THE J-VAP PROCESS – AN INTEGRATED, LOW TEMPERATURE, ENERGY EFFICIENT ALTERNATIVE TO CONVENTIONAL THERMAL DRYING OF BIOSOLIDS

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Abstract

This paper presents the J-Vap Process, a filter press dewatering/vacuum drying technology and its application as a biosolids dewatering and drying process at the City of Chattanooga (Tennessee, USA), Moccasin Bend WWTP. The City had been operating eight conventional recessed plate filter presses, conditioning solids with lime and ferric chloride prior to filtration, producing a Class B biosolid and had wanted to upgrade the operation to produce a Class A biosolid (as defined by the USA EPA in 40 CFR part 503B) for beneficial reuse. The City considered two different technology approaches, a filter press dewatering/vacuum drying system and centrifuges followed by thermal drying equipment. Based upon their evaluation, the filter press dewatering/vacuum drying system was chosen as the solution that best met their technical and commercial requirements.

Siemens J-Vap System was eventually selected, offering key benefits to the City with respect to lower operating temperatures for operator safety, reduced risk of combustion of the dried product, no air emissions from the drying process requiring scrubbing, overall energy efficiency and reuse of existing infrastructure. During the installation and start up of the 6 – 2M x 2M J-Vap filter presses, a component failure triggered a redesign of the J-Vap heating plate which improved the energy efficiency even further over the original design. Now operating at full capacity since July of 2009 the system has a rated capacity of over 10,000 tonnes per year dry solids based upon processing Waste Activated Sludge (WAS) only. In practice the City has been processing a combination of WAS and primary sludge obtaining throughputs almost 2 times the rated capacity. Through the data collected during more than 200 operating cycles during field performance trials and operational information from the City's operator logs this paper will demonstrate that the J-Vap System uses substantially less energy than conventional thermal drying systems for every kilogram of water removed, operating at maximum temperatures below 82°C.

Although the City is still disposing of the material as it were a Class B biosolid, they have embarked on a program to have the material classified as a Class A EQ quality biosolid to broaden its options for beneficial reuse.

Keywords

Biosolids, Class A, beneficial reuse, drying, vacuum drying, filtration, J-Vap

Background

The Moccasin Bend Wastewater Treatment Plant (WWTP) serves the City of Chattanooga and ten surrounding regional customers in southeast Tennessee and north Georgia. Improvements within the past decade have upgraded the liquids handling portion of the plant to 530,000 m3/day of secondary treatment capacity with an additional 303,000 m3/day of wet-weather treatment capacity.

An additional phase of the plant upgrade included improvements to the solids handling systems to give the plant the capability to produce Class A biosolids. Previous solids treatment consisted of anaerobic digestion of primary solids in six 65-foot anaerobic digesters, followed by blending with WAS and dewatering using plate-and-frame filter presses and centrifuges, both installed in the 1980's. All of the dewatered biosolids was disposed in landfills. Many of the major equipment systems had exceeded their useful service life with operational and maintenance costs continuing to escalate. The City decided that the WWTP's entire solids handling systems needed upgrading.

In the mid 1990's the City embarked on a program to update secondary dewatering capabilities. Principal dewatering was being accomplished with centrifuges followed by lime stabilization. The secondary dewatering system consisted of 8 Ingersoll Rand "Lasta", fully automatic recessed plate filter presses. Both systems were producing a Class B sludge. The filter press equipment had been operated for more than 20 years and was nearing the end of its useful life. The City wanted the ability to produce a Class A sludge for the 39 tonnes/day of WAS biosolids that would not be treated through an upgraded digestion process. They reviewed options for dewatering and drying using centrifuges followed by thermal drying and filter press dewatering/vacuum drying. The City reviewed both systems for safety, thermal efficiency, operating costs, civil requirements for installation, use of existing infrastructure and overall budget. The reuse of the existing building infrastructure was a key determinant in choosing the filter press dewatering/drying solution but safety concerns played a role in the decision. Explosions and fires at drying/pelletizing plants at the Millorganite Plant in Milwaukee, Wisconsin in 1996 and the MWRA Fore River facility in Quincy, Massachusetts in 1998 raised concerns that safe operation of these facilities were not yet at a level that was satisfactory to the City.

