ProsiectSlyri Project

Final Report

Developing an innovative, economically viable and environmentally friendly nutrient management process.

The Project received funding through the Welsh Government's Rural Communities Rural Development Programme 2014-2020, which is funded by the European Agricultural Fund for Rural Development and the Welsh Government.

Acknowledgements
This project was led by Coleg Sir Gâr and delivered by the team based at the Agriculture Research Centre at Gelli Aur in conjunction with project partners, Power & Water, a Swansea based company specialising in electrochemical water treatments.

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This project would not have been as successful if it were for the dedication of the team here at Coleg sir Gâr. I would like to thank Neil Nicholas (Research Officer), Ann Owen (Finance & Administration) who worked on the project from inception to the conclusion and Lesley Griffith (Project Officer) who was part of the team for the first two years. I would also thank the team at Power & Water for their support guidance and expertise that demonstrates how effective partnerships can deliver results.

We have also had communication support from our dissemination partners at AHDB Llaeth Cymru and Farming Connect and excellent technical guidance from GEA and Aquatreat product suppliers. Finally, we must acknowledge input and time afforded to the project by our Key Stakeholders, they have been instrumental in the guidance and support from start to finish, I hope the outcomes of this project make their input worthwhile and the developments to date match their expectations.

Introduction
The project was set up initially to deliver efficiencies and reduce the burden of storing vast amount of water that carries recyclable nutrients. Nutrients are important substances that provide nourishment essential for the maintenance of life and for growth. All farming manures (slurry, farmyard and poultry) contain these useful nutrients. Efficiently extracting nutrients from manures could save on the cost of commercial fertilisers and reduce serious environmental impact. However poor manure management can cause pollutants (including nutrients) to enter through run-off or drainage (for example, land drains).

With the intensification of the dairy industry, slurry management is becoming an issue for farmers, Welsh Government, Local Governments, Water Utilities and Natural Resources Wales (NRW). With the inevitability of tighter legislations, this will only add to the existing burden. For example, all Welsh farmers must comply to 'The Water Resources (Control of Pollution) (Silage, Slurry and Agricultural Fuel Oil) Regulations 2010 known as 'the SSAFO Wales Regulations' published by the Welsh Assembly Government.

According to the NRW in its 'Agricultural Pollution Issues – and the implications for natural resource management' document (Summer 2016), agricultural pollution is the third most frequent reason for failing to achieve good status in Wales. It affects some 180 individual waterbodies. The number of pollution incidents caused by dairy and beef farms across Wales has fluctuated between 85 and 120 for each of the last six (6) years. Recent wet winters and a significant downturn in the dairy market have added to the pressure on the environment and farmers; reducing their capacity to invest in slurry and silage store management.

Point source pollution incidents (such as those caused by overflowing slurry stores) are concentrated in particular parts of Wales. Over 60% of the incidents during the last three (3) years took place within the milk field of Carmarthenshire and Pembrokeshire.

So, has the project delivered on the original objective? Yes, in part although the water is not yet at a discharge quality. The project has delivered to the extent that commercial companies are keen to work with us to further develop the process to complement their systems and processes to achieve the original goal and much more.

Limited field trials have determined that the concentrated nutrient rich cake, if handled appropriately, can be used on farm as a very efficient nutrient recycling process, replacing slurry in a very efficient way with early indications showing very low risk of crop contamination, allowing application between silage crops for example. Cage trials have demonstrated better soil activity with increased earthworm counts in cages having received regular application of the cake.

I foresee very exciting times ahead in nutrient management developments, tighter legislation and increased public expectations will fuel demand for improvements. The next chapter will see more collaboration with commercial companies working alongside research organisations to deliver improvements in nutrient management. What we have achieved so far is only the start of greater things to come.
John Owen - Project Manager

Executive Summary

Farm slurry run-off from fields is a major cause of river pollution in Wales. The project hoped to address this issue through the use of innovative technology designed to aid slurry management. The objective was to treat raw slurry in such a way as to remove as much of the water contaminating elements of slurry before discharging the ‘cleaned’ liquid into a local watercourse under licence. This would be done through a process of primary course solids removal by mechanical separation followed by electro-chemical coagulation of colloidal and dissolved particulate. The electro-chemicals would be generated in a novel and patented sono-electrochemical reactor - Soneco©, developed by project partners Power and Water. Further secondary solid/liquid separation stages were employed to remove solids post-coagulation, including dissolved air flotation (DAF) and additional mechanical separation of the fines. A final advanced oxidation process (AOP) was included to oxidise and decrease levels of ammoniacal nitrogen and chemical oxygen demand (COD).

Consistent plant performance relies on stable feed stock. It became increasingly evident early on that the nature of the slurry matrix would frequently change – on occasion changing throughout the day. This proved problematic for the primary separation system to provide a steady uniform separated liquid suitable for down-stream processing. The variability in the level of total solids seen (between 2% - 11%) meant that the treatment regime had to be continually tweaked. This may have been achieved using in-line monitors constantly feeding back data to the Soneco© reactor PLC. However, the level of contaminants seen in the separated liquor would mean a considerable lag in reaching the coagulant levels required for adequate treatment, rendering the electro-coagulation reactor as unviable for achieving acceptable throughputs for working farms.

Additionally, the level of total solids in the liquor entering the reactor meant that higher electrical currents has to be applied in order for the metal from the anodes to dissolute

into the liquid at an appropriate rate as to allow correct treatment rates. The higher electrical currents across the electrodes consequently caused the negatively charged particles to migrate to the anode at a higher rate. The power-ultrasound system employed to prevent the solid particulate from adsorbing to the anode was ineffective at these higher percentage solids levels (>1%). As a result, the anodes would foul heavily preventing the flow of electrical current – and the treatment would stop. In order to try and circumvent this, it would be necessary to dilute the reactor influent to a level which allowed continuous treatment. This however, was seen as being counter-productive, as water would need to be blended with the slurry feed in order to later remove it.

Switching to the use of more traditional liquid chemical-based treatments already used in waste water management in other industries meant that treatment could continue regardless of the contamination level. Handling, storage and chemical spills are some concerns surrounding the use of chemicals, although farms already utilize chemicals in their everyday farm management, therefore this shouldn't be a significant issue.

The amount of chemical required is proportional to the level of contamination. High contamination levels would require additional plant infrastructure, increasing costs. As a result, blending raw slurry from a slurry store with farm dirty water for a 1.5% - 2.0% total solids final concentration is seen as a way forward in developing a successful treatment system. This would result in lower capital and operating costs whilst nevertheless reducing slurry and dirty water levels on the farm.

The Soneco© AOP reactor, designed to remove difficult to treat recalcitrant organic and many inorganic materials from the wastewater by oxidation using hydroxyl free radicals, in its current state of development did not result in adequate treatment rates to allow for the water to be discharged to the local watercourse. Further investigations are required in order to adapt and modify the reactor, which would enable greater rates of oxidation at the treatment plant scale.

Current Removal Rates

Excellent nutrient removal rates are seen, alongside total solids, as can be seen in the table below. However, due to higher than permitted COD levels, water quality is not yet good enough to discharge to a watercourse.

General Comments

- Higher than anticipated fluctuations in feed solids concentration affecting plant performance.
- Likely need for a buffer/balance tank system
- This will also enhance solids capture rate in primary solids removal.
- Reorder of process equipment to deal with increased solids load from primary solids removal.
- Modifications to AOP to deal with increased loads

Total Suspended Solids (% removed)	Total P (% removed)	Ortho P (% removed)	Total N (% removed)	Potassium (% removed)
99.92	99.85	99.81	99.96	77.74

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1.0 Project Overview

Over recent years, the over-application of farm slurries has become increasingly evident, with excess nutrient leaching into streams and rivers. This pollution of the waterways is having a dramatic negative effect on local stakeholders through its impact on water quality and watercourse biodiversity in many Welsh rivers, the unexplained decrease in salmon population, income from tourism and angling decline.

On 13th December 2017, to ensure water courses receive greater protection from agricultural pollution, Lesley Griffiths the Cabinet Secretary for Energy, Planning and Rural Affairs stated that she intends to introduce a whole Wales approach to tackling pollution from agriculture. This new legislation was due to be introduced in January 2020, but has been delayed by COVID 19.

Current slurry management regulation requires slurry tanks that work in part, but high rainfall causes capacity problems. Climate change is leading to a prolonged peak and extra-low flows and high-water temperatures exacerbating slurry management problems.

Overuse of slurry on land causes pollution, therefore farmers are looking for alternatives to traditional methods to build more resilience into the landscapes and to reduce siltation and diffuse pollution from farms.

