Environmental impact

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Novel methods for monitoring the sludge dewatering operation of a belt filter: a mill study

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Abstract: During recent decades the quality of pulp and paper mill sludge has changed. This has awakened the need for an applicable means to observe the sludge dewatering process diversely and accurately. To maximize the solids content and energy efficiency of board mill sludge dewatering, different process monitoring options were studied. Novel methods for monitoring the sludge dewatering operation of a belt filter were tested. Continuous run-time measurements and test response experiments were carried out at a board mill site. IR transmittance measurement through the filter web and sludge mat thickness measurement using a light curtain turned out to be very promising techniques. IR transmittance responded to the polymer content of the sludge without a notable time lag, while the solid content measurement of the filtrate did not give a measurable response.

Keywords: belt filter; belt press; board mill; process monitoring; pulp and paper; sludge dewatering.

Introduction

The rate at which sludge is produced places limitations on the use of simple disposal systems such as the lagooning of low-solids sludges or land filling of dewatered sludges. In general the most common sludge disposal methods have been land filling, land spreading and incineration (Scott and Smith 1995). Nowadays in many countries legislation places stringent limits on dumping untreated sludge as land fill (Disposal and recycling routes for sewage sludge Part 2 2001, Code of good practice for landspreading paper mill sludges 2014, Sludge management in pulp and paper industry 1993). The most common dewatering technologies used by the industry include vacuum filters, belt presses and solid bowl centrifuges. The use of belt filters has been a trend since the 1980s (Amberg 1984). The belt filter is a common apparatus used for sludge dewatering in industrial and municipal wastewater treatment. In the pulp and paper industry it is quite common that the dewatered sludge is incinerated in the furnace of a power plant.

The quality characteristics of the wastewater and water treatment process parameters influence the nature of the sludge characteristics. The optimization of the operational parameters in belt filter dewatering is crucial and is done during a series of related tests. Working conditions such as solids feed, sludge flow rate, polymer dosage, belt speed and tension and nip pressure are identified as being critical to belt filter press efficiency. It is expected that these optimum values vary depending on the sludge characteristics and other operational parameters (Johnson et al. 1992). The operation of a belt filter also depends on variables such as mixing intensity and sludge retention (Severin and Grethlein 1996, Design Information Report: Belt Filter Presses 1986, Miner 1980). The dewatering characteristic affecting the gravitational filterability of conditioned sludge is the suspended solids concentration of raw sludge and the moisture content of dewatered sludge is affected by the viscosity of the sludge. Factors affecting the viscosity are the intrinsic viscosity of alkaline extracts, the quantities per suspended solids (SS) such as the ratio of volatile suspended solids/SS in fiber, Ash/SS, Fiber/SS, and the charge density of sludge particles. Factors affecting the amount of residual solids on the filter cloths are the charge density of sludge particles and the fibrous content of the sludge (Hashimoto and Hiraoka 1990). However, in the continuous run of the belt filter it is common that its operation is observed typically only by camera and by online measurement of the nip pressure. In some cases, turbidity or conductance measurements are used with/without monitoring the solid content of the feed sludge.

During recent decades the quality of the wastewater from the pulp and paper industry has changed dramatically. The greatest cause of the change has been the increase in the brightness of paper and cardboard. The increase in the brightness is usually carried out by alkaline

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peroxide bleaching. The resulting increased pH has increased the chemical oxidation demand (COD) at biological water treatment plants, which means an increase in the amount of biological sludge. In the meantime, treatment processes of fiber-containing fractions have been upgraded, which means that fibers are more completely utilized in the end product. This has led to a decrease of fiber content and fibers and fillers, i. e. primary sludge, in wastewater (Mahmood and Elliot 2006). As a result, the relative fraction of bio sludge has increased remarkably from 20–30 % to 40–60 %. This has led to a reduction in the dry matter content of treated sludge. In many cases the dry matter content of dewatered sludge has decreased by 10–20 %, which means a remarkable decrease in the energy obtained during incineration. In addition to the change in quality of treatable sludge, the run-time variation of the relative amounts of bio sludge and primary sludge has also increased, which also enhances the need for observation of the dewatering process.

