Regional Workshop
Energy and Resource Efficiency in Urban Water Management
20th December 2013

Energy footprints of Wastewater / reuse and recycle:
Challenges and Options

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Director India Operations
NJS Consultants Co. Ltd., Japan

Unit Operations in Wastewater Treatment

Biological

<table>
<thead>
<tr>
<th>Aerobic Process</th>
<th>Suspended Growth</th>
<th>Attached Growth</th>
<th>Submerged Attached Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated Sludge (ASP)</td>
<td>CSTR, Plug flow, Sequencing Batch reactor, oxidation ditch, Orbal, Biolac, Cyclic ASP, Extended Aeration, aerobic/aerated lagoons</td>
<td>Trickling Filter and Trickling filter with solids contact system</td>
<td>Down flow attached growth process, upflow submerged attached growth, fluidized bed bioreactor, membrane separation aerobic process</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Anaerobic Process</th>
<th>Suspended Growth</th>
<th>Attached Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic contact process, anaerobic sludge blanket process UASB, anaerobic baffled reactor system</td>
<td>Up-flow packed bed attached growth, and expanded bed reactors, anaerobic fluidized bed reactors, anaerobic lagoons, membrane separation anaerobic process</td>
<td></td>
</tr>
</tbody>
</table>

Combination of aerobic and anaerobic process are used in tertiary treatment for the removal of nitrogen and phosphorus from the wastewater
Technologies and Configurations

Conventional Activated Sludge

Primary Clarifier → Activated Sludge → Secondary Clarifier → Sand Filter → Sludge Digestion → To Sludge Dewatering

Membrane Bioreactor

Zeolite® Modules → Activated Sludge → To Sludge Dewatering

Electricity Requirements for Activated Sludge Wastewater

- Aerators: 53.1%
- Return Sludge Pumping: 6.5%
- Gravity Thickening: 5.5%
- Anoxic Digester: 4.6%
- Chlorination: 3.0%
- Wet Press: 5.9%
- Mixing and Sampling: 0.2%
- Lighting & Buildings: 0.2%
- Cell 1.4%
- Clarifiers: 6.2%

Summary:
- Total: 100.0%
- Other: 0.1%
- Implementation of more stringent effluent requirements, including enhanced removal of nutrients and other emerging contaminants of concern that may, in some cases, lead to the use of more energy intensive technologies.

- Enhanced treatment of bio-solids including drying/pelletizing.

- Aging wastewater collection systems that result in additional inflow and infiltration, leading to higher pumping and treatment costs.

- Increase in electricity rates.
Integrated Processes for Nutrient Removal

Nitrogen Removal
- Attached Growth
- Immobilized Cells
- Fluidized Bed
- Moving Bed
- Stationary Bed
- Suspended Growth
- Single Sludge (Multi-Phased)
- Multiple Sludge (Multi-Zoned)
- Bardenpho™
- Carrousel™
- Modified Wuhrman
- Modified Ludzack Ettinger
- Two-Stage
- Four-Stage
- Modified Bardenpho™
- Single Sludge (Multi-Phased)
- Single Sludge (Multi-Staged)
- Single Sludge (Sidestream)
- SBR Phase Isolation Ditches
- Three Stage
- Five-Stage
- Bardenpho™
- A2/O™
- UCT VIP
- Orbal™
- Phostrip™
- SBR
- Ox
- An

Nitrogen & Phosphorus Removal
- Chemical Precipitation
- A2/O™
- Phostrip™
- Orbal™
- SBR

Phosphorus Removal
- OWASA
- Single Sludge Suspended Growth
- Single Sludge (Multi-Phased)
- Single Sludge (Multi-Zoned)
- Single Sludge (Multi-Staged)
- Single Sludge (Sidestream)
- Three Stage
- Five-Stage
- Bardenpho™
- A2/O™
- UCT
- Phostrip™
- A2/O™

Biological treatment

A2O process
- Simple & proven
- NO3 in RAS reduces P removal
- Only one internal recycle

UCT process
- Proven
- No NO3 to anaerobic zone, better P removal
- Two internal recycles
Nutrient removal is: ENVIRONMENTAL MANIPULATION OF THE BIOMASS

<table>
<thead>
<tr>
<th>ZONE</th>
<th>DISSOLVED OXYGEN</th>
<th>NITRATE OXYGEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic</td>
<td>Yes</td>
<td>Possibly</td>
</tr>
<tr>
<td>Anoxic</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Anaerobic</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

What is anaerobic, anoxic and oxic?