Purpose

The purpose of this paper is to provide an introduction to the J-Vap System installed at Chattanooga, and present operational data from the installation to illustrate the efficiency of the Siemens J-Vap System as compared to dewatering and drying of biosolids using a centrifuge followed by a thermal dryer.

Introduction

In 2001 Siemens was awarded the contract to install its J-Vap system consisting of 6 filter press dewatering/vacuum drying filter presses for the processing of 39 tonnes/day of waste activated sludge and producing a Class A biosolid. In 2006, during final performance trials, the system experienced a catastrophic failure of a key component of the system, the filter plates (THE J-VAP SYSTEM – AN ADVANCEMENT TO

FILTER PRESS/DRYER TECHNOLOGY ACHIEVING REDUCED DRYING TIME.,R. Bosgraaf, M. Bair, 2009). A re-design of the filter plates initiated an extensive remediation and re-engineering of the entire system and led to improved drying and dewatering efficiencies as compared to the original installation. Final performance testing was completed in June of 2009 and the system was turned over to the City for operation in September of 2009. The City has been running the equipment continuously since the hand over. The data presented in this paper is comprised of data collected during the performance period and from the City's operator logs for September 2010.

The J-Vap filter press dewatering/vacuum drying process technology uses a specially designed membrane squeeze filter press, modified to incorporate vacuum and heating processing circuits. The initial stages of filter cake filtration and mechanical compression of the filter cake are similar to that of standard membrane filter press operation. Once the filter cake is formed, the filter cake chambers are placed under vacuum, resulting in a lowering of the vapor pressure of material contained within the filter cake chamber. The filter cake is heated indirectly by circulating a heated medium (generally hot water or low pressure steam) through heating channels within the center web of the filter plates. Subsequently, the evaporated moisture is withdrawn from the filter press by the vacuum, condensed and removed from the system via the filtrate collection system. For increased efficiency, membrane squeeze pressure is continually applied to the filter cake as it reduces in thickness, keeping the heat transfer surface of the plates in contact with the filter cake. This process is continued until the desired dry solids content of the filter cake is achieved (fig. 1) followed by cake discharge.

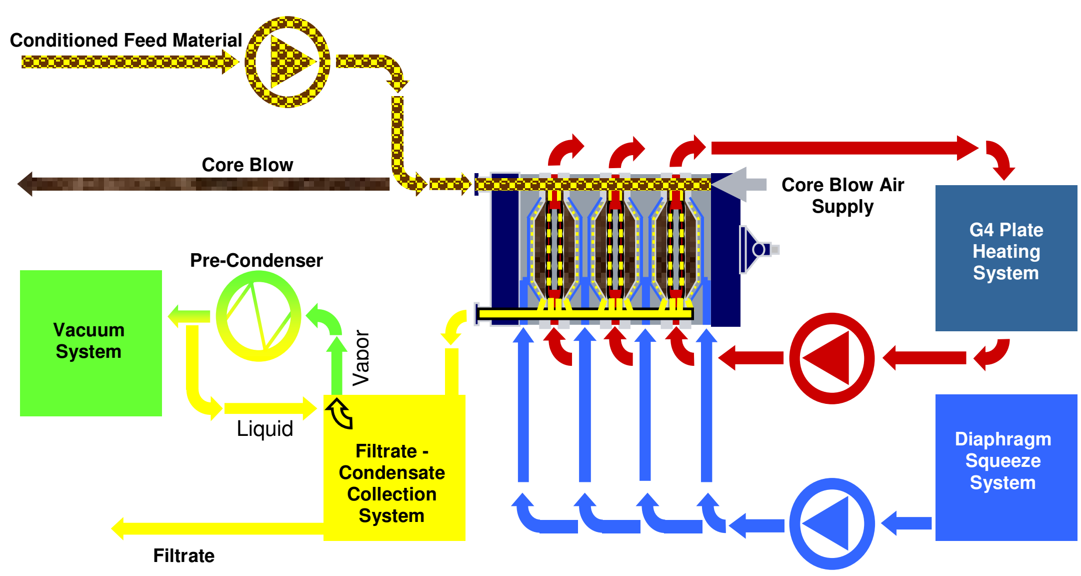

Figure 1: **Simplified Process Flow Diagram J-Vap System Gen4 Design**

The system as installed at Chattanooga (fig. 2) operates with 6 J-Vap filter presses and a number of supporting sub-systems. Of these, the sludge storage tanks, sludge conditioning system and solids collection systems were already existing. Requirements of the contract were that the new J-Vap System would use these existing infrastructure items and the filter presses would install in the same footprint as the previously installed Lasta filter presses.