On the other hand, water treatment plants and especially dewatering apparatuses are typically 15–30 years old and designed for the sludge of the time. This together with the change in the quality of the sludge to be treated awakens the need for applicable means to observe the sludge dewatering process diversely and accurately.

Materials and methods

Measurable variables

During this research, new methods and instruments were sought for monitoring dewatering by belt press filter and their applicability was tested with the belt filter situated at a Scandinavian board mill site. The test mill produces folding boxboard for food, healthcare and general packaging. The sludge is first fed to an approximately 2.5 m long belt filter that uses gravity for dewatering (manufactured by Aquaflow in 1995). After pre-filtering, the sludge is led to a belt filter that has a pressure section after the gravity section and one pressing cylinder pair at the end of the pressure section (manufactured by Ahlström in 1985). The belt wash water is raw lake water. The polymer used as sludge conditioner is cationic polyacrylamide. A schematic picture of the principle of the dewatering system is shown in Figure 1.

The selection of the variables to be monitored is a challenging and important task. It is a question of the relevance of the variables and ability to measure them with low-cost instruments. Companies tend to allow only minimal investments in their sludge treatment. In this research the web purity filter was chosen as the measurable variable because it tells us how well the sludge cake separates from the web and enables the condition of the web to be judged. The thickness of the sludge layer between the webs at the front of the pressing cylinders (nip) was chosen as a measurable variable because it gives crucial information for optimizing the pressure between the cylinders. In addition, the pressure of the pressing cylinders affects the blinding of the web. There is usually a particular hydraulic cylinder pressure limit a belt filter can handle safely without breaking. The hydraulic cylinder pressure also affects the blinding of the web through nip pressure and belt tension. Image capturing was chosen to give visual information about the condition of the web. The image information

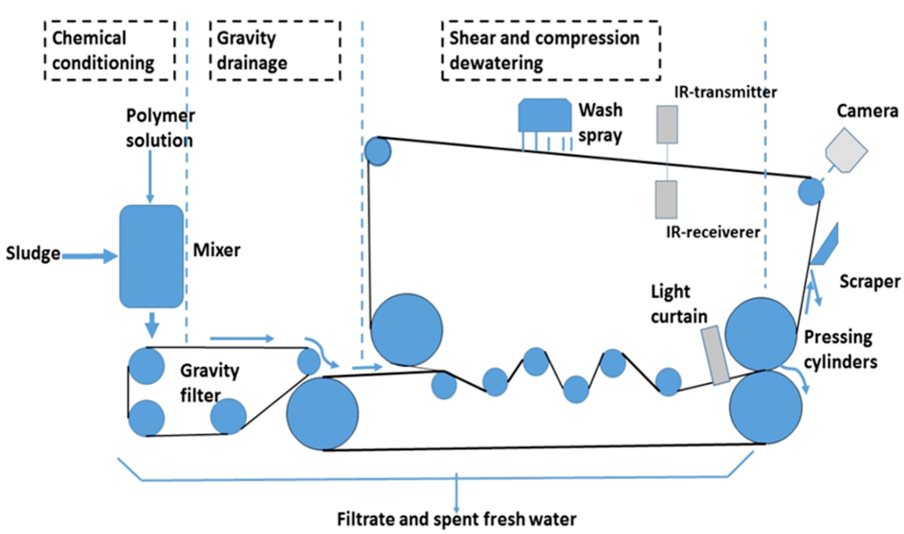

Figure 1: Schematic picture of dewatering in a box board mill.

supports and qualifies the data obtained from the purity measurement and vice versa. Veal and Edwards discuss remarkable savings in polymer costs when machine vision is used to analyze the drainage zone (gravity zone) (Veal and Edwards 2001).

The filtrate water properties were measured to obtain other measurable variables supporting the information. During the step response experiments, the solid content was measured for the feed sludge, filtrate and dewatered sludge cake as well as to obtain supporting information.

