高速砂ろ過水の 72hrTHM も低くなる。

樹脂処理は THMFP 等，溶解性有機物の低減化に有効であるとともに，BVTR を下げることにより，THMFP 等の除去率が向上し，BAC の有効使用期間の延長が期待出来る結果となった。

しかし，BVTR を下げると，樹脂の再生回数が増えるとともに，再生費用や廃液の処理費用が増加する。

このため，今後，BVTR を低くした連続運転を行い，データを蓄積するとともに，BAC の交換費用や樹脂処理の運転費用等を考慮し，安定的で且つ効率的な運転条件を確立したいと考えている。

O7-13

UF膜ろ過装置におけるオンライン差圧予測システムの開発

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キーワード:浄水技術, 膜ろ過, 予測, モニタリング

抄録

UF（限外ろ過）膜ろ過は素材、運転方法など様々な面から研究開発が進められ、UF 膜を用いた水処理技術は飲料水製造だけでなく、海水淡水化の前処理、廃水処理など世界各地に普及している。膜ろ過システムは既存の浄水技術と比べ維持管理が容易であるものの、原水水質や環境が刻々と変化する中、適正な運転状態を実現するにはノウハウや経験が必要である。そこで、既に開発した UF シミュレーション技術を活用し、原水や環境条件が変化した際にも UF 膜装置の差圧上昇をリアルタイムで定量的に予測する運転監視システムを開発した。これにより、差圧上昇時に必要な薬品洗浄（CIP）のタイミングを事前に把握可能となるため、生産水計画の調整や薬液・作業員の事前手配を可能とし、さらに適切なタイミングでの CIP 実施により、過度な CIP による膜の化学劣化の抑制や CIP 遅延による膜性能の悪化を抑制可能となる。

1. はじめに

UF(限外濾過)膜ろ過は素材、運転方法など様々な面から研究開発が進められ、UF 膜を用いた浄水処理は世界各地に広く普及している。

外圧型中空糸 UF 膜モジュールのろ過イメージを Figure 1 に示す。原水をモジュールに加圧供給することによって、原水中のコロイド物質、細菌、病原性微生物などの懸濁物質は中空糸膜表面に捕捉され、中空糸膜内側から清澄な膜ろ過水が得られる。このとき、同時に膜表面および細孔内部にて、目詰まり（ファウリング）が起こり、膜の運転性能指標の一つである膜間差圧（以下、差圧）が上昇し、性能が低下してしまう。

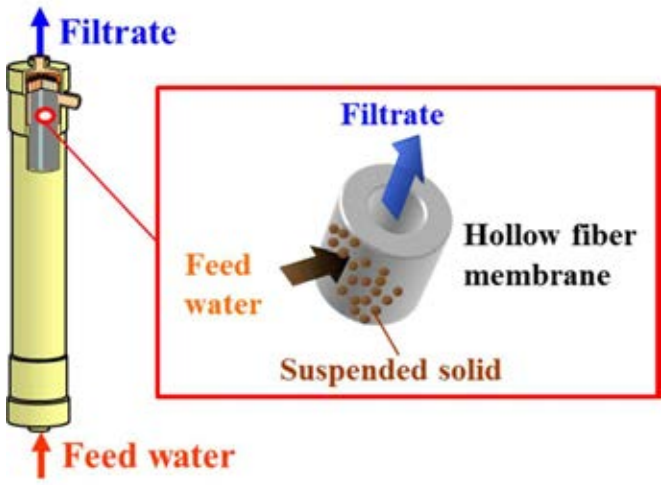


Figure 1 Image of UF membrane filtration

そこで、ろ過水などの清澄水を膜のろ過水側から原水側へ逆流させる「逆圧洗浄（Backwash）」や空気を膜の一次側に供給して膜の汚れを取る「空気洗浄（Air wash）」などの物理洗浄を定期的に実施し、膜性能の回復・維持を図るのが一般的である。しかし、物理洗浄のみでは洗浄が不十分であり、ファウリング物質の完全除去が困難な場合が多い。その際には、1 日 1 回程度の頻度で、有効塩素濃度(以後、塩素)300 mg-Cl_2/L 程度の次亜塩素酸ナトリウムを含む薬液で実施する薬液強化逆洗（CEB）、運転日数の経過と共にさらにファウリングが進行している際には、1 年に数回程度の頻度で、高濃度の塩素 3,000 mg-Cl_2/L や塩酸 0.1 N などを用いた薬液洗浄（CIP）を行い、膜の透水性能を回復させる。このように UF プロセスの設計は、膜とファウリング物質の複雑な相互作用、物理洗浄、及び化学洗浄の頻度に起因しているため、ファウリング成長を予測することは容易ではなく、深刻かつ敏感な問題である。 そこで我々は少量(約 5L）の原水を用いたラボ膜ろ過試験により、ろ過中に蓄積した抵抗である δA、逆洗で回復しない抵抗の上昇度 δB_{bw}、空洗で回復しない抵抗の上昇度 δB_{aw} といった原水由来のファウリングパラメータ（Figure 2 参照）を取得し、ファウリングパラメータをろ過理論や化学反応速度論などの

様々な理論を考慮したシミュレーションプログラムに組み入れることで差圧上昇予測を実施する手法を開発した[1]。

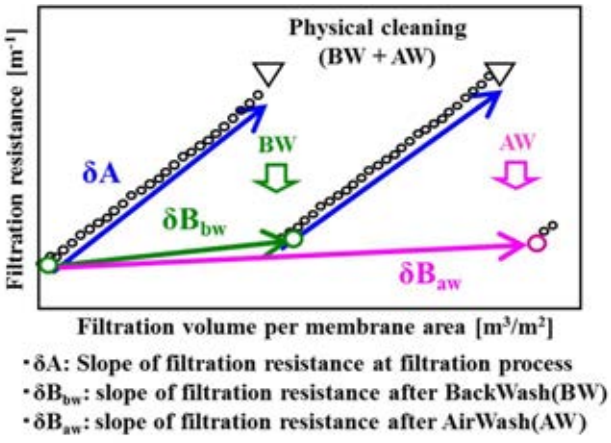


Figure 2 Fouling parameter with lab filtration test

しかし、刻々と変化する原水水質に対してオンラインで UF 膜装置の運転状況に併せて差圧予測を実施するためには、高頻度のラボ膜ろ過試験によるファウリングパラメータ取得が必要となるが、現場で実施困難である。

そこで今回、原水および運転状況においてオンラインで差圧予測を可能とする手法を開発した。

2. 方法

中空糸 UF 膜と膜モジュールの基本特性を Table 1,2 に示す。この膜モジュールには分画分子量 150,000 Da の低ファウリング性 PVDF 中空糸 UF 膜を用いた。ここで、UF 膜モジュールは外形寸法が直径 216 mm で長さ 2,160 mm、有効膜面積は 72 m^2 であり、ろ過方式は外圧式のデッドエンドろ過である。

Table 1 Specifications of PVDF Hollow Fiber UF Membrane

Item	UF membrane
Membrane material	PVDF
Molecular Weight Cut Off	150,000 Da
Outer / Inner diameter	1.4/0.9 mm

Table 2 Specifications of Membrane Module

Item	Membrane Module
Flow direction	Outside-In
Module size	216 mm(8") dia. × 2,160 mm
Membrane area	72 m^2

Figure 3 には試験に用いた UF 装置の概略図を示す。UF 装置に設置されている圧力計 PT1 と PT2 の差分を取ることで算出する実差圧データと Darcy の法則から、Figure 4 に示す 1 回のろ過工程のろ過抵抗上昇度 ΔR_A、物理洗浄後のろ過抵抗上昇度 ΔR_{aw} を算出し、それらの算出値からろ過モデルに基づき可逆ファウリングパラメータ δA と不可逆ファウリングパラメータ δB_{aw} を取得した。また UF 膜ろ過装置の物理洗浄では通常逆洗と空洗を連続で実施するため、実差圧データから δB_{bw} を直接算出できないため、これまでの知見に基づいて算出することとした。

本手法で算出したファウリングパラメータを用いてシミュレーション結果と実運転データを比較検証した。

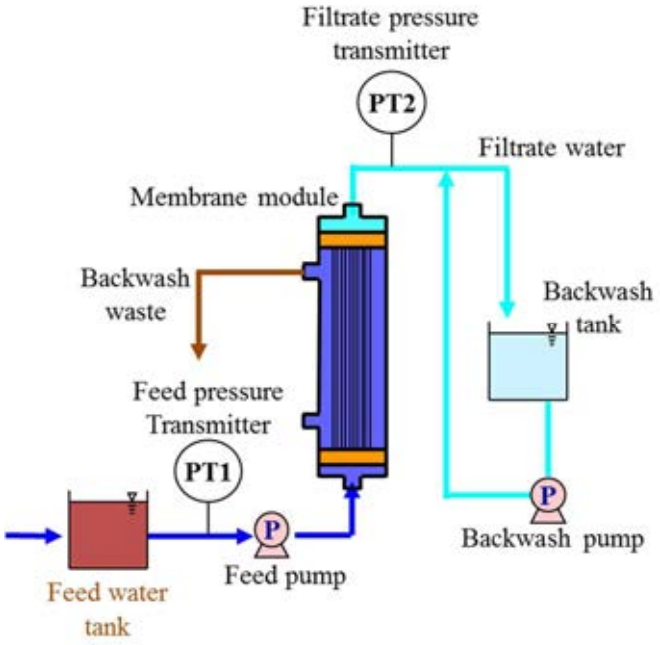
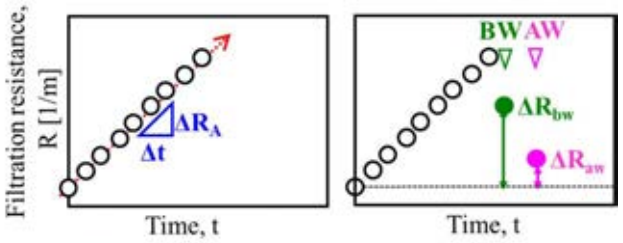


Figure 3 Schematic flow of UF test equipment



$$\Delta P = \mu \cdot J_{filt} \cdot \Delta R$$

$$\delta A = \frac{\Delta R_A}{\alpha \cdot J_{filt} \cdot \Delta t} \qquad \delta B_{aw} = \frac{\Delta R_{aw}}{\beta_{aw} \cdot J_{filt} \cdot \Delta t}$$

J_{filt} : Filtration Flux ($m^3/m^2/s$)

μ : Viscosity (Pa・s)

t : Operation time (s)

Figure 4 Calculation of UF filtrate resistance

3. 結果と考察

Figure 4, 5 と 6 には 6/19～9/20 までの UF 実差圧データとトラブル発生前、トラブル発生時、トラブル対策後のシミュレーション結果を示した。Figure 4 の通りトラブル発生前の予測結果は実差圧データと概ね一致していることが分かる。一方、Figure 5 では UF 装置の洗浄不良トラブルが発生し、実差圧が大きく上昇したが、Figure 6 のトラブル対策後、洗浄不良を解消することにより実差圧も低下した。このようなトラブル発生時とトラブル発生後の実差圧データの上昇に対し、シミュレーションも追従し、実差圧データと概ね一致した。即ち、実差圧データに基づいてファウリングパラメータを算出することで刻々と変化する原水水質及び膜のファウリング状態を把握可能であることを確認した。本シミュレーション技術とオンラインによる運転状況のデータ取得は、膜ろ過システムのトラブル発生時には要因解析に活用することも可能である。

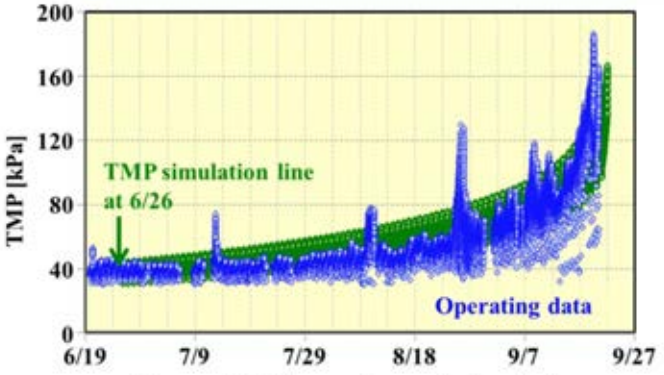


Figure 4 TMP operation and simulation prior to UF trouble

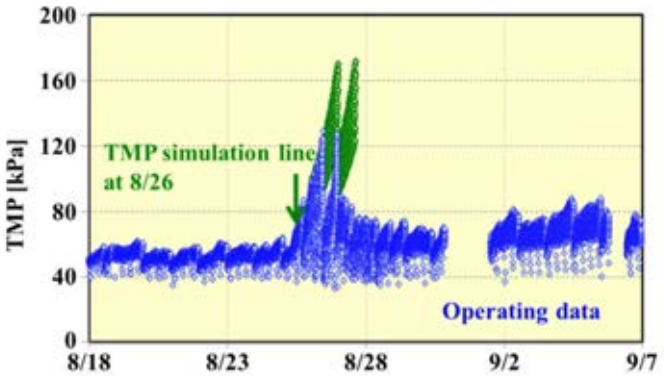


Figure 5 TMP operation and simulation at the time of UF trouble

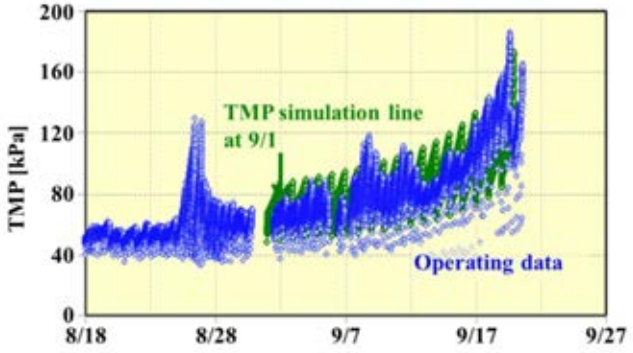


Figure 6 TMP operation and simulation after troubleshooting

4. 結論

実差圧データからファウリングパラメータをオンラインで取得する手法を構築し、取得したファウリングパラメータをシミュレーション計算式に組み込み、算出された UF 膜装置の差圧上昇予測と実差圧データが概ね一致することを確認した。本手法を搭載したオンライン差圧予測システムを開発し、刻々と変動する原水性状,UF 膜装置運転状況に合わせて定量化した CIP 実施日予測が可能となった。これにより、適切なタイミングで CIP を実施し、過度な CIP による膜の化学劣化や CIP 遅延による膜性能の悪化を抑制可能となった。

引用文献

[1] M. Shintani, T. Maeda, K. Okubo, and M. Taniguchi, Design Tool by Numerical Simulation Utilizing Laboratory Filtration Test, Conference of Aseanian Membrane Society 10, July 26-29, 2016

O7-14

Process, Organizational, and Operational Developments in Putatan Water Treatment Plant 1 from 2015 to 2017

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[1]Maynilad Water Services, Inc.

Keywords: water purification, wise use and development of water resources, water quality and pollution concerning water use

ABSTRACT

Putatan Water Treatment Plant 1 (PWTP 1) is vital in Maynilad's aim of providing new water sources to the south of Metro Manila's West Concessionaire Zone. The plant obtains its waters from the brackish Laguna Lake, which has a turbidity of 100-200 NTU and a seasonal taste and odor problem, among others. The plant has a design capacity of 150 million liters per day (MLD) at the end of 2015, but it only reached and exceeded this nameplate capacity by the middle of 2017. The challenges in lake water quality, as well as other difficulties, were addressed by these five general aspects: (1) inculcating the safety culture in the plant such as implementation of self-evaluation of the safety of the personnel's tasks, (2) improvement of process streams such as the inclusion of biological aerated filters (BAF) to address ammonia, (3) re-organization of personnel such as the addition of the technical wing, (4) maintenance schedules, which cater to the production demand, and (5) changes in operational philosophies, especially in cleaning of ultrafiltration (UF) membranes. These developments have increased the total treated water to the reservoir by a 36% difference from the 2015 to the 2017 yearly average, which means more water is provided to the community.

1. INTRODUCTION

PWTP 1 taps the Laguna Lake as its source in order to provide potable water to the residents and establishments located at the southern part of the West Concessionaire Zone of Metro Manila, such as in Las Piñas, Muntinlupa, and certain areas of Cavite.

The Laguna Lake has brackish water, with turbidity ranging from 100-200 NTU, and a total dissolved solids (TDS) level greater than 400 mg/L. Its waters may have seasonal taste and odor problems, and algal blooms may occur in it. Laguna Lake water also has high levels of total organic carbon (TOC) and ammonia.

The process of PWTP 1 in 2015, which addresses these concerns, can be divided into two major sections: the Pretreatment Section, which consists of a basin called the Forebay and the Dissolved Air Flotation (DAF) system; and the Membrane Section, which is composed of Microfiltration (MF) and then Reverse Osmosis (RO) Membranes. After the treatment process, the water is chlorinated for potable use. Figure 1 shows a simplified block flow diagram of PWTP 1 in 2015.

With this set-up, problems in water quality (such as high TDS and discoloration of product water) are almost always solved by running the RO Membranes, which only had a capacity of 30 MLD. The RO permeate is blended with the MF filtrate, in ratios depending on the water quality. It is possible that the product of the plant reaches as low as 30 MLD due to unpredictable lake water quality.

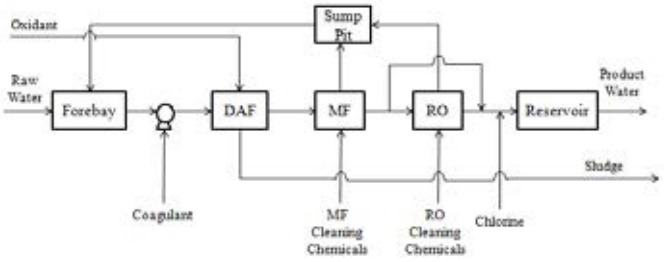

Fig. 1 Simplified block flow diagram of PWTP in 2015.

However, due to the changes which will be discussed in this paper, in 2017 the plant has even exceeded its nameplate capacity of 150 MLD, as seen in Figure 2.

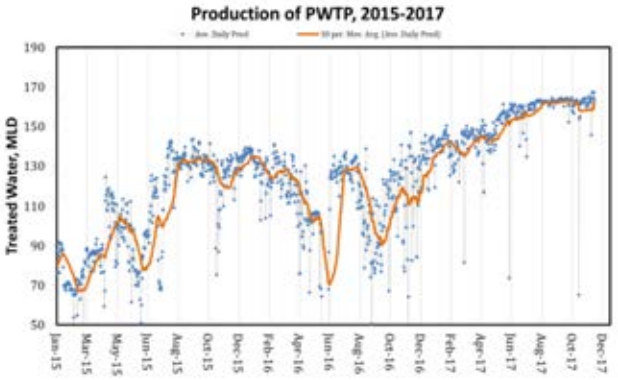

Fig. 2 Average daily production of PWTP 1, 2015-2017.

This paper tackles the programs placed in order to address high water volume demand and lake water quality issues, which can be outlined in five major areas: (1) inculcation of safety culture among the personnel, (2) process improvements, (3) specialization of the organizational hierarchy, (4) arrangements in the maintenance schedule, and (5) improvement in the operational philosophies. These areas constitute the following sections in this paper.

2. SAFETY CULTURE

PWTP 1 has inculcated into the personnel three simple and effective means in order to maintain their safety: First, the Take 5 Form, which was put in place to address the knowledge gap and skills gap of the personnel. One stops for five minutes to consider whether the personnel knows what he/she will be doing, the hazards and risks involved, and the PPEs required while doing the activity. This has caused a decrease in the mishandling of the operations of the plant.

Second, the Near Miss Reporting has been set up to address hazards. PWTP 1 has been recognized for making its company reach a thousand near miss reports in a year. Third, the personnel are assigned an area for housekeeping in order to keep the place neat and safe. Other risk management tools have also been introduced in the plant, such as Job Safety and Environment Analysis (JSEA) and Quantitative Risk Assessment (QRA).

3. PROCESS IMPROVEMENTS

Each of the circuits have been improved and upgraded. First and foremost, the biological aerated filters (BAF) have been added and the dissolved air flotation (DAF) has upgraded its capacity both in 2015, and the membranes have been replaced in the span of 2015–2017. Figure 3 shows the simplified block flow diagram of the improved process of PWTP 1.

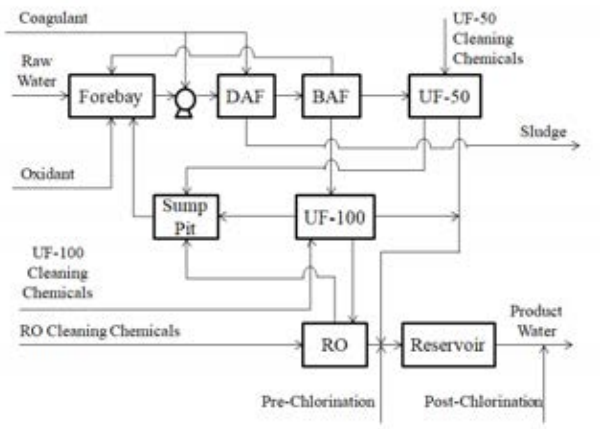

Fig. 3 Block flow diagram of the updated PWTP 1.

Before, the issues in lake water quality, particularly high manganese and high ammonia have been both addressed mainly by a decrease in production. This is the least viable option both in terms of the business and the benefit of the customers. Now, each of this has been addressed by the proper solution. High manganese has been resolved by changing the dosing points and increasing the aerators; meanwhile, high ammonia has been addressed by the BAF.

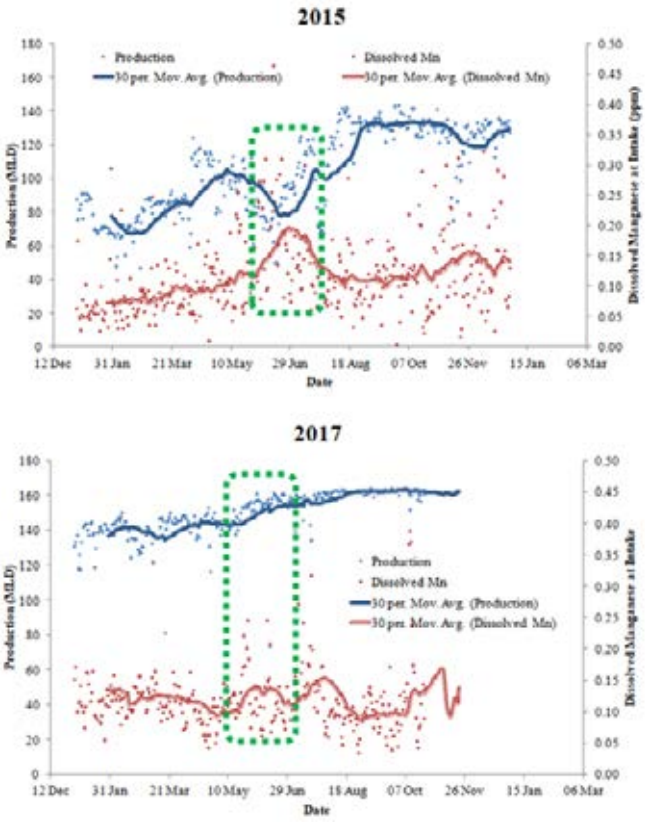

Fig. 4 Before (2015) and After (2017): Effect of Manganese Levels in Production.

In 2015 (refer to top part of Figure 4), the manganese spike (red line) causes a drop in production (blue line). On the other hand, the production is not affected by the manganese spikes in 2017.

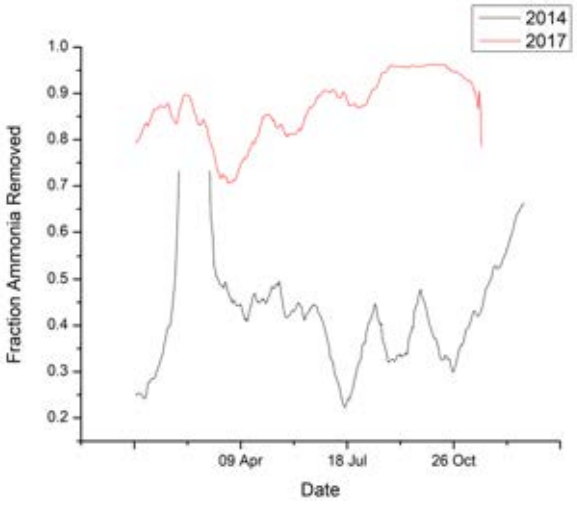

Fig. 5 Fraction of Ammonia Removed.

