EGU2019-1400: Laboratory investigation of hydraulic and chemical behavior of woodchips to better understand performance of denitrifying bioreactors

Luca Trevisan

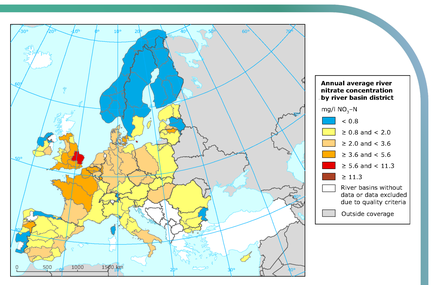
Institute for Hydromechanics, Karlsruhe Institute of Technology, Karlsruhe, Germany (luca.trevisan@kit.edu)

EGU General Assembly
Vienna | Austria | 7–12 April 2019

Photography encouraged
CC BY

Karlsruhe Institute of Technology
Institute for Hydromechanics

1. Motivation



Subsurface agricultural drainage can lead to high levels of nitrate (NO_3) in tile water, which can pollute rivers, eventually causing **eutrophication** of larger water bodies. **Denitrifying Woodchip Bioreactors (DWB)** are a recent practice that can help reduce the amount of NO_3 carried by field drainage water.

The European Nitrates Directive has set a **maximum contaminant level of NO_3** in drinking water of **50 mg/l (equivalent to 11,3 mg N/l)**, which continues to be exceeded by 17% of the monitored sites.

DWB's performance depends on several factors, including **loading flow rates**, **influent NO_3 concentrations**, **dissolved oxygen concentrations**, **water temperature**, and **woodchips flow and transport parameters**.

The **hydraulic residence time (HRT)** is one key factor controlling the efficiency of denitrification. When HRT is too low, contact time with denitrifying bacteria can be insufficient for NO_3 to be completely reduced and microbial activity can lead to the **production of greenhouse gases** like carbon dioxide, nitrous oxide, and methane. Another key parameter affecting NO_3 removal rates is the size of woodchips, which correlates to the specific surface area of the porous medium.

2. Research Objectives

The aim of this work is two-fold:

a. to characterize **denitrification efficiency** of woodchips with different average particle size (d_{50}) and to investigate the effect of HRT on NO_3 removal under variable flow conditions and temperature;

b. to find a possible correlation between bioreactor's **effective porosity** and the **nitrogen gases** generated by denitrifying bacteria.

For this purpose, a series of 50-cm-long column experiments and 130-cm-long rectangular flume experiments are conducted under well-controlled laboratory conditions.

3. Other Laboratory-Scale Studies

	This work	Chun et al. (2009)	Robertson (2010)	Healy et al. (2012)	Ghane et al. (2014)	Hoover et al. (2016)	Abusallout & Hua (2017)	Christianson et al. (2017)
d_{50} (cm)	*0,2-1,6*	0,9	1,6	-	0,8	0,65	2	0,6
Effective porosity (cm^3/cm^3)	*0,6-0,7*	0,39-0,88	0,6-0,67	0,5-0,67	0,52	0,59	0,5	0,72
Hydraulic conductivity (cm/s)	*0,5-5*	2,7-4,9	9-16	$5x10^{-6}$-$5x10^{-2}$	2,4-8,4	-	-	7,33-11
Bulk density (g/cm^3)	*0,2*	0,2	-	-	0,2	0,56-0,62	-	0,27
HRT (h)	*0,5-2*	1-12	24-31,2	13-17,5	0,05-0,21	2; 8; 12; 18; 24	6; 12; 24	7,2-51
T (°C)	*15-25*	20-25	21-23,5	10	8-13	10, 15, 20	20-23	15,6-19,6
Q (ml/min)	*10-100*	186-1680	22,5-26,5	0,16	441-1764	3-37	-	2,7-20
input [NO_3-N] (mg N/l)	*10-50*	8-33,7	3,1-48,8	19,5-32,5	-	10; 30; 50	20-50	23-32
NO_3 removal rate (mg N/l/h)	-	-	0,38-0,96	0,06-0,08	-	0,49	0,42-0,79	0,37-0,75

4. Experimental Design

a. Particle size analysis

The woodchips are placed on a stack of six sieves sitting on a large shaking machine;

b. Synthetic water preparation

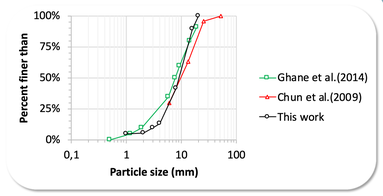
Influent [NO_3] = 140 mg/l is attained by dissolving 22,8 g of KNO_3 in 100 l of DI water ➔ [NO_3-N] = 31,6 mg/l;

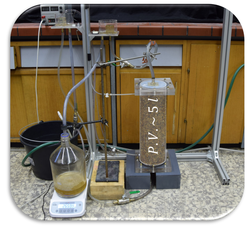
c. Water analysis via **ion-selective electrode (ISE)** and **spectrophotometry**

In order to constrain measuring accuracy of the cheaper ISE method, NO_3 concentration of one every ten samples is measured with the more reliable spectrophotometer;

d. **Vertical acrylic column** employed to estimate transport parameters of woodchips in 1D upwards flow experiments;

e. **Horizontal acrylic flowcell** employed to observe effects of variable flow geometries on DWB performance and to quantify gas generated by cellular respiration.



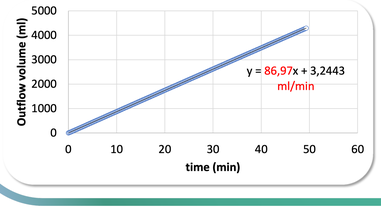


I.D. = 15 cm
L = 45 cm
V = 8 l

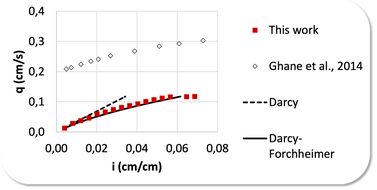
L = 148 cm
W = 10 cm
H = 20 cm
V = 26 l

5. Preliminary Results

Flowrate (Q) is measured by continuously weighing outflow



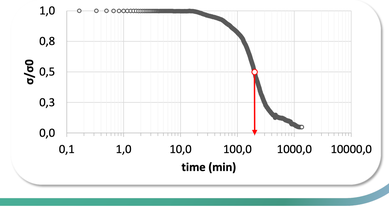
Hydraulic gradient (i) is plotted as a function of specific discharge (q) to test validity of **Darcy's law (laminar flow)** or **Darcy-Forchheimer law (inertial effects)**



Using DI water as tracer, HRT is estimated as time at **50% decrease** of electrical conductivity (σ): **200 min**

Knowing the **flowrate: 87 ml/min**

Pore volume (P.V.), hence **effective porosity** can be estimated: **0,67**



Acknowledgements

Funding for this research is provided by the Baden-Württemberg Region (Germany).

I thank Sweta Patel and Victoria Grießmeier for their help with collection and analysis of lab samples.