UNIVERSIDADE DA CORUÑA

Effect of different bypass rates in hybrid vertical-horizontal flow constructed wetlands treating synthetic and real municipal wastewater

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- MATERIAL AND METHODS
- RESULTS
- CONCLUTIONS

I. INTRODUCTION

Constructed wetlands (CWs) vantages:

- Low cost and eco-flriendly technologies
- Natural processes to remove pollutants
- Avoiding the use of chemical products
- Avoiding the use of external energy

I.

CWs limitations:

- Single stage CWs are not able to get the more stringent discharge limits for nitrogen due to their inability to provide alternant aerobic and anoxic conditions for the nitrification/denitrification processes
- High land area requirement

Classical nitrification-denitrification routes require:

- maintaining alkalinity
- sequential aerobic-anaerobic conditions
- availability of ready biodegradable carbon in the anoxic step

Intensified CW systems consist of more sophisticated process design, including:

- hybrid or staged CW systems,
- recirculation of wastewater,
- continuous or intermittent artificial aeration

I.

One of the simplest hybrid CWs configuration: VF+HF (= sequential aerobic and anaerobic conditions)

Reviewed hybrid CW systems (Gaboutloeloe et al., 2009; Vymazal, 2013):

- VF+HF hybrid CWs are slightly more efficient in ammonia removal than other hybrid configurations
- All types of hybrid constructed wetlands are more efficient in total nitrogen removal than single HF or VF constructed wetlands
- The most limiting factor TN removal in hybrid VF+HF systems was nitrate accumulation
- This was due to the excessive carbon depletion during the aerobic phase (VF step)

Torrijos et al., 2016:

- **HF/VF area ratio:** 0.5-7.6 (2.7 on average in literature)
- Influent **bypass** to the second HF unit has not been reported

O.

OBJECTIVES

Previous work (Torrijos et al., Wetpol 2015):

- Hybrid VF+HF CW, HF/VF area ratio = 2.0, bypass up to 50% → $Bp(VF:HF)_{1:2}$ system
- Ammonia and mainly nitrate accumulated in the effluent
- Conclusion: even at 50% bypass, operational conditions in HF unit (DO, ORP, COD/TN ratio) were not suitable enough for advanced denitrification.

Hypothesis: a lower HF/VF area ratio would require a lower bypass ratio, improving denitrification and TN removal. Thus, we study the following system:

Hybrid VF+HF CW, HF/VF area ratio = 0.5, by-pass → $Bp(VF:HF)_{2:1}$ system

And the objective is:

- to check the effect of bypass and HF/VF area ratio on TN removal in a hybrid VF+HF CW.
- to check if synthetic and real municipal wastewater gives different results

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M&M

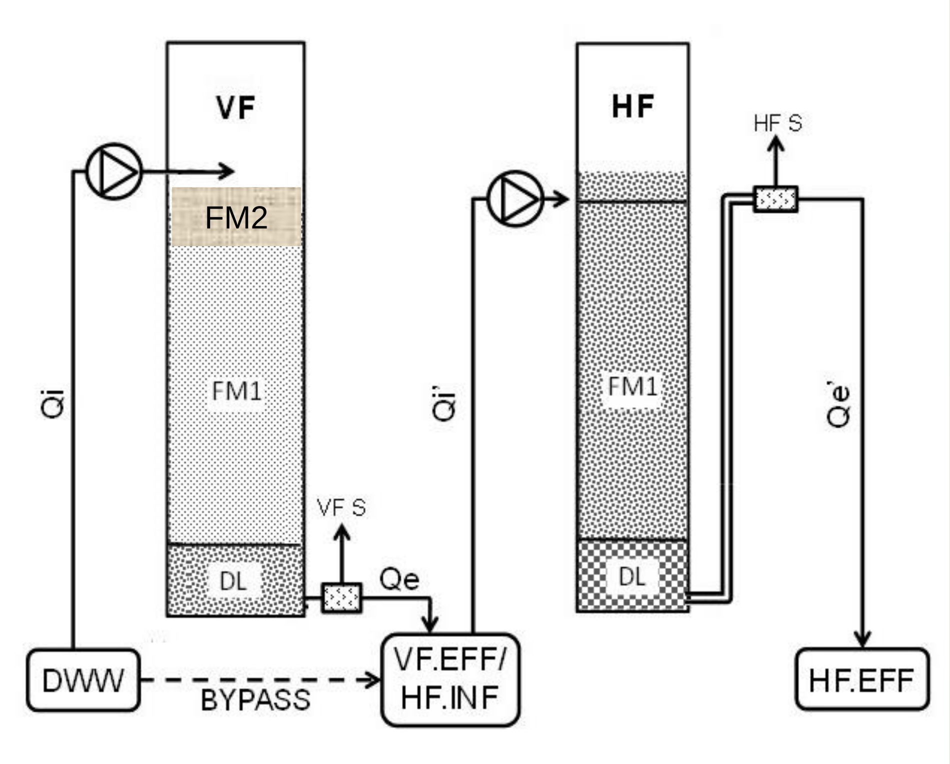
Configuration of the hybrid Bp(VF+HF)$^{2:1}$ system

