

# Multiwalled carbon nanotubes-Titanium dioxide (MWNTs-TiO<sub>2</sub>) composite for sustainable water treatment at the point-of-use

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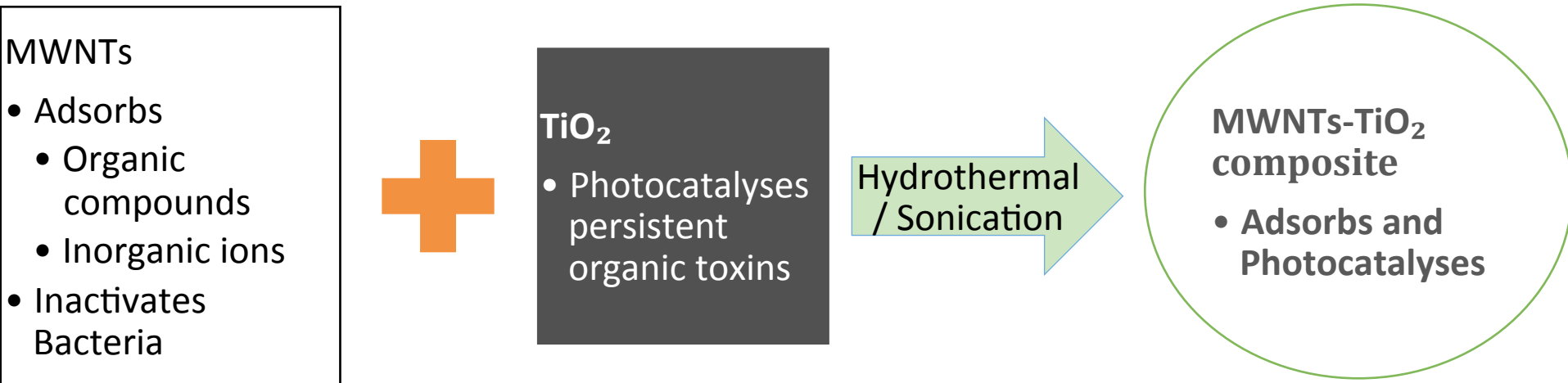
Abu Dhabi, UAE

Oct 12, 2016

# Contents

1. What is a MWNTs-TiO<sub>2</sub> composite?
2. What it can remove from water (to clean it)?
3. How the composite can be sustainably used for water treatment?
4. What is the current R & D status of the composite ?

