

Effect of hydraulic loading rate, filter media, and type of wastewater on the purification performance of multistage wetland systems for agricultural wastewater treatment with special attention to oxygen transfer rate

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Abstract

The relationship between oxygen transfer rate (OTR) and hydraulic loading rate (HLR), filter media and type of wastewater was evaluated from the treatment performance data of 15 full scale subsurface flow constructed systems that treat agricultural organic wastewater in Japan and Vietnam for about 16 years in total. As a result, it was found that OTR tends to decrease as the HLR increases when the load (concentration times flow rate) is same. And the rate of OTR decrease was $H > V_r > V$. And it was also found that porous filter media have better purification performance than solid filter media. And purification performance varies depending on the type of wastewater (food & dairy > starch > swine). These results are applied for the design of treatment wetlands for different kind of organic wastewater.

Keywords

Abstract; multistage constructed wetland; vertical flow with recirculation; hydraulic loading rate; porous filter media; dairy and swine wastewater; organic wastewater

INTRODUCTION

We had revealed that the relations of load–oxygen transfer rate (OTR), COD–ammonium, and a Arrhenius temperature dependent equation enable the basic design of a reed bed system in 2013 (Kato et al. 2013b), but we could not clarify the effect of hydraulic loading rate, type of filter media and type of wastewater. So, we investigated and verified the treatment performance of 15 full scale subsurface flow constructed wetland systems those treat agricultural organic wastewater from dairy farming, pig farming, starch factory, etc., in Japan and Vietnam, and tried to improve the model for estimating the treated water quality with special attention to oxygen transfer rate.

SYSTEM DESIGN AND METHODS

System design, water type, and other information

15 wetland systems, from single to maximum eight multistage for treating agricultural wastewater, were evaluated since 2005. The location, wastewater type, in flow, temperature, assessment period and number of sampling times of those systems are listed in Table 1. And bed type and stages, bed area, bed material and main vegetation are listed in Table 2. Those systems are equipped with bypass structure and floating cover material to overcome clogging (Kato et al. 2013a, Kato et al. 2013b). Vertical flow beds are using self-priming siphon and initial stage bed surfaces are partitioned for drying during the growing season like French system (Molle et al. 2005). Some V flow bed effluents were recirculated (Vr) to the inlet with a pump to improve performance.

Table 1. Location, wastewater type, in flow, temperature, assessment period, number of sampling times of each system

No.	System name	Location	Types of wastewater	Average in flow (m ³ /d)	Average temperature* (°C)	Assessment Period (number of sampling times)
1	Dairy K	Bekkai, Hokkaido, Japan	milking parlour	30.4	5.7	Nov. 2005 - Nov. 2017 (n=148)
2	Dairy S	Embetsu, Hokkaido, Japan	milking parlour	4.7	8.0	Nov. 2006 - Apr. 2014 (n=95)
3	Dairy N	Bekkai, Hokkaido, Japan	milking parlour	20.3	7.0	Jun. 2008 - Jun. 2014 (n=55)
4	Pig food A	Atsuta, Hokkaido, Japan	pig liquid food washing	4.1	8.0	Nov. 2008 - Oct. 2010 (n=20)
5	Pig O	Chitose, Hokkaido, Japan	pig manure fluid	10.8	7.5	Nov. 2009 - Aug. 2016 (n=58)
6	Starch P1 **	Kiyosato, Hokkaido, Japan	potato starch factory	17.8	16.8	May-Aug. 2009, 2010, 2011 (n=11)
	Starch P2 **		decanter waste liquid	7.8	12.6	Sep.-Nov. 2009, 2010, 2011 (n=13)
7	Dairy G	Takinoue, Hokkaido, Japan	milking parlour	32.6	7.0	May 2011 - Nov. 2016 (n=38)
8	Dairy E	Ebetsu, Hokkaido, Japan	milking parlour	18.2	8.5	Jun. 2011 - Sep. 2014 (n=37)
9	Chicken egg C	Shizukuishi, Iwate, Japan	Chicken egg washing	7.8	8.9	Oct.2011 - Sep. 2013 (n=24)
10	Biogas BPS	Shizukuishi, Iwate, Japan	dairy manure, biogas digestive juice	2.2	10.3	Nov. 2015 - Nov. 2017 (n=23)
11	Pig TG	Thai Nguyen, Vietnam	pig biogas digestive juice	62.0	25.1	Oct. 2016 - Dec. 2018 (n=9)
12	Pig HD	Hai Duong, Vietnam	pig biogas digestive juice	71.9	25.0	Oct. 2017 - Jan. 2019 (n=10)
13	Pig SF	Hachinohe, Aomori, Japan	pig manure fluid	11.4	11.1	Dec. 2017 - Dec. 2021 (n=29)
14	Pig IF	Morioka, Iwate, Japan	pig manure fluid	0.87	11.1	Sep. 2018 - Dec. 2021 (n=41)
15	Dairy BC	Daisen, Tottori, Japan	milking parlour & dairy manure fluid	48.5	15.5	Aug. 2020 - Dec. 2021 (n=17)

* Average temperature from AMEDAS (Automated Meteorological Data Acquisition System) data of the Japan Meteorological Agency or locally measured values at the sites in Vietnam, during the assessment period.

