Nanotechnology-Enabled Water Treatment for improved Food Safety and Public Health

A joint study in Swaziland by the

Food and Agriculture Organization of the United Nations

and

Rice University (Houston, Texas)

Water quality and food safety: a global public health priority

- 884 million people in the world do not have access to safe water (37% in Sub–Saharan Africa)

- 2 million people die annually for causes related to unsafe water, poor sanitation and hygiene.

- \> 1.5 million children < 5 years of age die annually of diarrhoeal disease
  - Diarrhoea kills more children every year than AIDS, and malaria combined

Water contaminants and Food Safety

Microbiological contaminants

Water can be an important vehicle for transfer of pathogens from human and animal sources into food

Chemical contaminants

Water can also carry heavy metals from the ground and/or persistent organic pollutants and endocrine disruptors (EDs) from the environment into the food chain

Food Safety is strongly linked to the quality of water used at each step of the food chain from production to consumption

Why this study?

Ensuring reliable access to affordable and safe sources of water is critical to both global health and economic development. This challenge is rapidly growing as:

- the world's population increases;

- global climate change threatens to take away already scarce fresh water resources;

- agricultural and industrial contamination further limits the availability of adequate water supply;

- Etc.

- We need to keep abreast of new technologies as well as of new developments in more conventional systems and see which could offer best opportunities to face these critical issues

- Among the various technological innovations for water treatment, **nanotechnologies are emerging with great potential for water treatment and recycle**.

The TECHNOLOGY to be investigated should be based on the criteria of **safety**, **affordability**, **low maintenance**, and **minimal energy requirements**

Photo-reactive trough/liner reactor
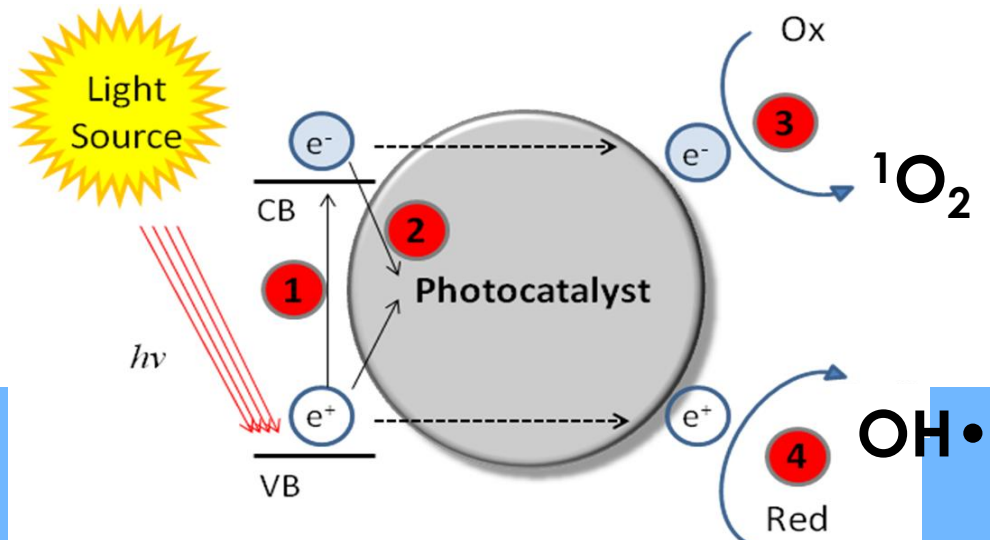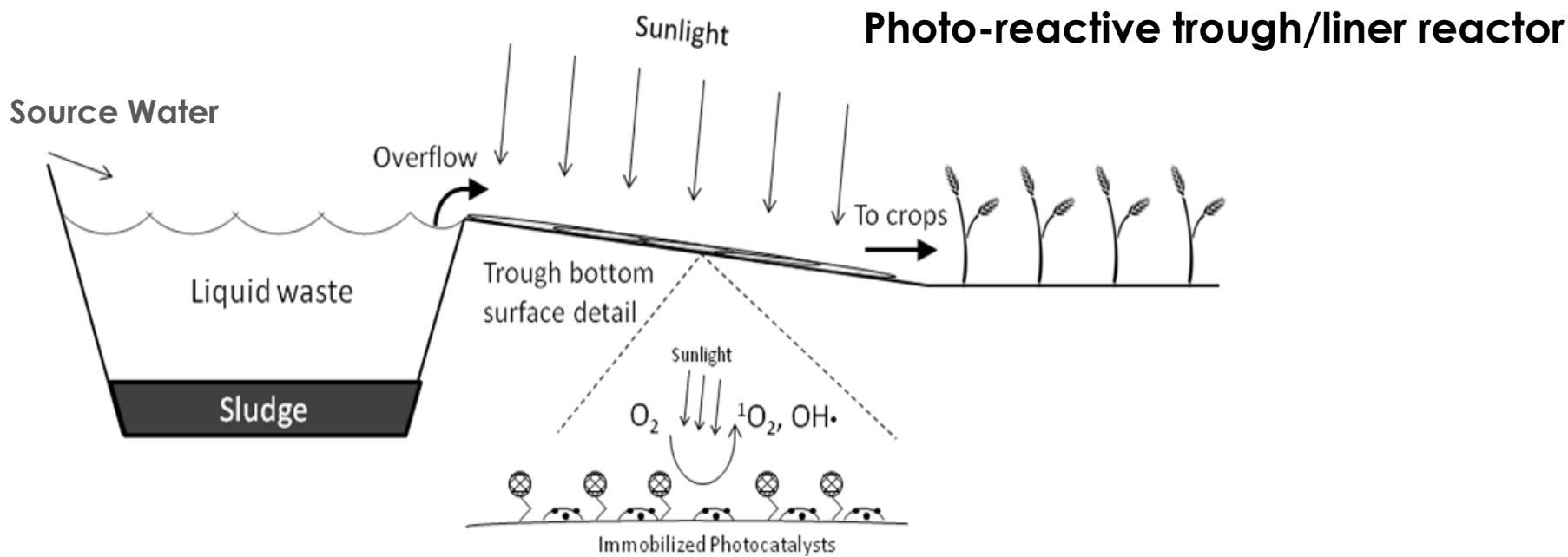
Objectives of the study

The FAO collaboration with Rice *aims to assess the feasibility of applying an innovative nanotechnology in Swaziland*

The specific objectives of the study are:

1 Define local conditions including:

- specific characteristics of the sites
- volume of water to be treated
- water quality characteristics
- Needs and capacities of the final users

2 Generate performance data of the nano-based treatment unit by

- Evaluating treatment efficiency for the identified priority water contaminants,
- Evaluating treatment efficiency under local climatic conditions
- Evaluating the potential food safety and environmental risks arising from the technology
- Defining best operating conditions of the demo unit

3 Determine the technology potential, feasibility and cost

Study's Activities

- Survey by a national consultant to collect, review and analyze existing national data on water quality characteristics and other relevant parameters.

