Advanced Wastewater Treatment Technologies

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Introduction

- Industrial wastewater - variety of pollutants with varying concentrations and properties
- No single technology available to treat all industrial wastewaters
- Technology selection - based on type of pollutants, concentration of pollutants and treated water quality requirement
- Treatments: A combination of Physical, physico-chemical and biological processes
Physical Processes

• Sedimentation
• Filtration
  – Surface filtration
    • Sieves, cloth filters, membrane filters
  – Deep filtration
    • Sand filter
    • Other media filters
• Evaporation
  – Natural evaporators
  – Vacuum Evaporators
  – Mechanical evaporators
• Gas Transfer
Physico-Chemical Processes

- Coagulation and flocculation, electro coagulation
- Adsorption - New and tailor made adsorbents
- Ion Exchange -
- Precipitation
- Membranes – RO, CDI, electro dialysis
- Oxidation Reduction
  - Advanced Oxidation
Biological Processes

• Aerobic
• Anaerobic
• Biological processes can be modified by using enriched microbes for selective complex organic wastes.
Advance oxidation processes (AOPs)

- Volume and treatment time is considerably reduced.
PLASMA

OH^\circ

H^\circ

O^\circ

O_2

HO_2

H_2O_2

O_3

UV

High electric field

Intense wave

Reactive species

Advance Oxidation

Oxidation potential

3.03

2.80

2.42

2.07

1.78

[V]

F_2

OH

O

O_3

H_2O_2
Quantification of ROS
Trend of ROS formation

Haber and Weiss, 1934

\[ \cdot \text{OH} + \cdot \text{H}_2\text{O}_2 \rightarrow \cdot \text{H}_2\text{O} + \cdot \text{HO}_2 \cdot \]

\[ \cdot \text{HO}_2 \cdot + \cdot \text{H}_2\text{O}_2 \rightarrow \cdot \text{H}_2\text{O} + \cdot \text{O}_2 + \cdot \text{OH} \]

\[ \cdot \text{OH} + \cdot \text{OH} \rightarrow \cdot \text{H}_2\text{O}_2 \]

Singh et al., 2016c
Effects of system parameters on ·OH formation

- **Voltage**
  - 17 kV
  - 20 kV
  - 23 kV
  - Graph shows concentration over time.

- **Frequency**
  - 20 Hz
  - 25 Hz
  - 30 Hz
  - Graph shows concentration over time.

- **pH**
  - pH 4
  - pH 7
  - pH 9
  - Graph shows concentration over time.

- **Alkalinity**
  - 200 mg/L
  - 400 mg/L
  - 600 mg/L
  - Graph shows concentration over time.

- **Humic acid**
  - 1 mg/L
  - 5 mg/L
  - 10 mg/L
  - Graph shows concentration over time.
Effects of system parameters on $\text{H}_2\text{O}_2$ formation

**Voltag**

**Frequenc**

**pH**

**Alkalinity**

**Humic acid**

**Glucose**

Singh et al., 2016c
# Kinetics study of ROS formation

<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>Rate of Reaction for OH radical (mol L$^{-1}$ s$^{-1}$)</th>
<th>Rate of Reaction for H$_2$O$_2$ (mol L$^{-1}$ s$^{-1}$)</th>
<th>Rate of Reaction for O$_2^{2-}$ (mol L$^{-1}$ s$^{-1}$)</th>
<th>Rate of Reaction for O$_3$ (s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>3.1</td>
<td>1.0</td>
<td>0.4</td>
<td>0.195</td>
</tr>
<tr>
<td>20</td>
<td>4.0</td>
<td>2.0</td>
<td>0.6</td>
<td>0.225</td>
</tr>
<tr>
<td>23</td>
<td>5.3</td>
<td>3.4</td>
<td>1.0</td>
<td>0.28</td>
</tr>
</tbody>
</table>

*Note:* The unit for $r_{\text{OH}}$, $r_{\text{H}_2\text{O}_2}$ and $r_{\text{O}_3}$ is $10^{-6}$ mol L$^{-1}$ s$^{-1}$, $10^{-6}$ mol L$^{-1}$ s$^{-1}$ and $10^{-6}$ mol L$^{-1}$ s$^{-1}$.

