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Development of a Standard Method for Testing Mechanical Manure Solids Separators

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Abstract. *Mechanical manure solids separators are used in conjunction with animal waste management systems for multiple purposes. These include reduction of solids for effluent recycle as flush water, reduction of organic loading into manure storage and treatment systems and recovery of manure fiber. The performance of mechanical manure solids separators varies as the total solids content and characteristics of the input manure change. To properly size and install mechanical manure solids separation units, the separators' performance characteristics must be known for the specific manure slurry found at the farm in question. Papers currently in publication use different methods to calculate solids capture efficiency. This makes it inappropriate to compare many reported separation efficiencies directly. Where sufficient data has been presented to compare efficiencies calculated with different published approaches using a common data set, calculation differences of over 25% in efficiency result. Also, much of the currently published performance data was taken at a single manure input total solids concentration, and is only meaningful for manure at the same total solids level. This paper describes a protocol developed by the Biosystems Engineering and Environmental Science Department at The University of Tennessee for testing mechanical solids separation devices. The capture efficiency is reported on a dry-mass basis in this protocol. This protocol tests* *manure solids separator performance across a range of input manure slurry TS concentrations, and provides information about influent and effluent mass flow rates, dry mass capture efficiencies and nutrient partitioning. At present, a standard protocol for testing and reporting on the performance of mechanical manure separators is not in common use. The acceptance of a standard testing and reporting protocol would provide performance information that would allow engineers and producers to make direct comparison of mechanical manure separation devices.*

Keywords. Mechanical solids separation, manure, standard method, separator efficiency.

Introduction

Animal waste management systems using hydraulic-flush manure collection systems routinely rely on solids separation in order to achieve an effluent that is low enough in solids to recycle as flush water. In cases where a use for recovered manure fiber exists, such as dairy bedding material or as a compost, mechanical solids separators are routinely used. To properly size and install mechanical manure solids separation units, the separators' performance characteristics must be known for the specific manure slurry found at the farm in question. The performance of mechanical manure solids separators varies with the total solids (TS) content and the solids characteristics of the input manure. Manure slurries encountered in solids separation applications are typically within the range of 1% – 8% TS. Generally, mechanical screw-press separator performance increases as input manure TS concentrations increase in this range (Burns & Moody, 2001a). In addition to the percent TS of the manure, the type of solids also impacts separation performance. Accordingly, animal species, feed type and bedding type (if present) will have a significant impact on separator performance. A review of published papers concerning the performance of mechanical manure solids separators found that different methods to calculate separator efficiency are in use (Burns & Moody, 2001a; Chastain et al., 2001; Converse et al., 1999; Godbout et al., 2002; Zhang and Westerman, 1997). This makes it inappropriate to compare many reported separation efficiencies directly. Where sufficient data has been presented to compare efficiencies calculated with different published approaches and the same data set, differences of over 25% in efficiency result. Also, much of the currently published performance data was taken at a single manure input total solids, and the associated efficiency is only accurate for that single point.

In an effort to provide comparable performance data with a common basis for the selection of mechanical separators, the Biosystems Engineering and Environmental Science Department at The University of Tennessee has developed a standard testing protocol for mechanical manure solids separators. This protocol evaluates mechanical manure solids separators based on dry mass capture efficiency across a range of input manure slurry TS concentrations commonly encountered. It is intended to provide consultants, engineers and producers with separator performance data that can be used in the selection of mechanical solids separators for use with animal manures. The testing protocol generates data on liquid effluent (press-liquor) mass flow rates over a range of influent TS concentrations as well as recovered solids (press-cake) mass flow rates, TS concentration and the dry-mass capture efficiency of the unit.

Methods

Performance Tests

This testing protocol measures separation efficiency based on the capture efficiency of solids on a dry mass basis. Measurement of the mass and total solids of the press liquor and press cake over a measured operational time is required to calculate the separator dry-mass capture efficiency. Mechanical separator performance is manure specific. Two manure characteristics that greatly influence mechanical separator performance are manure total solids and solids density. For these reasons, separator performance tests should be conducted across a range of TS concentrations from 1% - 8%, and be reported by animal species and include information on bedding or any other materials in the waste stream.

