

PREDICTING SLUDGE DEWATERABILITY: A REVERSE-RUN MASS BALANCE APPROACH TO CLOSE THE *EXPECTATION GAP*

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Abstract

Sludge dewatering is integral to the cost effective recycling of Municipal Mesophilic Anaerobic Digestate to land. Any mass balance or cost model for a plant in the municipal MAD market will make reasonable assumptions based upon a historical database for: i) the dry solids content (%DS) of the cake; ii) the mass of polymer or conditioning agent and dry solids (kg poly/tds); and iii) the quality of the return liquors.

A dewatering asset is designed to achieve performance guarantees for these measures and this is critical to the long term financial and operational success of any given project. For new build assets the process guarantees are held by the principle contractor, often with a back-to-back agreement with the equipment supplier, and the contract will only be awarded to those willing to sign up to the guarantees. It is imperative therefore that all parties have a good understanding of the feed sludge characteristics and how changes in these may impact upon performance. Asset standards can be used to provide an indication of how the sludge and performance may vary, but they are not a guarantee that the feedstock to be processed will be within the limits defined. Where there is a difference in what is achieved through dewatering and what is anticipated (*Expectation Gap*) the mass balance can become a source of debate and controversy. Quantifying why there is an *Expectation Gap* is therefore essential to achieving long term project success.

Depending upon the contract, the specified limits will be 'easier' or 'harder' to meet. The volatile solids content of the sludge is increasingly understood as being critical to both polymer consumption and cake dry solids, whilst it has been suggested that orthophosphate-P can also adversely affect the outputs.

This paper reviews the factors known to influence sludge dewaterability; it details the investigative analysis required to input into a 'reverse-run' mass balance to provide a realistic output product quality for a range of different feedstocks.

Key Words

Keywords: cake dry solids, dewaterability optimisation tool, dewatering, polymer consumption

Introduction

There is often a gap in what is thought to be achievable from a belt press, centrifuge, Bucher press or other dewatering asset and what is actually achieved. It is not unusual for the final product quality to be lower and the chemical consumption higher than expected, and when this is the case operational budgets will be stretched for the life of the assets.

Where a new build plant is installed and there is an *Expectation Gap* naturally this will lead to potential conflict between equipment supplier – polymer supplier – principle contractor – client. Take a large plant, by way of example, that delivers 30,000 tonnes of dry solids to the dewaterers, and the:

1. product quality is 22% dry solids rather than designed for 27%;

2. rate of polymer consumption is 5 kg/poly/TDS higher than expected.

The additional cost for this would equate to ~£300,000 p/a for polymer and for a water company paying £2.50¹ per wet tonne for haulage, the additional volume cost is ~£63,000; in excess of £7 million over the asset life. Indeed, this is a conservative cost estimate, as farmers will pay less for a lower quality product and should the product stackability be affected then mitigation (e.g. baling) is required in-field, and fines from the Environment Agency can be incurred.

This *Expectation Gap* varies from water company to water company, and from contract to contract and this raises the question of why? Some performance guarantees may or may not include clauses for:

- The volatile solids, for example where this is over ~60% then the guarantees for product dry solids and polymer may not be applicable.
- Average dry solids content of the cake versus 95th percentile or minimum and maximum acceptable levels.
- The proportion of primary or secondary sludge in the feed to the digester.

This paper seeks to draw some of the key factors influencing cake quality and polymer consumption, from Aqua Enviro's experiences and the literature. In addition, Aqua Enviro has developed an investigative laboratory method (Dewaterability Optimisation Tool: DOT), that is repeatable and representative of full scale conditions. This is currently being used to optimise sludge handling at over 30 sites in the UK. It is also used for research purposes to for example investigate the impact of phosphate on dewaterability.

The DOT test therefore occupies a vacant slot in the sludge process train and can be employed to reduce the size of the *Expectation Gap*.

Mass Balances

Early in the design phase of a new build or upgrade scheme a mass balance for the process will be developed. Typically, this will include fixed values for flow, dry solids and volatile solids, plus subsequent calculations for tonnes of dry solids and tonnes of volatile solids. The mass balance (MB) will be used to help size different unit operations, however it will include a number of assumptions and decisions, including:

- Performance of digester in terms of volatile solids destruction.
- Performance of thickening and dewatering assets with fixed values for dry solids and return liquor quality.
- Running the mass balance at the mid or design point as opposed to extremities for flows and dry solids.

Any mass balance produced is one fixed scenario for a fixed set of conditions and that is how it should be viewed.

