PHYTOREMEDIATION OF ILLEGALLY DUMPED PETROLEUM HYDROCARBON-CONTAMINATED WASTEWATER USING VETIVER (VETIVERIA ZIZANIOIDES (L.) NASH)

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ILLEGAL DUMPING OF PHENOL- AND TPH-CONTAMINATED WASTEWATER
PAST KING BHUMIBOL ADULYADEJ PIONEERED AND CONTINUOUSLY PROMOTED RESEARCH AND APPLICATION OF VETIVER IN THAILAND SINCE 1991
With aeration, vetiver plantlet on a floating platform can effectively detoxify phenol.

- Two-Phase Behavior
- Phenol = 500 mg/L
- Phenol = 100 mg/L inhibits microbial growth and activity
- Using aeration alone, it will take 235 days to degrade phenol
- With vetiver plantlet (57% plant coverage), it takes 31 days

WELL-DEVELOPED VETIVER RHIZOSPHERE COATED WITH BIOFILM ENHANCES PHENOL DEGRADATION EVEN MORE

- Two-Phase Behavior
- 2 times faster in Phase I if with biofilm and well-developed rhizosphere
- 5 to 10 times faster in Phase II if with biofilm and well-developed rhizosphere
- With vetiver +biofilm (57% plant coverage), it takes 7.8 days in comparison to 31 days without biofilm and 235 days without vetiver.
TPH CONTAMINATED WATER AND SEDIMENT: FIELD-SCALED TREATMENT
FROM LAB TO LIFE WITH SOCIAL ENGAGEMENT
SUCCESSFUL FIELD-SCALED APPLICATION OF WATER TREATMENT ALL BY COMMUNITY
NATURAL ATTENUATION: TPH DEGRADATION IN WATER WITHOUT VETIVER

\[
TPH_{\text{final}} = TPH_{\text{std}} + A \exp(-Bt)
\]

<table>
<thead>
<tr>
<th>TPH</th>
<th>A (µg/L)</th>
<th>B (Day(^{-1}))</th>
<th>TPH\textsubscript{std} (µg/L)</th>
<th>R(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C10-C14</td>
<td>335</td>
<td>0.204</td>
<td>95.98</td>
<td>0.9960</td>
</tr>
<tr>
<td>C15-C28</td>
<td>303</td>
<td>0.0012</td>
<td>0</td>
<td>0.0023</td>
</tr>
<tr>
<td>C29-C36</td>
<td>445.55</td>
<td>0.018</td>
<td>0</td>
<td>0.7140</td>
</tr>
<tr>
<td>Overall</td>
<td>239</td>
<td>0.159</td>
<td>578</td>
<td>0.9779</td>
</tr>
</tbody>
</table>

Cleanup Level = WHO Guideline
PHOTOREMEDIATION: TPH DEGRADATION IN WATER WITH VETIVER

\[ TPH_{\text{final}} = TPH_{\text{std}} + A \exp(-B*t) \]

<table>
<thead>
<tr>
<th>TPH</th>
<th>A (µg/L)</th>
<th>B (Day(^{-1}))</th>
<th>TPH(_{\text{std}}) (µg/L)</th>
<th>(R^2)</th>
<th>Enhanced Removal Rate Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>C10-C14</td>
<td>335</td>
<td>0.592</td>
<td>0</td>
<td>0.9968</td>
<td>2.90</td>
</tr>
<tr>
<td>C15-C38</td>
<td>453.46</td>
<td>0.791</td>
<td>118</td>
<td>0.9825</td>
<td>659</td>
</tr>
<tr>
<td>C29-C36</td>
<td>303.95</td>
<td>0.079</td>
<td>76.25</td>
<td>0.8663</td>
<td>4.38</td>
</tr>
<tr>
<td>Overall</td>
<td>1058</td>
<td>0.328</td>
<td>244</td>
<td>0.9779</td>
<td>2.06</td>
</tr>
</tbody>
</table>
FIELD-SCALED APPLICATION FOR SEDIMENT TREATMENT ALL BY COMMUNITY
### NATURAL ATTENUATION: TPH DEGRADATION IN SEDIMENT WITHOUT VETIVER

**Equation:**

\[ TPH_{\text{final}} = TPH_{\text{std}} + A \exp(-B \times t) \]

<table>
<thead>
<tr>
<th>TPH</th>
<th>A (mg/kg)</th>
<th>B (Day(^{-1}))</th>
<th>(TPH_{\text{std}}) (mg/kg)</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C10-C14</td>
<td>8.5</td>
<td>0.774</td>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td>C15-C38</td>
<td>57.17</td>
<td>0.0025</td>
<td>0</td>
<td>0.859</td>
</tr>
<tr>
<td>C29-C36</td>
<td>61.10</td>
<td>0.0032</td>
<td>0</td>
<td>0.7763</td>
</tr>
<tr>
<td>Overall</td>
<td>127.16</td>
<td>0.0036</td>
<td>-</td>
<td>0.8506</td>
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</tbody>
</table>

**Cleanup Level:** 50 mg/kg
PHYTOREMEDIATION: TPH DEGRADATION IN SEDIMENT WITH VETIVER

\[ TPH_{\text{final}} = TPH_{\text{std}} + A \exp(-Bt) \]

<table>
<thead>
<tr>
<th>TPH</th>
<th>A  (mg/kg)</th>
<th>B  (Day(^{-1}))</th>
<th>TPH(_{\text{std}}) (mg/kg)</th>
<th>(R^2)</th>
<th>Enhanced Removal Rate Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>C10-C14</td>
<td>8.83</td>
<td>0.06</td>
<td>2.20</td>
<td>0.9963</td>
<td>-</td>
</tr>
<tr>
<td>C15-C38</td>
<td>59.57</td>
<td>0.017</td>
<td>0</td>
<td>0.9825</td>
<td>6.8</td>
</tr>
<tr>
<td>C29-C36</td>
<td>62.17</td>
<td>0.018</td>
<td>76.25</td>
<td>0.9831</td>
<td>5.6</td>
</tr>
<tr>
<td>Overall</td>
<td>131.89</td>
<td>0.018</td>
<td>0</td>
<td>0.9676</td>
<td>4.95</td>
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</tbody>
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MICROBIAL DIVERSITY IN SEDIMENT

PCR-DGGE: universal primers 5' - CCT ACG GGA GGC AGC AG - 3' and 5' - ATT ACC GCG GCT GCT GG - 3'

- (S19) Planococcus plakoidis
- (S17) Uncultured gamma proteobacterium
- (S16) Uncultured Burkholderiales bacterium
- (S14) Halothiobacillus neapolitanus
- (S13) Duganella sp.
- (S12) Uncultured Ralstonia sp.
- (S11) Bacterium GSM 16S
- (S8) Acidithiobacillus ferrihydrits
- (S6) Alicyclobacillus fermentans
- (S4) Acidithiobacillus ferrooxidans
- (S2) Alicyclobacillus aeris
MICROBIAL DIVERSITY ON VETIVER ROOT

CONCLUSION

- Natural attenuation alone cannot degrade TPH in contaminated water and soil to the cleanup level in the treatment period.

- Vetiver speeded up TPH degradation to comply with the cleanup levels in both contaminated water and soil.
  - 28 days for water.
  - 76 days for soil.

- Presumably, H$_2$O$_2$ and POD together with rhizomicrobes enhanced TPH degradation.

- Phytoremediation using Vetiver is easy and can be implemented by affected villagers.
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