Analysis of Separation Process: The Screw Press

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ABSTRACT

A screw press is designed to act as a mechanical separated process. It is a machine that uses a large screw to force a liquid or slurry through a tube past a cylindrical screen. This produces a flow of separated solid at the end of the tube while it is controlled by a set of pressure plates.

The objectives for this study are to (1) analyze the screw press by using the mass balance equation and the flow equation and (2) solve for all values that can not be measured precisely from the screw press.

Samples were collected from the influent mixture, the effluent liquid, and the separated solids that were removed from the screw press. The samples were then analyzed to determine the concentration of the following: total solids (TS), volatile solids (VS), Kjeldahl nitrogen (TKN), ammoniacal nitrogen (TAN), phosphorous (P), and potassium (K).

By using the mass balance and flow equations, many un-measured values can be calculated. Also by analyzing these equations, the mass removal efficiency from the screw press can be calculated. The concentration removed is also correlated with these equations.

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INTRODUCTION

A mechanical separation process usually uses a screen to separate different components of an influent mixture that is based on particle size (Chastain, 2006). In this lab, a screw press will be used to represent a mechanical separation process.

A screw press is designed to act as a mechanical separated process. It is a machine that uses a large screw to force a liquid or slurry through a tube past a cylindrical screen. This produces a flow of separated solid at the end of the tube while it is controlled by a set of pressure plates. Therefore, the internal pressure in the tubes pushes the liquid out through the screen (Chastain, 2006).

The material that is being separated is usually pumped from a reception pit to the intake of the screw press. The flow that is supplied to the separator is always greater than the flow that is going through the screen. This is the case so a "biting" into a full pipe will always occur. Typically there is an excess flow that is then returned to the reception pit to be re-pumped back into the screw press. A vertical pipe at the influent port is used to vent. This vent pipe is used to facilitate gravity flow of the excess material back to the reception pit and limit the pressure at the intake of the screw (Chastain, 2006).

A stainless steel screw press was used to carry out this experiment. It has the following specifications:

- a 521mm long cylinder screen made from wedge wire that has 0.5 mm wide slots along the entire length,
- three phase motor that produces 4 kW of power to run the screw that turned at 36 rpm, and
- a single 40 kg counter weight on each pressure arm plate.

The problem in this experiment is that all the flow rates, concentrations, and densities for the screw press can not be measured accurately. Therefore, there needs to be a series of calculations with the known measured values to compute the values that can not be measured.

The objectives for this study are to (1) analyze the screw press by using the mass balance equation and the flow equation and (2) solve for all values that can not be measured precisely from the screw press.

ANAYLSIS AND RESULTS

Screw Press Schematic

It is necessary to create a schematic of the screw press. In this schematic, the flow rates, concentrations, and densities are shown for each of the influent, effluent, and separated solids. The representation of this mass balance system is shown in Figure 1.

