Integrating entrapped mixed microbial cell (EMMC) process for biological removal of carbon and nitrogen from dilute swine wastewater


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Received 8 January 2001; received in revised form 12 July 2002; accepted 13 July 2002

Abstract

An entrapped mixed microbial cells (EMMC) process was used to investigate the simultaneous removal of carbon and nitrogen from dilute swine wastewater. Cellulose triacetate was used as the matrix for entrapping the mixed microbial cells. The EMMC process was tested with various oxygen supply conditions (ratios of aeration to non-aeration times) and two types of carrier sizes (large and medium). Also, various pre-treatments with chemical coagulation, screen separation and ammonium crystallization prior to the EMMC process, and post-treatment after the EMMC process were investigated. It was found that at a hydraulic retention time of 30 h and one hour of aeration and one hour of non-aeration, the EMMC process packed with medium carriers after the pre-treatment of ammonium crystallization, exhibited the best total nitrogen removal efficiency of 95.1 ± 1.0% when compared to the other two pre-treatment methods. The total chemical oxygen demand (TCOD) and soluble chemical oxygen demand removal efficiencies were 83.5 ± 2.2% and 84.1 ± 1.1%, respectively. Lime post-treatment provided TCOD and total phosphorus removal efficiencies of 59.6 ± 2.7% and 98.0 ± 0.5%, respectively. Thus, a cost analysis for ammonium crystallization pre-treatment, EMMC process, and post-treatment with lime was conducted. The unit cost for a 2000 pig operation is $4.91/pig/year. For the application of the EMMC process with the proposed pre- and post-treatments, a suitable farm size needs to be greater than a 2000 pig operation. Because of the high efficiency and the simple operation of simultaneous carbon and nitrogen removal, the EMMC process has the potential for treatment of dilute swine wastewater in a land-limited area and can be manufactured as pre-fabricated wastewater treatment units.

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Keywords: Dilute pig wastewater; Entrapped microbial cell; Removal of carbon and nitrogen; Pre- and post-treatment; System application; Economic evaluation

1. Introduction

Wastewater generated from pig operations is a primary source of water pollution. The disposal/reuse of pig wastewater has always been a serious problem due to its high concentration of carbon and nutrients such as nitrogen and phosphorus. Conventional livestock wastewater treatment using activated sludge for removal of carbon and nitrogen (Loehr, 1984) is problematic for land-limited conditions as it requires large areas of land, a great deal of energy, and further treatment for reuse/disposal of treated effluent. Although various treatments of dilute swine wastewater have been investigated in the past at the University of Hawaii (Yang and Nagano, 1985; Yang and Chou, 1985; Yang and Moengangongo, 1987; Yang and Koba, 1988; Yang et al., 1993; Yang and Chen, 1994), it becomes apparent that various technical factors may heavily influence planning, design, construction and operation of a dilute pig wastewater treatment system. Therefore, the concept of pre-fabricated or pre-engineered packaged plants is being considered for treatment and reuse/disposal of dilute pig wastewater for land-limited conditions. Consequently, an effective treatment unit that is simple to operate and compact in nature are key factors for the development of a pre-fabricated plant. The EMMC process has been investigated at the University of Hawaii for various organic and inorganic wastewater (Yang et al., 1988;
Yang and Wang, 1990; Yang and See, 1991; Yang et al., 1991; Nitisoravut and Yang, 1992; Yang et al., 1994; Yang et al., 1995; Yang et al., 1997a). It was found to have a small land requirement, have stable operating characteristics and is easy to restart. The immobilized carriers which have been used for 6–7 years with various concentrations of synthetic and actual wastewaters are observed to have no signs of swelling, cracking or deformation. Recently, it was also found that the simultaneous removal of carbon and nitrogen in a single reactor (Zhang, 1995; Yang et al., 1997b; Yang and Cao, 1998; Yang and Chou, 1999) was useful in treating synthetic wastewater (a simulated domestic sewage). Therefore, the EMMC process, coupled with other pre- and post-treatments was further investigated for treatment of dilute swine wastewater for land-limited areas for potential reuse as an agricultural production system.

