ANAEROBIC TREATMENT OF LOW STRENGTH WASTEWATER

FATMA YASEMIN CAKIR
CIVIL & ENVIRONMENTAL ENGINEERING, UCLA
DECEMBER 5, 2001
SEMINAR OUTLINE

* INTRODUCTION
* PREVIOUS WORK
  - Anaerobic Contact Process
  - Anaerobic Filter (AF)
  - Upflow Anaerobic Sludge Blanket Reactor (UASB)
  - Hybrid reactors
* MODELING
* FUTURE RESEARCH
* CONCLUSIONS
INTRODUCTION

- Advantages of anaerobic treatment
- Why is anaerobic treatment not generally accepted for wastewater treatment?
- First attempts to use anaerobic treatment
- Objective of this seminar
ADVANTAGES of ANAEROBIC TREATMENT

- Low production of waste biological solids
- Low nutrient requirements
- No effluent recycle
- Production of methane
- No energy requirement for aeration (net energy producer, not a consumer)
SOME REASONS FOR POOR ACCEPTANCE

- Anaerobic reaction rates are slow – needed elevated temperatures to obtain reasonable rates in complete mixing reactors
- Process complexity and instability
- Breakthrough occurred when reactors were able to retain biomass independent of hydraulic retention time (analogous to the activated sludge process)
FIRST ATTEMPTS

- Anaerobic Contact Process
  - SCHROEPFER (1955)
- Anaerobic Filter
  - COULTER (1957)
  - YOUNG & McCARTY (1969)
- Upflow Anaerobic Sludge Blanket
  - LETTINGA (1980)
OBJECTIVE

DESCRIBE PREVIOUS WORK
- Conventional Process
- Anaerobic Contact Process
- Anaerobic Filter (AF)
- Upflow Anaerobic Sludge Blanket (UASB)
- Hybrid reactors

OUTLINE RESEARCH PLAN
- Modeling
- Future Research
CONVENTIONAL PROCESS

- Mesophilic (~37°C) & thermophilic (~55°C) operation possible
- Used for stabilizing sludge mainly from activated sludge process
ANAEROBIC CONTACT PROCESS

- Retains biomass in digester independent of HRT
- Problems encountered in separating sludge
SCHROEPFER et al. (1955)

- Developed anaerobic contact process
- **CHARACTERISTICS:**
  - Packinghouse waste (~1500 ppm BOD$_5$)
  - 16 ft*8 ft*6 ft digester, 8 ft*4 ft* 2ft 11in liquid depth separator
  - Separation problem encountered in the reactor
SCHROEPFER *et al.* (1955)

**RESULTS:**

- OLR up to 0.2 lb BOD/ft³ day
- RR=95 % BOD₅ at HRT < 12 hr
- Applies degasifier to evacuate the gas before separator
- Maintains high contact between waste and biological solids
COD REQUIRED FOR HEATING

Typically Needed Temperature Increase for Mesophilic Operation

100% Efficiency

50% Efficiency
ANAEROBIC FILTER

- Fully packed filter
- Retains biomass
  - in voids
  - on surface of packing
- A high specific surface area & high void rate gives better treatment
TYPICAL AF PLASTIC PACKING
YOUNG & McCARTY (1969)

- Developed anaerobic filter

**CHARACTERISTICS:**
- Synthetic waste (1500-6000 mg/l COD)
- OLR = 0.43-3.40 kg/m³.d
- HRT = 4.5-72 hr, Temp = 25°C

**RESULTS:**
- RR = 63-93%, efficient treatment for dilute soluble organic wastes
A combination of a digester & anaerobic filter

**CHARACTERISTICS:**
- Raw sewage (500 mg/l COD)
- Temp=20°C, HRT=24 hr
- Stone packing in filter with n=0.6
- 8 liter digester compartment
PRETORIUS (1971)