Lab columns were used to simulate CW units:

- VF: unsaturated unit
- HF: saturated unit

HF/VF area (cross-sectional**) ratio: 0.5**

Column	Drainage layer (DL)	Main filtering medium (FM1)	Upper layer (MF2)
VF	6-12 mm gravel	32 cm height 1-3 mm sand (d^{60} 2.5)	5cm height 0-2 mm sand (d^{60} 0.9)
HF	20 mm gravel	40 cm height 6-12 mm gravel	

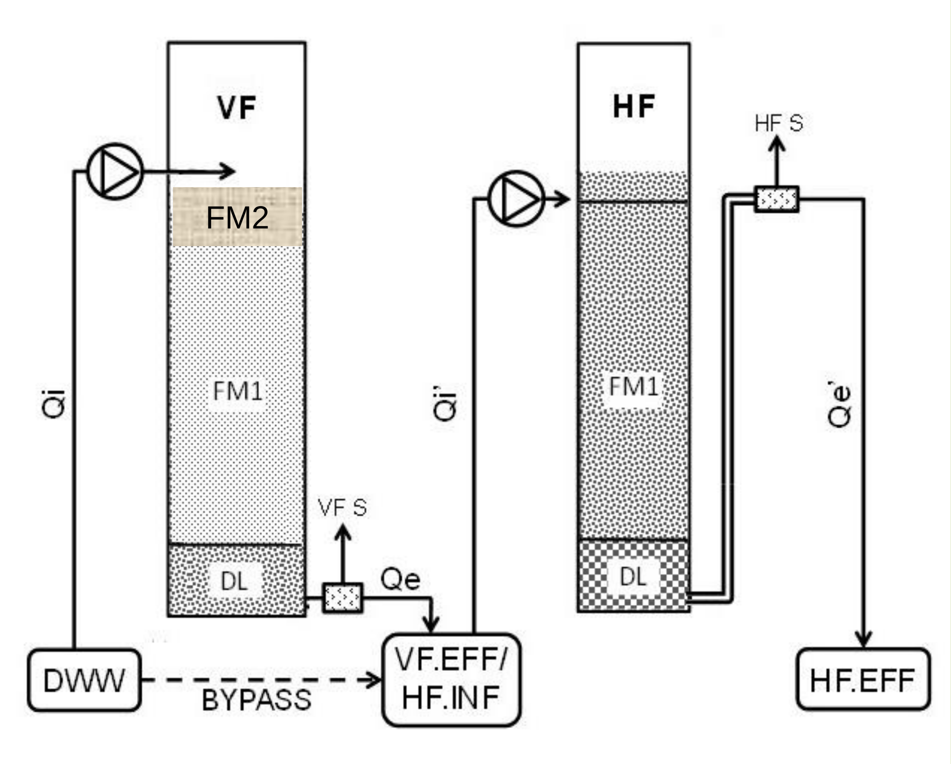


M&M

VF operation:
- 12 pulses per day, free drained
- Resting: 3 days ON, 4 days OFF

HF operation:
- Continuous saturated conditions
- Frequent pulses (>16 pulses a day)
- HF influent: VF effluent + raw wastewater (By-pass)

Other conditions:
- Thermostatic chamber at 20ºC
- Influent and effluent tanks: in fridge at 10 ºC
- Units not planted



M&M

Characteristics of influent wastewater

Influent	pH	TSS	VSS	COD	BOD_5	TN	NH_3-N	NO_3^--N	PO_4^{3-}-P
SW	7.0 ± 0.2	120 ± 32	106 ± 10	539 ± 48	260 ± 49	78 ± 8	8 ± 1	3 ± 1	11 ± 2
MW	7.2	81 ± 26	73 ± 27	405 ±49	225 ± 44	57 ± 3	45 ± 7	2 ± 1	5.4 ± 1

SW: synthetic domestic wastewater. MW: real municipal wastewater. Concentration in mg/L.