2. Methods

2.1. Characteristics of swine wastewater

Raw swine wastewater was collected from the Waialee animal research farm at the University of Hawaii. The raw swine wastewater was settled and the supernatant was used as a feed (dilute swine wastewater). Characteristics of the dilute swine wastewater are presented in Table 1. The composition of the wastewater varied with each time of field sample collection. Thus, characteristics are presented as ranges of values instead of the degrees of variance. With this range of variance, the EMMC process performance is expressed as removal efficiency instead of effluent quality. The stability of the EMMC process was also investigated with the large variance of influent wastewater characteristics.

2.2. EMMC process set-up and operation

A mixture of aerobic and anaerobic microbial cells sampled from the activated sludge process and anaerobic digestion process in an actual wastewater treatment plant was immobilized by Ma (1994) and Zhang (1995) and reused for this experiment. In this experiment, dilute swine wastewater was used as a substrate instead of synthetic wastewater, which was used in our previous study (Zhang, 1995).

Three 5.0 l Plexiglas up-flow bioreactors (0.15 m in diameter and 0.54 m in height) were installed as presented in Fig. 1. Packing ratios, ratios of carrier volume to total reactor volume, for the medium and large carriers were 31.6% and 28.3%, respectively. The experiment was conducted at a room temperature of 25 ± 2 °C. The feed solution was prepared and stored in a cooling tank at 5 °C. The substrate was transported by Peristaltic pump from the bottom of the EMMC reactor. The effluent from the top end of the unit was collected at a steady state (stable removal efficiencies of soluble chemical oxygen demand (SCOD) and total nitrogen (TN)) for further water quality analysis. An hydraulic retention time (HRT) of 30 h was maintained based on the results of a previous study using synthetic wastewater (Zhang, 1995) for the combined removal of carbon and nitrogen in one EMMC reactor. Intermittent aeration of 1 h of aeration/1 h of non-aeration, 1 h of aeration/2 h of non-aeration, and 2 h of aeration/1 h of non-aeration were operated and controlled by a timer. An air flowrate of 1 l/h of void reactor volume (total reactor volume – carrier volume)/min was maintained during the aeration period. The reactors were operated for 30 days at a given set of conditions. The 15 samples were collected at a steady state and used for data analysis.

2.3. Pre- and post-treatment

Three different pre-treatment methods, chemical coagulation, screening, and ammonium crystallization, were incorporated in this study. For pre-treatment by chemical coagulation, FeSO₄ and FeCl₃ were tested to select an optimum coagulant. For pre-treatment with
ammonium crystallization, MgCl₂ and KH₂PO₄ were used. The chemicals were added based on the concentration of NH₄⁻N at a ratio of 1.0:0.9:0.9 (NH₄⁻N:MgCl₂:KH₂PO₄). Post-treatment of the effluent from the EMMC process pre-treated with ammonium crystallization was also conducted using lime. The lime dosing rate was selected as a concentration of 700 mg/l which maintained the pH of the treated water below 9.0. A variable-speed mixer was mounted on the top of the reaction tank. The rotation speed and reaction time for chemical coagulation pre-treatment and lime coagulation post-treatment were 100 rpm and 12 min for rapid mixing followed by a 30 rpm and 3 min of slow mixing. For the ammonium crystallization treatment, the rotation speed and reaction time were selected at 175 rpm and 1 h for optimal nitrogen precipitation based on Maekawa et al. (1995). After 45 min of sedimentation, a total nitrogen removal of 34.9 ± 4.0% was achieved. The total chemical oxygen demand (TCOD)/TN ratio in the supernatant was increased from 1.85 to 4.07.

The dilute swine wastewater was double screened, with the sequence of passing 150 and 125 μm sieves, to separate the solid and liquid phase. This double screen was used to enhance the efficiency of screen work. The pre-treatments of screen, chemical coagulation, and ammonium crystallization of settled swine wastewater followed by the EMMC process were investigated for the removal of TCOD, SCOD, TN and total suspended solids (TSS).

