Hygienization of municipal sludge in automatically operated chamber filter presses with thermal vacuum drying

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Abstract This paper presents the state of the art of thermal vacuum drying in chamber filter presses for unattended automatic operation. The achieved results are exemplified by the treatment of the two stage digested combined primary, chemical and biological sludge created by the VEAS concept for nutrient removal from municipal wastewater at VEAS. The water removal rate in each stage of the drying process is described, with comments on the low energy needs. The advantages of one-sided heating, the capacity and the drying potential are discussed. The hygienization potential of the process is demonstrated by the effect on thermostable coliform bacteria, Escherichia coli, salmonella, the spores of sulfite reducing anaerobic bacteria, f-specific bacteriophages, the seeds of the weed, wild oat, Avena fatua, and the parasite eggs of the potato cyst nematode, Globodera rostochiensis. A more complete paper with the VEAS-concept is found on the VEAS homepage (www.veas.nu).

Keywords Automatic operation of filter presses; hygienization of sludge; parasite eggs; spores of bacteria; vacuum drying in filter presses; weed seeds

Introduction

The VEAS WWTP is an underground direct precipitation plant with nutrient removal. The retention time of the water in the VEAS concept treatment process is only 3 hours. The VEAS concept for nutrient removal, was implemented in the period 1991–96 (Sagberg et al., 1998). The concept is an integrated solution of mainstream, side stream and sludge treatment to minimize the area of the plant, maximize the energy production and at the same time produce useful and safe by-products.

One of the by-products is the remaining solids from the two staged anaerobic digestions of the combined primary, chemical and biological sludge. Regulations in Norway and a working document for a proposed new sludge directive from the European Union have called for a high degree of hygienization prior to sludge utilization on farmland. Unfortunately a precise definition of this target has not been formulated in the Norwegian regulations. In the working document for an EU directive a 5 or 6 log$_{10}$ reduction in E. coli has been suggested.

In 1997, VEAS decided to rebuild their existing one stage chamber filter presses, giving a dry solids content of around 35%, into vacuum drying filter presses to achieve a good hygienization and mass reduction, with 75% DS as the goal. Two companies had marketed such equipment, Bertram from Switzerland and DryVac from California, US. Only DryVac declared that they could meet the requirements in the call for tenders and a contract was signed. Unfortunately for VEAS, the equipment from DryVac could not produce the capacity called for, even when in manual operation. The feed system, the filtrate water removal system, the lack of flatness of plates necessary for automatic operation, the lack of strength of the plates and the use of two-sided heating, did all contribute to a total failure of the system. Less than 50 cycles were actually performed over an 8-month period. All the supplied equipment was returned to DryVac because of their lack of technical capability and financial strength to solve the problems.
The German company, Lenser Filtration, installed a system based on one-sided heating in a mixed pack of heating plates and PP-membrane plates based on their existing membrane plates and their earlier research at the University of Karlsruhe (Korger and Stahl, 1992; Ruh, 1998). The Teflon coated aluminium heating plates, made from two halves, did not have the necessary strength and started leaking and had some deformation. In agreement with Lenser, and with financial aid from the Norwegian Industrial Development Bank, the company, Hydro Marine Aluminium, undertook the job to design a 30-mm thick straight 1.5-m × 1.5-m plate with smooth surface with internal hot water circulation. The plate was produced by friction welding of extruded profiles. The heating plates must tolerate contact with several chemicals like slaked lime, strong hydrochloric acid, ammonia and hot water vapor containing traces of different organic solvents. To achieve this, the aluminium plates had to be coated with materials with protection properties. A costly trial and error process has led to a solution with paint coating and PP-cloth for good cake release.

Material and methods

The thermal vacuum drying chamber filter press

Figure 1 demonstrates the behavior of the plate pack during the different stages. The filter press consists of 71 membrane filter plates made of polypropylene, size 1.5-m × 1.5-m, with center feed and filtrate water collection channels in the four corners. The plates have an inner core of solid plastics and a membrane material welded to the core. In between these two layers water can be injected. This is done in stages 2 and 3 of the operation cycle. The membrane has a pipped surface supporting the filter cloth made from PP. A series of holes around the edge of the membrane plates, on the inside of the sealing o-rings, behind the cloth, leads the filtrate water to collecting channels in the corners. O-rings around filtrate water channels and around the full plate seal against leakage.