Economic market pressures are driving expansion & intensification of farms making the slurry problem worse, but creating a new market for nutrient management.

Over application of slurry, in particular, is creating farming inefficiencies, therefore farms are not as profitable as they could be. ProsiectSlyri Project has identified possible efficiency gains to the Welsh dairy industry to the value of £50M through improved nutrient management, including appropriate application rates and timing for optimum crop growth with better utilisation of available nutrients.

The majority of farmers are working within limits of current best practice and technologies, but developments have not kept pace with the need for expansion. Farmers feel they are regulated but not supported with tools to deliver a good solution.

Too much water is wasted and the industry needs to explore opportunities to improve efficiency. By extracting water from cattle slurry, which on average is 90% of the total volume, the dairy industry could reduce dramatically the demand on clean water. Even in Wales, recent dry summers have demonstrated the pressures on the supply of sufficient clean water. The implications of developments for recycling has far-reaching worldwide environmental benefits.

What We Proposed to Do

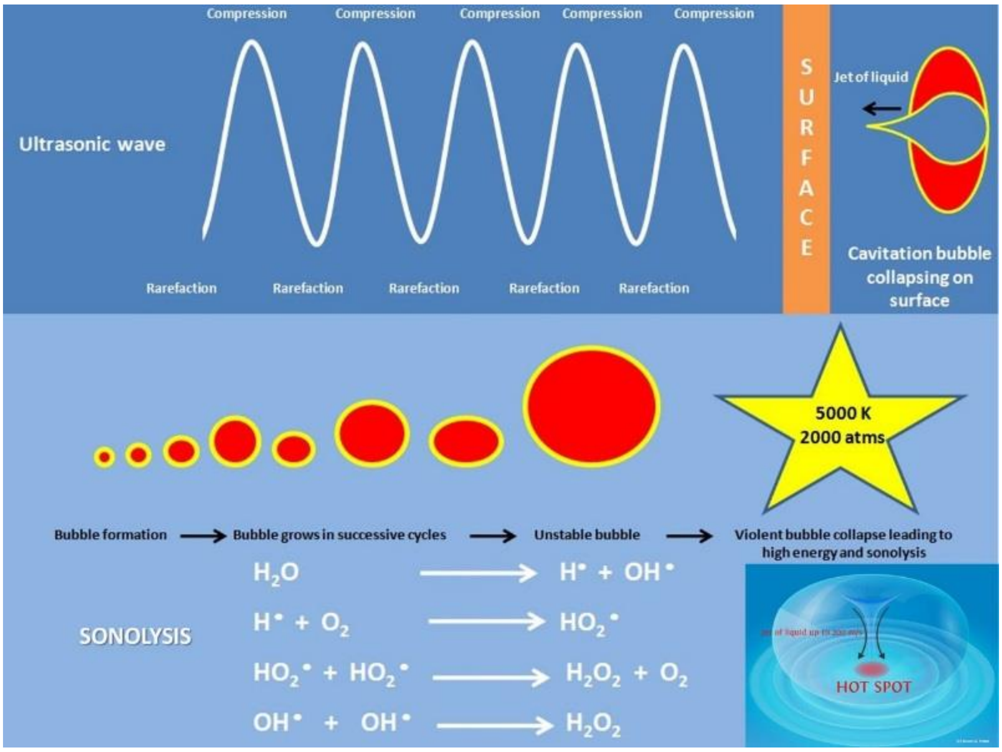
This project brought together a collaborative research and development partnership project combining industry and FE to:

- Apply innovative and proven concept technology, to the agriculture sector
- Reduce significantly the risk of pollution from farm slurry
- Maximise the potential recycling nutrient value
- Reduce considerably the storage and handling cost of slurry
- Design, develop and test, bespoke economically viable systems that can be scaled up to work on all dairy herd sizes

Power and Water (KP2M Ltd) developed a patented technology (Soneco©) which combines power ultrasound and electrolysis for water treatment, a technology called 'Sono-electrochemistry' (www.sonoelectrochemistry.com). This enabling technology was at the core of the pilot processing system.

This innovative and ground-breaking technology is based on generating electrons and cavitation to accelerate the efficient removal of inorganic, organic and nutrient compounds as well as purifying the wastewater (and sludge) of pathogenic bacteria. Cavitation is the formation of vapour cavities in a liquid – i.e. small liquid-free zones ("bubbles" or "voids") – that are the consequence of forces acting upon the liquid. Cavitation caused by ultrasonic and hydrodynamic equipment and techniques have been used for catalysis of many known and well-defined endothermic reactions traditionally implemented with high temperature/high pressure processes for many years. The advantage of cavitation is the effect of high pressure and temperatures achieved in the domain of effect near the collapsed bubble, the rate of heating being sufficient to start and sustain reactions in aqueous and other solutions.

Figure 1. Effect of ultrasound in liquids (© Bruno G. Pollet)

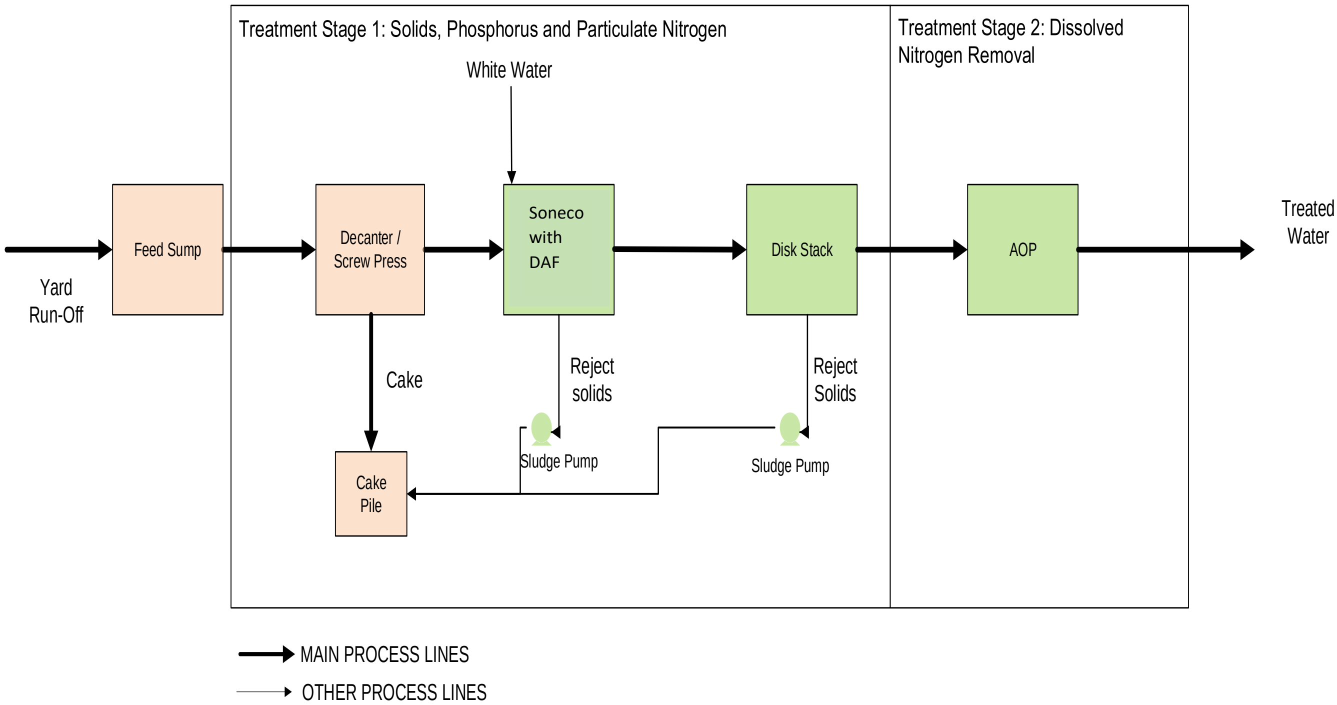


Two versions of the Soneco™ reactor were deployed in the system in order to achieve:

- Charge neutralisation through electrochemical dosing (converting soluble contaminants to an insoluble form – which can be easily separated out)
- Advanced Oxidation Process (AOP) treatment – this mineralizes re-calcitrant organics, and breaks down ammonia

The overall treatment plant design is illustrated in Figure 2 below and indicates the flow of the material through the plant, from raw yard slurry inlet to treated water outlet.

Figure 2. Illustration of the modular design and treatment process.