Purity measurement of the filter web

Fouling of the web was measured using a 1-channel amplifier. The amplifier works with modulated infrared light which provides high immunity to ambient light. The electronic circuit is designed to detect only signals with the correct frequency and phase relation. The analog output, which supplies a voltage between 0 and 10 V in dependence of the received power, can be used to adjust the transmitter and receiver to measure the turbidity between transmitter and receiver. IR and near-IR sensors have been used for example to measure suspended solids in activated sludge processes (Urrutikoetxea, García-Heras and Gregory 1993) and analyze soil properties (Ben-Dor and Banin 1995).

Measurement of the sludge thickness between the filter webs

The sludge thickness is measured by a light curtain just before the pressing cylinder pair, where local cake thickening between the two webs tends to take place. The Telco Spacescan™ SS 02 light curtain has 25 channels with spacings of 5 mm. The light beams work at an infrared wavelength of 880 nm.

Image capturing of the web

The web was photographed at 20-minute time intervals to evaluate the cleanness and blinding of the web. The final aim was to analyze the web using intelligent image processing. The camera optics was equipped with a remote controlled pressure wash system. During the project, the online camera image could be seen remotely, which in addition to monitoring helped with maintenance of the camera.

Turbidity, conductance, pH and temperature measurements of the filtrate

The turbidity, conductance, pH and temperature of the filtrate water were measured using WTW IQ Sensornet series online analyzers. The amplifier unit was equipped with a data acquisition function.

Assembly of the test measurement instruments

Online filtrate water measurements

The online filtrate water measurements were carried out in a reservoir. The filtrate water from the nip section was conducted continuously through the reservoir with a volume of 50 liters. The flowrate was approximately 1 l/min.

Assembly of the light curtain

The distance between the transmitter and detector is around 3.5 m which is a little longer than the transverse measure of the belt at 3.2 m. In the pressure section, the two webs travel above one another with the sludge between them. The optimal position would be perpendicular assembly so that the middle level of the two webs was exactly in the middle of the 25 cm long transmitter (and detector). By that arrangement, the thickening of the sludge between the belts could be measured basically as the sum of the two opposite dimensions. However, the pressing cylinder's gear box is situated on the other side of the belt filter, which limited the usable positions of the detector in relation to the belts. For this reason the thickening of the sludge could be measured only in one direction from the belt level. The assembly of the light curtain is shown in Figure 2.

Belt fouling measurement using IR

The transmitter and receiver probes of amplifier were attached to two 1.3 m arms made of PVC tube, with one arm on each side of the belt. The assembly was such that the probes could be pulled away from the belt for cleaning the probes, maintenance of the belt, etc. The assembly of the IR-transmission measurement is shown in Figure 3. The transmitter probe was situated above the web and the receiver below it.

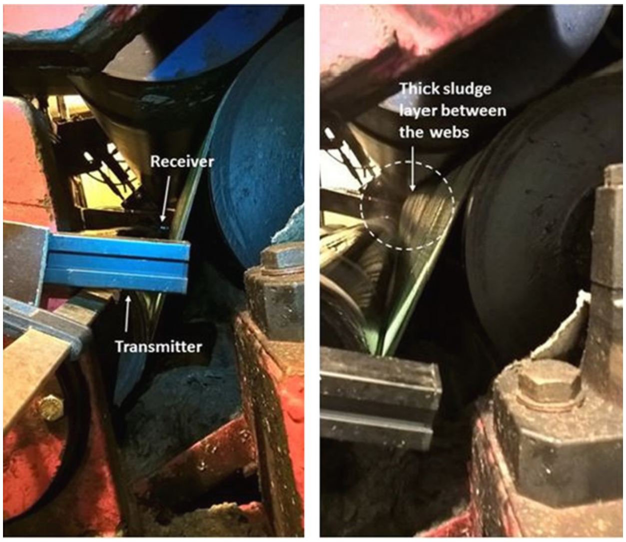

Figure 2: Light curtain assembly.

Figure 3: IR-transmission measurement.

Figure 4: Camera assembly for capturing images of the condition of the filter web.