Between two membrane filter plates an aluminium heating plate of size 30-mm × 1.51-m × 1.51-m, with hot water circulated inside and holes for the passage of the sludge feed and the filtrate water, is mounted. The recess in the membrane plates makes room for a 25-mm initial cake thickness on each side. A hydraulic piston closes the stack of plates.

In the first stage of operation the press is filled with lime and polymer conditioned sludge by a frequency regulated eccentric screw pump, forming the filter cake. In the second stage, feeding is stopped and the membrane filled with water. After 2/3 of the time in

![Figure 1](http://iwaponline.com/wst/article-pdf/50/7/53/419678/53.pdf)
In this stage, circulation of hot water in the aluminium plates starts. At the end of this stage, the feed line is cleaned sequentially by water and air. The filtrate water from the two first steps is pumped to the stripping tower to produce ammonium nitrate, NH₄NO₃.

In the stage 3, the circulation of hot water in the heating plates continues and the filtrate water pipes are connected to a vacuum system providing –0.93 bar at the filtrate pipe. At this pressure the water boils off rapidly when the hot plate has a temperature above 80°C. At the end of this stage, air is blown into the closed press to force the membrane water out of the plates, back into the reservoir tank. To empty the press, the hydraulic piston is withdrawn. Then a chain plate transporter carries one plate at a time to the side. The cakes drop by themselves into a bunker where chain conveyor removes the dried cakes.

The heating and energy recovery system

Figure 2 shows the system. The aluminum plates are heated in stages 2 and 3 with circulating hot water, about 85°C, from the gas diesel engine producing electricity or from the boilers. The average filtrate water temperature is around 38–40°C, very suitable for the ammonia stripping. In stage 3 where a vacuum of –0.93 bar is applied, the water boils off at a temperature of about 42°C. The vapor is first condensed in a heat exchanger where the regained heat is used for preheating the sludge entering the digesters. In a second heat exchanger, cold seawater from 20-m depth in the Oslofjord further condenses the vapor to reduce the need for the final vacuum pumping. To keep the vacuum in the condensate pipes, the condensate water is directed to a collecting tank more than 10 m below the press. This provides a natural vacuum in the draining pipes.

Testing of hygienization

To demonstrate how effective the vacuum drying process is in destroying some unwanted forms of life in sludge, several kinds of tests were performed:

- tests on naturally occurring thermotolerant coliform bacteria (TCB) and salmonella in the dried sludge;
- tests on naturally occurring *Escherichia coli*, spores of sulfite reducing anaerobic clostridia (SRC), mostly *Clostridium perfringens* and f-specific bacteriophages in all stages of the sludge treatment;
- an in-process test of samples of weed seeds and parasite eggs.

Figure 2  The vacuum, heating and energy recovery system of the filter presses at VEAS
Samples for thermotolerant coliform bacteria and salmonella were taken monthly from the product silos over a year and analyzed by Næringsmiddeltilsynet i Drammen (The Food Safety Control Laboratory in Drammen) according to the standard NS-4714. Salmonella was tested for in 11 of the samples, according to an internal method. The Norwegian School of Veterinary Science tested the reduction of both E. coli and the spores of the sulfite reducing anaerobic clostridia (SRC) through all stages of the sludge handling. The details of the methods and results are reported separately (Østensvik et al., 2003). The seeds of the weed, wild oat, Avena fatua, and the cysts of the potato cyst nematode (PCN), Globodera rostochiensis, were used as examples. No spreading of these through sludge, causing problems, are however known. The two organisms were selected because they are very resistant to destruction. The eggs of the PCN are well protected inside a cyst, and the seeds of wild oat can be dormant for long time even when given favorable conditions for germination. The details of testing and results are reported separately (Magnusson et al., 2003).