The following equipment comprises the complete sludge dewatering and drying system. All components, with the exception of the 500 gpm transfer pumps, were included in the energy usage calculations in the subsequent tables.

- 2 - 20,000 gallon sludge holding tanks and 4 - 500 gpm transfer pumps (existing)
- 2 - Sludge conditioning systems and chemical supply (existing)
- 6 - 800 gpm sludge feed pumps
- 6 - J-Vap filter presses
- 6 Filter cake collection systems (existing)
- Hot water supply and circulation system
    - 3 - Primary hot water boilers
    - 6 - Secondary hot water circulation pumps
- 2 - Diaphragm squeeze systems
- Vapor withdrawal and filtrate/condensate collection system
    - 4 Vacuum pumps
    - 6 Pre-condensers
- 3 – Cooling towers for cooling water supply
- Integrated controls package

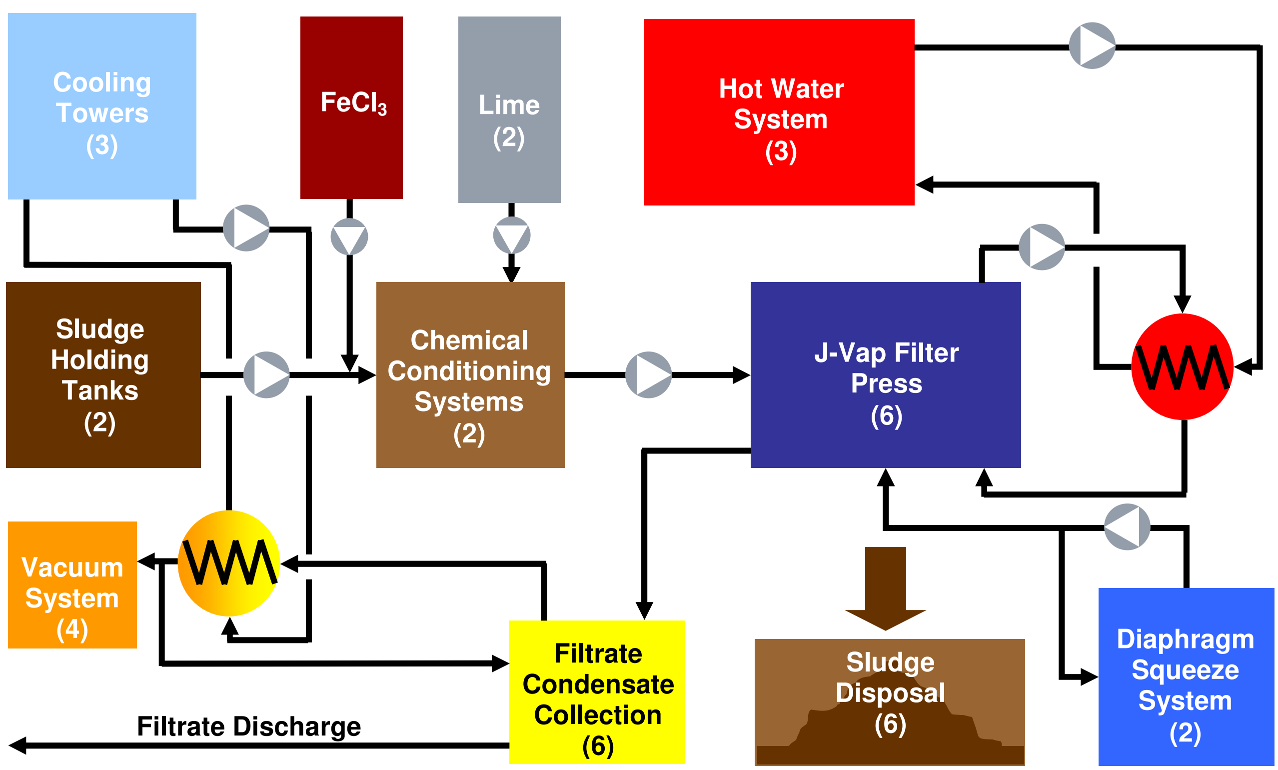

Figure 2: **Process Flow Diagram J-Vap System, Chattanooga**

Process Description

The basis for design at the Moccasin Bend facility is to dewater 39,008 kg/day of undigested waste activated sludge on a dry weight basis. The target for the filter cake discharged from the system was 78% dry solids and the production of a Class A biosolid. The conditioning chemistry employed would be a combination of ferric chloride and lime added at approximately 9% Fe and 20% of CaO respectively.