Test Set-up

The separator to be tested must be properly installed and set-up correctly for the manure type in order to generate meaningful results. Screen sizes and back-pressure settings (on screw-press units) should be set according to the manufactures specifications before conducting the testing. To conduct testing over a range of manure slurry TS concentrations between 1% and 8%, a quantity of the manure with a minimum TS of 8% is required. A TS analysis must be run on the initial manure to determine the dilution water volume that is required to prepare a range of input manure slurries down to the low end of the test range. To facilitate the mixing of manure slurries with different TS concentrations a tank that can be well agitated is required. The authors have found that a 1,893 liter (500 gallon) poly tank with a 38 cm (15 inch) opening is convenient to moisture adjust manure slurries for testing. This size tank is easily mixed and provides an adequate volume for many screw-press and smaller static screen separators. To ensure the separator is achieving maximum capacity throughout the tests, the pump used to feed the separator should be capable of oversupplying the influent to the separator intake. Additionally, if sufficient, the overflow from the intake can provide mixing in the tank to keep the solids in suspension during the tests. This can be accomplished by using two values in a "T" piping arrangement such that return flow-rate can be controlled and routed back into the tank.

Both effluent streams must be recovered from the separator in order to complete this testing protocol, the liquid stream and the separated solids. In this paper, the liquid stream will be referred to as the press liquor and the separated solids will be referred to as the press cake. To perform a mass based analysis, the press liquor and the press cake need to be collected and weighed. In the performance tests completed by the authors, press liquor was collected in a 190 L (55 gallon) plastic drum. Press cake was collected in a 0.65 m^3 (23 ft^3) rectangular plastic container. Both press liquor and press cake were weighed on a *True-test* load cell (Model #703, *Test-test*, Mineral Wells, TX). Press liquor volume and influent volume were calculated from mass measurements using density.

Influent Slurry Preparation

This protocol requires testing the separator at multiple manure influent TS concentrations. The test concentrations are intended to represent manure slurry TS concentrations likely to be encountered when using a manure solids separator at a livestock facility. Total solids concentrations of 8, 6, 4, 2 and 1% are recommended for testing. To achieve the recommended TS concentrations, an initial manure source of 8% TS or greater must be used. The initial manure must be analyzed for TS, then, a calculated mass of water is added to a known mass of manure in the tank to achieve 8% TS slurry.

During tests at The University of Tennessee Dairy Experiment Station, collected manure and bedding material were mixed with dilution water for 30 minutes in a 500 gal tank to achieve an 8% slurry. The slurry was mixed with an electric paddle mixer, and then pumped to the separator using a centrifugal wastewater pump (Model #N267-F, *Zoeller Pump Co.*, Louisville, KY). Overflow piping carried excess manure slurry back to the tank to provide mixing. To perform further tests at subsequent TS concentrations, slurry in the tank was further diluted with water and remixed using the electric paddle mixer.

Sampling and Analysis

Testing at each manure TS input concentration must be conducted for a sufficient length of time to allow separator performance to reflect the current input manure TS. An initial test run should be conducted to allow calculation of the manure residence time in the separator. It is suggested that the test length be three times the calculated residence time.

Influent and effluent samples should be taken simultaneously halfway through each test. The influent and the press liquor can be collected in 500 mL wide-mouthed bottles, and the press cake can be collected in 3.8 L sealable plastic bags. Samples should be packed on ice in a cooler and transported to the lab after the performance testing. At a minimum, sample analysis should include total and volatile solids using Standard Method 2540 G (Standard Methods, 1998), soluble and total phosphorus (where soluble phosphorus is analyzed after filtration through 0.45 µm), and total kjeldahl nitrogen. Total and volatile solids analysis involving solid samples should be reported as a percentage and not in mg/L. To ease comparison between press cake and separator influent and press liquor, results should be reported as a percentage. An example data set showing nutrient information is provided in the Appendix (Burns and Moody, 2001b).

Performance Calculations

A standard method for reporting the results of solids separation performance tests would aid in the comparison between machines. Four important results from the tests are volumetric flow rate through the separation unit, TS concentration of the press cake, separation efficiency of the unit and partitioning of the nutrients. Since the testing protocol collects all data on a mass basis, the volumetric flow rates reported for press liquor are calculated using the density of water. A example data set for performance calculation information is provided in the Appendix (Burns and Moody, 2001b), it includes examples of typical graphical analyses of separator performance.