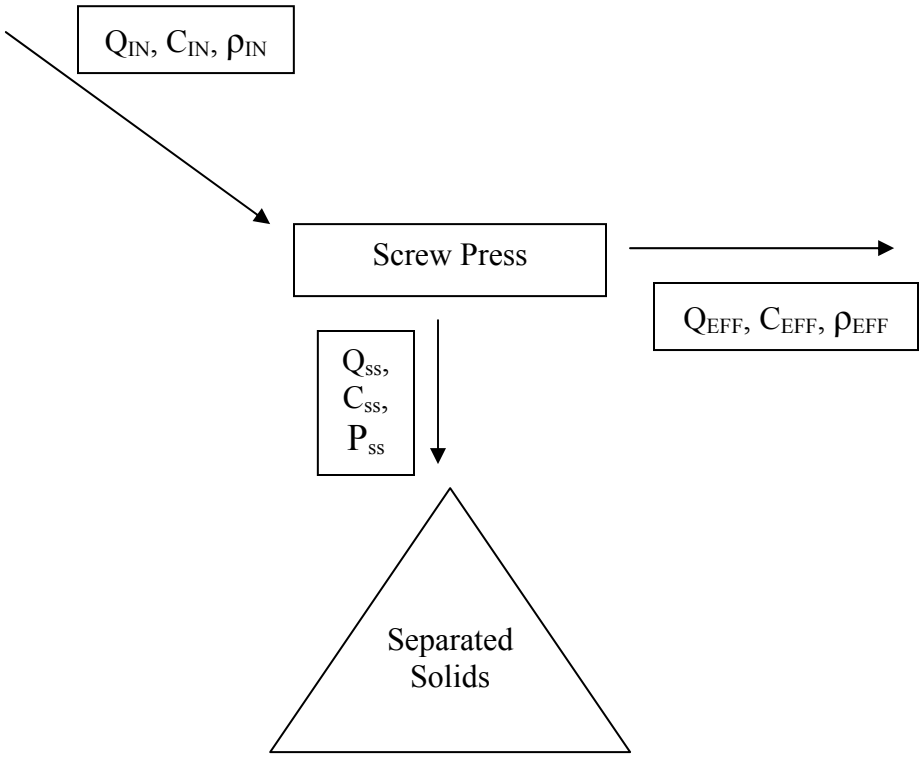

Figure 1. The schematic of the mass balance system for the screw press.

Constituent Concentrations

Samples were collected from the influent mixture, the effluent liquid, and the separated solids that were removed from the screw press. These were collected and analyzed to determine the concentration of the following: total solids (TS), volatile solids (VS), Kjeldahl nitrogen (TKN), ammoniacal nitrogen (TAN), phosphorous (P), and potassium (K). The given concentrations of each sample are presented in Table 1.

Table 1. Concentrations of the defined constituents in the influent, effluent, and separated solids for the screw press (wet basis).

Constituent	Influent Mixture (mg/L)	Liquid Effluent (mg/L)	Separated Solids (mg/kg sample)
TS	20000	17580	275000
VS	13282	11170	NM [1]
TKN	2240	2083	7704
TAN	1270	1310	2114
P	1040	914	2492
K	1165	1146	2004

[1] Not measured.

Calculated Density

For this experiment with the screw press, the densities could not be measured. The density of a liquid mixture varies with the solid content. This proves that in many cases the densities of the influent, effluent, and separated solids are different. Therefore, it is incorrect to neglect the densities of the influent, effluent, and separated solid for the screw press.

Calculations need to be preformed to find the densities of the influent, effluent, and separated solid for the screw press. The density of a fluid mixture can be calculated as:

$$\rho_{MIX} = (1 - f_S)\rho_W + f_S * \rho_S . \quad (1)$$

Where,

ρ_{MIX} = density of the mixture, kg/m^3,
ρ_W = density of water, 997.6 kg/m^3,
f_S = solids fraction of mixture, and
ρ_S = density of dry solids, 1232 kg/m^3.

By using equation 1 and calculating the densities with extrapolation; Table 2 shows the density values for the influent, effluent, and separated solid.

Table 2. Calculated densities for influent, effluent, and separated solid with using extrapolation.

Constituent	Influent Density (kg/m^3)	Effluent Density (kg/m^3)	SS Density (kg/m^3)
TS	1002.28	1001.71	1062.06

Mass Balance on Screw Press

Application of the law of conservation of mass on the screw press gave:

$$Q_{IN} * C_{JIN} = C_{EFF} * Q_{EFF} + C_{JSS} * Q_{SS} . \quad (2)$$

Where,

Q_{IN} = initial flow of liquid into the screw press (L/min),
C_{JIN} = initial concentration of liquid through screw press (mg/L),
C_{EFF} = effluent concentration of liquid through screw press (mg/L),
Q_{EFF} = effluent flow of liquid through screw press (L/min),
C_{JSS} = concentration of separated solids (mg/L), and
Q_{SS} = flow of the separated solids (L/min).

The mass balance equation was then written to find C_{JIN} by dividing equation 2 by Q_{IN} in result of:

$$C_{JIN} = \frac{C_{EFF} * Q_{EFF} + C_{JSS} * Q_{SS}}{Q_{IN}} . \quad (3)$$

The separated solid volume fraction was then defined as:

$$SSVF = \frac{Q_{SS}}{Q_{IN}} . \quad (4)$$

Furthermore, the separated solid volume fraction can be described as:

$$SSVF = \frac{C_{IN} - C_{EFF}\left(\frac{\rho_{IN}}{\rho_{EFF}}\right)}{C_{SS} - C_{EFF}\left(\frac{\rho_{SS}}{\rho_{EFF}}\right)} . \quad (5)$$

Where,

ρ_{IN} = influent fluid density (kg/m^3),
ρ_{EFF} = effluent fluid density (kg/m^3), and
ρ_{SS} = separated solid density (kg/m^3).