2.4. Experimental procedure

In order to evaluate the EMMC process for dilute swine wastewater, various treatment processes were conducted and operated as shown in Table 2. Three pre-treatment methods, such as screening, chemical coagulation, and ammonium crystallization, were incorporated with the specific purpose to reduce influent solids, organics, and nitrogen concentrations in order to meet the optimum carbon to nitrogen (C/N) ratio and reduce the suspended solid concentration prior to application of the EMMC process. Lime treatment was used as a post-treatment process to remove residual phosphorus. The statistic t-test was used to determine the difference of operational conditions for process performance. This method is used to test the significant difference between two results based on independent random samples and is applied for a small number of samples (Mendenhall, 1993). A significance of 0.025 was chosen for this test, and the critical value for a two-tailed test was ±2.048.

2.5. Analytical methods

Samples of liquid manure, feed, and effluent were analyzed for pH, TCOD, SCOD, total Kjeldhal nitrogen (TKN), NH₄⁻N, NO₃⁻N, TSS, and total phosphorus (TP). Composite samples were taken from the effluent reservoir of the EMMC process after 6 h of collection. All water quality analyses were conducted using standard methods (APHA, 1995), except NO₃⁻N and TP. The NO₃⁻N and TP were analyzed using the HACH cadmium reduction method (HACH, 1992) and the HACH acid persulfate digestion and molybdovanadate method (HACH, 1992), respectively. Dissolved oxygen (DO) was measured using a DO Analyzer (Model DO-40, made by Yellow Springs Instrument Co., Inc., Ohio, USA). The pH was measured using an Orion 501 pH Analyzer.

3. Results and discussion

EMMC processes packed with large or medium carriers were operated and evaluated for process performance at loading rates of 0.67–1.07 g TCOD/L/day and HRT of 30 h based on the previous study by Zhang (1995). The dilute swine wastewater was pre-treated by chemical coagulation, screening, or ammonium crystallization, and was used as a feed for the EMMC process. Process performance of the EMMC process was evaluated for various aeration schedules. The dissolved oxygen concentration in the reactor was maintained at 4.0–6.0 and 0.3–0.5 mg/l during the aeration and non-aeration periods, respectively.

3.1. EMMC process performance subsequent to chemical coagulation pre-treatment

In order to avoid solid plug formation within the carriers, chemical coagulation pre-treatment was conducted prior to the EMMC process. The jar-test result (single data) showed that the removal efficiencies of TCOD, TKN and TSS were higher when 1000 mg/l of
ferric sulfate (Fe₂(SO₄)₃ · xH₂O) was used in comparison to ferric chloride (FeCl₃) as presented in Fig. 2. The TCOD, TKN and TSS removal efficiencies were 45.7%, 17.5% and 83.0%, respectively, when ferric sulfate was used. A considerable amount of TSS in the swine wastewater was removed by chemical pre-treatment, but TCOD and TKN removal efficiencies were maintained at a lower level. This suggests that removal is difficult for the soluble fractions of organic and nitrogen components in the swine wastewater when using chemical precipitation. After chemical coagulation pre-treatment, the TCOD/TKN ratio was ≈1.85.

Based on the results of the jar-test, swine wastewater was pre-treated using ferric sulfate as a chemical coagulant. The pre-treated wastewater was fed to the EMMC processes operating with intermittent aeration. The average TCOD removal efficiencies (not including chemical coagulation pre-treatment) of the EMMC processes subsequent to chemical coagulation pre-treatment are shown in Table 3. Among the various aeration schedules, the schedule of 1 h of aeration and 1 h of non-aeration is the highest for average TCOD, SCOD, and TN removal efficiencies in EMMC processes packed with large and medium carriers. At this aeration schedule, the EMMC processes packed with medium carriers achieved higher performances as shown in t-test results of Table 3 which was compared with large carriers. The TCOD and SCOD removal efficiencies including chemical coagulation and EMMC processes operated with 1 h of aeration and 1 h of non-aeration using medium carriers are 84.8 ± 3.9 and 82.6 ± 3.2%, respectively, as shown in Table 4. The TN removal efficiency of the EMMC process (operated with 1 h of aeration and 1 h of non-aeration and packed with medium carriers) with pre-treatment of chemical coagulation is 90.9 ± 1.9%. The TSS removal efficiency of 81.2 ± 7.5% can be achieved in this combined system. Most of the TSS from dilute swine wastewater is removed in the chemical pre-treatment process.