- **An**: Anaerobic: DO < 0, NO₃ absent
  - P accumulation organisms (PAOs) grow only under strictly anaerobic condition
  - NO₃ removal prior to anaerobic tank improves P removal as rbCOD is made available to PAOs

- **Ax**: Anoxic: DO between 0 to 0.2, max 0.5
  - High DO inhibits growth of denitrifiers

- **Ox**: DO > 0.5
  - DO > 1 recommended for nitrification
Power consumption vs. N removal

![Graph showing the relationship between power consumption and N removal.]

Table 2. Energy Demand for Wastewater Treatment, by Plant Size and Operational Capacity, for Onsite Metered Electric Energy and Source Energy.

<table>
<thead>
<tr>
<th>Plant Capacity</th>
<th>Plants Operating at 80% Influent Capacity</th>
<th>Plants Operating at 50% Influent Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary Source Energy</td>
<td>Secondary (Site) Electrical Energy</td>
</tr>
<tr>
<td>----------------</td>
<td>----------------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>1 MGD</td>
<td>196 GJ/day, 1,692 kWh/ mg</td>
<td>27.2 GJ/day, 2,263 kWh/ mg</td>
</tr>
<tr>
<td>5 MGD</td>
<td>15.2 GJ/day, 1,254 kWh/ mg</td>
<td>22.8 GJ/day, 1,988 kWh/ mg</td>
</tr>
<tr>
<td>10 MGD</td>
<td>13.3 GJ/day, 1,117 kWh/ mg</td>
<td>20.9 GJ/day, 1,741 kWh/ mg</td>
</tr>
<tr>
<td>20 MGD</td>
<td>11.4 GJ/day, 990 kWh/ mg</td>
<td>19.0 GJ/day, 1,584 kWh/ mg</td>
</tr>
<tr>
<td>50 MGD</td>
<td>8.9 GJ/day, 742 kWh/ mg</td>
<td>16.5 GJ/day, 1,377 kWh/ mg</td>
</tr>
<tr>
<td>100 MGD</td>
<td>7.0 GJ/day, 585 kWh/ mg</td>
<td>14.7 GJ/day, 1,220 kWh/ mg</td>
</tr>
</tbody>
</table>

- **Energy Conservation measures for Pumping**
  - Pumping designs, VFD application, motors and efficient pumps

- **Design and Control of Aeration System**
  - Design of aeration systems and automated aeration control; conventional control based on dissolved oxygen (DO) measurements and emerging control strategies. Innovative and emerging technologies for automated control of biological nitrogen

- **Blower and Diffuser Technology**
  - Blower and diffuser equipment, blower types such as single-stage centrifugal, high-speed turbo, and screw compressors, new diffuser technology, material of cover, strip v/s disc vs tubular – retrievable v/s non-retrievable

- **Adaption of new disinfectants**
  - Chlorine v/s UV disinfection

- **Adapt an innovative energy management system**
  - Develop energy management – conduct routine energy optimization exercise
    - Plan- Do – Check - Act
Table 1. Energy Efficiency Practices and Related Savings.

<table>
<thead>
<tr>
<th>Wastewater Sector Energy Efficiency Practice</th>
<th>Savings Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switch to variable frequency drives to match output to load requirement</td>
<td>Savings of 10-40% by replacing a throttling valve with a VFD</td>
</tr>
<tr>
<td>Operational flexibility</td>
<td>Savings typically 10-25%</td>
</tr>
<tr>
<td>Manage for seasonal peak by flexible, staged design</td>
<td>Savings can reach 50% during off-season</td>
</tr>
<tr>
<td>Optimize aeration system</td>
<td>Savings of 30-70% of total aeration system energy consumption is typical</td>
</tr>
<tr>
<td>Fine bubble aeration</td>
<td>Savings between 20-75% of aeration unit's energy consumption</td>
</tr>
<tr>
<td>DO monitoring and control equipment</td>
<td>Savings between 20-50% of aeration unit's energy consumption</td>
</tr>
<tr>
<td>Reuse of final effluent to replace potable water for tank rinsing</td>
<td>Savings may reach 50% of total system energy</td>
</tr>
<tr>
<td>Conduct annual energy survey</td>
<td>Savings range from 10-50% of the total system energy. Several projects have resulted in energy savings of 65%.</td>
</tr>
<tr>
<td>Use real time energy monitoring</td>
<td>Range of energy savings is typically 5-20% when energy efficiency is viewed as a daily performance goal.</td>
</tr>
<tr>
<td>Install high efficiency motors</td>
<td>Savings of 5-10% of the energy used by the lower efficiency motor to be replaced</td>
</tr>
<tr>
<td>Optimize pumping systems</td>
<td>Savings of 15-30% is typical, with up to 70% available in retrofit situations where a service area has not grown as forecasted</td>
</tr>
</tbody>
</table>

WERF 2012

Table 3. Summary of Potential Savings Through Use of Best Practices.

