Reclamation of Nutrients and Irrigation Waters from Livestock Wastewater

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Introduction

Disposal of livestock wastewater effluent **(LWE)** is a costly expense for dairy farmers. The LWE contains high levels of orthophosphate **(PO4-P)**, ammonium **(NH4-N)**, nitrate **(NO3-N)**, total suspended solids **(TSS)** and biochemical oxygen demand **(BOD)**. One approach for disposal of LWE is to use it as a fertilizer as part of a crop nutrition plan. This is done by application to the topsoil of crop fields by spraying. Such treatment is a costly addition to farm production costs, and poses risks for environmental problems such as leaching of NO3-N into groundwater, and deposition of particulate phosphate PO4-P to surface waters.

As an alternative to direct reuse of LWE, reclamation of nutrients and water from LWE is evaluated using an aerated fluidized bed reactor **(aerated-FBR)**, coupled with constructed wetland treatment **(CWT)**. This method first reclaims nutrients as **struvite** ($MgNH_4PO_4•6H_2O$) then refurbishes effluents as irrigation water with BOD and TSS removal.

Methods

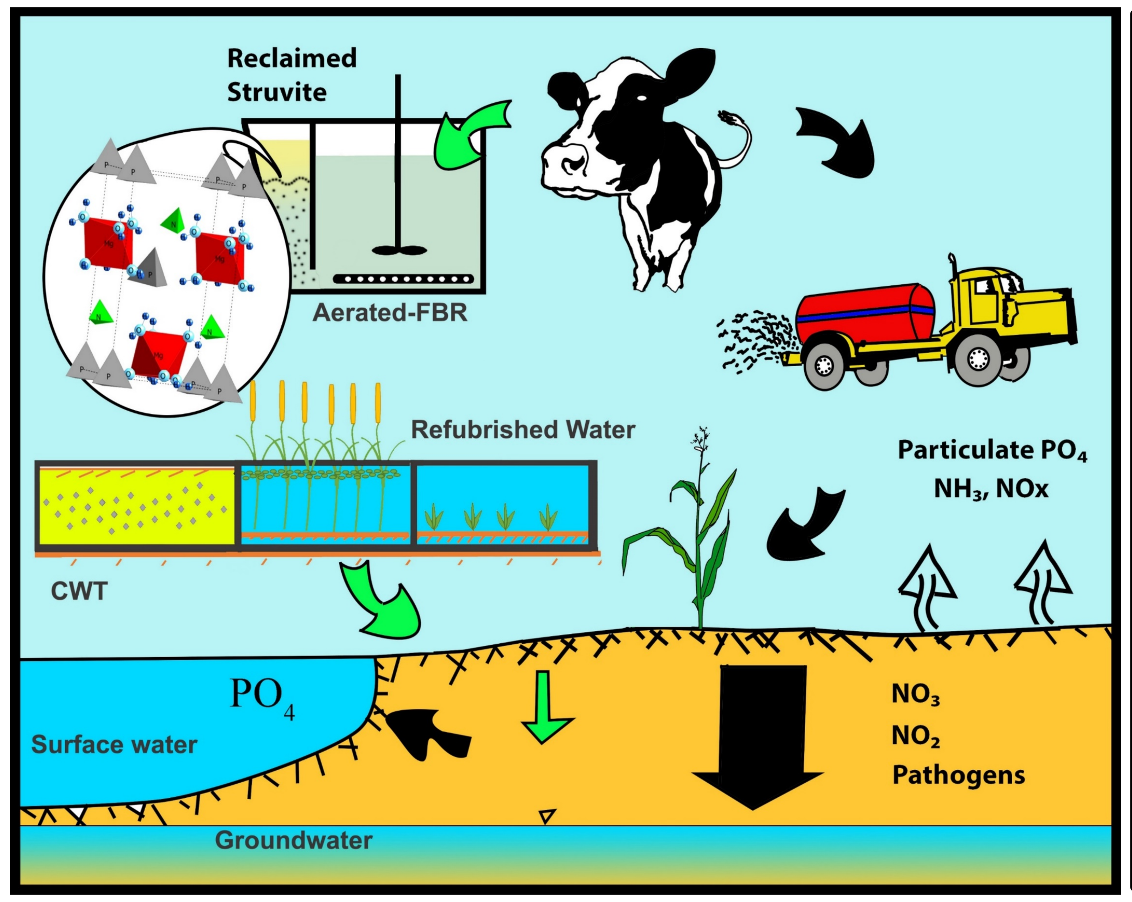
Aerated-FBR: A Bench scale 40 L reactor is tested at a dairy and swine farms in New Jersey. This experiment tests the effect of magnesium concentration and aeration rate on nutrient recovery, and assess their economic impact on nutrient recovery and LWE related costs.