Conditioned sludge is fed to the J-Vap filter presses by progressive cavity pumps and is dewatered to approximately 22% dry solids before the J-Vap cycle is initiated. After dewatering is completed the filter cake is held under membrane squeeze pressure of 4 bar and is heated to a temperature of 72°C and held at that minimum temperature for 22 minutes (a minimum of 20 minutes is required). This step is necessary to meet the EPA time-temperature regime (Regime A) for Class A Pathogen Reduction under Alternative 1 (40 CFR Part 503, Subpart D). Cake temperatures are measured with RTD's (resistance temperature detectors) mounted in the filter pack and in direct contact with the filter cake. After completion of this step a vacuum is initiated, holding the filter cake chambers under a vacuum of approx. 610 mm Hg while the cake continues to be heated with 88 degree C hot water circulated within the heating filter plates. During this heating/vacuum cycle the 4 bar of pressure is continually applied to the cake by means of the membrane squeeze sub-system. The water vapor is withdrawn from the filter press and condensed for discharge back to the head of the waste water plant along with the filtrate removed during the dewatering step.

This process continues for a prescribed period of time until the desired filter cake dryness is achieved. This timing is based upon experience with previous operating cycles. The cake is then discharged and the filter press is prepared for another cycle.
The following is the approximate cycle timing for the J-Vap installation at Chattanooga, allowing for each J-Vap filter press to be operated 5 times in 24 hours.

Table 1: Typical J-Vap Cycle Duration at Chattanooga

Process Step	**Elapsed Time (min.)**
Close Filter Presses	2
Feed/Fill	90
Membrane Squeeze Initiation	5
Core Blow/Core Flush	2
Cake Heating to 72°C	45
Pathogen Reduction (Class A step)	22
Vacuum Drying	85
Membrane Retraction	2
Open Filter Press	2
Discharge Filter Cake	30
Typical Complete Cycle Time	**285**

The other protocol required to achieve a Class A biosolid is the attainment of vector attraction reduction. The protocol chosen to meet this requirement is Option 6 under the Requirements for Reducing Vector Attraction (40 CFR Part 503, Subpart D). Lime is added during the sludge conditioning process to a level that ensures a pH of 12 is achieved for a minimum of 2 hours and held at 11.5 for a minimum of 22 hours to meet vector attraction reduction requirements. In practice it was found to require as much as 26.6% of CaO on a weight/weight basis to the WAS dry solids. It is believed this may be due to the level of carbonate hardness in the raw wastewater which buffers the effects of the CaO on pH.

Energy Efficiency and Operating Costs

Performance Test June 2009

Energy efficiency was not one of the criteria used to validate the system operation during the performance test. However the data collected allow for the reporting on energy use and operating costs (exclusive of operating labor, and building costs). During the performance test in June 2009 each filter press in the J-Vap System was run continuously for approximately 53 hours. Five hours constituted a pre-heating cycle and 48 hours for performance testing. Per the contract requirements, 4 of 6 machines were run continuously without interruption. Forty four cycles were run and a total of 97.4 tonnes of WAS were processed. This equates to 44.1 tonnes of WAS solids per day or 11.0 tonnes/day per machine. The goal of 39 tonnes per day is predicated on operating 5 machines or 7.8 tonnes/day per machine. The actual throughput represents a 41 percent increase over the target goal.

Table 2 delineates the usage of chemicals, WAS processed and energy usage. Energy usage is shown for both gas and electric and is based upon all material processed as this is indicative of the actual water removal rates. We have based the energy usage on the water removed during the thermal drying step to better illustrate the kWh used in this step. Operating costs are reported both in terms of total solids and WAS solids for comparison with centrifuge dewatering followed by thermal drying (table 4). All costs were adjusted to 2010 values.