When the BAF has not been operational (i.e., in 2014), the ammonia removal averaged at 40%. In 2017, this removal has increased to around 85%. This removal is measured based on the difference in ammonia levels between the lake water and the filtrate.

An additional process control system was also installed in the lake water feed to the plant. This reduced the noise of the input to the plant, as shown in Figure 6. As seen in this figure, the plant noise was abruptly reduced; thus the level of the DAF was disturbed less, which encouraged the formation of flocs. Figure 7 shows the effect of this process improvement: a change in the process control has increased the turbidity reduction of the DAF.

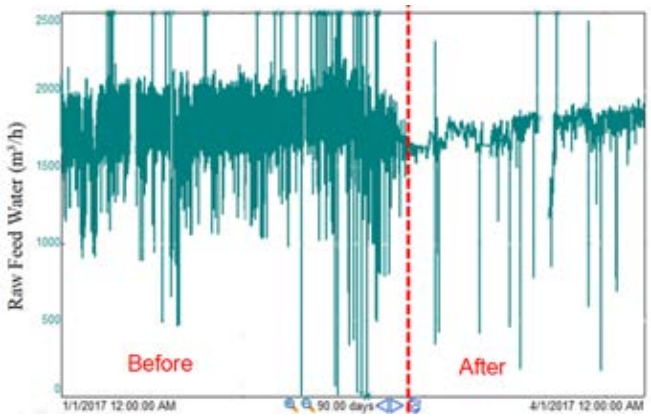

Fig. 6 Lake Water Feed to PWTP1, Jan – Apr 2017.

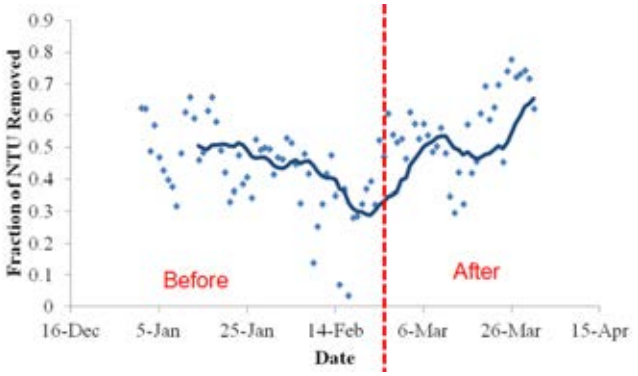

Fig. 7 Turbidity Removal in the DAF, Jan – Apr 2017.

4. ORGANIZATIONAL HIERARCHY

Before, the six complex circuits of the PWTP 1 were controlled by one shift officer. This shift officer acted both as a supervisor and as the control room operator. Now, the control room engineers have been instituted, who were also trained in field operations. PWTP 1 has also introduced the technical wing, who watches the overall process on a day-to-day basis, because lake water quality changes every hour and PWTP 1 has to be proactive in addressing these issues.

5. MAINTENANCE SCHEDULE

The community's demand for water is low at certain moments of the day. PWTP 1 has taken advantage of this low demand in order to perform prolonged cleaning of the BAF cells and the ultrafiltration membranes, as well as the maintenance of pumps and valves. Therefore, PWTP1 has achieved performing maintenance schemes without stopping the plant.

6. OPERATIONAL PHILOSOPHIES

PWTP 1 has installed heaters for chemical cleaners. This is in alignment with the thinking that the UF membranes serve as polishers, not as pretreatment.

Operational limits for residual alum entering the UF membranes have also been established, since an aluminum-based coagulant is used upstream of the UF membranes.

Operation of the UF membranes has also changed. Before, the feed setting to the UF was according to the capacity as indicated by the designers, i.e., 100 MLD for UF-100 and 50 MLD for UF-50. However, the filtrate production will be less than these feed settings since some of the water will be used in the flushing scheme. Therefore, upon discussion with the consultant and design review, the feed setting to the UF membranes was increased. Production in some days of November 2017 even reached an average of 165 MLD, which is beyond the nominal capacity of PWTP.

7. CONCLUSION

PWTP 1 has consistently achieved the high production rate in 2017 by improvements in the safety culture; process streams; organizational structure, which was more specialized depending on the needs of the plant; maintenance schedule, which was adjusted based on the demand for water; and operational philosophies, especially with regards to the ultrafiltration system.

Detailing the developments in the process streams, the BAF has been added in the Pretreatment Section in order to address high ammonia levels in the lake water. In order to address high manganese, aerators were added and oxidant dosing points were placed further upstream to allow prolonged reaction. The lake water feed's controls were also improved in order to stabilize the incoming flow rate, thus lessening the disturbance in the floc formation of the next process stream.

These improvements have strengthened water security in the south of Metro Manila, and the spirit with which it was done will be reflected in future projects of water production.

O7-15

Characterization and Treatment of Stormwater Runoff from the Nainital Lake Catchment in the Himalayan Region of India

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Keywords: Stormwater runoff characterization, runoff treatment, ballasted sand flocculation, Nainital lake

ABSTRACT

Stormwater runoffs are one of the primary causes for deteriorating water quality in the Nainital Lake, a lake of national importance in Himalayan region of India. The Nainital lake is a prominent tourist attraction and the sole drinking water source for the habitants of Nainital city. The aim of this study is to investigate the characteristics of pollutants of Lake's catchment area and performance assessment of Ballasted Sand Flocculation (BSF) technology during monsoon season of year 2017. A 1 MLD capacity pilot plant was installed (land space: 54 sq.m.) and applied for treatment of stormwater runoffs from Nainital Lake's catchment. A conventional treatment method would require large land footprint, which is a big constraint in the Nainital because of hilly region. The water quality results showed marked variation during different storms especially for TSS, TP, COD, FC, Cu, Pb and Zn with maximum concentration of 864 mg/l, 1.2 mg/l, 388 mg/l, $14x10^4$ MPN/100 ml,73µg/l, 83 µg/l and 890 µg/l respectively. The performance analyses result of the pilot plant revealed that the contaminants including trace metals in the stormwater runoff were reduced appreciably. The removal efficiency of Turbidity, TSS, Total Phosphorous, COD, FC, Cu, Pb and Zn are 86-96%, 69-93%, 75-95%, 41-82%, 61-96%, 40-82%, 56-87% and 51-77% respectively. The performance analysis results of BSF system have been found to be a promising technology for treatment of storm runoff.

1. INTRODUCTION

Stormwater runoff is an important transporting medium for various pollutants to transport from land to surface water bodies such as lakes. Urban storm runoff pollution problems are more difficult to manage than steady-state point discharges because of the sporadic characteristic of rainfall and runoff. Urban runoff pollution has been studied in developed countries [1,2]. However, little information is available on storm runoff pollution from urban area in developing counties, including India. There are very few reports or research papers are available about the characterization of surface runoff in an urban catchment environment in India including stormwater inflow to the Lake of national importance such as Nainital Lake. Nainital Lake (India) receive polluted runoff and thus face the deteriorating water quality problem [3,4]. The Nainital Lake is one of the major sources of water supply to the Nainital city, and also attracts thousands of tourists every year due to its scenery beauty. The economy of Nainital region is directly or indirectly dependent on this lake. Therefore, there is a need to devise an appropriate storm-water runoff treatment plant to improve the lake water quality. Availability of land is a critical factor in Nainital to adopt a conventional treatment plant. One of the technologies, which proven to be effective for surface water and combined sewerage overflow (CSO) is ballasted sand flocculation, also known as high rate clarifier which require very less space [5]. There are hardly any attempts to employ the BSF technique at full scale or laboratory scale in India as per author's best of knowledge. In the present paper, stormwater runoff was characterized and treatment efficiency of BSF technology was evaluated.

2. METHOD

Study Area

Nainital Lake, India (Latitude-29^0 23.127' and Longitude-79^0 27.656') has a crescent shape and is situated in Nainital district of Uttarakhand, India. The maximum length of lake is 1.4 km and maximum width is 0.45 km and maximum depth 27.32 m with mean depth of 18.5 m [4]. The catchment area of lake is 4.9 sq. km and average annual rainfall in the basin is 203 cm. The pilot plant of 1 Mld (42 m^3/hr) capacity was installed near storm water drain (locally called Naina Devi drain) Nainital, India. Naina Devi drain is the major drain in the Lake's catchment, which contributes 60% of runoff to the Nainital Lake (NIH, 2000).

Description of pilot plant

The ballasted flocculation technology is mainly based on physical-chemical treatment process that uses a continuous recycled medium along with chemicals to improve the settling properties of suspended solids through improved floc bridging [6,7].

The BSF unit involves three-stage process i.e injection, maturation and settling. The technical design detail of BSF pilot plant has been given in Table 1. The total

hydraulic retention time (HRT) of the plant was 16 min, which corresponds 2-2-6-6 design that means 2 min retention time in coagulation tank, 2 min in flocculation tank, 6 min in maturation tank and 6 min settling time. The coagulation, flocculation and maturation tank were equipped with mixers, which provides high mixing speed (160-180 rpm) in the first two tanks and low mixing speed in the maturation tank (40-60 rpm). The different processes is shown in Fig. 1. and actual experimental set-up (1 Mld pilot-plant) has been shown in Fig 2.

Table 1 Technical design detail of BSF pilot-plant

Parameters	Unit	Value
Design flow	m^3/hr	42
Coagulation tank size	m^3	1.62
Flocculation tank size	m^3	1.62
Ballastation tank size	m^3	5.76
HRT	minutes	16
Rise rate	m/hr	40

The inlet and outlet samples of BSF unit were collected during nine different storm events. Number of samples for each storm event varied from three to seven depending upon the duration of event. Samples were collected after 10 minutes of rainfall initiation and then after, at every twenty minutes interval till the flow in Naina devi drain reach to its initial flow.

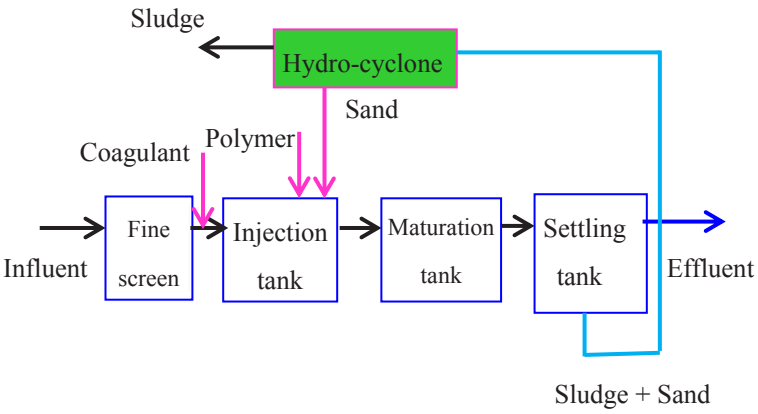

Fig. 1 Schematic diagram of BSF unit

Fig. 2 Actual Experimentation set-up at Nainital

3. RESULTS AND DISCUSSION

Table 2 summarizes the results (influent-effluent concentration and removal rate of pollutants) obtained during the study period. There are large fluctuations in the influent concentration for all the parameters. The value of COD and BOD reached upto 388 and 224mg/l respectively (Table 2) indicates that there may be mixing of sewage due to bursting or choking of sewer pipeline during some events. Total phosphorous concentration ranges from 0.08- 1.2 mg/l, which is much higher than the threshold value causing eutrophication in the lake. Most pollutants in the storm runoff are characterized by the tendency that the concentrations increase with the increased runoff flow rate at rising limb of hydrograph and then concentration decreases following the trend of hydrograph.

Figure 3 indicates that the peak concentrations reaches near the peak runoff flow rate for both storm events and after the peak, the pollutant concentration rapidly reduced. This characteristic of pollutograph is reported to hold true when the watershed area is small (Lee and Bang, 2000).

The chemical dosages of the plant were optimized by conducting modified jar test in the laboratory before the field application of the plant. The optimum chemical dosages ranged between 20 - 80 mg/l of alum ($Al_2SO_4.18H_20$); 30-120 mg/l of ferric chloride ($FeCl_3.6H_2O$) and 8 g/l of micro-sand.

The removal efficiency of pilot plant is presented in Table 2. Results showed that BSF unit is highly efficient in removing particulate matter and phosphorous and it also exhibit a significant removal of other pollutants. Turbidity, TSS and TP removal rates ranged from 86 to 96%, 69-93% and 75-95% whereas COD and BOD removal rate ranged between 41-82% and 29-82%. The average removal rate of ammonical nitrogen is 8 % but no removal of nitrate nitrogen was found out. Phosphorous removal is

important, as phosphorous is the limiting factor for eutrohication of Nainital Lake. The removal efficiency of pollutants is comparable with other reported studies based on the performance of BSF systems for CSO/surface water of similar characteristic of influent [6,7].

Table 2 Influent and Effluent concentration with removal efficiency of BSF unit

Parameters	Influent Concentration Average (min-max)	Effluent concentration Average (min-max)	% Removal Average (min-max)
pH	7.54(6.8-8)	7.31(6.9-7.8)	-
Turbidity (mg/L)	135(21-635)	2.45(1.2-4.8)	95(86-96)
TSS (mg/L)	185(38-864)	14(6-45)	88(69-93)
COD (mg/L)	118(21-388)	30(12-78)	71(41-82)
BOD (mg/L)	46(7-224)	08(3-34)	72(29-82)
NH_4^+-N (mg/L)	1.53(0.26-3.55)	1.3(0.12-3.50)	8(0-46)
NO_3-N (mg/L)	0.62(0.10-2.25)	0.75(0.13-2.71)	No removal
TP (mg/L)	0.47(0.08-1.2)	0.07(0.02-0.22)	83(75-95)
FC (MPN/100 ml)	$19x10^3$($15x10^1$-$14x10^4$)	$59x10^1$($2x10^1$-$39x10^2$)	84(61-96)
Cu(µg/l)	38 (5-73)	12(3-32)	65(40-82)
Pb(µg/l)	25(7-83)	8(2-32)	67(56-87)
Zn(µg/l)	625(368-890)	226(126-327)	64(51-77)

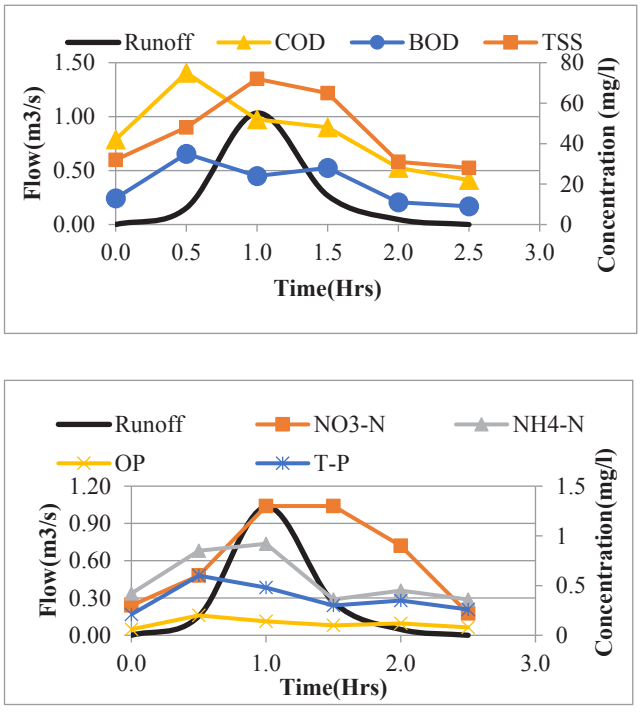

Fig. 3 Typical hydrograph and pollutograph for a storm event

4. CONCLUSION

The characterization and performance of BSF unit was evaluated for stormwater runoff of a hilly catchment area i.e Nainital, India. A 1 Mld pilot-plant was installed near Naina devi storm-water drain which carries variety of pollutants. The pollutants showed a marked variation during different storm events. The particulate matter, phosphorous, COD and BOD showed a very good removal during the overall experimental campaigns. The treatment of storm water runoff with average removal rate was found out to be 95% for turbidity, 88% for TSS, 83% for T-P, 71% for COD and 72% for BOD. Findings of present study suggest that the BSF unit can be suitable for treatment of urban runoff.

REFERENCES

[1] Gnecco I, Berretta C, Lanza L G et al., 2005. Storm water pollution in the urban environment of Genoa, Italy[J]. Atmospheric Research, 77: 60–73.

[2] Suarez J, Puertas J. Determination of COD, BOD, and suspended solids loads during combined sewer overflow (CSO) events in some combined catchments in Spain. Ecol Eng. 2005;24:199–217.

[3] National Institute of Hydrology, Roorkee, Technical report on "Water quality studies of lake Nainital and surroundings". 2000; CS/AR-1/1999-2000.

[4] D. Singh, S.P. Rai, B. Kumar, Sanjay K. Jain, S. Kumar, "Study of hydro-chemical characteristic of lake Nainital in response of human interventions and impact of twentieth century climate change," *Environ Earth Sci.,* Vol. 75, pp.1380, Oct. 2016.

[5] S. Kumar, N.C. Ghosh, A.A. Kazmi, "Ballasted sand flocculation for water, wastewater and CSO treatment," *Environmental technology reviews*. vol. 5, pp. 57-67, July 2016.

[6] V. Plum, C.P. Dahl, L. Bentsen, C.R. Petersen, L. Napstjert, N.B. Thomsen, "The actiflo method," *Water Science and Technology*, vol. 37, no. 1, pp. 269-275,1998.

[7] J. Gasperi, B. Laborie, V. Rocher, "Treatment of combined sewer overflows by ballasted flocculation: Removal study of a large broad spectrum of pollutants," *Chemical Engineering Journal*, vol. 211-212, pp. 293-301, Nov. 2012.

O7-16

Field Experiments on Runoff Reduction Using Terrestrial Alga as Topsoil Nutrient Absorber

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Keywords: control of point and non-point source pollution, nitrogen and phosphorus cycle, nutrient dynamics

ABSTRACT

Nutrient runoff into aquatic systems leads to eutrophication. The Institute for Clean Earth developed a new technology using terrestrial microalga (a drought-tolerant cyanobacterium *Nostoc* sp.) that could reduce the amount of nutrients in surface runoff. The field-scale experiments examined whether the technology would reduce the water-soluble nutrients in the topsoils in water's edges. The experimental approach consisted of the following: assessment of the topsoil nutrient runoff risk, application of the technology, and evaluation of the efficacy. For the assessment, the topsoils were collected from various types of water's edges. Unexpectedly, most unfertilized topsoils around lakes (Biwa-ko, Imba-numa and Kasumiga-ura) and in planting beds, contained high amounts of water-soluble inorganic nutrients: above 1.2 kg N/ha and above 0.2 kg P/ha. Algal inoculated plots and the control (plots without algal inoculation) were used in the application experiments. The reduction values of N and P amounts in the topsoils were estimated to be from 1.3 to 5.4 kg N/ha, and 0.4 to 1.6 kg P/ha. Judged these values from the published information, the results suggest that the algal inoculation onto the topsoil is a promising technology for reducing water-soluble inorganic N and P in surface runoff.

1. INTRODUCTION

There are few technical measures to reduce the nonpoint pollution[1, 2]. Many microalgae including cyanobacteria (blue-green algae) can utilize inorganic nitrogen (N)[3] and inorganic phosphorus (P)[3] during efficient photosynthetic CO_2 fixation[4]. Some terrestrial cyanobacteria absorb ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), urea and phosphate in the topsoil, and produce organic matters such as proteins and saccharides during photosynthesis. These matters have very long term mean residence time (ca. 40 years) in soil[5]. Considering these facts, the Institute for Clean Earth (ICE) developed a new technology against the nutrient runoff from the topsoils, using photosynthetic terrestrial cyanobacterium. This technology was registered on March 2016 (No. KT-150125-A) in the NETIS of the Japanese Ministry of Land, Infrastructure and Transport.

2. METHOD

Assessment of the nutrient runoff risk

Surface soils from 0 to 2 cm depth[6] were collected from water's edge plots around lakes (Biwa-ko, Imba-numa, and Nishi-ura in Kasumiga-ura), around ponds and/or on bayshore (in Tokyo Metropolitan Parks), and in planting beds (near gutter gratings in Tokyo and Saitama Prefecture).

Water-soluble NH_4^+[7] and inorganic P[6] may be the most appropriate estimators of the concentrations in runoff water. NO_3^- can be easily extracted from most soils[8]. Therefore, the amount of water-soluble nutrients (Table 1) was used as the relative index of the nutrient runoff risk for giving priority level. The deionized water extraction procedure[9] was performed at 24~26C: Soil to water mass ratio in centrifugation tube was 1 to 5, and the extraction time on a reciprocal-shaker at 90 rpm was 30 min. After centrifugation at 1,000 g for 10 min, the floating debris was eliminated, and the resulting supernatant was used as the extracted solution. First of all, the measurement of pH and electrical conductivity (EC) of the extracted solution was performed. Quantitation of NH_4^+ and phosphates in the extracted solution was performed using indophenol blue and molybdenum blue, respectively. NO_3^- was quantitated using the Griess reagent after removal of NO_2^- in the extracted solutions.

Application of the technology

Nontoxic terrestrial cyanobacterium *Nostoc* sp. was autotrophically cultured in 1,000 L liquid medium, collected, mixed with sterile perlite particles, and followed by drying. A part of the mono-algal production system for the quality maintenance was developed by the support from the Zenkoku Chûôkai grant in Japan. The dry alga-perlite particles ($\varnothing \leq 3$ mm) were inoculated onto the following plots: lawn soil surface of 40, 100 or 300 m^2 (at the rate of 0.6 mg chlorophyll *a*/m^2) in the river levees of Ara-kawa, Maruyama-gawa (an upper stream of Ramsar wetlands in Hyogo Prefecture), Tone-gawa and Watarase-gawa (an upper stream of Ramsar wetlands and the Tone-gawa), and the planting beds of 8 m^2 (at the higher rate of 2.3 mg chlorophyll *a*/m^2).

Evaluation of the efficacy

At the start and end (α months later: $0.6 < \alpha \leq 2.5$) of the experiments, the topsoils were collected from inoculated and uninoculated plots, and sieved with 2 mm mesh to remove rock debris including moss-covered clod and crust. Chlorophyll *a* (Chl*a*) content was spectrophotometrically determined in the ethanol fraction[10] extracted from the sieved soil. The algal biomass can be expressed using Chl*a* amount. The Chl*a* increment during α months ($\delta_{\alpha\ months}$) was calculated as follows: $\delta_{\alpha\ months}$ = (Chl*a*-e − Chl*a*-s), where Chl*a*-s is Chl*a* amount per area at the start of the field experiments and Chl*a*-e at the end. Preliminary experiments at the ICE in spring and fall showed that the alga grew linearly on the outdoor soil surface during 2.5 months. Therefore, $\delta_{2.5months}$ was calculated from $\delta_{\alpha\ months}$. In order to offset the effects of native algal species and unknown factors, the values of the alga inoculated plot ($\delta_{2.5months\text{-}A}$) and uninoculated control ($\delta_{2.5months\text{-}C}$) were used. The increment of Chl*a* ($\delta_{2.5months}$) by using the present technology was calculated as follows: $\delta_{2.5months} = (\delta_{2.5months\text{-}A} - \delta_{2.5months\text{-}C})$. The reduction of N and P amounts (Table 2) were estimated from $\delta_{2.5months}$, the algal protein N content, and Redfield stoichiometry: N/P = 16.

3. RESULTS

EC and pH values in the extracted solutions varied by location and with seasons. The average EC values (mS/cm) were as follows: over a range of 0.14~0.34 at Imba-numa and Kasumiga-ura; 0.09 at Biwa-ko; 0.07 at Saitama (Kurihashi and Okabe). Most extracted solutions from the plots showed around neutral pH. The average concentrations (mg/L) of inorganic N ($NH_4^+ + NO_3^-$) and P in the extracted solutions were above 1.2 and above 0.2 (Table 1).