** P1 was preserved wastewater from May to August and P2 was fresh wastewater from September to November.

Table 2. Bed type, number of stages, bed material and vegetation of each system

No.	System name	Bed type*1	Stages	Bed area m ²	Main bed material	Main vegetation
1	Dairy K1	V - V - H - V	4	1174	Volcanic pumice	Phragmites
	Dairy K2	V - Vr - H - V	4	1686	Volcanic pumice	Phragmites
2	Dairy S	V - Vr - H	3	656	River gravel & sand	Phragmites
3	Dairy N	V - Vr - H - V	4	1789	Volcanic pumice	Phragmites
4	Pig food A	Vr - Vr - V	3	168	Shale gravel	Phragmites
5	Pig O	Vr - Vr - V - H - V	5	1472	Volcanic pumice	Phragmites
6	Starch P	Vr - Vr - Vr - H - Vr	5	2151	Volcanic pumice	Phragmites
7	Dairy G	V - V - V - H - V	5	3048	River gravel & sand	Phragmites
8	Dairy E	Vr	1	529	Volcanic pumice	Phragmites
9	Chicken C	V - V	2	46	Volcanic pumice	Carex dispalata
10	Biogas BPS	Vr - Vr - Vr - Vr - H - Vr	6	320	Volcanic pumice	Phragmites, Carex
11	Pig TG	V - V - V - V	4	1868	Crushed stone with sand	Phragmites
12	Pig HD	V - V - V - H - V	5	1220	Crushed stone with sand	Phragmites
13	Pig SF	Vr - Vr - Vr - Vr - Vr - V	6	1245	Crushed stone with sand	Phragmites, Grass
14	Pig IF	Vr - Vr - Vr	3	152	Volcanic pumice	Phragmites, Grass
15	Dairy BC	Vr - Vr - Vr - Vr - Vr - Vr - H - Vr	8	9453	Crushed stone with sand	Phragmites, Grass

*1 : V, vertical flow; H, horizontal flow; Vr, vertical flow with recirculation pump. Vr, recirculation within a single bed.

Water flow and water quality measurement

Water flow was calculated by monitoring the change in the water table at each self-priming siphon or pumping hall. Water samples were collected at every inlet and outlet of each reed bed. Samples were taken once per month and the water was analysed for COD, NH₄-N and total nitrogen (TN).

The analysis method and specific data of some systems are described in the past papers (Sharma et al. 2013, Zhan et al. 2016, Harada et al. 2016, Kato et al. 2013a, Kato et al. 2013b).

RESULTS AND DISCUSSION

Water quality trends trough stages

Organic pollutants are purified through stage (Fig.1). Manure from pigs and cows (and methane fermented digestive juice made from it) tends to have a smaller reduction rate of organic matter (COD) than dairy wastewater. Dairy wastewater tends to have a small reduction rate of ammonia nitrogen. Therefore, it is necessary to adjust the mathematical formula for estimating the treated water quality according to the properties of the wastewater.

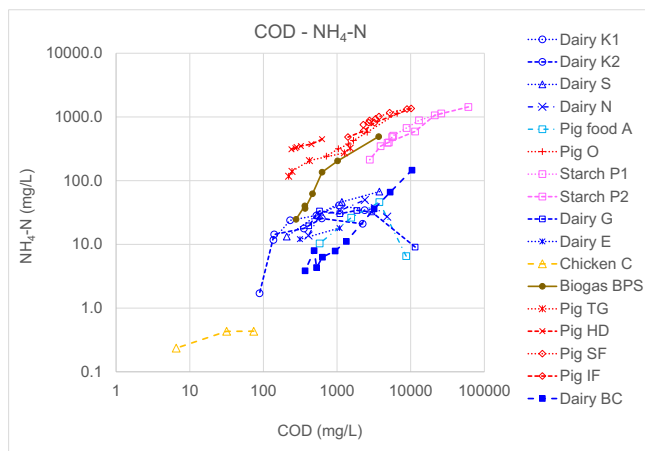


Figure 1. Interstage content of COD and NH₄-N for each system (average data)

Relationship of hydraulic loading rate (HLR), filter media and type of wastewater with oxygen transfer rate (OTR)

It was confirmed that the purification efficiency = oxygen transfer rate (OTR) tends to decrease as the hydraulic loading rate (HLR) increases (Fig.2). This tendency is large for Vr and H and small for V.