Table 2: Energy Use and Operating Costs – Performance Test Period

Chattanooga J-Vap Performance Trials - June 2009		
Dry WAS Material Processed	97,393.5	kg
CaO added (based on average usage of 26.26% of WAS)	25,575.5	kg
FeCl3 added (based on average usage of 9.44% of WAS)	9,193.9	kg
Total Dry Material Processed	**132,163**	**kg**
Average Cake Dryness After Filtration Step	22.00%	
Average Cake Dryness At Final Discharge	67.68%	
Cake Weight After Filtration	600,741	kg
Cake Weight At Final Discharge	195,276	kg
Net Water Removed through thermal drying	**405,464**	**kg**
Energy Used		
Fuel - Natural Gas	10,260.5	m3
Thermal Content	109,167	kWh
Power to Operate J-Vap System	19,140	kWh
Total Energy Used	**128,306.9**	**kWh**
Gas Usage for Water Removal - Thermal Drying	**0.269**	**kWh/kg H20 removed**
Based on Water Removal during Thermal Drying	**0.316**	**kWh/kg H20 removed**
Based on Dry Solids Processed	**1,317.4**	**kWh/tonne Dry Solids**
Operating Costs		
CaO - $135/ton (High Calcium 85% active)	£77.68	per Tonne
Unit cost per active ingredient	£0.11	per kg
Total Quicklime Cost	**£2,827.97**	
Ferric Chloride (35% active)	£343.05	per Tonne
Unit cost per active ingredient	£1.19	per kg
Total Ferric Cost	**£10,972.88**	
Gas Cost	£21.60	per MWh
Total Gas Cost	**£2,357.54**	
Electricity	£0.019	per kWh
Total Electrical Cost	**£363.42**	
Estimated Disposal Costs for City Landfill	£14.38	per Tonne
Total Disposal Cost	**£2,808.92**	
Total Operating Costs during Performance Test	**£19,330.73**	
Operating Cost - Based on Water Removal	**£0.048**	**per kg of H2O removed**

Operating Data September 2010

The data presented in Table 3 represents information from 3 weeks of operation in September 2010. A number of differences in the operation from that during the performance test have resulted in some changes in the results. The J-Vap System is being used to dewater a combination of primary and digested waste resulting in larger processing volumes. The presses are also being operated to produce approximately 65% dry solids. Dusting increased significantly as the cake dryness increased above 70% and cake discharge was not as efficient. The resulting lower mass of dried material did not auto-discharge consistently requiring more operator intervention. The City chose to operate at the higher moisture content and did not consider the impact to landfill costs detrimental to the operation.

Total energy usage on the basis of water removal rate during the drying step remained constant from the performance test period to the operating period one year later with values of 0.316 kWh/kg of H2O removed and 0.328 kWh/kg of H2O respectively.

Table 3: Energy Use and Operating Costs – September 2010 Operating Period

Chattanooga J-Vap Operational Data - September 2010		
Dry WAS Material Processed	366,606	kg
CaO added (based on actual)	127,380	kg
FeCl3 added (based on actual)	52,108	kg
Total Dry Material Processed	**546,095**	**kg**
Average Cake Dryness After Filtration Step	22.00%	
Average Cake Dryness At Final Discharge	65.15%	
Cake Weight After Filtration	2,482,248	kg
Cake Weight At Final Discharge	838,211	kg
Net Water Removed during termal drying	**1,644,037**	**kg**
Energy Used		
Fuel - Natural Gas	43,502.7	m3
Thermal Content	462,847	kWh
Power to Operate the J-Vap Syem	76,125	kWh
Total Energy Used	**538,972.2**	**kWh**
Gas Usage for Water Removal - Thermal Drying	**0.282**	**kWh/kg H20 removed**
Based on Water Removal during Thermal Drying	**0.328**	**kWh/kg H20 removed**
Based on Dry Solids	**1,470.2**	**kWh/tonne Dry Solids**
Operating Costs		
CaO - $135/ton (High Calcium 85% active)	£77.68	per Tonne
Unit cost per active ingredient	£0.11	per kg
Total Quicklime Cost	**£14,084.83**	
Ferric Chloride (35% active)	£345.22	per Tonne
Unit cost per active ingredient	£1.19	per kg
Total Ferric Cost	**£62,190.60**	
Gas Cost	£21.60	per MWh
Total Gas Cost	**£9,995.53**	
Electricity	£0.02	per kWh
Total Electrical Cost	**£1,445.41**	
Estimated Disposal Costs for City Landfill	£14.38	per Tonne
Total Disposal Cost	**£12,057.12**	
Total Operating Costs during Performance Test	**£99,773.50**	
Operating Cost - Based on Water Removal	**£0.06**	**per kg of H2O removed**
Operating Cost - Based on Total Dry Solids	**£182.70**	**per Tonne Dry Solids**
Operating Cost - Based on WAS Dry Solids	**£272.15**	**per Tonne Dry WAS Solids**

