Evaluation of biogas sanitation systems in Nepalese prisons

Summary Presentation of Evaluation Results
August 09
# Table of contents

1. **Introduction**
   - 1.1 Background
   - 1.2 Objectives
   - 1.3 Methodologies

2. **Monitoring**
   - 2.1 Monitored systems
   - 2.2 Treatment efficiency
   - 2.3 Biogas

3. **Evaluation**
   - 3.1 Technical
   - 3.2 Organizational
   - 3.3 Economic
   - 3.4 Environmental
   - 3.5 Socio-cultural
   - 3.6 Sanitation/Health

4. **Discussion**
   - 4.1 Recommendation
   - 4.2 Conclusion
January 2007
Agreement between ICRC and local expert partner BSP-N to implement 5 biogas systems in 3 Nepalese prisons

May 2008
End of construction -> start of operation

April-June 2009
External evaluation by Eawag/Sandec
Objectives of biogas installations

• Improvement of human excreta disposal and management (reduction of health risks)

• Provision of renewable energy source as alternative to wood and kerosene

• Improvement of kitchen environment (reduction of health risks)

• Use of slurry as fertilizer

• Promote the construction of biogas plants on institutional level
Location of evaluated district jails

<table>
<thead>
<tr>
<th>District Jail</th>
<th>Altitude (m amsl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kanchanpur District Jail</td>
<td>116</td>
</tr>
<tr>
<td>Kaski District Jail</td>
<td>819</td>
</tr>
<tr>
<td>Chitwan District Jail</td>
<td>240</td>
</tr>
</tbody>
</table>

Biogas digesters

- Kaski: 10m³ and 20m³
- Chitwan: 10m³ and 35m³
- Kanchanpur: 10m³
Methodologies

1. Introduction

2. Monitoring

3. Evaluation

4. Discussion

• Measurements/analyses on-site
  - Gas production & composition
  - pH, Temp., Redox, EC
  - COD, NH4-N, N total, P total
  - VFA, alkalinity, A/TIC-ratio
  - E.Coli

• Analyses in lab
  - TS (Total Solids), VS (Volatile solids) -> KU lab
  - Helminth eggs -> Swiss Tropical Institute

• Observations and Interviews
  - Gas tightness of dome & piping
  - Fuel savings, living conditions before/after biogas plant
  - Construction, operation, maintenance and problems
1. Introduction

2. Monitoring

3. Evaluation

4. Discussion
1. Introduction

2. Monitoring

3. Evaluation

4. Discussion

Kaski District Jail:
Altitude: 819m above mean sea level
(Digester Size: 10m³ and 20m³)

Number of detainees
Initial capacity of jail: 60 pers.
Pre-construction planning: 187 pers.

Chitwan District Jail:
Altitude: 240m above mean sea level
(Digester Size: 10m³ and 35m³)

Number of detainees
Initial capacity of jail: 55 pers.
Pre-construction planning: 321 pers.
Evaluation period 2009: 268 pers.

Kanchanpur District Jail:
Altitude: 116m above mean sea level
(Digester Size: 10m³)

Number of detainees
Initial capacity of jail: 75 pers.
Pre-construction planning: 74 pers. (•)
Evaluation period 2009: 106 pers. (•)
Evaluation of biogas sanitation systems in Nepalese prisons

1. Introduction
2. Monitoring
3. Evaluation
4. Discussion

**Efficiency**

- **Reduction of Solids and Organic load**
  95 - 98% reduction of Total Solids and Organic Load

- **Reduction of pathogen**
  > **E.Coli**

  WHO guideline values for agricultural use of greywater, excreta and faecal sludge:
  - Restricted irrigation: $< 10^5$ CFU/100ml
  - Unrestricted irrigation of crops eaten raw: $< 10^3$ CFU/100ml

  • Requirements for restricted irrigation fulfilled

  > **Helminth eggs**

  WHO guideline values:
  - Restricted/unrestricted irrigation: $< 1$ ova/L

  • Requirements only partially fulfilled
## Result of Pathogenic Analysis

<table>
<thead>
<tr>
<th>Descriptions</th>
<th>Chitwan</th>
<th>Kanchanpur</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10m3</td>
<td>35m3</td>
</tr>
<tr>
<td><strong>E.Coli</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction- Influent vs Effluent in</td>
<td>92.0%</td>
<td>98.5%</td>
</tr>
<tr>
<td>Compensation Chamber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction- Influent vs Effluent in</td>
<td>99.9%</td>
<td>99.9%</td>
</tr>
<tr>
<td>Storage Pit</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Helminth</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction- Influent vs Effluent in</td>
<td>87.3%</td>
<td>94.4%</td>
</tr>
<tr>
<td>Compensation Chamber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction- Influent vs Effluent in</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Storage Pit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Influent data for Kaski unavailable
- Due to limited samples results are not statistically representative
## Evaluation of biogas sanitation systems in Nepalese prisons