Solids Capture Efficiency

Separation efficiencies, sometimes referred to as solids capture or removal efficiencies, should be calculated on a mass basis, and are not the same as percent reductions in TS concentration. In many manuscripts, the percent reduction in TS is reported as the separator solids removal efficiency. However, removal efficiency is correctly calculated on a dry mass basis; the calculation must take into account that the mass entering the separator does not equal the mass leaving the separator in the press-liquor alone. The mass collected as solids (both solids and moisture) must be accounted for. The authors believe the most appropriate way to calculate the solids capture efficiency of a manure solids separator is on a dry mass basis and not as a percent reduction in TS. The calculation for dry mass capture efficiency is shown in Equation 1. For comparison the equation used to calculate a percent reduction in TS is provided as Equation 2.

$$Eff.\ (\%)_{Capture} = \frac{m_{in}\left(\%TS_{in}\right) - m_{PL}\left(\%TS_{PL}\right)}{m_{in}\left(\%TS_{in}\right)} \times 100 = \frac{m_{PC}\left(\%TS_{PC}\right)}{m_{in}\left(\%TS_{in}\right)} \times 100 \qquad \text{(Equation 1)}$$

$$TS\ (\%)_{Red.} = \frac{\%TS_{in} - \%TS_{PL}}{\%TS_{in}} \times 100 \qquad \text{(Equation 2)}$$

The equation symbols are defined as follows; *Eff.* $(\%)_{Capture}$ is dry mass capture efficiency, *TS* $(\%)_{Red.}$ is percent reduction in total solids, m_{in} is influent mass, m_{PL} is press liquor mass, m_{PC} is press cake mass, $\%TS_{in}$ is percent total solids in the influent, $\%TS_{PL}$ is percent total solids in the press liquor, and $\%TS_{PC}$ is percent total solids in the press cake.

Reporting $TS\ (\%)_{Red.}$ as the removal or separation efficiency, especially without defining the procedure, can lead to misinterpretation of the data by the end user. Table 1 shows the percent difference between the dry mass capture efficiency ($Eff.\ (\%)_{Capture}$) calculation and the percent reduction in TS ($TS\ (\%)_{Red.}$) calculation for computing separation efficiency using the example KP-6L data set. The dry mass capture efficiency was an average of 34% greater than the percent reduction in TS. In a similar study, Converse et al. (1999) reported separation efficiencies using a mass basis and using the percent change in concentration. The separation efficiencies calculated on a mass basis were an average of 28% greater than the calculations using the percent change in concentrations.

Table 1. Percent difference between the dry mass capture efficiency ($Eff.\ (\%)_{Capture}$) calculation and the percent reduction in TS $TS\ (\%)_{Red.}$) calculation to compute separation efficiency on data collected by the University of Tennessee on a Vincent KP6-L screw press solids separation unit.

$\%TS_{in}$	$\%TS_{PL}$	$\%TS_{PC}$	m_{in} (kg)	m_{PC} (kg)	$Eff.\ (\%)_{Capture}$	$TS\ (\%)_{Red.}$	Calculation Difference (%)
8.3	5.0	19.9	234.9	53.3	54.8	40.08	27.0
6.0	3.9	21.1	213.1	31.1	51.8	35.0	32.4
4.5	2.7	20.7	202.4	18.0	40.8	39.8	2.3
2.5	1.8	26.7	187.8	3.0	45.9	28.0	39.1
1.0	0.9	21.6	185.0	1.1	33.8	11.2	66.7

Discussion

The flow rate of waste through a separator is dependent on influent TS concentration. In Figure 1, data collected by The University of Tennessee for a Vincent KP-6L screw-press separator is shown as an example to indicate how press liquor flow rate and solids capture efficiency are effected by influent TS. For this screw-press, as influent TS increases press liquor flow rate decreases. Separation efficiency follows an opposite trend by increasing with input manure TS. Note that the press liquor flow rate ranges from a high of nearly 30 gpm with a 1% TS manure input slurry to a low of 6 gpm at an 8% TS manure input slurry. In contrast the solids capture efficiency is at a low of 18% with an input manure slurry of 1% TS and increases to a high of 56% when manure input TS is increased to 8%.

