Heli Karaila*, Lasse Järvinen, Ari Oksanen

Mass flow-based controls with solids measurements reduce sludge handling costs

Abstract: The Tampere Water Viinikanlahti wastewater treatment plant in Tampere, Finland has commissioned what is believed to be the world's first multi-variable predictive controller (MPC) of a centrifuge sludge dewatering operation based on multiple online measurements of solids content. The online measurements have replaced manual testing that was considered too slow or not timely enough for optimum real time control. In addition to the centrifuge mass flow-based control other unit operations such as primary clarifier sludge pump scheduling and optimization of anaerobic digester input solids are now based on mass flow values rather than volumetric values. The project objectives of minimizing the recirculation of material inside the plant and optimizing the solid amount in the dewatered dry cake were more than met in addition to achieving significant chemical and energy savings.

Keywords: wastewater, centrifuge, dewatering, optimization, MPC

***Corresponding Author:** Business manager Heli Karaila, E-mail: heli.karaila@valmet.com

Second Author: Lasse Järvinen
lasse.jarvinen@tampere.fi, Ari Oksanen
ari.oksanen@tampere.fi

1 Introduction

At the wastewater plants it is still typical that monitoring and control of the sludge process is done based on laboratory samples follow up and visual look of the process. In order to optimize the process there are needed online measurements with the control application. In this article is descriped Tampere Water Viinikanlahti wastewater treatment plant project with the results in Tampere Finland. In the project there was added multiple real time solids measurements to the sludge process in order to replace manual laboratory follow and optimize the process with the massflow based controls. At the centrifuge there was commissioned multi-variable predictive controller (MPC) of a centrifuge sludge dewatering operation based on online measurements of solids content.

2 Tampere Viinikanlahti process

Fig. 1. Seventy-five per cent of Tampere's wastewater is processed at the Viinikanlahti wastewater treatment

The biological and chemical wastewater treatment in Viinikanlahti is based on an activated sludge process coupled with phosphorus precipitation by ferric sulfate. The process consists of screening, grit removal, primary sedimentation, aeration and secondary sedimentation. Wastewater sludge is digested in anaerobic digesters after which the sludge is dewatered by centrifuge. The daily flow is about 70,000 m^3 (230,000 p.e.); producing approximately 63 m^3 of sludge is per day. Biogas from the digester is used to generate electrical energy and heating for the plant.

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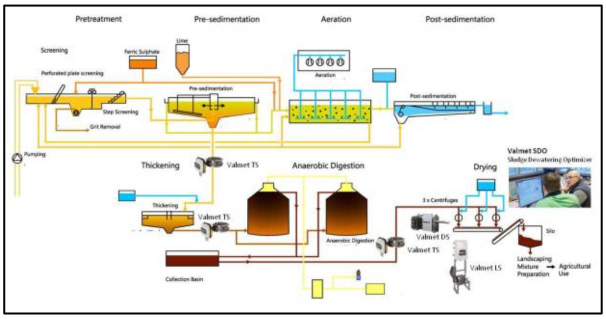

Fig. 2. Tampere Water Viinikanlahti wastewater treatment plant with Valmet's solids measurement (TS, LS and DS) locations and Valmet SDO

3 The need for reliable online measurements

Traditionally the only reliable online measurement available to wastewater process engineers has been flow. Laboratory test results only partially support the optimization process. This is because laboratory tests are carried out rather seldom and the results are archived after a considerable delay. As an example of the need of online measurement instead of laboratory measurement is shown in this example of a centrifuge centrate measurement made in an earlier trial at a wastewater plant in Southern Finland (Fig. 3). On the basis of the laboratory measurement, it is not possible to follow the process dynamics for the correct polymer dosage, because the situation changes immediately after the laboratory sample is taken.