Real wastewater (MW): raw influent to the municipal treatment plant of A Coruña, after 2 h settling.
Concentrated SW and MW batches kept at 4 ºC until the moment of use.

MW had a slightly lower concentration and was highly ammonified

M&M

Sampling and analysis

Integrated daily samples

Parameters: TSS, VSS, COD, BOD_5 (only for the final effluent), ammonia, nitrate and TN.

In situ (on stream) parameters: pH, ORP, DO (dissolved oxygen)

$Q_{INHF} = Q_{VF} + Q_{Bp}$

$S_{INHF} = (Q_{VF} \cdot S_{VF} + Q_{Bp} \cdot S_{WW}) / Q_{INHF}$

$Bp\ (\%) = (Q_{Bp} / Q_{VFIN}) \cdot 100$

Q_{VF}: VF effluent pumped to the HF column

Q_{Bp}: bypass flow to HF column

Bp (%): bypass flow as percentage of influent flow to VF

S_{INHF}: calculated influent concentration to HF

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R.

Operational characteristics

1st part: SW

PERIOD (days)	I (0-49)	II (50-75)	III (76-104)	IV (105-125)	V (126-153)	VI (154-165)	VII (166-180)
Wastewater	SW	SW	SW	SW	MW	MW	MW
Bypass to HF (% Inf. VF)	0	26.0	39.7	38.6	34.4	18.1	30.3
Overall HLR (mm/d)	76.5	96.8	109.3	128.7	124.2	72.6	79.5
Overall SLR ($g/m^2 \cdot d$)							
TSS	9.3	11.7	13.2	15.6	9.9	6.0	6.5
COD	45.1	57.0	64.4	75.8	53.0	27.9	30.6
BOD_5	19.4	24.5	27.6	32.6	28.9	16.0	17.5
TN	5.8	7.3	8.2	9.7	7.0	4.3	4.7
VF SLR ($g/m^2 \cdot d$)							
TSS	14.2	14.3	14.6	17.3	11.4	7.8	7.7
COD	69.4	69.7	70.9	84.1	60.6	36.4	36.1
BOD_5	29.8	29.9	30.4	36.1	33.1	20.8	20.7
TN	8.9	8.9	9.1	10.8	8.0	5.6	5.5
HF SLR ($g/m^2 \cdot d$)							
TSS	4.8	8.0	13.7	24.2	22.7	7.5	12.6
COD	11.8	31.9	59.0	85.0	80.0	24.5	32.3
TN	13.7	13.8	19.2	22.0	14.1	12.6	11.3

R.

