WaterTech 2010

Ozone-Based Advanced Oxidation Processes in Water and Wastewater Treatment

Pamela Chelme-Ayala and Mohamed Gamal El-Din

Department of Civil and Environmental Engineering

University of Alberta, Edmonton, Canada

April 23, 2010

Presentation Outline

1. Process Fundamentals
2. Application in Water Treatment
3. Application in Wastewater Treatment
4. Concluding Remarks

1. Process Fundamentals

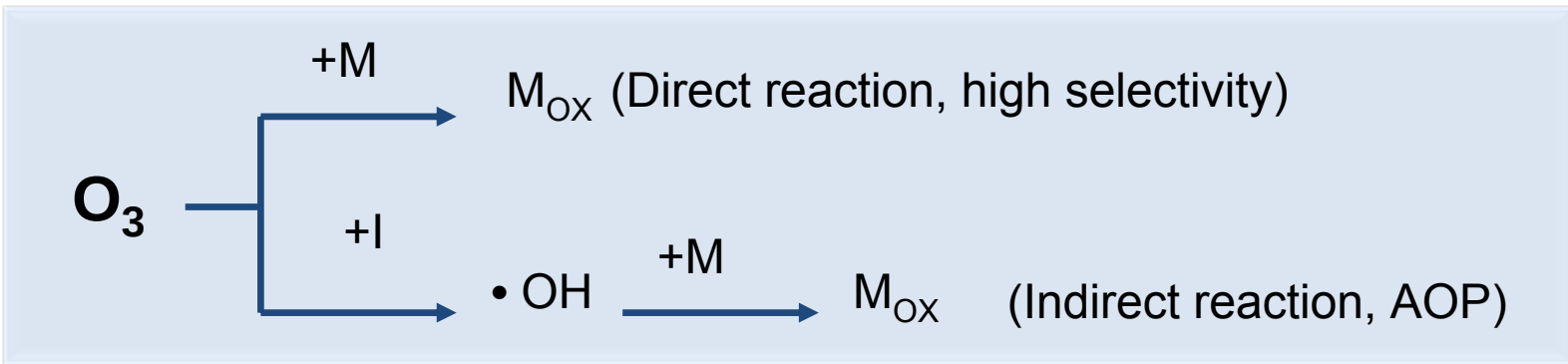
Advanced Oxidation Processes

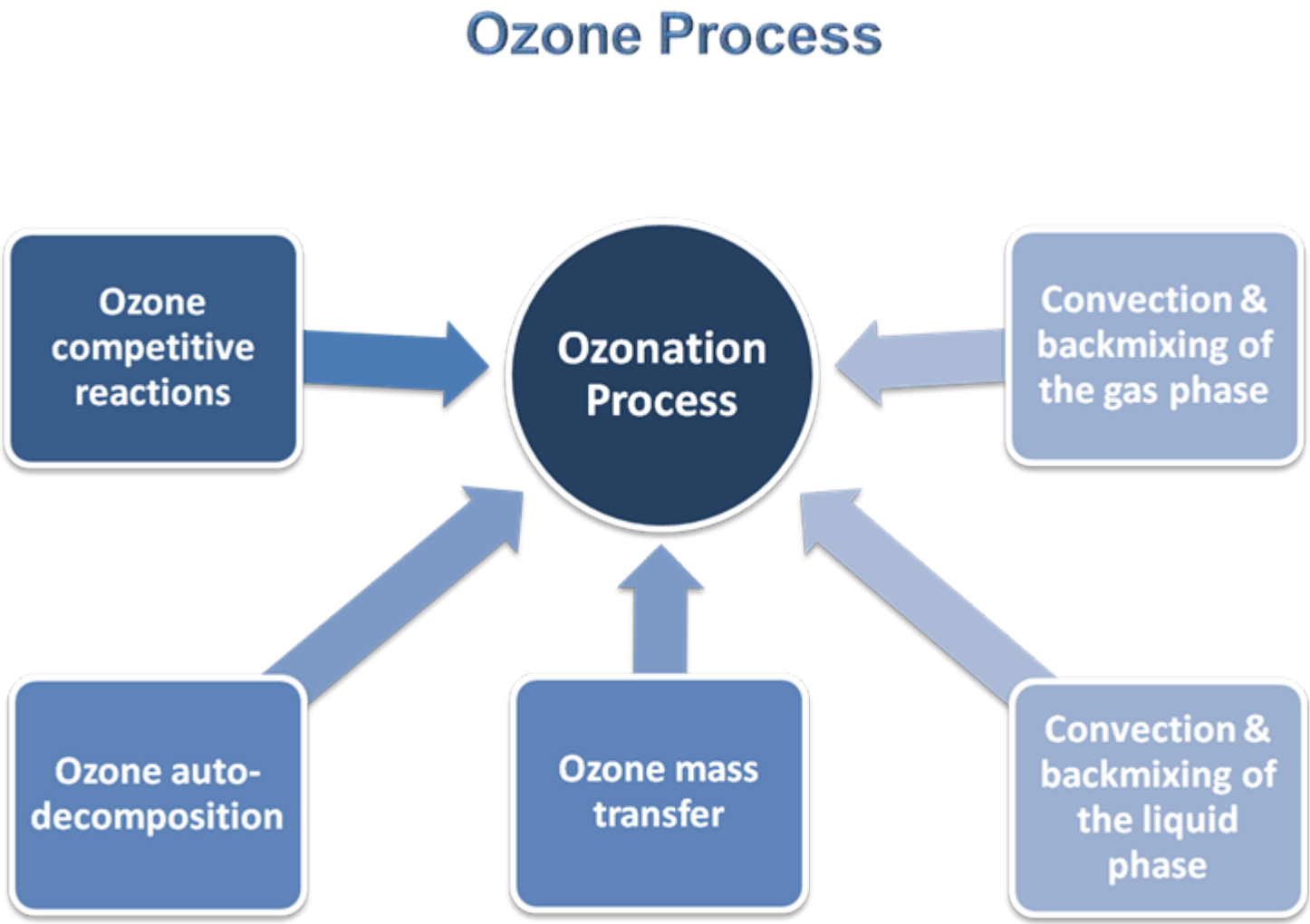
Ozone-Based Process	Non-Ozone-Based Processes
Ozonation	Ultraviolet light (UV)/H_2O_2
Ozone (O_3)/hydrogen peroxide (H_2O_2)	Vacuum UV
O_3/UV	TiO_2/hv
O_3/H_2O_2/UV	Photo-Fenton (UV/H_2O_2)
O_3/ Titanium dioxide (TiO_2)	Anodic Fenton (iron electrode)