Camera assembly

The camera assembly for the image capturing is shown in Figure 4. The distance between the camera and the web was around 1.4 m. The camera was situated in the middle of the crossing dimension of the web. The image capturing took place toward the drum and the belt just after the cake scraper and before the belt washer. The idea was that the shine of the metal of the drum below the belt would show the unblocked slots of the belt.

The locations of the test measurement instruments in the dewatering system are shown in Figure 1.

Test response experiments

During the test period, separate test response experiments were carried out to be more accurately aware of the running conditions and their effects on the dewatering process. In addition, the test response experiments were conducted to check that the measurements really measure the quantities they are intended to measure; that is, the directions of the responses are correct and identical to the continuous measurement data during the test period. Information about the size of the response was compared to the change in the test variable. In other words, we obtained information about sensitivity.

The test response experiments consisted of the following parts:

1) Reduction in the velocity of the web
   Reduction of the web velocity causes an increment in the sludge thickness which should be seen in the light curtain measurement at the pressing cylinders. The test time was planned to be about 1–2 hours.
2) Increase of the sludge mass flow
   The idea was to adjust the pressure of the pressing cylinders to as high as is still safe to run with no danger of equipment breakage. The feed velocity was increased so that the sludge mat thickness between the webs increased and could be measured at the pressing cylinders. The test time was planned to be about 1–2 hours.
3) Reduction in the polymer dosage
   The amount of polymer per kg of sludge was reduced using steps starting from the running situation

as long as a clear response was obtained in the IR-transmission measurement. After that it was returned to the original running dosage. Samples from the feed sludge, filtrate and dewatered sludge were taken. The estimated test time was planned to be about 1–3 hours.

4) Increase of the relative amount of bio sludge
The relative amount of the bio sludge was increased step by step as long as the sludge dewatering was still runnable. After that it was returned to the original amount of bio sludge. Samples from the feed sludge, filtrate and dewatered sludge were taken. The estimated test time was planned to last about 1–3 days.

Results and discussion

Results of the test response experiments

During the test response tests, the suspended solids content (SS) of primary sludge was 0.8 % and the SS of primary sludge was 3.5 %. In the belt filter run the SS values were: After the gravity filter 4.4–5.2 %, in the dewatered filter cake 24–31 % and in the filtrate 0.1 %. The relation of dry mass to bio sludge/primary sludge was approximately at a level of 40 %. The fiber length of the primary sludge is shown in Figure 5.

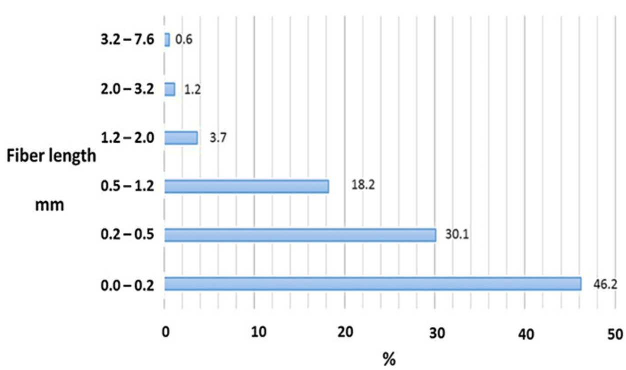

Figure 5: Population fractions of fibers in the primary sludge.

Reduction in velocity of the web

The velocity of the web could be adjusted at the control panel next to the belt filter, which made it possible to get immediate visual feedback. The hydraulic pressure of the filter pressing was adjusted to 40 bar. The sludge mat thickness was approximately 3 mm at the beginning of the experiment. The velocity of the web was decreased by 1 m/min step starting from 4 m/min, the velocities being 4.0 m/min, 3.5 m/min, 3.0 m/min and 2.5 m/min. The results are shown in Figure 6. It can be seen that the thickness increases as the velocity decreases.