Operational characteristics

2nd part: MW

PERIOD (days)	I (0-49)	II (50-75)	III (76-104)	IV (105-125)	V (126-153)	VI (154-165)	VII (166-180)
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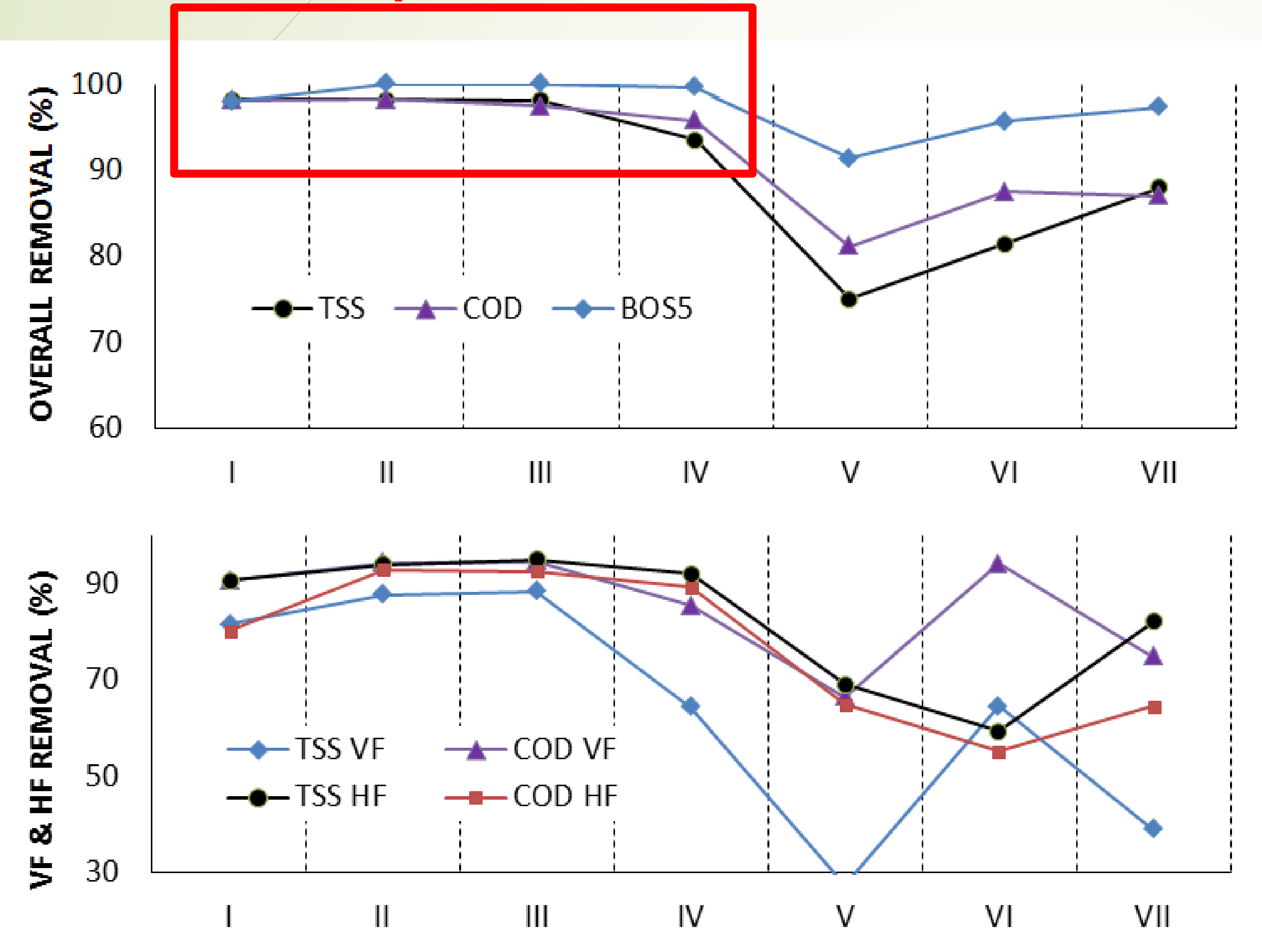
R. Organic matter removal