¹ WRAP (2013). Digestate Distribution Models. OMK006-001

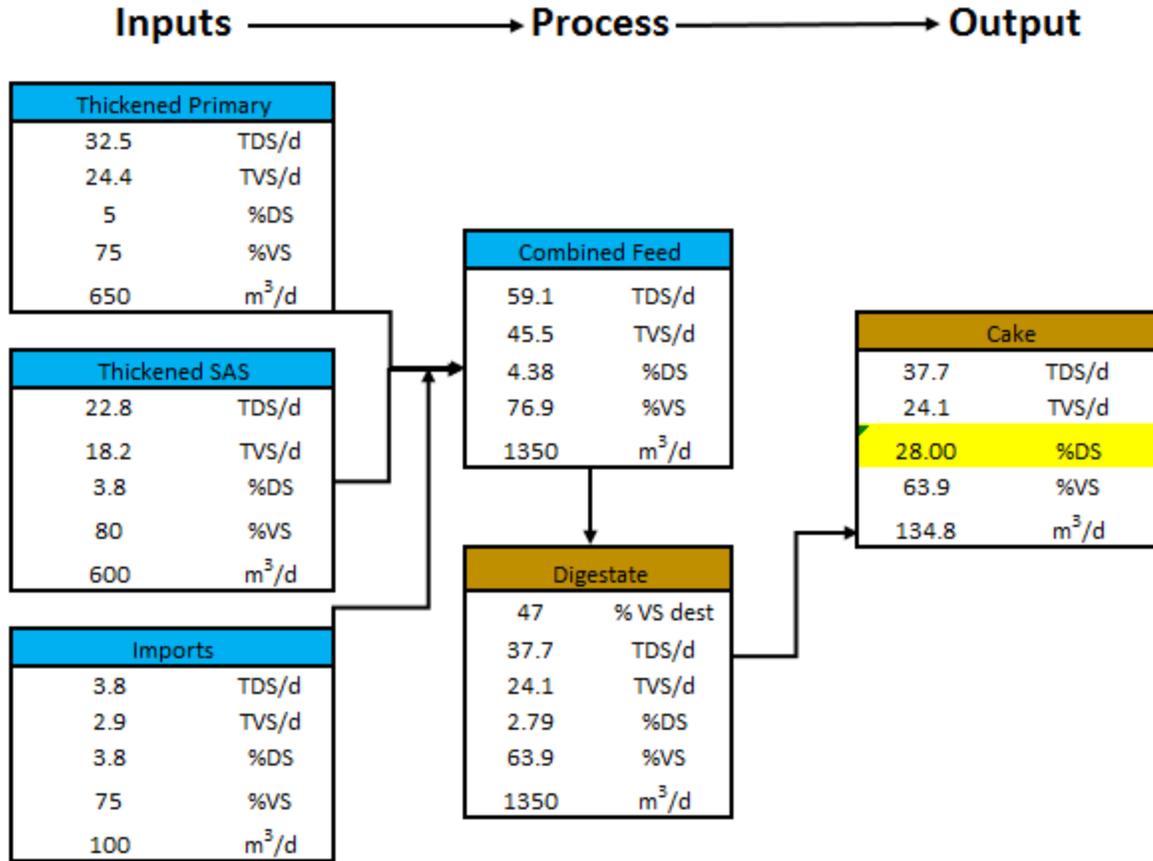


Figure 1: Mass balance. Yellow highlighted box is the performance guarantee for the dewatered cake

The cake dry solids to be achieved will be a performance test criterion and this will likely have been defined by the water company. The principle contractor will need to sign up to this and will have in place a back-to-back contract with the equipment supplier. It can be the case that there is little or no opportunity to negotiate on what must be achieved and the contractor (and equipment supplier) could be in a position that they would not get the contract awarded without taking on this guarantee. For that reason, the dewatering equipment supplier will set limits on the quality of the feed sludge in terms of flow and dry solids, as a minimum. Similarly, the contractor will design and procure equipment for the sludge defined in the mass balance. However, unless these limits cross over to the contract with the water company and are expressly stated there is no requirement on the water company to provide sludge at these levels. This means that what arrives in the inputs and is processed and dewatered will be very different to the mass balance. The limitations of a MB are further shown in Figure 2, whereby the only parameter changed is the cake dry solids figure (as the required performance guarantee is lower), everything else is the same, from the TDS to the type of dewatering equipment installed.