RESULTS:
- RR=90% achieved
- Digester part responsible for solids concentration and hydrolysis
- Filter responsible for gasification
PREVIOUS WORK at UCLA

- CHUNG (1982)
  - 720 liter column

- KOBAYASHI et al. (1983)
  - 16 liter column

- ABRAMSON (1987)
  - Two columns (668 & 728 liter)
PILOT SCALE AF’s

1m

3m
UPFLOW ANAEROBIC SLUDGE BLANKET

- Dense granular sludge bed at the bottom
- Full scale reactors in Europe, South America & South Asia in past 15 years
- GSS device at top
LETTINGA (1980)

- Developed UASB

**CHARACTERISTICS:**
- Raw domestic sewage (140-1100 mg/l COD)
- Ambient temp: 8-20°C
- 120 liter reactor
- Sugar beet waste cultivated seed sludge
LETTINGA (1980)

RESULTS:

- COD > 400-500 mg/l ➔ RR=65-90%
- COD < 300 mg/l ➔ RR=50-65%
- Use of granular sludge is suggested
- RR slightly affected by temp
FOLLOW-UP WORK

- **TARE et al.** (1997)  
  - India

- **CHERNICHIARO & CARDOSO** (1999)  
  - Brazil

- **KARNCHANANAWONG et al.** (1999)  
  - Thailand

- **RODRIGUEZ et al.** (2001)  
  - Colombia
HYBRID REACTOR

- Combination of an UASB and AF
  - Sludge bed at the bottom
  - Packing at the top
- Save cost of packing
- Reduce clogging
- Prevent floatation of poor settling particles

Biogas

Effluent

Packing

Sludge blanket

Influent
PREVIOUS WORK

- MIYAHARA & NOIKE (1994)
  - Japan
- TILCHE et al. (1994)
  - Italy
- Di BERARDINO et al. (1997)
  - Portugal
- ELMITWALLI et al. (2001)
  - Egypt
CHUNG & CHOI (1993)

CHARACTERISTICS:
- Naked barley distillery wastewater (3000-6000 mg/l)
- HRT=3-6 days, Temp=35°C
- Polyethylene rings
- Lab scale in Korea

RESULTS:
- RR=89-94 % 1/7 packing
- RR=91-94 % 1/2 packing
CHARACTERISTICS:
- Piggery wastewater
- HRT=3 days, Temp=31-36°C
- Polypropylene random packing
- Full scale in Italy

RESULTS:
- RR=55 %
BORJA et al. (1995)

CHARACTERISTICS:
- Slaughterhouse wastewater (2450 mg/l COD)
- HRT=2-12 hr, Temp=35°C
- 1/3 clay-ring support medium (bentonite)
- Lab scale in UK

RESULTS:
- RR=69-98 %
ELMITWALLI et al. (1999)

CHARACTERISTICS:
- Raw and pre settled sewage (344-456 mg/l COD)
- HRT= 8 hr, Temp=13°C
- Polyurethane foam sheets as packing
- Lab scale in Netherlands

RESULTS:
- RR=61-66 %
MODELING WORK

ANDREWS (1969)
LINDGREN (1983)
HANAKI & MATSUO (1985)
McCARTY & MOSEY (1991)
JEYASEELAN (1997)
WILSON et al. (1998)
BATSTONE et al. (2000)
ANDREWS (1969)

Anaerobic digestion model

KEY FEATURES:

- Use of an inhibition function to relate volatile acid concentration and specific growth rate
- Un-ionized acid as the growth limiting substrate and inhibiting agent
- Dynamic model to predict failure
JEYASEELAN (1997)

- Anaerobic digestion model
- **KEY FEATURES:**
  - Monod kinetics is applied to individual components (carbohydrate, lipids, proteins, others)
  - Steady state model for acid formation and methane formation steps
  - Kinetic coefficients chosen from literature
An empirical model for anaerobic filter