Singh et al., 2016c
3. Methylene Blue Degradation Study

Effects of system parameters

**Voltage**
- % Degradation vs. Time (min)
- Different voltages (23 kV, 20 kV, 17 kV, 15 kV, 12 kV)

**Frequency**
- % Degradation vs. Time (min)
- Different frequencies (20 Hz, 25 Hz, 30 Hz)

**pH**
- % Degradation vs. Time (min)
- Different pH levels (pH 4, pH 7, pH 9)

**Alkalinity**
- % Degradation vs. Time (min)
- Different concentrations (0 mg/L, 5 mg/L, 10 mg/L, 15 mg/L, 20 mg/L)

**Humic Acid**
- % Degradation vs. Time (min)
- Different concentrations (0 mg/L, 5 mg/L, 10 mg/L, 15 mg/L, 20 mg/L)

**Glucose**
- % Degradation vs. Time (min)
- Different concentrations (0 mg/L, 5 mg/L, 10 mg/L, 15 mg/L, 20 mg/L)

Singh et al., 2016c
Mass Spectra for Methylene blue and its intermediates

Blank

0 min

Singh et al., 2016c
Benetoli et al., 2012

Singh et al., 2016c
Technical Achievements

Rapid degradation and mineralization of Methylene blue (dye)

• **Description:**
  Investigation of PPT efficiency for the degradation of dye.

• **Novelty:**
  - Different ROS such as $\cdot$OH, $\text{H}_2\text{O}_2$, $\text{O}_3$ and $\text{O}_2\text{'}$ quantification in different environmental conditions.
  - Effect of different *system parameters* on treatment efficiency.
  - Under PPT, methylene blue *degradation pathway* was proposed.
Pesticide - Carbofuran

Initial Concentration – 1ppm

Voltage effect

Frequency effect

Singh et al., 2016d
Effects of Environmental Parameters

**Alkalinity**

**Humic acid**

**pH**
Effect of Initial Carbofuran Concentration
Table – Degradation kinetics of carbofuran degradation

<table>
<thead>
<tr>
<th>Initial concentration (mg/L)</th>
<th>First order rate constant (min(^{-1}))</th>
<th>(R^2)</th>
<th>(t_{1/2}) (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>2.68</td>
<td>1.00</td>
<td>1.0</td>
</tr>
<tr>
<td>1</td>
<td>1.71</td>
<td>0.93</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>0.82</td>
<td>0.97</td>
<td>1.3</td>
</tr>
<tr>
<td>5</td>
<td>0.57</td>
<td>0.97</td>
<td>1.6</td>
</tr>
<tr>
<td>10</td>
<td>0.61</td>
<td>0.92</td>
<td>2.5</td>
</tr>
<tr>
<td>20</td>
<td>0.23</td>
<td>0.91</td>
<td>3.5</td>
</tr>
<tr>
<td>30</td>
<td>0.32</td>
<td>0.95</td>
<td>5.6</td>
</tr>
</tbody>
</table>
## Main Carbofuran Intermediates – LC/MS analysis

<table>
<thead>
<tr>
<th>Compound</th>
<th>Molecular mass (m/z) with Na⁺ adduct</th>
<th>Actual molecular mass (m/z)</th>
<th>Chemical structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbofuran</td>
<td>244</td>
<td>221</td>
<td><img src="image" alt="Chemical Structure" /></td>
</tr>
<tr>
<td>A</td>
<td>260</td>
<td>237</td>
<td><img src="image" alt="Chemical Structure" /></td>
</tr>
<tr>
<td>B</td>
<td>232</td>
<td>209</td>
<td><img src="image" alt="Chemical Structure" /></td>
</tr>
</tbody>
</table>

Singh et al., 2016
<table>
<thead>
<tr>
<th>Compound</th>
<th>Molecular mass (m/z) with Na$^+$ adduct</th>
<th>Actual molecular mass (m/z)</th>
<th>Chemical structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>187</td>
<td>164</td>
<td><img src="image1" alt="Chemical structure" /></td>
</tr>
<tr>
<td>D</td>
<td>159</td>
<td>136</td>
<td><img src="image2" alt="Chemical structure" /></td>
</tr>
<tr>
<td>E</td>
<td>232</td>
<td>209</td>
<td><img src="image3" alt="Chemical structure" /></td>
</tr>
<tr>
<td>F</td>
<td>133</td>
<td>110</td>
<td><img src="image4" alt="Chemical structure" /></td>
</tr>
<tr>
<td>G</td>
<td>166</td>
<td>143</td>
<td><img src="image5" alt="Chemical structure" /></td>
</tr>
</tbody>
</table>
Proposed pathway for Carbofuran degradation

Singh et al., 2016d
Eco-toxicity assay for Carbofuran degradation

- Model Micro-alga – *Chlorella Vulgaris*
Pesticide: 2-4-D

Voltage and Frequency effect

Effect of radicals quencher
Pharmaceuticals Active Compounds (PACs)