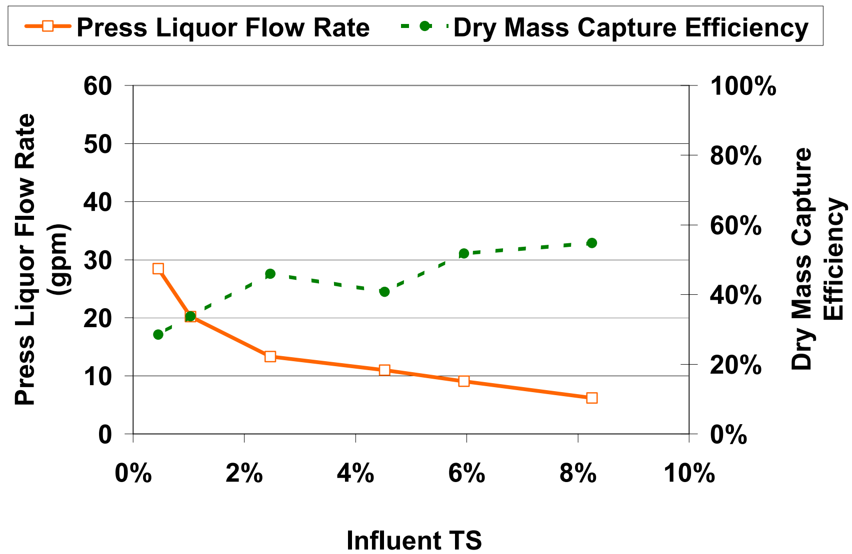

Figure 1. Press liquor flow rate and dry mass capture efficiency from a Vincent KP-6L separator as a function of influent TS.

These large variations in performance for the same separator when functioning with differing input manure TS levels highlight the importance of having performance data across a range of input TS concentrations when selecting equipment.

In addition to providing performance data across a range of input TS, separator efficiency data should be reported on a dry mass basis for captured solids. It is important to recognize that the percent reduction in TS from across input manure TS and output press liquor TS does not equate to solids capture efficiency for a solids separator.

Conclusion

The reporting of separator performance across a range of input manure slurry TS would be a great benefit in the selection of manure solids separators. By having separator performance data for the expected manure TS to be processed, designers would have more accurate information available to size separator pumping and piping systems as well as solids storage space requirements.

The adoption of a standard for calculating and reporting mechanical manure solids separator performance would assist consultants, engineers and producers in selection of the units by allowing meaningful comparisons of performance data. The most appropriate method for expressing mechanical manure separator performance is on a dry-mass basis.