By substituting equation 4 into equation 3, the new mass balance is written in terms of SSVF because all the values in equation 4 were measured. This equation result is:

$$C_{JIN} = C_{EFF}\left(\frac{Q_{EFF}}{Q_{IN}}\right) + C_{SS} * SSVF . \quad (6)$$

The fluid mass balance equation is:

$$\rho_{IN} * Q_{IN} = \rho_{EFF} * Q_{EFF} + \rho_{SS} * Q_{SS} . \quad (7)$$

The fluid mass balance equation was written to solve for (Q_{EFF}/Q_{IN}) by using equation 4 and equation 7 to yield:

$$\frac{Q_{EFF}}{Q_{IN}} = \frac{\rho_{IN}}{\rho_{EFF}} - \frac{\rho_{SS}}{\rho_{EFF}} * SSVF . \quad (8)$$

By using equations 6 and 8, the mass fraction removed from the screw press is written as:

$$MFR = \frac{C_{IN} - C_{EFF}\left[\frac{\rho_{IN}}{\rho_{EFF}} - \frac{\rho_{SS}}{\rho_{EFF}} * SSVF\right]}{C_{JIN}}. \quad (9)$$

By rearranging equation 9, the mass fraction removed can also be calculated by:

$$MFR = 1 - \left[\left(\frac{\rho_{IN}}{\rho_{EFF}}\right) - \left(\frac{\rho_{SS}}{\rho_{EFF}}\right) * SSVF\right]. \quad (10)$$

This proves that the mass removal efficiency is:

$$MRE = 100 * MFR. \quad (11)$$

The concentration reduction of the screw press is

$$CR = \frac{C_{IN} - C_{EFF}}{C_{IN}} * 100. \quad (12)$$

Volume of Separated Solids Removed

To find the separated solids removed, it is essential to use the settled volume fraction that is represented in equation 5. The settled volume fraction is the volume of the settled material normalized to the initial volume placed in a graduated cylinder. Furthermore, in this design the initial volume would be the wastewater that flows into the screw press throughout a given time period.

The value of SSVF for the TS constituent is shown in Table 3. For this constituent the fraction removed per day was 8.81 mL.

Table 3. Change in volume of the settled material for the initial TS concentration.

Constituent	Separated Solids (mg/kg sample)	Fraction Removed (L/day)
TS	275000	8.81E-03

Volume of the Effluent and Separated Solids Produced

The volume of the fluid mixture produced was 160,000 L/day. However, it was impossible to measure the volume of the liquid effluent or the mass of the separated solids accurately.

By multiplying the fraction removed of separated solids with the amount of mixture produced per day the volume of separated solids produced is establish. By calculating this, it proves that there is just over 1,410 L/day of separated solids produce by the screw press. This is displayed in Table 4.

The effluent flow produced from the screw press with a total mixture produced of 160,000L/day was found next. This was executed by using equation 8. The calculated value for the volume of effluent produced is almost 158,595 L/day. This value is also presented in Table 4.

Table 4. Volume of effluent and separated solids produced per day.

Constituent	Mixture Produced per Day (L)	Volume of Effluent Produced (L/day)	Volume of Separated Solids Produced (L/day)
TS	160000	158594.648	1410.316

If the densities were not known, a quick and easy assumption can be made. The assumption is that all the densities are relatively the same; therefore, in equation 8 the densities can be canceled. If this way was used to calculate the volume of effluent produced the estimated value would be 158,590 L/day.

The percent error for the volume of effluent produced using the density and without using the density is 0.0032%. This proves that canceling the density gives a great estimate, although it is always better to use the correct calculated value.

Constituent Concentrations

To find out weather or not the screw press significantly influenced the concentrations of each constituent; the concentration removed from the separated solids was calculated. The concentration removed was computed by using equation 12. These values are presented in Table 5.

Table 5. The concentration removed for each constituent.