PACs – Diclofenac, Carbamazepine and Ciprofloxacin – 1ppm

Voltage – 25 kV and Frequency – 25 Hz
LC-MS Analysis

[LC-MS spectrum image with m/z values and intensity scale]
Diclofenac (DCF)

Before Treatment
Diclofenec

After 4 min treatment
Carbamazepine (CBZ)

Before Treatment

CBZ without Na+

CBZ with Na+ ion
Carbamazepine

After 4 min Treatment
Ciprofloxacin (CPF)
Ciprofloxacin

After 6 min Treatment
Effect of pH and radical scavengers

Time for complete degradation (min)

pH 5  pH 7  pH 9  Alk 200 mg/L  Alk 400 mg/L  HA 5 mg/L  HA 10 mg/L

Rate constant k (min⁻¹)

Y (g/kWh)
Single and mixed pollutant degradation
Toxicity assay

The graph shows toxicity assay results over different incubation times (24, 48, and 72 hours) and at various time points (0 min, 2 min, 4 min, 6 min). The graph compares different treatments (DCF, CBZ, CPF, Mix) in percentage toxicity vs control.
5. Continuous Reactor study
Continuous Reactor

• Reaction volume – 29 cm x 19 cm x 0.5 cm
• Spacing between the needles = 2 cm (optimized in batch reactor)
• Optimized flow rate = 10 mL/min
ECs degradation study

- Initial concentration – 1ppm
ECs degradation study

- Initial conc. – 10 ppm
Summary/Conclusion

• Different ROS such as $\cdot$OH, $\text{H}_2\text{O}_2$, O$_3$ and O$_2$· quantification in different environmental conditions.

• Effect of different time mode on disinfection efficiency.

• Combined effect of system parameters on disinfection efficiency and empirical model development.

• Understanding the bacterial disinfection mechanism in PPT.

• Study on dye degradation and its fate in PPT process.
Summary/Conclusion

• Complete degradation of ECs (Carbofuran, 2-4-D, DCF, CBZ and CPF) was achieved within 4 to 6 min treatment time in batch study.

• **Environmental parameters** significantly affect the degradation efficiency.

• Possibility of **Reductive pathway in plasma technology** – not only oxidative pathway.

• **Complete mineralization and detoxification of ECs** was achieved.

• Continuous reactor – design and efficiency was evaluated.
Development and Performance Evaluation of a Hybrid Treatment System for the Complete Treatment of Pharmaceutical Wastewater
INTRODUCTION

PROCESS IN PHARMACEUTICAL INDUSTRY

DISTRIBUTION OF VOLATILE SOLVENTS IN WASTEWATER

MAJOR PROBLEM: VOC emissions during the treatment of pharmaceutical wastewater.

LIMITATION OF EXISTING TREATMENT SYSTEMS

- Only focus on removal of organic pollutants
- Emission of VOC is not accounted

Saravanane et al., 2001; Ince et al., 2002; Raj and Anjaneyulu, 2005
“Reduction of VOC emission from the treatment units”

### LIMITATIONS IN EXISTING TREATMENT SYSTEM FOR REMOVAL OF VOC

- Individual pollutant study  
  - Cattony et al., 2005
- Degradation of VOC at low concentration  
  - Quesnel and Nakhla, 2005
- No focus on the reduction of VOC emission from bioreactors  
  - Ozdemir et al., 2010
  - Dawery, 2013

Presence of high biomass is reported to reduce VOC emissions

- **Submerged aerated biological filter (SABF) and Membrane bioreactor (MBR)**  
  - Cheng, 2009; Min and Ergas, 2006
- Need to evaluate the performance **SABF** to treat mixture of VOC
- Effect of operational parameters like air flow rate, hydraulic retention time (HRT) and organic loading rate (OLR) on VOC emission is an area to be explored
- Feasibility of **Membrane bioreactor** as a post treatment unit and its potential to reduce VOC emission is an area to be explored
ENRICHMENT OF AEROBIC CULTURE