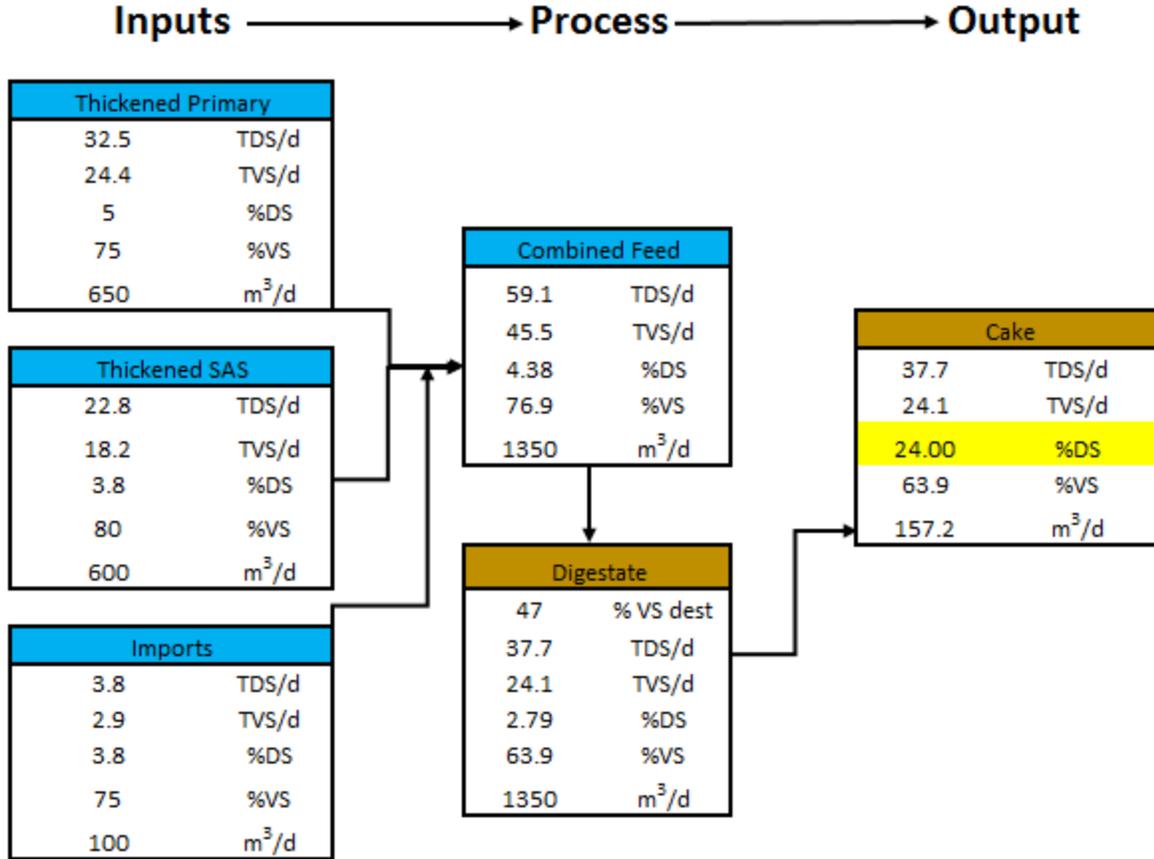


Figure 2: Compared to figure 1 the only parameter changed is the cake dry solids figure, everything else is exactly the same

Whilst there is limited opportunity to negotiate on the performance guarantees, absolute certainty on the inputs, processes and outputs is required, otherwise the risk of a protracted and expensive legal dispute will become a reality.

However, as a project develops, plant is upgraded/built and commissioned it is not uncommon for the mass balance to be viewed differently. The MB is not a dynamic model and it cannot be used to explain why – for example – the final product quality is not being achieved or why the rate of VS destruction is higher/lower than in the mass balance or why the feedstock inputs are not as detailed in the MB. That is not to say however that the MB cannot be updated during commissioning to help understand the *Expectation Gap* (why performance differs from the original MB). Essentially the MB can be reverse-run in that the final product quality is known (as is the polymer consumption and the return liquor quality), the digester performance is known, feed volumes and characteristics are known etc... To ensure this approach is valid there needs to be certainty that each unit operation has been optimised, for example:

- Digester mixing proven (this would form part of the performance/takeover test).
- Digester temperature, hydraulic retention time and organic loading rate are within 'normal' limits (Figure 3).
- Thickening and dewatering equipment is mechanically sound.
- Polymer type, mixing and dosing is optimised (Aqua Enviro's Dewaterability Optimisation Tool, DOT – discussed below).

Parameter	Units	Digesters fed with thermally hydrolysed sludge		Digesters fed with untreated sludge	
		Low	High	Low	High
1. pH		7.4	8.4	6.5	7.6
2. VFA (mg/l)	mg/l	2,000	6,000	200	500
3. VFA/alkalinity ratio			0.3		0.2
4. Methane	% vol	60		55	
5. Total Ammonia	mg/l		2,500		800
6. Digester Feed	%ds	8	12	5	8
7. Temperature	°C	36	39	32	38

Figure 3: Typical digester operating conditions (Jolly, M. 2013)

The data presented in Figure 4 is not uncommon in the UK and compared to Figure 1 and Figure 2 it can be seen that the original MB values for volatile solids content in the feed sludges were too low. Where this is the case the dewatering equipment will almost certainly fail to achieve its design.

The relationship between volatile solids content of the sludge and achievable cake dry solids is so strong that contractors should always seek to include a link to it within the performance guarantee. Contractors should also insist upon or undertake themselves an extended period of analysis of the different feedstocks to ensure that the mass balance assumptions are as close to reality as possible.

