DESIGN OF A MIXING TANK

INDIVIDUAL PROJECT

presented to
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ABSTRACT

Disposal of waste is a problem for many swine producers, since they often do not have the necessary land base to dispose of the waste. A possible solution, would be to use cement kiln dust to enhance the settlement of the manure. This would permit more economical transportation of the solids and disposal of the supernatant liquid on available land.

Some studies have been made on this subject. The purpose of this study is to design a mixing tank, for future studies that need to be done. The square-baffled tank and flat-bladed impeller design has improved settlement of manure over the previously used cylindrical vessel without baffles and propeller impeller. Preliminary tests suggest that, a ratio of 1:8 cement kiln dust to manure, seems to be a promising ratio. Of the mixing speeds investigated, 500 rpm gave the best results.
ACKNOWLEDGEMENTS

I would like to take this opportunity to thank my wife Line Côté, for her help, support and understanding.

I would also like to thank Dr. Suzelle Barrington for her support and for giving me the latitude to act on my own in this project.

Finally, I would like to thank Samson A. Sotocinal for building the apparatus and suggesting modifications where it was needed.
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INTRODUCTION

Many swine producers do not have the necessary land base to dispose of their waste. This has led to excessive doses of manure spread on land and even dumping of waste into rivers.

The use of cement kiln dust, a waste product of cement manufacturers, has been found to enhance the fertilizer value of swine manure by adding calcium and potassium as well as by stabilizing the waste, this preventing organic N degradation into NH₃ (Barrington and Mackenzie, 1989).

It has also been shown that the incorporation of cement kiln dust to swine manures does improve their settling and produces supernatant liquids of lower N, COD and P levels (Barrington et al., 1990). However, the study also reported high levels of potassium in the supernatant liquids, limiting the possibility of land disposal.

Further studies need to be done and literature on wastewater treatment suggest that the mixing of the product into the wastewater is an important part of the coagulation and flocculation process.
In this previous study a cylindrical vessel without baffles and a propeller impeller were used to mix the slurry with the kiln dust. This equipment caused the formation of a vortex during mixing, thus diminishing the effectiveness of the mixing.

The objectives of this project are to design a suitable mixing tank for laboratory tests involving the use of cement kiln dust for the treatment of swine manures, to improve their settling. The tank should be designed to permit its use for both the rapid mix operation and the subsequent slow mixing operation. Some preliminary tests will also be done to study the effects of mixing speed on settlement.
LITERATURE REVIEW

Coagulation is a process in which charged particles are destabilized to permit their agglomeration into flocs, which can be removed by gravity (flocculation).

H.E. Hudson (1965) showed that rapid mixing during coagulant addition prior to slow mixing was important for effective flocculation and that the flocs formed following rapid mixing contain appreciably more solids than those formed without a rapid-mix operation.

O'Melia (1969) reported that insufficient mixing may result in poor floc formation, while intense mixing for too long may break up previously-formed flocs causing restabilization of repulsive forces.

Metcalf & Eddy (1991) state that as a general rule, the higher the velocity and the greater the turbulence, the more efficient the mixing. They also stress the importance of restricting vortexing, in which the fluid gains rotational momentum thereby reducing turbulence and frequency of collisions between particles and resulting in poor mixing. This can be inhibited by the use of stators (baffles). Baffles restrict rotational motion and promote vertical mixing.
In the design of a mechanical rapid mix reservoir, literature agrees on the following:

- better performance of a square vessel over that of a cylindrical vessel (Letterman);
- baffles improve performance (Camp);
- a flat bladed impeller performs better than a propeller type impeller (Letterman);
- coagulants should be introduced at impeller to improve coagulation (Hudson, 1974).

In order to limit shear on long-chain-molecule polymers, paddle tip speed should not exceed 5 m/s (Awwa, 1990).

Metcalf and Eddy (1991) suggest paddle tip speed of 0.6 to 0.9 m/s to achieve sufficient turbulence without breaking up floc during slow mixing process.

Manure slurries are non-Newtonian fluids. Conventional equation from wastewater treatment literature for power requirement and velocity gradient cannot be used because they assume Newtonian fluids. Chen (1981) studied impeller power consumption in mixing livestock manure slurries.
In this study Chen proposes a method of calculating the power requirement, using the following equation.

\[ P = \rho D^5 N^3 N_p \]

Where

- \( P \) = power (W)
- \( D \) = impeller diameter (m)
- \( N \) = impeller rotational speed (rps)
- \( N_p \) = power number

![Figure 1: POWER CURVE TAKEN FROM CHEN (1981)](image)

The power number is found from Figure 1 which relates the power number to the Reynolds number. Although this curve is for beef cattle slurries, it is the only reference available. For the purpose of this project, it will be assumed a valid approximation of the power number for swine manure slurries.
The Reynolds number can be calculated using

\[ N_{RE} = \frac{\rho D^2 N}{\mu_e} \]

Where
- \( \rho \) = fluid density, kg/m\(^3\)
- \( D \) = impeller diameter, m
- \( N \) = impeller rotational speed, rps
- \( \mu_e \) = effective viscosity, Pa.s