# What is a multiwalled carbon nanotubes/titanium dioxide (MWNTs-TiO<sub>2</sub>) composite ?



# How the composite works?

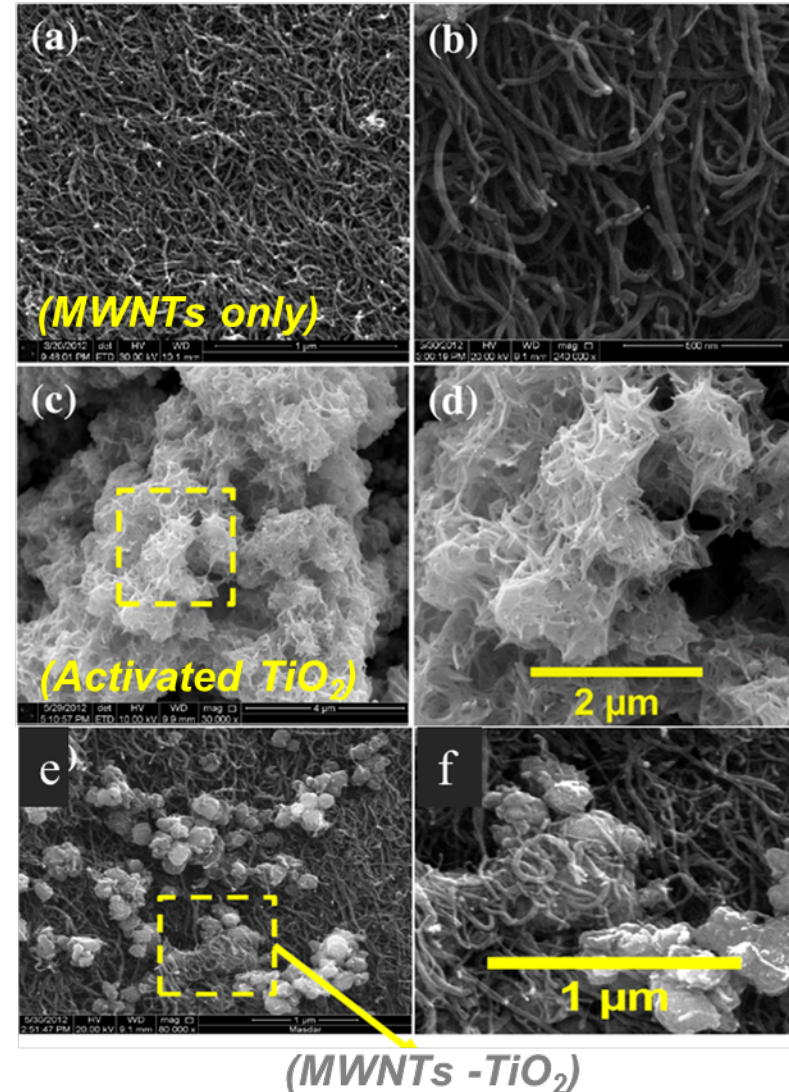
## Photo-regenerable nanocomposite



Photocatalyst

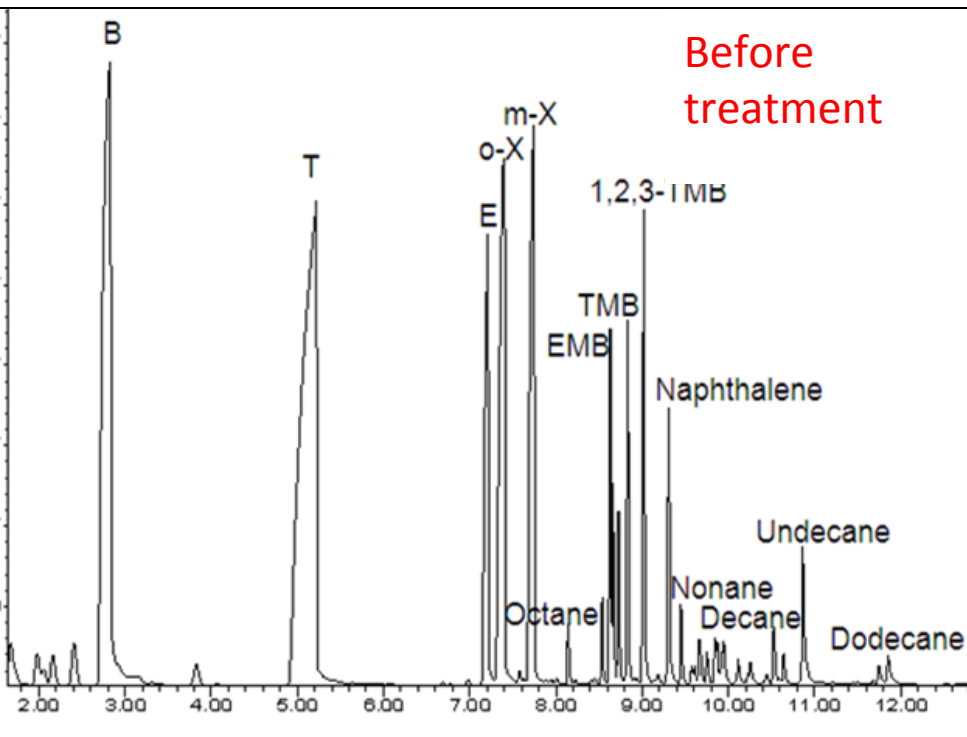
MWNT Carbon-based Sorbent

Clean Water



# What it can do?

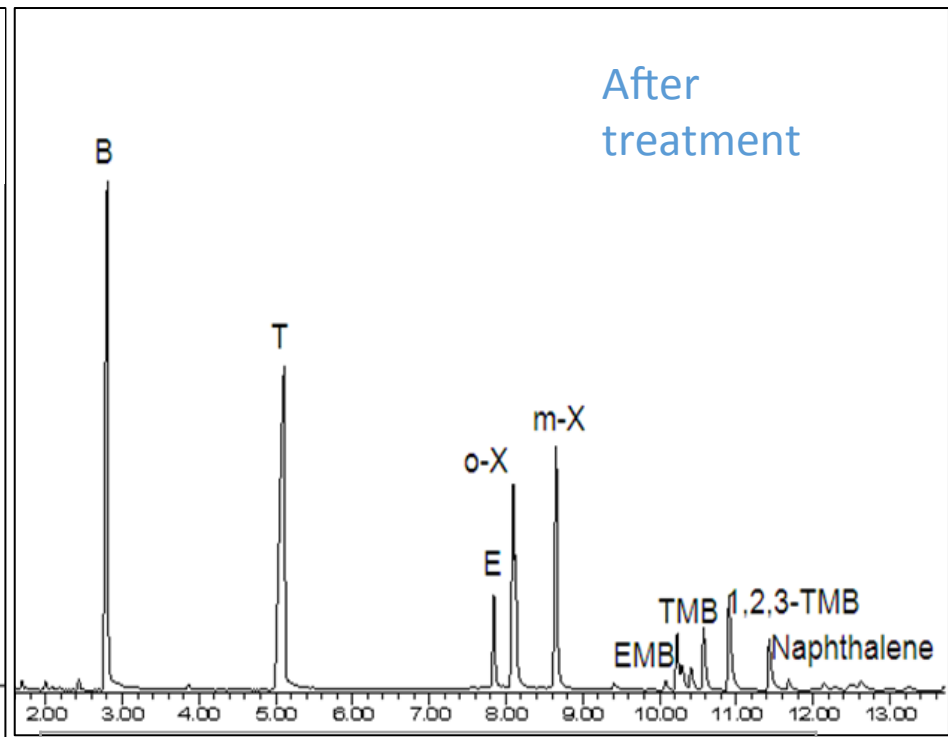
## Removes organic compounds from water



**Before treatment**

Aliphatic fractions of crude oil

High BTEX conc.



**After treatment**

No Aliphatic fractions of crude oil

Low BTEX conc.

# What it can do?

## Removes inorganics and inactivates bacteria

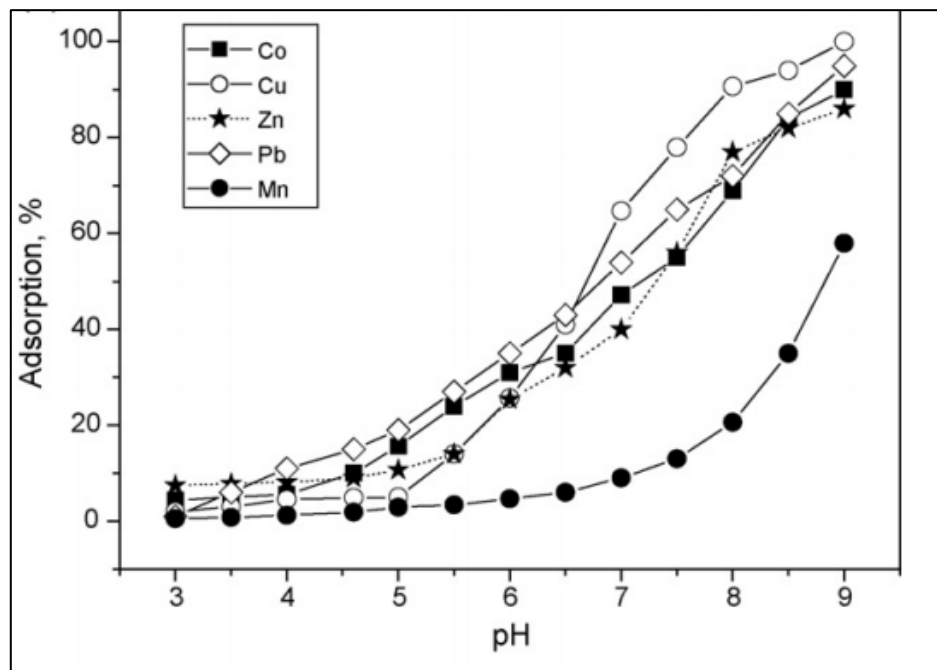
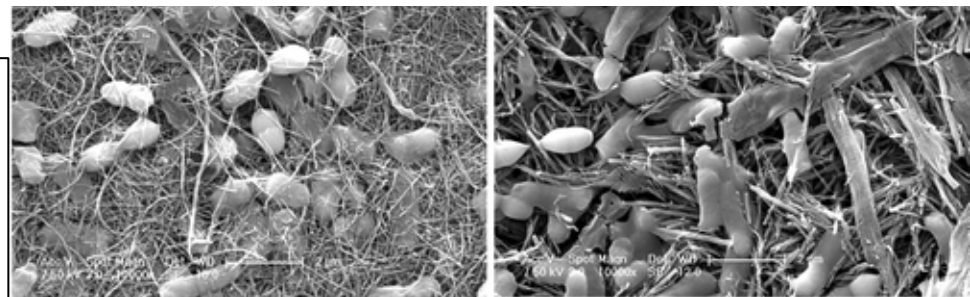