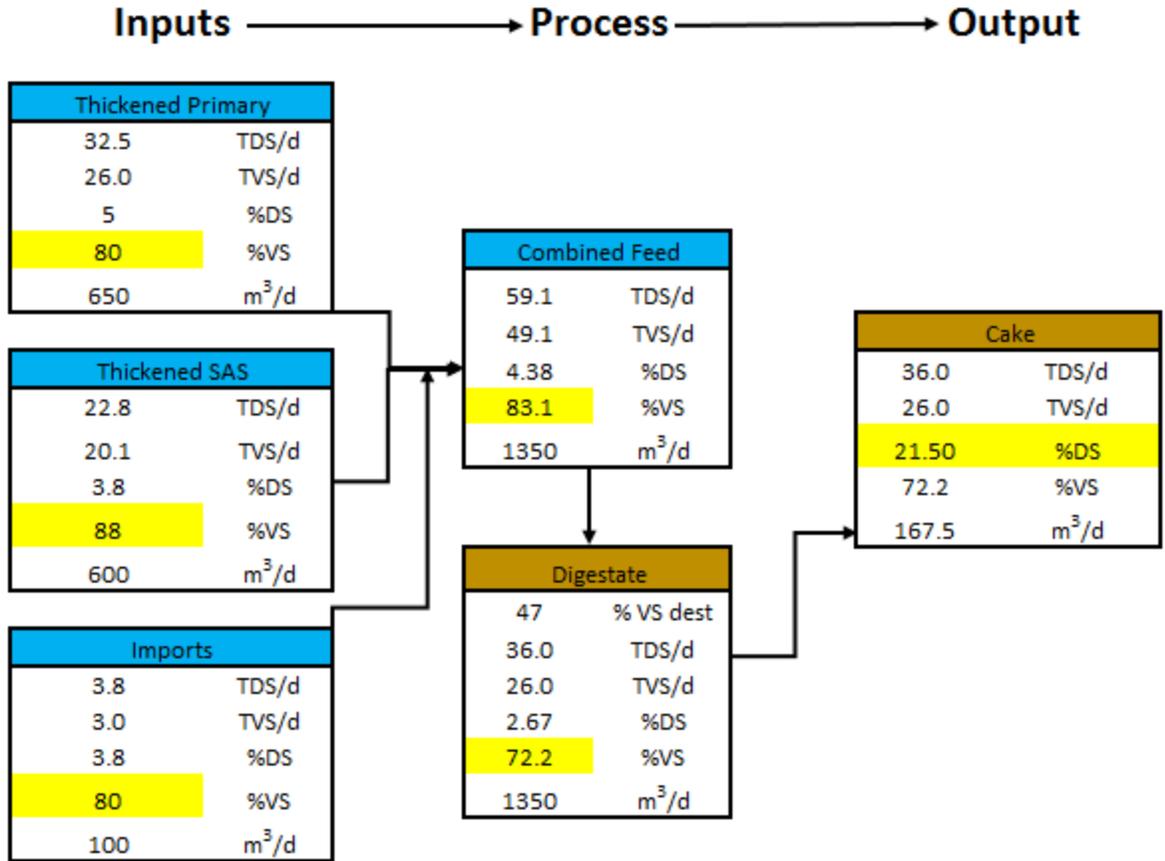


Figure 4: Higher VS content in the feed sludges leads to lower achievable cake dry solids

By understanding how volatile solids (and other factors) influence sludge dewaterability we can begin to quantify the *Expectation Gap* at the design phase, develop more realistic reverse-run mass balance scenarios, and put forward a case for revised guarantees.

Factors Affecting Sludge Dewaterability

Dewatering equipment is expected to achieve a given performance and this is often defined in Asset Standards, the use of which varies from water company to company. During commissioning, takeover and performance testing, however, the equipment must achieve a defined product quality, which may or may not reflect what is written in the contract and could well be different to what is stated in the asset standard. The level of dry solids to be achieved varies between contracts, as does the number of samples / frequency that they must pass (Table 1). Contracts that include just this level of detail place a large amount of risk on the contractor and in turn the equipment supplier. This basic type of guarantee does not account for variations in the nature of the sludge fed to the asset.

Table 1: Belt Press Performance Guarantee

Target Cake dry solids	Frequency
>28%	Average
>25%	Minimum

A more detailed performance requirement will include aspects such as a variable product output that accounts for the influence of higher or lower than expected volatile solids content. This is a sensible approach as there is a proven link between VS content and achievable dry solids content; the higher the VS content in sludge fed to the asset, the lower the achievable dry solids in the cake product.

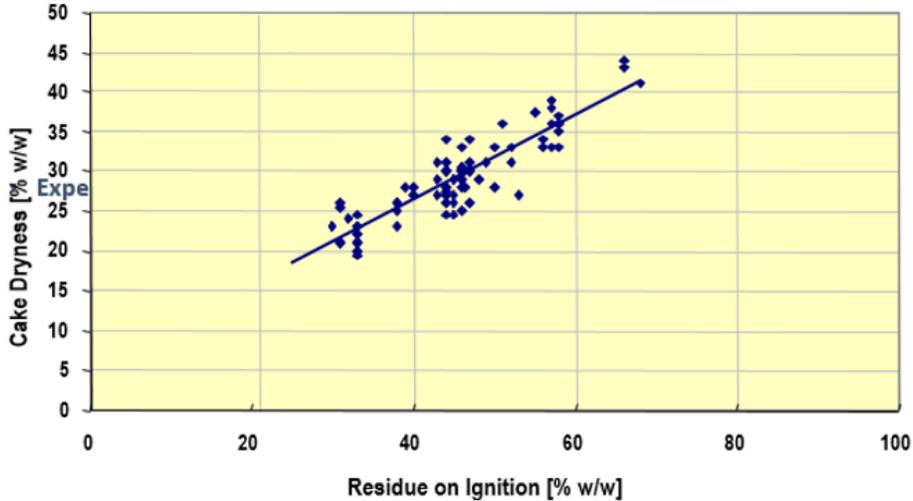


Figure 5 : Cake dryness based on residue on ignition (Laughton, C. & Hallam, R., 2014)

Accepting the relationship between VS content and cake dry solids raises further questions, including: 1) What is the composition of the feedstock in terms of VS?; 2) What is the rate of VS destruction in the digesters?; 3) What flexibility is there in the design, operation and the contract to ensure as low a VS content as possible in the feed to the dewatering asset?