Ozone Chemistry

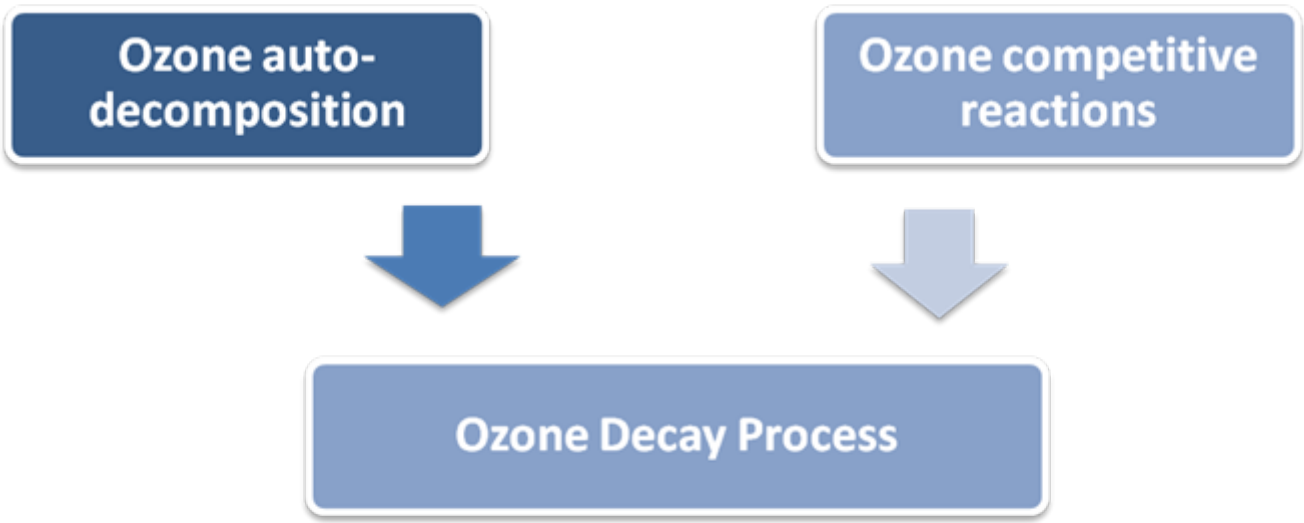
	O_2	ClO_2	Cl_2	MnO_4^-	H_2O_2	O_3	·OH
E_o (V)	1.23	1.27	1.36	1.67	1.77	2.07	2.80

Mechanisms

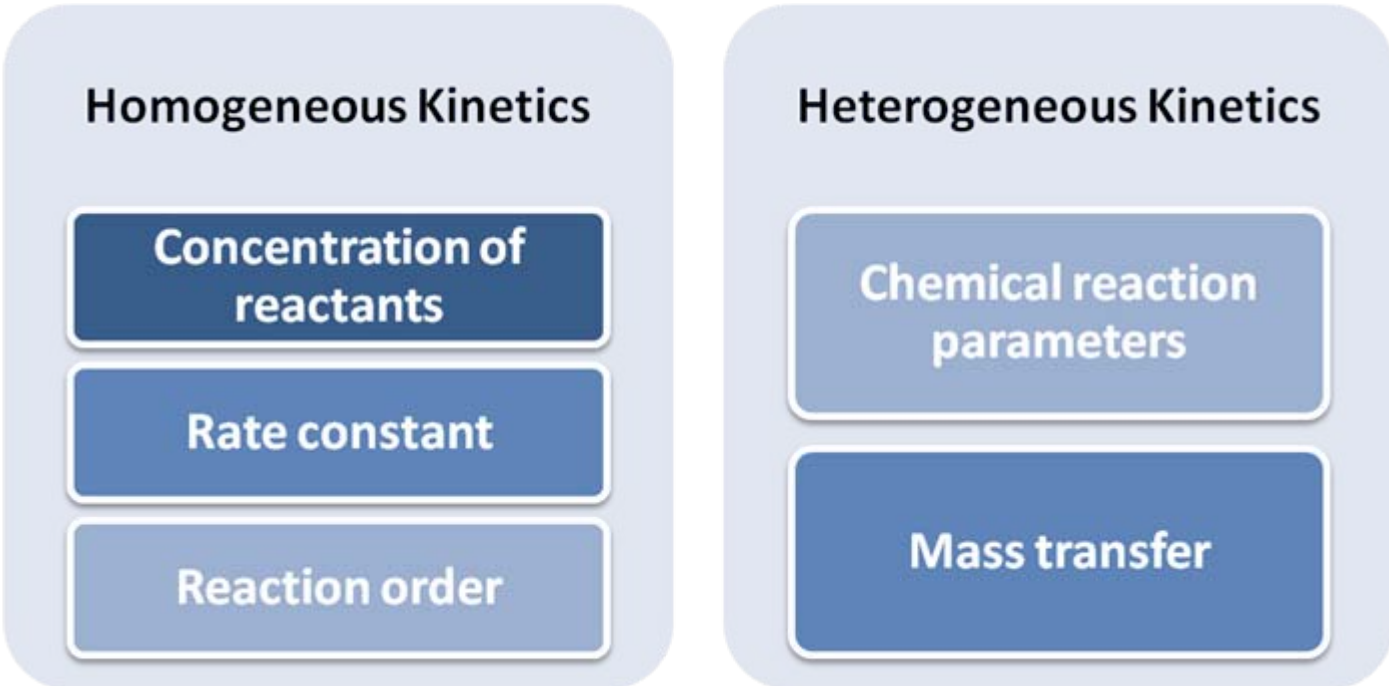



Ozone Process
Ozone competitive reactions
Ozonation Process
Convection & backmixing of the gas phase
Ozone auto-decomposition
Ozone mass transfer
Convection & backmixing of the liquid phase

Ozone Decay Process



Ozonation Kinetics



Reactivity and Kinetic Regimes

Wastewater	Specific contaminant	Kinetic Regime	Pathway	Treatment
Swine Manure	Odor compounds	Fast regime	Direct Ozone reaction	AOP not recommended
Petrochemical	Benzoic acid	Very slow regime	Indirect Reaction	AOP recommended
Municipal	Ammonia	Very slow regime	Indirect Reaction	AOP recommended
Textile	Azoic dyes	Fast regime	Direct Ozone reaction	AOP not recommended

2. Application in Water Treatment

Applications in Water Treatment

- Enhancement of Coagulation-Flocculation
- Taste and Odor Removal
- Disinfection
- Removal of Micropollutants

Degradation of Pesticides in Natural Water

Application in Water Treatment:

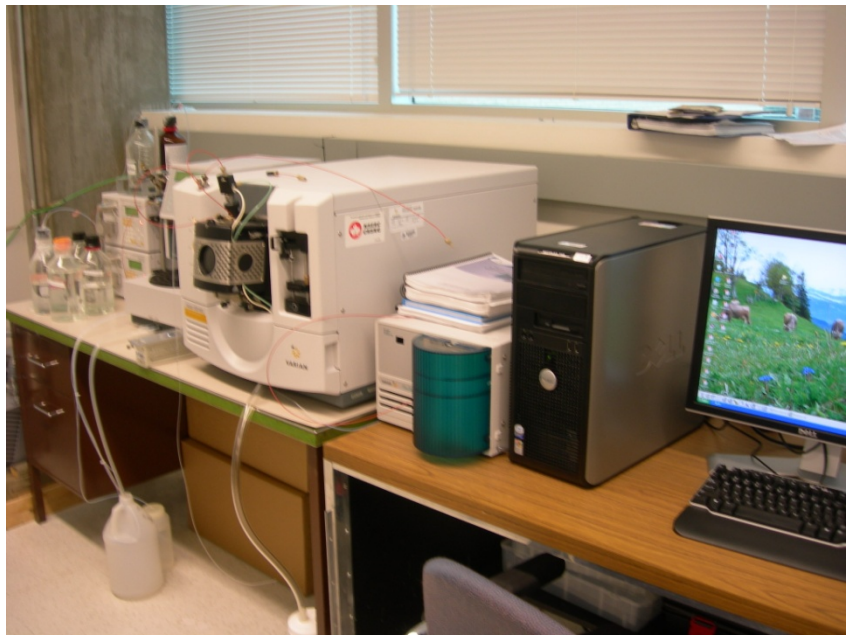
Degradation of Pesticides in Natural Water

Degradation of Pesticides in Natural Water

Concerns	• Less than 1% of pesticides used reach their target organisms
Pesticides	• Bromoxynil • Trifluralin

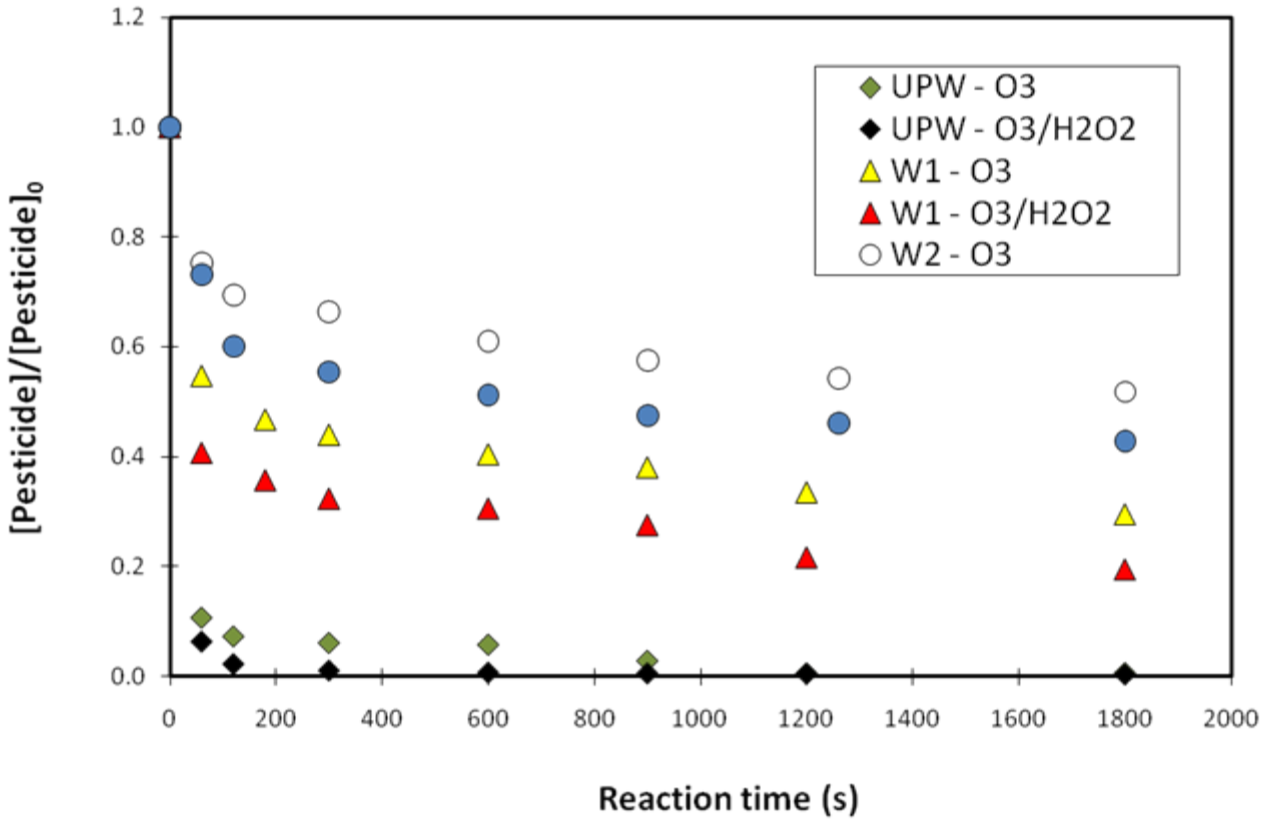
Degradation of Pesticides in Natural Water

- Pesticide degradation in river water and irrigation return flow water
- Toxicity assessed using Microtox® bioassay
- By-product identification