The effective viscosity can be found using

\[ \mu_e = C (K_1 N)^{n-1} \quad (Chen, 1981) \]

Once the effective viscosity and power requirements are known for different mixing speeds, a velocity gradient \((G)\) can be found using the following equation, adapted from Metcalf & Eddy (1991)

\[ G = \sqrt{\frac{P}{\mu_e V}} \]

Where
- \( P \) = power, W
- \( G \) = velocity gradient, s\(^{-1}\)
- \( \mu_e \) = effective viscosity, Pa.s
- \( V \) = volume of fluid
Figure 2 provides dimensions of tank components and impeller in terms of ratios with respect to tank diameter. This source was used in dimensioning the tank and impeller. However, some modifications were made and will be explained in the following section.
MATERIALS AND METHODS

Construction of mixing unit:

The tanks dimensions were chosen to be 6" X 6" X 14" (152 X 152 X 356 mm) giving the reservoir a capacity up to 5 litres (sufficient for laboratory use) and still leaving enough freeboard to control splashes.

The tank is made of 3/8" (95 mm) acrylic and the baffles of 3/16" (5 mm) acrylic. This material provides sufficient strength and permits observation of the fluid as it is mixing. Parts were joined using methyl chloride, which provides good bondage without disturbing the materials transparency.

A clearance of 1/2" (12.7 mm) was left between the baffles and the tank bottom, to facilitate cleaning and permit the installation of an outlet in the future.

The impeller was machined from stainless steel and the blades were cut from a 24 gage stainless steel plate (3/8" or 9.5 mm). The size of the impeller blades was chosen to be 3/4" (19 mm). This is slightly larger than what is suggested by Figure 1. According to the reference the blade dimensions for a 6" (152 mm) tank diameter would have been 10.2 mm X 12.7 mm or 0.4" X 0.5". This did not leave enough blade surface for effective sweeping at low speed.
The shaft (3/8" or 9.5 mm) was machined from brass. This material was chosen because it is easy to machine and permitted a tight fit of the impeller onto the shaft. The impeller was pressed onto the shaft eliminating the need for set screw.

Due to the length of the shaft, it was mounted on a pin at the bottom of the tank in order to limit its translational movement, but permitting its rotational motion. A rubber coupling was installed between the motor and the shaft to reduce vibrations and correct for misalignment.

Preliminary tests:

Materials: - mixing unit
- 1 l and 4 l cylinders
- electronic scale
- electronic rpm meter
- stop watch

Methods:

Swine manure was collected from the grower barn of the MacDonald Campus farm. The manure was then diluted to 6% T.S. since rheological data was available for swine manure at 6% T.S. (Zhang and Day, 1990).
Batches of 3 l of manure were mixed with cement kiln dust. Ratios of cement kiln dust to manure of 1:2, 1:4, 1:8 and 1:12 were tested. Each batch underwent a rapid mix period of 2 min followed by a 10 min period of slow mixing. Then the mixture was transferred to cylinders where it was allowed to settle for 48 hrs.

For testing the effects of mixing speed on manure settlement, a ratio of cement kiln dust to manure of 1:8 was used.

An electronic rpm meter was used to measure the shaft velocity. Speeds of 500, 750 and 1000 rpm were tested using the same procedure outlined above.
RESULTS AND DISCUSSION

The mixing tank functions well. It promotes vertical mixing and at high speed it is evident that it creates great turbulence and even aerates the fluid.

The results of different treatments with cement kiln dust are shown in Table 1. Although they are preliminary results, the results contain some interesting information. It is evident that greater the ratio of cement kiln dust, the greater the volume of settle sludge. More importantly the ratio of 1:8 seems most promising. It has 23% more settled sludge than the ratio of 1:12 and only 4% less than that of the 1:4 ratio. This is significant because between ratios 1:8 and 1:4 the settled volume only increases by 5% whereas the ratio is doubled. There is an obvious reduction in the effectiveness of the treatment between 1:8 and 1:4.
### TABLE 1

<table>
<thead>
<tr>
<th>RATIO \ Dust: manure</th>
<th>AVERAGE SETTLED VOLUME (%)</th>
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<tbody>
<tr>
<td>Zero</td>
<td>46</td>
</tr>
<tr>
<td>1:2</td>
<td>88</td>
</tr>
<tr>
<td>1:4</td>
<td>77</td>
</tr>
<tr>
<td>1:8</td>
<td>73</td>
</tr>
<tr>
<td>1:12</td>
<td>56</td>
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Ratios were measured on a wet weight basis rapid mix operation was done at 1000 rpm for 2 min.

### TABLE 2

<table>
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<tr>
<th>R.P.M.</th>
<th>AVERAGE SETTLED VOLUME (%)</th>
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<tr>
<td>500</td>
<td>66.5</td>
</tr>
<tr>
<td>750</td>
<td>61.5</td>
</tr>
<tr>
<td>1000</td>
<td>60</td>
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A ratio of 1:8 cement kiln dust to manure was used for this test.
The effects of mixing speed on the sludge settling volume is shown in Table 2. The results indicate that better settlement is achieved at 500 rpm than at higher speeds. At higher speeds (750 and 1000 rpm) a layer of floating material was present after settlement occurred. This was most evident at 1000 rpm were a layer of 1 cm on average was present, thus reducing settled volume. The manure is very high in organic matter and at high velocity the shear stress is probably too high. Also the retention time of 2 min. under such vigorous mixing, is perhaps too long. This corroborates what O'Melia (1969) stated, intense mixing for too long may break up flocs causing restabilization.