BATCH STUDIES

CONTINUOUS STUDIES

SINGLE SUBSTRATE

DUAL SUBSTRATES

MULTIPLE SUBSTRATES

PERFORMANCE EVALUATION OF SUBMERGED AERATED BIOLOGICAL FILTER

PERFORMANCE EVALUATION OF ACTIVATED SLUDGE PROCESS

EFFECT OF BIOLOGICAL TREATMENT UNIT ON MEMBRANE BIOREACTOR

EXTERNAL CONFIGURATION

EFFECT OF SUBMERGED AERATED BIOLOGICAL FILTER EFFLUENT

EFFECT OF ACTIVATED SLUDGE PROCESS EFFLUENT

INTERNAL CONFIGURATION

EFFECT OF SUBMERGED AERATED BIOLOGICAL FILTER EFFLUENT

EFFECT OF ACTIVATED SLUDGE PROCESS EFFLUENT

TARGET POLLUTANTS

Methanol, acetone, dichloromethane, benzene and toluene

METHODOLOGY

START-UP PHASE

EFFECT OF AIR FLOW RATE

EFFECT OF HYDRAULIC RETENTION TIME

EFFECT OF ORGANIC LOADING RATE
Studies with single substrate biodegradation

<table>
<thead>
<tr>
<th>Methanol, acetone, benzene</th>
<th>Toluene</th>
<th>Dichloromethane (DCM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100, 300, 500, 700 and 1000 mg/L</td>
<td>100, 300 and 500 mg/L</td>
<td>10 and 20 mg/L</td>
</tr>
</tbody>
</table>

Dual substrate interaction studies with dichloromethane

<table>
<thead>
<tr>
<th>Low concentration studies</th>
<th>High concentration studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol- DCM / Acetone- DCM</td>
<td>Methanol- DCM / Acetone- DCM</td>
</tr>
<tr>
<td>Benzene- DCM/ Toluene- DCM</td>
<td>Benzene- DCM/ Toluene- DCM</td>
</tr>
<tr>
<td>Non chlorinated solvent ~ 100 mg/L , DCM ~ 50mg/L</td>
<td>Non chlorinated solvent ~ 1000 mg/L, DCM ~ 50mg/L</td>
</tr>
</tbody>
</table>

Multiple Substrate Interaction studies

| In the absence and presence of Dichloromethane | Mixture of methanol, acetone, benzene dichloromethane and toluene at equal concentration (50, 100, 200 mg/L) |

POLLUTANTS IN UNTREATED PHARMACEUTICAL WASTEWATER IN INDIA

Methanol (2500–3000 mg/L), Acetone (500 mg/L – 1000 mg/L), Benzene and toluene (400–700 mg/L), Dichloromethane (120 - 380 mg/L)

(Gupta et al., 2005, Vimig et al., 2003)
BATCH BIODEGRADATION RESULTS

SINGLE SUBSTRATE DEGRADATION

- Degradation of Non chlorinated pollutants were faster
- Dichloromethane was observed to recalcitrant to biodegradation
- *Burkholderia kururiensis* and *Bacillus cereus* were predominant species.
- Monod inhibition model predicted single pollutant biodegradation

DUAL SUBSTRATE INTERACTION STUDIES

Degradation of 50 mg/L of dichloromethane in the presence of 100 mg/L of non chlorinated solvents

Degradation of 50 mg/L of dichloromethane in the presence of 1000 mg/L of non chlorinated solvents
Absence of DCM: All the non chlorinated solvents were degraded much faster compared to their degradation in a single pollutant system.

Presence of DCM: Presence of DCM prolonged the degradation of all the non chlorinated solvents.

Enhanced degradation of dichloromethane in the presence of other solvents.
CONCLUSION FROM BATCH STUDIES

- All the target pollutants were degraded in the aerobic conditions
- **First report on the enhanced degradation of dichloromethane in the presence of other non chlorinated pollutants**
- Low concentrations (100 mg/L) of non chlorinated solvents did not interfere with the DCM degradation
- High concentrations of non chlorinated solvents (1000 mg/L) enhanced the DCM degradation and a severe competition between the chlorinated and the non chlorinated solvents was observed.
- In multiple substrate system also, presence of DCM prolonged the degradation of the other non chlorinated solvents.