It is at this stage that it becomes possible to model different scenarios, using actual data from sludge treatment facilities.

Table 2 : Example of feedstock characteristics

Feedstock	TDS/d	VS Content (%)	VS destruction in AD
Primary	20-40	65-75	65
THP SAS	40-60	78-88	50

The question now becomes: what should be designed for – the average, the minimum or the maximum VS? Taking the extremes from Table 2, the output VS content could be 52% or 76.8% which will result in two very different cake products with a dry solids as low as 18% or as high as 30%.

Table 3 : Scenario planning

Feedstock	TDS/d	VS Content (%)	VS destruction in AD	TVS in digestate	Cake VS%	Cake %DS predicted
Primary	40	65	65	24.7	52	26-30
THP SAS	40	78	50			
Primary	20	75	65	40.45	76.8	18-22
THP SAS	60	88	50			

Models can be further expanded upon to account for technology type, but key to all scenarios is understanding the characteristics of the sludge.

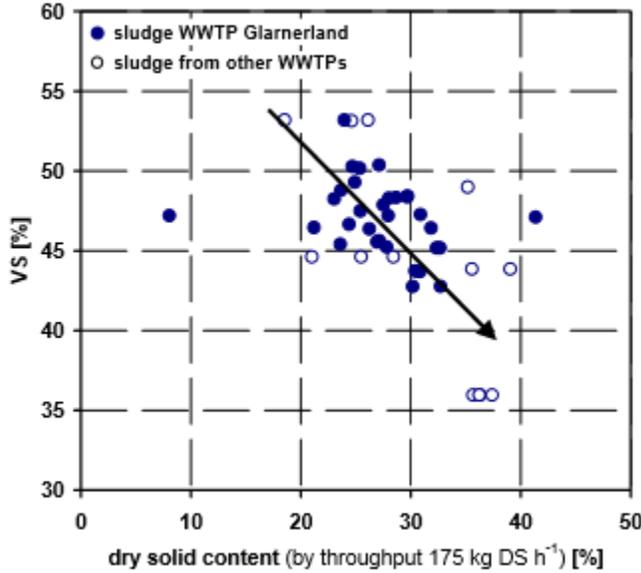


Figure 6: Bucher press cake dryness based upon residue on ignition (Boehler *et al*, 2004)

An approach that encompasses the impact of volatile solids upon cake dry solids would include a tiered reduction as the VS content increases, but would likely still retain a minimum accepted for all samples.

Table 4: Centrifuge Performance Guarantee

Target Cake dry solids	VS Content %	Pass/Fail
26.5%	55.8-62.7	95 th %ile
28%	<55.8	
26%	N/a	All samples

Many other factors can be built into the prediction, including particle size and free water availability, however one area that can be overlooked at the site level when the assets are being optimised is polymer conditioning. To achieve optimum dewatering it is essential that the maturation time is adequate to charge and stretch powdered polymer, and this means 45 minutes of maturation – but it is also essential that the poly is used within 4 hours, and that there is a 2 chamber dilution system to vary poly concentration. While poly concentration can be relatively easily measured through the electropotential, this provides no indication of polymer suitability.

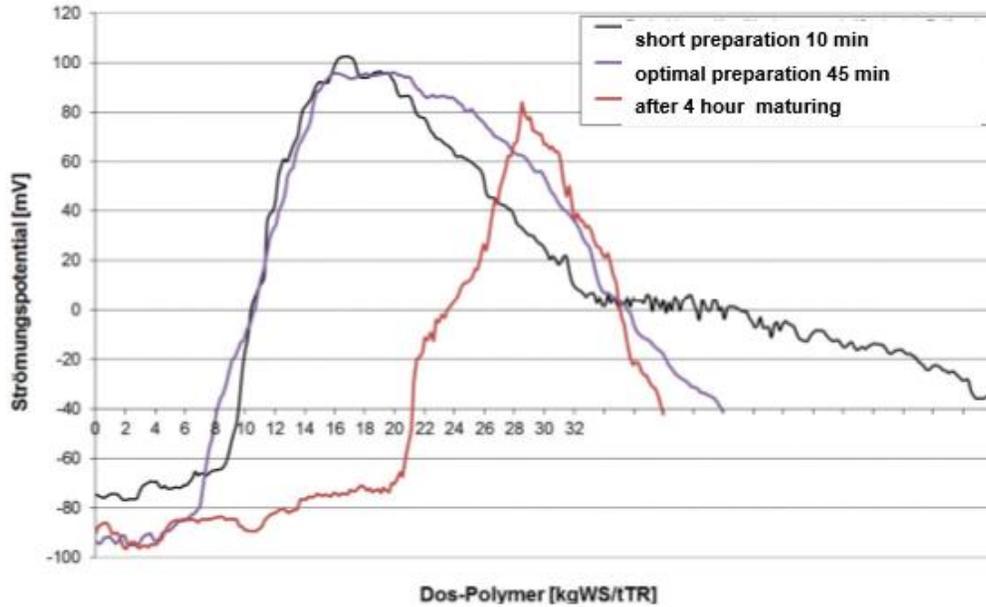


Figure 7: Electropotential as a measure of polymer effectiveness (Kopp,2014)