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APPENDIX

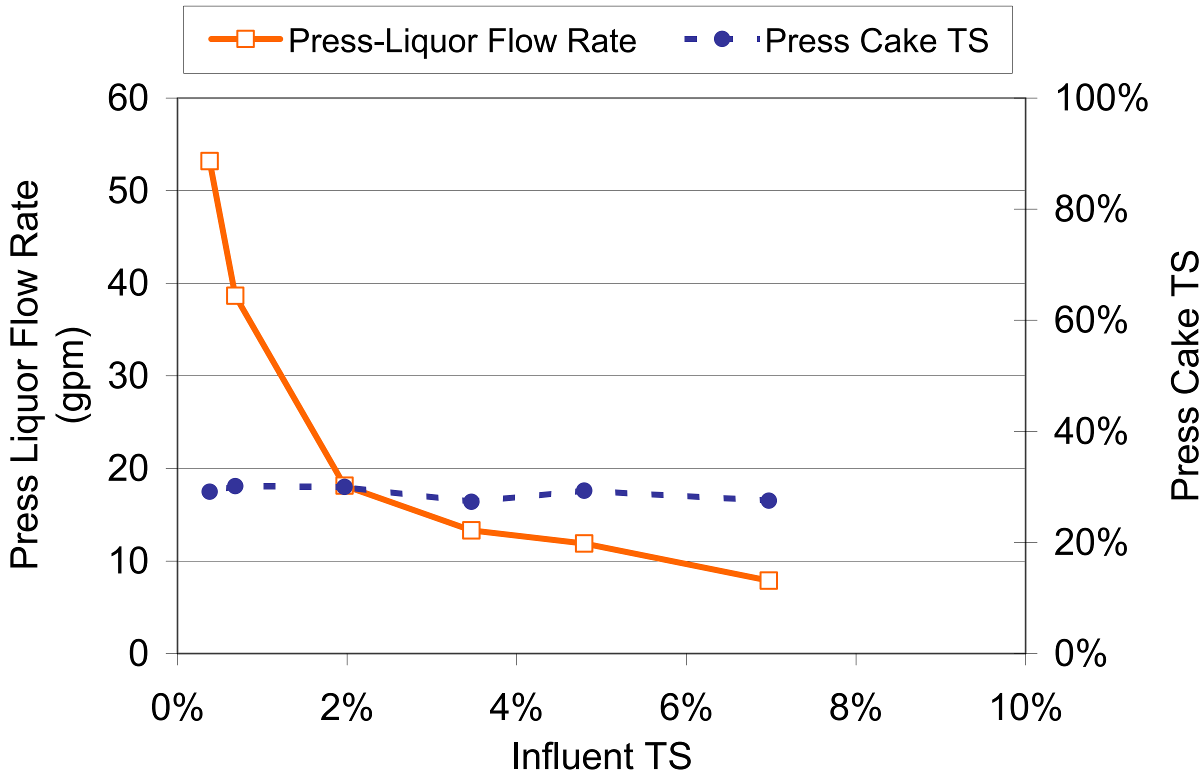
Example Data Set and Graphical Analysis

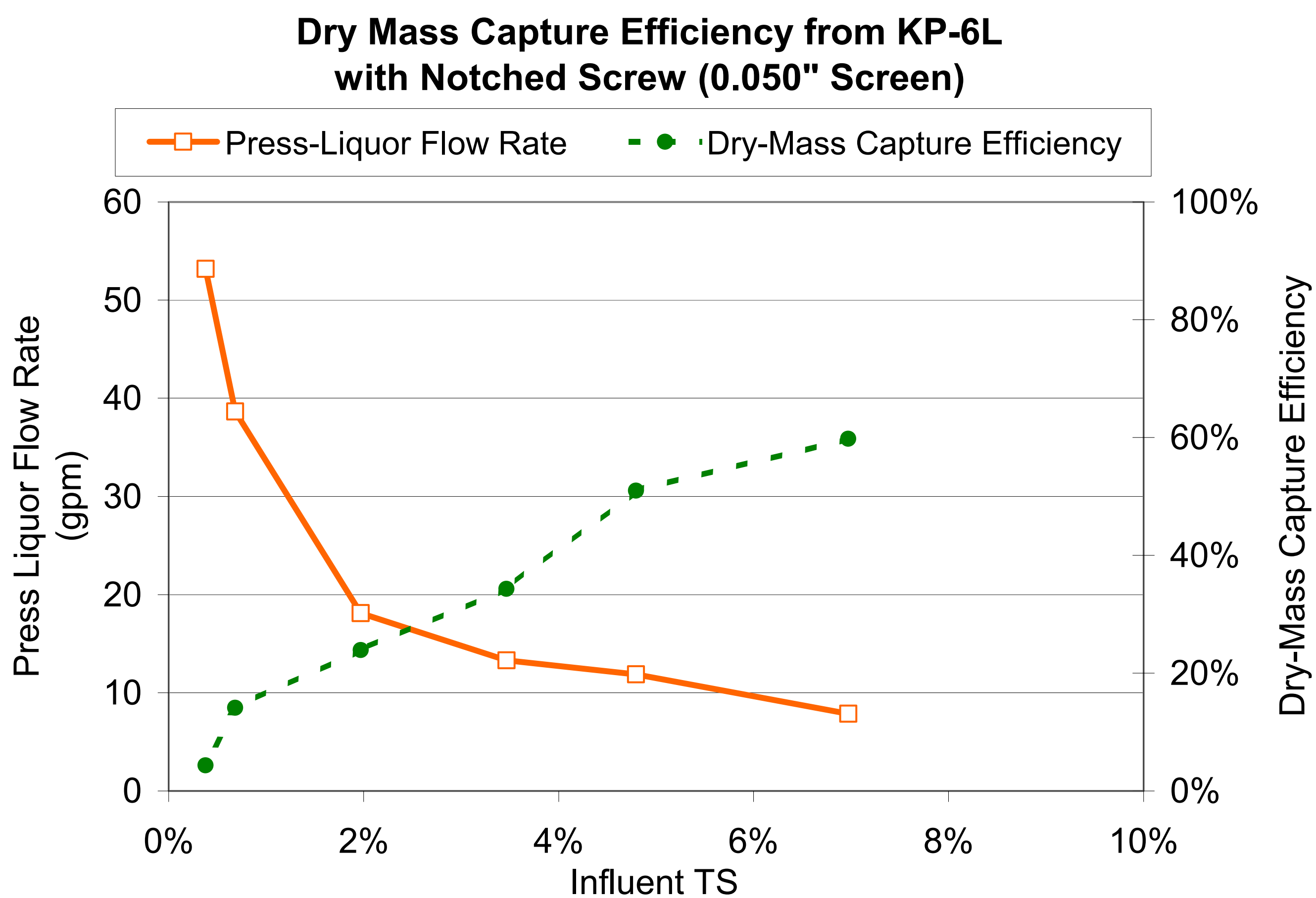
Using Mechanical Solids Separation Testing Protocol