Table 1 Water-soluble N and P concentrations of topsoils in water's edges

Water's Edges	(no. of plots)	*Sampling date	N (mg/L) NH_4^+	N (mg/L) NO_3^-	P (mg/L) PO_4^{3-}
around Lakes [unfertilized plots]					
Biwa-ko	(13)	11 Nov.	0.8	0.4	0.6
Imba-numa	(12)	29 Jun.	0.8	8.0	0.2
	(12)	29 Aug.	1.8	1.7	0.3
	(12)	29 Dec.	1.3	8.9	0.7
Kasumiga-ura	(12)	30 Jun.	1.4	4.5	0.6
	(12)	1 Sep.	0.1	1.2	0.7
	(12)	28 Nov.	1.5	6.0	0.4
in Planting Beds [unfertilized plots]					
**Saitama	(12)	13 Sep.	4.8	1.4	1.0
Unoki	(1)	5 Dec.	3.5	1.3	0.2

*Samples obtained in 2016 (Imba-numa, Kasumiga-ura, Unoki in Tokyo) and in 2017 (Biwa-ko, **Kurihashi and Okabe in Saitama Prefecture).

Assuming that specific gravity of the soils was 2.0 and the topsoil consists from 0 to 2 cm depth, then the amounts per area (kg/ha) of water-soluble topsoil inorganic nutrients were estimated to be above 1.2 of N and above 0.2 of P. No relationship was found between EC and NO_3^- concentration in the extracted solutions from the unfertilized water's edge.

Several weeks after the algal inoculation, sparse spots of algae including cyanobacteria (*i.e.*, algal crust) on the soil surface became visible to the naked eye. This corresponded to very early stage of ecological succession on land. Culture experiments *in vivo* by using each extracted solution as algal medium showed that *Nostoc* sp. efficiently absorbed NH_4^+, NO_3^- and phosphate during photosynthetic growth. Similarly, the algal cells on outdoor plots probably absorbed these inorganic nutrients, and reduced these amounts (Table 2).

Table 2 Reduction of N and P amounts of topsoils in water's edges after using the present technology

Water's Edges	(no. of plots)	N (kg/ha)	P (kg/ha)
around Lake [unfertilized plots]			
Kasumiga-ura	(4)	*2.1	*0.6
in River Levees [fertilized plots]			
Ara-kawa	(1)	3.1	0.9
**Maruyama-gawa	(1)	1.6	0.5
Tone-gawa	(3)	*2.0	*0.6
**Watarase-gawa	(1)	1.3	0.4
in Planting Beds [unfertilized plots]			
Saitama	(2)	4.9	1.5

* One ineffective result is included: Two heavy rain events (Typhoon No.21 & 22 in 2017) caused the sediment accumulation on the soils during the study period, and hindered the algal growth.
**An upper stream of Ramsar wetlands.

4. DISCUSSION

There are strong linear relationships between EC and NO_3^- concentration in the extracted solutions from agricultural soils[11]. NO_3^- amount can be estimated from EC value in such a case. Whereas, nitrate ion-meter is better choice to measure NO_3^- amount in the solutions from water's edge around lakes.

N and P pollution in runoff is caused primarily by agricultural and urban activities[1]. Land use can disrupt the surface water balance[12]. Atmospheric deposition[13] may affect the topsoil fertility. Some agricultural chemicals degrade into NH_4^+ and/or phosphate by the action of microbes[14]. If limited to the lakes, storm waves may carry the lake nutrients over to the topsoils. However, the real cause of the high amounts of N and P (Table 1) in unfertilized plots remains to be clear.

Fertilizers were applied globally in 2013 at 74 kg N/ha and 12 kg P/ha[15]. River levees (Table 2) are covered with fertilizing lawn soil surface (annual rates in the plots: ca. 30 kg N/ha and ca. 10.5 kg P/ha). Generally, fertilizer N and P losses in runoff are below 5% of that applied[1]. These values suggest that the annual N and P amounts in surface runoff from worldwide croplands are below 3.7 kg N/ha and 0.6 kg P/ha. Those from the river levees may be below 1.5 kg N/ha and 0.53 kg P/ha. These estimated nutrient runoff values roughly match with the reduction amounts by "one-time use of the algal inoculation" (Table 2). In the experiments, the inoculation was performed not in whole

but in limited area. Therefore the nutrient inflow from the surrounding area to the experimental plots could occur naturally. Additionally, runoff water contains particulates[1, 16] and organic matters, which are rich in nutrients[17]. The algae in the experimental plots might utilize these nutrients as well as water-soluble ones. It is no wonder that the reduction of P amounts on planting beds in Saitama (1.5 kg P/ha, Table 2) exceeded the estimated amounts of water-soluble inorganic P (1.0 kg P/ha) in the same plot.

5. CONCLUSION

The treatment of wastewater with aquatic microalgae to remove inorganic nutrients was proposed over 60 years ago[18], and many experimental studied on the process have been constructed[19,20]. Meanwhile, terrestrial microalgae have been used in the eco-friendly tools in soil fertilization and desertification reversal[21]. No technical measure of nutrient runoff was proposed using terrestrial algae. Field experiments showed that the present technology using terrestrial cyanobacterium could reduce the nutrients in surface runoff.

Some microalgae can utilize hardly-soluble materials as their nutrients (N of uric acid; P of $AlPO_4$; K of potassium feldspar; Mg of $Mg(OH)_2$; S of $BaSO_4$) as well as water-soluble ones during photosynthetic growth[22]. At present, the efficacy of the technology against nutrient pollution from the eroded soil remains to be clear. Improvement of the technology is now in progress at the ICE.

The riparian buffer zone removes efficiently inorganic N and P of runoff from agricultural fields[1]. Judged from the plant community, the soil is likely to remain uncovered by the terrestrial algae during several months after its installation. The present technology could synergistically reduce surface inorganic nutrients in the zone. Now is the time to take action against the non-point source pollution, by using various measures including the present technology.

REFERENCES

[1] S.R. Carpenter, N.F. Caraco, D.L. Correll, *et al*.: Nonpoint pollution of surface waters with phosphorus and nitrogen, Ecol. Appl., Vol. 8, pp. 559-568, 1998.

[2] J. Battiata, K. Collins, D. Hirschman, and G. Hoffmann: The runoff reduction method, J. Contemp. Water Res. Educ., Vol. 146, pp. 11-21, 2010.

[3] G. Markou, D. Vandamme, and K. Muylaert: Microalgal and cyanobacterial cultivation: The supply of nutrients, Water Res., Vol. 65, pp. 186-202, 2014.

[4] K. Aizawa, and S. Miyachi: Carbonic anhydrase and CO_2 concentrating mechanisms in microalgae and cyanobacteria, FEMS Microbiol. Rev., Vol. 39, pp. 215-233, 1986.

[5] M.W.I. Schmidt, *et al*.: Persistence of soil organic matter as an ecosystem property, Nature, Vol. 478, pp. 49-56, 2011.

[6] D.H. Pote, *et al*.: Relating extractable soil phosphorus to phosphorus losses in runoff, Soil Sci. Soc. Am. J., Vol. 60, pp. 855-859, 1996.

[7] B.E. Haggard, P.B. DeLaune, D.R. Smith, *et al*.: Nutrient and β_{17}-estradiol loss in runoff water from poultry litters, J. Am. Res. Assoc., Vol. 41, pp. 245-256, 2005.

[8] G. Griffin, W. Jokela, and D. Ross: Recommended soil nitrate-N tests, *in* Recommended soil testing procedures for the Northeastern United States. U. Delaware Agric. Exp. Stn. Bull., 403, pp. 22-39, 1995.

[9] J.K. Fuhrman, H. Zhang, J.L. Schroder, *et al*.: Water-soluble phosphorus as affected by soil to extractant ratios, extraction times, and electrolyte, Comm. Soil Sci. Plant Anal., Vol. 36, pp. 925-935, 2005.

[10] S. Lan, L. Wu, D. Zhang, *et al*.: Ethanol outperforms multiple solvents in the extraction of chlorophyll-*a* from biological soil crusts, Soil Biol. Biochem., Vol. 43, pp. 857-861, 2011.

[11] D.G. Patriquin, H. Blaikie, M.J. Patriquin, *et al*.: On-farm measurements of pH, electrical conductivity and nitrate in soil extracts for monitoring coupling and decoupling of nutrient cycles, Biol. Agr. Horti., Vol. 9, pp. 231-272, 1993.

[12] J.A. Foley, *et al*.: Global consequences of land use, Science, Vol. 309, pp. 570-574, 2005.

[13] R. Vet *et al*.: A global assessment of precipitation chemistry and deposition of sulfur, nitrogen, sea salt, base cations, organic acids, acidity and pH, and phosphorus, Atm. Environ., Vol. 93, pp. 3-100, 2014.

[14] B.K. Singh, and A. Walker: Microbial degradation of organophosphorus compounds, FEMS Microbiol. Rev., Vol. 30, pp. 428-471, 2006.

[15] C. Lu, H. Tian: Global nitrogen and phosphorus fertilizer use for agriculture production in the past half century: shifted hot spots and nutrient imbalance, Earth Syst. Sci. Data,Vol. 9, pp. 181-192, 2017.

[16] L.L. McDowell, G.H. Willis, C.E. Murphree: Nitrogen and phosphorus yields in run-off from silty soils in the Mississippi Delta, U.S.A., Agr. Eco. Environ., Vol. 25, pp. 119-137, 1989.

[17] M.K. Zhang, L.P Wang, Z.L. He: Spatial and temporal variation of nitrogen exported by runoff from sandy agricultural soils, J. Environ. Sci., Vol. 19, pp. 1086-1092, 2007.

[18] W.J. Oswald, and H.B. Gotaas: Photosynthesis in sewage treatment, Trans. Am. Soc. Civil. Eng., Vol. 122, pp. 73-105, 1957.

[19] G. Markou, and D. Georgakakis: Cultivation of filamentous cyanobacteria (blue-green algae) in agro-industrial wastes and wastewaters: A review, Appl. Energy, Vol. 88, pp. 3389-3401, 2011.

[20] J.P. Maity, J. Bundschuh, C-Y. Chen, *et al*.: Microalgae for third generation biofuel production, mitigation of greenhouse gas emissions and wastewater treatment: Present and future perspectives – A mini review, Energy, Vol. 78, pp. 104-113, 2014.

[21] F. Rossi, H. Li, Y. Liu, *et al*.: Cyanobacterial inoculation (cyanobacterisation): Perspectives for the development of a standardized multifunctional technology for soil fertilization and desertification reversal, Earth-Sci. Rev., Vol. 171, pp. 28-43, 2017.

[22] K. Aizawa: Culture medium for microalgae, WO patent: WO2013005799A1, issued 10 Jan., 2013; K. Aizawa: Culture medium for microalgae (in Japanese), JPN patent: JP5588069B, registered, 1 Aug., 2014.

O7-17

水質安定化と省エネルギーを実現する硝化制御技術の実証

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キーワード:硝化制御、アンモニア計、ICT

抄録

アンモニア計を活用し、水質安定化と省エネルギーを実現する硝化制御システムを国土交通省 B-DASH プロジェクトにて実証した。硝化制御システムによる制御運転の結果、98 日間の運転の平均として処理水 NH_4^+-N 濃度を 0.33 mg-N/L（目標 1.0 mg-N/L 以下）、風量削減率 16.9%減（従来 DO 一定制御比、目標 10%以上）を達成した。また、異なる処理水目標値での運転においても、目標を満足する水質に制御できた。アンモニア以外の有機物、窒素、リンに関しては、従来 DO 一定制御と同等以上の処理性能を示した。以上の結果より、硝化制御システムは良好な水質を維持しつつ、消費エネルギーを低減できることを実証した。

1. はじめに

国内では閉鎖性水域などを中心に水質汚濁防止のため、窒素・リン除去といった高度処理化が推進されている [1)]。また、近年は、冬期に下水処理水中の栄養塩類濃度を上げ、ノリの生育を促進させるなど、豊かな海の形成を図る季節別運転管理も注目されている [2)]。このように放流先水域の多様なニーズに応じた下水処理制御技術の重要性が高まっていくと考えられる。

同様に、地球温暖化防止を目的とした CO_2 排出量抑制も水環境や生態系の保全には重要となってくる。下水処理過程での CO_2 発生源としては、ブロワでの消費電力が大きな割合を占める。ブロワからの送風は活性汚泥に酸素を供給するものであり、生物処理性能に大きく影響する。そのため、水質と消費電力低減の両方の観点から適切に送風量を制御する必要がある。

以上の背景を踏まえ、本研究では窒素除去の重要な工程であり、酸素消費量も大きい硝化を対象とし、安定的かつ効率的な下水処理制御技術（以下、開発制御）を開発・実証したので、報告する。なお、実証は国土交通省の下水道革新的技術実証事業（B-DASH プロジェクト）「ICT を活用した効率的な硝化運転制御の実用化に関する技術実証研究」（2014~2015 年度）において、国土技術政策総合研究所の委託研究として日立製作所・茨城県の共同研究体により実施した。

2. 開発制御の概要

2.1 特徴

図 1 に開発制御の概要を示す。本制御は2台のアンモニア（以下、NH_4^+-N）計（第1 NH_4^+-N 計:好気槽よりも上流側、第 2 NH_4^+-N 計:好気槽中間地点）による水質計測と情報通信技術 (ICT; Information and Communication Technology)を組み合わせた3つの機能により、水質安定化、消費電力低減、維持管理業務の軽減を図る技術である。以下、各機能について述べる。

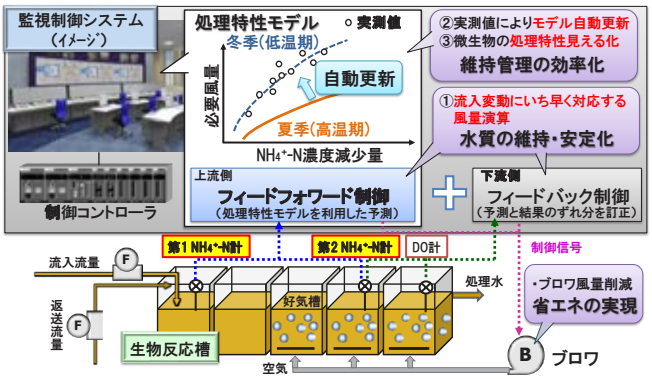


図 1 開発制御の概要（仮）

1つ目の機能として、流入負荷変動にいち早く対応する風量制御機能がある。本機能では第 1 NH_4^+-N 計の計測値に基づくフィードフォワード(FF)制御風量と、第 2 NH_4^+-N 計の計測値に基づくフィードバック(FB)制御風量を重みづけして足し合わせ、硝化制御風量として出力する。FF 的要素と FB 的要素をバランスすることで、流入変動にいち早く対応し、送風量の適正化、処理の安定化を実現する。

2つ目の機能は、風量演算モデルの自動更新機能である。例えば、低水温となる冬季には生物活性が低下するなどして、処理に必要な風量は年間を通じて変化する。そこで、本機能では、FF 制御風量の演算において、運転実績に基づき自動更新する処理特性モデルを用いる。処理特性モデルは NH_4^+-N 濃度の減少量に

対する必要風量の関係を表しており、運転実績として NH_4^+-N 計設置区間の NH_4^+-N 濃度減少量と供給した風量から、所定周期ごとにモデル式を自動更新する。この自動更新機能により、必要風量の予測精度を自動的に担保し、処理水質の安定化を図る。

3つ目が処理特性の見える化機能である。活性汚泥の性状の急変や運転異常の傾向を早期に検知することは、安定した運転には重要である。そこで、本機能では、処理特性モデルの自動更新機能と連携し、モデル式やグラフ上のプロット値の変化を追跡することで、活性汚泥のもつ処理特性の変動を見える化する。

2.2 風量制御方法

FF, FB 制御では、処理水 NH_4^+-N 目標値までの通過点として、第 2NH_4^+-N 計設置位置での予測値（以下、中間 NH_4^+-N 予測値、式(1)参照）に基づき風量を演算する。式(1)の中間処理率は、処理水目標値に対して好気槽上流側（第 2NH_4^+-N 計まで）でどれだけ処理するかを表す制御パラメータである。FF 制御では、流入濃度（第 1NH_4^+-N 計計測値）と中間 NH_4^+-N 予測値との差分を処理特性モデルに入力し、必要風量を予測する。一方、FB 制御では、第 2NH_4^+-N 計計測値と中間 NH_4^+-N 予測値とを流下時間を考慮して比較し、その偏差から風量を演算する。このように、制御パラメータとして、中間処理率と処理水 NH_4^+-N 目標値を設定することで、硝化制御を適用できる。

また、開発制御では、過度な DO 低下を防ぐため、運用管理上の DO 下限値に基づく DO 制御を硝化制御と並行して演算し、より大きい風量を採用する。

$$NH4_{md\_tgt} = NH4_{in} - \mathrm{R_{up}}\left(NH4_{in} - \mathrm{NH4_{out\_tgt}}\right) \qquad (1)$$

ここで、$NH4_{md\_tgt}$(mg-N/L)：中間 NH_4^+-N 予測値、$NH4_{in}$(mg-N/L)：流入 NH_4^+-N 濃度、$\mathrm{R_{up}}$(-)：中間処理率、$\mathrm{NH4_{out\_tgt}}$(mg-N/L)：処理水目標値とする。

3. 実証実験方法

3.1 実験施設

実証実験は、茨城県流域下水道事務所霞ケ浦浄化センターの2つの処理系列（No.5 池、No.6 池）にて実施した。どちらの系列も凝集剤併用型循環式硝化脱窒法であり、2つの無酸素槽、3つの好気槽から構成される。実証では、No.5 池を実証系列として開発制御を適用し、No.6 池は対照系列として従来の DO 一定制御を継続した。No.5 池、No.6 池の設備構成を図 2 に示す。No.5 池では、無酸素槽1、好気槽2に新設した NH_4^+-N 計を用いて、開発制御により風量を制御した。

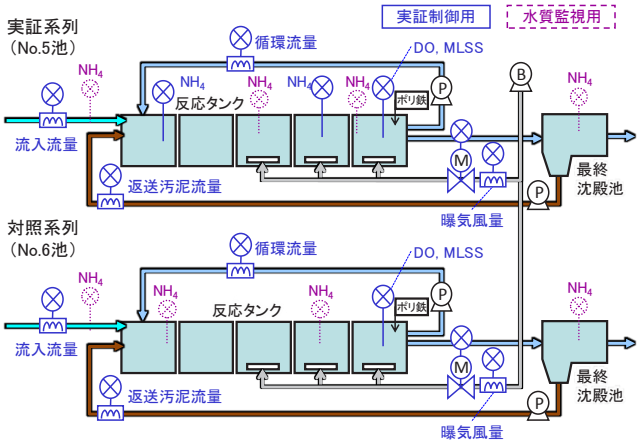


図 2 実証設備の概要

3.2 運転条件

B-DASH プロジェクトでは、平均処理水 NH_4^+-N 濃度を 1.0 mg-N/L 以下に制御しつつ、従来 DO 一定制御と比べて風量を 10%以上削減することを実証目標とした。2015 年度の実証条件を表 1 に示す。実証では、処理水 NH_4^+-N 目標値を実証目標の 1.0 mg-N/L のほか、0.1, 2.0 mg-N/L にも設定し、複数の目標値に対する制御効果を検証した。

表 1 実証実験における運転条件

ID	実験期間（日数※）	処理水NH_4^+-N目標値	DO下限値
No.1	2015/6/4-/7/14 (38日)	0.1 mg-N/L （想定：完全硝化）	0.50 mg/L
No.2-1	2015/7/18 - 8/4 (15日)	1.0 mg-N/L （実証目標）	0.50 mg/L
No.2-2	2015/8/5 - 12/27 (83日)		0.30 mg/L
No.3-1	2016/1/7 - 1/17 (11日)	2.0 mg-N/L （想定：硝化抑制）	0.15 mg/L
No.3-2	2016/1/25 - 2/3 (8日)		0.30 mg/L

※ 既設運転、工事期間、非定常運転時をのぞく

3.3 採水調査

実証研究では、NH_4^+-N に加えて BOD など他の項目の処理性能も比較するため、両系列で通日採水調査を実施した。調査は 2015 年 9 月、11 月、12 月の計 3 回実施し、最初沈殿池流出水（以下、初沈流出水）、生物反応槽、処理水、返送汚泥において BOD や全窒素、NH_4^+-N、全リン濃度などを分析した。

4. 結果および考察

4.1 採水調査結果

採水調査における流下方向の水質変化の例として、図 3 に 2015 年 11 月調査での全窒素(T-N)、NH_4^+-N 濃度の通日平均値を示す。対照系列に比べて実証系

列では硝化をより適正化し、過剰曝気の領域を削減できた。全窒素については、実証系列の方が好気槽内で低くなった。これは、開発制御適用により従来DO 一定制御と比べて低 DO での運転となり、同時硝化脱窒が進行したためであると考えた。

採水調査における両系列の処理状況を比較するため、各項目の除去率を表2に示す。実証系列のBOD、全リン、NH_4^+-N の除去率は対照系列と同程度であり、全窒素の除去率は高くなった。以上の結果から、実証実験条件では、開発制御により従来制御と同等以上の処理性能を達成できることが分かった。

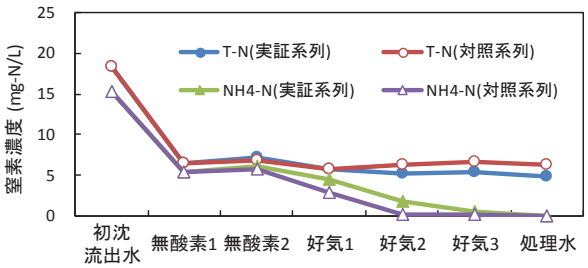


図 3 採水調査における窒素濃度の推移

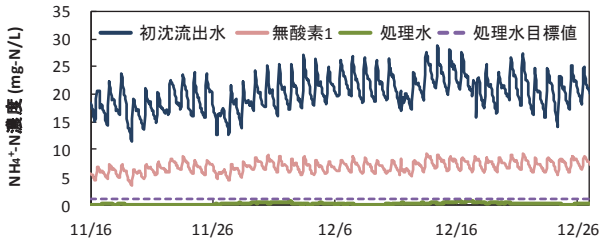
表 2 採水調査結果まとめ

項目	系列	第1回 (2015/9)	第2回 (2015/11)	第3回 (2015/12)
水温 (℃)	実証・対照	27.0	22.9	21.8
BOD除去率 (%)	実証	98	96	95
	対照	98	96	95
T-N除去率 (%)	実証	74	77	78
	対照	68	70	71
NH_4^+-N除去率 (%)	実証	99	100	98
	対照	100	100	100
全リン除去率 (%)	実証	100	99	96
	対照	96	97	94

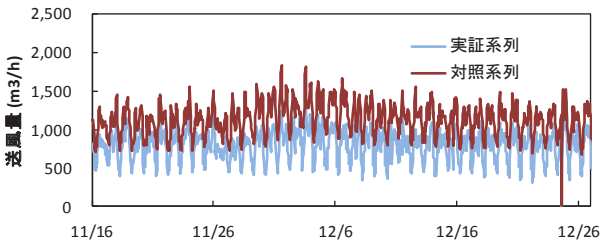
4. 2 開発制御による連続運転結果

開発制御による制御結果の例として、2015 年 11 月 16 日～12 月 27 日を対象に、図 4 (a)に NH_4^+-N 濃度、図 4 (b)に送風量の 1 時間平均値の推移を示す。流入水質が変動する中、処理水 NH_4^+-N 濃度は目標値以下に制御しつつ（図 4 (a)）実証系列の方が送風量は低くなった（図 4 (b)）。以上の結果より、開発制御により安定的に水質目標を満足しつつ、従来制御と比べて送風量を削減できた。