The aim of ProsiectSlyri Project was to innovatively reduce farm waste, help safeguard the environment and address the agricultural industry's impact on ecosystems by developing a dewatering and purification system to manage slurry on farms. With the intensification of the dairy industry, slurry management is becoming an increasing issue for farmers and the environment.

Driving the project were Coleg Sir Gâr’s Gelli Aur agricultural campus in Carmarthenshire and Power & Water, a Swansea based company specialising in electrochemical-based water treatments.

The project received funding through the Welsh Government’s Rural Communities Rural Development Programme 2014-2020, which in itself was funded by the European Agricultural Fund for Rural Development and the Welsh Government. The project applied innovative, proven concept technology to reduce air and water pollution and to reduce the overall volume of slurry by up to 80%. A de-watering and purification system would be developed that removed the water from slurry and treated the separated water with the aim that it would be acceptable for reuse on the farm or be suitable for safe discharge. The system also utilised nutrients from the slurry to produce good quality fertiliser.

The aim was to reduce significantly the risk of air and water pollution at the same time as maximising the recycled nutrient value. The process was designed to considerably reduce storage of slurry on farms as well as handling costs.

Efficiently extracting nutrients from manures could save on the cost of commercial fertilisers and considerably reduce environmental impact.

The project aimed to design, develop and validate an economically viable treatment system that would be made available commercially to be used on farms.

Problem

- Agricultural waste has high nutrient value and polluting potential in the water cycle
- Larger herd sizes and intensive farming increases storage needs and spreading issues
- Increasing rainfall (climate change) requires tighter control of waste slurries and wastewater management on farms

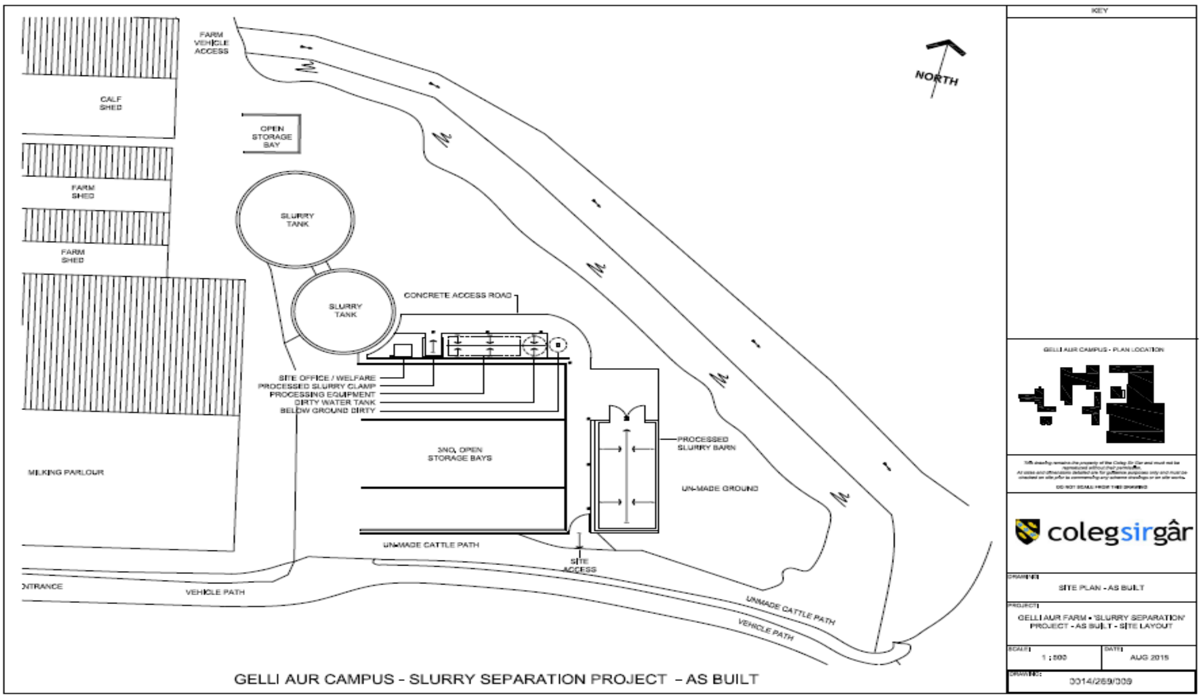
Potential Solution

- Apply innovative and proven concept technology
- De-water slurry
- Reduce the risk of pollution
- Maximise the recycling nutrient value
- Reduce storage and handling cost

Facility Layout

Research facilities are situated at the Coleg Sir Gar - Gelli Aur dairy farm and illustrated in Figure 3. From the plan, you can see cattle sheds from where the slurry is collected, two large slurry storage tanks, modular slurry treatment equipment constructed on bunded concrete pads and a storage shed for the separated high nutrient solids.

Figure 3. Slurry Separation Site (as-built)



Separation of Colloidal and Dissolved Material

The plant is designed to remove suspended colloidal material as well as the dissolved charged particles found in cow slurry. This is accomplished through electrostatic mechanisms for particle coagulation and flocculation.

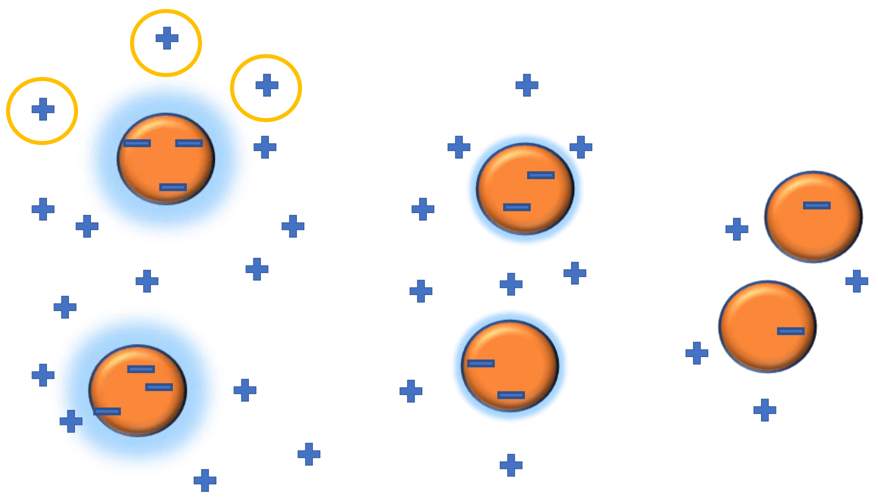
Two main mechanisms are employed for the removal of charged particles from waste water streams. These are charge neutralisation and sweep flocculation.

What is Charge Neutralisation?

Coagulation is the process of neutralising the electronic surface charges of particles, fibres and colloidal material in water and keep them suspended.
Colloidal material can be described as any matter that is one-tenth of a millimetre or smaller which is suspended in an aqueous solution

The addition of cationic charges neutralizes the anionic surface charges, allowing the particles to come within contact with one another

Figure 4. Charge Neutralisation Illustration



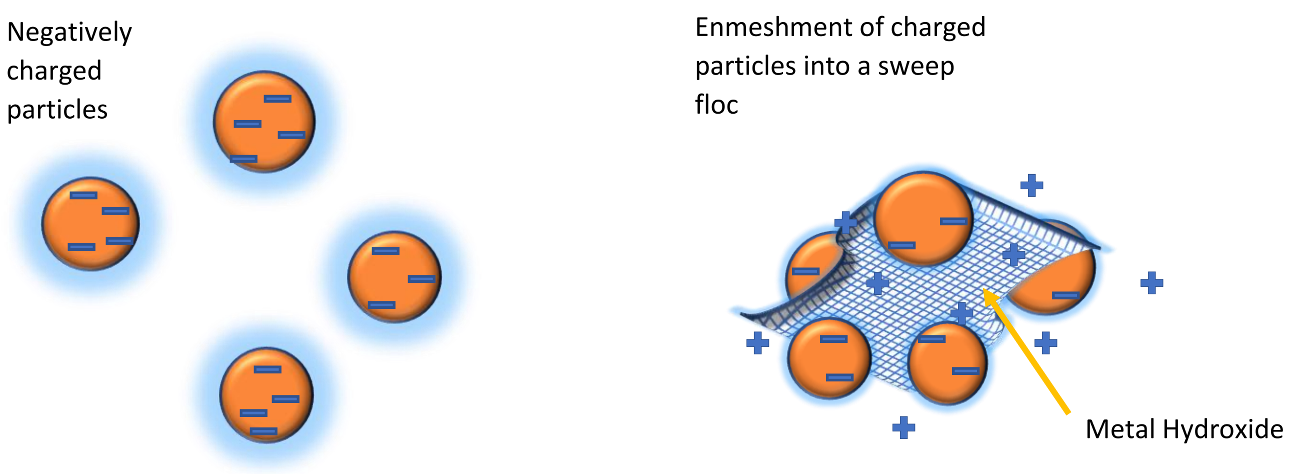
Adapted from Image courtesy of ChemTreat

A flocculant can then be used to bind the coagulated particles together. Flocculants tend to have opposite charges to the coagulant which then attract and agglomerate the particles.