Sample Identification	Screw Type	% TS	% VS	Wt. of eff.	mass in PC wet basis	Dry Wt. of Eff.	dry mass capture eff	Vol of eff.	Time of run	Flow rate
		%	%	(lb)	%	(lb)	%	(gal)	(min)	(gpm)
Screw Press in	Notched	6.97%	82.62%	426.75		0.30			5.52	
Screw Press in	Notched	4.79%	79.71%	450.6		0.22			4.17	
Screw Press in	Notched	3.47%	82.79%	426.58		0.15			3.68	
Screw Press in	Notched	1.97%	80.02%	417.56		0.08			2.72	
Screw Press in	Notched	0.68%	80.75%	420.34		0.03			1.3	
Screw Press in	Notched	0.38%	87.04%	419.237		0.02			0.78	
Screw Press Cake	Notched	27.48%	82.86%	64.75	15%	0.18	59.79%		5.52	
Screw Press Cake	Notched	29.30%	93.09%	37.6	8%	0.11	51.00%		4.17	
Screw Press Cake	Notched	27.32%	90.80%	18.58	4%	0.05	34.33%		3.68	
Screw Press Cake	Notched	30.00%	92.45%	6.56	2%	0.02	23.92%		2.72	
Screw Press Cake	Notched	30.11%	92.42%	1.34	0%	0.00	14.10%		1.3	
Screw Press Cake	Notched	29.15%	92.23%	0.237	0%	0.00	4.34%		0.78	
Screw Press Liquor	Notched	4.18%	75.83%	362		0.15		43.41	5.52	7.86
Screw Press Liquor	Notched	2.92%	74.48%	413		0.12		49.52	4.17	11.88
Screw Press Liquor	Notched	2.26%	75.82%	408		0.09		48.92	3.68	13.29
Screw Press Liquor	Notched	1.44%	84.40%	411		0.06		49.28	2.72	18.12
Screw Press Liquor	Notched	0.71%	78.82%	419		0.03		50.24	1.3	38.65
Screw Press Liquor	Notched	0.43%	83.50%	346		0.01		41.49	0.78	53.19