The City also did not operate all equipment continuously during this period as the machines are dewatering solids more efficiently than originally designed for and solids were not being generated at quantities requiring continual operation. This would result in higher energy usage per unit operation as the boilers would be kept at temperature even when J-Vap filter presses were not in operation. Ferric Chloride usage was inexplicably higher which also resulted in lime usage being increased in order to maintain a pH of 12 in the conditioned sludge per the Class A requirement.

Centrifuge – Thermal Dryer Comparison

For comparison purposes we have taken the solids dewatering requirements for the Chattanooga J-Vap installation and estimated the operating data for an installation of centrifuge dewatering followed by thermal drying, using a Siemens CTD triple pass dryer (Table 4) rated for a water removal rate of 8000 liters per hour. The dewatering is based on using a 760 mm diameter centrifuge rated for 110 m3/hr. The input values are based on the same influent and solids conditions found in the original performance test (Table

2.) and producing a product that is classified as Class A. Since this system uses polymer for sludge conditioning prior to dewatering the EPA protocol requires drying of the bio-solids to a minimum of 90% to achieve the vector attraction requirement (Table 5-8, Option 8, Summary of Options for Meeting Vector Attraction Reduction, 40 CFR Part 503) of the Class A designation.

Table 4: Energy Use and Operating Costs – Centrifuge/Thermal Drying

Chattanooga Estimate with Centrifuge Dewatering and CTD Dryer	
Dry Material Processed	97,393 kg
Average Cake Dryness After Filtration Step	20.00%
Average Cake Dryness At Final Discharge	90.00%
Cake Weight After Filtration	486,967 kg
Cake Weight At Final Discharge	108,215 kg
Net Water Removed	**378,752 kg**
Energy Used	
Fuel - Natural Gas used for Dryer per Day	24,784.0 m3
Thermal Content of Gas	263,693 kW
Power to Operate CTD for 2.2 days (44 cycle equivalent)	18,800 kWh
Power to Operate Centrifuge for 2.2 days	15,300 kWh
Total power for dewatering and drying kW	34,100 kWh
Total Energy Used	**297,793.0 kWh**
Gas Usage for Water Removal - Thermal Drying	**0.696 kWh/kg H20 removed**
Energy Usage - Based on Water Removal	**0.786 kWh/kg H20 removed**
Energy Usage - Based on Dry Solids	**3,057.6 kWh/tonne Dry Solids**
Operating Costs	
Polymer Use -	12.50 kg per Tonne
Unit cost of Polymer	£2.78 per kg
Total Polymer Cost	**£3,390.28**
Gas Cost	£21.60 per MWh
Total Gas Cost	**£5,694.65**
Electricity	£0.02 per kWh
Total Electrical Cost	**£647.47**
Estimated Disposal Costs for City Landfill	£14.38 per Tonne
Total Disposal Cost	**£1,556.60**
Total Operating Costs during Performance Test	**£11,289.00**
Operating Cost - Based on Water Removal	**£0.03 per kg of H2O removed**
Operating Cost - Based on Total Dry Solids	**£115.91 per Tonne Dry Solids**
Operating Cost - Based on WAS Dry Solids	**£115.91 per Tonne Dry WAS Solids**

Comparative Operating Costs and Energy Usage

Table 5 compares the energy usage and operating cost from the 3 previous tables. The operating cost per unit volume relative to total dry solids processed shows that the J-Vap (performance test) operates 20% more expensively than the thermal dryer. However the cakes discharged from the J-Vap include precipitated lime and ferric hydroxide which add to the total dry solids processed. The more relevant measure is the operating cost based upon the total WAS processed. Here the J-Vap has statistically a higher operating cost then the thermal dryer by 72% when using the performance test model as a basis for comparison. However the City's operating of the J-Vap (table 4) is more costly by 136.6% than that of the thermal dryer. Evaluating the City's operating data the chemical costs as a percentage of total operating cost is higher that those in the performance test by approximately 5% and the lower moisture percentage in the filter cake also increases the cost of disposal by approximately 2%. The majority of increased operating cost comes from the over use of ferric chloride. This indicates that the City is not optimizing the operation with respect to chemical addition and drying cycles. Chemical costs in general are higher for the J-Vap installation in Chattanooga and make up as much as 76% of the total operating cost. When reviewing the centrifuge/thermal dryer chemical costs it is noted that polymer usage is approximately 30% of the total.