What is Sweep Flocculation?

Sweep flocs can be described as large aggregates of mineral salt hydroxides e.g. $Al(OH)_3$ or $Fe(OH)_3$ that are formed when salts of aluminium (Al) e.g. poly-aluminium chloride or iron (Fe) e.g. ferric chloride is added to water. Further, the insoluble hydroxides (at neutral pH) form an electrostatically positively charged molecular net which attracts, captures and binds on to the negatively charged colloidal particles in the liquid, causing the colloids to become enmeshed in the sweep floc.

Figure 5. Sweep Flocculation Illustration



2.0 Laboratory Process Testing and Preliminary Sample Analysis

Prior to the treatment plant being delivered, installed and commissioned at Gelli Aur College Farm, samples were taken for laboratory testing from Gelli Aur College Farm and also, another local farm, which already operated a screw press filter. This provided the opportunity to trial various treatment parameters and analyse the results in the laboratory. This enabled calculating the capacity of the power supply, transformer and electrode material required, amongst others, to achieve the desired treatment levels. Beaker tests were initially used to determine the best electrode material to use on the sample, electric current requirement and retention time. Secondly, a mini benchtop reactor (Soneco©), incorporating ultrasound was used to further investigate and simulate the farm scale treatment plant design.

Jar test methodology:

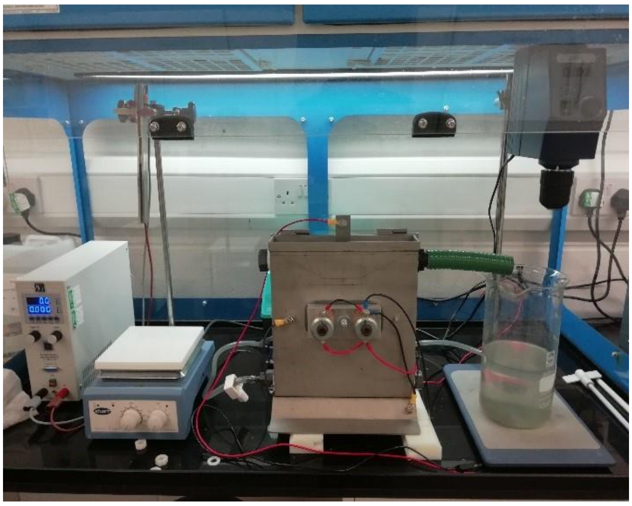
1. Place a sample of the separated liquid fraction of the slurry in to a beaker with two electrodes (+ve and –ve) connected to a fixed current power supply.
2. Continuously stir to ensure a homogenous sample throughout. During electro treatment, this allows for an increased probability of the reacting molecules coming into contact.
3. At fixed intervals, take small samples and test for floc generation and density, phosphate, nitrate and potassium concentration amongst others, as well as chemical oxygen demand (COD).
4. Parameters such as current settings, flow rates etc can be adjusted as required.
5. Samples may be inserted into a variable speed flocculator and stirred where required in order to grow the flocs.
6. Sample analysis was conducted using a HACH DR3900 spectrophotometer and associated test kits.

Photo 1: Jar Test

Benchtop reactor (with ultrasound) test methodology:

1. Place a sample of the separated liquid fraction of the slurry into the bespoke sono-electrochemical benchtop reactor (Soneco©) (1200ml) and beaker reservoir (500ml)
2. Continuously stir the reservoir using an overhead mixer
3. Pump the contents of the beaker into the reactor inlet using a variable flow pump (peristaltic) and allow to level of liquid in the reactor to increase

Photo 2: Benchtop Reactor Test



until the liquid flows through the outlet and back into the beaker.

4. Turn on the power supply to the electrodes and ultrasonic generator/transducers (Ultrasonic frequency generator/transducers were fixed at 28kHz – 32kHz).
5. At fixed intervals, take small samples and test for floc generation and density, phosphate, nitrate and potassium concentration amongst others, as well as chemical oxygen demand (as above).
6. Parameters such as current settings, flow rates etc can be adjusted as required.
7. Samples may be inserted into a variable speed flocculator and stirred where required.
8. Sample analysis was conducted using a HACH DR3900 spectrophotometer and associated test kits.

Once these system parameters were defined, the laboratory results data was used to calculate the requirements of upscaling the process.

Laboratory tests concluded that the highest nutrient removal rates were seen when using aluminium as the anode material, when compared to other materials e.g. iron/steel. The floc size and density were superior when aluminium electrodes were used. Later work conducted by Power and Water suggested that this may be because ferrous (Fe^{++}) was being generated and released into the liquid rather than the more effective ferric (Fe^{+++}) form of iron. Therefore, the electro-coagulation reactor with dissolved air flotation was supplied with aluminium electrodes.

Determinant Analysis

The samples collected during the course of the project were analysed for the following as and when required:

% Total Solids (TS)	% Total Suspended Solids (TSS)
Chemical Oxygen Demand (COD)	Biological Oxygen Demand (BOD)
Total Phosphorus	Ortho Phosphate (Dissolved Phosphate)
Total Nitrogen	Total Potassium
Total Aluminium	Total Iron
Alkalinity	Turbidity
pH	

What Does BOD and COD mean?

- **BOD (Biochemical Oxygen Demand)**: The rate at which organisms use oxygen in the sample while stabilizing organic matter. This measures the strength of the water based on the amount of oxygen the bacteria consume, typically the test is run for 5 days (BOD5) and incubated at 20 degrees C. The higher the BOD, the stronger the waste.
- **COD (Chemical Oxygen Demand)**: COD is a measure of the amount of oxygen that can be consumed by chemical reactions in a given volume of sample and is an important parameter for determining the amount of organic material in the sample and therefore potential pollution of watercourses (there is often a correlation between COD and BOD). In this instance, the preference was to test for COD rather than BOD as analysis of BOD5 requires 5 days), whereas COD can be analysed in a matter of hours.

Preliminary Pre-Installation Test Results

Results from early laboratory analysis of the separated slurry from a local farm where a screw press separator was already in use can be seen in the below table, indicating the nutrient split between solid and liquid fractions:

Table 1. Nutrient Separation Analysis of Separated Slurry from a Nearby Farm

Determinant	Raw slurry	Separated liquid	Separated solid
Total Phosphorus	340 mg/l	390 mg/l	400 mg/l (0.4kg/m3)
Total Nitrogen	3200 mg/l	1300 mg/l	14000 mg/l (14kg/m3)
Potassium	2010 mg/l	1530 mg/l	1690 mg/l (1.69kg/m3)

- **Phosphorus** – equally distributed between the separated solid and liquid phases with approx. 18% increase in concentration in both when compared to raw slurry
- **Total Nitrogen** – Over 400% increase in conc. in separated solids verses raw slurry. The separated liquid saw a 60% reduction in conc. when compared to raw slurry (of this, around 75% could be removed during down-stream processing).
- **Potassium** – Lower conc. seen in both solid (approx.20%) and liquid phases (approx.30%) when compared to raw slurry.
- **Dry Matter** – Large increase in % dry matter content of the solids, as expected (from 8% to 36%)

3.0 Installation and Commissioning of the Treatment Plant

The plant installation was completed by late summer 2018. The correct commissioning of the treatment plant was essential to the future effective and safe operation of the plant. Due to the nature of the treatment process, it was prudent for the plant be commissioned in sections rather than a whole. These sections are as follows:

1. **Front-end Separation** – comprising of the slurry feed pump and both screw press and decanter centrifuge separators.
2. **Soneco© Sono-electrocoagulation with Dissolved Air Floatation** (DAF).
3. **Disk Stack Centrifuge** separator
4. **Soneco© Sono-electro-oxidation with Advanced Oxidation Process** (AOP)