1st part: SW

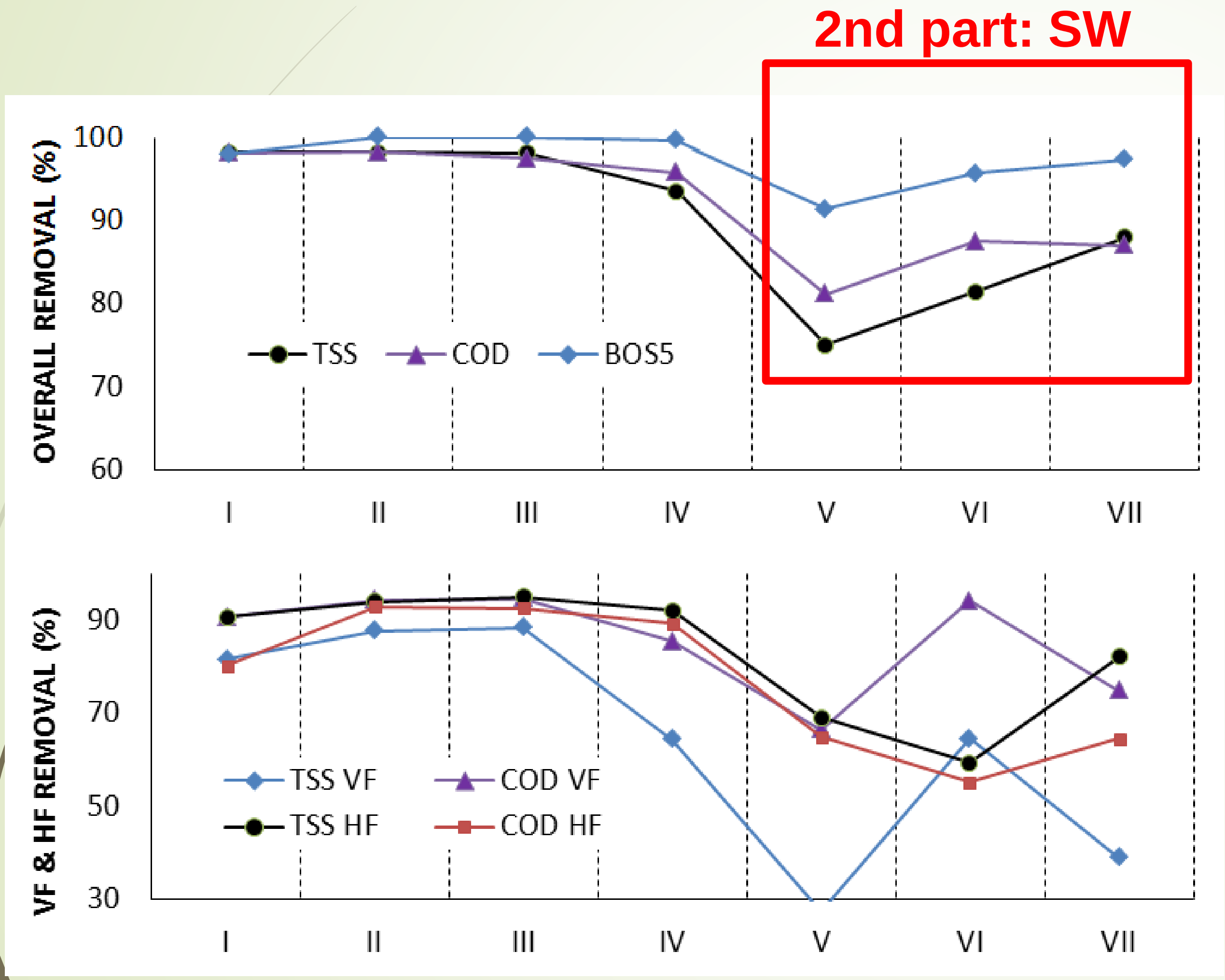


Organic matter removal efficiency was very high in the overall systemn: 94% - 99% for TSS, COD and BOD5

The same occurred in the individual units, although the VF unit accused the increase in HLR during period IV

R.