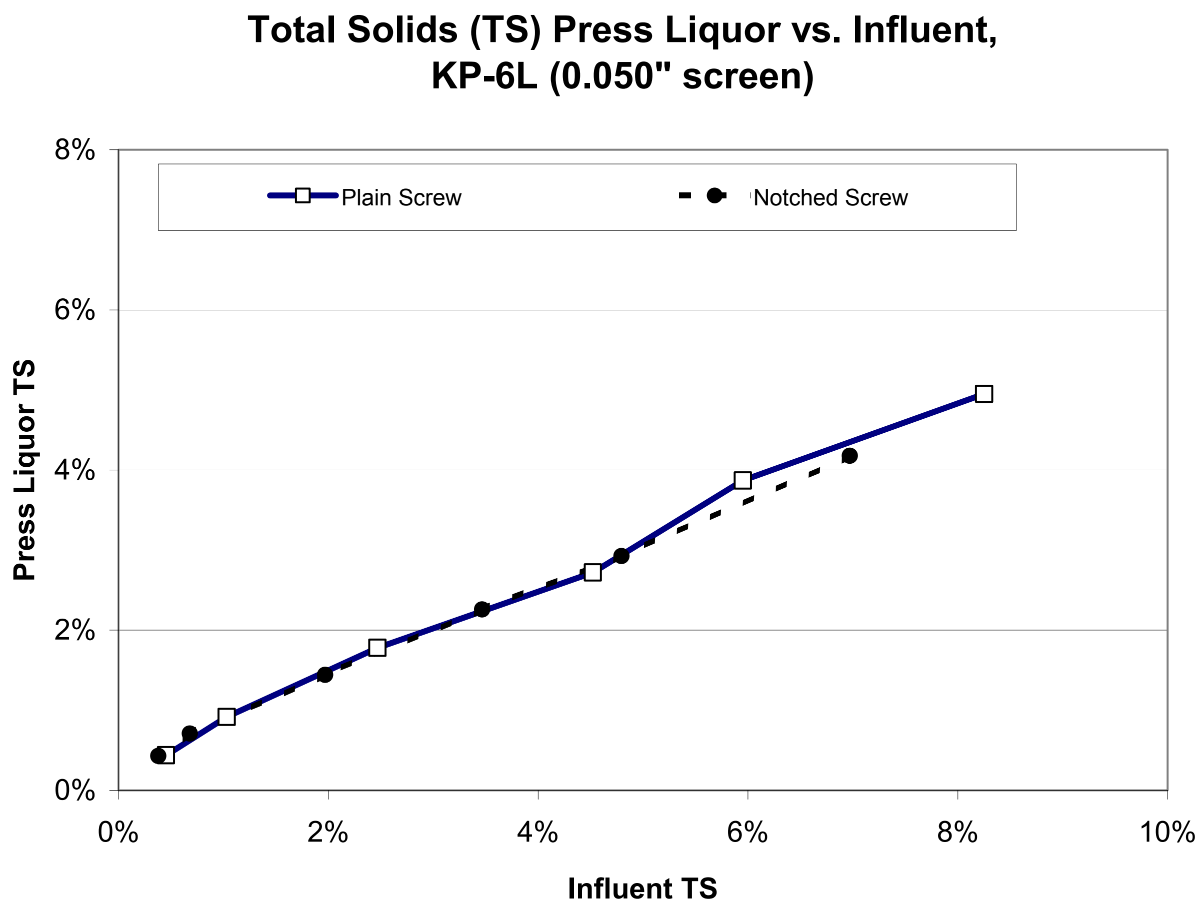
Sample Identification	Screw Type	SP conc. (mg/L)	SP mass g	SP % removed in PC	TP conc. mg/L	TP mass g	TP % removed in PC	TKN conc. mg/L	TKN mass g	TKN % removed in PC
Screw Press in	Notched	64.2	12.44	5%	694.1	134.48	18%	3527	683.34	18%
Screw Press in	Notched	52.8	10.80	3%	469	95.94	18%	2647	541.50	14%
Screw Press in	Notched	39.9	7.73	2%	319	61.78	11%	1873	362.74	8%
Screw Press in	Notched	41.4	7.85	1%	244	46.26	5%	1210	229.38	4%
Screw Press in	Notched	29.1	5.55	0%	109	20.80	3%	450	85.88	3%
Screw Press in	Notched	25.5	4.85	0%	62.5	11.90	1%	205	39.02	1%
Screw Press Cake	Notched	20.16	0.59		828	24.34		4103	120.61	
Screw Press Cake	Notched	16.14	0.28		1038	17.72		4296	73.33	
Screw Press Cake	Notched	16.86	0.14		770	6.50		3227	27.22	
Screw Press Cake	Notched	13.62	0.04		820	2.44		3446	10.26	
Screw Press Cake	Notched	18.66	0.01		1036	0.63		3691	2.25	
Screw Press Cake	Notched	12.72	0.00		728	0.08		2500	0.27	
Screw Press Liquor	Notched	73.5	12.08		730	119.97		89.21	3907	
Screw Press Liquor	Notched	54.6	10.24		463	86.81		90.48	2402	
Screw Press Liquor	Notched	45.9	8.50		326	60.39		97.74	1770	
Screw Press Liquor	Notched	38.7	7.22		219	40.86		88.34	1182	
Screw Press Liquor	Notched	31.5	5.99		115	21.88		105.17	520	

Percentage of Total Solids (TS) in the Press-Cake from KP-6L Using Notched Screw (0.050" Screen)





Dry Mass Capture Efficiency from KP-6L
with Notched Screw (0.050" Screen)
Press-Liquor Flow Rate
Dry-Mass Capture Efficiency
Press Liquor Flow Rate (gpm)
Dry-Mass Capture Efficiency
Influent TS
0
10
20
30
40
50
60
0%
20%
40%
60%
80%
100%
0%
2%
4%
6%
8%
10%


Total Solids (TS) Press Liquor vs. Influent,
KP-6L (0.050" screen)
Plain Screw
Notched Screw
Press Liquor TS
Influent TS
0%
2%
4%
6%
8%
10%