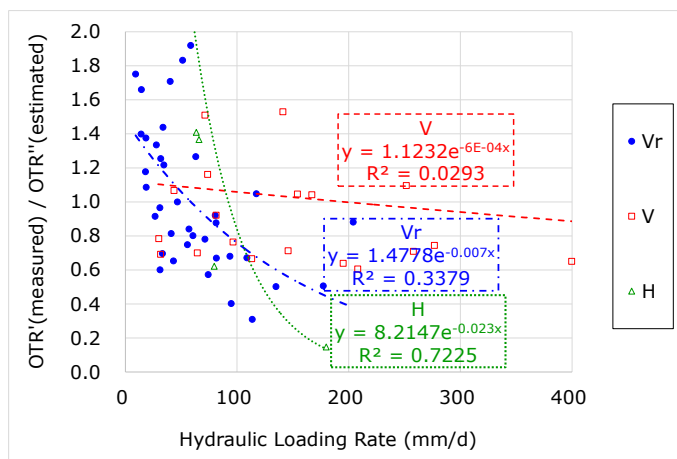


Figure 2. Relationship of hydraulic loading rate (HLR) and oxygen transfer rate (OTR) measured / estimated

Relationship of load and OTR is adjusted with same hydraulic loading rate in the Figure 3. When measured OTR = estimated OTR', the HLR is 55.8cm for Vr, 193.6cm for V and 69.3cm for H, respectively.

And it was also found that porous filter media have better purification performance than solid filter media (Fig.3). And purification performance varies depending on the type of wastewater (food & dairy > starch > swine; Fig.4). These results are applied for the design of treatment wetlands for different kind of organic wastewater.

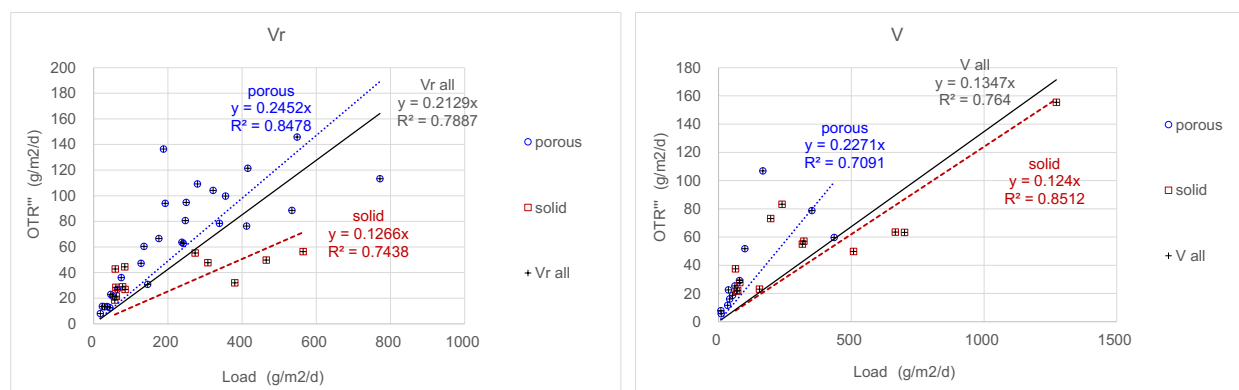


Figure 3. Porous filter media have better purification performance than solid filter media

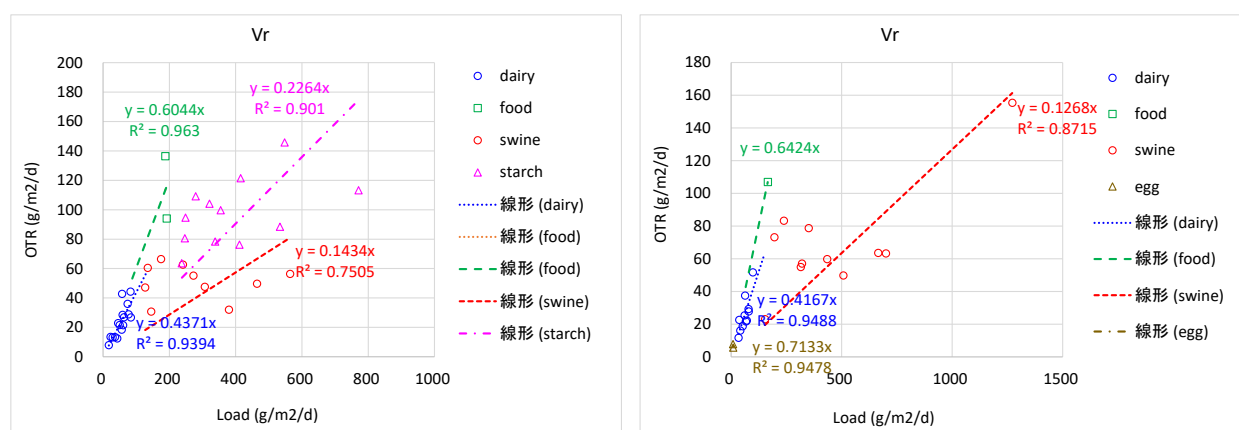


Figure 3. Purification performance varies depending on the type of wastewater (food & dairy > starch > swine)

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