- Analysis of water samples from the selected sites to identify and quantify water contamination

- First mission to define, the required characteristics of the system, the local context specificities.

- Generation of performance data of the nano-based treatment unit

- Final workshop aimed at presenting the study results and discussing with local stakeholder the technology and the alternatives including comparison of the cost and efficiency of this system versus other alternatives

First mission (April 2012)

Three dams sites were visited: Mcozini Dam, Lubhuku Dam, and Mlawula Dam

Mcozini seemed to offer the best conditions
- Water turbidity is high but not so much to require an additional step (like coagulation) before the photo—catalysis.
- The field area to be watered is not excessive
- The site is easily accessible

Series of consultations were held:

- Local farmers were informed about the study, its objectives and modalities.

- National authority (Min of Agriculture) was briefed and informed about the study and its expected outcomes

- Other concerned stakeholders (including Swaziland Water Corporation Services) offered additional important information

Study findings

- Based on the info/data collected through the survey by the national consultant and during the first mission and, Rice University team refined and tested the water treatment technology
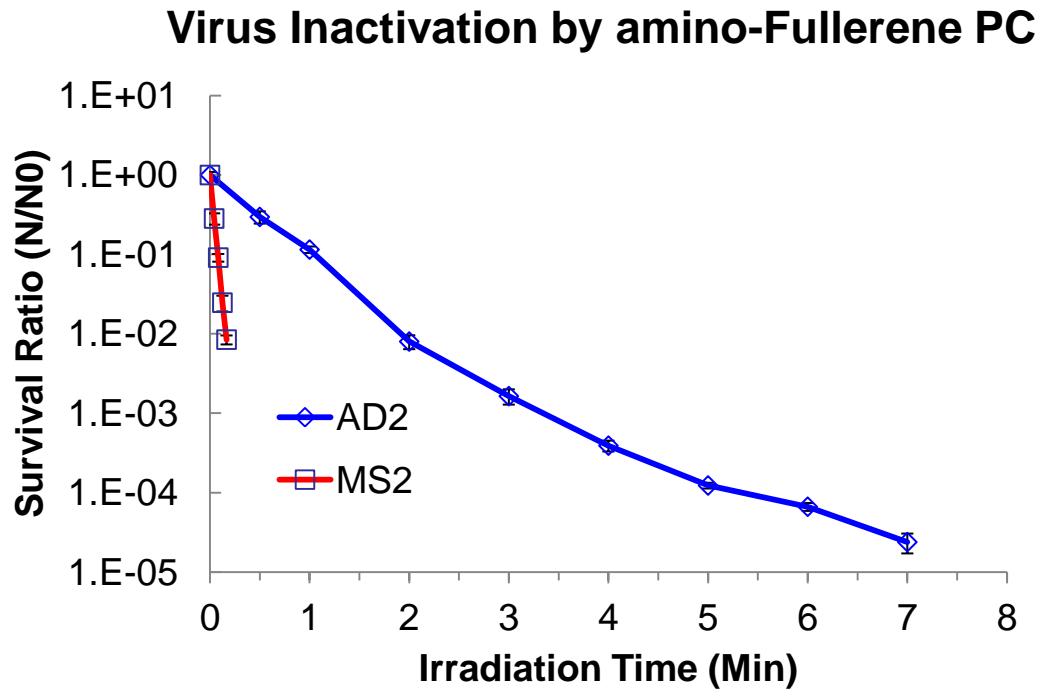
- Let's look at the results

Water Quality

	Mcozini Dam	Lubhuku Dam	Mlawula Dam	National Standard Irrigation (Drinking)
Total coliform (per 100 mL)	4001.2**	1498.2**	4025.3**	1-10 (0)
Fecal coliform (per 100 mL)	87.2**	123.0**	162.0**	1-10 (0)
Turbidity (NTU)	9.0**	304.6**	202.4**	5 (5)
BOD (ppm)	5.5*	1.0	0.7	10 (5)
COD (ppm)	19.4*	23.4*	18.0*	75 (10)

* indicates value above National drinking water standards

**** indicates value above National drinking *and* irrigation water standards**

Visible light PCs for Liner

- Virus removal
  - Very efficient
  - Realistic contact times

Virus Inactivation by amino-Fullerene PC

A graph plotting Survival Ratio (N/N0) on a logarithmic y-axis (from 1.E-05 to 1.E+01) against Irradiation Time (Min) on the x-axis (from 0 to 8), showing two data series: AD2 (blue) and MS2 (red).