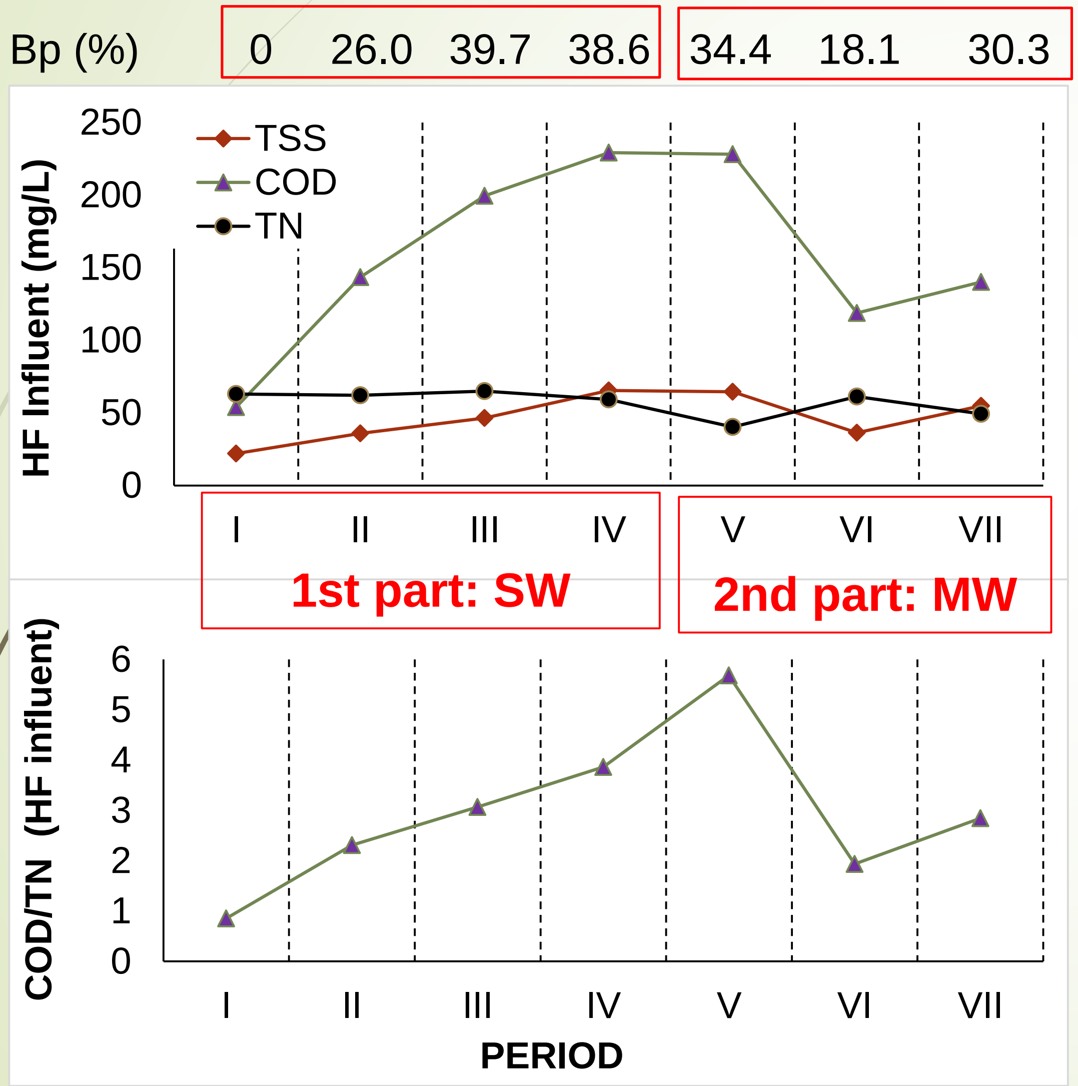
Organic matter removal



Real MW:

- Removal efficiency decreased and was partially recovered after the reduction in HLR and SLR
- Average removals (V-VII) were: 82% TSS, 85% COD and 95% BOD5

R. Influent concentration to HF unit



SW

Effect of bypass (from 0 to 40%) on COD and TN concentration influent to HF:

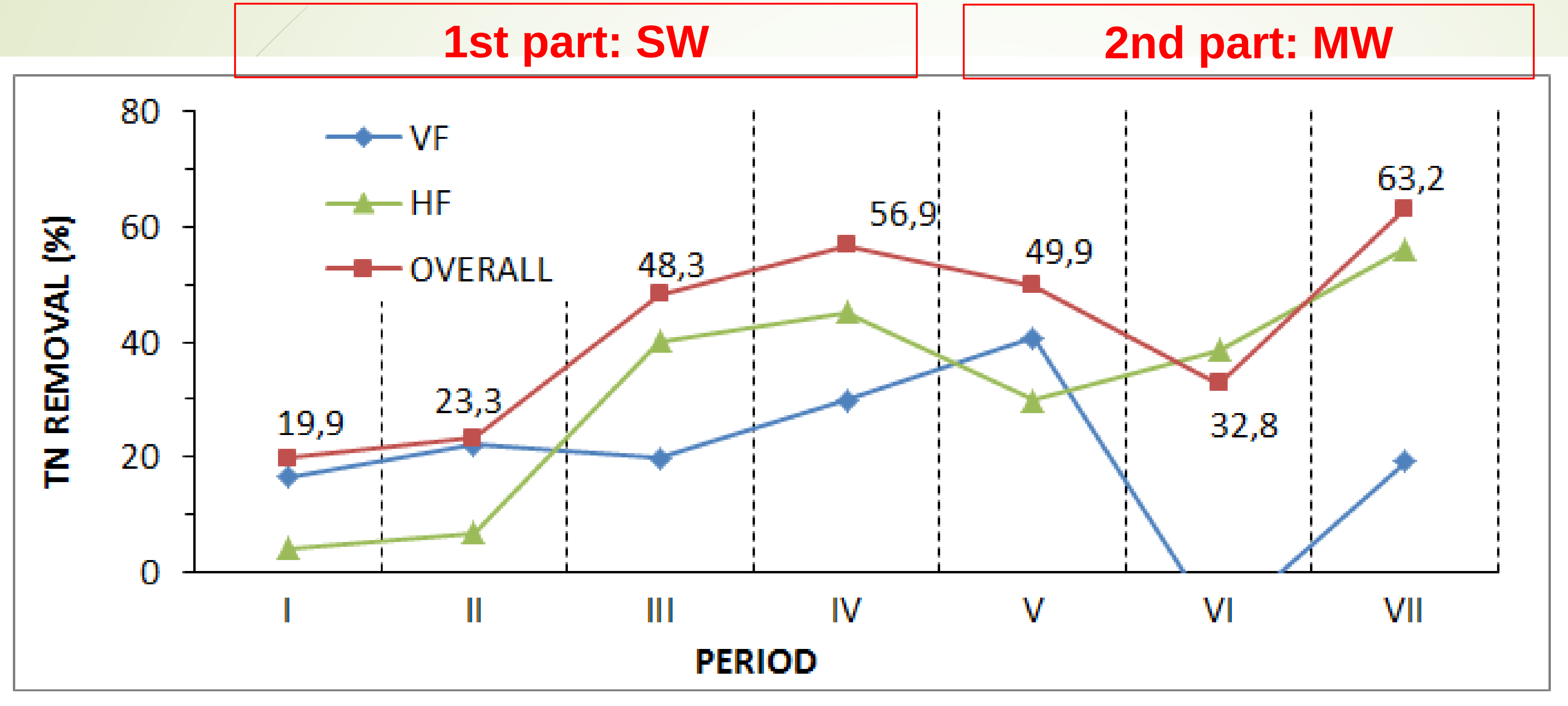
- constant TN concentration
- sharp increase in COD and TSS
- COD/TN ratio increase from 0.9 to 3.9