次に、複数の目標値に対する運転結果として、処理水 NH_4^+-N 濃度と DO 濃度、風量削減率の関係を表 3 に示す。本研究では 0.1~2.0 mg/L の範囲で処理水 NH_4^+-N 目標値を設定したが、どの目標値に対しても満足する処理水質が得られた。実証目標の処理水目標値 1.0 mg-N/L に対しては、実証期間中（No.2-1, 2-2）の平均値として処理水 NH_4^+-N 濃度 0.33 mg-N/L、風量削減率 16.9%となり、目標を達成した。



(a) NH_4^+-N 濃度



(b) 送風量

図 4 実証実験における NH_4^+-N，送風量の変動例

表 3 実証実験での処理水質と風量削減率の結果

ID	期間 (日数)	処理水NH_4^+-N (mg-N/L) 目標値	実測値		DO (mg/L) 下限値	実測値	風量削減率	
No.1	2015/6/4 - 7/14 (38日)	0.1	0.09 (平均)		0.50	0.85	12.9% (平均)	
No.2-1	2015/7/18 - 8/4 (15日)	1.0	0.14	0.33 (平均)	0.50	0.58	12.5%	16.9% (平均)
No.2-2	2015/8/5 - 12/27 (83日)		0.36		0.30	0.45	17.7%	
No.3-1	2016/1/7 - 1/17 (11日)	2.0	1.20	1.19 (平均)	0.15	0.44	22.0%	20.2% (平均)
No.3-2	2016/1/25 - 2/3 (8日)		1.18		0.30	1.06	17.8%	

5. 結論

NH_4^+-N 計を活用した効率的な硝化制御システムを国土交通省 B-DASH プロジェクトにて実証した。2015 年度の実証では、複数の処理水 NH_4^+-N 目標値に対して処理水質を満足しつつ、従来 DO 制御と比べて風量を削減できた。また、採水調査の結果、BOD, 全窒素、全リンにおいても開発制御では従来制御と同等以上の処理を実現した。以上の結果より、水質・省エネルギーの両面で開発制御の効果を実証できた。

引用文献

1) 国土交通省：新下水道ビジョン, http://www.mlit.go.jp/mizukokudo/sewerage/mizukokudo_sewerage_tk_000307.html (2018/04/09 アクセス)

2) 国土交通省：栄養塩類の循環バランスに配慮した運転管理ナレッジに関する事例集, http://www.mlit.go.jp/common/001033458.pdf (2018/04/09 アクセス)

O7-18

下水処理における窒素除去を向上させるための曝気プロセスの検討

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キーワード:浄水・排水処理技術, 霞ケ浦, 下水道, 窒素除去, 同時硝化脱窒

抄録

茨城県の潮来浄化センターは霞ケ浦流域に処理水を放流している。霞ケ浦への窒素負荷を低減するため, 活性汚泥による下水処理における窒素除去率を向上させる検討を行った。6 槽からなる反応タンクにおける処理フローを, 嫌気-無酸素-無酸素-無酸素-好気-好気から嫌気-無酸素-好気-無酸素-好気-好気に変更し, 3 槽目を好気槽とすることで硝化を促進し, 4 槽目での脱窒を促す試みを行った。その結果, ねらいどおり, 3 槽目で生じた硝酸性窒素が 4 槽目で脱窒されることによる窒素除去が確認できた。さらに, 3 槽目の好気槽においても脱窒が見られ, その窒素除去量は 4 槽目の無酸素槽での脱窒よりも多かった。好気槽における脱窒は, 低 DO 条件で起こる同時硝化脱窒によると考えられる。無酸素槽での脱窒のほか, 好気槽での同時硝化脱窒も考慮した DO 設定の最適化により, 窒素除去率のさらなる向上が期待できると考えられる。

1. はじめに

茨城県潮来市に位置する潮来浄化センターは, 処理能力 11,230 m^3/日(A 系 7,450 m^3/日, B 系 3,780 m^3/日)の流域下水処理場である。処理水を霞ケ浦流域へ放流しているため, 閉鎖性水域への排出源対策が必要とされている。

本研究では, 霞ケ浦において富栄養化の原因物質となる窒素を対象とした除去率向上の検討として, 反応タンクの処理フローにおいて A_2O 法の槽配置から無酸素槽中央部に曝気槽を設置する槽配置に変更し, 窒素の硝化, 脱窒をさらに促す試みを行ったので報告する。

表 1 霞ケ浦水郷流域下水道事業概要

系列	A系	B系
処理開始	昭和52年	平成10年
処理面積(ha)	921.0	
処理人口(人)	23,691	
処理能力(m^3/日)	7,450	3,780
放流先	霞ケ浦	

2. 方法

下水処理における生物学的窒素除去法では, まず曝気を行っている好気槽(O)で硝化菌の働きによりアンモニア性窒素を亜硝酸性窒素, 硝酸性窒素に硝化した後, 無酸素槽(AO)で脱窒菌の働きにより窒素をガスとして放出する。

潮来浄化センターでは図 2 で示したように反応槽を嫌気槽, 無酸素槽, 好気槽の順に配置し, 好気槽から無酸素槽に循環させる A_2O 法を利用しており, 第 5,6 槽の好気槽で硝化した硝化液を第 2 槽の無酸素槽に循環させて, 第 2～4 槽の無酸素槽で脱窒し, 窒素を除去している。

本研究では平成 29 年 6 月初旬～8 月末を対象期間として, 反応槽における処理フローを嫌気-無酸素-無酸素-無酸素-好気-好気から嫌気-無酸素-好気-無酸素-好気-好気に変更し, 3 槽目を好気槽とすることで硝化を促進し, 4 槽目での脱窒を促して, 窒素除去の向上を図った。運転変更後, 各反応槽での各態窒素(アンモニア性窒素, 亜硝酸性窒素, 硝酸性窒素)を測定し, その効果を評価した。

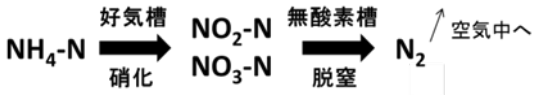

図 1 窒素除去反応の過程

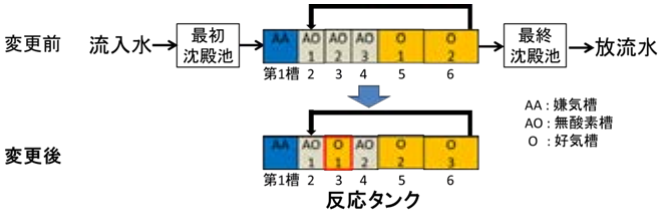

図 2 潮来浄化センター反応タンクの概要図

3. 結果

・COD 除去率

本研究では窒素除去の向上を対象としているが，その際，有機物の処理も問題なく行える必要がある。今回の運転変更における有機物処理状況を確認するため，図 3 に平成 27～29 年度の COD 除去率を示した。

COD 除去率

=(最初沈殿池の COD/最終沈殿池の COD)×100

6 月に運転変更をしてから，運転変更前の平成 27，28 年度と比べ，除去率に大きな差はなく，90%以上で安定していた。以上より，本研究の水処理運転では，有機物処理への影響が出ることはないと考えられる。

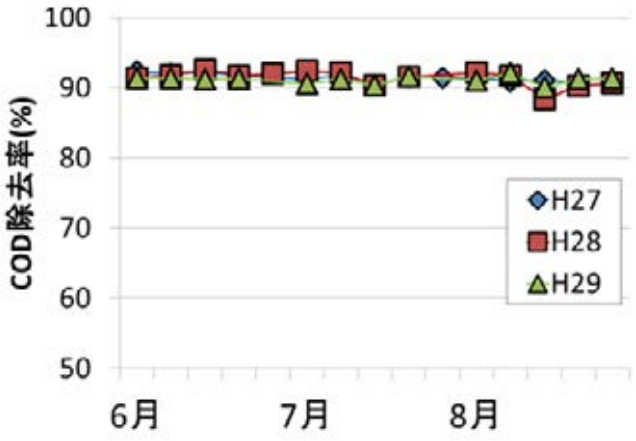

図 3 COD 除去率

・窒素の除去状況

運転変更後の窒素除去の状況を評価するため，図 4 に反応タンクの各反応槽における溶存無機窒素濃度(アンモニア性窒素，亜硝酸性窒素，硝酸性窒素濃度の和)を示した。本研究で新たに設置した 3 槽目の好気槽(O1)から 4 槽目の無酸素槽(AO2)にかけて，溶存無機窒素濃度の低下がみられた。

また，3 槽目は好気槽であり硝化がおきる場であるため，窒素除去を期待する槽ではないが，本研究ではこの 3 槽目の好気槽(O1)においても溶存無機窒素の低下がみられた。日によって差はあるが，3 槽目の好気槽(O1)の方が 4 槽目の無酸素槽(AO2)よりも窒素除去がよい傾向にあった。

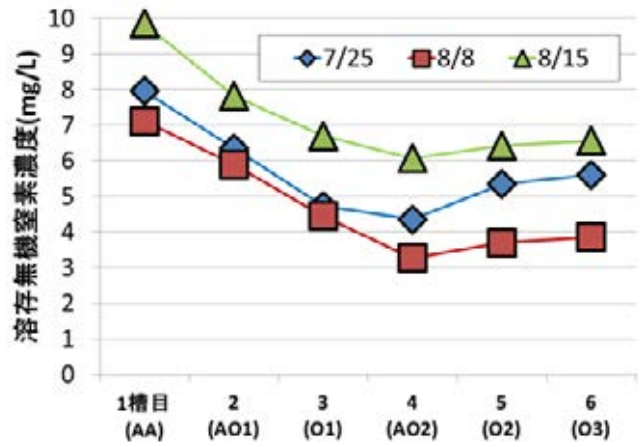

図 4 各反応槽の溶存無機窒素

・各反応槽の形態別窒素濃度

この窒素除去の挙動の原因を調べるため，各槽における形態別窒素濃度を調べた。図 5 にその結果の代表的な例である 8 月 15 日の結果を示した。硝化促進のため導入した3槽目の好気槽(O1)では，ねらいどおり硝酸性窒素の増加がみられた。また，4 槽目の無酸素槽(AO2)においても，3 槽目の硝化分が脱窒されて減るだけではなく，それ以上の硝化が確認できた。

さらに，2 槽目の無酸素槽(AO1)では硝酸がないのにもかかわらず，3 槽目の好気槽(O1)では溶存窒素濃度が減っていた。このことから，好気槽である 3 槽目でも脱窒が起きていると考えられた。

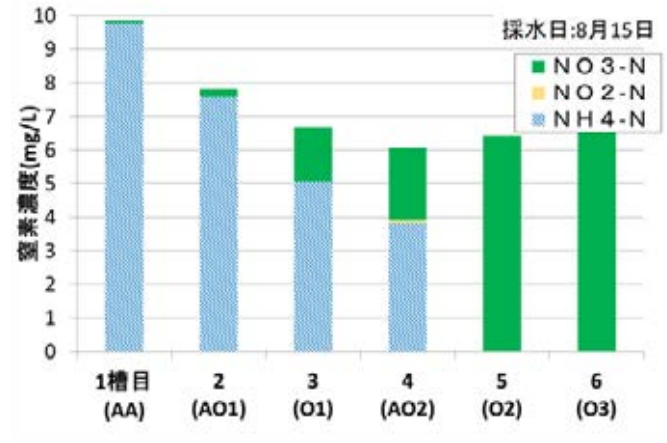

図 5 各反応槽の形態別窒素濃度

4. 考察

3 槽目を好気槽にすることにより，本研究のねらいどおり硝化がおこり，4 槽目で脱窒によるさらなる窒素除去をおこせたと考えられる。ただし，4 槽目でも硝化が進ん

でおり，3 槽目からの DO の持ち込みがおきていることが示唆された。本研究では 3,4 槽目の DO は確認していないため，3 槽目から 4 槽目への DO の持ち込み状況の定量的な確認はできないが，これにより 4 槽目の無酸素槽における脱窒の能力は低減されており，窒素除去の条件として最適化できていなかったと考えられる。このことより，3 槽目の硝化槽で硝化を促進すれば窒素除去が促進されるとは限らないことが示唆される。

次に 3 槽目にて好気槽であるにもかかわらず窒素濃度の減少がみられたが，これは好気槽内での同時硝化脱窒によるものと考えられる。同時硝化脱窒の考え方として，図 6 に周囲の DO 値により変化する活性汚泥フロックの内部モデル[1]を示す。周囲の DO 値が高い場合，好気槽では活性汚泥フロック全体で硝化が進行する。一方，好気槽であっても周囲の DO 値が低い場合，活性汚泥フロックの内部に無酸素領域が形成され，外側で硝化，内側で脱窒が同時に起こるため，窒素除去がおこる。本研究では，3 槽目の DO 値がこの同時硝化脱窒がおきる領域の値であったものと考えられる。同時硝化脱窒では，フロック内での硝化と脱窒のバランスが脱窒量に影響するため，そのバランスが適切になるような DO の最適化が必要になると考えられる。

これまでの結果より，本研究の反応槽の処理フローでの窒素除去の向上においては，3 槽目の好気槽で硝化し 4 槽目の無酸素槽で脱窒する反応を促進することのほか，3 槽目の好気槽内での同時硝化脱窒の影響も大きく，その促進もあわせた 2 つの要素を考える必要があることがわかった。これは，そのそれぞれの反応について単独に最適化をはかるのではなく，両方の反応をあわせた結果の窒素除去量が最大となるような最適化が必要であることを示唆する。平成 25 年度に北見らが行った調査研究[2]では無酸素-無酸素-無酸素-好気-好気-無酸素-好気の処理フローでの検討において，5 槽目の好気槽での窒素の硝化率を 3 段階に設定して窒素除去率を評価したところ，高硝化率または低硝化率ではなく，中程度の硝化率のときに窒素除去量が最大になることを報告しており，本研究と同様に，同時硝化脱窒と無酸素槽での脱窒をあわせて考えることの必要性を指摘している。

以上より，本研究の処理フローでは 3 槽目の好気槽の曝気の仕方が重要であり，その最適化により，窒素除去の向上が期待できることがわかった。

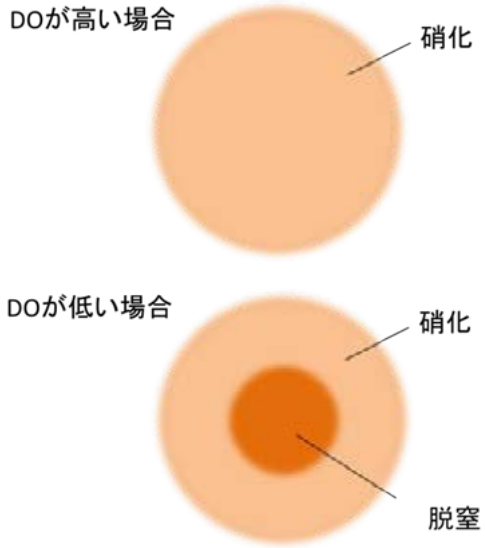

図 6 活性汚泥フロックの内部モデル

5. 結論

・下水処理場の反応槽において，嫌気-無酸素-無酸素-無酸素-好気-好気から嫌気-無酸素-好気-無酸素-好気-好気に変更することで，3 槽目の好気槽での硝化，4 槽目の無酸素槽での脱窒により窒素除去が向上すると考えられる。

・さらに，4 槽目の無酸素槽だけでなく 3 槽目の好気槽でも窒素除去がみられ，その量は 4 槽目の無酸素槽での除去率よりも大きかったことから，好気槽の同時硝化脱窒が窒素除去に寄与する影響が大きいことも確認された。

・好気槽で硝化し，無酸素槽で脱窒するプロセスに加え，好気槽での同時硝化脱窒も考慮した DO 設定の最適化により，窒素除去率のさらなる向上が期待できると考えられる。

6. 謝辞

本調査の実施にあたり潮来浄化センターの指定管理者である鹿島都市開発株式会社に多くのご協力を賜りましたので，ここに感謝の意を示します。

引用文献

[1] Bruce E. Rittmann and Wayne E. Langeland: Simultaneous denitrification with nitrification in single-channel oxidation ditches,Journal. Water Pollution Control Federation, ol57, No.4, 300—308,1985.

[2] 北見康子ら:既存水処理施設における窒素除去の向上を目指した新しい運転管理指標の提案，第 50 回下水道研究発表会講演集，P820−822, 2013.

O7-19

Realization of partial nitritation for mainstream deammonification

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Keywords: sewage, nutrient, denitrification

ABSTRACT

Performance of novel nitritation process using gel entrapment carrier for municipal waste water treatment (mainstream anammox with gel-carrier) was investigated. Purpose of the study was to assess the stability of this process under low ammonium concentration (40 mg-N/L) and low water temperature (20 degrees C) condition. We applied heat-shock treatment to some portion of the nitritation gel carrier frequently for suppressing nitrite-oxidizing bacteria (NOB), and as a result, we succeeded to operate the process stably more than 3 months with suppression of the activity of NOB. In addition, it was confirmed that half-nitritation is possible at a high rate of HRT 1 hour, and that the concentration ratio of ammonium and nitrite can be maintained optimally by DO control.

1. INTRODUCTION

It is important to remove nutrients such as nitrogen from wastewater for improving the water quality in closed water area. Anaerobic ammonium oxidation (anammox) process is a novel biological denitrification process for nitrogen wastewater treatment. Since both ammonium and nitrite are needed for the anammox reaction, part of the ammonium in wastewater has to be oxidized to nitrite with pre-treatment, such as nitritation process. This nitritation-anammox (deammonification; N-A) process is less-energy and cost-effective way to remove ammonium nitrogen compared with conventional nitrification-denitrification process.

However, this N-A process has only been applied to the sidestream municipal wastewater (digester supernatant) treatment and some specific industrial wastewater treatment with high ammonium concentration and high temperature, yet not to the mainstream municipal wastewater treatment with low ammonium concentration and low temperature.

The main challenge for applying N-A process to mainstream treatment is to keep the appropriate ratio between nitrite and ammonium concentrations stably under low ammonium concentration and low temperature condition, because nitrite easily changes to nitrate under that condition.

In our previous works, the full-scale nitritation-anammox plant using gel entrapment technology was successfully operated for industrial wastewater treatment [1]. Especially, it is possible to keep nitritation without nitrate production by giving the intermittent heat load (heat-shock) for gel [2].

In this study, heat-shock technology was applied to the nitritation process under low ammonium concentration and low temperature condition for investigating the possibility of applying N-A process to mainstream municipal wastewater treatment.

2. METHOD

In this study, gel entrapment technology was applied to immobilization of bacteria. For the nitritation process, gel carriers that immobilized ammonium-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB) inside were used. The size of the gel carrier is 3 mm cubes and the base material is Polyethylene Glycol. A complete mixing tank having volume of 0.5L was prepared as the nitritation reactor, and 0.05L of gel carriers (10%) was charged therein. Synthetic wastewater adjusted to ammonium concentration of 40 mg-N/L with ammonium sulfate was continuously fed to the reactor. The HRT was kept 1hour. In order to suppress the activation of NOB, 4% of the gel carriers were immersed in hot water at 60 degrees C for 60 minutes once a day. Dissolved oxygen (DO) concentration was controlled to achieve the appropriate ratio between ammonium and nitrite concentrations during the experiment.

Temperature of the feed water and the reactor was kept 20 degrees C. In order to evaluate nitritation performance, influent and effluent water were analyzed for ammonium, nitrite and nitrate.

3. RESULTS and DISCUSSION

Heat-shock technology was applied to the nitritation reactor from start-up period for investigating the

effectiveness of suppressing the nitrate production. Figure 1 shows the nitrogen concentrations in nitritation reactor with heat-shock technology. After 20 days, the ammonium and nitrite concentrations maintained both approximately 20 mg-N/L stably. It was an appropriate ratio for anammox process. In contrast, nitrate was not produced for 3 months. NOB in the gel carrier could be completely inactivated by the heat-shock treatment effect. Moreover, it was confirmed that the nitritation process was operated with a short HRT of 1hour, and half-nitritation was achieved. DO concentration during the experiment was controlled about 1 to 4 mg/L for controlling the concentration ratio of ammonia and nitrite to be 1:1. This ratio is appropriate for the anammox phenomena. In this test, the ammonium loading rate and nitrite production rate were approximately 0.9 and 0.4 kg-N/m3-reactor/d, respectively. Very fast nitrification performance was observed even though the packing ratio of the carrier was 10 percent.

4. CONCLUSION

In this study, nitritation performance using gel entrapment technology at low ammonium concentration and low water temperature was investigated for the purpose of applying N-A process to mainstream municipal wastewater treatment.

In the nitritation process, it was clarified that NOB can be inactivated stably by periodic heat-shock treatment to a part of the gel carrier. In addition, it was confirmed that half-nitritation was achieved at a high rate of HRT 1 hour, and that the concentration ratio of ammonium and nitrite can be maintained optimally by DO control.

As mentioned above, it was concluded that partial nitritation process under low ammonium and low temperature condition was substantiated by applying the gel entrapment technology and heat-shock technology to the nitiritation process. This conclusion suggests that it is possible to apply the N-A process using gel carriers to mainstream municipal wastewater treatment.

REFERENCES

[1] Isaka, K., Kimura, Y., Matsuura, M., Osaka, T., & Tsuneda, S.: First full-scale nitritation-anammox plant using gel entrapment technology for ammonia plant effluent, Biochemical Engineering Journal, Vol. 122, pp. 115-122, 2017

[2] Isaka, K., Sumino, T., & Tsuneda, S.: Novel nitritation process using heat-shocked nitrifying bacteria entrapped in gel carriers, Process Biochemistry, Vol. 43(3), pp. 265-270, 2008

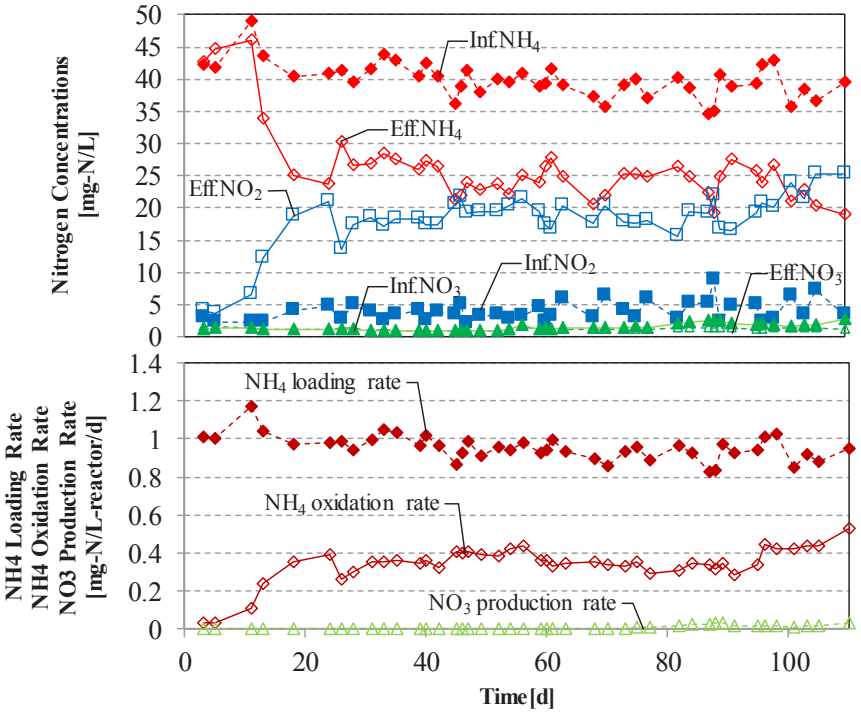

Fig. 1 Performances of the nitritation reactor using heat-shocked gel carriers.

O7-20

Simultaneous removal of nitrogen and priority phthalates from municipal wastewater for management of fresh water sources

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Keywords: Emerging contaminants, Fate, IFAS process, Phthalates, Removal, Wastewater treatment.