Constituent	CR (%)
TS	12.10
VS	16.60
TKN	7.01
TAN	-3.15
P	12.12
K	1.63

After calculating the concentration removed, it proves that overall the screw press did significantly influence the concentration of each constituent. The most remove was the voluble solids with 16.6% and the least was the total ammoniacal nitrogen with -3.15%. Even though the TAN was negative, it does not mean that more was put into the solution. It just might mean that the TAN concentration in the separated solids might be very difficult to measure. In general, the soluble compounds in water were not removed easily, although the constituents that do not dissolve in water had a good yield for the concentration removed.

Concentration Reduction and Mass Removal Efficiency

The concentration reductions are found from Table 5, and the mass removal efficiencies were calculated using equation 11. With using the measured values given, these equations were used to calculate the results that are shown in Figure 2.

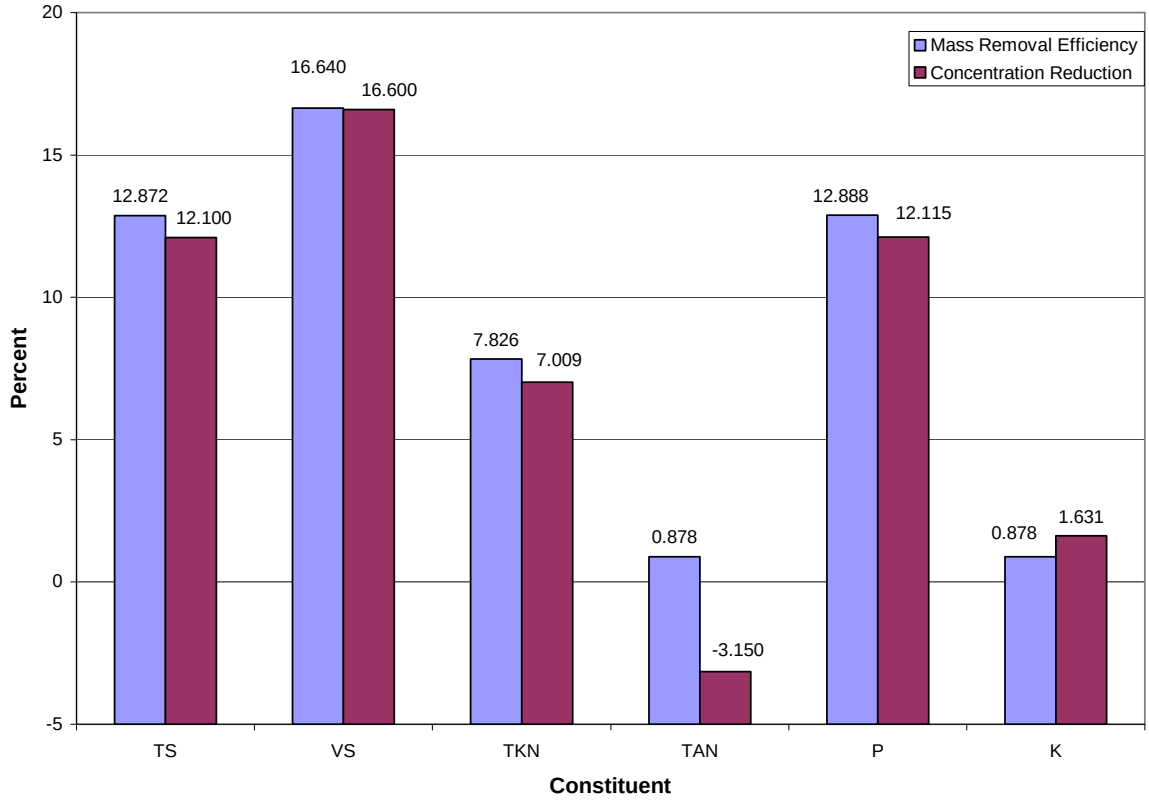

Figure 2. Concentration reductions and mass removal efficiencies for each constituent from the screw press.

This graph shows that VS has the highest concentration reduction and mass removal efficiencies. The VS calculated values for concentration reduction and mass removal efficiencies are both almost 17%.

The supernatant concentrations of the soluble constituents, TAN and K, were not affected by gravity setting. This is known through the amount of separated solids removed. This also reflects on the concentration reduction values. The concentration reduction for TAN is about -3% and K is about 2%.

For the two constituents that have lowest concentration reduction, a modified version for calculating the mass removal efficiency was used. Therefore, the TAN and K values for the mass fraction removed were found by using equation 9. Both of these values are 0.88%. To obtain these values, the information from TS was used.