Measuring the influence of different parameters upon dewaterability

Aqua Enviro's Dewaterability Optimisation Tool (DOT) has been developed over the past 3 years and is now a commercial service used by water companies to optimise the performance of dewatering assets.

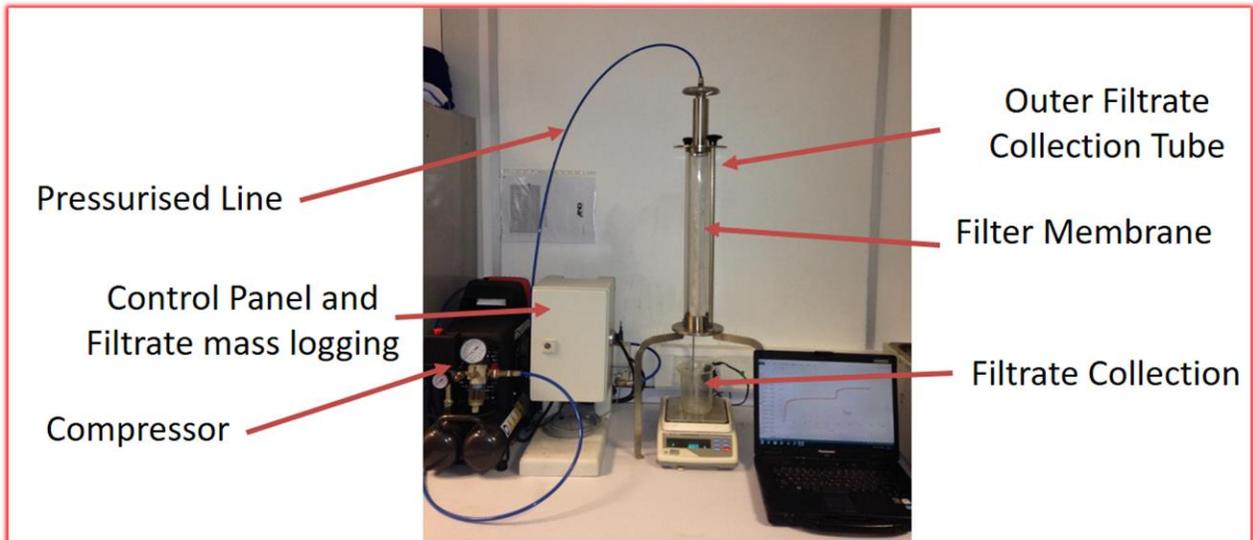


Figure 8 : Aqua Enviro's DOT Tester

It uses a dewatering membrane which can be pressurised internally up to 5 bar, forcing solids into the membrane fabric and separating liquor through the membrane walls. During testing, the operational pressure and mass of liquor generated are measured and logged using online data logging systems.

The software linked to the DOT tester produces graphs of the rate and quantity of water release over time.

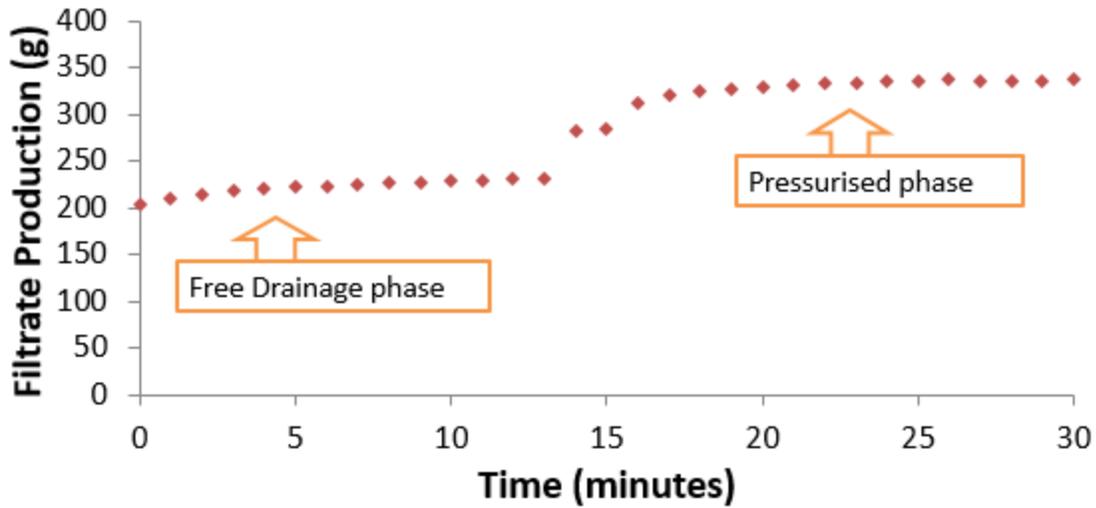


Figure 9: Water release during the DOT test

The free drainage phase quantifies water release at atmospheric pressure, and step changes are observed as the pressure is increased. This is related to dry solids, although the final cake and filtrate quality are both physically measured (Figure 10 to Figure 12).