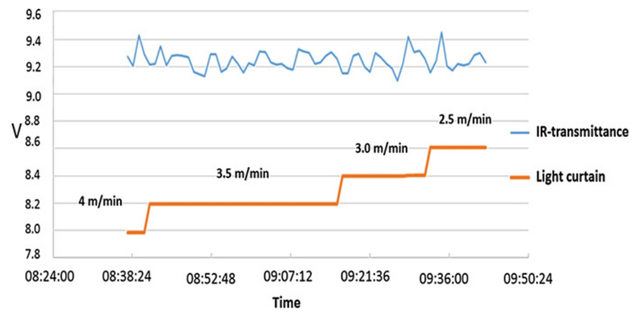

Figure 6: Reduction in velocity of the web. The light curtain measurement interval of 8–8.6 V corresponds to 15 mm sludge mat thickness.

Change in the sludge mass flow

Figure 7 shows the sludge mat thickness before the pressing cylinders. The sludge feed rate was adjusted from 600 l/h to 750 l/h. After 45 minutes, the feed rate was set back to 600 l/h. It can be deduced that the sludge mat thickness follows the change in the feed velocity.

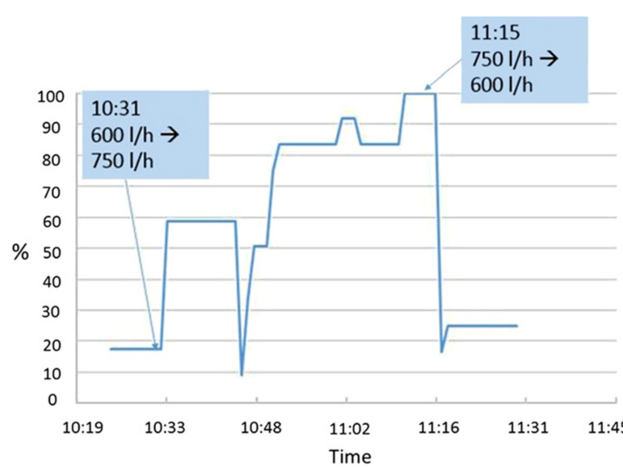

Figure 7: Effect of sludge feed mass flow on light curtain measurement 100 % ≈ 5 cm.

Effect of polymer dosage on IR transmittance

The effect of the polymer mass-based fraction is seen in Figure 8.

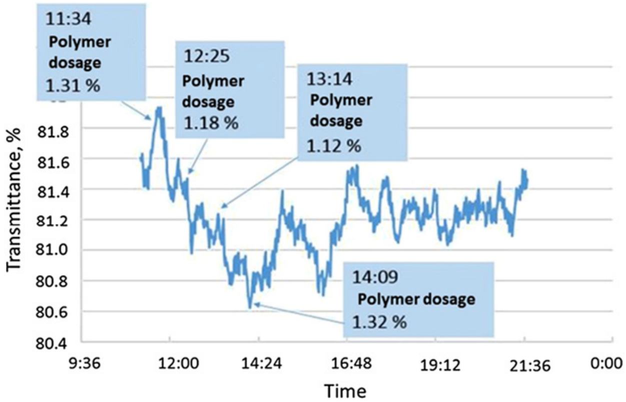

Figure 8: Effect of polymer dosage on IR transmittance in the measurement of the filter web.

Figure 8 shows that a change of 19 % in polymer dosage drops the IR transmittance through the web by about 1 %. The relative change in transmittance is small but clearly measurable. IR transmittance responded to the polymer content of the sludge at once without a notable time lag. At the same time, there was no measurable difference in the dry mass of filtrate between the polymer dosages of 1.31 % and 1.12 %. Both the small drop in transmittance and the constant dry mass of the filtrate suggest that the polymer was used somewhat more than was needed. The pilot data for sludge filter belt treatment in the pulp and paper industry has shown that a polymer sludge relation of 0–0.5 % is capable of generating filter cakes with consistencies of 30-40 % solids (Miner, Marshall and Gellman 1978).

Effect of the relative amount of bio sludge

The effect of the relative amount of bio sludge on IR transmittance through the web is seen in Figure 9.

The percentage of bio sludge is a mass-based value.