The reactor recovers nutrients as struvite by precipitation at pH 9. Aeration and the addition of caustic soda (NaOH) are used to raise the LWE pH, where the aeration reduce the need for applying costly caustic soda. Magnesium chloride is added to LWE to promote the formation of struvite, rather than precipitating phosphate rock (hydroxyapatite).

CWT: Wetland treatment use microbial and flora activity to remediate wastewater by sequencing and filtering BOD and TSS.

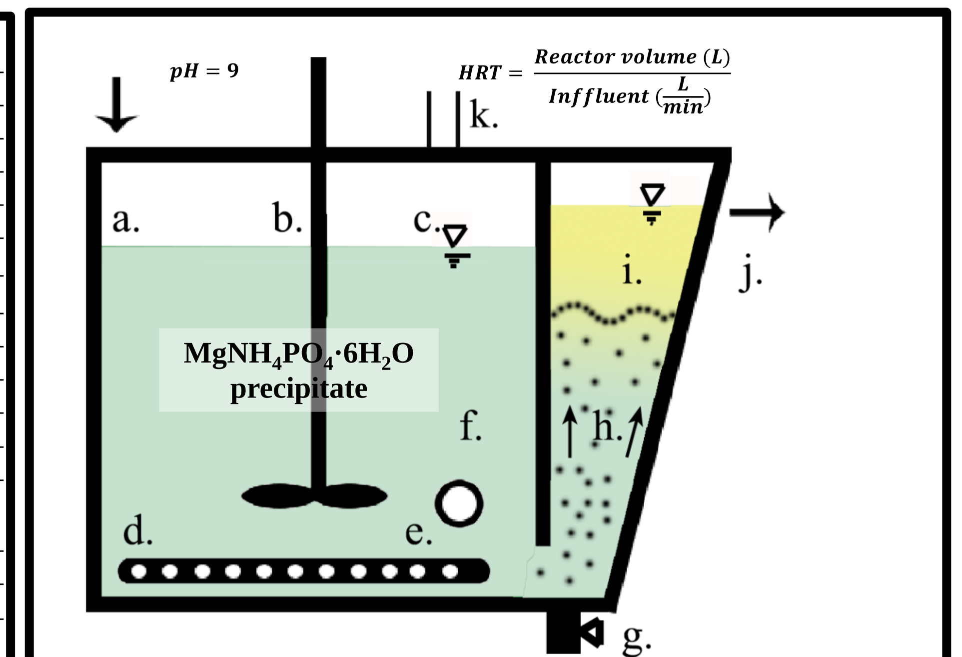
Three CWT canals of free water surface **(FWS)** and vegetated submerged bed **(VSB)** are used. The volume of each cell is 100 cubic feet and effluent residence time is estimated at two days per cell. Effluent with high pH and rich with dissolved oxygen enter the VSB cell, where microbial activity introduce carbon dioxide that reduces the LWE pH, consuming nutrients and BOD. Topsoil of VSB is vegetated with smooth Cordgrass (*Spartina alterniflora Lois.*) to prevent erosion.

Sequenced flow into a FWS cell with emerged plants treat the effluent for nutrient /BOD and TSS removal.