Results

Operational parameters and results from each step

In stage one, lime conditioned sludge is pumped through a polymer-mixing device into the press. The dry solid of the mixture is approximately 3.5%. The feed flow is pressure regulated. Filling volume will vary with feed content, conditioning and mixing parameters, filling time and time since last filter cloth washing. The typical value is 37 m³ after 42 min, giving a cake volume of 5.9 m³ and 31.2 m³ filtrate water. In stage 2 water is pumped into the membrane at a squeezing pressure of 6 bar for 24 min. This is followed by hot water circulation in the aluminium plates for another 12 min. Typically, 2.3 m³ of water is removed in this stage. In stage 3, the filtrate line is evacuated by –0.93 bar or to an absolute pressure of 0.07 bar. The membrane pressure is reduced to 4 bar while the temperature out of the heating plate is maintained 80–85°C. Condensate is collected in a pit 10 m below the presses. Typical water collection during a 90-min vacuum cycle is 1.6 m³. Assuming a condensation efficiency of 89% before the vacuum pumps, 1.8 m³ of water is removed from the cake in this stage. Of this amount some 30% may be pushed out as drops or droplets by the vapor, less at high final dry solid content. 1.3 m³ of water is thus actually evaporated. The heat of vaporization is regained from 0.8 m³ of water in the first heat exchanger. Factors influencing the capacity and dry solids content are discussed later in the paper.

As the sludge becomes drier, problems with dust may occur, especially around a crushing mill. This could constitute explosion risk, but investigations have found the dust at VEAS to be non-explosive (Eliassen, 2001). The reason for this is the high content of inorganic material from the chemical flocculation, the lime conditioning and the high degree of degradation of organic material in the two-stage digestion. To reduce dust problems, a system to keep underpressure in the bunker during cake release is being mounted.

For 130 hours per week the process operates in an automatic unattended mode. During this period the computer system can call for manual aid from the operator on home duty, if major faults occur. The presses require washing of the filter cloth every 2–3 weeks and acid washing every 2–3 months. A system for hot water washing of the plates is just installed. Hopefully this will reduce the need for acid washing. 90 minutes are needed for the washing cycle per press. Acid washing is usually done overnight.

Results from the hygienization of sludge at VEAS

Salmonella and Thermotolerant coliform bacteria. Salmonella was not found in any of the samples of vacuum dried sludge. The MPN for thermotolerant coliforms were less than 1/g in all 12 samples.
E. coli, spores of sulfite reducing clostridia, SRC and f-specific bacteriophages. No E. coli or f-specific bacteriophages were detected in the vacuum dried sludge. Figure 3 demonstrates the reduction of E. coli through the different stages of the sludge handling. In the sludge coming from the sedimentation tanks, the geometric mean of MPN of E. coli as $\log_{10}$ content per gram dry matter was 7.3. After thermal vacuum drying no E. coli were found. This means that the $\log_{10}$ reduction is better than 7. This is better than what is called for in the working documents for a proposed EU directive. From the sedimentation tanks to the sample point ahead of the filter presses the $\log_{10}$ reduction was better than 5. From an initial content of 4.2 $\log_{10}$-units no f-specific bacteriophages were found after lime addition and after vacuum drying.

The reduction of the spores of bacteria measured as SRC is less, from a geometrical mean of 6.2 $\log_{10}$-units per gram dry matter in the sedimentation tank to some 2.9 $\log_{10}$-units in the vacuum dried sludge. Only a little more than tenfold reduction was achieved in the vacuum drying stage. Figure 4 demonstrates the reduction of SRC through the different stages of the sludge handling.

Weed seeds and parasite eggs. No wild oat seeds or potato cyst nematodes survived the vacuum treatment regardless of pretreatment with 4 days submerging in wet anaerobic sludge or dry mounted samples. Table 1 demonstrates the results.

**Discussion**

Figure 5 demonstrates the accumulated water removal during the three stages of the thermal vacuum drying, under the conditions cited in the paper, during a 3-hour cycle.

86% of the original water is separated during the initial pumping through the filter cloth at a pressure increasing up to 7 bar. 6.3% of the water is separated during the 40-min membrane squeezing at 6 bar. A final 4.9% of the water is removed during vacuum drying at –0.93 bar, heating with water at 85°C and membrane squeezing at 4 bar for 90 min. Only 3.5% of the original water evaporates. The heat of evaporation is regained with an
efficiency of about 60% from 2.2% of the original water, making the process very energy friendly.

Testing with extended vacuum drying time gives DS up to 98% after 7 hours. Further optimisation is expected to reduce this time.