MW

The bypass has been reduced to 30% (period VII) and the COD/TN ratio decreased to 2.8 (VII)

R.

Nitrogen conversion and TN removal



TN removal clearly increased with Bp due to enhanced denitrification in the HF unit:

- Maximum TN removal with SW: 57% at 39% Bp
- Maximum TN removal with MW: 63% at 30% Bp and lower SLR

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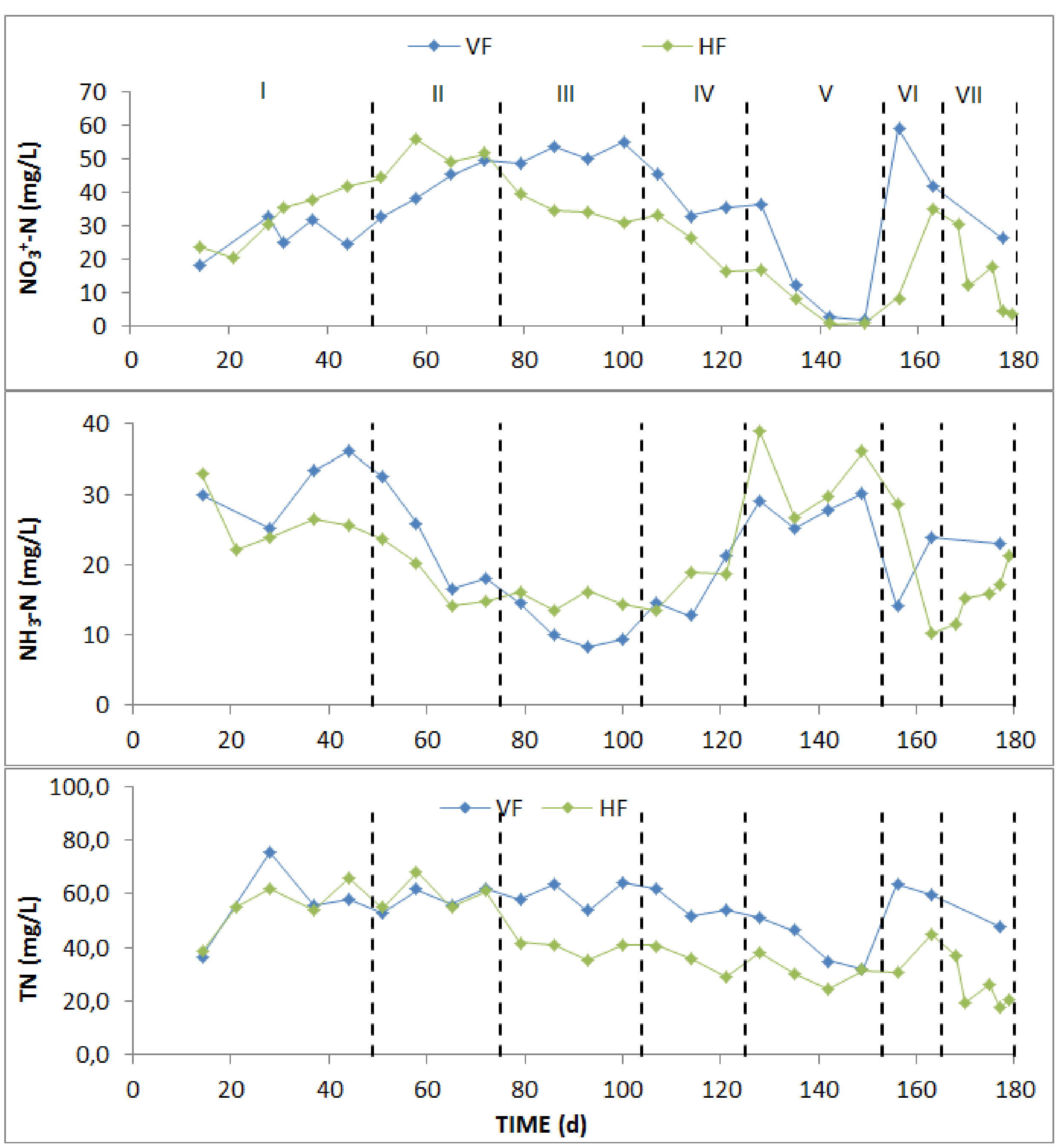