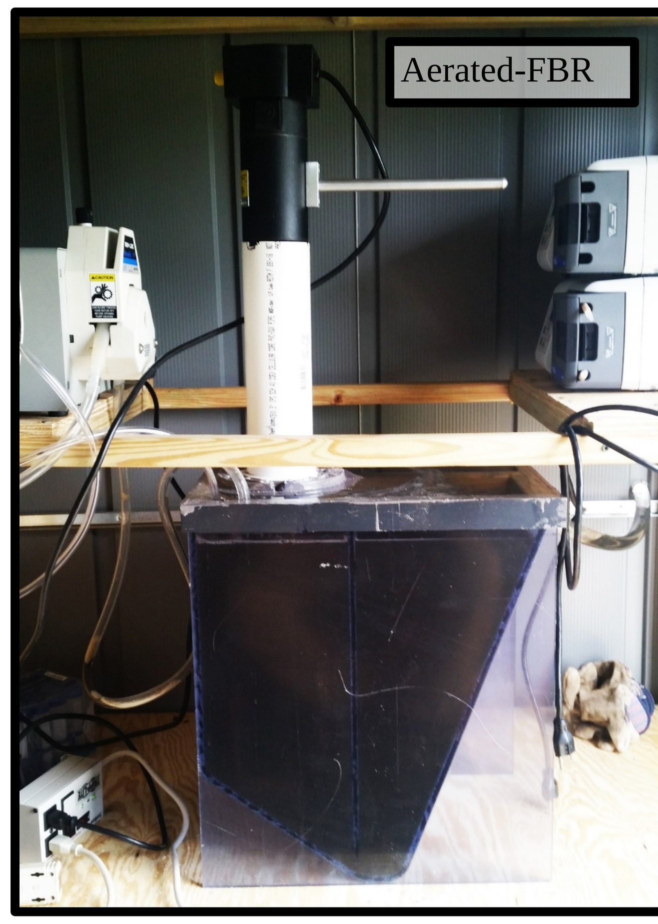


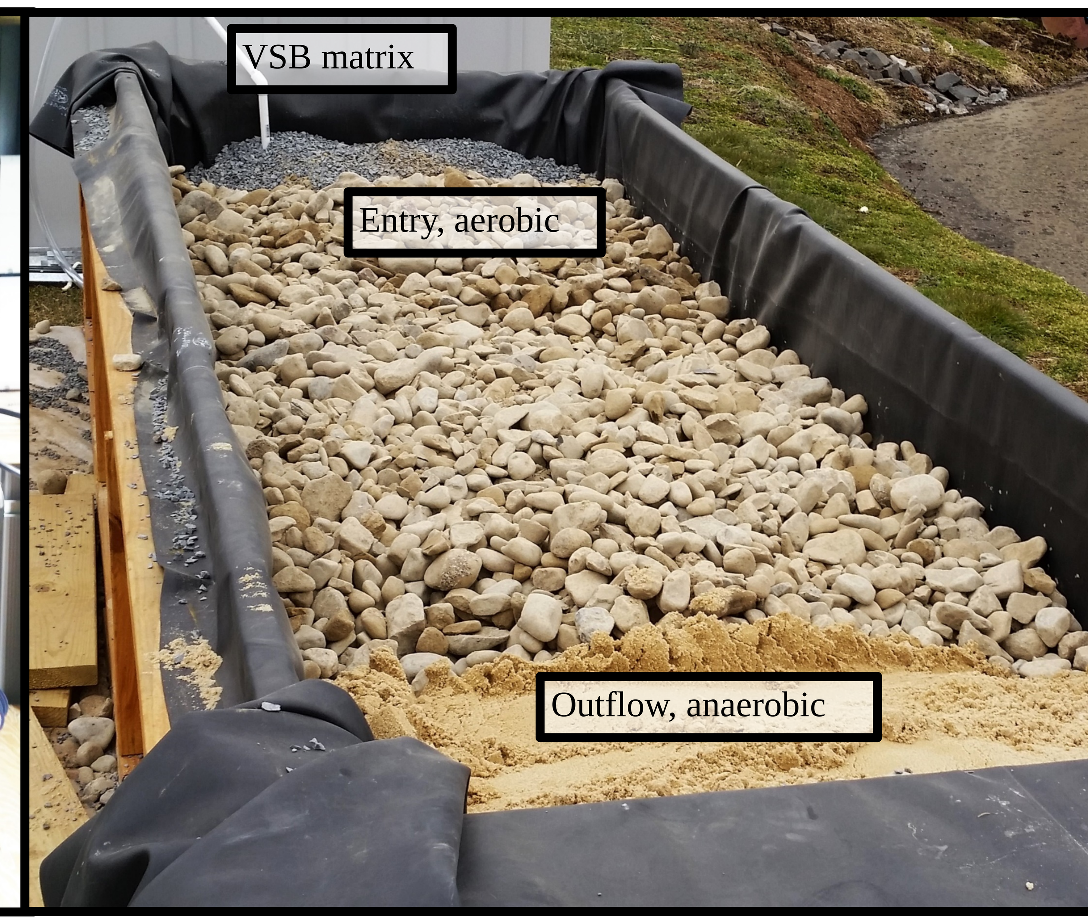
Influent	D-WW	S-WW
Major constituents (ppm)		
NH_4-N	800	426
PO_4-P	27	62
Mg	120	22
Cl	1000	240
CO_3^{2-}	4100	1330
NO_3^-	158	70
K	760	200
Na	308	132
Ca	200	40
Organics (mg/L) [a]		
DOC	800	200
Total organics	1500	230
Other chemical properties		
pH [b]	7.9	6.8
I [c] (mM)	107	45
Struvite SI at pH 9 [c]	1.4	1.72
Calcite SI at pH 9 [c]	2.52	1.59