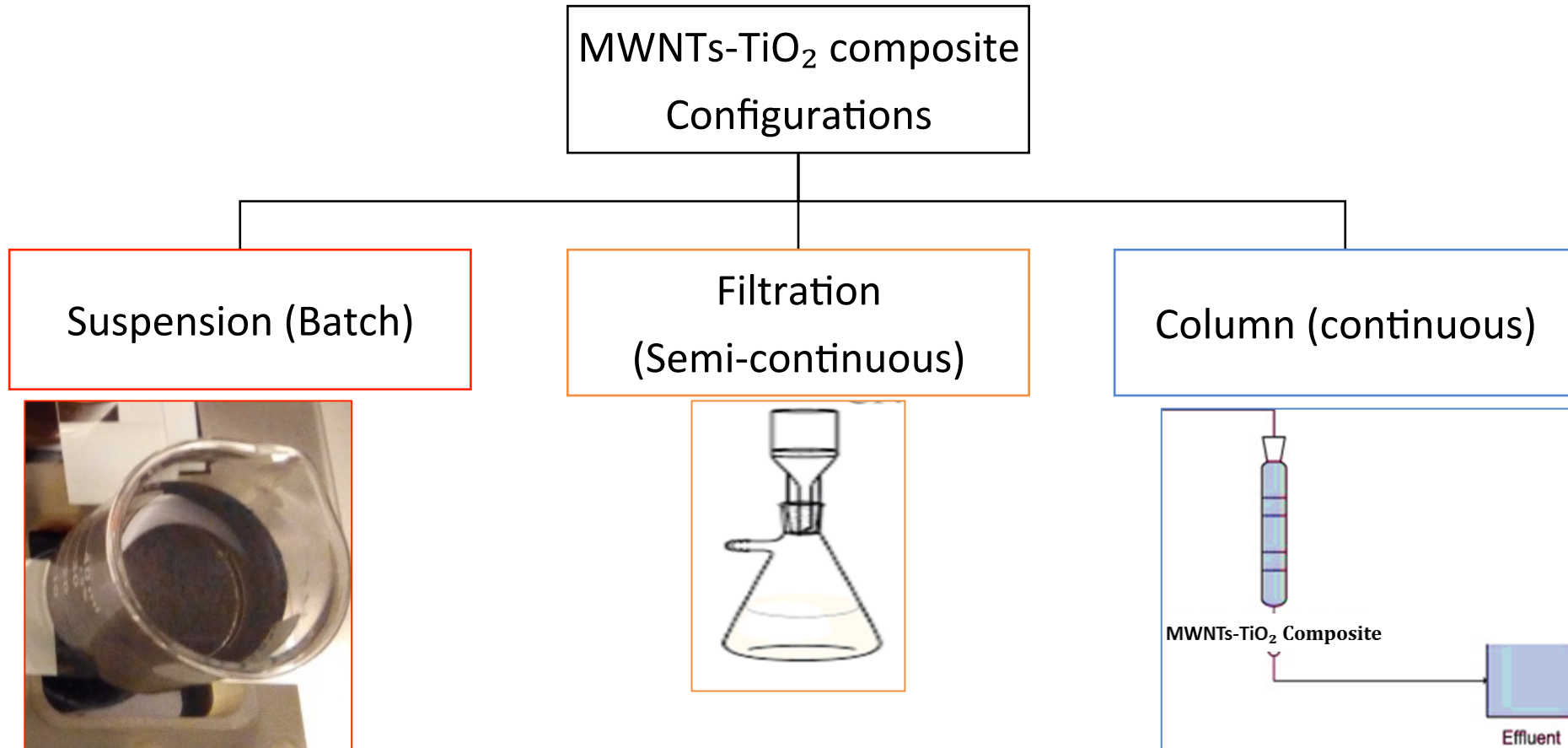
Fig. Adsorption removal of heavy metals by MWNTs



| Toxicity Classification <sup>b</sup>  | Low-range |         | Mid-range |         | Upper-range |        |
|---------------------------------------|-----------|---------|-----------|---------|-------------|--------|
| Amorphous Carbon Present <sup>c</sup> |           | ✓       |           |         |             |        |
| Uncapped <sup>d</sup>                 |           |         | ✓         | ✓       | ✓           | ✓      |
| Debundled <sup>e</sup>                |           |         |           | ✓       |             | ✓      |
| Short Length <sup>f</sup>             |           |         |           |         | ✓           | ✓      |
| Dispersed in Solution <sup>g</sup>    |           |         |           |         | ✓           | ✓      |
|                                       | DO-MWNT   | AP-MWNT | AN-MWNT   | AT-MWNT | s-MWNT      | f-MWNT |

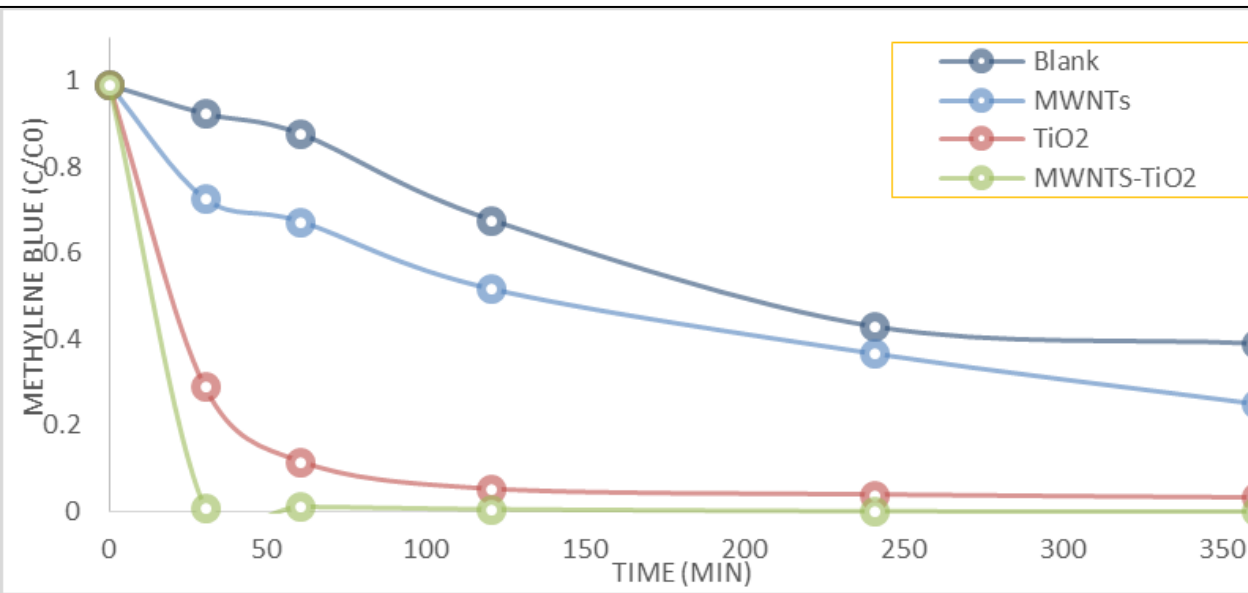
Fig. (Above) Cell wall damage and Table (Below) Toxicity classification of various types of MWNTs towards bacteria