**KEY FEATURES:**
- Si and HRT are used as variables to predict effluent COD
- Modification of Young & McCarty’s model
- Lab scale experiments on domestic and soybean processing wastewater
OUR MODEL

- Anaerobic filter model
- **KEY FEATURES:**
  - Biomass balance equation is modified to include the biomass retained in the filter
  - Dynamic model
  - Temperature effects on growth rate and Henry’s constants are included
  - System of ODE is solved using MATLAB
OUR MODEL

BIOLOGICAL PHASE

\( S_0, \mu_{\text{max}}, K_s, Y, k_d, Q, V \)

\[ \frac{dX}{dt}, \frac{dS}{dt} \]

R

R1, R2, R3, R4, R5, R6

S, X

LIQUID PHASE

\( Z_0, Q, V, K_{La}, K_H, C_o, pH_o \)

\[ \frac{dC}{dt}, T_{Gi}, ALK \]

\( Q_g, P_i \)

GAS PHASE

V, V_g, P_T

\[ \frac{dP_i}{dt}, T_{Gi} \]
BIOLOGICAL PHASE

\[
\frac{dX}{dt} = \frac{Q}{V} \left( X_o - X_E \right) + \left( \mu - k_d \right) X
\]

\[
\frac{dS}{dt} = \frac{Q}{V} \left( S_o - S \right) - \frac{\mu X}{Y_{XS}}
\]

\[
\mu = \frac{\mu_{max} S}{K_S + S}
\]

\[
\mu_{max} = f \left( Temp \right)
\]
LIQUID PHASE

\[ \frac{dC}{dt} = \frac{Q}{V} \left( \text{Inf} - \text{Eff} \right) + \text{Rate} \]

\[ T_{G_i} = K_L a_i \left( C_i^* - C_i \right) \]

\[ C_i^* = K_{Hi} P_i \]

\[ \text{ALK} = [HCO_3^-] + 2 [CO_3^{2-}] + [NH_3] + [OH^-] - [H^+] \]
### RATES

| \( R_1 \) | \( \mu X Y_{CO_2} X^1 \) |
| \( R_2 \) | \( k_d X Y_{CO_2} X^2 \) |
| \( R_3 \) | \( \mu X Y_{CH_4} X^1 \) |
| \( R_4 \) | \( k_d X Y_{CH_4} X^2 \) |
| \( R_5 \) | \( -\mu X Y_{NH_3} X^1 \) |
| \( R_6 \) | \( k_d X Y_{NH_3} X^1 \) |

<table>
<thead>
<tr>
<th>Dissolved Components</th>
<th>Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO(_2)</td>
<td>( T_{G1} + R_1 + R_2 )</td>
</tr>
<tr>
<td>N(_2)</td>
<td>( T_{G2} )</td>
</tr>
<tr>
<td>CH(_4)</td>
<td>( T_{G3} + R_3 + R_4 )</td>
</tr>
<tr>
<td>NH(_3)</td>
<td>( R_5 + R_6 )</td>
</tr>
</tbody>
</table>
\[ \frac{dP_i}{dt} = -P_T DT_i G_i \left( \frac{V}{V_g} \right) - P_i \left( \frac{Q_g}{V_g} \right) \]

\[ Q_i = -DVT_i G_i \]

\[ Q_g = \sum_{i=1}^{3} Q_i + Q_{H_2O} \]

\[ P_{H_2O} = f \left( \text{Temp} \right) \]