The course of nitrogen forms can explain the treatment efficiency and the selection of operational conditions made.

The criterion: Predominant accumulation of one of the nitrogen forms in the final effluent indicates unbalanced situation (HLR, SLR, %Bp)

The objective: optimum TN removal

R.

Clogging risk and green house gas emssions

- VF flow profiles and drainage flow from HF indicate absence of clogging
- Overall greenhouse gas emissions were 30 (CO_2), 0.11 (N_2O) and 0.41 (CH_4) g/m^2·d
- N_2O and CH_4 emissions were in the range of mean emission factors reported in literature, but higher than those of the Bp(VF+HF)$_{1:2}$ system receiving lower SLR

Greenhouse gas emission rates

	VF			HF			Overall		
	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4
Emission rate (mg/m^2·d)	38578	160	164	14669	0	873	30021	109	414
Emission factor (%)[a]	108.5	1.0	1.3	38.3	0	6.3	94.2	0.7	3.6

R. **Effect of HF/VF area ratio:** Comparing systems Bp(VF+HF)$_{1:2}$ and Bp(VF+HF)$_{2:1}$

SW:

- Similar COD/TN of 3.1-3.2 but at different bypass ratios of 50% and 40%
- Bp(VF+HF)$_{2:1}$ reached 2 to 3 times higher SLR and SRR (COD and TN)

System	Bp(VF+HF)$_{1:2}$	Bp(VF+HF)$_{2:1}$	Bp(VF+HF)$_{2:1}$
Wastewater	SW	SW	MW
HF/VF area ratio	2.0	0.5	0.5
Bypass to HF (% Inf. VF)	50	39.7	30.3
Overall HLR (mm/d)	40.4	109.3	79.5
Overall SLR (g COD/m^2·d)	23.8	64.4	30.6
Overall SLR (g TN /m^2·d)	3.1	8.2	4.7
COD/TN Influent HF	3.2	3.1	2.8
Overall TN removal (%)	50.0	48.3	63.2
Overall SRR (g TN/m^2·d)	1.6	4.0	3.0
Reference	Torrijos et al., 2015	This study	This study

MW:

- good performance of the Bp(VF+HF)$_{2:1}$ system at middle SLR

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C.

CONCLUSIONS

- A lower HF/VF area rate requires a lower bypass ratio in order to obtain reducing conditions in the second HF unit and allows higher SLR

Synthetic wastewater:

- $Bp(VF+HF)_{2:1}$ system: 48-57% TN removal at 40% Bp, 33 g $BOD_5/m^2 \cdot d$ and 10 g $TN/m^2 \cdot d$ of SLR
- $Bp(VF+HF)_{1:2}$ system: 50% TN removal at 50% Bp, 10 g $BOD_5/m^2 \cdot d$ and 3 g $TN/m^2 \cdot d$ of SLR

Actual municipal wastewater:

- $Bp(VF+HF)_{2:1}$ system: 63% TN removal at 30% Bp, 18 g $BOD_5/m^2 \cdot d$ and 4.7 g $TN/m^2 \cdot d$ of SLR

- Maximum TN removal efficiency limited to 50-60% in the Bp(VF+HF) irrespective of the HF/VF area rate, SLR or wastewater type, indicating a limitation of the bypass strategy in order to achieved complete TN removal in this type of CW.

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THANK FOR YOUR ATENTION

the international water association

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