# How the composite can be sustainably used for water treatment?



# How it is can be used?

## Suspension



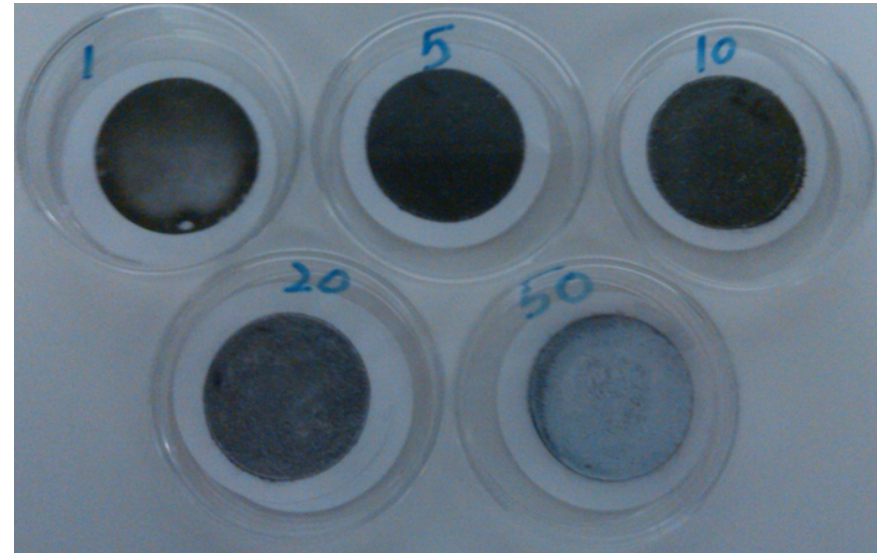
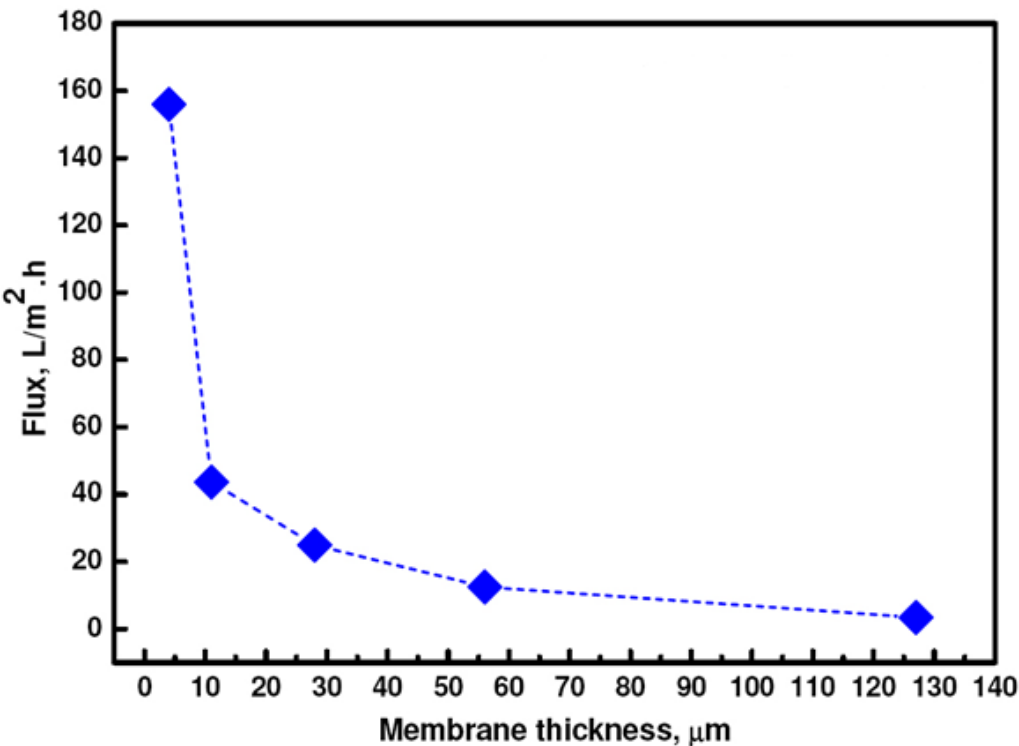
**Left:** Photocatalytic degradation of methylene blue.

**Right:** Photocatalytic setup of Methylene Blue and Methylene Red degradation. UV irradiation wavelength was 320 nm and thermal oxidation was controlled by creating thermal buffer by air and glass slide



# How it is can be used?

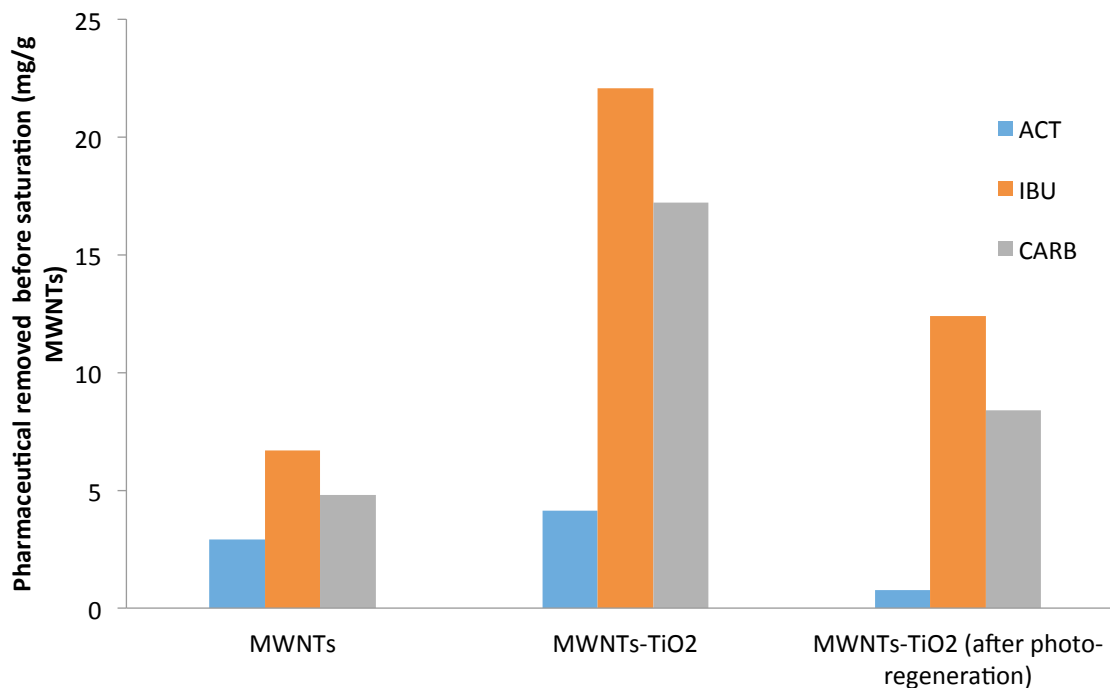
## Filtration



**Fig. .** The permeate flux of MWNTs-TiO<sub>2</sub> membranes for water were proportional to their thicknesses. The plot shows flux of deionized water through MWNTs-TiO<sub>2</sub> membranes of various thicknesses under the effect of gravity. The pressure was kept constant at 3.43 N/cm<sup>2</sup> by controlling water head

# How it is can be used?

## Filtration



**Fig..** The mass loadings of pharmaceuticals on (i) MWNTs membranes, (ii) MWNTs-TiO<sub>2</sub> membranes during 1<sup>st</sup> run, and (iii) MWNTs-TiO<sub>2</sub> membranes after photo-regeneration.

The pharmaceuticals mass removal was calculated when the membranes fully saturated with pharmaceuticals and their pharmaceutical removal efficiency reached zero.