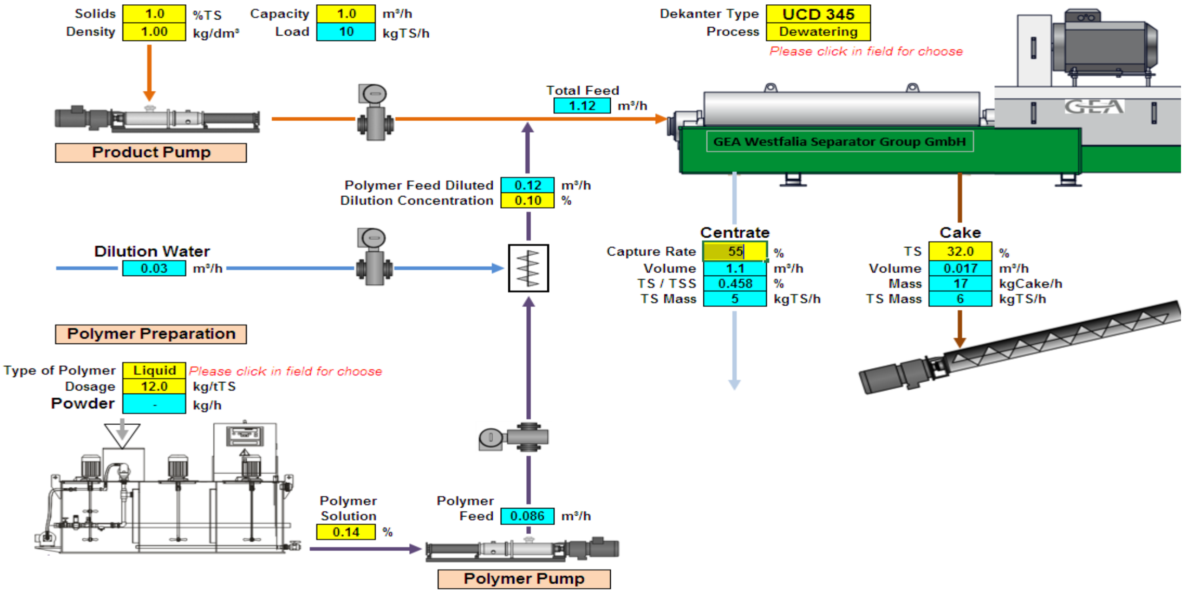
Once each section had been suitably commissioned, the next section would follow in turn, until the whole plant was ready to operate safely and effectively.

Photo 3: Treatment Plant at CSG

Solids/Liquids Mass Balance Calculations

In order to establish the distribution of suspended solid material in the slurry and subsequent separated slurry components, it was necessary to conduct mass balance calculations. Below is an example of a GEA developed calculator which was used for decanter centrifuge separation. Alternative calculators were also developed by Power and Water which included screw press separation modelling. Both calculators were used to determine the performance of the two primary separation methods.

Figure 6. Example of Mass Balance Calculator used in the project (courtesy of GEA)



The plant commissioning process greatly increased our understanding of what is required to safely treat farm slurry. From frequent changes in total solid content (ranging from 3% in summer to 11% in winter), to the proportion of dissolved solids which the plant had to manage and deal with (this can be as high as 70%). An appreciation of the material incorporated within the slurry matrix has proven key to achieving a positive outcome. As a result of our increased knowledge we adapted the plant in order to better manage the process and to include a conditioning stage prior to primary solid/liquid separation. As a consequence, we were better able to treat the resulting effluent.

Using the pre-treatment/conditioning stage, we were able to transform the slurry from a deep brown to a translucent pale-yellow colour. Laboratory analyses indicated that a considerable reduction of some of the key determinants was possible.

Commissioning of the Primary Front-end Separation Process

The movement of slurry at Gelli Aur College Farm can be described briefly as follows: The slurry leaves the cattle shed and enters a collecting channel before emptying into a collecting pit. From here the slurry can be pumped directly to the slurry store, or fed to either of the two front-end primary separators via a variable speed electrically operated vertical long shaft pump and mixer.

Primary Solids Removal

The purpose of the primary solids removal stage was to remove the bulky coarse solids from the effluent stream. The separated solids would form a stable stackable cake that could be stored during closed season. The separated liquid produced should be low enough in total solids to not overload the down-stream processes. By removing as much of the solid particulate at this stage meant that a proportion of the nutrients (particulate) would also be removed, meaning less nutrient loading on the treatment process.
Two primary separation units were trialled:

1. Screw Press – lower capex, simpler to operate but reduced solids removal

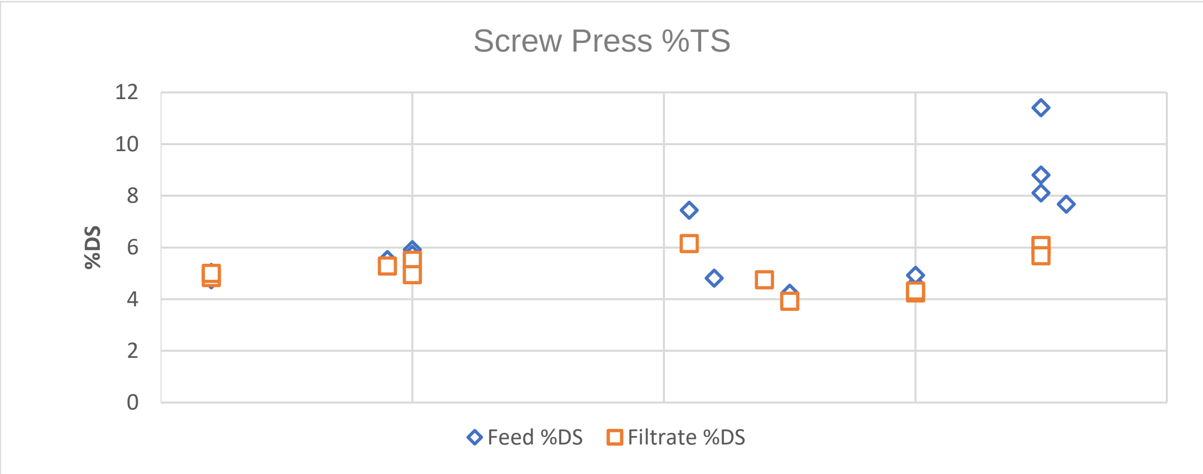
2 Decanter centrifuge – higher capex, more energy but enhanced solids removal

Screw Press Separator – SPS (Cri-man SP/260 Mini)

Photo 4: Screw-press Separator

Samples were collected of the raw feed, liquid filtrate and solid cake at equal intervals, three times a day – 9 samples in total. The samples were analysed for percentage total solids (%TS) in order for mass balance calculations to be performed on what's entering and leaving the system. The output of these calculations informed the commissioning and treatment process in section 2 (Soneco© sono-electrocoagulation with DAF).

Chart 1. Screw Press Solids Removal



Screw Press

- Average feed 6.2%Total Solids
- Average filtrate 5.1%Total Solids
- Average removal 17.1%
- Cake 29%Total Solids

Comments

1. Good stackable cake produced
2. Reduced solids removal rate (compared to decanter)
3. Fine solids passing through screw filter
4. Overloading of downstream treatment
5. Finer screen should be trialled
6. Equipment designed to produce a dry cake rather than treated water with low solids.
7. OPEX Costs – the screw-press uses an average of 5kWh of energy when in production. This equates to £0.75 per hour or £2,190 per year (based on 8 hours a day; 365 days per year).

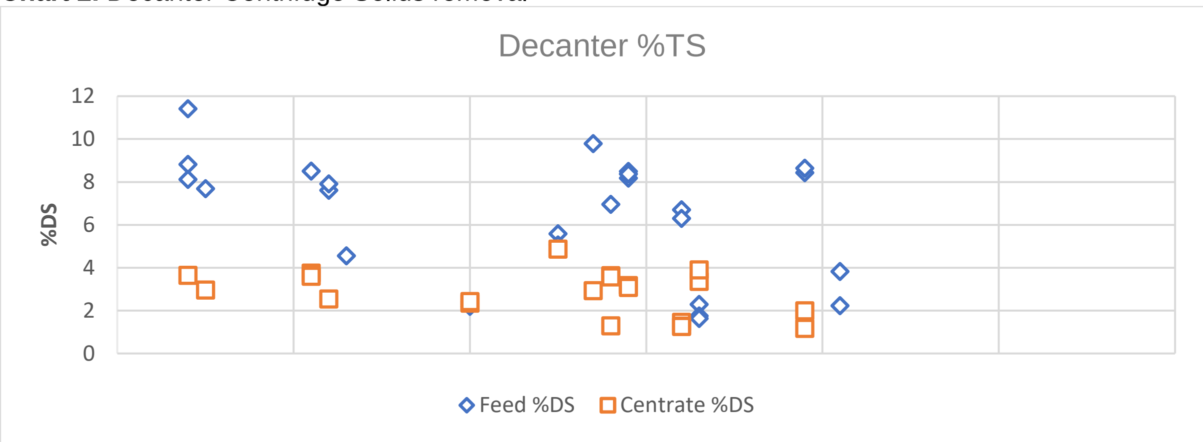
The standard screen size for slurry separation as provided by the manufacturer was 0.5mm. Later a 0.25mm screen was purchased and also trialled in comparison to a decanter centrifuge.