Degradation of Pesticides in Natural Water

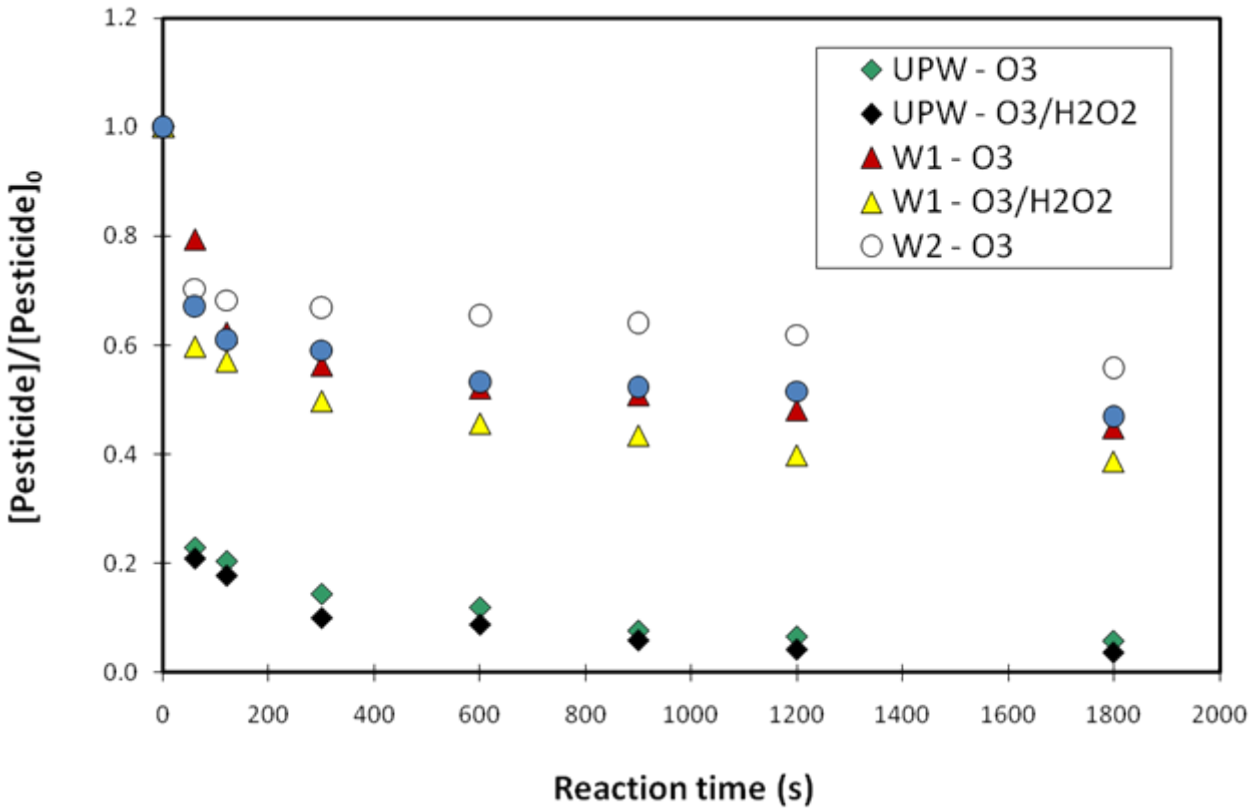
Bromoxynil decay



UPW: Ultrapure water
W1: Saskatchewan River water
W2: Irrigation return flow water flowing into the Redwater River

Degradation of Pesticides in Natural Water

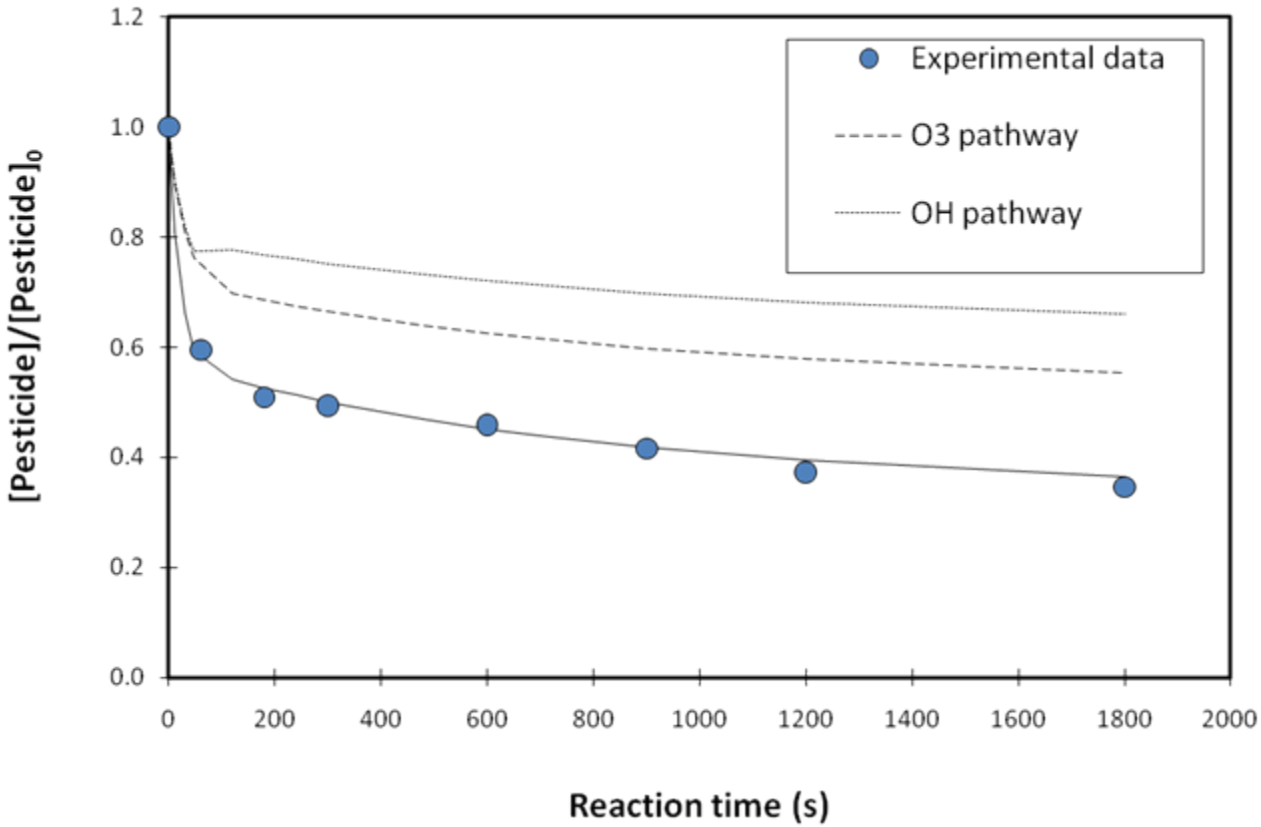
Trifluralin decay



UPW: Ultrapure water
W1: Saskatchewan River water
W2: Irrigation return flow water flowing into the Redwater River