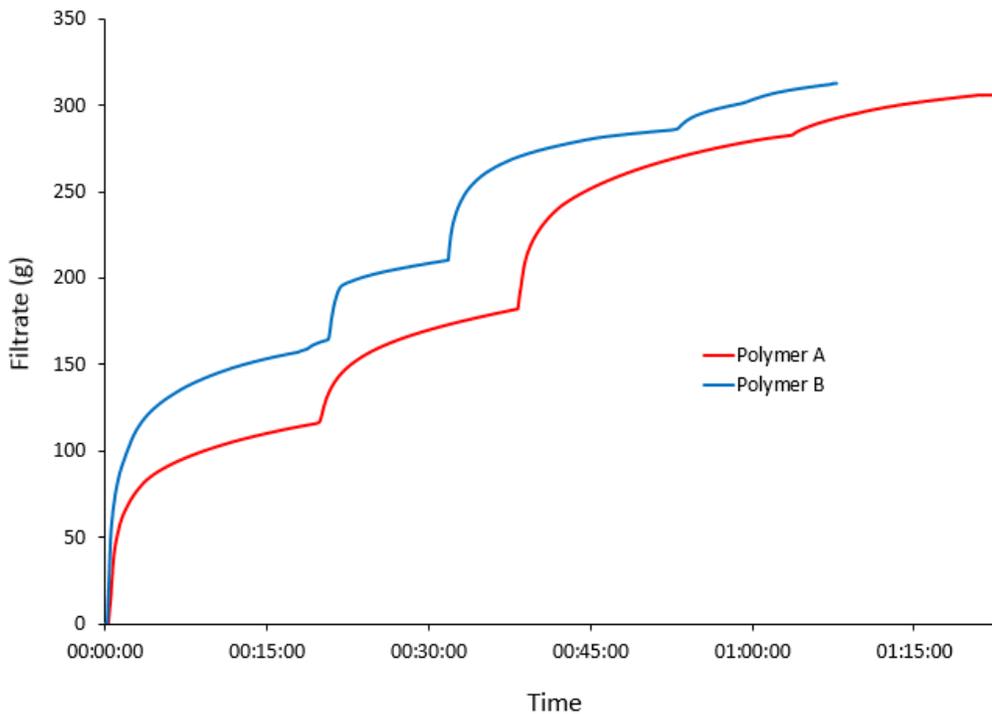


Figure 10 : DOT curves showing different rates and levels of water release between different polymer products



Figure 11 : Cake removed from the DOT tester (left and middle) and filtrate (right)

The DOT tester can be used to test the impact of different polymer types, conditioning of the polymer itself or different dose rates (Figure 12).

Polymer (kg/tds)	Filtrate (g)	Filtrate TSS (mg/l)	Product (%DS)
6	199.1	5,500	4.6
12	286.5	3,000	15.8
16	301.4	5,300	22.6
25	284.2	1,800	24.5
30	330.1	4,200	26.3

Figure 12 : Multiple DOT test runs on food waste digestate

The DOT test has been shown to be comparable to full scale technologies (

Figure 13). Suggested or actual operational changes can be tested on the DOT tester and where there is a difference between the DOT testing result and the actual performance of the asset it is possible to optimise polymer type, dose, mixing time etc...

The DOT tester is being used currently to evaluate sludge dewaterability at more than 30 sites in the UK. It is also being applied within the industrial market.