<table>
<thead>
<tr>
<th>Energy Conservation Measure</th>
<th>Treatment Stage</th>
<th>Energy Savings Range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater pumping optimization</td>
<td>Throughout system</td>
<td>&lt;0.7%</td>
</tr>
<tr>
<td>Aeration system optimization</td>
<td>Secondary treatment</td>
<td>~15 to 38%</td>
</tr>
<tr>
<td>Addition of pre-anoxic zone for BNR</td>
<td>Secondary treatment</td>
<td>~4 to 15%</td>
</tr>
<tr>
<td>Flexible sequencing of aeration basins</td>
<td>Secondary treatment</td>
<td>~8 to 22%</td>
</tr>
<tr>
<td>High-efficiency UV</td>
<td>Disinfection</td>
<td>~4%</td>
</tr>
<tr>
<td>Lighting system improvements</td>
<td>Support facilities (buildings)</td>
<td>~2 to 6%</td>
</tr>
<tr>
<td></td>
<td>AVERAGE RANGE</td>
<td>5.6 to 14.3%</td>
</tr>
</tbody>
</table>

WERF, 2011.
BIOFILM PROCESSES

- Biofilm is subject to operation of system
  - Fixed vs Moving
- Fixed systems have little control of biofilm growth and sloughing
  - Increase Aeration under fixed system
- Sponge systems require “squeezing” method to control MLSS inside sponge
- Plastic Media Systems are self controlling, however media type play's into diffusion through biofilm

Energy Efficiency and Conservation
Anammox – the next BIG thing!!

- 63% reduction in oxygen
- No supplemental carbon for denitrification
**Activated sludge treatment, including N, P removal**

**Anammox: less energy for nitrification!**

\[ \text{NH}_4^+ + \text{NO}_2^- \rightarrow \text{N}_2 + 2\text{H}_2\text{O} \]

Removes:
- 'C': <30 mg BOD/l
- 'N': < 10 mg/l
- 'P': < 1 mg/l

**Conventional Activated Sludge: Energy Recovery via Sludge Digestion**

5-6 times energy requirement...

Chemical energy in organic matter (= COD)

\[ 1 \text{ kg COD} = 13.5 \text{ MJ} \geq 3.8^* \text{ kWh} \]

Energy recovery ??

Energy recovery!

(covers 40% of current fossil use)
Combined C/N removal for effluent N adjustment (re-use)

- Necessity depends on growth stage and cropping season
- UASB used for N solubilisation and denitrification
- N is oxidised in post treatment and recycled to UASB

- System stability
- Long-term reliability
- On-off switch possible

PhD research Ghada Kassab (2009)

Sewage

UASB

Combination of UASB and DHS

DHS concept

DHS - Biotower

No need of External aeration input

Prof. Harada, Nagaoka University, Japan
Electricity through Microbial Fuel Cell

All biological sludge produced in wastewater treatment should be anaerobically digested for methane production.

The option of thermophilic digestion should be tried on the pilot scale in India. If the pilot program is successful, full scale plants of this type may be considered.

The methane gas generated from sludge digestion should be converted to electricity using gas engines. Use of dual-fuel engines is discouraged as such units have been proven to be uneconomical.
Fuel Materials Generated in Biosolids Gasification

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Energy as a Percentage of Natural Gas</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low energy gas</td>
<td>10-27</td>
<td>Gas turbine fuel, boiler fuel</td>
</tr>
<tr>
<td>Medium and high energy gas</td>
<td>27-94</td>
<td>Hydrogen production, fuel cell feed, chemical and fuel synthesis</td>
</tr>
<tr>
<td>Substitute natural gas</td>
<td>&gt;94</td>
<td>Directly substitute for natural gas with no additional treatment</td>
</tr>
</tbody>
</table>

WERF, 2011.