ABSTRACT

The study was focused on pilot scale experiments in order to understand the impact of carbon removal and nitrogen removal configuration on phthalate removal in an integrated fixed film activated sludge (IFAS) system which can be used to save lakes and fresh water sources from pollution. To achieve these objectives, four priority phthalates (DEP, DBP, BBP and DEHP) were chosen. Run I was carbon removal process and run II was nitrogen removal process. It was observed that during run I when there was intensive carbon removal process, the percentage removal was in the range of 40 – 78% (DEP), 64 – 85% (DBP), 40 -98% (BBP) and 65 – 90% (DEHP) respectively. Comparatively to run I, the percentage removal in run II, the percentage removal of phthalates varied over a smaller range. The range of percentage removal in run II increased to 84 - 96% (DEP), 83 – 97% (DBP), 85 – 99% (BBP) and 87 – 95% (DEHP). During run I, there were fluctuations in the removal of DEP, DBP and BBP with average removal of 60±13%, 75±8% and 76±21% respectively. During run II, when the anoxic zone was developed with inlet diversion, the removal of all four phthalates was steady and higher. The maximum contribution to the overall removal was observed in the secondary oxic tank in both operational runs. Biodegradation was observed a main contributor to the overall removal. Mass balance calculations showed that during run I, 62% of influent DEP, 65% of influent DBP, 68% of influent BBP and 61% of influent DEHP was removed by biodegradation while as during run II, 90% of influent DEP, 90% of influent DBP, 91% of influent BBP and 89% of influent DEHP was removed by biodegradation.

1. INTRODUCTION

Large usage of phthalate acid esters (PAEs) or phthalates in manufacturing of polyvinyl resins, wall coverings and car coatings etc. and their release into the environment have made their presence ubiquitous in the environment [1,2]. Their release into the environment is because most of the phthalates are not chemically bound to the product. High concentration of phthalates is detected in influents of wastewater treatment plants and the inefficient removal of these compounds in the treatment plant is considered as one of the main source of their presence in fresh water sources [3, 4]. Our earlier study Gani and Kazmi [5] with full scale wastewater treatment facilities observed that phthalate removal was highest in nutrient removal based sequencing batch reactor (SBR) based wastewater treatment plant. Fate study also confirmed that the biodegradation was also highest in this treatment configuration compared to conventional activated sludge process and upflow anaerobic sludge blanket reactor followed by polishing pond.

The objective of this study was to investigate the impact of nitrogen removal configuration and carbon removal sequence on phthalate removal. To achieve these objectives, four priority phthalates (DEP, DBP, BBP and DEHP) and an integrated fixed film activated sludge (IFAS) process was chosen because IFAS process has mounting market attention and contain features of both activated sludge process and attached growth process.

2. METHOD

2.1 IFAS process based reactor

A 35 L bioreactor composed of three reaction tanks and a settler was used in the study (Figure 1). The three reaction tanks were 1) media tank with aeration 2) an anoxic tank 3) an oxic tank and the reaction volume was 10 L each. A 5 litre settling tank with rotating scraper was installed at the end of treatment process. The media used in first tank was polyvinyl alcohol gel beads occupying 10% or 1 L of reactor volume. Aeration in media tank and oxic tank was provided with diffusers placed at bottom. Continuous mixing was carried out in anoxic tank with the help of rotating shaft. Initially for 64 days the raw sewage inflow was completely fed to media tank. After that 20% of raw sewage was fed into anoxic tank for external BOD loading for denitrification. Total HRT of

the wastewater in the reactor system was 6 hours with 2 hours in each tank. Sludge recirculation was carried into the anoxic tank with flow rate of 60 L/d (Table 1).

Table 1 Operational information of the PVA gel based IFAS pilot plant.

Parameter	Run I	Run II
HRT (hours)	6	6
Flow (L/d)	120	120
SRT (days)	7.3	7.5
External carbon source flow rate (L/d)	-	24

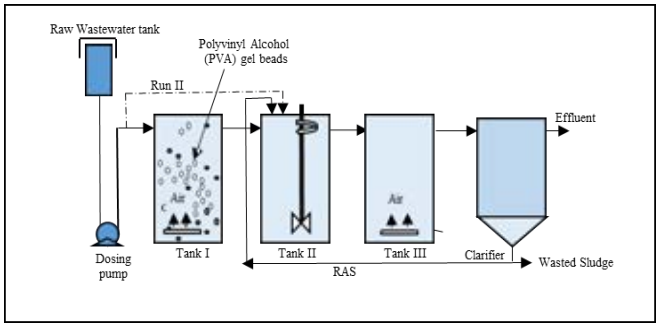

Fig. 1 Flow diagram of the IFAS pilot plant.

3. RESULTS AND DISCUSSIONS

3.1 Treatment performance of the IFAS bioreactor

Figure 2 and Table 2 shows the COD and BOD removal performance of the IFAS reactor system in different stages. It took almost 40 days for the bio reactors to get stable and perform at steady rate. However, stability of the bioreactor with respect to carbon removal (COD and BOD) was comparatively faster than nitrification. COD in the effluent of the bioreactor continued to be less than 100 mg/L from 15th day of start of operation while as the ammonia removal stabilized after 40 days. The longer time for nitrification to get stabilized was due to washout of biomass from the media tank and attachment to the media. It was observed that the biomass in mixed liquor reduced to less than 500 mg/L after inoculation with 1500 mg/L of MLSS in the beginning and the trend was not changing till 40th day of operation. From 45th day to 50th day, the wasted sludge was manually recirculated to media tank which enhanced nitrification to a steady rate of more than 90%.

Table 2 Performance of wastewater treatment in IFAS reactor.

	Startup	Phase 1	Phase 2
Influent COD (mg/L)	388±211	375±65	435±124
Efficiency (%)	77±18	91±3	93±3
Influent BOD (mg/L)	185±74	199±47	188±59
Efficiency (%)	82±11	91±6	96±2
Influent TSS (mg/L)	-	250±86	313±45
Efficiency (%)	-	94±4	98±1
Influent NH_4^+-N (mg/L)	47±25	43±9	17±8
Efficiency (%)	31±30	97±2	95±5
Influent TN (mg/L)	59±28	68±1	39±11
Efficiency (%)	31±30	71±9	70±15
Influent PO_4^{3-}-P (mg/L)	14±3	7±2	8±1
Efficiency (%)	49±15	37±13	25±24

3.2 Phthalate removal performance of IFAS bioreactor

Figure 2 shows the removal of phthalates in the IFAS process during two different operational scenarios. Phthalate monitoring in the samples from IFAS process was carried out after stabilization of carbon and nitrogen removal. During run I i.e. unavailability of anoxic zone, there were fluctuations in the removal of DEP, DBP and BBP. The average removal of DEP, DBP and BBP in this run was 60±13%, 75±8% and 76±21% respectively. During run II, when the anoxic zone was developed with inlet diversion, the removal of all four phthalates was steady and higher. The average removal of DEP, DBP, BBP and DEPH was 89±4%, 93±4%, 95±5% and 94±5% respectively. The steadiness in removal during run II may be due to availability of different reaction environments which enhanced the removal by providing different metabolic pathways. Enhanced removal of micro pollutants in a membrane bioreactor (MBR) having several aerobic and anoxic zones was observed by Phan et al. [6] than a pilot scale MBR having only one aerobic and anoxic reactor.

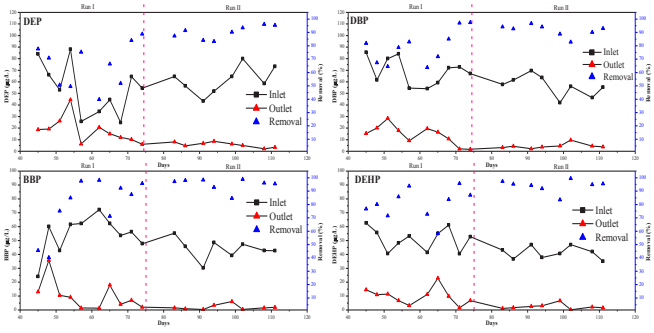

Fig. 2 Phthalate removal in IFAS pilot plant.

3.3 Phthalate mass balance

From fate calculations the contribution of the sorption to the overall removal was very less (Figure 4). The reasons for this was less wastage of sludge from the pilot plant

rather than low sorption of phthalates to suspended bio solids. The average concentration of four phthalates attached to bio solids in three tanks was in confirmation with previous studies such as that of Gao et al. [3] and Gani et al. [5].

Biodegradation was observed a main contributor to the overall removal. Mass balance calculations showed that during run I, 62% of influent DEP, 65% of influent DBP, 68% of influent BBP and 61% of influent DEHP was removed by biodegradation while as during run II, 90% of influent DEP, 90% of influent DBP, 91% of influent BBP and 89% of influent DEHP was removed by biodegradation. This implies that the increase in removal of the phthalates during biological nitrogen removal configuration (run II) was due to enhancement is microbial degradation rather than sorption. Earlier field scale studies such as that of Gani et al. [5] have also observed the higher contribution of biodegradation to the overall removal in nutrient removal treatment technologies.

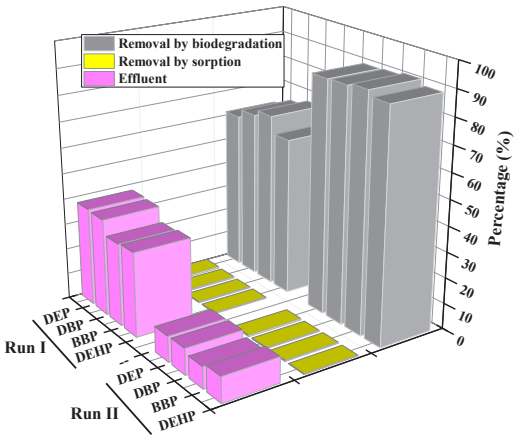

Fig. 3 Mass balance of phthalate removal in IFAS pilot plant.

4. CONCLUSIONS

This study was aimed to investigate and report the treatment of phthalates in biological wastewater treatment under carbon and nitrogen removal conditions. After start of the operation of the pilot plant, stability of the IFAS bioreactor with respect to carbon removal (COD and BOD) was comparatively faster than nitrification and the treatment performance was conforming the discharge criteria of India. The removal of phthalates during nitrogen removal configuration (run II) was more than the removal during intensive carbon removal configuration (run I). Not only there was increase in average removal of phthalates in run II but there was steadiness in the removal performance of these compounds which can be owed to the different reaction environments in run II. The removal of phthalates in the presence of external carbon source enhanced in anoxic zone. Finally, fate studies were carried out in this study from which it was observed that under similar operating parameters, main process of removal of phthalates in IFAS reactor is biodegradation.

REFERENCES

[1] Staples, C.A., Peterson, D.R., Parkerton, T.F., Adams, W.J., 1997. The environmental fate of phthalate esters: a literature review. Chemosphere 35, 667–749.

[2] Fromme, H., Küchler, T., Otto, T., Pilz, K., Müller, J., Wenzel, A., 2002. Occurrence of phthalates and bisphenol A and F in the environment. Water Res. 36, 1429–1438.

[3] Gao, D., Li, Z., Wen, Z., Ren, N., 2014. Occurrence and fate of phthalate esters in full-scale domestic wastewater treatment plants and their impact on receiving waters along the Songhua River in China. Chemosphere 95, 24–32.

[4] Gani, K. M., Rajpal, A., Kazmi, A. A. 2016. Contamination level of four priority phthalates in north Indian wastewater treatment plants and their fate in sequencing batch reactor system. Environmental Science: Processes & Impacts 18, no. 3 (2016): 406-416.

[5] Gani, K. M., & Kazmi, A. A. (2016). Comparative assessment of phthalate removal and risk in biological wastewater treatment systems of developing countries and small communities. *Science of the Total Environment*, *569*, 661-671.

[6] Phan, H.V., Hai, F.I., McDonald, J.A., Khan, S.J., Zhang, R., Price, W.E., Broeckmann, A. and Nghiem, L.D., 2015. Nutrient and trace organic contaminant removal from wastewater of a resort town: Comparison between a pilot and a full scale membrane bioreactor. *International Biodeterioration & Biodegradation*, *102*, pp.40-48.

O7-21

Comparison of Effluents Characteristics from Full-Scale Wastewater Treatment Plants in Thailand, USA, and Japan before Discharging to Lakes

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ABSTRACT

Three full-scale systems wastewater treatment plants (WWTPs) from Thailand, United States of America (USA), and Japan were used as study sites. All of these WWTPs were designed and operated for biological nitrogen removal (BNR) by using nitrification-denitrification processes. In general, the WWTPs in Thailand operated at higher values of temperature, HRT and SRT comparison to USA and Japanese WWTPs. Influents and effluents from these sites are compared and discussed in terms of BNR, dominant nitrifying and ammonia oxidizing archaea (AOA) microorganisms, and WWTP engineering design. Polymerase chain reaction coupled with denaturing gradient gel electrophoresis was used to identify dominant bacteria involved in nitrogen transformations: ammonia-oxidizing bacteria (AOB), nitrite-oxidizing bacteria (NOB), and nitrate reducing bacteria (NRB). AOB Nitrosomonas sp. was found only in Thailand where aerobic HRT was ≥ 4 hours and SRT was ≥15 days. Furthermore, AOB Nitrosospira sp. were found only in Japan at aerobic HRT ≤ 4 hours and SRT≤ 13 temperature (21-27°C). NOB Nitrospira sp. was found at aerobic HRT ≥ 4 hours and SRT ≥ 6 days. Interestingly, Nitrotoga sp. was found in the aerobic tank one in Thailand and one in Japan and co-occurred with NRB Burkholderia denitrificans. The higher wastewater temperature and lower influent nitrogen concentration in Thailand appear to promote a different AOB and NOB community structure than in Japan. The conditions at the Thai WWTP promoted the dominance of AOA amoA genes over AOB amoA genes, while conditions at the WWTPs in Japan and USA promoted growth of AOB. The Thai WWTP is a unique system that can be used to better understand.

1. INTRODUCTION

Nitrogen in municipal wastewater is source of water pollution which reduces oxygen concentration. Nitrogen should be removed before it is discharged into the environment. Nitrogen forms can have deleterious effects on human health, aquatic life, and environment. For example, ammonia (NH3) is toxic to fish and many other aquatic organisms. Nitrate (NO3-) is a significant potential public health hazard in drinking water which presents the risk of methemoglobinemia (blue baby syndrome) in infants. Nitrogen is the major nutrient that enhance eutrophication of freshwater and lakes. Domestic sewage, agriculture, and industries are sources of nitrogen. In Thailand, domestic sewage is a main source of nitrogen. In Japan and USA, runoff from agriculture is significant source of nitrogen. However, it is quite different to control runoff from agriculture because there are more land and area. Also standard of effluent discharging from agriculture is not too rigid. In general, WWTPs in Japan and USA report higher nitrogen removal than WWTPs in Thailand. However, there is little information available to elucidate the factors responsible for the lower nitrogen removal efficiency of WWTPs in Thailand (humid tropical climate) relative to the WWTPs in Japan and USA (humid subtropical climate). Potentially important differences include climate, influent wastewater characteristics, WWTP design and dominant bacteria that oxidize or reduce nitrogen.

2. METHODS

Influent and effluent wastewater quality was determined

according to *Standard Methods for the Examination of Water and Wastewater* (APHA et al. 1995). All effluent samples were collected every day for one year. All samples were kept at 4°C until analysis. Effluent characteristic quality was determined by measuring biochemical oxygen demand (BOD), organic nitrogen, ammonium, nitrate, and total nitrogen and phosphorus. All the effluent samples from points from each WWTP were taken in duplicate.

DGGE analysis and sequencing of DGGE fragments

For DNA analysis effluent samples from three WWTPs were collected twice in one year. All the samples of DNA analysis from this work were only collected in the aerobic basins because of focus on nitrifying and ammonia oxidizing archaea (AOA) microorganisms.

3. RESULTS

These WWTPs were selected as study sites because each WWTP has biological nutrient removal (BNR) (nitrification and denitrification process) and had been designed and similar operation for municipal treatment system. Average physical and chemical characteristics of influent and effluent of these three WWTPs are shown in Table 1. The qPCR results show the relative abundance of AOA and AOB amoA genes at the three WWTPs.

Table 1 Characteristics of the activated sludge systems at the WWTPs in Thailand, USA, and Japan.

Parameter	unit	Wastewater Treatment Plants		
Treatment Process		Thailand OD	USA OD	Japan AO
Flow rate	m^3/day	28,735	15,160	92,300
Temp.	°C	30	16	22
pH		7.2	6.7	6.2
BOD_{inf}	mg/L	174	336	110
$BOD_{eff.}$	mg/L	3.7	3.7	2
$NH_4^+{}_{inf}$	mg-N/L	15.9	35.8	15.9
TN_{inf}	mg N/L	25.3	56*	24.7
$NH_4^+{}_{eff}$	mg-N/L	8.7	0.7	6.5
$NO_3^-{}_{eff}$	mg-N/L	3.2	3.2	12.2
MLSS	mg/L	7,180	2,330	920
Organic Loading rates	Kg/day	5,000	5,094	10,153

4. DISCUSSION

The levels of AOA amoA gene in the WWTPs in Japan and USA were below the quantification limit of 1.0×101 copies/ng-DNA, corresponding to 7.6×102 and 3.9×102 copies/mL-sludge, respectively. In contrast, the copy number of AOB amoA gene averaged 2.4×105 copies/ mL-sludge for both the WWTPs in Japan and USA. This indicates that ammonium oxidation was conducted by AOB but not AOA in Japanese and USA WWTPs.

5. CONCLUSION

The effluent characteristics quality both chemical and biological quantity from USA and Japan are lower than the standard. For Thai's effluent on quantities of fecal coliform and E-coli are significantly lower than Thai's and US EPA's standards. The effluents could not usage as an indirect potable water reuse.

REFERENCES

[1] Noophan, (Lek) Pongsak; Phanwilai, Supaporn; Kasahara, Tamao; Munakata-Marr, Junko; and Figueroa A. Linda (2017) Comparison of Nitrogen Removal and Full-Scale Wastewater Treatment Plant Characteristics in Thailand and Japan, EnvironmentAsia Vol. 10 No. 1, 92-98.

[2] Noophan ,(Lek) Pongsak; Paopuree, Pongsri; Kanlayaras, Kullaya; Sirivitayaprakorn, Sanya, and Techkarnjanaruk, Somkiet (2009) Nitrogen Removal Efficiency at Centralized Domestic Wastewater Treatment Plants in Bangkok. Environment Asia Vol. 2 No. 2 (July), 30-36.

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Development of Design Method for Localization of Japanese Johkasou to EU Area

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Keywords: small-scale wastewater treatment facility, localization, performance evaluation test, domestic wastewater solution, design method

ABSTRACT

For environmental conservation of closed water bodies such as lakes and bays, the promotion of wastewater treatment facilities that can remove not only BOD but also nitrogen, one of the causes of water-bloom and red tide, is desirable. To apply Japanese johkasou to other countries, it is necessary to modify the design of johkasou to harmonize with the local life style and environmental characteristics. For this purpose, this study examined the localization of Japanese johkasou for the EU region where the performance evaluation method for such facilities has been established. Focusing on the amount of wastewater and the pollutant load which differ in the performance evaluation tests between EU and Japan, an EU-oriented facility was designed with BOD volumetric load equal to Japanese facility. This facility was experimented in France, and the results were compared to those of the Japanese prototype model. As a result, the effluent quality of the EU-oriented facility was maintained at the same level as the Japanese model even when the influent BOD load increased to 120% of the preset value. This result indicates that the most common design method in Japan using BOD volumetric load is effective for designing EU-oriented facilities, but there is a possibility that the volume of the facility may be over-designed. Furthermore, to maintain the ability to remove nitrogen, it is important to the keep the water temperature in the facility above 13°C.

1. INTRODUCTION

The Sustainable Development Goals (SDGs) entered into force on 1 January 2016. To achieve one of the targets to halve the proportion of untreated wastewater, countries need to improve their wastewater treatment facilities correspondingly over the next 15 years. Moreover, in the event that domestic wastewater is discharged into a closed water body, such as a lake or a bay, it is desirable that in addition to BOD, the treatment facilities are able to remove nitrogen and phosphorus, two of the causes of water-bloom and red tide.

Wastewater treatment infrastructure in Japan includes centralised treatment – the sewerage system, and decentralised treatment – johkasou. Centralised treatment suits densely populated areas, whereas decentralised treatment is suitable for sparsely populated mountainous areas. Currently, johkasou is expected to be the solution for the latter areas as they have lower population coverage of wastewater treatment. Johkasou is a type of wastewater treatment facility uniquely developed in Japan. Furthermore, new types of johkasou that can remove nitrogen and phosphorus have been developed in recent years. For these reasons, johkasou has been drawing attention from other countries, and a number of technology transfers have been accomplished. On the other hand, in regions with an established performance evaluation method for johkasou and other small-scale wastewater treatment facilities, these facilities cannot be installed if their performance test results using the established method failed to meet local effluent standards. Regarding the testing method, differences exist between EU and Japan in influent conditions such as influent volume and pollutant load, and testing conditions such as water temperature and maintenance interval. Also, different effluent standards exist among EU member states. Due to these facts, no significant progress has been made for localization of johkasou. If a design method that allows redesigning Japanese johkasou to meet standards of various countries can be discovered, johkasou's contribution towards the popularization of wastewater treatment facilities that harmonize with local features could be further expected.

In this study, an EU-oriented small-scale wastewater treatment facility and a Japanese johkasou were put into operation in France and Japan respectively for a period of more than one year to investigate and analyze the influence of different performance evaluation methods on the treatment performance.

2. METHOD

(1) Method of examination

In EU, EN12566-3+A2 regulates the performance evaluation method for small-scale wastewater treatment facilities. In Japan, on the other hand, johkasou performance testing standard was established based on the Building Standard Law. A brief description of the testing methods in EU and Japan is shown in Table 1.

Analysis of the performance of the EU-oriented small-scale wastewater treatment facility (the "EU model") was carried out with the following steps in this study: (1) clarify the differences in performance testing method between EU and Japan, then review the design of johkasou (the "Japanese model") for use in the EU region; (2) regarding testing the effluent, prolong the testing duration designated in EN12566-3+A2 for the EU model, meanwhile, test the Japanese model in Japan using the testing method for johkasou; (3) based on the results from (2), comparatively analyze the BOD and nitrogen in the effluent, and examine the influence of different testing methods on treatment performance.

(2) Testing method for the EU model

Testing for the EU model, carried out by a French testing institute, lasted for 63 weeks (442 days) in total, including a 38-week (263 days) test based on EN12566-3+A2 shown in Table 2, and an additional test, which included a 2Q overload test to examine the performance in the overloading condition. Water volume 1Q was 750 L/day. Influent quality, effluent quality as well as water temperature were measured 38 times each throughout the test. In terms of maintenance during the test, based on the local testing method, desludging was set to be conducted when settled sludge reaching 1/3 of the designed volume of primary process chamber, whereas maintenance and operation would be carried out in the event of a malfunction, such as a breakdown. This test will be referred to as the "EU test".

Table 1 Testing methods in EU and Japan (5 P.E)

		Unit	EU test	Japanese test
Inflow rate		(L/day)	750	1,000
Influent	BOD	(mg/L)	150 ～ 500	200（180 ～ 220）
	TKN	(mg/L)	25 ～ 100	45（40 ～ 50）
	NH_4-N	(mg/L)	22 ～ 80	-
Water temperature		(℃)	-	20, 13 (low temperature test)

※(　　): range; ※※T-N measured in Japanese test was substituted for TKN

Table 2 Details of the EU test

Items	Testing duration (days)			Times of measurement		
	EN12566-3+A2	Additional	Total	EN12566-3+A2	Additional	Total
Start-up(1.0Q)	34	0	34	0	0	0
Routine(1.0Q)	205	95	300	25	0	25
Low load(0.5Q)	28	0	28	3	0	3
Low stress	14	41	55	0	3	3
Overload(1.5Q)	16	0	16	2	0	2
Overload(2.0Q)	0	43	43	0	5	5
Total (excl. Start-up)	263	179	442	30	8	38
Total	297	179	476	30	8	38

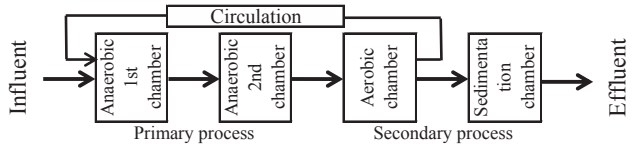

Fig.1 Treatment process of the EU model

(3) Testing method for the Japanese model

As shown in Table 1, standard duration of a johkasou test is 16 weeks which is considered difficult for comparison with the 63-week EU test. For this reason, actual duration of the performance test in Japan was adjusted to 52 weeks (to match the once/year desludging interval regulated by Johkasou Act). Moreover, for comparison with the EU model, a 5 P.E facility was chosen as the Japanese model to be used in the test, with an influent volume of 1.0Q (1,000L/day). Objects being tested were set the same with the EU test and measured 26 times in the test. This test will be referred to as the "Japanese test".