3.2. EMMC process performance subsequent to screening pre-treatment

In order to simplify the separation of solid and liquid phases in dilute swine wastewater, the screening pre-treatment was employed prior to the EMMC treatment process. The use of screening as pre-treatment allows for 11.2% removal efficiency of TCOD, 7.1% removal efficiency of TN, and 64.6% removal efficiency of TSS. The TCOD/TKN ratio resulted in an average of 3.0 after pre-treatment of screening.

The removal efficiencies of organics between large and medium carriers were very similar at both aeration schedules of 1 h aeration/2 h non-aeration and 1 h aeration/1 h non-aeration as shown in Table 5. However, there were significant differences between the carriers for nitrogen removal efficiency at both aeration schedules. The average TCOD, SCOD and TN removal efficiencies of the EMMC process (not including screening pre-treatment) packed with medium carriers and operated with an aeration schedule of 1 h of aeration and 1 h of non-aeration were 80.9 ± 2.2%, 82.7 ± 2.6% and 89.9 ± 2.2%, respectively. As shown in Table 4, the overall TCOD, SCOD and TN removal efficiencies including screening pre-treatment and EMMC processes operated with 1 h of aeration and 1 h of non-aeration and packed

![Combined mixing: 100 rpm for 12 min and 30 rpm for 3 min. Coagulant concentration: 1,000 mg/L.](image)

Fig. 2. Variations of removal efficiency using ferric sulfate and ferric chloride as coagulant.

<table>
<thead>
<tr>
<th>Aeration to non-aeration ratio</th>
<th>1 h/2 h</th>
<th>1 h/1 h</th>
<th>2 h/1 h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large</td>
<td>Medium</td>
<td>Large</td>
</tr>
<tr>
<td>TCOD (%)</td>
<td>63.0 ± 3.2</td>
<td>60.4 ± 3.5</td>
<td>74.1 ± 4.1</td>
</tr>
<tr>
<td>SCOD (%)</td>
<td>55.0 ± 5.1</td>
<td>52.9 ± 4.1</td>
<td>71.3 ± 3.4</td>
</tr>
<tr>
<td>TN (%)</td>
<td>87.5 ± 13.3</td>
<td>80.1 ± 11.6</td>
<td>87.5 ± 2.4</td>
</tr>
</tbody>
</table>

| t-Value for TCOD*              | 21.123 | 1.275 | 0.323 |
| t-Value for SCOD*              | 1.243  | 3.705 | 1.289 |
| t-Value for TN*                | 1.624  | 3.146 | 2.368 |

* t-Test between large and medium carriers (significance: 0.025, critical value: ±2.048).
with medium carriers were 83.0 ± 3.1, 82.7 ± 2.8 and 90.6 ± 2.2%, respectively. The average TSS removal efficiency of this combined treatment alternative was 79.2 ± 7.0%.

3.3. EMMC process performance subsequent to ammonium crystallization pre-treatment

In order to increase the C/N ratio, ammonium crystallization pre-treatment was employed prior to the EMMC process. In this pre-treatment process, ammonium is expected to be removed by the addition of magnesium salt and phosphate to form MgNH4PO4·6H2O crystals. The stoichiometric equation is as follows:

\[
\text{Mg}^{2+} + \text{NH}_4^+ + \text{PO}_4^{3-} + 6\text{H}_2\text{O} \rightarrow \text{MgNH}_4\text{PO}_4\cdot6\text{H}_2\text{O}
\]

The crystallized precipitate is dependent on the pH range of the solution. It is either acid soluble (pH < 6) or forms MgPO4 in basic solution (pH > 10) (Maekawa et al., 1995). The initial \( \text{NH}_4^+:\text{Mg}^{2+}:\text{PO}_4^{3-} \) molar ratio, reaction time, reaction temperature, interaction among temperature, and pH, have a great influence on the residual concentration of ammonium and its ratio (Maekawa et al., 1995). The MgCl2 and KH2PO4 were dosed with the ratio of \( \text{NH}_4^+:\text{MgCl}_2:\text{KH}_2\text{PO}_4 \) of 1.0:0.9:0.9 for the diluted swine wastewater and mixed for 1 h at 175 rpm as suggested by Maekawa et al. (1995). After 45 min of sedimentation, this pre-treatment achieved an average removal efficiency of 8.3% for TCOD, 3.4% for SCOD, 47.2% for \( \text{NH}_4^-\text{N} \) and 34.9% for TN. The ratio of TCOD to TN in the wastewater was increased to 4.07 after the ammonium crystallization pre-treatment.