Visible light PC for Liner

- POP Removal
  - Some easily removed
  - Some more recalcitrant

- Disinfection
  - Poor removal efficiency
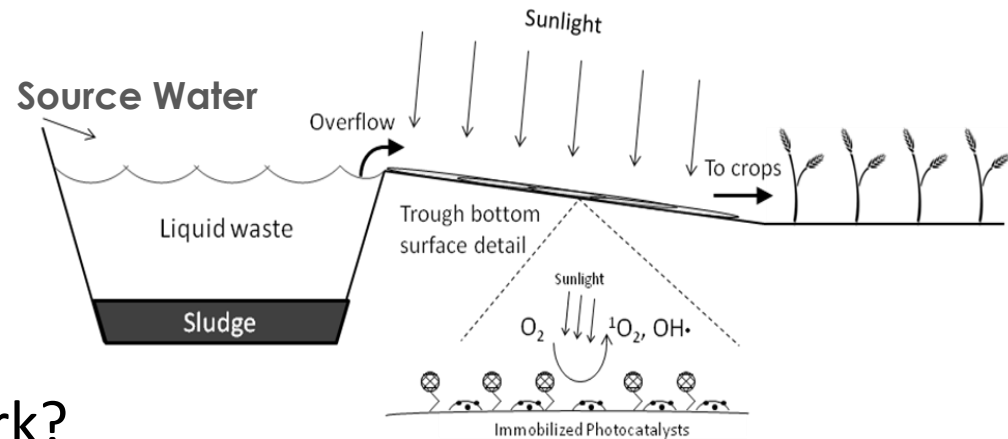 - Combined w/ Sunlight?
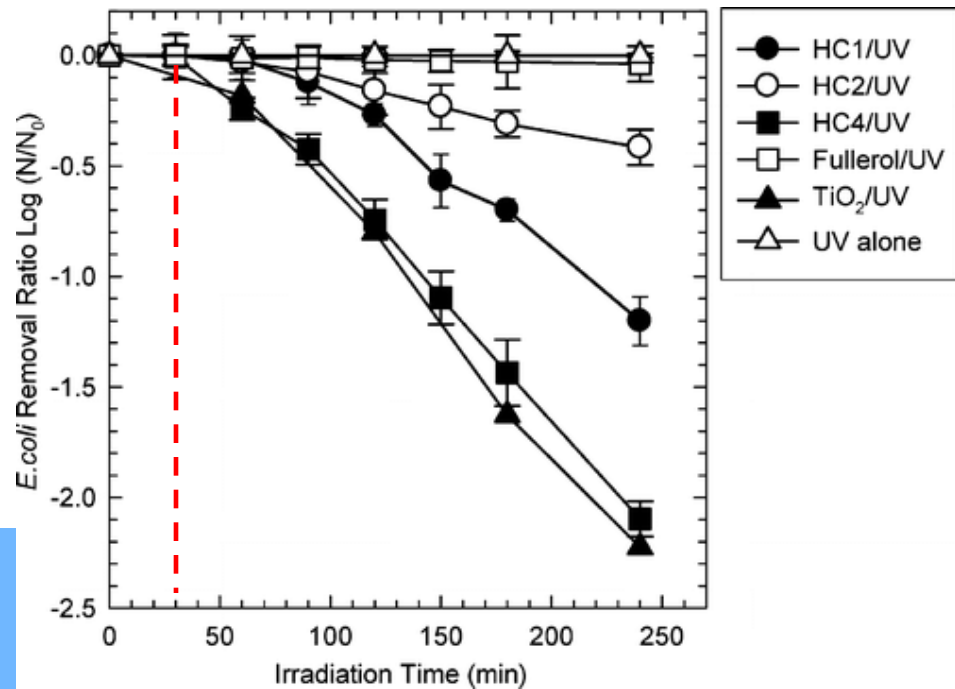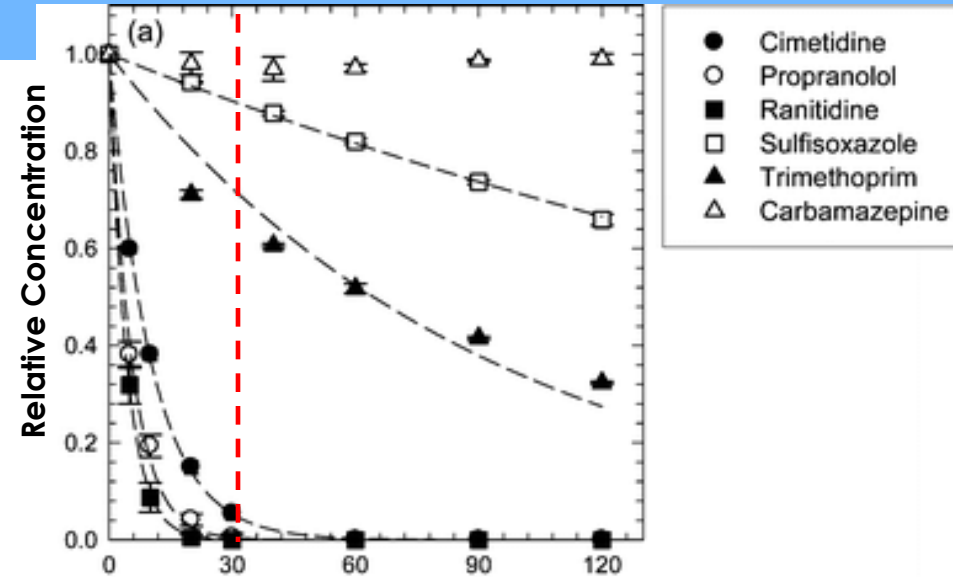
Liner Reactor
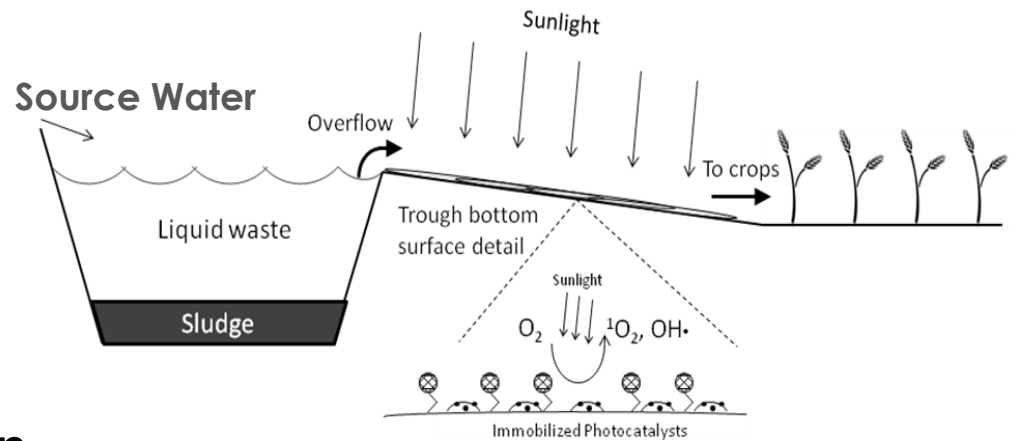
- Opportunities
  - Ease of use/operation
  - No external energy (sunlight and gravity)
  - Longer contact times
- Drawbacks
  - Only active w/ sunlight (not w/ cloud, at night)
 - Sedimentation
  - Infrastructure

Could the Liner reactor work in the observed context ?