### 1. Introduction

### 2. Monitoring

#### Monitoring:
- Measurement/Observation/Estimation

<table>
<thead>
<tr>
<th>Date</th>
<th>Kaski 10m3</th>
<th>Kaski 20 m3</th>
<th>Chitwan 10m3</th>
<th>Chitwan 35m3</th>
<th>Kan'pur 10m3</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 2009</td>
<td>1260</td>
<td>8620</td>
<td>2610</td>
<td>1920</td>
<td>3130</td>
</tr>
<tr>
<td>May 2009</td>
<td>260</td>
<td>8210</td>
<td>3260</td>
<td>2500</td>
<td>-</td>
</tr>
<tr>
<td>June 2009</td>
<td>2120</td>
<td>9210</td>
<td>3310</td>
<td>4800</td>
<td>3450</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cooking time (h)</th>
<th>Kaski 10m3</th>
<th>Kaski 20 m3</th>
<th>Chitwan 10m3</th>
<th>Chitwan 35m3</th>
<th>Kan'pur 10m3</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5</td>
<td>3</td>
<td>45</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### 3. Evaluation

### 4. Discussion

#### Biogas

<table>
<thead>
<tr>
<th>Pre-Construction: Planning/Expectation</th>
<th>Daily kitchen waste feeding</th>
<th>No. of detainees</th>
<th>Biogas output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>68</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>119</td>
<td>4000</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>115</td>
<td>3000</td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>206</td>
<td>7000</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>74</td>
<td>2000</td>
</tr>
</tbody>
</table>

#### Difference between expected & measured daily biogas production

<table>
<thead>
<tr>
<th></th>
<th>+6%</th>
<th>+130%</th>
<th>+10%</th>
<th>-31%</th>
<th>+73%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of detainees</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biogas output</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Technical aspects**

**Process stability** (Inhibiting factors)

<table>
<thead>
<tr>
<th>Ø</th>
<th>Kaski 10</th>
<th>Kaski 20</th>
<th>Chitwan 10</th>
<th>Chitwan 35</th>
<th>Kanchanpur 10</th>
<th>Optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.17</td>
<td>7.05</td>
<td>7.11</td>
<td>7.44</td>
<td>7.20</td>
<td>6.5 - 7.5</td>
</tr>
<tr>
<td>Temp. [°C]</td>
<td>26.4</td>
<td>25.6</td>
<td>29.8</td>
<td>28.8</td>
<td>30.0</td>
<td>25 - 35</td>
</tr>
<tr>
<td>Redox [mV]</td>
<td>-372</td>
<td>-401</td>
<td>-389</td>
<td>-391</td>
<td>-402</td>
<td>&lt; -330</td>
</tr>
<tr>
<td>VFA [mg/L]</td>
<td>49</td>
<td>95</td>
<td>28</td>
<td>46</td>
<td>31</td>
<td>&lt; 1000</td>
</tr>
<tr>
<td>NH4-N [mg/L]</td>
<td>504</td>
<td>697</td>
<td>356</td>
<td>458</td>
<td>443</td>
<td>&lt; 1500</td>
</tr>
</tbody>
</table>

**Hydraulic Retention time**

<table>
<thead>
<tr>
<th>HRT [days]</th>
<th>23</th>
<th>21</th>
<th>14</th>
<th>33</th>
<th>15</th>
<th>70 - 90</th>
</tr>
</thead>
</table>
Technical aspects

Feeding input -> Biogas output (theoretical and measured)

<table>
<thead>
<tr>
<th></th>
<th>Kaski 10</th>
<th>Kaski 20</th>
<th>Chitwan 10</th>
<th>Chitwan 35</th>
<th>Kanchanpur 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of persons</td>
<td>65</td>
<td>135</td>
<td>115</td>
<td>155</td>
<td>106</td>
</tr>
<tr>
<td>Feaces [0.4kg/cap/d]</td>
<td>26</td>
<td>54</td>
<td>46</td>
<td>62</td>
<td>42</td>
</tr>
<tr>
<td>Flush water [3L/cap/d]</td>
<td>195</td>
<td>405</td>
<td>345</td>
<td>465</td>
<td>318</td>
</tr>
<tr>
<td>Urine [1.5L/cap/d]</td>
<td>97.5</td>
<td>202.5</td>
<td>172.5</td>
<td>232.5</td>
<td>159</td>
</tr>
<tr>
<td>Kitchen waste KW [kg/d]</td>
<td>3</td>
<td>45</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Gas per faeces [30L/cap/d]</td>
<td>1950</td>
<td>4050</td>
<td>3300</td>
<td>4650</td>
<td>3180</td>
</tr>
<tr>
<td>Gas per KW [115L/kg/d]</td>
<td>345</td>
<td>5175</td>
<td>0</td>
<td>345</td>
<td>0</td>
</tr>
<tr>
<td>Total gas potential [L/d]</td>
<td>2295</td>
<td>9225</td>
<td>3450</td>
<td>4800</td>
<td>3180</td>
</tr>
<tr>
<td>Total gas (June 09) [L/d]</td>
<td>2120</td>
<td>9210</td>
<td>3310</td>
<td>4995</td>
<td>3450</td>
</tr>
</tbody>
</table>

> Average biogas output from faeces: 28 NL/cap./day
> With addition of kitchen waste: 62 NL/cap./day
Evaluation of biogas sanitation systems in Nepalese prisons