The EMMC processes packed with large and medium carriers were operated using diluted swine wastewater pre-treated by ammonium crystallization. The aeration schedule was maintained at 1 h of aeration and 1 h of non-aeration based on prior experiments.

Based on the \( t \)-test, the TCOD removal efficiencies are very similar, with percentages of 82.7 ± 2.8% and 83.5 ± 2.2% for both large and medium carriers as shown in Table 6. However, a significant difference between the carriers for SCOD and TN removal efficiencies was apparent.

Higher TN removal efficiencies of 92.7 ± 1.5% to 95.1 ± 1.0% (EMMC process alone) were achieved when...
the dilute swine wastewater was pre-treated by the ammonium crystallization technique compared to the chemical coagulation and the screening pre-treatments. This may be due to the higher ratio of TCOD/TN when the ammonium crystallization pre-treatment was applied. This agrees with our previous finding of using synthetic wastewater as substrate (Yang and Cao, 1998). Compared to the other pre-treatment methods, the ammonium crystallization pre-treatment coupled with the EMMC process exhibited the best removal efficiency of TN as shown in Table 4.

3.4. Post-treatment with lime

The guidelines for agricultural reuse of wastewater was developed by the USEPA (1992). The treated wastewater, after disinfection, is acceptable to be reused for commercially processed food crops, surface irrigation of orchards and vineyards, and for non-food crops and pasture for milking animals, fodder, fiber and seed crops depending on the quality of treated wastewater to be reused. As shown in Table 7, the TP concentration in the effluent was rather high (currently, USEPA does not regulate this component for agricultural reuse). It may pose some adverse changes of soil properties for crop production whenever a high concentration of phosphorus is applied.

In order to remove residual phosphorus in the effluent of the EMMC process (packed with medium carriers) subsequent to ammonium crystallization pre-treatment, the chemical post-treatment with lime, Ca(OH)₂, was followed. The dosing concentration of lime was selected at 700 mg/l in order to maintain a pH value below 9. The test performances are shown in Table 8. The chemical coagulation with lime treatment removes the TP from the effluent of the EMMC process pre-treated by ammonium crystallization method effectively (98.0 ± 0.5%). With this post-treatment, the residual TCOD removal efficiency was 59.6 ± 2.7%. For TN removal efficiency, it was 12.7 ± 6.4%. Removal efficiency for TSS was 85.8 ± 5.2%. The total dissolved solids (TDS) concentration (830 mg/l) was less than the 2000 mg/l suggested by the Food and Agriculture Organization (Pescod, 1992) for a suitable agricultural production system. Thus, this combined treatment of dilute swine wastewater contributes significant potential for agricultural reuse of treated wastewater and of the product (of the N–P–Ca–inert organic substance complex) generated from the pre- and post-treatment processes for fertilizer/soil conditioners.

Additionally, the performances of overall treatment (i.e., settled, ammonium crystallization pre-treatment, EMMC, and lime post-treatment) of dilute swine wastewater was able to achieve an average of 93.9%, 97.7%, 96.4%, and 97.3% for TCOD, TSS, TN, and TP, respectively. The effluent from this overall treatment of the swine wastewater may meet the direct effluent discharge standards for disposal in some countries after disinfection is followed.

3.5. Economic evaluation

Based on the process performance of the EMMC process for the treatment of dilute swine wastewater, it was demonstrated that the simultaneous removal of carbon and nitrogen is technically possible through the EMMC process. The treated wastewater and the product of precipitated complex of N–P–Ca with an inert organic substance could also be reused for agricultural
production. However, the economical evaluation needs to be conducted in order to determine whether or not it is feasible and competitive to other treatment alternatives. Therefore, a combined unit process of pre-treatment with ammonium crystallization, EMMC and post-treatment with lime was used for cost evaluation.