Source Water

Overflow

Sunlight

To crops

Liquid waste

Trough bottom
surface detail

Sunlight

O_2 $^1O_2$, OH·
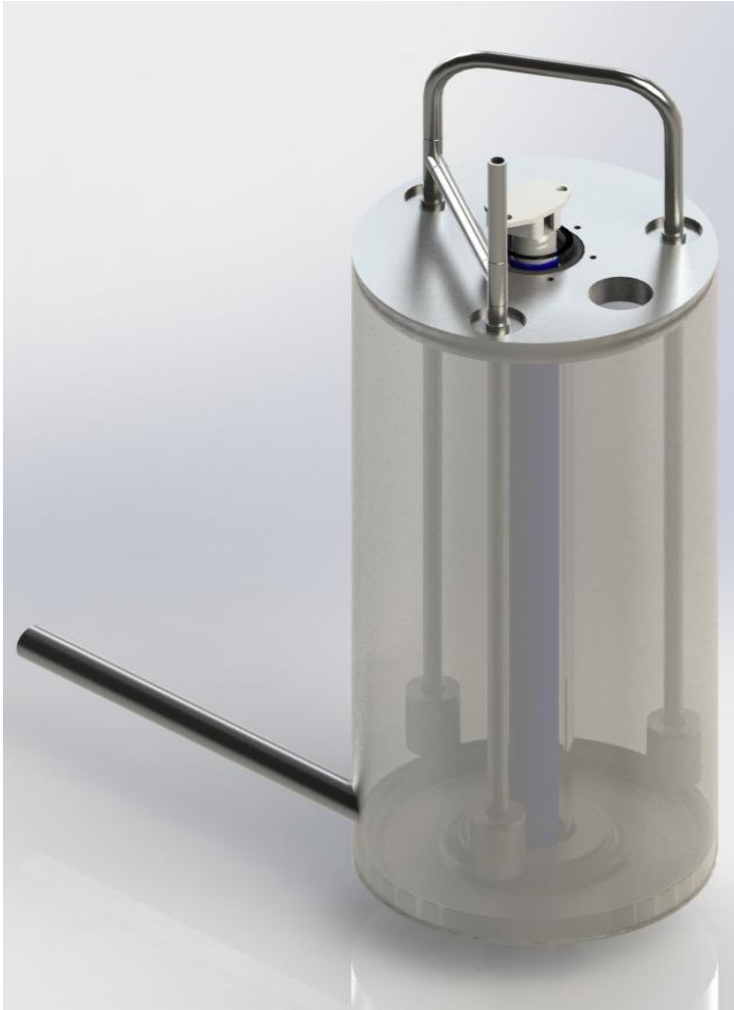
Sludge

Immobilized Photocatalysts

- Could the Liner reactor work?
  - Add small sedimentation pond
  - Remove pipe system and replace with a trough
    - Very small slope
    - Protected from livestock, etc.
  - Use current pipe system for rinsing trough?
  - Distance is critical (not too close, too far)

Fluidized bed photoreactor
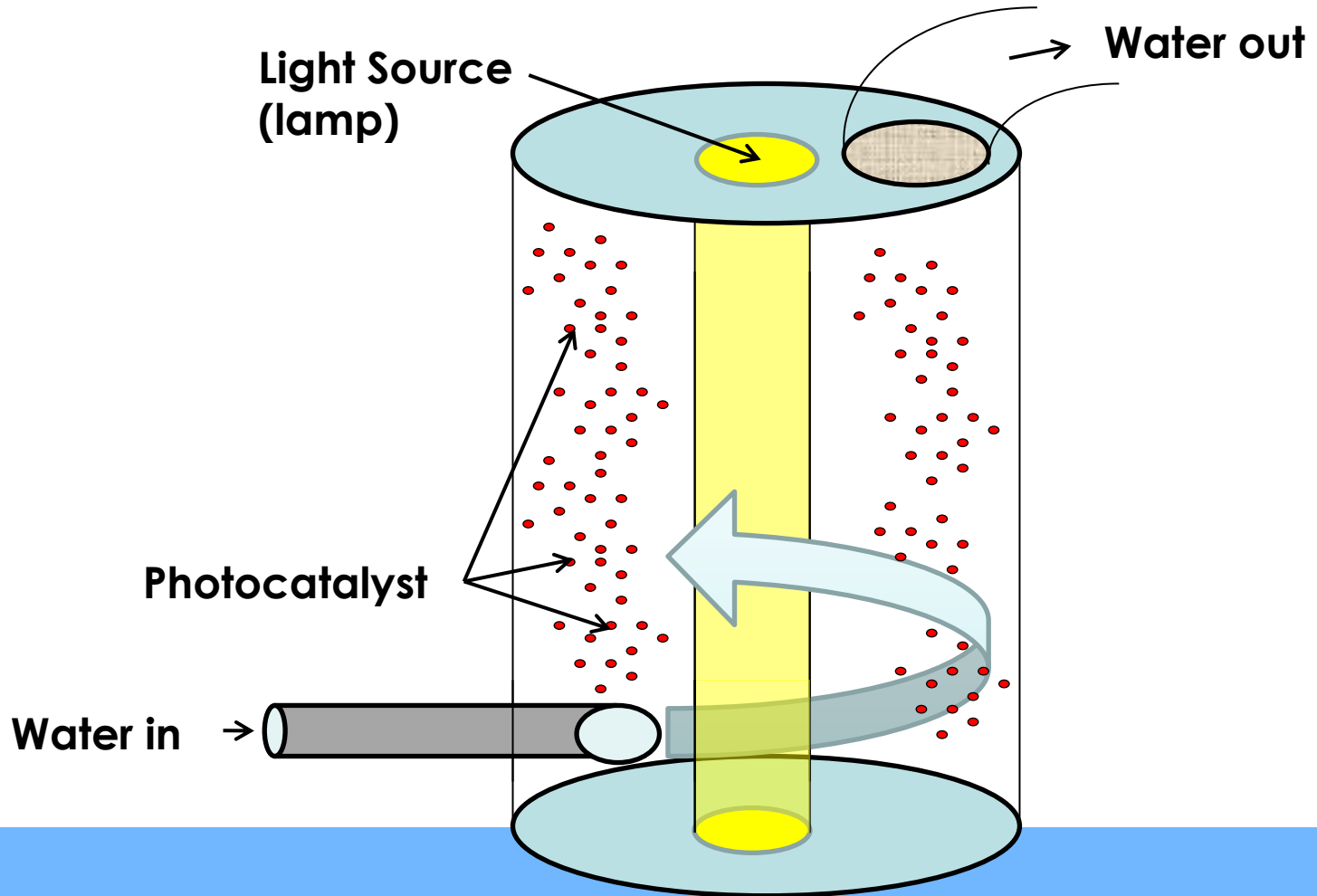
Fluidized Bed Photoreactor (FBPR)

Photocatalysis Parameters

- Materials
  - TiO_2
  - Fullerenes (C_{60})
  - Porphyrins
- Light Source
  - Visible
  - UV-A (350 nm)
  - UV-C (254 nm)
- Substrates
  - Silica gel
  - Quartz sand

Attachment
- **Covalent binding (C_{60})**
- Heat deposition (TiO_2)
- **Sol-gel methods (TiO_2)**

- *Requirements:*
  - *Efficiency*
  - *Stability*
  - *Reusability*
 - *Safety*

Photocatalytic activity

| k_{eff} (min^{-1}*10^{-4}) $\pm$ one SD				
Material	**Attachment**	**Visible Light (400-800 nm)**	**UV-A Light (300-400 nm)**	**UV-C Light (254 nm)**
TiO$_2$	**Powder (no substrate)**	18.1±1.9	548.7±133.8	4766.6±362.5
	Sand (heat, H20)	0	29.2±1.3	321.3±23.1
	Sand (heat, solvent)	0	0	332.9±52.8
	Sand (sol-gel)	0	31.8±3.4	275.5±18.9
	Silica (sol-gel)	5.9±0.6	511.5±83.2	491.9±28.8
Fullerenes	**Silica**	68.8±1.0	145.2±1.2	17.0±1.4
Porphyrins	**Powder (no substrate)**	245.2±60.7	215.3±154.7*	0
	Silica	11.3±0.4	19.0±1.6	0
*=large error due to limited sample availability (insufficient replicates)				