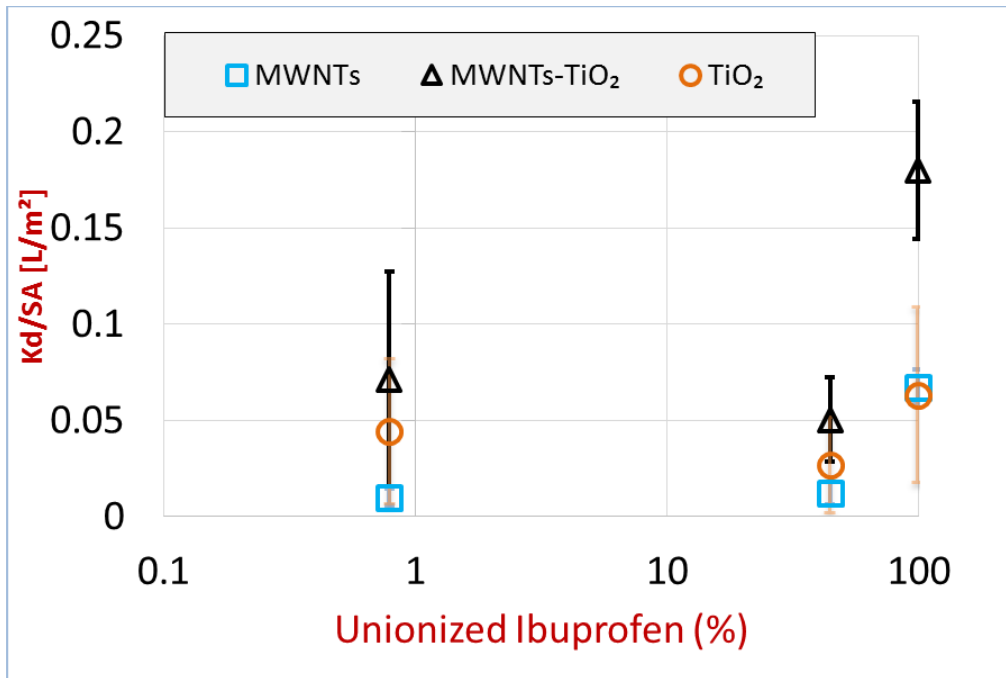
The influent concentration of acetaminophen, ibuprofen, and carbamazepine was 10 mg/L each in deionized water (18  $\mu$ S/cm).

Table. Physical properties of Compounds (SRC, 2011)

| Compound      | CAS        | Formulae   | Structure | Mol. Wt (g/mol) | Log <i>K<sub>ow</sub></i> | Water Solubility (25 °C) mg/L | Absorption wavelength (nm) | p <i>K<sub>a</sub></i>    |
|---------------|------------|--|-----------|-----------------|---------------------------|-------------------------------|----------------------------|---------------------------|
| Acetaminophen | 103-90-2   | C <sub>8</sub> H <sub>9</sub> NO <sub>2</sub>    |           | 151.17          | 0.46                      | 1.40E+04                      | 244                        | 9.5                       |
| Ibuprofen     | 15687-27-1 | C <sub>13</sub> H <sub>18</sub> O <sub>2</sub>   |           | 206.29          | 3.97                      | 21                            | 222                        | 4.9                       |
| Carbamazepine | 298-46-4   | C <sub>15</sub> H <sub>12</sub> N <sub>2</sub> O |           | 236.28          | 2.45                      | 17.7                          | 284                        | 13.9 (Bui and Choi, 2010) |

# How it is can be used?

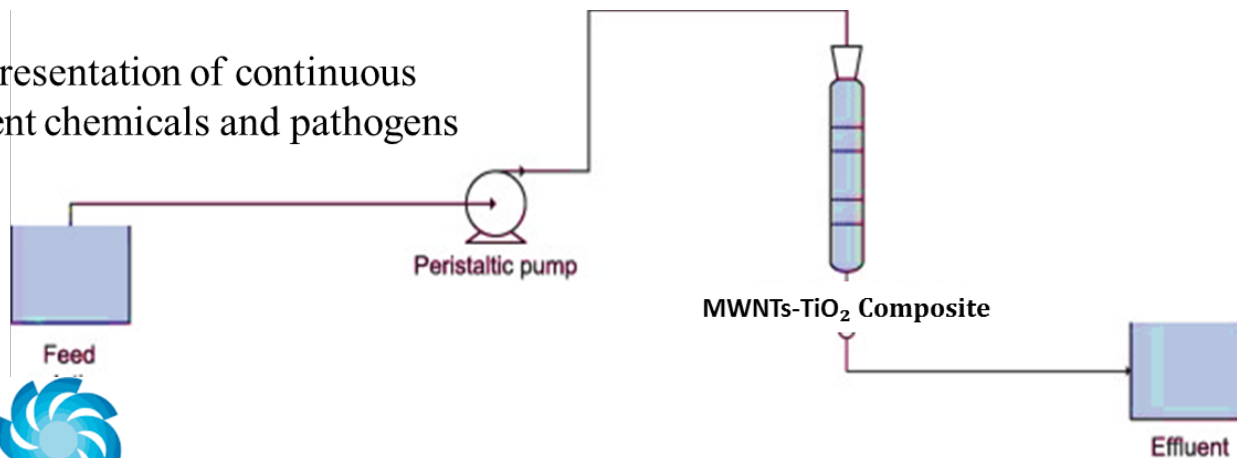
## Continuous column



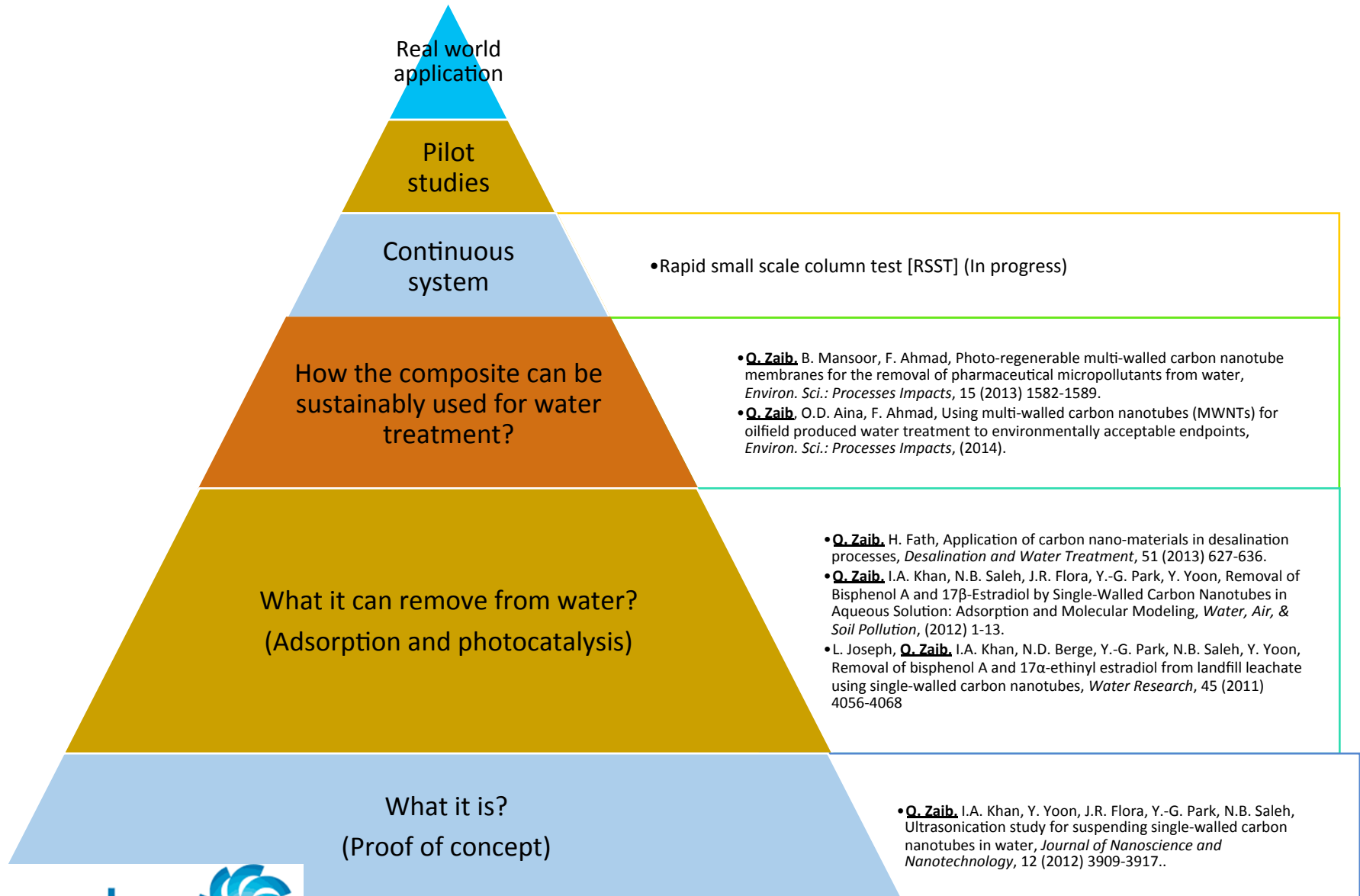
Surface normalized adsorption of ibuprofen was highest for neutral ibuprofen on MWNTs-TiO<sub>2</sub>