According to Blamer and Mattsson (1994), the major costs of any treatment process are land, construction, operation and maintenance. Therefore, the cost analysis of this treatment alternative for dilute swine wastewater consists of capital, operation and maintenance of pre- and post-treatment with the EMMC process. Based on the data provided by Koba (1986), the wastewater generated per pig per day was 22.7 l in the state of Hawaii. The land cost was assumed to be US$ 9.88/m² (Nitisoravut, 1991). The life span of the treatment system was assumed to be 10 years, and the annual interest rate of 6% was used. The by-product generated from the pre- and post-treatment of the EMMC process was also calculated as a profit for fertilizer and soil conditioner.

The packing ratio of the carriers for the EMMC process was assumed to be 32% and the HRT of 30 h was designed for the operation of the EMMC process. Net present worth (NPW) was calculated using the following equation:

\[ NPW = C + A \left( \frac{(1 + i)^n - 1}{(1 + i)^n} \right) \]

where \(C\) is the capital cost, \(A\) is the annual operational and maintenance cost, \(n\) is the life-span of treatment system (assume 10 years) and \(i\) is the annual interest rate (assume 6%).

Costs for pig farms with the sizes of 300, 1000, 2000, 3000, and 5000 pigs are presented in Table 9. Apparently, a farm operation of 2000 or more pigs was required to achieve the lowest unit cost. The polymer of cellulose triacetate used in the preparation of the carrier is a reagent grade which can be much lower in cost compared to the industrial grade. More importantly, the benefit of reusing treated wastewater was not included for cost evaluation which may provide lower investment of the treatment cost.

### 3.6. System application

Based on the process performance and economic evaluation of the present treatment system, it is apparent that the present treatment system could be applied for land-limited areas, and the treated wastewater could be reused for agricultural production systems based on the USEPA requirement (USEPA, 1992). Various pre-treatment alternatives with the incorporation of the EMMC process with or without post-treatment provide various options of application and treatment alternatives to meet various requirements. This provides the agricultural producers with many types of treatment alternatives in order to meet the environmental regulation and the economic condition requirements.

### 4. Conclusion

Various pre-treatment methods with the incorporation of the EMMC process for the treatment of dilute swine wastewater were investigated. It was found that the integration of the EMMC process with ammonium crystallization pre-treatment and lime post-treatment was successful for removal of carbon, nitrogen, and phosphorus, and was recommended for further economic evaluation. It was found that the minimum requirement for the size of pig operation requires more than 2000 pigs in order to achieve the lowest cost based on the evaluation of NPW and the number of pig operation. The effectiveness and compactness of the EMMC process for the simultaneous removal of carbon and nitrogen in one single reactor provides potential for further development of a pre-fabricated wastewater treatment plant. The treated wastewater (after disinfection) holds significant potential for reuse of treated wastewater for agricultural production systems and possible direct discharge in some countries without deteriorating the environment. This result provides swine producers with various options in selecting the

<table>
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<th>Item</th>
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<th>2000</th>
<th>3000</th>
<th>5000</th>
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<td>8211</td>
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<td>24,624</td>
<td>32,832</td>
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<tr>
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<td>60,220</td>
<td>120,440</td>
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<td>301,100</td>
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<td>Pipe cost</td>
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<tr>
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<td>84</td>
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<tr>
<td>Operation and maintenance cost per year</td>
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<td>7026</td>
<td>7192</td>
<td>14,057</td>
<td>21,254</td>
</tr>
<tr>
<td>NPW</td>
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<td>78,345</td>
<td>98,379</td>
<td>165,677</td>
<td>261,705</td>
</tr>
<tr>
<td>US$/pig/year</td>
<td>20.0</td>
<td>7.8</td>
<td>4.9</td>
<td>5.5</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Unit: US$. 

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**Table 9**

Cost of swine wastewater treatment for various farm sizes
treatment/reuse method for managing their dilute swine wastewater.

Acknowledgements

The funding for this research was supported, in part, by the College of Tropical Agriculture and Human Resources and Water Resource Research Center, University of Hawaii, Honolulu, Hawaii, USA.

References


Ma, T., 1994. Entrapped mixed microbial cells technology for small wastewater treatment in the strictly land limited area. MS Thesis, University of Hawaii at Manoa, Honolulu, Hawaii, USA.