Repetition

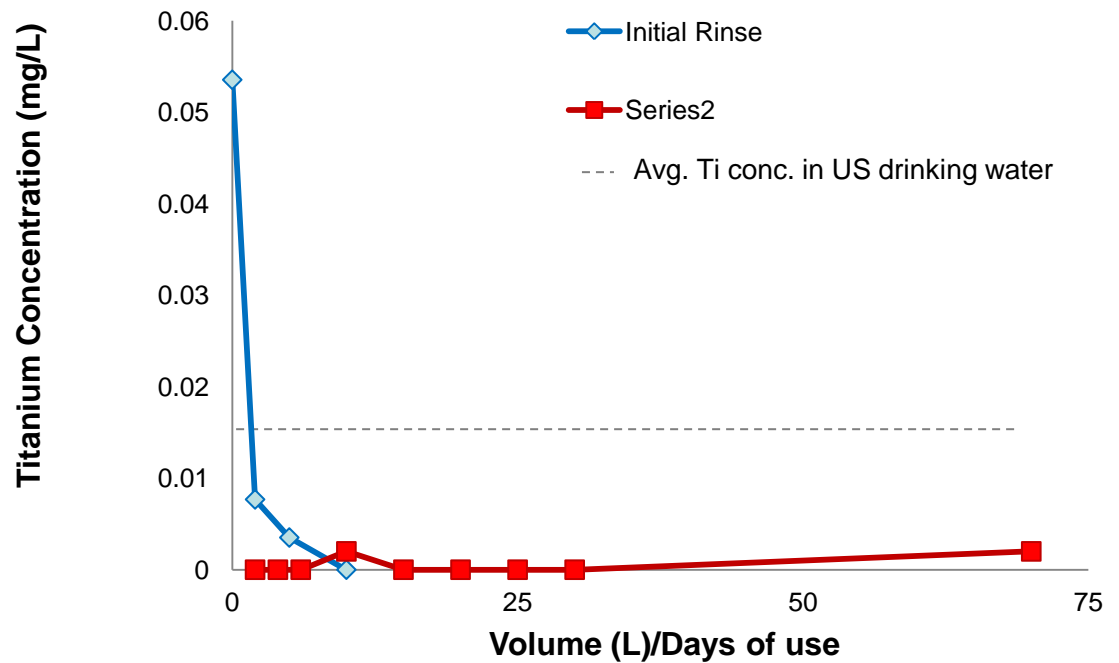- Fullerene
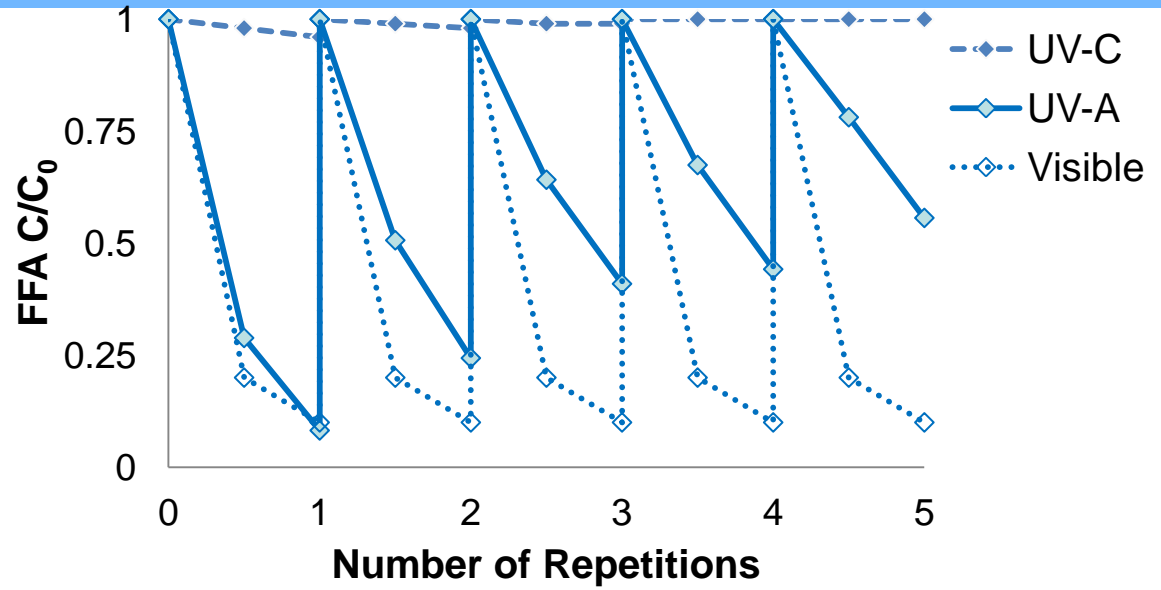
- TiO$_2$
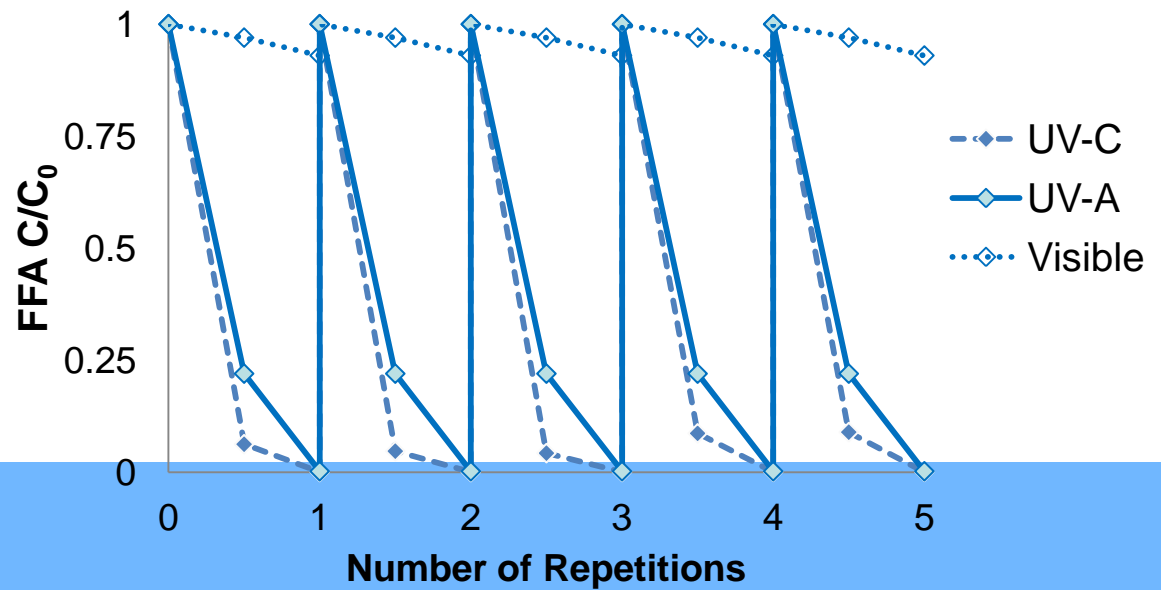
Long-term reuse (TiO$_2$)