It should be noted that experiments done with this mixing unit have consistently given a greater settled volume than previous experiments done with a cylindrical reservoir without baffles and a propeller type impeller (Barrington, 1990). The comparison of the two systems are shown in Table 3.

<table>
<thead>
<tr>
<th>RATIO</th>
<th>SETTLED VOLUME</th>
<th>COMMENTS</th>
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<tbody>
<tr>
<td>1:4</td>
<td>77%</td>
<td>square tank baffles and flat bladed impeller</td>
</tr>
<tr>
<td>1:4</td>
<td>47%</td>
<td>cylindrical tank and propeller impeller</td>
</tr>
<tr>
<td>1:8</td>
<td>73%</td>
<td>square tank, baffles and flat bladed impeller</td>
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CONCLUSIONS

The results of preliminary tests can be used as a guideline for future more in depth studies on cement kiln dust. A ratio of 1:8 cement kiln dust to manure seems promising. This ratio and others near it should be the object of further studies. A mixing speed of 500 rpm with a retention time of 2 min yielded the best results in this study. However retention time versus mixing speed should be investigated further in order to find the best combination for treatment of swine manure with cement kiln dust.

The superiority of the square baffled vessel using a flat bladed impeller has clearly been shown. Therefore it can be said that the objectives of this project have been met.
REFERENCES


APPENDIX A

SAMPLE CALCULATIONS

Maximum and minimum allowable mixing speeds:

- Maximum paddle slip speed: 1.2 m/s (Azeez, 1999)
- Impeller diameter = 6.25 x 10⁻⁴ m
- Impeller radius = 3.125 x 10⁻⁴ m

For clarification purposes, suggested paddle slip speed from 0.6 m/s to 0.9 m/s. Ideally,

w = 0.12 x 0.6 m/s = 3.75 x 10⁻⁷ m / 197.48 rad/s

Therefore, \( N_p = 1300 \text{ rpm} \)

For flocculation:

\( N_p = 27 \) rpm

\( N_p = 130 \) rpm
SAMPLE CALCULATIONS

Maximum and minimum allowable mixing speeds:

- Maximum paddle tip speed of 5 m/s (Awwa, 1990)
- Impeller diameter = $63.5 \times 10^{-3}$ m
- Impeller radius = $31.75 \times 10^{-3}$ m

\[ v = w \cdot r \]
\[ w = \frac{v}{r} = 5 \text{ m/s} \div 31.75 \times 10^{-3} \text{ m} = 157.48 \text{ rad/s} \]

Therefore \( N_{\text{max}} = 1500 \text{ rpm} \)

- For flocculation process, suggested paddle tip speed from 0.6 m/s to 0.9 m/s (Metcalf & Eddy, 1991).

\[ w = \frac{v}{r} = 0.9 \text{ m/s} \div 31.75 \times 10^{-3} \text{ m} = 28.35 \text{ rad/s} \]

Therefore for flocculation \( N_{\text{max}} = 271 \text{ rpm} \)
\( N_{\text{min}} = 180 \text{ rpm} \)
Calculation of power requirement at 1000 rpm (16.7 rps):

- Effective viscosity at 16.7 rps
  \[ \mu_e = C (K_1 N)^{n-1} \]

  Where
  \[ C = 0.035 \] and \[ n = 0.76 \] (Zhang and Day, 1990)
  \[ K_1 = 10.3 \] (Chen, 1981)

  \[ \mu_e = 10.175 \times 10^{-3} \text{ Pa.s} \]

- Reynolds number becomes
  \[ N_{RE} = \frac{( - \rho D^2 N )}{\mu_e} \]

  Where
  \[ \rho = 1000 \text{ kg/m}^3 \]
  \[ D = 63.5 \times 10^{-3} \text{ m} \]
  \[ N = 16.7 \text{ rps} \]
  \[ \mu_e = 10.175 \times 10^{-3} \text{ Pa.s} \]

  \[ N_{RE} = 6618 \]

  From Figure 1, \( N_p \approx 2.8 \)

- The power requirement
  \[ P = \rho D^5 N^3 N_p \]

  \[ P = 13.5 \text{ W} \]
- The velocity gradient

\[ G = \sqrt{\frac{P}{V \mu_e}} \]

Where \[ V = 3.5 \times 10^{-3} \text{ m}^3 \]

Therefore \[ G = 616 \text{ s}^{-1} \]
APPENDIX B

GRAPHS OF SETTLED VOLUME
SETTLEMENT

% VOLUME

RETENTION TIME: 48 HR.
EFFECTS OF MIXING SPEED

% VOLUME SETTLED

RETENTION TIME: 48 HR.
APPENDIX C

IMPELLER DESIGN