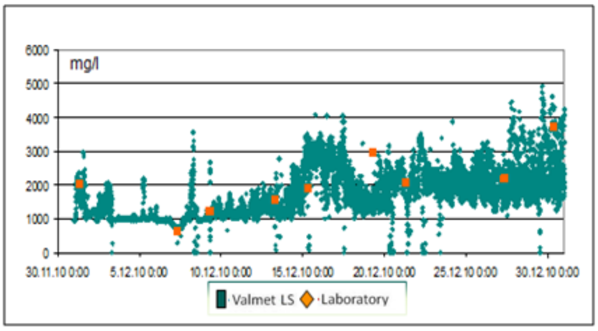

Fig. 3. Laboratory samples taken normally twice per week provide no information of the actual dynamic situation

4 Clarifier and thickener solids measurements

Valmet TS has been developed from a third generation microwave solids transmitter originally designed for use in the demanding environment of a pulp and paper mill. It uses patented microwave-based technology, which allows it to measure total solids content, unaffected by affected by flow rate or color of the process stream. Solids conduct microwaves faster than water so that shorter microwave transmission times correlate to higher solids content. The relationship is linear, making it is easy to calibrate the device regardless of what is being measured.

Fig. 4. *Valmet TS microwave total solids transmitter*

Three Valmet Total Solids transmitters (Valmet TS) are used to measure total solids after pre-sedimentation, after thickening and before the dewatering centrifuge. An immediate advantage after installation was now process parameters could now be seen based on solids mass rather than the volumetric total flow. The four circular primary clarifiers in the Viinikanlahti pre-sedimentation stage allow solids in the wastewater to settle to the bottom of the clarifier before being pumped to the sludge thickening tank. Prior to the Valmet TS installation, pumping from the four clarifiers was controlled in a timed sequence, which meant that from time to time a clarifier would be emptied of solids and only water would be pumped to the thickening tank. With Valmet TS measuring the total solids content, the pumping sequence from the four clarifiers is now controlled by the solids content to avoid excess water being pumped to sludge thickening.

A second Valmet TS monitors solids content after thickening and enables the optimization of the thickener to increase solids content to the digester. The higher solids content to the digester reduces heating demand, increases digester residence time and produces more biogas.

5 Centrifuge measurements

The third Valmet TS is used to stabilize the mass flow to the centrifuge, now measured in kilos of sludge per hour. In the first phase of centrifuge optimization, performed in December 2015, this allowed dewatering polymer to be controlled as a ratio to the mass flow rather than the cubic meter-based flow rate previously used. With the mass flow under control, the second phase of optimization in January 2016 was to optimize solids in the centrate and moisture in the dry cake with a combination of torque control and polymer. A Valmet Low Solids Measurement, (Valmet LS), was installed in the centrate outflow and another specialized measurement, Valmet DS, measures the solid content of the dry cake as it falls to the conveyor.

The Valmet Low Solids Measurement (Valmet LS) measures a continuous sample flow through the system by utilizing an integrated centrifugal pump. The system has two LED light sources in a flow through measurement cell where absorption, scattering and depolarization signals from both of the light sources are measured. Valmet LS continuously measures both the entrained air index, which indicates overdosing of polymer, and the suspended solids content within the range of zero to 5,000 mg/l. The measurement cell utilizes an extremely strong sapphire glass with high optical properties and is cleaned automatically together with the sample lines at given intervals.

Fig. 5 *Valmet LS measures solids in the range of 0 to 5,000 mg/l.*

The Valmet Dry Solids Measurement (Valmet DS) extracts a continuous sample from the falling cake flow after a centrifuge or screw press and measures the solid content before returning the sample back to the process. Utilizing Valmet's proven patented microwave technology and requiring no special certification or safety procedures, it makes a stable and accurate measurement of cake solids up to 35%.