**Fig.** Schematic representation of continuous removal of persistent chemicals and pathogens from water



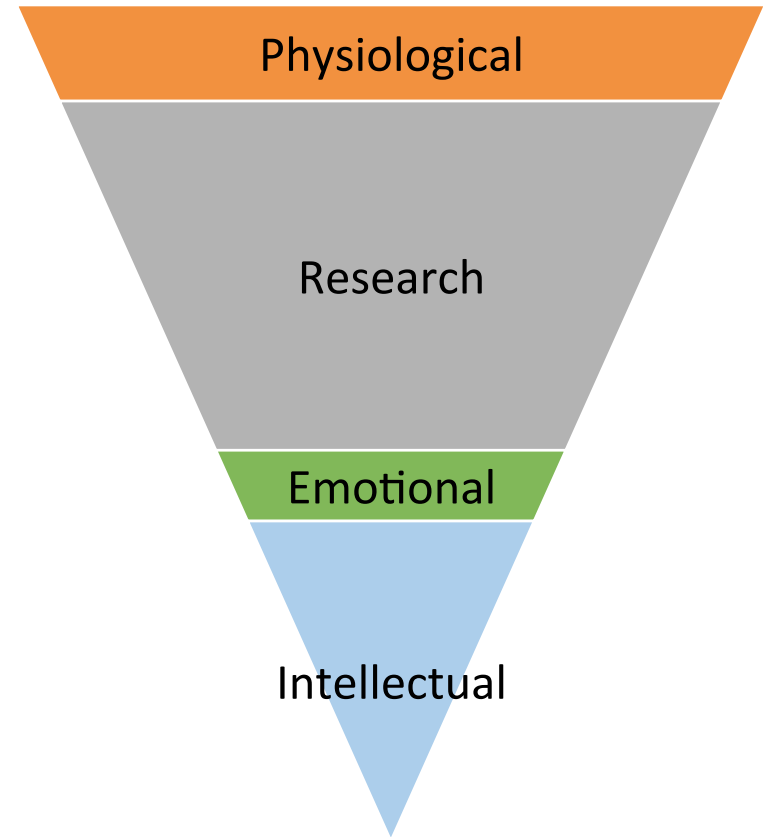
# What is the R&D status of composite?



# Acknowledgements

(modified Maslow's hierarchy of needs)

- MIT and MI Cooperative Program
- My PhD Advisors
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  - Dr. Philip M. Gschwend (  Massachusetts Institute of Technology )
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- Scientists/statisticians
  - George E. P. Box
  - Pierre Curie and Jacques Curie
  - Sumio Iijima
  - .....countless others



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# References

## PUBLICATIONS

### PATENT

- [1] Ahmad F, **Zaib Q**, Photo-regenerable filters useful for the removal of organic compounds. Application number 14/609,696, Jan 29, 2015.U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