3. Design of the EU model

(1) Summary of the design

The prototype of the EU model was chosen from johkasous qualified in the Japanese performance test. The design was then reviewed based on the differences in testing method between EU and Japan. The reviewed design is described below.

(2) Effluent quality and treatment process

Effluent standards in the EU regions are different from the Japanese standard for johkasou (BOD≤20mg/L; T-N≤20mg/L). However, as the objective of this study is to examine the appropriateness of the method of johkasou localization, the Japanese standard was adopted as the preset value for the EU model, except for T-N which was not measured in the EU regions. In response, TKN was used as the nitrogen indicator for the EU model. Moreover, taking account of maintainability, a combination of two simplified anaerobic chambers without flow adjustment or filtration, an aerobic chamber and a sedimentation chamber (Fig.1) was chosen as the treatment process (structure) of the EU model. Moreover, as disinfection was not required in EU, the disinfection chamber was deleted.

(3) Volume of the EU model

In Japan, the most common method to design the necessary volume of treatment facilities with various inflow rates was to calculate pollutant volumetric load and wastewater volumetric load of the influent, separately, then adopt the higher value [1]. In this study, volumetric loads of BOD, TKN and wastewater of the Japanese model were used for the calculation for the EU model. As a result, the highest value was 2.838m^3, calculated from the BOD volumetric load, and was adopted as the necessary volume (necessary volume of the Japanese model is 1.892m^3). Moreover, assumed influent quality

Table 3 Effluent results of EU model and Japanese model

Items		Inflow rate	BOD (mg/L)		Removal rate	TKN (mg/L)		Removal rate
			Influent	Effluent		Influent	Effluent	
EU test	Condition	1.0Q	400	20.0	95%	80	20.0	75%
	EU model	average	481	10.7	98%	102	20.2	80%
		1.0Q	488	11.1	98%	104	20.5	80%
		0.5Q	493	12.0	98%	105	16.1	85%
		1.5Q	335	9.5	97%	83	52.2	37%
		2.0Q	492	7.4	98%	101	11.5	89%
Japanese test	Condition	1.0Q	200	20.0	90%	45	20.0	56%
	Japanese model	1.0Q	207	11.9	94%	47	16.3	65%

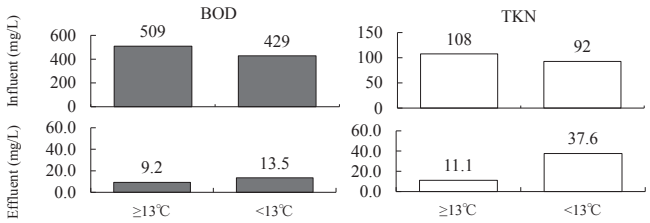

Fig.2 Effluent results by water temperature

of the EU model in this calculation was BOD 400mg/L and TKN 80mg/L, taking into account variations.

4. RESULTS

(1) Effluent results of EU model and Japanese model

Effluent results of the EU model and the Japanese model were shown in Table 3. As shown, in the EU test, the average BOD in the influent (481mg/L) was 1.2 times the preset value - close to the maximum value of the testing condition, meanwhile, the average TKN in influent (102mg/L) exceeded the maximum value. As a result of the fluctuating inflow rate between 0.5Q and 2Q, the average effluent BOD (10.7mg/L) was at the same level with the Japanese model, and was below the preset value (20mg/L), however, average effluent TKN (20.2mg/L) exceeded the preset value slightly.

(2) Maintenance in the EU test

In the EU test, it took 476 days to reach the requirement for desludging. During this period, no functional deterioration had been observed, thus no need for maintenance work.

5. DISCUSSION

(1) Design method based on volumetric load

As the EU test had a higher influent BOD concentration than the preset value, the BOD volumetric load (0.13 BOD-kg/m^3・day) was higher than the Japanese model (0.11 BOD kg/m^3・day). In addition, the inflow rate fluctuated intentionally. Considering these facts, analysis of the influence on effluent BOD load was made with a non-exceedance probability of 90%. The BOD in the effluent of the EU model was 17.2 mg/L, which was almost the same as the calculated value of the Japanese model (17.0 mg/L). It indicates that using the same BOD volumetric load is an effective design method for calculating the necessary volumes of facilities with various influent loads. However, it is also suggested that this method may cause over design. In terms of TKN volumetric load (TKN-kg/m^3), the EU model (0.028) was higher than Japanese model (0.025). It is considered that the EU did not meet the preset value of TKN.

(2) Influence of water temperature on performance

Water temperature in the low-water-temperature test in Japan was set to 13°C. In the 26 measured results, only one result was below 13°C (12.7°C). On the other hand, results from the EU test were categorized into <13°C and ≥13°C (Fig.2). Effluent BOD, TKN at <13°C were worse than at ≥13°C, regardless of influent pollutant concentrations being lower. Also, although variation of effluent BOD stayed below the effluent preset value, TKN at <13°C significantly exceeded the preset value. As a result of analysis, nitrification rate (mg-N/g-SS・hr), which is the decreasing rate of ammonia nitrogen, of the Japanese model was 1.70, similar to the EU model at ≥13°C (1.65). However, the rate at <13°C fell to 0.88. Therefore, in order to maintain the ability to remove nitrogen throughout a whole year, water temperature needs to be kept above 13°C.

6. CONCLUSION

This study aimed to find out the design method that allows redesigning the Japanese johkasou to meet various standards in different countries for its overseas application. And the following conclusions were made.

1) As a method that allowed Japanese anaerobic-aerobic johkasou to meet the low-volume and high-concentration loading condition in the EU regions, an EU-oriented wastewater treatment facility with the same BOD volumetric load was designed. As a result, the effluent BOD in the EU test met the preset value based on the Japanese model. Moreover, during the 476 days of the test, no desludging or maintenance work was required.

2) Although influent BOD in the EU test was higher than the preset value, the effluent was at the same level as the Japanese model. As a design method for wastewater treatment facilities for various influent loads, using the same pollutant volumetric load is effective. However, it is suggested that this may cause over design.

3) In the EU test, effluent TKN worsened when the water temperature was below 13°C. As this was caused by decreased nitrification rate under low water temperature, keeping the water temperature in the facility is considered important in order to maintain the ability to remove nitrogen.

REFERENCES

[1] The Building Center of Japan: Johkasou no Kouzoukijun・Doukaisetu (2016) (Japanese), pp.229-230, 2006.

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印旛沼流域におけるナガエツルノゲイトウ問題
～治水リスクの軽減にむけた外来種管理の持続可能な取り組み～

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キーワード:印旛沼開発事業, 利水施設, 特定外来生物, SDGs, 地域活性化

抄録

千葉県北西部に位置する印旛沼では, 出水時に治水対策として大和田排水機場よりポンプ排水を行っている. しかし, 印旛沼の流入支川に大量に繁茂している特定外来生物ナガエツルノゲイトウ(以下, ナガエ)が, 出水時に大和田排水機場に漂着し, スクリーンに詰まることによるポンプ排水への影響を回避するため, 重機や手作業で漂着したナガエの駆除活動を実施している. このような状況を未然に防ぐために, 千葉県では市民や学生ボランティアとともに駆除活動を行っている. 本論文では, 印旛沼におけるナガエの問題について経緯と現状, 今後の課題を整理するとともに, ナガエに関する取り組みの中で培われてきた地域との連携や, 課題解決が地域活性化に繋がる可能性について考察した. また, このような活動は SDGs の達成に向けた具体的な施策である生物多様性の保全にも関連していると考えられ, 分野を超えた連携強化の必要性が示唆された.

1. はじめに

グローバルリスク報告書 2018 によれば, 発生確率の予測が難しく, ひとたび発生すれば甚大な被害をもたらす「異常気象」が高リスクの自然災害として挙げられている[1]. 国や自治体はこうした気象災害への備えとして, 河川や湖沼における治水対策の強靭化を図っているが, 流域における土地利用の変化, 特に表面流出量の増加をもたらす森林や草原・湿地環境の減少という想定項目に加え, 侵略的外来種の侵入定着がさらなる阻害要因として顕在化し, 自然災害の防止・低減方策の実現が困難さを増している.

本論文は, 気候変動下における総合治水を念頭に, 印旛沼流域水循環健全化会議(印旛沼流域における課題解決のため千葉県が 2001 年に設立)が行ってきた特定外来生物ナガエツルノゲイトウ(以後, ナガエと略称する)対策の取り組みを紹介する. それによって, 類似の課題に直面する地域や自治体との情報交換・経験の共有を図り, 実行可能かつ効果的な解決策への道筋を見出すことを目的とする. なぜならば, 印旛沼流域におけるナガエの何が問題であり, だれが利害関係者(ステークホルダー)なのか, そしてなぜ河川管理者が様々な協力者とともにこの課題に取り組まなければならないのかは, ナガエの存在が知られてからしばらくの間, 曖昧模糊とした状態であり, 駆除活動も手探り状態であった. そして, 現在もナガエ問題の本質がどこにあるのか, 明らかになったとは言い難いからである. そのため, ナガエ問題の経緯と現状, 今後の課題を可能な限り整理し, 見える化させる意義は小さくない.

2．ナガエの生態的特徴と印旛沼流域での生育状況

ナガエは水際に生育する南米原産の多年生植物であり, 水際に大群落をつくる. 茎断片からの栄養繁殖が旺盛で, 流下した断片が漂着した先でも群落を

形成する．日本では 1989 年に近畿地方で初めて記録され，印旛沼地域では 1990 年に，西沼に流入する鹿島川でナガエが確認された．1997 年には西沼に分布を拡げ，2000 年頃までに周辺河川，水路や農地にも侵入がみられた．現在では，西沼・北沼およびすべての流出入河川と水田での生育が確認されている．

３．ナガエによる被害の本質

印旛沼は利根川の下流域にある霞ヶ浦，北浦，手賀沼と同様に，縄文海進後に形成された海跡湖である．江戸時代から始められた印旛沼開発事業が昭和 44 年に完成し，湖沼の開水面の面積が大幅に減少し、多くの水利施設（排水機場，揚水機場）によって水位調節される広大な干拓農地が創出された．現在の印旛沼は，農業用水，工業用水，飲料水の水源として人為的に管理されている湖沼である．

印旛沼におけるナガエ問題は，主に利水，治水，そして農業に及ぼす影響である．繁茂した群落が開水面を塞ぎ，内水面漁業への航路障害については，定かではない．利水上の悪影響は，揚水機場に漂着した大量の群落がスクリーンに張り付くため，清掃作業の負担が増え，取水障害を起こしていることである．治水上の悪影響は，台風や大雨による増水時に排水機場を通じて東京湾にも強制排水を行う際に発生している．

排水ポンプ稼働時にスクリーンに張り付いた大量のナガエを取り除き，処分するためには，多額の経費が生じるばかりでなく，清掃作業時に排水ポンプを停止しなくてはならない.そのため，強制排水が制限され，沼の水位を下げることが出来なくなり，内水氾濫が発生する可能性があり、治水対策としてナガエの適切な管理の重要性が増している[2]．実際に，2015 年 9 月には台風に伴う排水時にナガエが大和田排水機場に漂着し，重機や人員による駆除作業を行ったもののポンプ全台の緊急停止が発生し，水位は計画高水位にせまり，堤内の水田が調節池の様相を呈し，一部の地域では農業揚水機場のポンプが水没する事態が発生した．

流域の水田へは，用水施設を通じて，沼や河川内に生育するナガエの群落からちぎれた茎断片が侵入して繁茂し，水稲との生育競合のほか，コンバインによる収穫作業の障害となっている．水田畦畔に蔓延したナガエが除草作業によって断片化した茎が排水路を通じて河川や湖沼に流出し，散布体の供給地となってしまうことも懸念される．

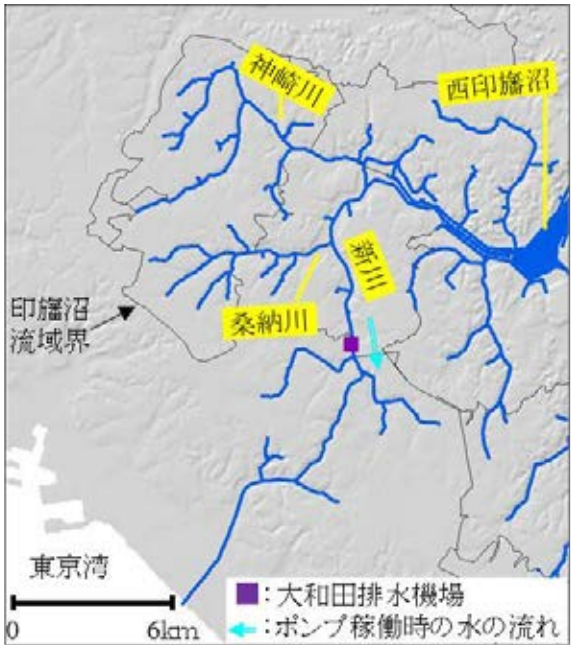

図 1 印旛沼流域に位置する大和田排水機場

4. ナガエ群落防除体系確立にむけた基礎研究

湖内における群落や茎断片の漂流，漂着，さらには水質改善の目的で行われる循環灌漑によって，ナガエは印旛沼流域の隅々に配られ，生育適地に群落を形成している．そのため，現在はすでに初期防除の段階を過ぎ，根絶は現実的な目標とはなり得ない．したがって，求められる現実的な対応とそのための基礎研究は，主に以下の4つに絞られる．

1）治水リスク軽減に資する効率的な駆除方法を確立する． 2）河川や湖内に生育する群落の成長と脱落・漂流量をあらかじめ低減するための効果的な駆除方法を確立する． 3）降雨時にナガエ群落が排水機場に漂着するタイミングと量を予測し警告を発する予報システムを構築する． 4）水利システムを介して流域内で侵入と定着を繰り返しているナガエの循環を断ち切るための効率的な駆除方法を確立する．

印旛沼環境基金の助成によって，平成 18 年から継続して行われてきたナガエ群落の分布モニタリングは，上記基礎研究の進展に不可欠な貴重なモニタリングデータを提供してきた．今後は，担い手の確保を考慮し，河川の流況データと連動する定量的なナガエ群落の挙動データの自動的取得システムの開発研究も含めたモニタリング体系の構築が不可欠である．

現在の印旛沼が農業用水，工業用水，飲料水の水源として人為的に管理されている湖沼であることを認めつつも，気候変動下における気象災害の予測可能性の低下，地盤沈下による堤防高の低下，流域の開発による土地利用の変化，施設維持費の社会コストの増加を考慮し，花見川への強制排水に大きく依存する体制からの脱却，生態系を活用した減災・防災を展望しつつ，印旛沼の在り方そのものを再検討する意義は小さくない．生物多様性の保全と生態系サービスを享受する地域社会の実現に向けた基礎研究を進め，賢明な合意形成のための社会知を蓄積することの重要性はますます大きくなるであろう．

5. ナガエ群落の体系的・組織的な防除を地域で持続的に実現する組織のあり方

外来植物の駆除については，重機や人員等の費用面に加え，外来種の取り扱いや仮置き場等の運営面が挙げられるが，財政状況や人口減少・高齢化を踏まえると，外来種への対応は後手となる可能性が高い．2015 年に国連で採択された SDGs の達成に向けて，具体的な目標として生物多様性の保全が位置づけられている社会情勢を考慮すると[3]，これらの課題解決は必要不可欠である．

印旛沼流域水循環健全化会議では，2016 年より NPO 法人国際ボランティア学生協会（以下，IVUSA）[4] とともにナガエの駆除活動を行っている[5]．

参加者の多少，経験者の参加状況，重機の有無，駆除対象とする群落サイズにより様々な駆除方法について試行錯誤され，河川区域内における群落の効果的な駆除方法については確立されてきた。

写真　水域班、陸上班、船班に分かれた多様な主体による駆除活動

状況に応じたナガエ駆除手法を取り入れながら，ナガエ駆除活動の経験者が多くなるにつれて，ナガエ駆除量の増加に繋がる事が予想される．

2018 年度は，学生・行政・企業・NPO 等が参加しやすい時期を関係者と調整しながら設定しており，さらに広報活動の工夫により，より多くのナガエが駆除される事が期待される．

7. まとめと今後の課題

効率のよい駆除手法については確立されてきたものの，治水上，管理可能な駆除量については明らかになっていない．そのため，前述の基礎研究を進める必要がある．

また，駆除した植物は現在焼却処分となっているが，印旛沼流域水循環健全化会議では，駆除植物の堆肥化について実現性を確認し，ナガエ由来の堆肥活用に向けた営農計画への適用について検討を進めており，今後は農業分野との連携強化が重要と考える．

さらに，SDGs の目標達成を念頭に置いた場合，課題解決に取り組むには関係者との連携が重要である．

多様な主体が駆除というイベントに参集し，駆除活動を通じて現地状況や課題を実感することは，持続可能性を考慮した上で重要である。また，駆除活動というイベントに「楽しい」、「達成感」といった要素が見いだせれば，ナガエの駆除活動自体が地域活性化に繋がる可能性も含め，特定外来生物の駆除問題への関わり方の良好事例となり得る可能性がある．

本論文に発表者として名を連ねた関係者が一体となってナガエ問題に取組む事により，幅広い繋がりが構築された．今後はいっそう連携を強化し，ナガエの駆除活動自体が地域活性化の一端となる事を願っている．

謝辞：本論文では，印旛沼流域水循環健全化会議委員やアドバイザー，桑納川流域において調査研究等を進められている方々から有益なご助言を頂いた．ここに記して深甚なる謝意を表します．

引用文献

[1] The World Economic Forum: The Global Risk Report, Vol.13, pp. 1-68, 2018.

[2] 農林水産省：外来生物対策指針，Vol. 1, pp. 1-31, 2008.

[3] 一般社団法人 SDGs 市民社会ネットワーク：基本解説そうだったのか．SDGs，pp.1-106，2017

[4] http://www.ivusa.com/

[5] いんばぬま情報広場　http://inba-numa.com/

O7-24

印旛沼に自生するヒシの機能性と活用について

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キーワード:ヒシ、化粧品、有効利用、ポリフェノール

抄録

千葉県の印旛沼で繁茂しているヒシ(図 1)は富栄養化により年々増え続け、従来使用されていた漁場や観光航路が確保できなくなるだけでなく、水質の悪化や悪臭なども問題となっている。これにより、毎年刈取り陸揚げ作業(図 2)が行われているが、廃棄処理コストが嵩むことも問題となっている。[1]本研究は、印旛沼に繁茂しているヒシに含まれるポリフェノールが、美容効果があると言われている緑茶カテキンより効果が高いことを明らかにした。これを化粧品に利用することで印旛沼周辺の活性化につなげていく。

1. はじめに

昭和 38 年の印旛沼開発干拓事業が行われた。その結果、面積の半減と沼が二分化されたことにより、水の流れが悪くなり水質が悪化し始めた。また昭和 59 年頃から漁業に影響が出るほどヒシが異常に繁茂し始めた。

ヒシは、池や沼に自生する一年生の浮葉植物で、2 本または 4 本の棘を持つのが特徴である。(図 3) 昔から、ヒシの実は食用とされるほか、民間薬としても利用されてきた。[2]これまでの研究で、ヒシの外皮(図 4) には、ポリフェノールが多く含まれていることが明らかになっている。[2]本研究では、印旛沼ヒシ外皮に含まれるポリフェノールの化粧品素材としての機能性について検討した。

図 3

図 4

図 1

図 2

2. 方法

① ポリフェノールの成分分析

ヒシ果皮を粉砕し、1:9～2:8 の混合抽出液に漬込み、これを濾過後、濃縮させた。吸着剤に濃縮液を通液させ、溶媒で粗ポリフェノールを脱着させ、純化したヒシ果皮ポリフェノール抽出物を作製。さらにヒシ果皮ポリフェノールそれぞれを成分分析するとトラパイン、オイゲニイン、TGG（1,2,3,6-tetra-O-galloyl-ß-D-glucopyranose）の 3 成分が特に抗酸化力を強くし示していることが分かった。(図 5)

② コラゲナーゼ活性阻害試験

シミ抑制や抗シワ効果としてコラゲナーゼ活性阻害試験とエラスターゼ活性阻害試験を行なった。試料サンプルとして、印旛沼オニビシ外皮から抽出した粗ポリフェノール、オイゲニイン、Tetra-GG、トラパイン、そして、ポジティブコントロールとしてEDTA、比較検討としてしわたるみ効果で知られている緑茶のポリフェノール（カテキン）の一種である（－）-エピガロカテキンガレートEGCGを用いた。実験方法は、次のとおりである。マイクロチューブ（2mL）にサンプル溶液15 ・lを入れ、コラゲナーゼ酵素溶液（0.1mg/ml、pH7.1）15 ・l を加えた。基質（Pz-Pro-Leu-Gly-Pro-D-Arg-OH, Trifluoroacetate、0.5 mM、pH7.1）溶液を120 l を入れ、37℃で30 分間インキュベートした。その後、25 mM クエン酸（反応停止液）300 lを入れ、酢酸エチルを1.5mL 入れ、激しく振とうし、抽出させた。さらに、遠心分離（3000rpm、10 分）を行い、上清の酢酸エチル層をセルに入れ、分光光度計（Ubest-V560、日本分光）にて320nm における吸光度の測定を行った。

③ エラスターゼ活性阻害試験

ポジティブコントロールとしてオレアノール酸、比較検討として同じくEGCGを用いた。実験方法は、次のとおりである。マイクロプレートに試料溶液50 ・l を入れ、エラスターゼ酵素溶液（10・g/ml、pH7.5）50 ・l、基質溶液（1mM のN-Succinyl-Ala-Ala-Ala-p-nitroanilide、pH7.5）を100 ・l を加えた。さらに、25℃で50 分間インキュベートし、マイクロプレートリーダー（Synergy HT、Bio Tec）にて波長415 nm における吸光度を測定した。

2. 結果

○コラゲナーゼ活性試験結果について

コラゲナーゼ活性阻害が50%の時のサンプルの濃度を示すIC50 値をまとめた。IC50 値が小さいほど高いコラゲナーゼ阻害活性を示すことから、粗ポリフェノール、オイゲニイン、Tetra-GG、トラパインは、ポジティブコントロールであるEGCG やEDTA に比べて、高い値を示した。特に、トラパインのIC50が最も小さく、高いコラゲナーゼ阻害活性を示すことがわかった。【表1】

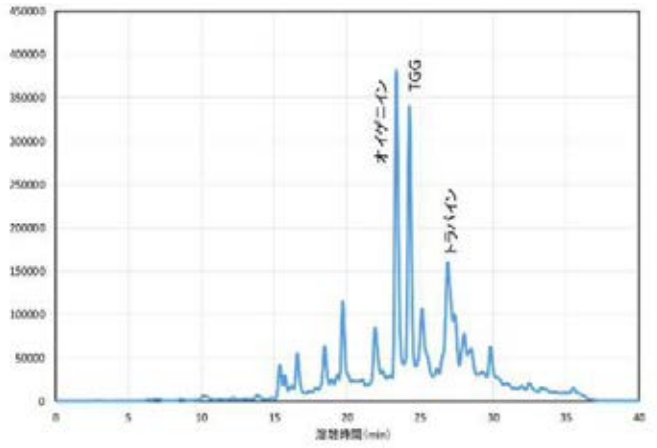

図 5 グラフを表す図

表 1　コラゲナーゼ阻害活性を示す IC50

No	化合物名	IC_{50}	
		μg/ml	μM
1	粗ポリフェノール(20170331製造)	120	-
2	オイゲニイン	104	110
3	TGG	114	145
4	トラパイン	52	54
5	EDTA・2Na（ポジティブコントロール）	556	1494
6	EGCG（(-)-エピガロカテキンガレート）	622	1356