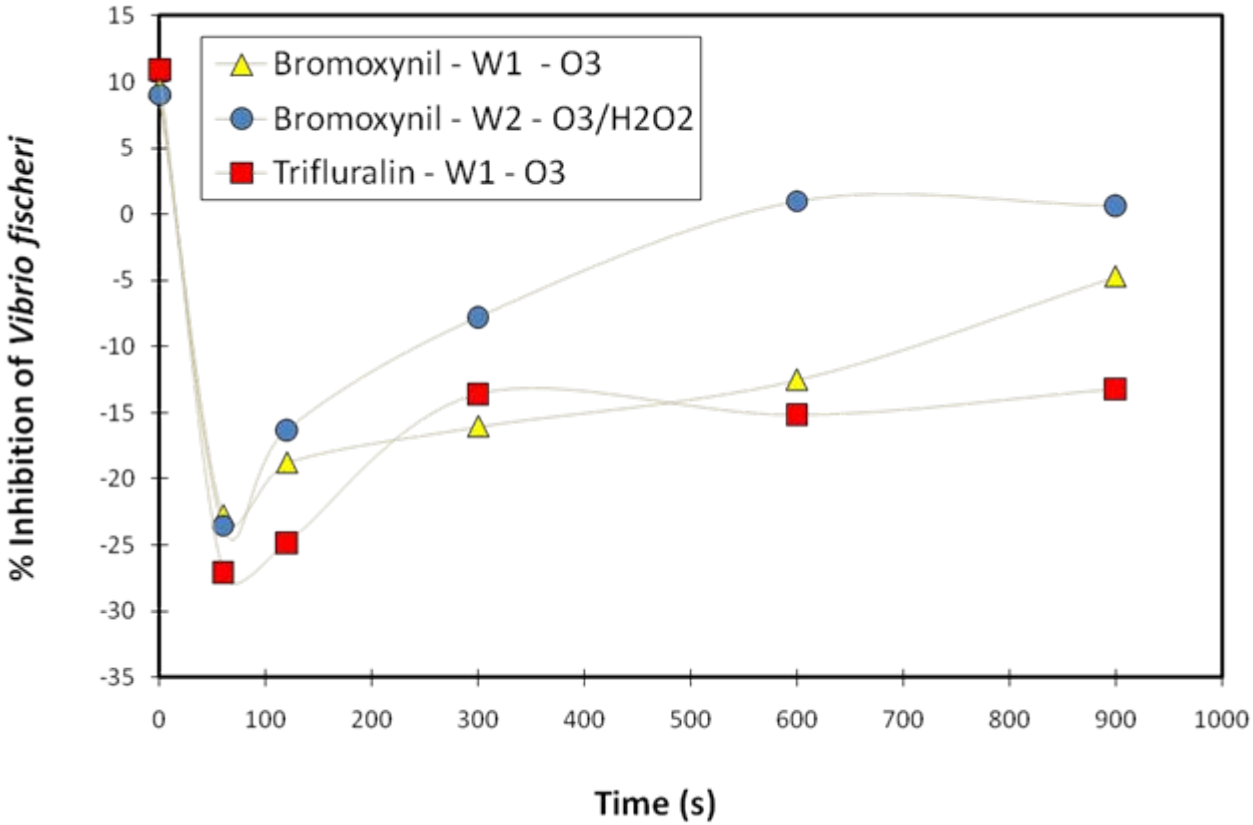
Degradation of Pesticides in Natural Water

Predicted bromoxynil oxidation by O_3 and ·OH pathways



Degradation of Pesticides in Natural Water

Toxic effects of bromoxynil and trifluralin on *Vibrio fischeri*



W1: Saskatchewan River water
W2: Irrigation return flow water flowing into the Redwater River

Degradation of Pesticides in Natural Water

By-product identification

Bromoxynil

- 3,5 dibromo-2,4-dihydroxybenzonitrile
- 3-bromo-4,5-hydroxybenzonitrile
- 3-bromo-4-hydroxybenzonitrile
- 4-hydroxybenzonitrile

Trifluralin

- α,α,α-trifluoro-4,6-dinitro-5-(dipropylamino)-o-cresol
- α,α,α-trifluoro-2,6-dinitro-*N*-dipropyl-*p*-toluidine
- 2,6-dinitro-4-trifluoromethyaniline
- 4-trifluoromethyaniline

Degradation of Pesticides in Natural Water

Summary

- Bromoxynil and trifluralin could not be significantly degraded during conventional ozonation in natural water.
- Toxicity bioassay indicated a decrease in toxicity during the first minutes of reaction. However, an increase in toxicity was observed in the following minutes of reaction.

3. Application in Wastewater Treatment

Applications in Wastewater Treatment

- Disinfection After Secondary Treatment
- Removal of Refractory and/or Toxic Compounds
- Sewage Treatment
- Reuse Applications

Ozonation of Oil Sands Process-Affected Water

Application in Wastewater Treatment:

Ozonation of Oil Sands Process-Affected Water

Ozonation of OSPW

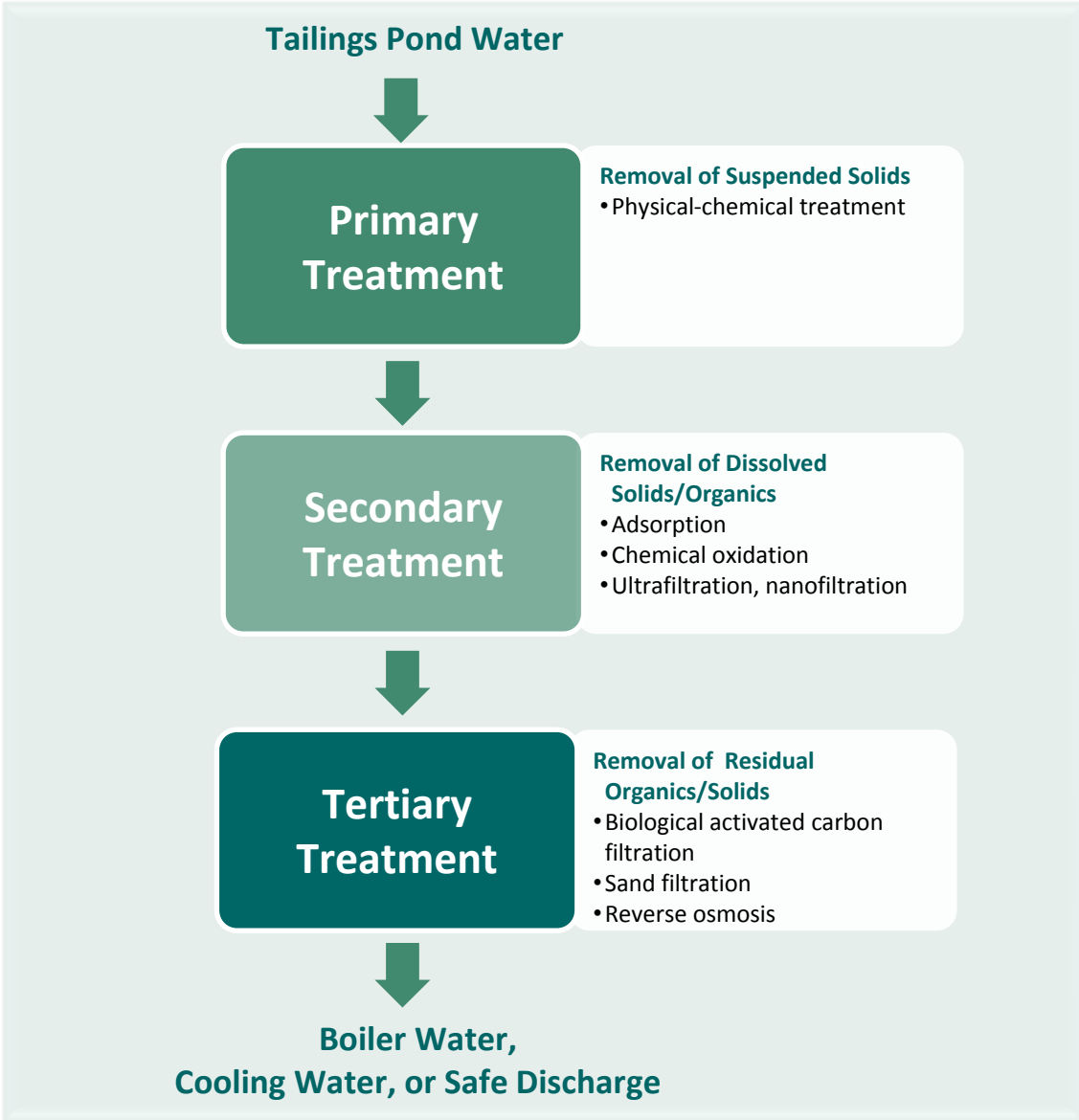
Characteristics

- OSPW is estimated to be 1 billion m^3 in the Athabasca oil sands region by 2025

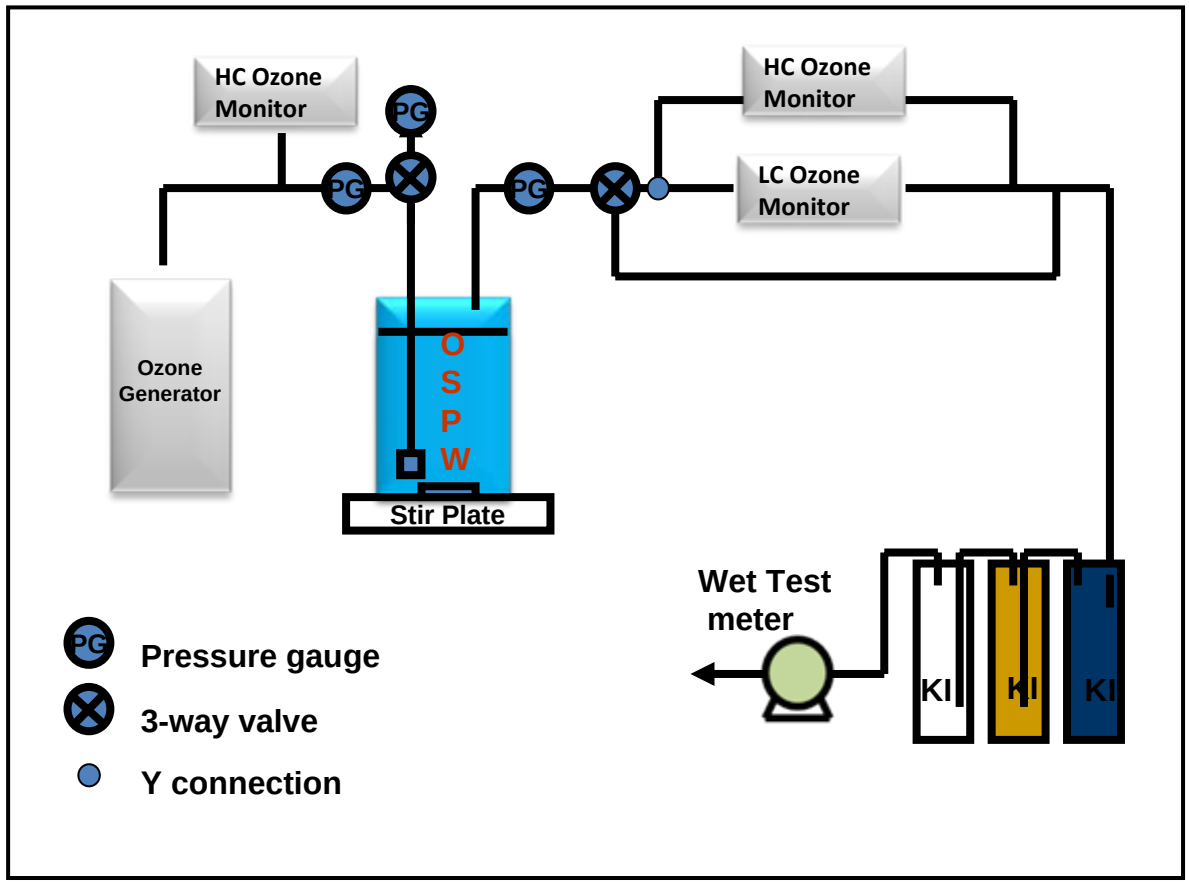
Concerns

- Naphthenic acids (NAs) are natural low molecular weight surfactants released from bitumen during extraction of oil sands ore.