Summary of Energy Recovery Potential using Established Technologies

<table>
<thead>
<tr>
<th>Biosolids Technology</th>
<th>Percent of Net Energy “Gap” Reduction Possible</th>
<th>Other Technology</th>
<th>Percent of Net Energy “Gap” Reduction Possible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anoxic Digester (AD) Biogas with boilers</td>
<td>13 – 57%</td>
<td>Enhanced solids removal</td>
<td>10 – 71%</td>
</tr>
<tr>
<td>AD Biogas with co-gen engines</td>
<td>11 – 57%</td>
<td>Anaerobic primary treatment</td>
<td>25 – 139%</td>
</tr>
<tr>
<td>AD Biogas with microturbines</td>
<td>5 – 38%</td>
<td>Heat recovery</td>
<td>13 – 49%</td>
</tr>
<tr>
<td>AD Biogas with turbines</td>
<td>7 – 48%</td>
<td>Hydraulic</td>
<td>0%</td>
</tr>
<tr>
<td>AD Biogas with fuel cell</td>
<td>6 – 42%</td>
<td>Ammonia as fuel</td>
<td>6 – 12%</td>
</tr>
<tr>
<td>AD Biogas after WAS pretreatment</td>
<td>3 – 68%</td>
<td>Heat from centrate</td>
<td>13 – 49%</td>
</tr>
<tr>
<td>AD Biogas with Co-digestion</td>
<td>2 – 129%</td>
<td>Microbial fuel cells</td>
<td>8 – 110%</td>
</tr>
<tr>
<td>Incineration</td>
<td>2 – 68%</td>
<td>Biofuel from algae</td>
<td>39 – 208%</td>
</tr>
<tr>
<td>Gasification</td>
<td>9 – 62%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

WERF, 2011.
Wastewater Treatment Industry – Main Trends

- Environmental awareness
- Regulation (Nutrients & odors)
- Energy costs
- Sludge disposal costs
- Chemicals costs
- Fresh water price

- Fresh water availability
- Available land for wastewater treatment plants
- Infrastructure quality (aging)
**Resource Sustainability**

**Fresh Water**
- Source Availability and location
- Allocation (reservations for various Applications)
- Interstate Disputes
- Increased O&M – Theft, pipeline management
- Higher Cost to Industries

**Recycled Water**
- Captive Resource
- No issues with Allocations
- **No Interstate Disputes**
- Reduced O&M, Short distances
- Lower Cost to Industries

**Trends in Water Cost - India**

![Graph showing trends in water cost across different cities in India from 1995 to 2015.](image-url)
GoK has allocated 600 cusec or 17 Cumecs (1469 Mld) of raw water from Cauvery River to BWSSB, with CWSS Stage IV - Phase I commissioning, raw water drawl is about 929 Mld

Balance raw water available is about 540 Mld

**Raw Water (Mld) from Cauvery river**
- Stage I (1974) : 150
- Stage II (1982) : 150
- Stage III (1994-95) : 314
- Stage IV Phase I (2002) : 315
- Stage IV Phase II : 500
- Total Abstraction 1429

Source Availability

**135 MLD Reuse Process Scheme – Indirect Potable use**
## Recycle reuse Vs Krishna water

<table>
<thead>
<tr>
<th>Option</th>
<th>Capacity</th>
<th>Capital cost</th>
<th>Annual O&amp;M</th>
<th>Rs./m³</th>
<th>R&amp;R</th>
<th>NRCD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MLD</td>
<td>Rs.Cr.</td>
<td>Rs.Cr.</td>
<td>Capital O&amp;M</td>
<td>R&amp;R</td>
<td>NRCD</td>
<td></td>
</tr>
<tr>
<td>Krishna</td>
<td>820</td>
<td>2100</td>
<td>218.16</td>
<td>9.63</td>
<td>7.29</td>
<td>-</td>
<td>19.8</td>
</tr>
<tr>
<td>Swap</td>
<td>300</td>
<td>618</td>
<td>36.65</td>
<td>6.85</td>
<td>3.35</td>
<td>11.96</td>
<td>13.12</td>
</tr>
<tr>
<td>Jagguda</td>
<td>10</td>
<td>16</td>
<td>0.88</td>
<td>4.97</td>
<td>2.41</td>
<td>7.38</td>
<td>9.79</td>
</tr>
<tr>
<td>Nagole</td>
<td>70</td>
<td>186</td>
<td>7.06</td>
<td>8.51</td>
<td>2.76</td>
<td>11.27</td>
<td>12.78</td>
</tr>
<tr>
<td>N.Cheruvu</td>
<td>10</td>
<td>10</td>
<td>0.61</td>
<td>3.34</td>
<td>1.68</td>
<td>5.02</td>
<td>7.48</td>
</tr>
</tbody>
</table>

Annual interest rate: 10%, Amortization period: 24 years (till year 2031)
Energy Management – adopted in Water and Wastewater along with Recycle and reuse could prove exceptionally beneficial

- Potable Water
- High-Quality Reuse Water for All applications
- Treatment for Recycle and Reuse
- Sewage