Decanter Centrifuge (GEA UCD 345)

Photo 5: Decanter Centrifuge

As with the Screw Press Separator (SPS) the aim was to collect samples of the raw feed, liquid centrate and solid cake at equal intervals, three times a day – 9 samples in total. The samples were again analysed for percentage total solids (%TS) for mass balance calculations to be performed on what's entering and leaving the system. The output of these calculations informed the commissioning and treatment process in section 2 (Soneco© sono-electrocoagulation with DAF).

Chart 2. Decanter Centrifuge Solids removal



Decanter

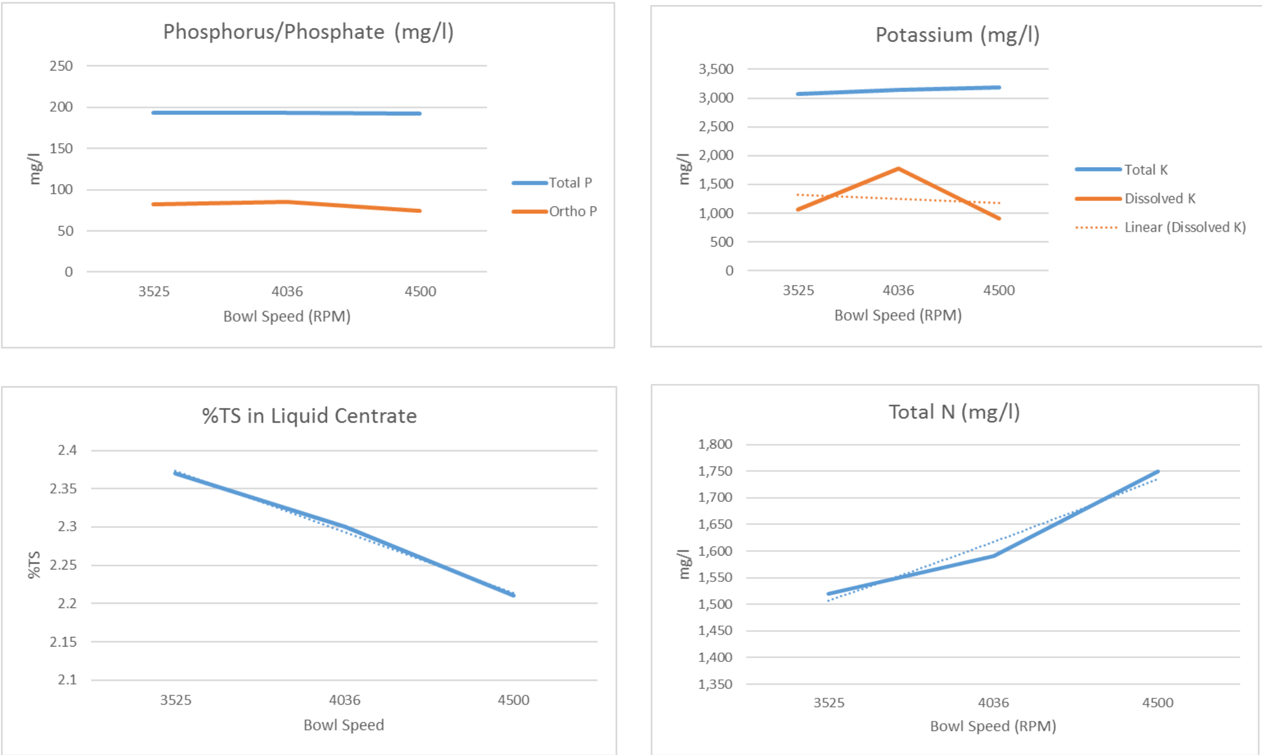
- Average feed 5.7%Total Solids
- Average centrate 2.7%Total Solids
- Average removal 52%
- Cake 25%Total Solids

Comments

1. Good stackable cake produced
2. Improved solids removal rate (compared to screw press)
3. Fine solids less of an issue
4. Reduced load onto downstream treatment
5. Equipment designed to produce a dry cake rather than treated water with low solids.
6. OPEX Costs - the decanter uses 6kWh of energy when in standby and 8kWh when in production modes. If the cost of energy is 15p/kWh, then this would equate to £0.9 and £1.20 per hour respectively during operation, meaning an annual production operational cost of £3,500 per year (based on 8hours per day; 365 days per year).

Decanter Centrifuge – Nutrient Separation in Relation to Bowl Speed (Liquid Fraction)

Charts 3-6: Decanter Centrifuge Bowl Speed Trial Results



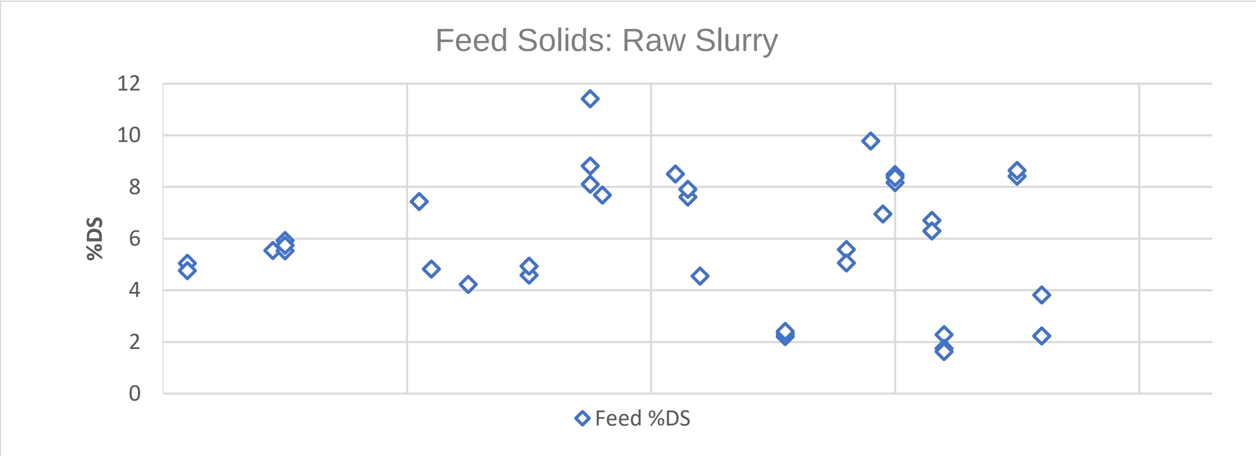
The bowl speed and therefore centrifugal force, can have a significant effect on the efficiency of how the solids (and therefore the nutrient concentration contained within the solids) are separated. Although Total-N and Total-K were seen to increase it was imperative to remove as much of the suspended solids as possible in order not to overload the downstream treatment processes. As such the plant operated with maximum bowl speed for the duration of the project.

The results obtained from laboratory analysis clearly showed that the decanter centrifuge was superior to the screw-press for the purpose of delivering a 'cleaner' separated liquid which was pivotal for allowing other processes to occur downstream without overloading the system.

Total Solids Analysis (%)

Inconsistencies in the plant feed made it difficult to maintain appropriate treatment levels, without the need for in-line monitoring systems. These systems can be expensive and were not included in the original project plan.