Figure 9 shows that when the hydraulic cylinder pressure reached the alarm limit ≈ 50 bar, the sludge feed to belt press was reduced from 900 l/min to 650 l/min. It is very probable that the both the effect of the relative fraction of bio sludge and the effect of sludge feed velocity were seen at the same time. Because of the running mode of the sludge treatment process it was difficult to set up the experiment so that only the fraction of bio sludge changed. The most important task was to obtain a response from the IR measurement. However, from the results of Figure 9 it can be seen that the transmittance is lower at a bio sludge percentage of 45 % than at 39 % with a constant sludge feed of 650 l/min.

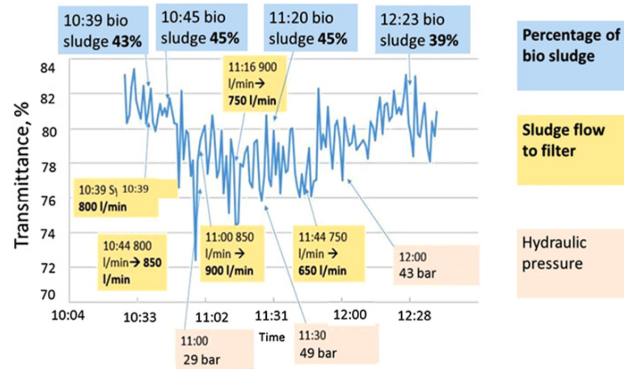

Figure 9: Belt press run with changing amount of bio sludge.

Results of the continuous run-time monitoring

In addition to the test response measurements, an abundant amount of run-time data was obtained from continuous data acquisition during the nine-month test period. A large amount of the data was connected to changes in the running modes and failures of the sludge treatment and changes in the run parameters of the belt press. In certain conditions, a belt web can get fouled and may become blinded easily. The factors affecting IR transmittance were for instance faults in sludge pumping or polymer dosing. For example, drying of the filter web during stoppages and wetting and fouling during and after filter start-up can be seen in the measurements.

Figure 10 shows the response of the filter web IR transmittance to erroneous polymer dosing and in Figure 11 shows the response to problems in primary sludge pumping.

Figure 12 shows that the IR transmittance after cake release and the thickness of the sludge mat before the pressing cylinders can correlate with each other depending on the conditions of the belt filter. Certain sludge processing faults tend to increase the thickness of the sludge mat between the webs. In general, a thick sludge mat causes increased pressure between the pressing cylinders, resulting in more sludge being attached to the web.

The tendency of the IR transmittance to move gradually back toward the original level can be seen In Figure 12. Fouling of the web may, depending on the running conditions, reduce transmittance to a practically constant level. So one then has a temporal base level. However, the experience obtained during the test period of this research suggests that the sensitivity of the IR device changes negligibly as a function of transmittance. Another location for IR transmittance measurement in addition to the point after the cake release would probably be the after the web

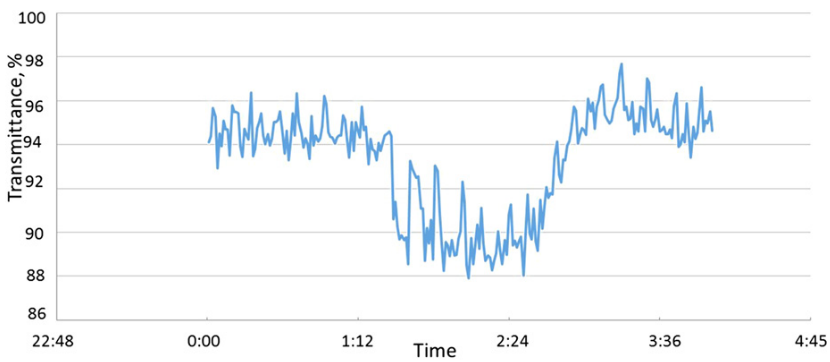

Figure 10: Response of IR transmittance caused by temporal decrease in polymer dosing.