### PEER REVIEWED PUBLICATIONS

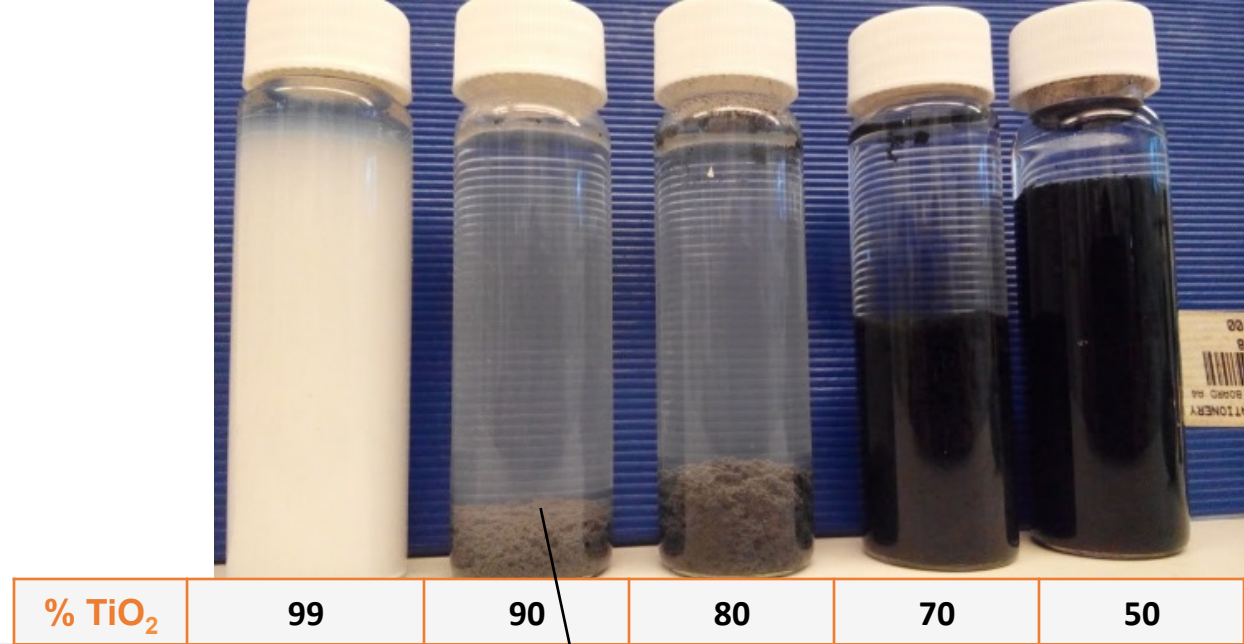
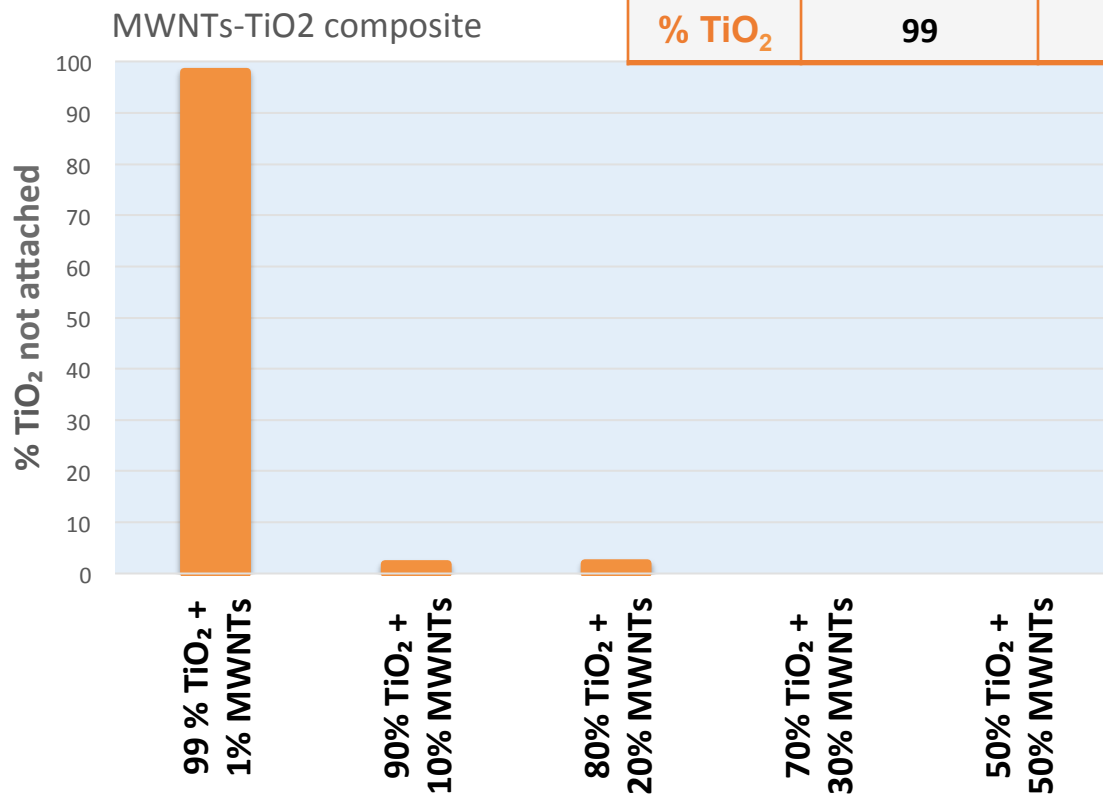
- [6] **Q. Zaib**, O.D. Aina, F. Ahmad, Using multi-walled carbon nanotubes (MWNTs) for oilfield produced water treatment to environmentally acceptable endpoints, *Environ. Sci.: Processes Impacts*, (2014).
- [5] **Q. Zaib**, B. Mansoor, F. Ahmad, Photo-regenerable multi-walled carbon nanotube membranes for the removal of pharmaceutical micropollutants from water, *Environ. Sci.: Processes Impacts*, 15 (2013) 1582-1589.
- [4] **Q. Zaib**, H. Fath, Application of carbon nano-materials in desalination processes, *Desalination and Water Treatment*, 51 (2013) 627-636.
- [3] **Q. Zaib**, I.A. Khan, Y. Yoon, J.R. Flora, Y.-G. Park, N.B. Saleh, Ultrasonication study for suspending single-walled carbon nanotubes in water, *Journal of Nanoscience and Nanotechnology*, 12 (2012) 3909-3917.
- [2] **Q. Zaib**, I.A. Khan, N.B. Saleh, J.R. Flora, Y.-G. Park, Y. Yoon, Removal of Bisphenol A and 17 $\beta$ -Estradiol by Single-Walled Carbon Nanotubes in Aqueous Solution: Adsorption and Molecular Modeling, *Water, Air, & Soil Pollution*, (2012) 1-13.
- [1] L. Joseph, **Q. Zaib**, I.A. Khan, N.D. Berge, Y.-G. Park, N.B. Saleh, Y. Yoon, Removal of bisphenol A and 17 $\alpha$ -ethinyl estradiol from landfill leachate using single-walled carbon nanotubes, *Water Research*, 45 (2011) 4056-4068.

### SELECTED CONFERENCE PROCEEDINGS

- [10] **Zaib Q**, and Ahmad F. Ibuprofen Sorption on Regenerable Networked Carbon Nanotubes." In *Gordon Research Conference on Environmental Nanotechnology*. Mount Snow in West Dover VT United States 2015.
- [9] **Zaib Q**, Aina O.D., Ahmad F. "Using Multi-Walled Carbon Nanotubes for Oilfield Produced Water Treatment to Environmentally Acceptable Endpoints." In *Gordon Research Conference on Environmental Nanotechnology*. Mount Snow in West Dover VT United States, 2015.
- [8] **Zaib Q**, Mansoor B., Ahmad F. MWNTs-TiO<sub>2</sub> water permeable membrane adsorbs and photo-catalyzes organic micropollutants in water. 11<sup>th</sup> IWA Leading Edge conference; 2014 May 26–29; Abu Dhabi, UAE; 2012.
- [7] **Zaib Q**, Aina O.D., Ahmad F. Adsorption removal of BTEX during produced water treatment using multiwalled carbon nanotubes. 11<sup>th</sup> IWA Leading Edge conference; 2014 May 26–29; Abu Dhabi, UAE; 2012.
- [6] **Zaib Q**, Mansoor B., Ahmad F. Removal of acetaminophen, ibuprofen, and carbamazepine from water by photo regenerative multiwalled carbon nanotubes-titanium dioxide. IWA Conference Micropol & Ecohazard, June 16-20, 2013 in Zurich, Switzerland, 2013.
- [5] **Zaib Q**, Mansoor B., Ahmad F. Continuous removal of pharmaceuticals from water using a regenerable MWNTs-TiO<sub>2</sub> membrane. IWA 2<sup>nd</sup> water research conference; 2013 Jan 20–23; Singapore; 2013.
- [4] **Zaib Q**, Fath H. Application of carbon nano-materials in desalination processes. Desalination for the environment, clean water, and energy; 2012 April 22–26; Barcelona, Spain; 2012.
- [3] **Zaib Q**, Khan IA, Flora J, Park Y-G, Saleh NB, Yoon Y. The Effects of Water Chemistry on Removal of Bisphenol A and 17- beta Estradiol by Single-walled Carbon Nanotubes. Water Quality and Technology Conference, AWWA, ; 2011 Nov 14-18; Savannah, GA, USA; 2011.
- [2] Joseph L, **Zaib Q**, Berge N., Flora J, Park YG, Khan IA, et al. Removal of Bisphenol A and 17 $\alpha$ -Ethinyl Estradiol from Landfill Leachate Using Carbon Nanotubes. Annual Conference & Exposition, AWWA, ; 2011 June12-16; Washington, DC, USA; 2011
- [1] Afroz AN, **Zaib Q**, Decho AW, Saleh NB. Role of Nanoparticle Geometry on Nano-bio Interaction: A Quest to Separate Physics from Chemistry. ACS National Meeting, 2010 Aug 22-26; Boston, MA, USA: ACS; 2010.