- 2 Months with no loss in efficiency (< 3%)

- Slight variability after 60+ days   (~10%)
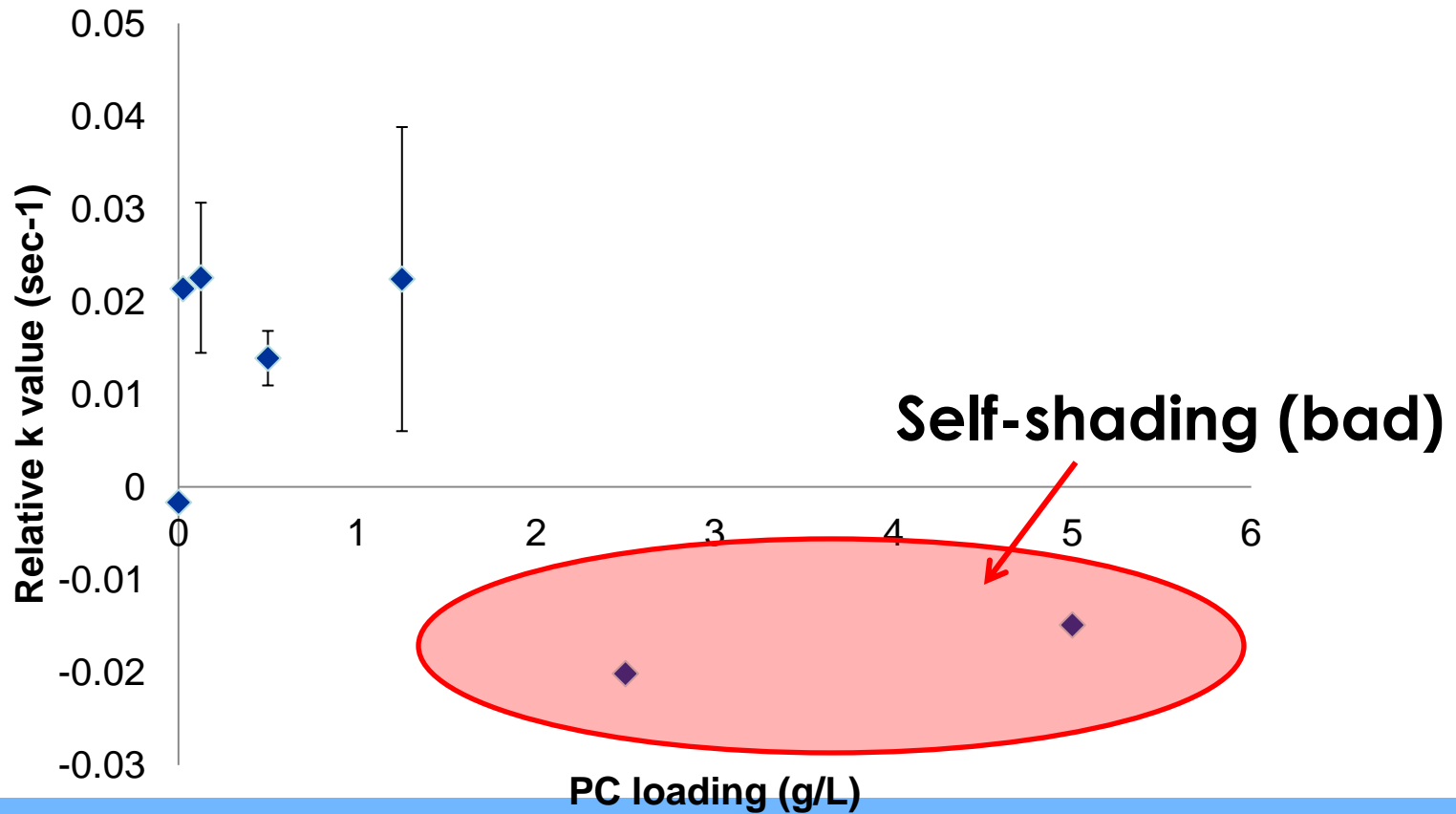 - May have to be replaced after several months
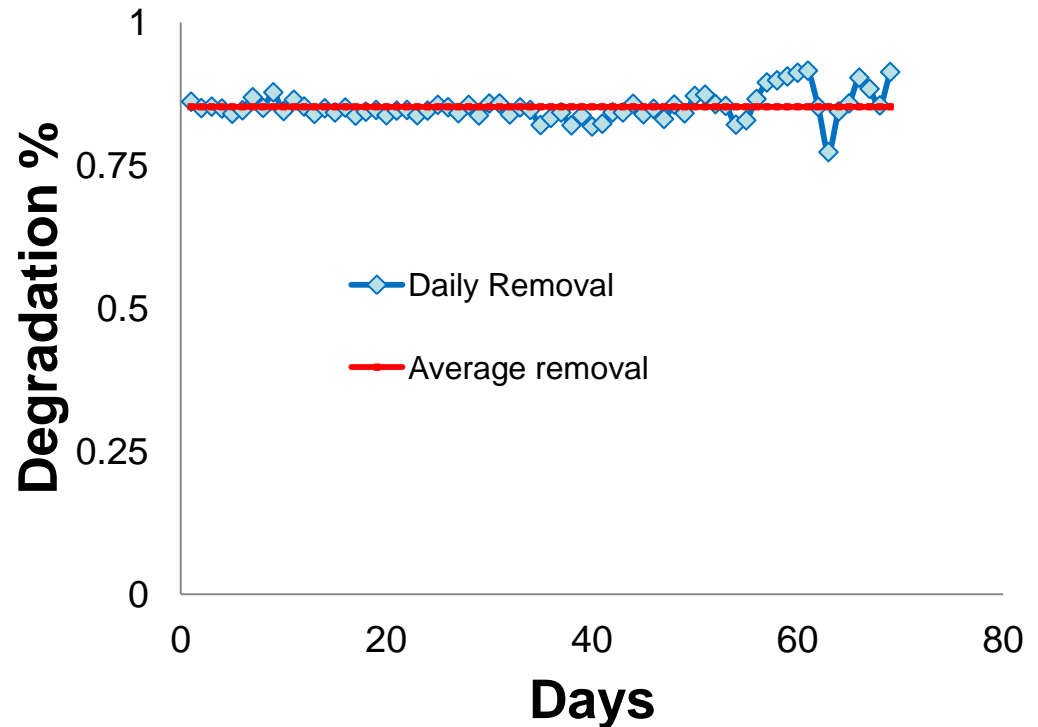
Does the PC leach?