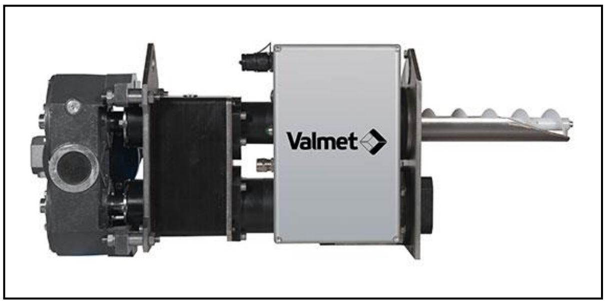

Fig. 6. *Valmet DS measures cake solids up to 35%.*

6 Centrifuge control

Traditionally the only online measurement at the sludge dewatering phase is flow; the process is controlled with laboratory based measurements or visually based on the color of centrate or dried cake appearance. When centrate color is dark, more polymer is added and operators normally overdose polymer in order to limit the recirculation of reject (centrate) solids. However this is not only wasteful in terms of polymer but can lead to foaming in the centrifuge and inefficient centrifuge operation. Centrifuge torque also has an effect on centrate solids but is very seldom changed. The lack of information, only provided by infrequent laboratory samples with often a day's delay, means that centrifuge operation has been very much a "dark art" and very difficult to optimize.

This is where the multivariable model predictive control (MPC) as employed by the Valmet Sludge Dewatering Optimizer (Valmet SDO), a small-scale Valmet DNA control system, comes into play. With continuous centrate and dry cake solids information from Valmet LS and Valmet DS together with the stabilized mass flow to the centrifuge, the control can combine the optimum torque and correct polymer dosage. The result optimizes both energy and polymer while achieving the target reject solids and higher dryness in the dry cake from the centrifuge.

MPC uses process models (Fig 7) to predict the interactions between the modified variables (polymer and centrifuge torque). This allows the operator to make set point changes and follow up as for normal single loops. The interactions of the separate loops are taken care of automatically as a background task of the optimizer.

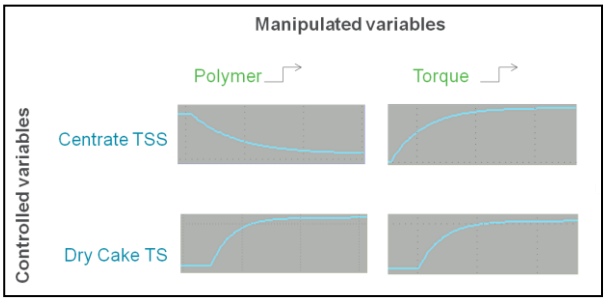

Fig. 7. *Polymer and Torque process models to centrate TSS and Dry Cake TS*

As the centrifuge torque is increased, more water is extracted from the sludge and the total solid (TS) content increases in the dry cake, but at the same time centrate total suspended solids (TSS) increase to be wastefully re-circulated through the plant reducing capacity. Increasing polymer dosage increases the solid content of the dried sludge and also reduces centrate solids. The dynamic relationship of these interactions is difficult, if not impossible, to control separately with single PID controllers but with MPC control it is easy to take care of the effects.

The MPC control principle is based on following control strategy (Fig 8.):

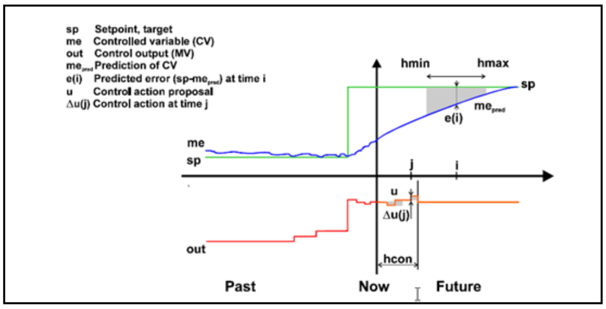

Fig. 8. Control principle of MPC for one controllable parameter

1. At each control execution moment, the controller performs a forecast of the process output, i.e., it predicts the future behavior of the controlled variables. Predictions are made over a certain time horizon *hmax* and are based on process models and known control actions (history).

2. The controller calculates the optimal subsequent *hcon* control actions, which keeps the number of errors occurring between setpoints and predicted process outputs as small as possible during the time period *hmin--hmax.* The calculation is based on an optimization of the cost function, which presents how the smallest possible error occurrence is achieved with minimal control actions.

3. First, one of the proposed control actions is applied to the process. All other actions are ignored and the whole procedure is repeated, leading to updated control actions with corrections based on the latest measurements.