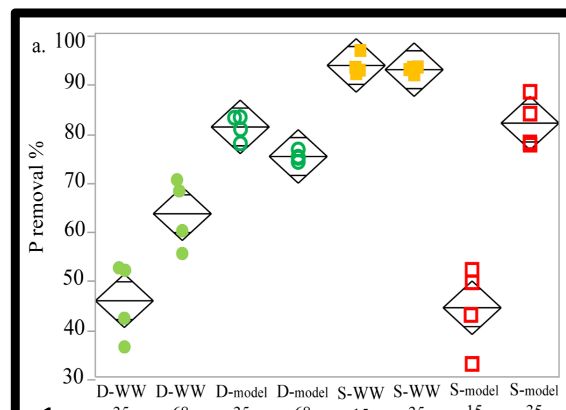
[a] as TOC mg/L, [b] initial pH, [c] calculated using Vminteq 3



a. continuous flow stirred-tank reactor (CSTR), 33 L reaction chamber. **b.** overhead mixer shaft. **c.** effluent level. **d.** air frit. **e.** wall mounted pH meter; pH 9. **f.** narrow 0.5 inch slit passage from CSTR to fluidized bed (FB) 7 L chamber. **g.** solid collection drain valve. **h.** effluent flow direction (arrows). **i.** depiction of solid crystals (dots) forming a fluidized bed. **j.** effluent exit tube. **k.** vacuum tube for foam removal for livestock wastewater samples.







b.

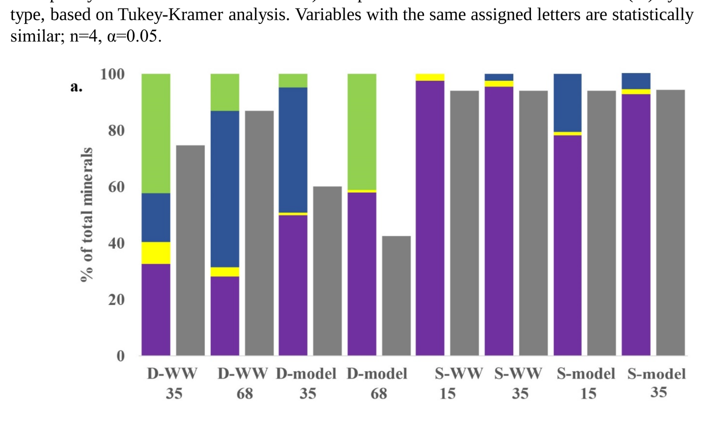
Treatment	Level				Mean P removal (%)	Arcsine values
S-WW 15	A				93.5	131.5
S-WW 35	A				92.6	129.6
S-model 35		B			81.7	113.2
D-model 35		B			80.9	112.0
D-model 68		B	C		74.9	104.6
D-WW 68			C		63.3	92.1
D-WW 35				D	45.5	74.0
S-model 15				D	44.1	72.5

1.

a.) P removal with aerated-FBR treatment. The span of the diamonds is the confidence interval range for the Tukey-Kramer analysis, the central line is the mean, closed symbols are livestock samples, and open symbols are model solutions. b.) Comparison of mean dissolved P removal (%) by influent type, based on Tukey-Kramer analysis. Variables with the same assigned letters are statistically similar; n=4, α=0.05.