Applications in Wastewater Treatment

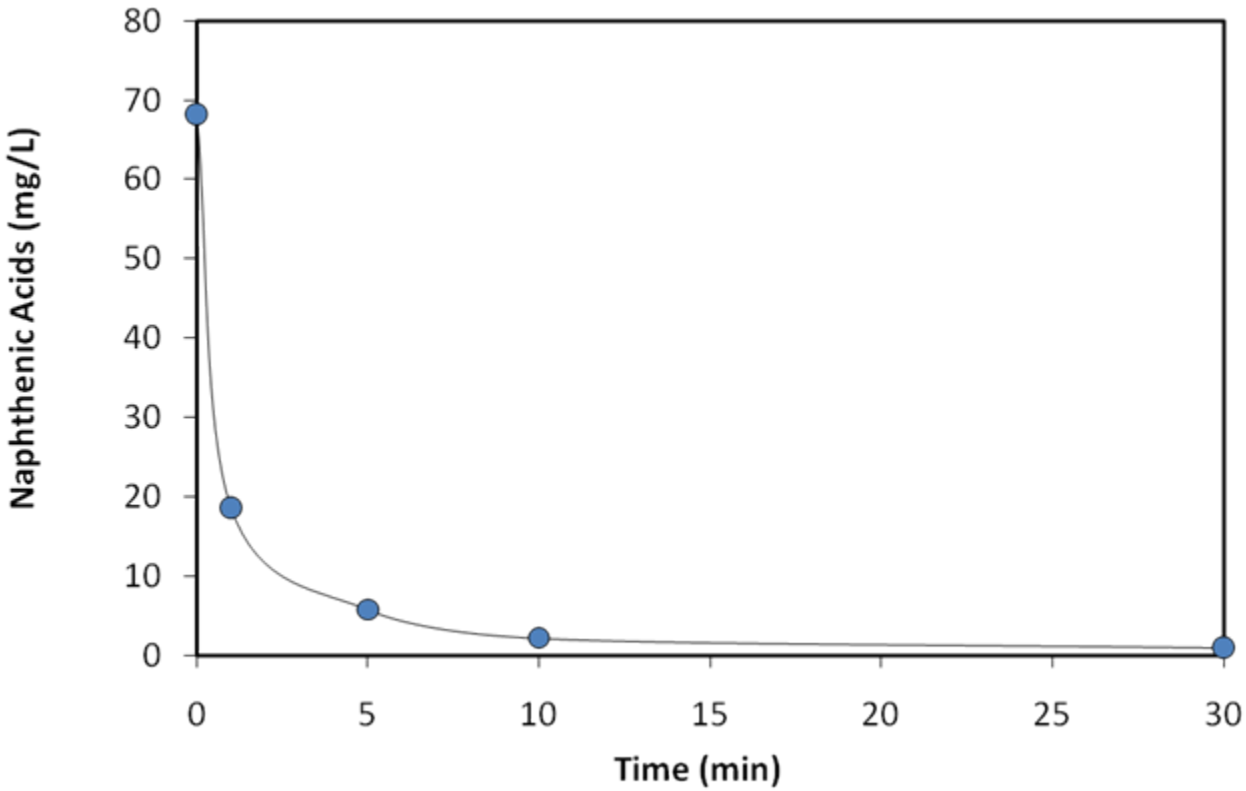


- Degradation levels
- Biodegradability
- Toxicity assessment



Ozonation of OSPW

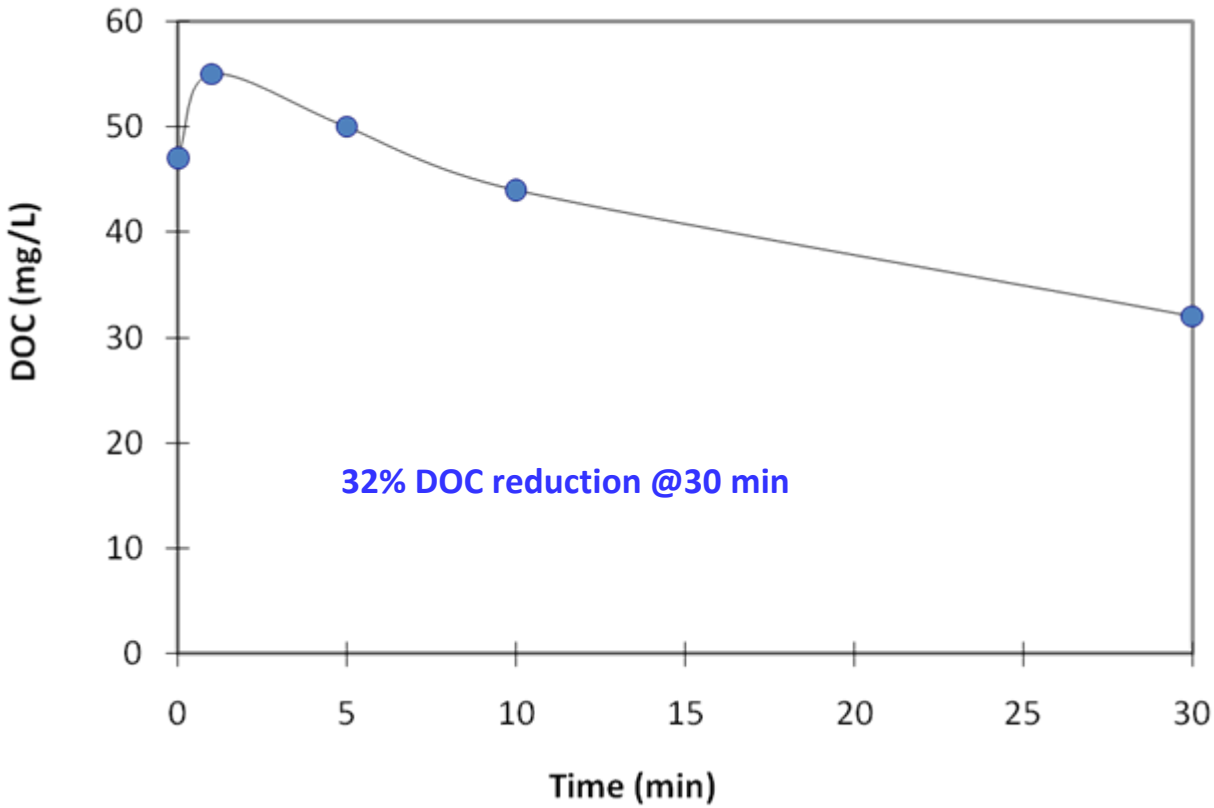
Degradation of Naphthenic Acids



- ozone contactor with a capacity of 1000 mL (222×56 mm i.d.)
- gas flow rate:2 L/min
- ozone concentration in the feeding gas: 25 g/m^3.