Chart 7: Slurry Feed Pit % Total Solids Analysis

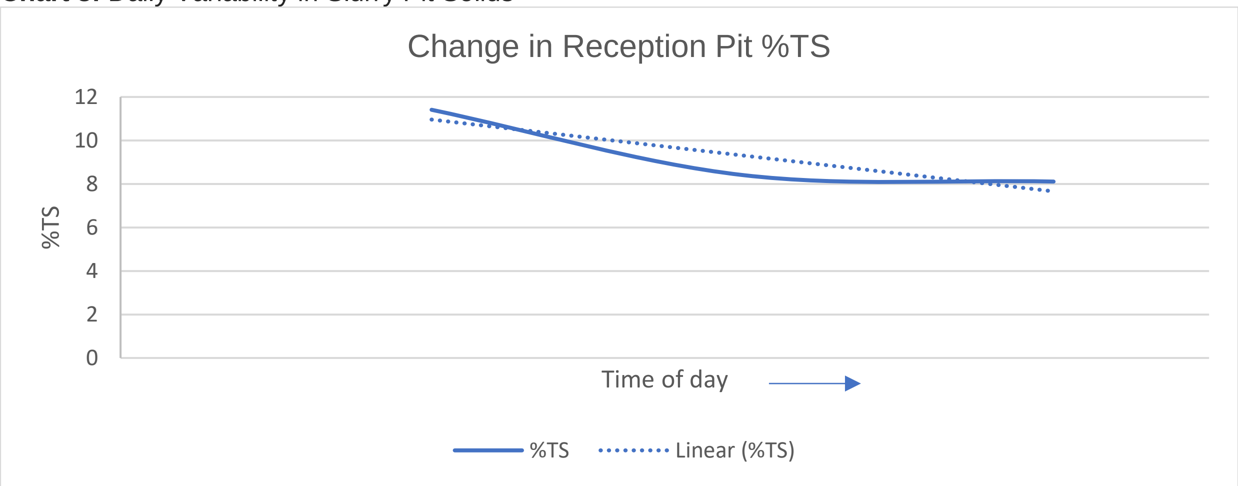


The chart above indicates the wide variation in total solids concentration in the feed pit experienced during the commissioning phase. On occasion, hourly changes in the feed stock would result in inconsistent performance of the separators.

The high solids concentrations (hence solid loads) tended to overload the treatment plant as originally designed.

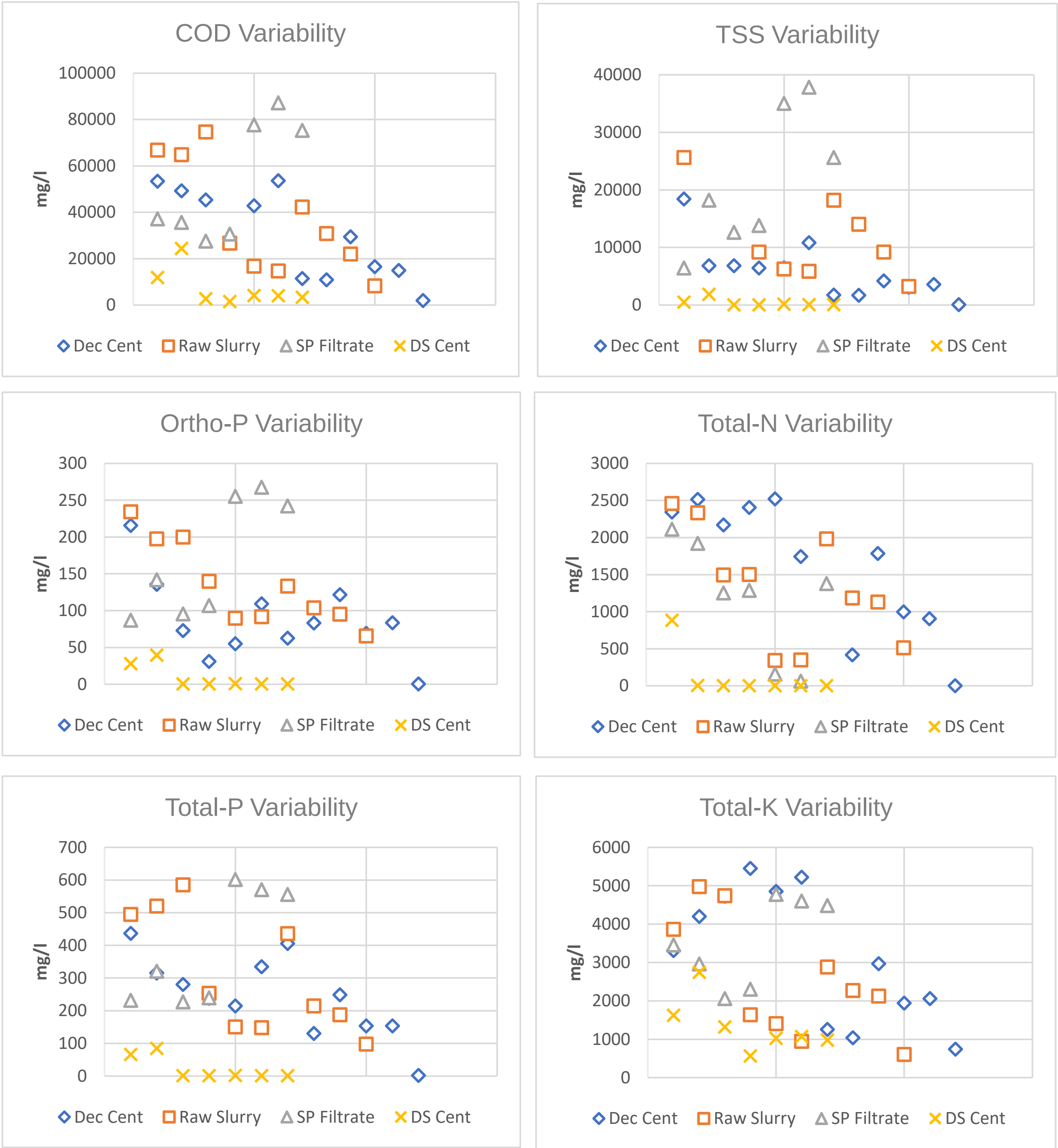
In addition, slurry samples taken from the reception pit at fixed periods throughout the day and analysed for %Total Solids often showed a marked change in solids concentrations. Inevitably, a change in weather conditions contributed to this, but also slurry levels in the pit (the emptier the pit the more dilute the slurry would become during times of prolonged rain).

Chart 8: Daily Variability in Slurry Pit Solids



It also followed that inconsistencies in the raw slurry in the pit would result in inconsistencies in the subsequent liquid at the separation stages. The charts below illustrate the variability in some of the key determinants as followed through the mechanical separation processes.

Charts 9-14: Determinant Variability



Fluctuating concentrations seen in the plant influent clearly signifies a correlation seen in the plant effluent. This significant variation can cause issues to arise when dosing coagulant, where under dosing would result in higher levels of contamination in the effluent and over dosing would result in higher concentrations of residual coagulant in the effluent with resulting increase in operational costs.

Maintaining consistency of feed is seen as key to establishing consistent treatment levels.

Particle Size Distribution Analysis (PSDA)