Preliminary analysis of reclaimed nutrient minerals from dairy (D-WW) and swine (S-WW) using .aerated-FBR. Samples were compare to model dairy (D-model) and swine (S-model) LWE that are organic free to evaluate the effect of dissolved organics on nutrients recovery. **1.** phosphate recovery from LWE; **2.** minerology of solids collected from aerated-FBR; **3.** Thermal properties of solids collected from aerated-FBR

(Rabinovich, A., Rouff, A. A., Lew, B., & Ramlogan, M. V. (2017). Aerated Fluidized Bed Treatment for Phosphate Recovery from Dairy and Swine Wastewater. ACS Sustainable Chemistry & Engineering, 6(1), 652-659).



b.

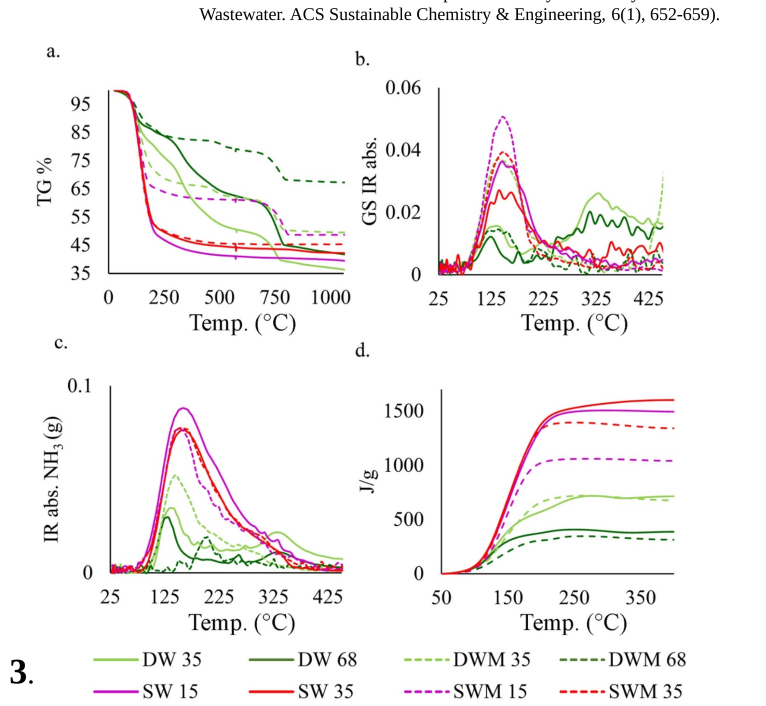
AFBR solid samples

Sample	D-WW 35	D-WW 68	D-model 35	D-model 68	S-WW 15	S-WW 35	S-model 15	S-model 35
Rwp	8.44	14.38	10.8	12.2	22.22	22.95	20.46	19.54
GOF	2.06	3.12	3.61	4.19	9.01	9.46	7.69	8.09