ODEGRADATION STUDIES IN CONTINUOUS BIOREACTORS

CONTINUOUS BIOREACTORS

SUBMERGED AERATED BIOLOGICAL FILTER

ACTIVATED SLUDGE PROCESS
CONTINUOUS BIOREACTORS

**Influent COD**

**SABF - Effluent COD**

**VOC emission**

**Wet biomass (g)**
PERFORMANCE OF SUBMERGED AERATED BIOLOGICAL FILTER (SABF) UNDER DIFFERENT OPERATING CONDITIONS

COD REMOVAL FROM SABF

VOC EMISSION FROM SABF

Priya.V.S., Philip,L. Treatment of Volatile Organic Compounds in Pharmaceutical Wastewater using Submerged Aerated Biological Filter (Accepted in Chemical Engineering journal)
PERFORMANCE OF ACTIVATED SLUDGE PROCESS (ASP) UNDER DIFFERENT OPERATING CONDITIONS

**Influent COD**

- Days: 0 to 215
- COD (mg/L): 0 to 10,000

**ASP-Effluent COD**

- Days: 0 to 215
- COD (mg/L): 0 to 6,000

**VOC emission**

- Days: 0 to 215
- VOC emission (mg/d): 0 to 400

**COD removal efficiency (%)**

- Different operating conditions: Start-up, Air Flow Effects, Effect of HRT, Effect of OLR

- Varying values: 1 to 12 (kg/m³/d), 0.8 to 20 (L/min), 2 to 20 (h), 0.8 to 20 (kg/m³/d)
PERFORMANCE EVALUATION OF MEMBRANE BIOREACTOR

SABF COMBINED WITH MEMBRANE BIOREACTOR

- Suspended solids: 60mg/L
- EPS: 12mg/g

ASP COMBINED WITH MEMBRANE BIOREACTOR

- Suspended solids: 2000mg/L
- EPS: 100mg/g

CONTINUOUS BIOREACTORS

MEMBRANE BIOREACTOR
TREATMENT OF EFFLUENT FROM SUBMERGED AERATED BIOLOGICAL FILTER USING MEMBRANE BIOREACTOR

RESULTS

VARIATION IN FLUX

VARIATION IN TRANSMEMBRANE PRESSURE

VARIATION IN COD REMOVAL

VARIATION IN VOC EMISSION
TREATMENT OF EFFLUENT FROM AERATION TANK OF ACTIVATED SLUDGE PROCESS USING MEMBRANE BIOREACTOR

VARIATION IN FLUX

VARIATION IN TRANSMEMBRANE PRESSURE

Performance of Hybrid treatment system

<table>
<thead>
<tr>
<th>Condition</th>
<th>Permeate COD (mg/L)</th>
<th>% COD reduction</th>
<th>VOC emission (mg/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SABF + External MBR</td>
<td>622</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>SABF + Internal MBR</td>
<td>0.04</td>
<td>99</td>
<td>nil</td>
</tr>
</tbody>
</table>
CONCLUSIONS

- Submerged aerated biological filter were more resistant to higher organic loading rate than compared to activated sludge process.
- Limited mass transfer of VOC to the gas phase at low air flow rate reduced VOC emission from submerged aerated biological filter.
- Optimization of operating conditions such as air flow rate, hydraulic retention time and organic loading rate reduced the VOC emissions from submerged aerated biological filter.
- Effluent from SABF were effectively treated using membrane bioreactor.
- Complete removal of VOC from SABF effluent was achieved while adopting internal MBR configuration.
- Flux reduction and TMP rise were more significant during the treatment of ASP effluent.
- SABF can be coupled along with the MBR operated under internal configuration for the complete removal of VOC from the pharmaceutical wastewater.
BIOREMEDIATION OF Cr(VI) CONTAMINATED SOIL AND GROUND WATER SYSTEMS
TamilNadu Chromate Chemicals Limited, Ranipet, Vellore District, Tamilnadu.
Chromium waste
Disposal area: 5 acres (2 hectares)
$2 \times 10^5$ Tones of waste)
Chromium Leachate in Ground Water
Cr(VI) Concentration in open wells/bore wells in and around TCCL (Prepared by IIT Madras)

<table>
<thead>
<tr>
<th>Location</th>
<th>Cr(VI) Concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulian Kannu Eri</td>
<td>178 mg/l</td>
</tr>
<tr>
<td>Karai Eri</td>
<td>9.6 mg/l</td>
</tr>
<tr>
<td>To Ranipet/Chennai</td>
<td>0.31 mg/l</td>
</tr>
<tr>
<td>To Bangalore</td>
<td>271 mg/l</td>
</tr>
<tr>
<td>SIPCOT Service Road</td>
<td>141 mg/l</td>
</tr>
<tr>
<td>TCCL</td>
<td>34 mg/l</td>
</tr>
<tr>
<td>BDL</td>
<td>21 mg/l</td>
</tr>
<tr>
<td>BDL</td>
<td>141 mg/l</td>
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<tr>
<td>BDL</td>
<td>271 mg/l</td>
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<td>BDL</td>
<td>34 mg/l</td>
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</tr>
<tr>
<td>BDL</td>
<td>0.31 mg/l</td>
</tr>
</tbody>
</table>