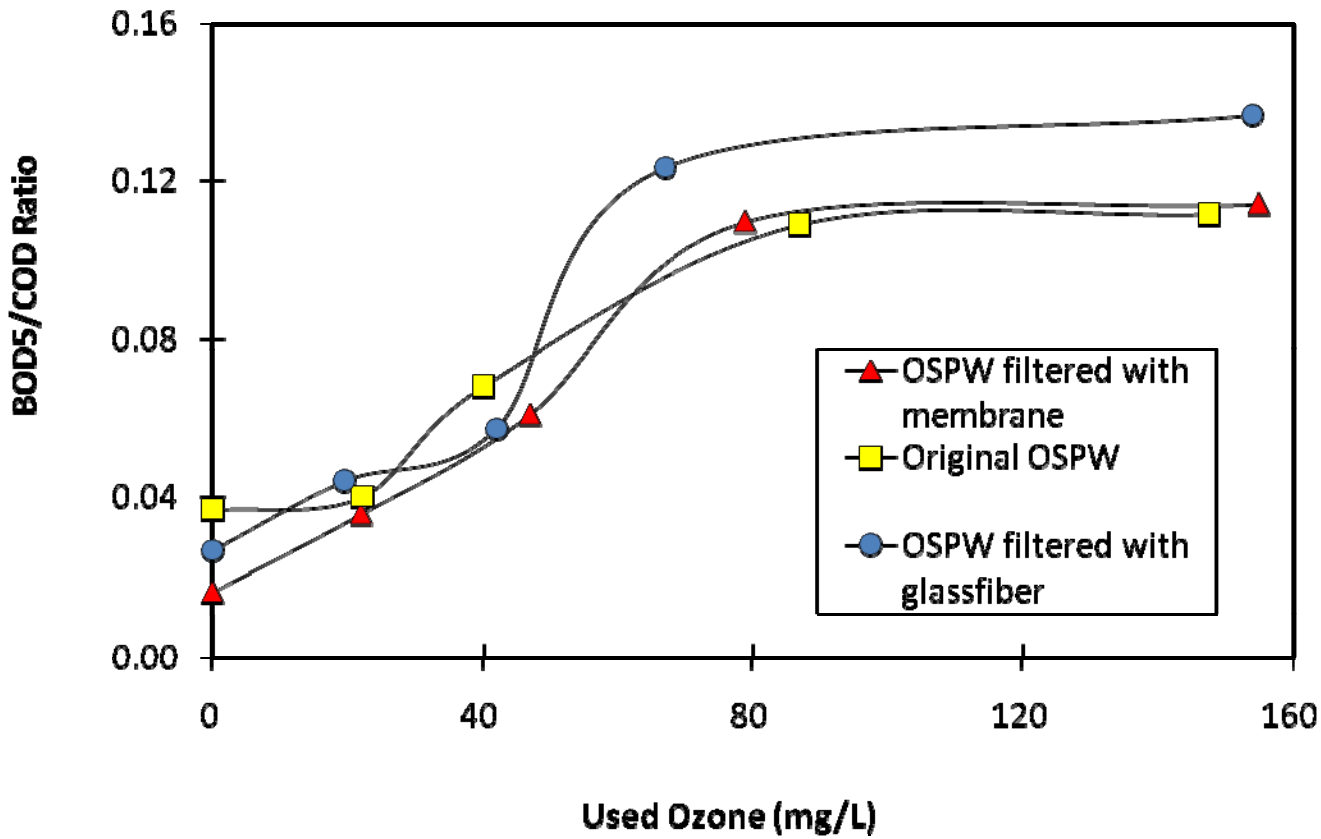
Ozonation of OSPW

Effect of ozonation on DOC



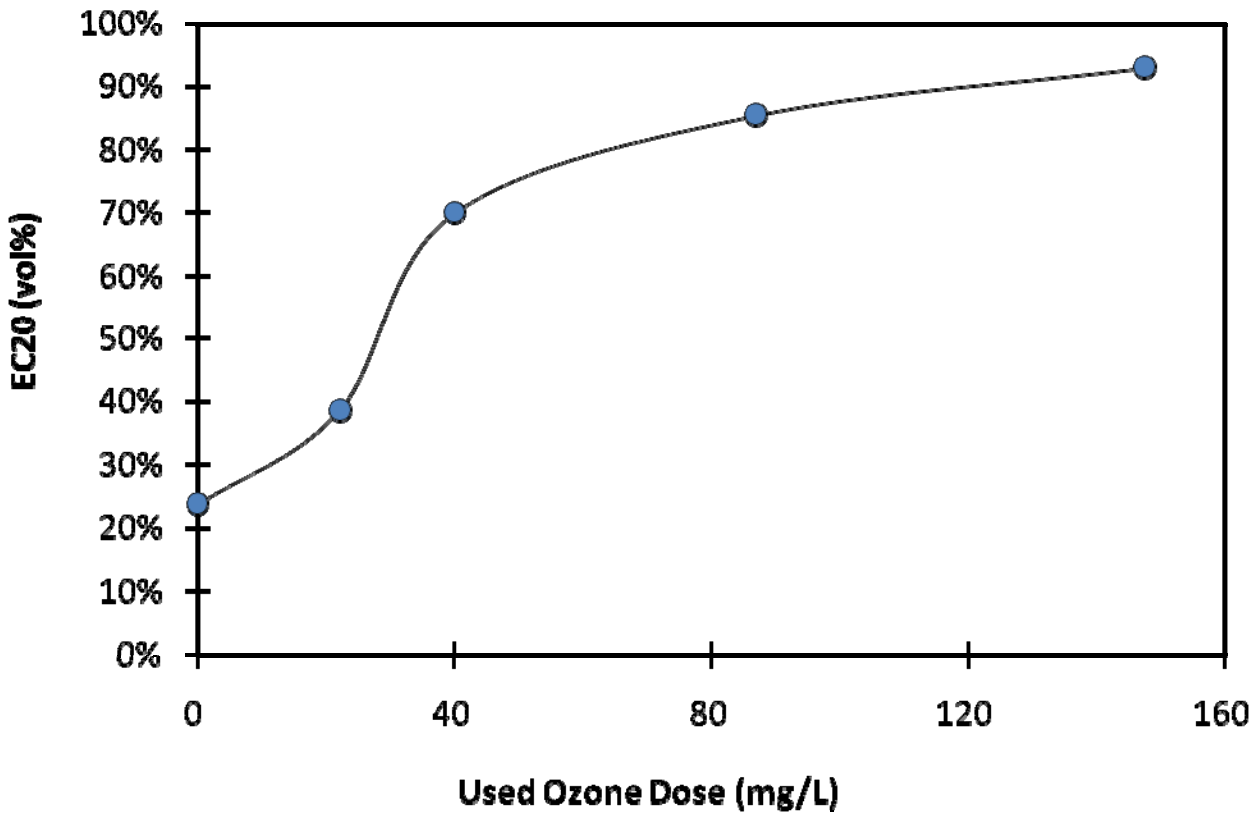
Ozonation of OSPW

Effect of ozonation on BOD_5/COD ratio



Ozonation of OSPW

Toxicity of ozonated OSPW



Ozonation of OSPW

Summary

- Ozone is a promising advanced treatment technology for the naphthenic acids removal from OSPW (>99% removal).
- Ozone treatments increase the biodegradability of OSPW.
- OSPWs have less toxicity after ozone treatments.

Future Works

- ✓ Enhance the ozone use efficiency
- ✓ Assess process scalability
- ✓ Apply AOPs
- ✓ Understand the mechanism of degradation
- ✓ Characterization of by-products

4. Concluding Remarks

- ✓ **Ozone-based AOPs are effective technologies in removing many organic, inorganic and microbiological pollutants.**

- ✓ **Areas that require further development:**
  - **By-product toxicity**
  - **Energy efficiency**

Acknowledgements

- ✓ Daniel W. Smith, Ph.D., P.Eng.
- ✓ Helen Fu, Ph.D.

- ✓ Technical staff of the Environmental Engineering Program at the University of Alberta

- ✓ Financial support provided by:
  - Alberta Ingenuity Center for Water Research (AICWR)
  - Natural Sciences and Engineering Research Council of Canada (NSERC)
  - Canada Foundation for Innovation (CFI)
  - Alberta Ingenuity Fund (AIF)

Thank You For Your Attention!

For More Information

Pamela Chelme-Ayala, Ph.D., E.I.T.

chelmeayala@ualberta.ca