minerology analysis output

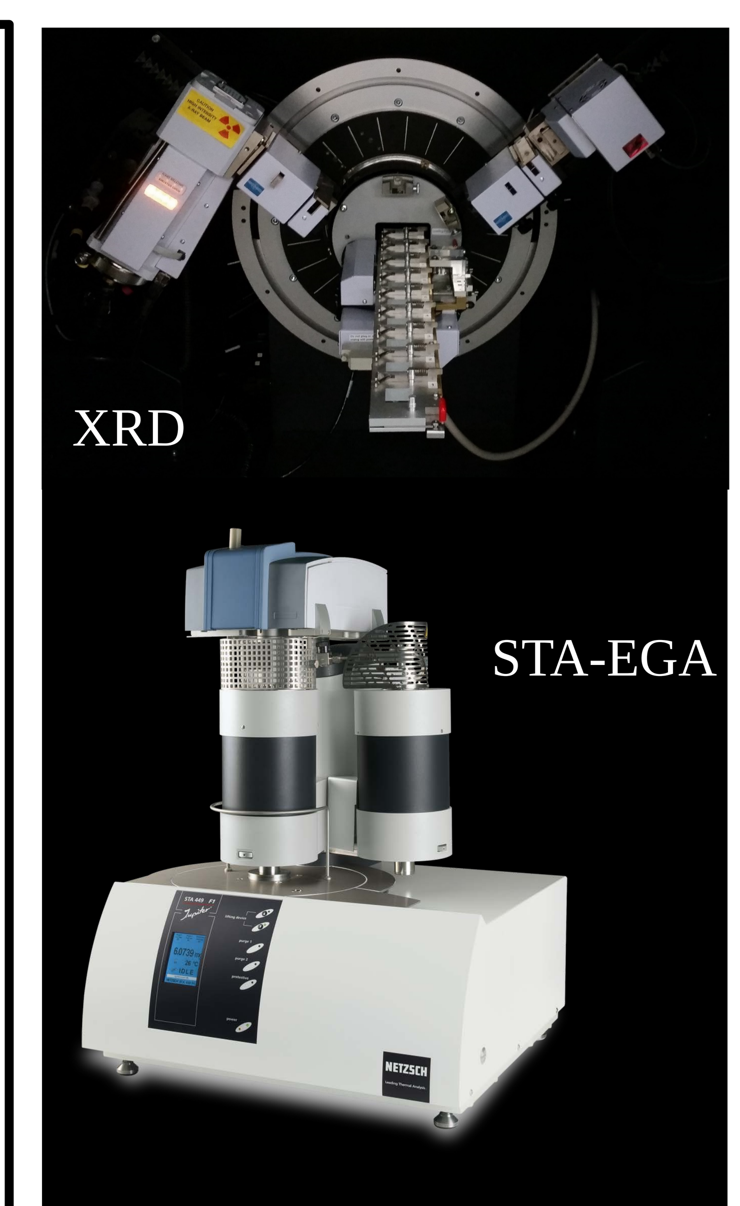
2.

a)Weight percent of each mineral phase based on CPF-FPA analysis of XRD patterns, and elemental analysis of solids, b) Statistical output of CPF-FPA analysis, where Rwp is the cumulative model error estimate and GOF is the ratio between calculated Rwp and an estimated minimal cumulative error for each solid sample



3.

STA-EGA analysis of aerated-FBR solids: (a) TG % mass (b) GS curve for total absorbance in the IR; (c) intensity of NH3(g) IR absorption at 966 cm−1 bandwidth; and (d) integrated enthalpy (J/g) over the 50−400 °C temperature range at which NH3(g) is released.



Saline tolerant emerging plants such as Sweetflag (*Acorus americanus*) and floating Duckweed (*Lemna minor*) are used in FWS with emerging plants.

Finally, treatment of LWE in FWS with submerged plants oxygenates the effluent for a final nutrient removal, while higher sunlight radiation improves microbial removal. Switchgrass (*Panicum virgatum*) is used as a submerged oxiginator plant.

Analytical methods: Fertilizer collected from aerated-FBR was analyzed for mineral composition with X-ray diffraction (XRD; Bruker, D-8 advance). Thermal stability of the fertilizer product is evaluated using simultaneous thermal analysis with evolved gas analysis (STA-EGA; Netzsch, Perseus). Effluent composition for nutrient and pollutants removal is tested using colorimetry (DR-3900, Hach) and inductively coupled plasma optical emission spectrometry (ICP-OES).

Preliminary Results

Characteristics of LWE: Sampled dairy wastewater had higher nutrient, dissolved organics that generate BOD, Ionic strength and TSS, compared to effluents from the swine lagoon. For dairy LWE the overall phosphate content was higher compare to swine and 80% of it was in the form of organic phosphate.

Nutrients removal: Recovery of PO_4-P from dairy LWE (D-WW) with the aerated-FBR was 63% at HRT of 68 minutes. Aeration had limited impact on ammonium loss through ammonia gas (NH_3) emission (<10%). Aeration raised LWE from 8 to 8.5 at HRT of 68 min, and NaOH was needed to reach the pH 9 goal. The presence of DOC in LWE hinder struvite formation, where for D-WW with much higher DOC and dissolved calcium, lower PO_4-P removal was observed. When DOC free model LWE (D-model) was tested, PO_4-P recovery significantly improved.

Mineral composition: solids from aerated-FBR had struvite, potassium struvite ($MgKPO_4•6H_2O$), calcite ($CaCO_3$), and monohydrocalcite ($CaCO_3•H_2O$). The thermal stability of ammonium in solids collected from D-WW was better than all other solids with higher NH_3 (g) emission temperature.

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