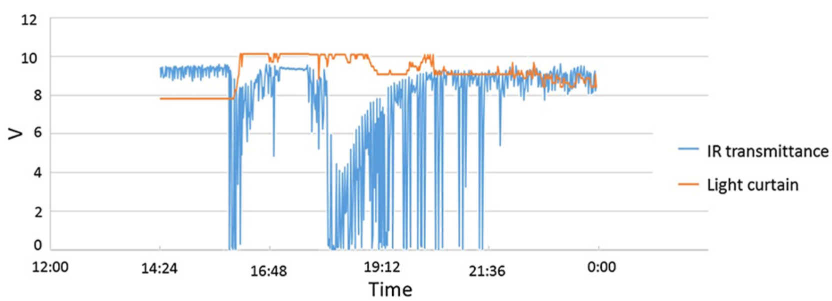

Figure 11: Fault in primary sludge pumping resulting in the feed flow to the belt filter consisting mostly of bio sludge. Between the minimums of the transmittance curve there is a short lag period during a stoppage. During that period the transmittance decreases slightly because of drying of the filter web.

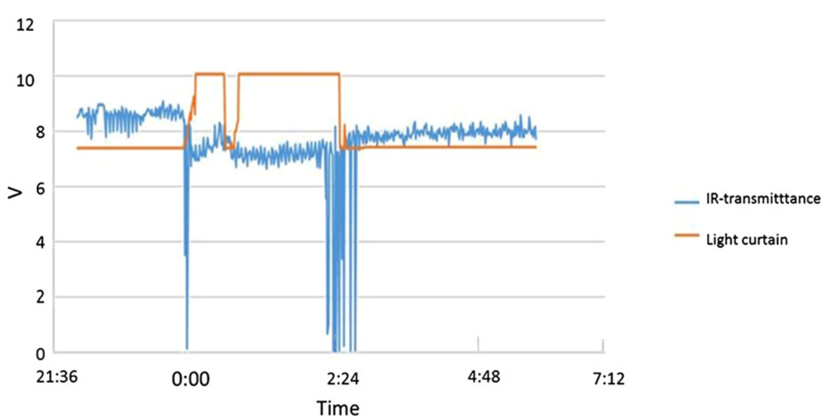

Figure 12: Correlation between IR transmittance after the scraper and sludge mat thickness before the pressing cylinders.

washing system, which is the actual apparatus for hindering fouling.

Image data analysis

A large amount of image data was obtained during the nine-month measurement period. The detailed analysis of this data will be published in future work. The preliminary visual inspection suggests that at least some of the image data may be applicable for machine vision purposes and for constructing automated image analysis. Some of the picture data seemed not to be very consistent with the other measurements. The web of the belt press was photographed against a steel cylinder which seemed to foul to some extent. A considerable amount of particles attached to the web, such as wood splinters and fibers were found. Cylinder fouling and attachment of sludge to fibers and wood particles may complicate figure analysis. Figure 13 shows a comparison of a pure web and a partly fouled web.

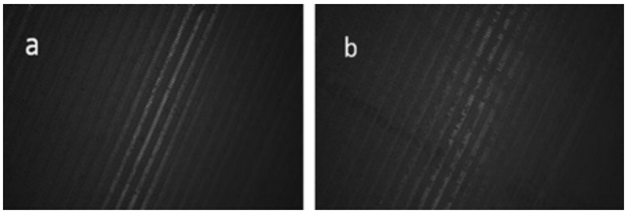

Figure 13: Comparison of pure a) and fouled web b) of the belt press.

In future applications it could be better to photograph the web with a light source or illuminated surface on the other side of the web.

Conclusions

Continuous run-time measurements and test response experiments were carried out on the belt filter of the sludge treatment process at a box board mill site. All the test apparatus worked well without faults and little maintenance was needed, which is crucial for taking these techniques into industrial use. In the example, the IR transmitter and receiver were cleaned once in three months and the light curtain receiver and transmitter were cleaned approximately once a month. The IR transmittance measurement through the filter web and the sludge mat thickness measurement using the light curtain turned out to be very promising techniques for monitoring the operation of the belt filter. Both techniques seemed to be sensitive to process variations. The IR transmittance particularly responded to the polymer content of the sludge at once without a notable time lag, while the solid content measurement of the filtrate did not give a measurable response.

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