- During normal use, the effluent titanium concentration was consistently zero, with only two samples measuring any titanium (at the lowest possible detection level-10 µg/L)
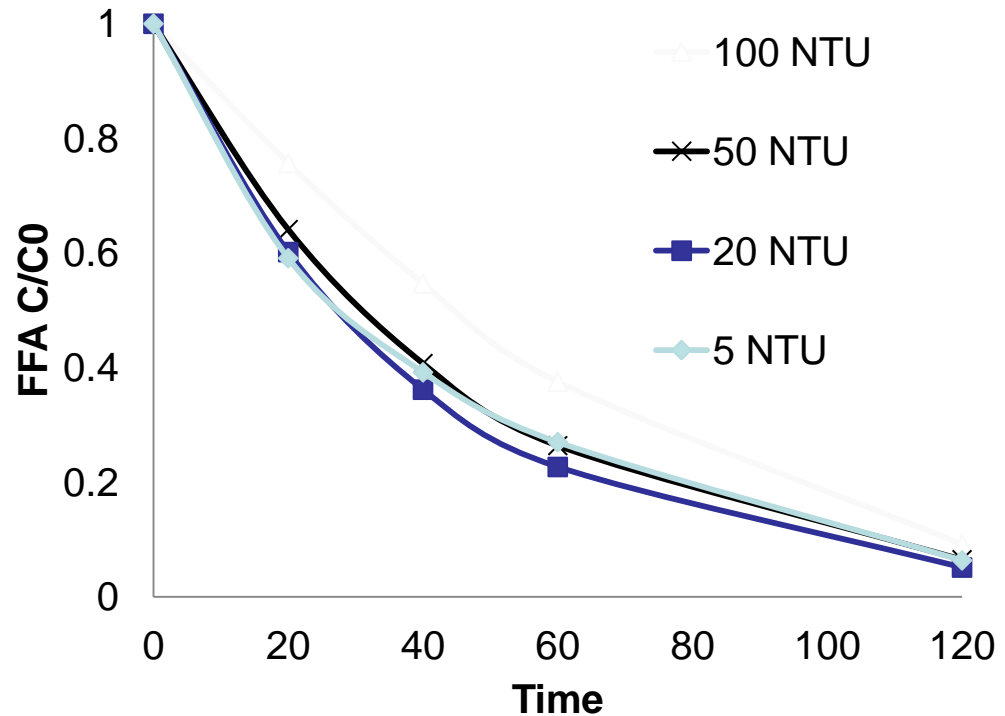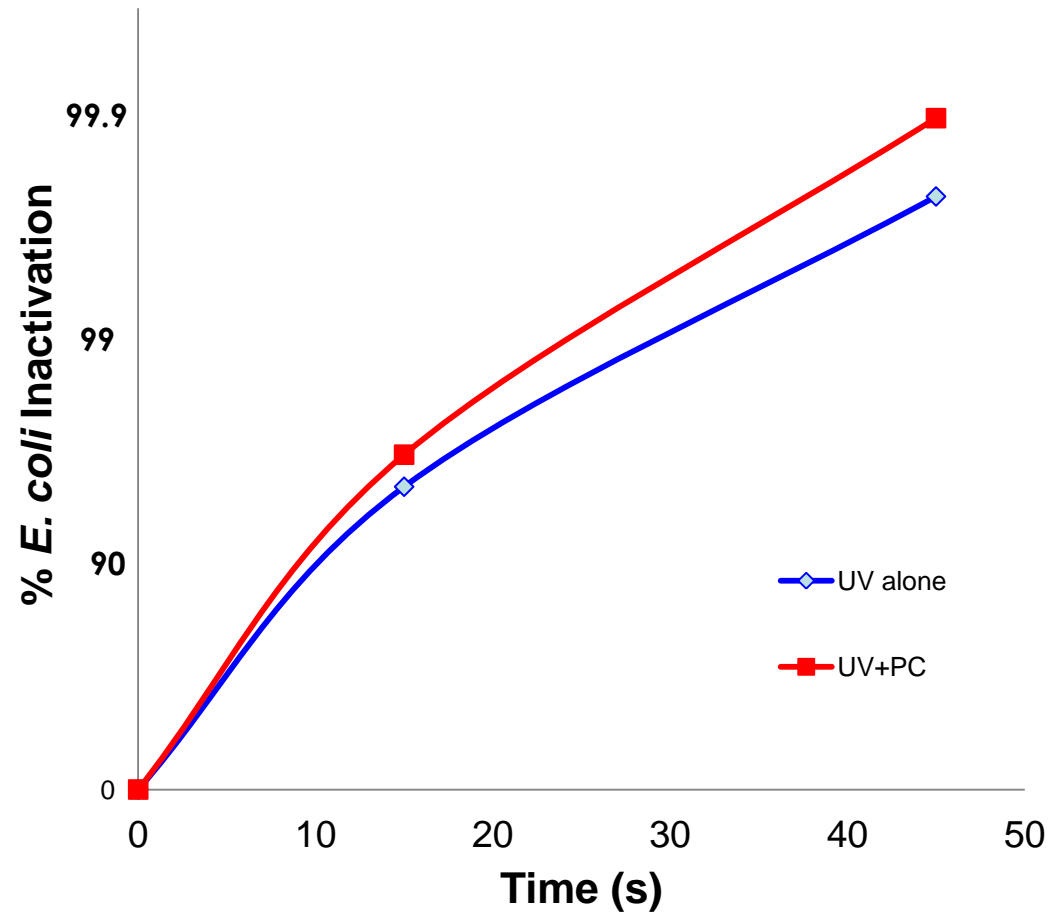
Loading-How much PC?

Does turbidity have an effect?