○エラスターゼ活性阻害試験について

また、エラスターゼ活性阻害が50%の時のサンプルの濃度を示すIC50 値をまとめた。IC50 値が小さいほど高いエラスターゼ阻害活性を示すことから、粗ポリフェノール、オイゲニイン、Tetra-GG、トラパインは、ポジティブコントロールであるEGCG に比べて、高い阻害活性を示した。特に、オイゲニイン

とトラパインのIC50 が小さく、ポジティブコントロールのオレアノール酸よりも高いエラスターゼ阻害活性を示すことが明らかになった。【表2】

表２　エラスターゼ阻害活性を示す IC50

No	化合物名	IC_{50}	
		μg/ml	μM
1	粗ポリフェノール	55	-
2	オイゲニイン	1.2	1.2
3	TGG	115	146
4	トラパイン	4.5	4.7
5	オレアノール酸	44	96
6	EGCG	288	628

3. 考察

印旛沼ヒシの実は栗のように甘く、小動物などの外敵も多い。その自衛策として、外皮に多くのポリフェノールを含有し、苦味を感じさせることで外敵から身を守っていると考えられる。そうした防御本能から、抗酸化力の強いポリフェノールが精製されているのではないかと推測される。もともとヒシは美白効果としてチロシナーゼ活性阻害効果、ヒアルロニダーゼ活性阻害効果[3]が低い濃度で効果があったことから、同じようにコラゲナーゼ活性阻害効果、エラスターゼ活性阻害効果があるのではないかと推測する。

4. 結論

エラスターゼおよびコラゲナーゼの阻害活性は肌のハリや弾力性に効果を示す。したがって、印旛沼に繁茂するヒシは機能性化粧品素材として、有用なものであることが分かった。

この結果を踏まえ、今まで廃棄されていたヒシに新たな価値を生み出させることができる。ヒシの存在価値が見直されれば印旛沼流域においても、ヒシ事業を通して地域が活性化し、印旛沼流域をさらに豊かにすることができると考える。

参考文献

[1]　印旛沼環境情報（No32）

[2]　菱の抗酸化性について　安田みどり

[3]　西九州大学　大曲希実,「ヒシポリフェノールの化学的特性生理機能性に関する研究」, 修士論文, 41-43,47-49,51-53 (2014) Yasuda M., Yasutake K., Hino M., Ohwatari H., Ohmagari N.,Takedomi K., Tanaka T., Nonaka G, Inhibitory effects of polyphenols from water chestnut (Trapa japonica) husk on glycolytic enzymes and postprandial blood glucose elevation in mice, Food Chem., 165, 42-49 (2014)

O7-25

Hygiene and Sanitation of people living on and around Tonle Sap Lake: Comparison of water based, water-land based and land based zones

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Keywords: Tonle Sap Lake, Water base, Water-landed base, Land base, and waterborne disease

ABSTRACT

This study aimed to collect the information on water use, hygiene and sanitation and waterborne diseases among people living on the lake and the lakeshore. The stratified sampling survey was conducted in three regions around Tonle Sap Lake (TSL) involving a total of 542 families, which were randomly selected for the interview, comprised of 202 Land base (LB) households, 132 Water-landed base (WLB) households and 208 Water base (WB) households. The results of the survey showed that TSL water was the principle drinking water source of WB population (52.9%). For populations in LB, well water was the main drinking water source (71.8%). Related to water treatment systems, 53.5% of LB, 34.9% of WLB and 22.6% of WB used filtration system to treat their drinking water. Boiling of water for drinking was done by 37.1%, 20.5% and 32.7%, of LB, WLB and WB, respectively. Diarrhea and severe diarrhea were waterborne diseases frequently found in this study. Diarrhea disease was found in 60.4%, 80.3% and 79.8%of adults, 39.8%, 61.3% and 75.3% of children under 5 years old and 42.4%, 67.1% and 72.9% of older children and adolescents, for LB, WLB and WB, respectively. People living in WB and WLB zones seems to have high incidence of diarrhea disease as compare to that living in LB zone. This may be due to the drinking water source, water treatment systems and flooded experiences.

1. INTRODUCTION

Cambodia is one of countries which are most famous for freshwater fisheries in the world since the permanent wetlands cover more than 30% of total national land represented by Tonle Sap Lake (TSL)[1]. The TSL is an invaluable natural resource of inland water for agriculture, fish production, biodiversity, water supply and sanitation, transport, and hydropower[2][3], supporting more than 1.7 million people living around it[4]. Communities in the TSL have adopted their living system based on the specific hydrological conditions of the lake, which form three different human settlement communities: “LB villages,” “WB villages,” and “WBL villages.” In LB ones, villagers are engaged more in farming and less in fishing depending on the distance from the lake. WB villages are floating villages on the lake, where fishing is the primary occupation for villagers. The third type is the WLB villages, which is usually located six months on water and six months on land, and both agriculture and fishing are the main activities for the villagers[2][5]. In recent year, the increases of agriculture activities, industrial development, numerous tourists and other human activities in/around the lake has been threatening the ecosystem and human health via pollution and contamination of lake water[6]. The aim of studies is to collect the necessary information on water use, hygiene and sanitation, waterborne and food borne diseases among people living on and around the TSL, focusing on the types of villages.

2. METHOD

Target population

The primary data has been collected through surveys implemented questionnaire to people at LB, WBL and WB areas around TSL. The target population is the completed set of people identified for the investigation according to the research objectives. The studied regions were purposively stratified selected from three provinces (Kompong Chhnang, Kompong Thom and Battambang province) around TSL (Fig.1). And in each province, the households and participants were randomly selected for the interview. In total, 27 villages were selected for the interview, in which 13 villages from LB areas, 6 villages from WLB areas and 8 villages from WB areas.

Survey conducted

The survey conducted questionnaire interview was face to face since the target people lack of access to the internet and literature[7]. A total of 542 families were randomly selected in this study where 202 households from LB, 132 households from WLB and 208 households from WB. The interview was completed at the

households considering the age groups (0-5 years old, 6-17 years old, and older (adult)) and sex of correspondents.

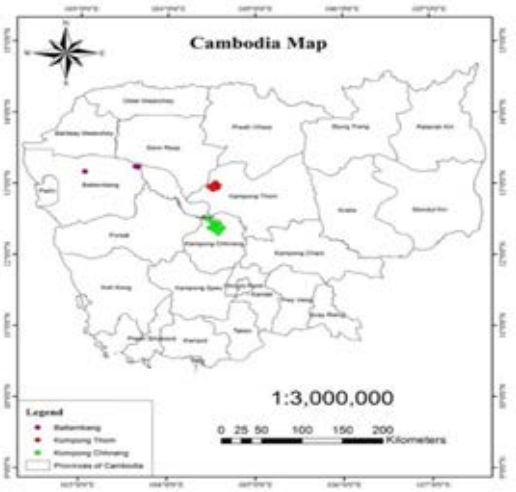

Fig. 1 Map of Tonle Sap Lake with three surveyed provinces

3. RESULTS

Hygiene and Sanitation

Currently there are no affordable sanitation options available for the floating communities of the TSL, and many other communities that live in challenging sanitation environments in Cambodia. Concerning hygiene section, among the surveyed households, 58.2% in WB area, 28.8% in WLB and 75.7% in LB did not have toilets. Interestingly, for the households in WB areas that have toilets in this survey, almost all of these toilets were the open toilet directly discharge into the lake. However, these results showed that the awareness of sanitation and hygiene practice in the communities is low. On the other hands, using soap was found in WB zone more frequently (80.3%) than WLB (68.9%) and LB (69.8%) zones. According to the data of baseline survey with children who live in LB, WB and WLB of TSL, the hygiene practice of children in WLB areas were very low compared to those in WB and LB areas. The percentage of children under five year olds who washing hand with soap before eating and after defecation were similar in these three different zone. But, the percentage of WLB children from 6-17years old who wash hand with soap before eating food and after defecation was 56.72%, while there were 69.57% and 75.56% for WB, and LB children, respectively.

Solid waste management

The surface water and ground water source were contaminated by leaching of non-disposed burned substance and impacted to population health such as air and water-borne disease. In this study was found that people in WLB (more than 50%) and WB (more than 80%) zones were directly disposed their waste into lake surrounding their living areas where they take the water to be use every day as their domestic water source and drinking water.

Waterborne diseases

Data reveals that most of waterborne diseases were diarrhea with level of 80.30% and 79.81% were found of people living in WLB and WB areas, respectively; while the lowest rate was from LB areas (60.40%). In the meantime, severe diarrhea happened in the rate of around 23% in WLB areas and the lowest was found in LB (11.88%) areas. The percentage of less than five years old children got diarrhea was 75.25%, skin problem was 69.31%, eyes problem was 64.40%, and severe diarrhea was 18.81% for these studied population. For children aged between 6-17 years old who faced with diarrhea was 72.90%, skin problem was 69.31%, eyes problem was 64.49% and severe diarrhea was 12.15% (Table 1). Children in these three different zones: LB, WLB and WB of TSL areas were suffered diarrhea, followed by eyes and skin problem and also severe diarrhea. These diseases were highly prevalence for children under five years old and aged between 6-17 years old who live in WB zone.

Table 1 Common disease in studied areas

Diseases (%)	LB	WLB	WB
Diarrhea	60.40	80.30	79.81
Severe diarrhea	11.88	23.48	23.08
Cough	47.03	68.18	69.23
Fever	53.96	78.03	79.33
Eye Problem	24.75	31.06	46.15
Skin problem	25.74	38.64	41.83
Others	30.20	33.33	28.37

4. DISCUSSION

The target of the Millennium Development Goals of Cambodia was to halve the proportion of people without access to sanitation by 2015. Cambodia's National policy on rural water and sanitation envisions that every person in rural communities has sustained access to safe water supply and sanitation services and lives in a hygienic environment [8]. However, the studied results showed that less than 15% of mothers wash their hands with soap after defecation, before preparing food, before feeding their child, before eating, before cleaning the child's bottom [9]. The very low awareness of hygiene awareness

of communities, especially of hygiene practice of children in WLB areas might be due to poor education and lack of support from related ministry and non-government organizations (NGOs). Most of NGOs and government have been focusing on people who live in WB zones by improving education, hygiene, and installed drinking water treatment system for some community. There is only a few of NGOs could access and supporting WLB community because this area is far from the province and lack of transportation that could access these communities.

In Cambodia, one of seven deaths of children was caused by diarrheal disease. Every day, 50 Cambodian children under five years old died from preventable disease such as diarrhea and pneumonia[10]. Children in these three different zones: LB, WLB and WB of TSL areas were suffered diarrhea, followed by eyes and skin problem and also severe diarrhea. These diseases were highly prevalence for children under five years old and aged between 6-17 years old who live in WB zone.

5. CONCLUSION

Considering hygiene and sanitation, adults in all three zones had used soap before eating and after defecation (it can be found most frequently in WB area).Among children, only 6-17 year-old children performed more this habit than those at 0-5 years old. The diarrhea disease was the main disease found in people living around TSL, especially children under five years old (75.3%). According to data analysis, improper water treatment, water storage system, hygiene and sanitation, and flooding were identified as the main causes of diarrhea in these studied zones.

REFERENCES

[1] Mak Sithirith: The Governance of Wetlands in the Tonle Sap Lake, Cambodia. Journal of Environmental Science and Engineering B, Vol. 4, pp. 331-346, 2015.

[2] ADB (Asian Development Bank): The Tonle Sap Bassin Strategy. Pp. 54, 2005.

[3] Keskinen M, Kummu M, Käkönen M, Varis O: Mekong at the Crossroads: Next Steps for Impact Assessment of Large Dams. Ambio, Vol.41, pp. 319-324, 2012.

[4] Saburo M, Marko K, Pech S, Masahisa. N: Tonle Sap. Experience and lessons learned brief. Pp. 408-415, 2011.

[5] Sithirith M: The Patron–Client System and Its Effect on Resources Management in Cambodia: A Case in the Tonle Sap Lake. Asian Politics & Policy, Vol 6, pp. 595–609, 2014.

[6] He Z.L, Yang X.E, Stoffella P.J: Trace elements in agro ecosystems and impacts on the environment. J. Trace Elem. Med. Biol, Vol. 19, pp. 125-140, 2005.

[7] Creswell J.W: Research design: Qualitative, quantitative, and mixed methods approaches (4th ed.), 2014.

[8] Bukauskas K, Dawes L: Emerging Technologies for Sanitation and Human Waste Disposal in Developing Communities (Tonle Sap Lake, Cambodia). Pp. 54, 2009.

[9] Oeur I, Dane S, Sopheakdey S: Community visioning and action plans: Tonle Sap hub. Penang, Malaysia: CGIAR Research Program on Aquatic Agricultural Systems. Program Report: AAS-2015-01.Research, pp. 47, 2015.

[10] UNICEF (United Nations International Children's Fund): Maternal Newborn and Child Health and Condition. Pp. 8, 2017.

O7-26

The Challenge for Lake Victoria Protection by the Ecological Sanitation Approach in Kenya

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Keywords: ecological sanitation, Lake Victoria, water pollution, income increase, women activity, village development

ABSTRACT

Lake Victoria faces serious water pollution by point and non-point sources. As to point pollution control, it is all most impossible to construct sewerage systems to all communities. House-hold sanitation system is instead affordable and preferable. Nippon International Cooperation for Community Development (NICCO) with the support of Kyoto University implemented an ecological sanitation project in Bushiangala Village of Kakamega County, Kenya, since 2014. It is a comprehensive village development, but water supply and ecological sanitation are key components to boost agricultural products and improve income. Along the comprehensive development project, women are strongly involved in the project so that women status is elevated. Nitrogen and phosphorus of point sources are derived from 35 million people of the entire catchment of Lake Victoria. Total construction cost of one million Eco-san toilets is estimated to be 300 US$ x one million which is most economical solution for water and sanitation issue that is the number six target of SDGs, clean water and sanitation.

1. INTRODUCTION

Lake Victoria faces serious water pollution by point and non-point sources. As to point pollution control, it is all most impossible to construct sewerage systems for all village communities in the catchment of Lake Victoria. House-hold sanitation systems are instead affordable and necessary. Nippon International Cooperation for Community Development (NICCO) with the support of Kyoto University has successfully implemented ecological sanitation (Eco-san) projects in Malawi during 2007-2014 [1]. It is necessary to repeat the similar Eco-san project to village communities in Kenya, because the conditions of Kenya villages are different from those of Malawi, in terms of climate, soil, crops, sanitation culture, education levels, and religions, etc. It was decided to introduce Eco-san project with a comprehensive development programs to Bushiangala Village of Kakamega County, Kenya, since 2014. The project covers 1,6,14 families with 8,203 people.

This paper discusses success and challenges of the project that shows similar as well as different from the results of the Malawi projects that are discussed in another paper of this conference. Upon the success of the Kakamega project, NICCO propose extension of the ecological sanitation projects to communities that locate around coastal countries of Lake Victoria, namely Kenya, Uganda, Tanzania, Rwanda and Burundi.

2. WATER AND SANITATUON IMPROVED HEALTH CONDITION

NICCO newly installed two suction pipe and pump systems of deep ground water for Bushiangala village. Pipes are extended to 12 km covering 5,887 people, including 6 schools, 4 churches, 2 clinics, and 334 households and five water kiosks. The village community realized the importance of maintenance of the water supply system, so that the water supply committee was established, which collect water fees, employed a water engineer to operate pumping station, and extend service pipes, etc. The water supply committee became a core

group for introducing Eco-san project. The restoration and extension of water supply system changed life style of the community in terms of labor time, school time and household management, etc. NICCO constructed total 216 units of Eco-san toilets (87 private houses and 129 public houses).Buyemi Health Center of Kakamega investigated the results of installation of Eco-san toilets in Mukongolo community of Kakamega comparing pit-latrine toilets, in terms of the people health relating diarrhea cases (2 Nov. 2017). The center gave a certification paper telling that (1) Eco-san toilets had improved public health compared to pit latrines, evidenced by reduction of diarrhea cases; (2) zero diarrhea cases were observed due to improved hygiene and reduced flies in Eco-san toilets; (3) the reduction number of flies in Eco-san toilets compared to that of pit latrines was the ration at 5:16.

3. URINE AND SANITIZED FECES (HUMANURE) WERE EXCELLENT ORGANIC FERTILIZER

The people of Bushiangala first did not believe in that urine and feces were organic fertilizer, as the people of Malawi project villages. In order to show safety of sanitized feces that were disinfected and fermented by ash application and stored in a feces compartment of an Eco-san toilet. NICCO asked the Laboratory Department of Kakamega County General Hospital to examine Eco-san manure in terms of infectious microbes. The results showed that Salmonella and Coliforms/E.Coli, were not detected, and Ovarian cysts were not seen (18 Sept, 2017). The nutritional value of Eco-san manure (Humanure) was analyzed by Non-ruminant Research Institute of Kakamega, Kenya Agricultural and Livestock Research Organization for different items. There was no analysis of K, but P, Ca and Mg were well included to fertile soil. Total nitrogen is low for fertilization of soil, due to decomposition of protein and dissipation of ammonia during fermentation. In order to improve soil condition of C/N without chemical fertilizer of N, P, K, it was recommended to use much urine in practical way.

Maize crop test was done using urine and humanure and chemical fertilizer in the test fields of Bushiangala, Kakamega, Sep.2015. It is obvious that soil condition is very important and without fertilizer it is difficult to get crop yield. It shows dramatic improvement of crop yields specially combination of urine and humanure. Nitrogen supply with urine was important as indicated N shortage in humanure. However, this test indicates another important improvement of soil condition, that is improvement of soil acidic condition by ash supply in disinfection of feces, as indicated pH 10.65 of the humanure. The people participated in this field test satisfied the results and got confidence to using Eco-san toilets and agriculture use.

4. CHANGES IN COMMUNITY ACTIVITIY

Bushangala community has changed its activity triggered by revitalization and extension of water supply systems, establishing four committees such as (1) Water supply committee (3 men and 2 women members), (2) Eco-san construction committee (6 men and 4 women members) (3) Agri-livestock committee (13 men and 9 women members), and (4) Women status elevation committee (2 men and 24 women members).

Eco-san construction committee promoted many workshops for propagation. They faced financial problems and established loan system. However, farmers must increase income to pay back to the construction fee. Based upon crops yields improvement, they started different crop culture than before introducing new types of crops and started processing the crops to more market oriented products. Soybean, sunflower seeds, and peanuts are such newly introduced. The committee asked women and elderly persons work for processing business, that increased income for those people. The agri-livestock committee started raising chickens at home. Chicken is good market item to increase income. The women status elevation committee started energy efficient oven construction, and seed & seedling business. Pot seedling business does not require heavy labor works. They select

vegetable, crops and tree seedlings and conduct pot seedling that help a lot farmers to avoid unsuccessful seedling in the fields.

Trees are essential for cooking, etc. Reforestation around the village is a key to survive. The pot seedling of useful trees is very important and good business. Many other ideas came to the committee and income for the participants remarkably increased. Based upon those Bushangala committee activities, NICCO think great potential of expanding Eco-san projects to village communities of other part of the catchment of Lake Victoria.

5. THE CHALLENGE FOR PROTECTION OF LAKE VICTORIA

Lake Victoria is shared by five countries in terms of lake surface are, catchment area, shoreline and population. Waste waters are generated by the people activities in the manner of point source and non-point source including agricultural activities. Pollutants such as BOD, COD, nitrogen and phosphorus cover all human activities. Lake Victoria Basin Committee estimated reginal point source loads of TP, TN and BOD for Tanzania, Uganda and Kenya. The point loads are proportional to population of the countries.

Eutrophication of Lake Victoria is caused by nitrogen and phosphorus loadings which are necessary for agriculture and food production. Nitrogen and phosphorus control is very difficult issue. We propose that the recycle of nitrogen and phosphorus from urine and humanure is the best solution for controlling eutrophication, reducing application of chemical fertilizer in agricultural fields. Eco-san toilets are the solution of recycling nitrogen and phosphorus.

NICCO propose the challenging project that if one million Eco-san toilets are provided to the people along coastal areas of Lake Victoria, point source loads of BOD, TN and TP are cut, that is equivalent 6 million population (6membaers per family) of 35 million of the catchment. Construction cost is estimated from Malawi and Kenya experiences to be around 300 US$ x 1 million, which is much less cost compared to any other sanitation systems.

6. CONCLUSION

Water supply systems were installed in Bushiangala, Kakamega, Kenya, which dramatically improved life style of the people. Eco-san project was introduced constructing for 216 units of the toilets (87 private houses and 129 public houses), which clearly showed improvement of health condition to the people who enjoyed clean water and good sanitation. Urine and sanitized feces were proved to be excellent fertilizer and soil amendment. Crops yields were increased to help income increase of the farmers of the village. The people want to install Eco-san toilets to their homes. Construction cost must be borne by the people in addition to some external subsidies or donation. They set up Eco-san committee to start a loan/ship system that is a new idea to disseminate the Eco-san project other part of the village communities around Lake Victoria Coastal countries. If one million Eco-san toilets are constructed in the catchment of Lake Victoria, 6 million people may enjoy good sanitation and practice recycling of nitrogen and phosphorus which are eutrophication pollutants. Nitrogen and phosphorus of point sources are derived from 35 million people of the entire catchment. Total construction cost of one million Eco-san toilets is estimated to be 300 US$ x one million which is most economical solution for water and sanitation issue that is the number six target of SDGs, clean water and sanitation.

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REFERENCES[1] Saburo Matsui, Hidenori Harada, David Mkwanmbisi, Moses B. Kwapata, Yusuke Mori, Norimasa Orii, Osamu Ono, Satoyo Ono,:The success story of ecological sanitation in Malawi with the comprehensive project for village development, Proceedings of The International Water Association (IWA) Development Congress & Exhibition 2013,Nairobi.

O7-27

Successful Results of the Ecological Sanitation Approach toward Harmonious Coexistence of the People and Lake Malawi, Africa

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Keywords: ecological sanitation, Lake Malawi, water pollution, humanure and comprehensive village development

ABSTRACT

Lake Malawi collects surface and ground water from the west bank. Water pollution of the lake is mainly caused by poor sanitation, domestic and agricultural waste waters. The rural communities still face famine, due to poor infrastructure hindering from their economic growth. Malawi rural communities need comprehensive development models that could solve the problems of infrastructure such as safe drinking water supply, proper hygiene and sanitation, and agricultural food security. Nippon International Cooperation for Community Development (NICCO) with Kyoto University implemented the comprehensive development projects for seven years.in two prefectures of Malawi covering about 3,600 families of 18,000 people, in the support of Mitsui & Co .Environment Fund, JICA and Ministry of Foreign Affairs of Japan. The programs of safe water supply and eco-logical sanitation (Eco-san) were essential to protect water environment of Lake Malawi. This paper discusses success, failure and the further problems of the ecological sanitation approach.

INTRODUCTION

Ecological sanitation (Eco-san) toilets were introduced two decades ago to Africa by many NGOs of Europe and North America. However many of them were abandoned facing difficulty of proper maintenance. Most important points of maintenance are, understanding of hygiene and proper practical use of the urine and feces separation toilets, and sanitation of feces and urine for agricultural use as fertilizer.

NICCO implemented comprehensive village development projects in Malawi since 2007 until 2014 [1].The ecological sanitation program is a key of the comprehensive projects that consist of seven programs such as (A) agriculture technology, (B)grain storage-seed bank, (C)reforestation - moringa tree, etc., (D)measures for infection—malaria, HIV/AIDS and schistosomiasis, (E)human-resource development-education, (F)water supply and (G)ecological sanitation. In order to overcome famine in under-developed villages, agricultural development is the major target. However, there are many obstacles to promote agricultural development. The seven programs were introduced in the good manner of coordination. Due to limitation of this paper room, we would like to focus on the ecological sanitation program, and analyses it in terms of success, failure and further problem.