Legend:
- BDL: Below Detection Limit
CLEANUP METHODS FOR FIELD CONDITIONS

GROUND SURFACE

LANDFILL

LEACHATE

WATER TABLE

INSITU BIO-REMEDIATION

Movement of Groundwater
Methods for Remediation of Cr(VI) Contaminated Aquifers

• Pump and Treat systems
• Geochemical fixation
• Permeable Reactive Barriers
• Reactive Zones
• Natural attenuation
• Phyto-remediation
Schematic Representation of a Permeable Reactive Bio-barrier
2

BATCH STUDIES

- Bio-kinetic parameters
- Adsorption Parameters
Cr(VI) Reduction Studies with CRB, SRB and IRB, in Combinations

1. CRB –Aerobic
2. CRB -Anaerobic
3. SRB-Anaerobic
4. IRB- anaerobic
5. CRB+IRB
6. CRB+SRB+IRB

Adsorption Studies
Adsorbents– Soil , Sand
Adsorbates:
1. Cr(VI)
2. Molasses/Sugar
3. Lithium
4. Cr(III)
Cr(VI) Reduction in Aerobic Conditions

**Chromium(VI) reduction**

**Growth curve**

**COD removal rate**
Cr (VI) Reduction by CRB under Anaerobic Condition

Growth curve

COD reduction curve

Cr reduction curve
Growth of CRB+IRB+SRB under Anaerobic Condition Fe(400ppm), Sulphate(500ppm)
Model

Suffix 1,2,3 represents CRB,SRB,IRB respectively

\[ M = \sum_{i=1}^{3} M_i \]

\[ S = \sum_{i=1}^{3} S_i \]

\[ Cr_6 = \sum_{i=1}^{3} Cr_{6i} \]

\[ S_i = S\left(\frac{M_i}{M}\right) \]

\[ Cr_{6,i} = Cr_6\left(\frac{M_i}{M}\right) \]
\[
\frac{dM_{\text{CRB}}}{dt} = \frac{M_{\text{CRB}} \cdot \mu_{\text{max,CRB}} \cdot S\left(\frac{M_i}{M}\right)}{K_{s,\text{CRB}} + S\left(\frac{M_i}{M}\right)} \left(\frac{K_{i,\text{CRB}}}{K_{i,\text{CRB}} + Cr_6\left(\frac{M_i}{M}\right)}\right)
\]

\[
\frac{dM_{\text{SRB}}}{dt} = \frac{M_{\text{SRB}} \cdot \mu_{\text{max,SRB}} \cdot S\left(\frac{M_i}{M}\right)}{K_{s,\text{SRB}} + S\left(\frac{M_i}{M}\right)} \left(\frac{K_{i,\text{SRB}}}{K_{i,\text{SRB}} + Cr_6\left(\frac{M_i}{M}\right)}\right)
\]

\[
\frac{dM_{\text{IRB}}}{dt} = \frac{M_{\text{IRB}} \cdot \mu_{\text{max,IRB}} \cdot S\left(\frac{M_i}{M}\right)}{K_{s,\text{IRB}} + S\left(\frac{M_i}{M}\right)} \left(\frac{K_{i,\text{IRB}}}{K_{i,\text{IRB}} + Cr_6\left(\frac{M_i}{M}\right)}\right)
\]
Cr(VI) reduction by CRB, SRB and IRB under anaerobic conditions for different initial Cr(VI) concentrations

Somasundaram et al., Jl. of Hazard. Mater., 2009
3

BENCH SCALE STUDIES
Outlet Reservoir

Inlet Reservoir

Perforate plate

Bio-barrier (soil C)

Sample ports

Soil B

Schematic of experimental setup
Cr(VI) break-through curve with biotransformation, Soil A

Shashidhar et al., Jl. of Hazard. Mater., 2006
Cr(VI) breakthrough just before and after Biobarrier BB1
(Bact conc= 0.0205 mg/g of soil)

Cr(VI) breakthrough just before and after Biobarrier (BB2)
(Bact conc= 0.205 mg/g of soil)
Initial pore velocity 7.3 cm/h

Shashidhar et al., Jl. of Hazard. Mater., 2007
4

PILOT SCALE STUDIES
Schematic Diagram of the Reactor

Inlet Chamber

Bio barrier-0.1M

Outlet chamber
Location of Wells

The diagram shows the location of wells in relation to a bio barrier, with distances marked in centimeters.
Cr (VI) Concentration before the Bio-barrier in Bioreactor