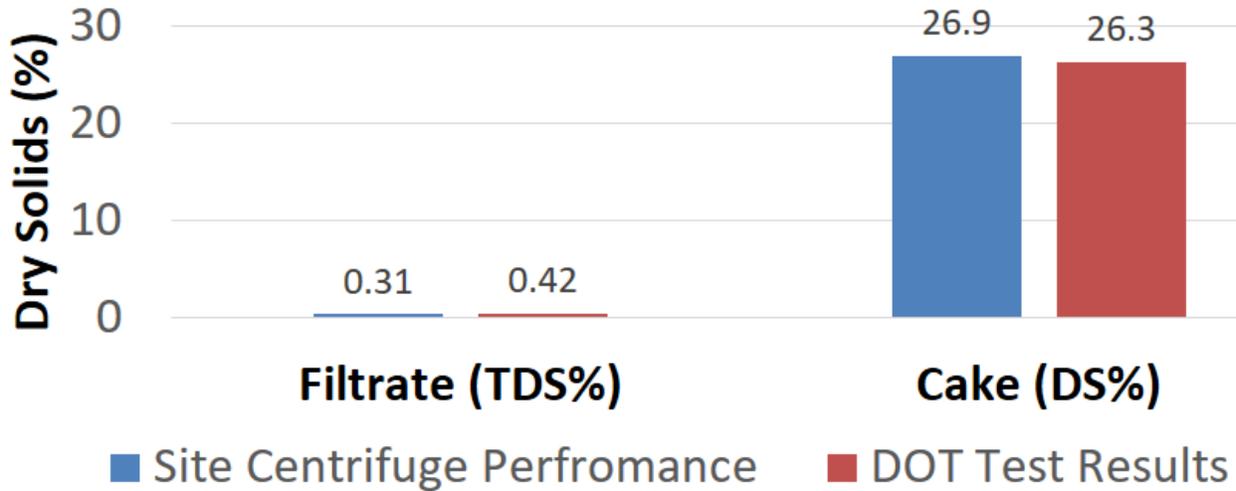


Figure 13: Similarity in results achieved at a full scale site and with the DOT tester (before optimisation by DOT)

DOT as a research tool

As well as optimising assets it can be used to examine how different factors may influence dewaterability. For example, it is increasingly suggested that phosphate can adversely affect dewaterability and polymer consumption, and the DOT tester can be used to examine this in a controlled, repeatable way.

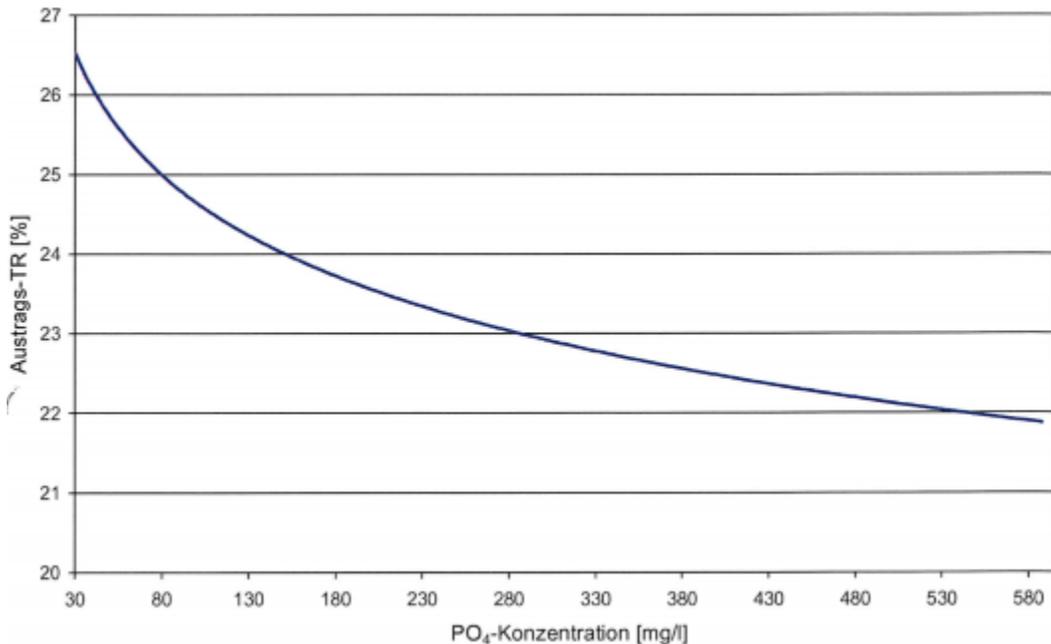


Figure 14: (Ewert, Wolfgang, 2009. DWA 2009, Hennef) (Austrag is dscharge)

Figure 14 shows a reduction in 'discharge' dry solids as phosphate increases, although no explanation is provided. Initial DOT testing has focused upon spiking sludge with phosphate and this has not shown any measurable difference in achievable cake DS, rate of filtrate production or deterioration in filtrate

quality up to a spiked concentration of 500 mg/l. We continue to search for sludges with appropriate innate phosphate concentrations, and that do not need to be spiked before testing.

Further research work being undertaken to evaluate sludges

In addition to the DOT test Aqua Enviro are developing a stackability test. Where product quality is 'low' the stackability can be adversely affected – reducing the value of the material and potentially increasing the requirement for in-field mitigations such as baling. Poor stackability and sludge slumping/movement or leachate generation can result in fines from the Environment Agency.



Figure 15: Excellent (left) and good (right) stackability

The stackability test involves a certified slump cone which is progressively charged and compressed. The method is reproducible, and will shortly be offered as a commercial service.



Figure 16 : Poor stackability

Conclusions

1. Mass balances are used as a starting point to size dewatering assets. However, if the information used to populate these is inaccurate or simply based upon an untested, but required level that must be achieved, the level of risk taken on by the contractor is excessively high.
2. The proportion of volatile solids in the feed to the dewatering unit (and hence from upstream sources) will influence greatly what can be achieved in terms of cake dry solids and also polymer consumption.
3. Aqua Enviro's Dewaterability Optimisation Tool (DOT) provides an opportunity to reduce doubts in what can be achieved (closing the *Expectation Gap*) as well as providing a reproducible method for optimising polymer type, mixing, dosing rate, cake dry solids and filtrate quality.

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