NICCO PROJECTS OF ECOLOGICAL SANITATION IN MALAWI

NICCO constructed ecological sanitation (Eco-san) toilets in three Districts of two Prefectures such as Nkhotakota and Lilongwe for the family of about 1000 with about 5000 people. NICCO also constructed shallow wells with supplying safe water for about 3600 families. Safe water supply and sanitation provision are minimum requirement. However, NICCO could not provide Eco-san toilets for all families due to limit of construction finance. The partial construction cost of Eco-san toilet must be borne by the families of the project. NICCO provided half of the total cost, and the half should be borne by the families. Financial problems still remain for expansion of ecological sanitation in rural areas.

BENEFITS OF ECO-SAN TOILETS FOR VILLAGE COMMUNITIES IN MALAWI

It is obvious that most villages in Malawi do not have proper water supply systems and sanitation. The people need safe drinking water, which can be provided by shallow water well systems, because water quality of the well is so far meeting to safe drinking standard. However, the contamination of shallow ground water is caused by poor sanitation such as dig-hole toilets namely pit latrines. In spite of that, Government of Malawi needs to introduce ground water supply systems for all villages. The question to good sanitation is very difficult to answer, because there are many obstacles to find good solutions. NICCO invited Mr.Uno Winblad who introduced the thought of ecological sanitation and edited two books, Ecological Sanitation by Sida (1998) and Ecological Sanitation, revised and enlarged edition by Stockholm Environmental Institute (2004). NICCO concluded to introduce Eco-san toilets in Malawi. We think the following problems must be overcome for the introduction of Eco-san toilets as a sanitation solution; (A) scientific understanding of urine and feces by the people, (B) proper disinfection of feces, (C) understanding of nutrient values of urine and feces by the people, (D) practical demonstration of treated feces and urine for agriculture, (E) health improvement such as less diarrhea, (F) agricultural yields increase with more income, and (G) other indirect benefits.

SUCCESFUL RERSULTS

In order to construct many Eco-san toilets, NICCO asked a Japanese specialist of architect to design the Malawi style urine-feces toilet and teach how to build

the toilets to village people. The construction work must be contributed by the owner of the toilet. NICCO organized a program, of Eco-san toilet builder workshops in which the specialist taught techniques of the buildings 14 people who later became a licensed builder by NICCO. In the end 1000 units of Eco-san toilets were constructed.

In general for Malawi people, human urine and feces are dirty untouchable matters, so that they practice open defecation or sanitation by dig-hole toilets that easily fed up and abandoned contaminating shallow ground water and surface streams. Maintenance of the toilets needs urine and feces recycle for agriculture activities. It was necessary for the people to understand urine is safe to touch after holding in tanks for a week, even urine comes from HIV/AIDS patients. HIV viruses are weak in infection through urine. Urine contains all necessary nutrient for agricultural cultivation, specially N, P, K , S, and other minerals such as Ca. Mg, Fe, Mn, and others. Human nutrition requires I, Zn, Cu. Co, Cr. and Se for hormone regulations. Dilution of urine is necessary for application to plants, that are very important knowledge for Malawi farmers to understand in practice. The problem is feces disinfection. NICCO decided to select the method of ash disinfection, in which the ash from oven was not at all utilized in families of the villages. They just discarded the ash elsewhere. However, the ash is excellent strong alkaline agent to kill any germ, viruses and eggs of intestinal worms. In addition to that, alkaline minerals such Ca, Mg, K are best soil improvement matters to acidic and poor soils of Malawi. NICCO asked Physics and Biological Department of University of Malawi to examine microbial analysis for Eco-san manure (humanure) and the result is shown in Table 1.
Organizing many workshops of Eco-san toilets and organic farming of application of urine and humanure, farmers gradually accepted Eco-san toilets.

Table I Microbial examination of Eco-san manure (Humanure) by University of Malawi

Parameter	Result
Salmonella	Not detected
Fecal Streptococcus	40 colonies/100g
Crystopordia	Not done, special microscope not working
Ascaris eggs	Not detected
pH	8.78
Moisture content	7.28%
Temperature	27°C

CONDITIONS OF PROJECT SITES BEFORE AND AFTER THE PROJECT

Generally the adoption of the Eco-san toilets technology gave an immediate solution to the problems on waterborne diseases which rise death from lack of proper disposal mechanisms of feces and urine. Comparative data were obtained at the inception of the project through the midterm reviews, which revealed a drop in water born disease cases and raised household incomes, showing a positive impact to the communities.

The other immediate result was from the use of urine on crops which would readily be used when diluted and applied to soils in the gardens or around homes kitchen garden. Such helps communities to earn income and nutrition from the crops in the home gardens. The project area of low income immediately improved outbreaks of waterborne diseases when the toilets are used. While the condition of increasing crop yields by the use of humanure would be realized after six months cultivation, the stabilization, decomposition and disinfection of feces required six months in the climate condition of Malawi, before applying the humaure to gardens where crops grow. Table 2 shows the results of maze harvest between application of Eco-san fertilizer (urine and humanure) and no fertilizer application. It was 2.4 times more harvest with Eco-san fertilizer.

Table 2 Results of maze harvest between application of Eco-san fertilizer (urine and humanure) and no fertilizer application.

Harvest place	Harvest date	Fertilizer conditions	Maize yield (kg)		
			Seed	Food	Total
Kalusa (100 ㎡)	14 April, 2012	Eco-san Fertilizer	5.0	31.5	**36.5**
		No fertilizer	2.5	20.0	**22.5**
Chiuzuula(100 ㎡)	18 April, 2012	Eco-san Fertilizer	3.5	58.7	**62.2**
		No fertilizer	0.0	8.0	**8.0**
Njumbla (100 ㎡)	14 April, 2012	Eco-san Fertilizer	1.5	29.3	**30.8**
		No fertilizer	1.0	22.5	**23.5**
Eco-san fertilizer yield					**129.5**
No fertilizer yield					**54.0**

PROBLEMS REMAINIG FOR FUTURE DEVELOPMENTP

Physical maintenance of the toilet structure is important for sustainability of Eco-san project. Although the brick and cement structure of the toilet is very robust and heavy, it may stand for 20 years, but there are problems remained such as roof broken, door broken and leaning of the toilet due to ground sinking by heavy weight. The toilets are strong to stand challenges of collapsing of soils in communities whose soils are sandy and soft, or weak and collapsing during rainy season as they are built on top of the ground.

Fourteen Eco-san toilet builders were established with their skills. Training on care and maintenance of the toilets has to be provided to the benefitting communities. Local masons who are trained to support the construction of the toilets in the project area also bring a rich pool of technicians who support the adoption of the technologies, when the project phased out. Eco-san builders can help other communities where the people require new construction of toilets. It is important that the owners of the toilets show a strong sense of ownership that requires good maintenance of the toilets.
Some religious groups such as Muslims use water for anal cleansing after defecation, which is a challenge to promote the current style Eco-san toilet. When water is introduced to a feces containment compartment, it delays the process of drying, disinfection and fermentation of the feces. However NICCO have the solution for this problem, providing another model of Eco-san toilet that allowed to use small water to anal cleaning for Muslims and Hindus communities.
In Malawi, there are still some traditional myths in pregnant mothers who stop using Eco-san toilets during pregnancy, because they feel a fear or think losing their fetuses during defecation. This kind of thought deprives them of the benefits in improved sanitation in the home forcing them to use alternatives ways. They are not good thereby bringing diseases and also not able to realize the use of Eco-san products in agriculture, which leads to increased crop yields when they are applied to soil where the crops grow.
In order to promote the Eco-san toilet model throughout village communities of Malawi, there needs a massive propagation of the information on the benefits. Many benefits are given by introduction of the system of Eco-san toilet and agricultural profits with good health and good water environment connected Lake Malawi. On the other hand, financial problems are most important to be solved. Governments of Malawi must seek for international aids one hand, but on the other hand, subsidies of the toilet construction by governments is also necessary. Furthermore, farmers must bear partial cost of the construction. It is estimated roughly to be total 300 US$/unit for a family. If introduction cost is provided by a community bank in a manner of loan, any project could start for the community. The loan could be paid back by increase profits form organic farming with humanure and urine. Financial problem is still a big problem remained for the future of Eco-san toilet model.

CONCLUSION

NICCO successfully constructed 1000 units of Eco-san toilets in two prefectures of Malawi during 2007 and 2014. Eighty percent of them is in use and successfully connected with agricultural production. The good practice of sanitation protects Lake Malawi from contamination of both shallow ground water and surface streams by discharging human feces and urine. It is expected to expand the Eco-san toilet model for other parts of village communities of Malawi. Technology of construction needs the solution of constructing heavy toilets over soft and weak ground soil. Financial problems are most important. Poor farmers need subsidies from governments and international aids for the construction with their own bearing the cost.

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REFERENCES

[1] Saburo Matsui, Hidenori Harada, David Mkwanmbisi, Moses B. Kwapata, Yusuke Mori, Norimasa Orii, Osamu Ono, Satoyo Ono: The success story of ecological sanitation in Malawi with the comprehensive project for village development, Proceedings of The International Water Association (IWA) Development Congress & Exhibition 2013, Nairobi.

O7-28

傾斜土槽法を用いた低エネルギー消費型の上下水処理

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キーワード:浄水・排水処理技術, 発展途上地域における適正技術, 傾斜土槽法, 自浄作用, 生物学的吸着作用

抄録

大気と接する土壌の表層は、自浄作用の強い場所である。傾斜土槽法は、この自浄作用を水質浄化に応用したものであり、底面が傾斜した薄層構造体に担体を充填し、これに原水を浸透流下させる方式である。様々な有機性排水浄化の実験結果より、本法の浄化特性は、(1)曝気が不要の低エネルギー消費型の好気性浄化、(2)有機性汚濁物質と栄養塩類の同時浄化、(3)汚濁物質と水の分離による滞留時間の短縮、(4)槽内の有機性汚濁物質の強い分解作用、(5)高次の食物連鎖による汚泥発生量の少なさ、等である。本法による飲料水のための浄水試験は、スリランカとバングラディシュで行われた。前者は、緩速ろ過法では処理不可能な平均 BOD37mg/L の原水を処理し、良好な処理水が得られた。後者は、重金属類で汚染された井戸水を処理し、鉄、マンガン、ヒ素の浄化が確認された。一連の実験結果は、傾斜土槽法が低コストで低エネルギー消費型の上下水処理技術であることを示している。

1.　はじめに

本研究の目的は、無曝気で好気性浄化を行う低エネルギー消費型の水質浄化技術の開発である。

水の飽和溶存酸素濃度は、僅かに 10mg/L 前後で、水には酸素が溶けにくい性質がある。水中での好気性浄化は不自然であり、この不自然さを補うために大量の電力とコストを消費して曝気を行っている。水を自然に好気性浄化するには、水中以外の場所が望ましい。水中以外の場所とは、水が不飽和状態の場所である。

水中以外での水質浄化では、陸上の浄化装置に原水をどのように流すのかがポイントとなる。流す方向には、(1)鉛直方向、(2)水平方向、(3)斜め下方の 3 通りがある。(3)の方式として、底面が傾斜した薄層構造体に担体を充填したものを傾斜土槽、これを用いた水質浄化法を傾斜土槽法(以下、本法という)と名付けた。

本法の浄化は、原水を層厚が 0.2m 程度の担体中に強制的に浸透流下させる方式であり、多段積みでコンパクトな浄化装置となる(図 1 参照)。本報では、本法を用いた上下水処理の実証試験で得られた知見について報告する。

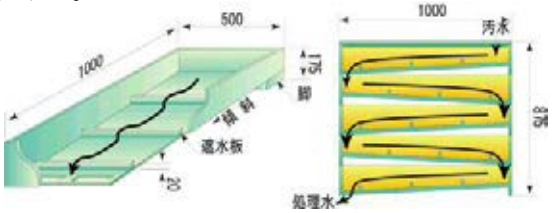

図 1　傾斜土槽と多段積みでの運用

2.　有機性排水の浄化実験と結果

2.1　台所排水の浄化

(1)国内での実験

図 1 の傾斜土槽の 3 段積みで 4 人家族の台所排水の浄化を行った。流し台からの落差を利用して、無動力で台所排水が最上段の傾斜土槽に流入するようにした(図 2 参照)。[1]

図2　台所排水の浄化実験

実験は、2001 年 7 月に通水を開始し、4 年 4 ヶ月間、毎月 1 回の水質調査を行った。この期間の総処理水量は 143.6m³、日平均処理水量は 92L であり、この期間中は担体（鹿沼土）の交換等の維持管理は何もしていない。設備費用は、工事費を含めて約 5 万円で、2018 年 5 月時点で運用を継続している。浄化結果を表 1 に示す。この結果より、本法では有機性汚濁物質と栄養塩類の同時浄化が可能で、浄化効果は長期間持続することがわかった。

表 1　国内の台所排水の浄化結果

項　目	水温 (℃)	SS (mg・l⁻¹)	BOD (mg・l⁻¹)	COD_{Mn} (mg・l⁻¹)	T-N (mg・l⁻¹)	T-P (mg・l⁻¹)
原　水	18.1 ±5.7	153 ±80	819 ±820	542 ±671	30.6 ±25.4	5.88 ±4.7
処理水	16.4 ±7.4	34 ±21	86 ±69	51 ±40	5.3 ±2.8	0.70 ±0.4
除去率	－ －	74% ±17%	83% ±13%	80% ±16%	73% ±16%	81% ±14%

※)±は、標準偏差を示す。

(2)インドネシアでの実験

インドネシアのジョグジャカルタ特別州の一般家庭で、図 1 を模した 4 段積みの木製の傾斜土槽で台所排水の浄化を行った。担体は 4 槽で 90L 分のスポンジで鶏糞肥料を種植した（図 3)。この材料費は、約 2,600 円（314,500 ルピア）であった。[2]

実験は、前日の夕方から実験日の朝にかけて採水貯留した原水を、落差を利用して 4 段積みの傾斜土槽を通過させ、通過前後の水質を測定した。

図3 インドネシアでの台所排水の浄化実験

実験は、2017 年 8 月から 9 月にかけて 13 回行った。この結果を表 1 に平均値で示す。また、原水と各段を通過した処理水の状況を図 4 に示す。

総リン(T-P)以外はよく浄化されていた。T-P は、槽内に投入した鶏糞肥料のリンが処理水に出ていた。

表 2 インドネシアでの台所排水の浄化結果

項目名	BOD	CODcr	T-N	T-P	SS
原水 平均値 (mg/L)	2091	3804	33.7	9.40	350
処理水 平均値 (mg/L)	223	376	5.5	30.0	8
平均除去率 (%)	88	87	73	-	95

図4 原水と各段通過の処理水の外観

2.2 各種の有機性排水の浄化実験

本法を用いた各種の有機性排水の浄化を行った。本法は、大気からの酸素供給で好気性浄化を行っている。単位 BOD 負荷量あたりの表面積が増えれば処理水は良好となり、逆に単位表面積あたりの BOD 負荷量が増加すれば除去率は低下する。

図 5 に各種の有機性排水の BOD 面積負荷量と BOD 除去率の結果を示す。この結果より、BOD が浄化しやすい排水（ドレッシング製造工場排水等）と浄化しにくい排水（バルク排水（搾乳設備洗浄排水）や製麺工場排水等）があることがわかる。[3]

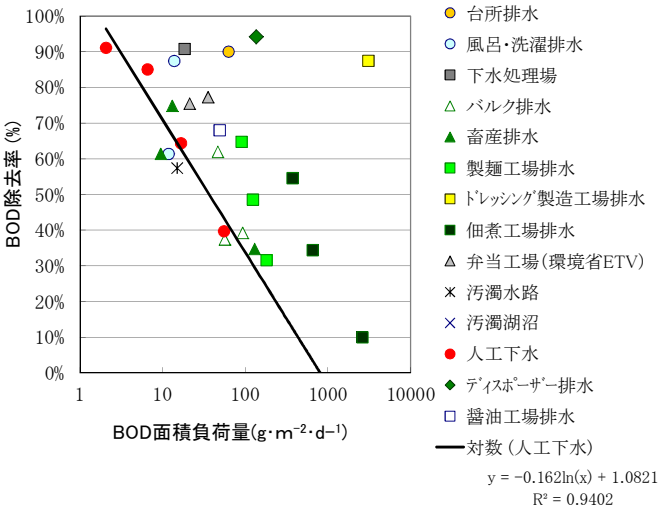

図 5 BOD 面積負荷量と BOD 除去率

3. 有機性排水の浄化機構の解明

3.1 滞留時間と BOD 除去率

スポンジを担体とした図 1 の傾斜土槽 9 段積みで、醤油製造工場排水の浄化実験を行った。原水は、毎分 1L でほぼ毎日 3 時間 180L を最上段に注水した。原水と 3 段、6 段、9 段の各段を通過した処理水の水質及び、注水開始から 9 段目の処理水が出るまでの滞留時間を測定した。原水の平均 BOD は 527mg/L、平均溶解性 BOD は 425mg/L で、BOD の多くは溶解性であった。[4]

図 6 に BOD 除去率、滞留時間の変化を示す。当初の BOD 除去は、物理学的なろ過や付着によるものである。時間経過に伴って 9 段と 6 段の除去率が上昇するのは、生物学的吸着作用の強化による。生物群が十分に育てば、滞留時間は約 30 分程度で BOD 除去率は 100%近くになることがわかる。

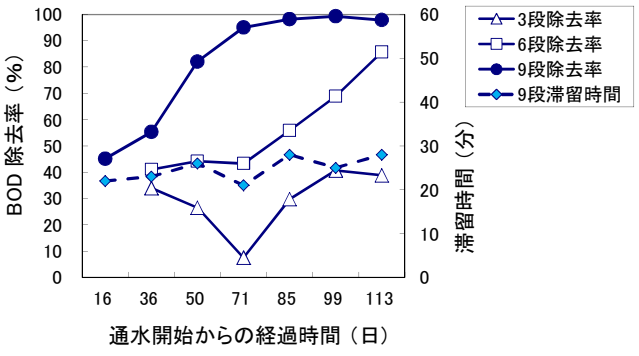

図 6 滞留時間と BOD 除去率

活性汚泥法のBOD浄化には8時間程度の滞留時間が必要といわれている。本法の短い滞留時間は、BOD成分と水とが生物学的吸着作用等によって 30 分程度で分離されるためである。捕捉された BOD 成分は、槽内で本来の浄化である有機物の無機化が進行する。

3.2 傾斜土槽の重量変化

前述3.1の9段積みの傾斜土槽の各段の重量変化を図7に示す。[4]1・2段目は、ろ過作用の重量増加があるので除いた。12 月から 4 月は重量が増加したが、連日の原水注水にもかかわらず 5 月に重量は減少した。これは温度上昇に伴い、微生物以上の高次の生物を含む食物連鎖が活性化し、冬季に溜まった過剰の有機物や生物膜が分解されるためである。この機構によって本法の汚泥発生量は少ない。また、過剰に有機物が蓄積した槽は、浄化系外に放置して有機物分解を促す養生操作を行うが、これも同じ食物連鎖によるものである。

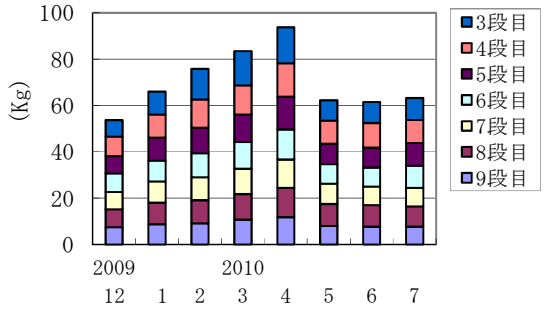

図 7　傾斜土槽の重量変化

4.　浄水処理への応用と結果

4.1 スリランカでの浄水処理

開発途上国では、河川等の水源の汚濁が進行し、緩速ろ過法では浄水が困難な事例も起きている。スリランカで平均 BOD が 37mg/L の原水について、緩速ろ過法の前処理として傾斜土槽法での浄水処理を行った。処理の流れは、原水→傾斜土槽①→傾斜土槽②→緩速ろ過→最終処理水である。傾斜土槽の仕様と日処理水量を表 3 の下部に示す。[5]

本法の酸素の供給能力は、緩速ろ過法よりも優れているために同法では浄水処理が不可能な原水についても浄水処理が可能である。なお、現在の本施設では、本法のみで浄水処理が行われている。

表 3　スリランカでの浄水処理の結果

試料名＼項目		濁度 (n.t.u)	BOD (mg/L)	COD_{Mn} (mg/L)	総無機態窒素 (mg/L)
原　水		13.5	37.1	10.0	11.6
処理水	傾斜土槽①	0.1	9.9	5.0	10.3
	傾斜土槽②	0.0	7.1	4.0	3.6
	緩速ろ過	0.0	2.1	2.3	3.6

（注）傾斜土槽①②は、各2×10m、担体は①は砂利、②はアンスラサイト、処理水量は$8m^3 \cdot day^{-1}$

4.2 バングラディシュでの浄水処理

バングラディシュでは地下水のヒ素等の重金属汚染が深刻である。同国チャンドプール県において、本法による汚染井戸水の浄化実験を行った。傾斜土槽は、図 1 を模して鮮魚運搬用の発泡スチロール容器を加工して作成し、担体はスポンジとした。実験は、実際に使用中の井戸の近傍に5段積みの傾斜土槽を設置し、無電源のため人力で井戸水を最上段に入れ、最下段の処理水を利用してもらった。水質が悪化すると、住民自らが汚れたスポンジを手洗いする維持管理を行った。[6]

表 4 に実験結果を示す。除去率は、鉄とマンガンはほぼ 100%で、ヒ素は 70%であったが、現地の上水基準は達成できた。ヒ素の除去機構は、鉄バクテリアによる酸化鉄との共沈作用と本法の汚濁物質と水との分離作用によるものである。なお、本実験の処理水によって、この村では初めて白いご飯が炊けたと喜ばれた。

表 4　バングラディシュでの浄水処理の結果

		ヒ素 (mg/L)			鉄 (mg/L)			マンガン (mg/L)		
上水基準	ﾊﾞﾝｸﾞﾗﾃﾞｨｼｭ	0.05			0.3 － 1.0			0.1		
	日本	0.01			0.3			0.05		
水質浄化結果	調査日	原水	処理水	除去率	原水	処理水	除去率	原水	処理水	除去率
	2015.7.4	0.22	0.15	31%	6.17	0.65	89%	0.76	0.17	78%
	2015.10.4	0.20	0.06	70%	3.45	0.00	100%	0.63	0.03	95%
	2016.3.23	0.18	0.06	66%	5.29	0.07	99%	0.64	0.03	95%
	2016.4.27	0.21	0.07	66%	5.81	0.05	99%	0.70	0.03	96%
	2016.5.29	0.13	0.05	63%	3.60	0.49	86%	0.60	0.16	74%
	住民が担体のスポンジを洗浄									
	2016.7.31	0.18	0.05	72%	5.64	0.00	100%	0.60	0.00	100%

5.　結論

本法は、低エネルギー消費と低コストで良好な上下水処理が可能なことから、開発途上国の水環境と水に係る衛生問題の改善に寄与することが期待される。また、湖沼の水質保全には、簡易な浄化方式で窒素・リンが浄化可能な本法は有効な対策の一つと考えられる。

引用文献

[1] 生地正人, 末次綾：水環境学会誌、傾斜土槽法による台所排水の有機性汚濁と栄養塩類の同時浄化、2005.5.

[2] 大野翔平ほか：第 52 回水環境学会年会要旨集、開発途上国における生活雑排水浄化を目的とした低コスト型傾斜土槽の開発、2018.3.

[3] 生地正人：愛媛大学大学院博士論文、傾斜土槽法によるBOD、窒素、リン含有汚水の浄化に関する研究、2012.2.

[4] 生地正人ほか: 水環境学会誌、スポンジ担体を用いた傾斜土槽法による有機性汚濁物質と栄養塩類の同時浄化、2014.7.

[5] 丸山和秀ほか: 有機汚染水（BOD30mg/L)を飲料水に浄化する生物浄化ユニットの開発、第 5 回緩速・生物ろ過国際会議要旨集、2014.6.

[6] 佐々原秀史ほか: 第 51 回水環境学会年会要旨集、スポンジ担体を用いた傾斜土槽法によるヒ素、鉄、マンガン、リン酸の同時浄化、2017.3.