- **NO**, up to 100 NTU

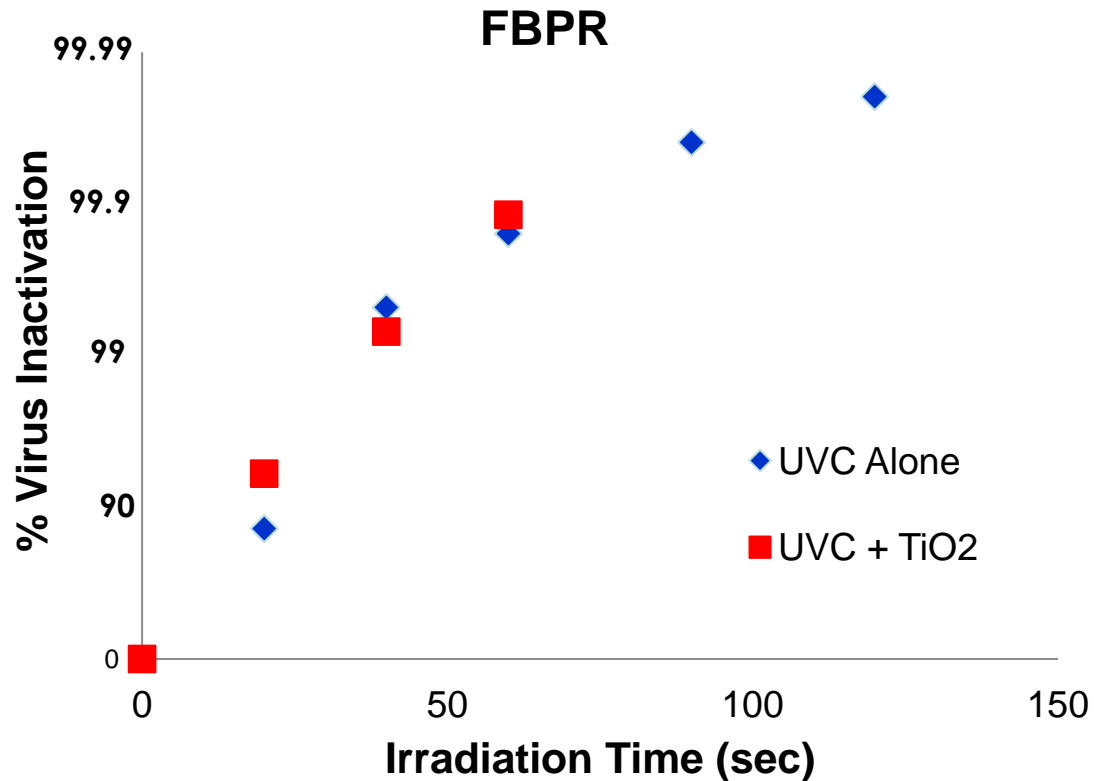- Mcozini: 10-20 NTU
- Other sites: 200-300 NTU

Disinfection

- 90% disinfection in 15 s, 99.9% in 45 s
- Most of the disinfection comes from UV alone
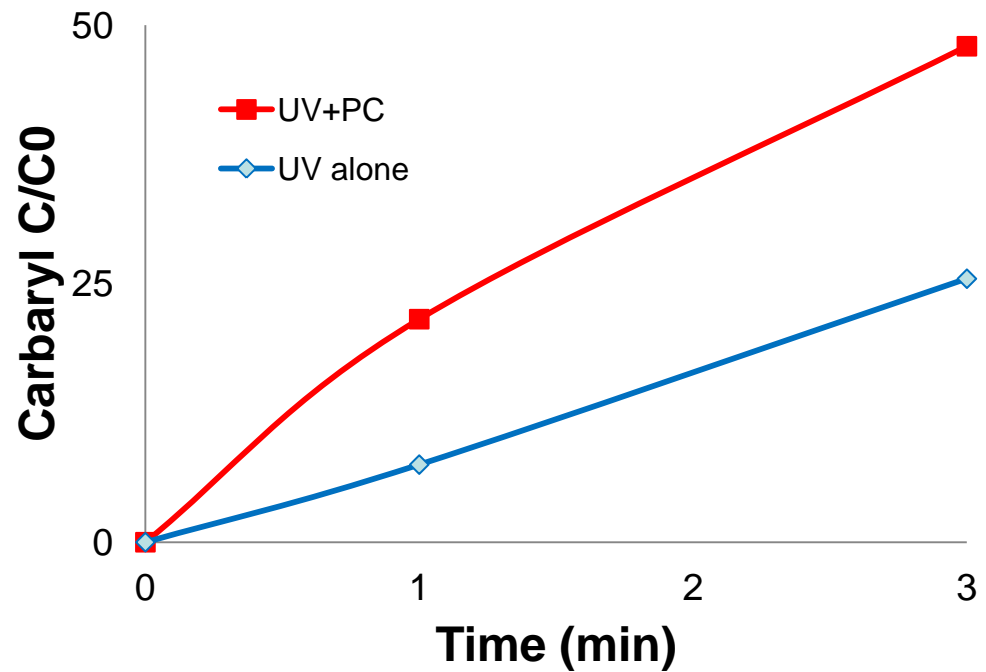- PC provides incremental added value

Virus removal

- Very little difference between UV alone and UV+PC
- No added value

Pesticide and PoP removal

- 50% removal in 3 min

- PC removes 2x more pesticide than UV alone

- Significant added value

Centralized conventional treatment comparison

Type of system	Treatment cost ($/1000L)	Approx. installation cost ($1000)
Conventional	1.10	40
Reverse Osmosis	2.78	50
Direct Filtration	1.10	35
Activated Carbon	1.05	100

POU treatment options

Type of POU system	Treatment cost ($/1000L)
Delivered (bottled) water	250
Disinfection tablets	200
Small Reverse Osmosis	77
Carbon-Block filtration	70
UV Disinfection	2

UV Disinfection capital cost: $3,000-$10,000

FBPR capital cost: ~$5,000

Conclusions

1. FBPR with TiO_2 is a promising technology but it currently does not show significantly higher disinfection efficiency over conventional POU treatment systems to merit pilot studies in a second phase.

    -   No higher bacterial or viral removal efficiency compared to UV alone, which was very efficient (> 99.9%) and left little room for improvement
    -   Enhanced removal of pesticides and possibly other trace organics, but with a contact time on the order of several minutes

2. Explore other options such as Photocatalytic reactive lining

    -   What are the merits and limitations of this approach and what interventions and in what scenarios would it be feasible?

3. Prevent the majority of bacterial contamination by fencing reservoirs and utilizing animal troughs

Recommendations

- Explore PC liner options
  - Feasibility
  - Cost
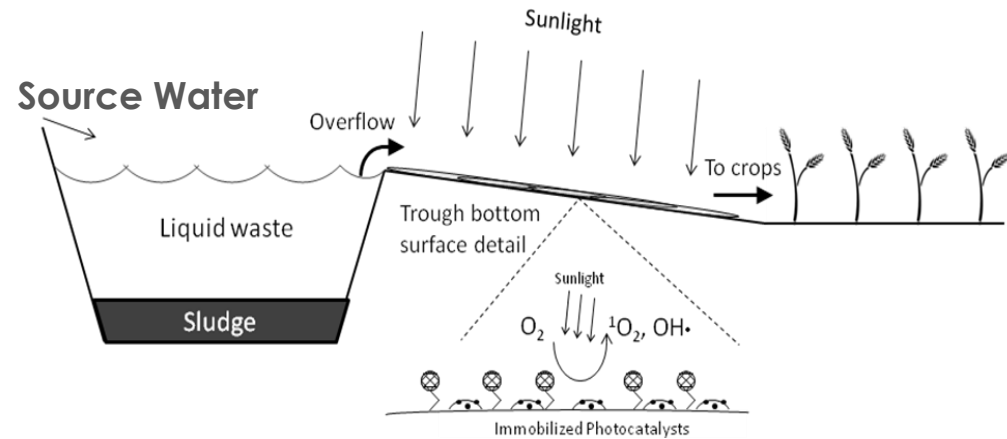
- Other treatment options
  - Commercial UV?

Recommendations

- Fencing!!
  - Isolate reservoirs
  - Utilize animal troughs
  - Could prevent majority of bacterial contamination