7 Results

Performance of Online measurements

After the calibration of the measurements laboratory samples were taken in order to follow up the performance of the measurements over a two month period (Fig. 9).

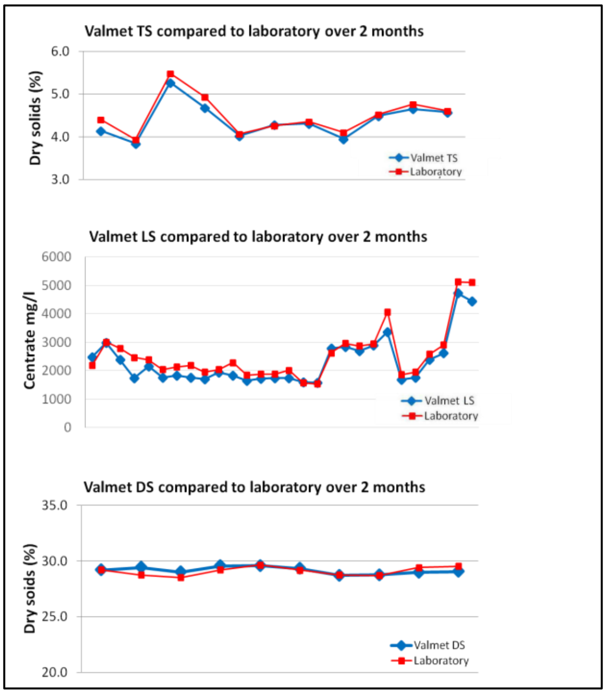

Fig. 9. Two month follow-up after initial calibration

Since startup, little or no maintenance has been needed. The optimization has been in use 24/7 and, apart from initial fine tuning of the DS dry cake measurement, all the measurements still use the same calibration parameters from start-up. Operators have found the control room display easy to understand and operate, providing them with a new window to the process (Fig 10).

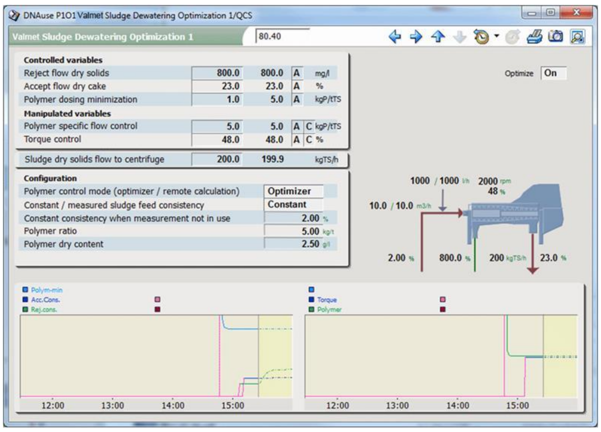

Fig. 10. Valmet SDO operator display provides a real-time picture of centrifuge operation.

8 Conclusion

In one year of operation, the measurements and control have proved to be very reliable. Measurement devices were acquired in order to have exact data from the process and this has enabled meaningful trials on the effectiveness and selection of polymers used in the plant. The controls have achieved the goals of polymer feed optimization, decreased energy consumption and savings in dry cake transportation costs. The project has also been a perfect opportunity to test new technology for the new Sulkavuori underground treatment plant being built in Tampere and estimated to start in 2023.

More than 140,000 €/year savings have been calculated as follows:

- Sludge pumping from clarifiers reduced from 76 m^3 to 50 m^3 an hour
  - Reduced excess water to thickening
  - Energy savings are approx. 37 %, 5,000 €/year
- Digester solids increased from earlier 3.5% to 5%
  - 32 % less sludge to treatment
  - Increased biogas production
- Solid content of centrate water is now 50 % lower and more stable
  - Polymer consumption has decreased almost 40 % from level 8 kg/ton
  - Savings with less material circulated, 10,000 €/year
  - Polymer savings, 49,000 €/year
- Dried cake solids content has increased by about 1-2 % from 29,7 % to over 31%

Saving in transportation costs approx. 80,000 €/a