\[ i = \begin{bmatrix} CO_2 \\ N_2 \\ CH_4 \end{bmatrix} \]
<table>
<thead>
<tr>
<th>SRT (days)</th>
<th>Temp (F)</th>
<th>HRT (days)</th>
<th>So (mM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>68</td>
<td>1</td>
<td>5.66</td>
</tr>
<tr>
<td>14</td>
<td>77</td>
<td>1</td>
<td>3.90</td>
</tr>
<tr>
<td>16</td>
<td>95</td>
<td>1</td>
<td>3.75</td>
</tr>
<tr>
<td>25</td>
<td>84</td>
<td>0.5</td>
<td>1.22</td>
</tr>
<tr>
<td>43</td>
<td>84</td>
<td>0.75</td>
<td>0.98</td>
</tr>
<tr>
<td>54</td>
<td>80</td>
<td>1.0</td>
<td>1.00</td>
</tr>
<tr>
<td>49</td>
<td>80</td>
<td>1.5</td>
<td>1.00</td>
</tr>
<tr>
<td>15</td>
<td>80</td>
<td>1.75</td>
<td>4.53</td>
</tr>
</tbody>
</table>

Sources: Kobayashi et al. 1983, Abramson 1987
SIMULATED GAS COMPOSITION vs SRT

Gas Composition (%)

Solid Retention Time (days)

- % CH4
- % CO2
- % N2
SIMULATED GAS COMPOSITION vs INFLUENT SUBSTRATE

- % CH4
- % CO2
- % N2

Influent Substrate (mMolar) vs Gas Composition (%)
CONCLUSIONS

- Previous pilot scale data are predicted well with our model.
- Anaerobic treatment is feasible & economical for low strength wastewater.
- Further research is needed in pilot & full scale.
- Post treatment is necessary to comply with secondary treatment & for nutrient removal.
FUTURE RESEARCH

PILOT SCALE EXPERIMENTS
- 4 columns (6 in i.d * 5 ft long)
- Locate at Terminal Island Treatment Plant

CHARACTERISTICS of COLUMNS:
- Anaerobic filter with low-tech packing \((AF_1)\)
- Anaerobic filter with high-tech packing \((AF_2)\)
- Hybrid reactor \((HAF)\)
- Upflow anaerobic sludge blanket reactor \((UASB)\)
Influent Pumps

Produced gas to measurement device (typical)

Liquid effluent

Sample taps at various heights (typical)

UASB

AF

AF

Hybrid

Primary Effluent

Influent Pumps

Produced gas to measurement device (typical)

Liquid effluent

Sample taps at various heights (typical)

UASB

AF

AF

Hybrid

Primary Effluent

Influent Pumps

Produced gas to measurement device (typical)

Liquid effluent

Sample taps at various heights (typical)

UASB

AF

AF

Hybrid

Primary Effluent

Influent Pumps
ME, MYSELF and the COLUMNS
## DESIGN PARAMETERS

<table>
<thead>
<tr>
<th>Type of reactor</th>
<th>HRT (hr)</th>
<th>OLR (kg/m³d)</th>
<th>Packing</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF₁</td>
<td>12-60</td>
<td>0.16-0.8</td>
<td>low-tech n:0.6</td>
</tr>
<tr>
<td>AF₂</td>
<td>12-60</td>
<td>0.16-0.8</td>
<td>high tech 44 ft²/ft³</td>
</tr>
<tr>
<td>HAF</td>
<td>12-60</td>
<td>0.16-0.8</td>
<td>high tech 44 ft²/ft³</td>
</tr>
<tr>
<td>UASB</td>
<td>6-24</td>
<td>0.4-1.6</td>
<td>no packing</td>
</tr>
</tbody>
</table>
EXPECTED OUTCOME OF FUTURE RESEARCH

- Improved model of AF to predict performance
- Documented performance of AF, UASB and hybrid reactors treating primary effluent
- Improved understanding of the choice of AF as compared to UASB reactors
- Improved understanding of the advantages of combining AF and UASB reactors in a hybrid configuration
EXPECTED OUTCOME OF FUTURE RESEARCH

- Improved understanding of the applicability of AF, UASB and hybrid reactors for treating domestic wastewater
- Improved understanding of the effect of packing type (properties) on reactor performance
- Predictions of AF, UASB and hybrid reactor effectiveness for partial treatment, secondary treatment, load reduction in an existing secondary treatment system
THANK YOU

fatma@seas.ucla.edu