![Graph showing Cr (VI) Concentration over time for different wells.](image-url)
Cr (VI) Concentration after the Bio-barrier in Bioreactor
Cr (VI) Concentration in the Blank Reactor before Barrier
Cr (VI) Concentration in the Blank Reactor after the Barrier

![Graph showing Cr (VI) concentration over time for Well B11 and Well B12. The graph plots Cr (VI) concentration in mg/L against time in days.]
PLAN VIEW OF REACTOR CONTAINING FOUR INJECTION WELLS

Injection wells

15 cm
35 cm
20 cm
25 cm
100 cm
15 cm
25 cm

Inlet Chamber
Cr (VI) Concentration in Reactor before four Injection wells

Cr(VI) concentration was increased from 60 to 250 mg/L. Bacteria were injected again.
Cr (VI) Concentration in Reactor after four Injection wells

Cr(VI) concentration was increased from 60 to 250 mg/L

Bacteria injected again

Expt well 13
Expt well 15
Expt well 17
Experimental and modeling results for temporal variation of Cr(VI) concentration in wells 11-16 (at a distance of 110 cm from inlet) in reactor R1

Jeyasigh et al., Chem. Engrg. Jl., 2011
Experimental and modeling results for temporal variation of Cr(VI) concentration in wells 11-16 in reactor R2

Jeyasigh et al., Chem. Engng. Jl., 2011
Experimental and modeling results for temporal variation of Cr(VI) concentration at well no 1 in reactor R4 (4 wells system)

Jeyasigh et al., Chem. Engng. Jl., 2011
Jeyasigh et al., Chem. Engrg. Jl., 2011
Jeyasigh et al., Chem. Engrg. Jl., 2011
Field Demonstration of Bioremediation of Cr(VI) Contaminated Soil and Aquifer in Ranipet, Tamilnadu
SCOPE

• Remediation of at least 5 tons of chromium sludge in the vicinity of Tamilnadu Chromates and Chemicals Limited (TCCL) at the site;

• Demonstration of in-situ bioremediation of Cr(VI) contaminated aquifer in a 5 m ×5 m area of aquifer in the vicinity of Tamilnadu Chromates and Chemicals Limited (TCCL), Ranipet, by injection well - reactive zone technology;
Well locations in the experimental plot

IW – Injection well
MW - Monitoring well
PW-Pumping Well

Bacteria Injected in the well shaded in gray color
RESULTS

Soil Remediation

Variation of Cr(VI) concentration with respect to time in solid waste remediation (Mass of untreated sludge added at various time is mentioned inside the graph)
Variation of total chromium concentration with respect to time in solid waste remediation
Remediated and un-remediated soils

Five Tones of Remediated Soil Leachate from remediated soil

Un-remediated Soil and Leachate from un-remediated soil
Aquifer Remediation

Bioresmediation using Molasses (Jaggery) as the Carbon Source

Variation of Cr (VI) concentration with respect to time in wells 1 and 2 (molasses as carbon source)
BIOREMEDIATION USING SUGAR AS THE CARBON SOURCE

- Remediation of Cr(VI) aquifers were also carried out using sugar as the carbon source.

- For this study the initial biomass concentration was reduced to 1/10th of that used in the previous case.

- Carbon source concentration also was reduced to 1/4th and feeding interval was increased to 7-10 days.

- The fate and transport of chromium (both Cr(VI) and Cr(III)), molasses and its derivatives, and microbes during the study period was monitored.
Bioremediation using Sugar as the Carbon Source: Cr(VI) concentrations

Cr(VI) Concentration for well 1 and 2

Cr(VI) concentration for well 3, 4, 5, and 6

Cr(VI) concentration for well 7, 8, 9, and 10

Cr(VI) concentration for well 11, 12, 13, and 14
COD concentrations in various wells during bioremediation using sugar as carbon source.
Total Cr concentrations in various wells during bioremediation using sugar as carbon Source.
Water samples from various wells after remediation
Water samples from various wells after remediation
## Analysis of Heavy Metals in Aquifer