One component of operating cost for the thermal dryer not included in this evaluation is the treatment of emissions from the dryer. This was not included due to the variability in these cost based on the constituents in the emissions. Emissions treatment will typically add anywhere from 20 to 40% to the operating cost.

The J-Vap performance trials and City's September operating data are similar when comparing the energy usage. In both cases the J-Vap energy usage is 60% more efficient that the centrifuge/thermal dryer model in water removal and 57% more efficient when measured on a dry solids processed basis. Even when comparing total water removal which includes the dewatering step, J-Vap uses 37% to 56% less energy.

Table 5: Comparison of Energy Use and Operating Costs – J-Vap and Centrifuge/Thermal Drying

Comparison of J-Vap Operation and Alternate Technology		J-Vap Performance Trial June 2009	J-Vap September 2010 Operation	Centrifuge/ Thermal Dryer
Energy Usage				
Based on Total Water Removal	kWh/kg H20 removed	0.0392	0.0272	0.0625
Based on Water Removal - thermal drying	kWh/kg H20 removed	0.316	0.328	0.786
Based on Dry Solids	kWh/tonne Dry Solids	1317.40	1470.20	3057.60
Total Operating Costs				
Based on Total Water Removal	per kg of H2O removed	£0.0059	£0.0050	£0.0024
Based on Water Removal - Thermal Drying	per kg of H2O removed	£0.0477	£0.0607	£0.0298
Based on Total Dry Solids	per Tonne Dry Solids	£146.26	£182.70	£115.91
Based on WAS Dry Solids	per Tonne Dry WAS Solids	£198.48	£272.15	£115.91

Total operating cost favors conventional thermal drying due to chemical costs and increased solids for disposal. The gap is closed somewhat when costs for chemical treatment of the dryer air emissions are considered. When J-Vap was selected as a technology the cost for both ferric chloride and lime were significantly lower that today by as much as 60%. Costs for these chemicals in the US have risen faster than that of energy (in Chattanooga) and have made the operation less favorable economically when comparing the technology to a centrifuge followed by thermal drying.

Since J-Vap is removing water at rates close to one-half the latent heat of vaporization (of water) at approximately 0.694 kWh/kg (J-Vap operates at approximately .32 kWh/kg), there are 2 theories regarding the high energy efficiency. A thermal dryer uses only heat energy to evaporate water however the J-Vap system uses a mechanical compression of the cake during evaporation to enhance the dewatering effect. In addition to the mechanical squeezing action of the membranes a second mechanism for water removal may be at work, vapor pressure dewatering (V. Krorger, W. Stahl, 1996). This is described as a mechanical thermal dewatering procedure based upon the principle of dewatering through gas differential pressure. In the J-Vap system filter cakes are heated from one side only. Vapor pressure, being higher at the heating surface of the heating plate, purges moisture toward the adjacent membrane plate further enhancing the water removal process.

One or both of these processes may be at work during the J-Vap thermal dewatering stage resulting in equipment that operates at the higher energy efficiency.

Summary

The J-Vap System is a very energy efficient alternative to thermal drying of bio-solids. The installation at Chattanooga demonstrates that it may be a financially acceptable alternative as well if chemical costs can be reduced. The J-Vap process in Chattanooga is dependent on inorganic chemical conditioning and this adds significant cost to the operation. When the project was originally developed these chemical costs were significantly less as a percentage of the total operating costs. These costs have risen faster than the cost of energy in the Tennessee area. Siemens is continuing to work with the City on alternative chemical conditioning and its affect on both energy efficiency and operating cost.

As a final note, since Chattanooga's evaluation of the hazards of thermal drying in the 1990's many advancements have been made to improve the safety of thermal systems. As such, safety should be evaluated on current standards when considering the installation of a thermal drying system.

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