It is important to select the right recess depth for the filter plates. A thick chamber may accept more initial feed, but the necessary time for squeezing and vacuum drying will be longer. Even thickness of cakes is important for good hygienization and high capacity. Several factors in the design and operation can influence this, e.g. distribution rings, number of filtrate holes, pre-filling of press with filtrate water, two sided filling and proper sludge conditioning.

One-sided heating is probably in addition to selection of right recess depth the most important factor for a successful vacuum drying system. When two-sided heating is used, the water vapor generated acts as a heat insulator. Instead of heat conduction, the drying depends on heat radiation which is a much slower process. By one-sided heating, good contact over the full surface is maintained. With pre-heating before vacuum is applied, a vapor front is created by flash evaporation, pushing some liquid water out of the cake. Cake release is much easier with a one-sided heating system with a smooth surface on the heating side. The negative effect of one-sided filtration is the reduced filtration during the initial feeding and squeezing. On one of the presses two-sided vacuum connection is established. This lowers the vacuum inside the filtrate water tubes in the plates by an average of 0.02 bar.

Bad conditioning and failure in the heat system has sometimes resulted in cakes being trapped between the edges of two plates. Operators on home duty are called to the

### Table 1

<table>
<thead>
<tr>
<th>The potato cyst nematode (PCN)</th>
<th>Wild oat seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of juveniles</td>
<td>No of living juveniles</td>
</tr>
<tr>
<td>Dry control</td>
<td>6,200</td>
</tr>
<tr>
<td>Wet control</td>
<td>1,600</td>
</tr>
<tr>
<td>Dry in-process</td>
<td>1*</td>
</tr>
<tr>
<td>Wet in process</td>
<td>1*</td>
</tr>
</tbody>
</table>

* Seemed to be dead

**Figure 5** Water removal through cycle of the vacuum drying system at VEAS
plant by the computer to get the press started again. This has not resulted in damage to the system.

The non-explosive nature of the dust from the process is caused by the high content of inorganic material in the highest oxidation stage, some of this is the ferric and aluminium salts and the lime.

The destruction of wild oat seeds and PCN eggs after 4 days submersion in digested sludge is notable. This might be caused by lack of oxygen or high ammonia concentration. This suggests, that under normal conditions, 22–24 days retention time in the sludge process, a lot of weed seeds will lose their ability to germinate and parasite eggs their ability to hatch, before the sludge is mixed with the lime and enters the presses. In theory, if all the tanks, the pre-storage, the first and second digester and the storage tank, all of which are in continuous operation, should have short circuit streams, some eggs and seeds may have a very short time in the process. Therefore the total destruction of the potato cyst nematodes and the wild oat seeds, when dry test material was put into the filter presses, was very positive. Here the effect of pH and internal boiling will be less than what can be expected from wet material, as is the case in real life application.

The lack of detection of thermotolerant coliform bacteria and salmonella, in the vacuum dried sludge, is not surprising since the sludge from the filter presses, without vacuum drying at VEAS, also was free from these. The content of \( \textit{E. coli} \) was already reduced by more than 5 log\(_{10}\)-units before filter pressing. The reason is the combined effect of anaerobic digestion and a pH > 10.0 in the conditioned sludge. In addition to the 80–85°C heating during the vacuum stage, heating of sludge in stage 2, and rapid application of vacuum in stage 3, will result in rupture of the cell walls when the water inside the cells boils. No \( \textit{E. coli} \) was detected in the final product. No \( f \)-specific bacteriophages were detected after lime addition. They were nearly completely destroyed already in the digestion process.

**Conclusions**

The long and thorny road to a successful implementation of an unattended automatic operation of vacuum drying in chamber filter presses is near completion. The high degree of reduction or total elimination of bacteria, bacteria spores and bacteriophages as well as resistant seeds and cysts of nematodes has been demonstrated. This high degree of hygienization exceeds the proposed requirements in working document for a new EU directive and should greatly reduce any fear of disease spreading to plants, animals or humans caused by land application of well treated municipal sludge.

The sludge is also cleaned by water vapor distillation, thus reducing volatile organic micro pollutants; even some of those with low vapor pressures. It is a low energy drying process.

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References