1. Introduction

2. Monitoring

3. Evaluation

4. Discussion

Operational aspects

- **Kitchen waste feeding**
  Only regularly done in Kaski Chitwan*/Kan’pur: Sold to piggery
  (* Since Sept 09 used to feed digester)

- **Slurry**
  No use as fertilizer
  No (aerobic) post-treatment

Maintenance aspects

- **Lack of internal and external maintenance strategy**
  (* In Sept 09 maintence calendar was drawn up and PMD reviewing maintenance)
3. Evaluation

**Cooking fuel: money saving**

- **Kaski District Jail**
  - Before biogas installation (2008): 290.3 NR/pers./d
  - After biogas installation (2009): 41.9 NR/pers./d
  - 41% saving

- **Chitwan District Jail**
  - Before biogas installation (2008): 149.0 NR/pers./d
  - After biogas installation (2009): 123.1 NR/pers./d
  - 17% saving

- **Kanchanpur District Jail**
  - Before biogas installation (2008): 145.5 NR/pers./d
  - After biogas installation (2009): 113.2 NR/pers./d
  - 22% saving
### Economic aspects

**Cost effectiveness**

<table>
<thead>
<tr>
<th></th>
<th>Kaski</th>
<th>Chitwan</th>
<th>Kanchanpur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saving of cooking fuel [NR/y]</td>
<td>29'400</td>
<td>84'000</td>
<td>41'100</td>
</tr>
<tr>
<td>Saving of septic tank emptying [NR/y]</td>
<td>46'000</td>
<td>22'000</td>
<td>2'200</td>
</tr>
<tr>
<td>Cost of biogas system(s) [NR]</td>
<td>511'000</td>
<td>577'000</td>
<td>160'000</td>
</tr>
<tr>
<td>Min. amortisation period [year]</td>
<td>1.5</td>
<td>5.4</td>
<td>3.7</td>
</tr>
</tbody>
</table>

* Not considered: Cost of
- Eventual repairing work
- Desludging of digester
- Changes in number of detainees
- Price fluctuations

**Lifespan of biogas system**

- Acc. BSP-N: Digester: min 20 years
- Acc. BAT (2009): Acrylic emulsion paint: 4-6 years
- Acc. BAT (2009): Piping: 7 years
Environmental aspects

- **Mitigating deforestation**
  > Annual saving of firewood:
    - Chitwan: 10 tons
    - Kanchanpur: 4 tons

- **Reduction of methane emissions**
  - If biogas properly burned
  - If gas escape minimized
Socio-cultural aspects (Interview with 63 detainees)

- **Knowledge of system**
  
  79% of total interviewees know the new sanitation system by name (biogas)

- **Objection**
  
  Only 7 detainees (1.2% of total) object biogas use because of faecal origin (Kan'pur)
  
  -> Acceptance is increasing

- **Improvement of living conditions?**
  
  98%: yes
  
  59%: Less smoke in kitchen
  49%: Improved sanitation/hygiene/health
  38%: Cleaner environment
  35%: Time saving
  35%: Money saving
Sanitation/Health aspects

- **Comparison Septic tank • biogas system**
  All interviewees prefer biogas system

- **Water use/hygiene**
  Recommended: 1L water per defecation
  Observed: 3L !

- **Kitchen: H2S, smoke**
  Hazardous H2S-content in biogas (>1000ppm)
  -> regular leakage check in kitchen
  -> complete combustion
  97% of interviewees prefer biogas cooking to firewood/kerosene
• **Design / Construction**

  > Buffer wall  
  -> increased solid retention time -> improved efficiency

  or: Digester inlet and outlet not in line
1. Introduction
2. Monitoring
3. Evaluation
4. Discussion

• Design / Construction

> Ensure sufficient inlet slope

> Promote slurry use for banana cultivation
  -> Widespread in Nepal
  -> No contact between fruit and slurry
  -> No risk of digester-damage by roots
  -> No extensive shading by leaves
  -> High nutrient demand
  -> High water demand (no water logging)

• Operation/Maintenance:

> Clarify/control responsibilities (duty calendar)
> Annual monitoring (after drawback of ICRC WatHab)
1. Introduction

2. Monitoring

3. Evaluation

4. Discussion

General

> Technology and design are suitable for treatment of human & kitchen waste on institutional level if system is properly operated and maintained

> Technology is favourably perceived by users
  (less indoor air pollution, better hygiene, easy cooking, money & time saving, cleaner environment)

> Domes are gastight

> Room for improvement: Inlet slope, user commitment

> Average quantity of toilet flush: 3L (not 1L) -> low HRT

> Reduction of organic load substantial

> Pathogen reduction needs further analyses

> Slurry is not used as fertilizer -> promote banana cultivation

> No regular maintenance work conducted -> jeopardizing sustainability
Objectives of biogas installations

- Improvement of human excreta disposal and management (reduction of health risks)
- Provision of renewable energy source as alternative to wood and kerosene
- Improvement of kitchen environment (reduction of health risks)
- Use of slurry as fertilizer
- Promote the construction of biogas plants on institutional level