# Maximizing Mass loading of $\text{TiO}_2$ on MWNTs



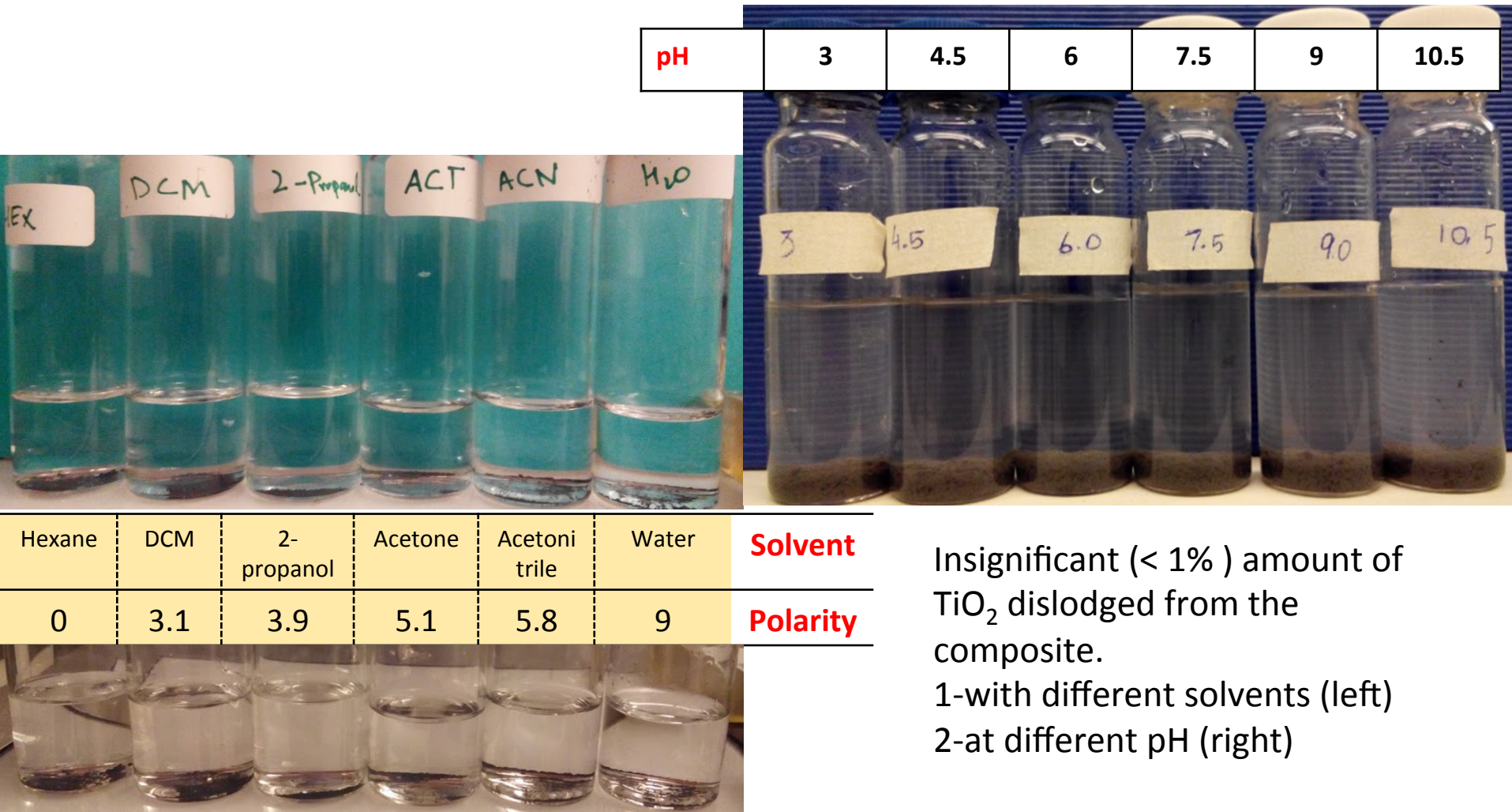
90%  $\text{TiO}_2$  + 10% MWNTs was selected

$$\rho_{\text{MWNTs}} = 1.33$$

$$\rho_{\text{TiO}_2} = 4.23$$



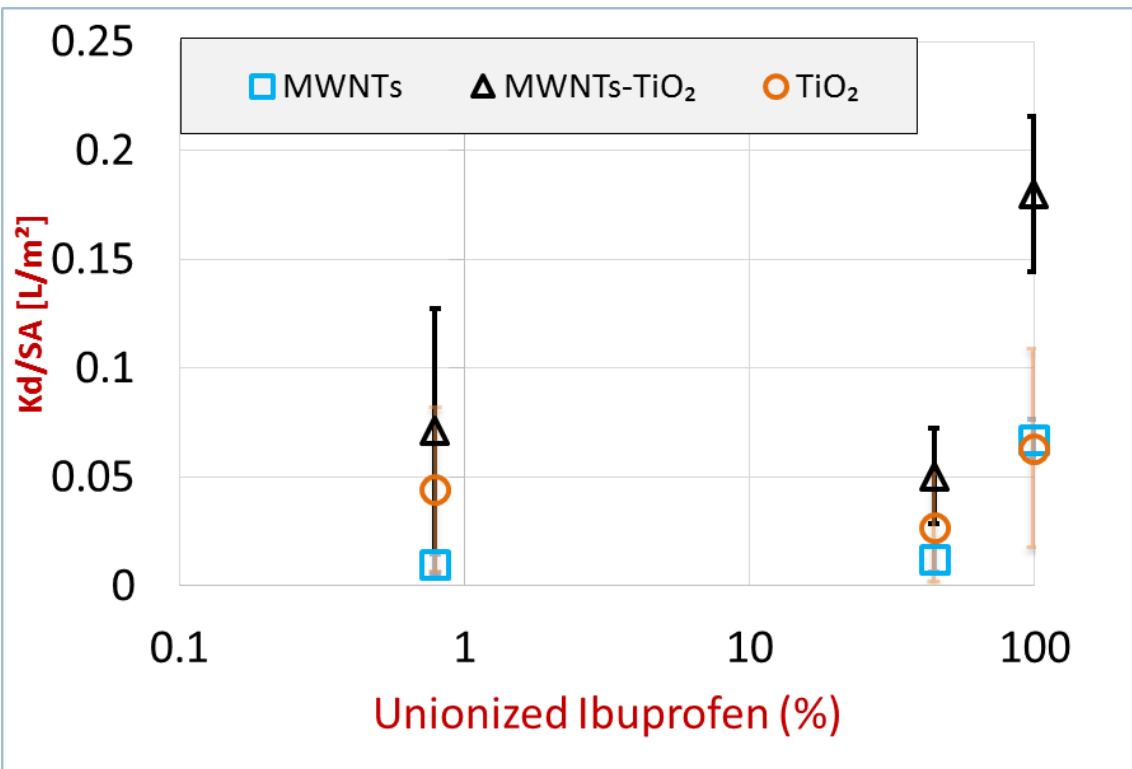
# MWNTs-TiO<sub>2</sub> composite testing



# How it is can be used?

## Continuous column

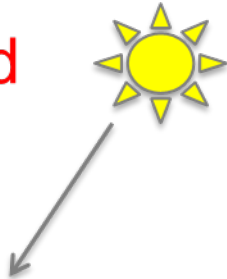
Surface normalized adsorption of ibuprofen was highest for neutral ibuprofen on MWNTs-TiO<sub>2</sub>



|          | MWNTs / MWNTs-TiO <sub>2</sub> |      |      | MWNTs-TiO <sub>2</sub> /TiO <sub>2</sub> |      |      |
|----------|--------------------------------|------|------|--|------|------|
| pH       | 3                              | 5    | 7    | 3  | 5    | 7    |
| p-values | 0.01                           | 0.04 | 0.12 | 0.01                                     | 0.21 | 0.46 |

# Photo-regenerable nanocomposite

Contaminated  
water



Photocatalyst

MWNT Carbon-based Sorbent



Clean Water