The concentration removed and the mass removal efficiency are directly related to one another. The lower the mass removal efficiency is the lower the concentration removed will be.

Concentration of Separated Solids

The concentration of VS in the separated solids could not be measured accurately; therefore it needed to be calculated. To compute this value, first the VS mass of separated solids was found. This was found by using the VS values in the following equation:

$$M_{SS} = \frac{CR}{100} * C_{IN} * 160000 . \quad (13)$$

Where,

M_{SS} = VS mass of separated solids, (mg sample).

Next, the concentration of separated solids was found for VS. This was established with the following equations:

$$C_{SS} = \frac{\left(\frac{M_{SS}}{V_{SS}}\right)}{\rho_{SS}} . \quad (14)$$

Where,

C_{SS} = VS concentration of separated solids, (mg/kg sample), and

V_{SS} = Volume of separated solids produced, (L/day).

The value for Vss is found in Table 3. The results of equations 13 and 14 are presented in Table 5. The concentration of separated solids for VS is over 235,500 mg/kg sample.

Table 5. The calculated values for finding the concentration of VS in the separated solids.

Constituent	M_{SS} [1] (mg sample)	C_{SS} [2] (mg/L)	C_{SS} [2] (mg/kg sample)
VS	3.53E+08	2.50E+05	235519.05

[1] VS mass of separated solids.
[2] VS concentration of separated solids.

Carbon Nitrogen Ratio

The carbon nitrogen ratio is always one of the key calculations with separated solids. This ratio is a great way in calculating if a product will be good for compost or not.

The carbon in the separated solids for the screw press was found with the following equation:

$$C_{DB} = \frac{100 - FS_{DB}}{1.8} . \quad (15)$$

Where,

C_{DB} = carbon content of litter on a dry basis, (%), and

FS_{DB} = fixed solids of litter on a dry basis, (%).

To compute the carbon to nitrogen ratio (C:N), first the dry basis was converted into the wet basis of carbon. Equation 16 was then used to find the carbon nitrogen ratio:

$$C:N = \frac{C}{TKN}. \tag{16}$$

Where,

C:N = carbon ratio, (%),
C = wet basis form of carbon, (mg/kg sample), and
TKN = TKN separated solids, (mg/kg sample).

The results for the carbon nitrogen ratio are shown in Table 6. The separated solid produced by the screw press has a C:N of almost 17%.

Table 6. Carbon nitrogen ratio of the separated solids.

Constituent	VSss (mg/mg TS)	Css Dry Basis (%)	Wet Basis (mg/kg sample)	C:N (%)
TKN	85.643	47.580	130843.916	16.984

Since the carbon nitrogen ratio results in approximately 17%, it will be a great product to start with for compost. A good quality product used for compost has greater than 20% carbon nitrogen ratio. Therefore, not too much needs to be added to the separated solid from the screw press for it to become a relatively good product for compost. For example, maybe some straw could be added to bump up the C:N level.

CONCLUSIONS

Samples from the influent, effluent, and separated solids were collected and the influent flow rate was measured. After the samples were stored properly, they were then each analyzed for their content levels of various plant nutrients. The samples were tested to determine the concentration levels of total solids (TS), volatile solids (VS), Kjeldahl nitrogen (TKN), ammoniacal nitrogen (TAN), phosphorous (P), and potassium (K).

The following conclusions were developed from the analysis and results from the mass balance and flow equations.

- With using these two equations many un-measured values can be calculated.
- Also, by analyzing the mass balance equation and the flow equation the mass removal efficiency from the screw press can be calculated.
- The concentration removed is also correlated with these equations.

Calculations were then performed to compute the un-measured values for the screw press. The conclusions are as follows.

- The total solids fraction removed per day was 8.81 mL.
- There was just over 1,410 L/day of separated solids produce by the screw press and the volume of effluent produced is almost 158,595 L/day.
- Compounds that are soluble in water were not removed easily, although the constituents that do not dissolve in water had a good yield for the concentration removed.

- The concentration removed and the mass removal efficiency are directly related to one another. The lower the mass removal efficiency is the lower the concentration removed will be.
- The calculated concentration of VS in the separated solids is over 235,500 mg/kg sample.
- The carbon nitrogen ratio from the separated solids is 17%. This proves to be a good starting material for compost.

REFRENCE

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