<table>
<thead>
<tr>
<th>Metals</th>
<th>Well 1 (mg/L)</th>
<th>Well 2 (mg/L)</th>
<th>Well 3 (Injection well)</th>
<th>Well 5 (Injection well)</th>
<th>Well 9</th>
<th>Well 13</th>
<th>Well 14</th>
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<tr>
<td>Copper</td>
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<td>BDL</td>
<td>BDL</td>
<td>BDL</td>
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<td>BDL</td>
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<tr>
<td>Lead</td>
<td>BDL</td>
<td>BDL</td>
<td>0.0925</td>
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<td>0</td>
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<tr>
<td>Manganese</td>
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<td>0.067</td>
<td>0.068</td>
<td>0.057</td>
<td>0.017</td>
<td>0.054</td>
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<tr>
<td>Zinc</td>
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<td>0.017</td>
<td>0.2825</td>
<td>0.2175</td>
<td>0.0225</td>
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<td>0.09</td>
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<tr>
<td>Cr(VI)</td>
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<td>140.2</td>
<td>BDL</td>
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<tr>
<td>Iron</td>
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<td>Nickel</td>
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Field Applications: Technology Transfer
Radiant Electroplaters

- MR. ALI AKBAR, Radiant Electroplaters, 32 KMA Garden Road, Kodungaiyur, Chennai-600118

NGT Case

- The wastes storage tank breached.
- Contaminated the neighboring industrial plot and groundwater
- Industry was closed
Munjal Showa Ltd.,

- Court Order to Close the Industry
- Fine Rs 5 crores.
# Hydro-Geological Conditions

<table>
<thead>
<tr>
<th>TUBEWELL NO.1</th>
<th>TUBEWELL NO.2</th>
<th>TUBEWELL NO.3</th>
<th>TUBEWELL NO.4</th>
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<tbody>
<tr>
<td>DEPTH: 100 MTRS</td>
<td>DEPTH: 150 MTRS</td>
<td>DEPTH: 105 MTRS</td>
<td>DEPTH: 105 MTRS</td>
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<tr>
<td><strong>STRATA</strong></td>
<td><strong>TABLE</strong></td>
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<tr>
<td>GL-12.5 M</td>
<td>DRY SAND &amp; CLAY</td>
<td>GL-12.5 M</td>
<td>DRY SAND &amp; CLAY</td>
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<tr>
<td>12.5-20 M</td>
<td>FINE SAND</td>
<td>12.5-20 M</td>
<td>FINE SAND</td>
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<tr>
<td>20-30 M</td>
<td>HARD CLAY</td>
<td>20-30 M</td>
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<td>50-60 M</td>
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<td>60-80 M</td>
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<td>80-100 M</td>
<td>FINE SAND</td>
<td>85-105 M</td>
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<td>105- BELOW</td>
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<td>105- BELOW</td>
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<tr>
<td>150 M</td>
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<td>TUBEWELL NO.5</td>
<td>TUBEWELL NO.6</td>
<td>TUBEWELL NO.7</td>
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<td>DEPTH: 105 MTRS</td>
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</tr>
<tr>
<td>20-35 M</td>
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<tr>
<td>35-55 M</td>
<td>FINE SAND</td>
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</tbody>
</table>
Shriram Pistons and Rings Ltd, Meerut Road, Ghaziabad, INDIA

MAP SHOWING 02 PLUME FORMATIONS IN AND AROUND LOHIA NAGAR

Between Dewan Rubber and Mascot

Contaminated Zone-1

LEGEND
(Hexavalent Chrome concentration)
- Red: 12-16 mg/L
- Brown: 8 – 12 mg/L
- Orange: 4 – 8 mg/L
- Yellow: 1 – 4 mg/L

CONTAMINATED ZONE IDENTIFIED FOR SETTING UP ETP
MAP OF LOHIANAGAR AND ADJOINING AREA
SHOWING SEGMENTS A – E
## Quantification of Contaminated Groundwater

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Segment</th>
<th>Quantity of Contaminated Groundwater, Q=A<em>Wlf</em>Sp.Y.</th>
<th>Range of Hexavalent Chromium in Mg/L</th>
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<tbody>
<tr>
<td>1</td>
<td>Segment A</td>
<td>69,600 cu.m./yr.</td>
<td>Nil – 3.4</td>
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<tr>
<td>2</td>
<td>Segment B</td>
<td>2,08,800 cu.m./yr.</td>
<td>0.2 – 16.3</td>
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<tr>
<td>3</td>
<td>Segment C</td>
<td>52,200 cu.m./yr.</td>
<td>0.1 – 1.3</td>
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<tr>
<td>4</td>
<td>Segment D</td>
<td>1,74,000 cu.m./yr.</td>
<td>1.3 – 15.4</td>
</tr>
<tr>
<td>5</td>
<td>Segment E</td>
<td>1,04,400 cu.m./yr.</td>
<td>Nil – 1.3</td>
</tr>
</tbody>
</table>
Thank you