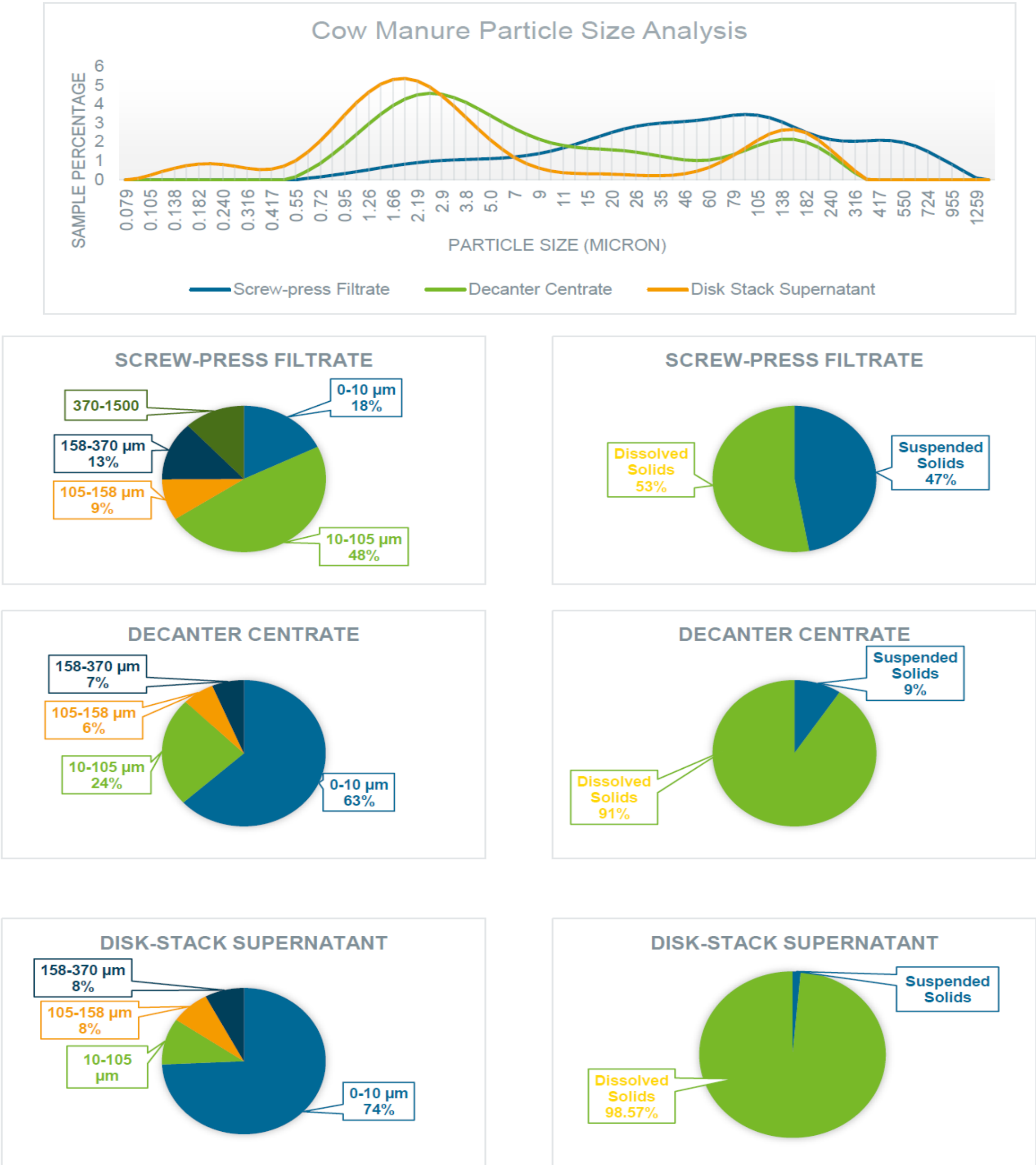
Feed System Operation

Due to poorer than anticipated initial primary solids removal, the feed system operation was reviewed.

Particle Size Distribution Analysis aimed to give an insight into the particle sizes of the suspended solids within the effluent stream. This allowed a better understanding of equivalent solids capture rates of both primary separators as well as the disk stack centrifuge and also, the solids coming through in the liquid fractions.

Charts 15-21. Comparing Particle Size Distribution for Mechanical Separation Equipment

Cow Manure Separation with Screw Press, Decanter & Disck Stack Separator



The above charts show what percentage of the total solids were suspended/dissolved in the liquid fraction from each separator and the percentage of suspended solid particle sizes found in the liquid. Comparing primary separator (screw-press and decanter) results indicates that the decanter's performance is superior to the screw-press for both suspended solids (with only 9% suspended) removal and particle size (with 63% of the remaining solids between 0-10µm).

PSDA was also conducted on samples taken from various locations of the process flow. These results charts can be viewed in as an appendix.

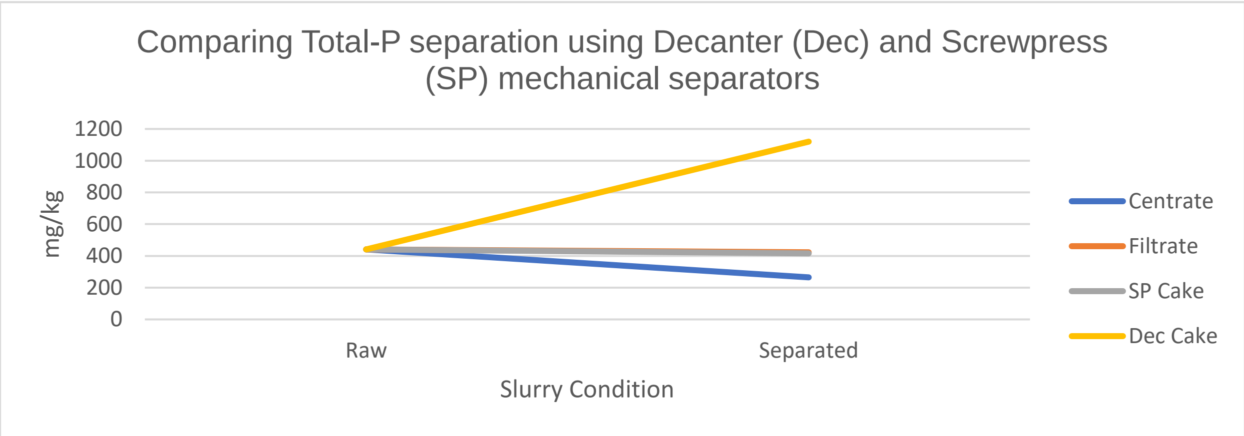
Comparing Primary Separator Performance

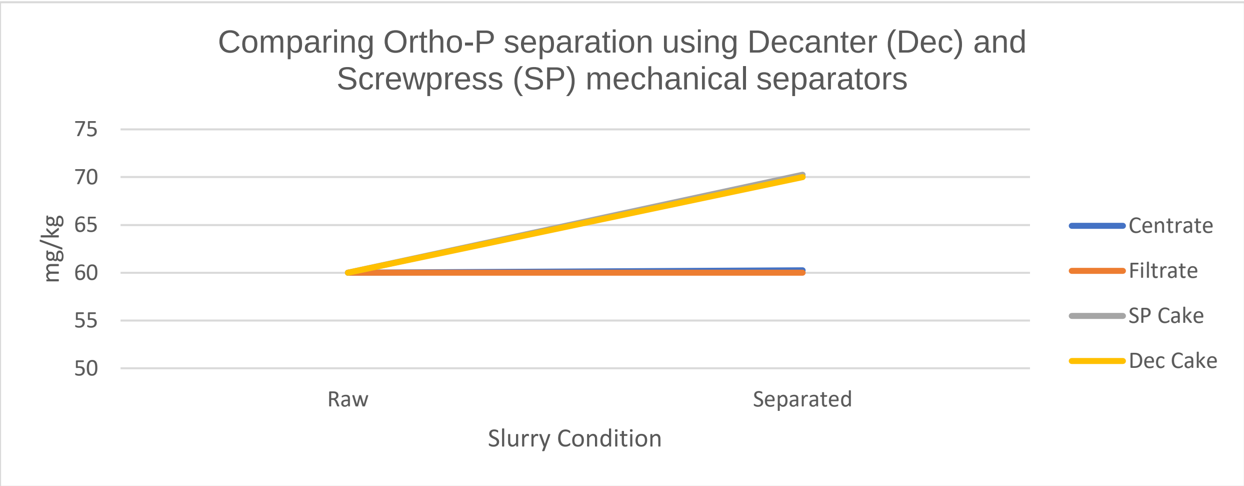
Decanter Versus Screw-Press (with 0.5mm screen installed)

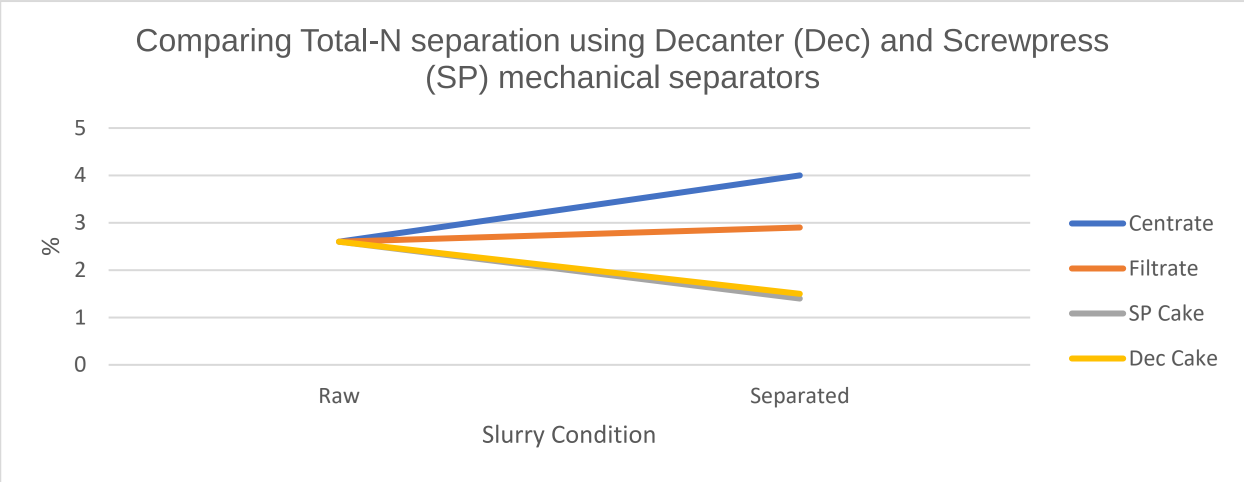
Table 2: Front-end Separator Comparison Sample Analysis Results

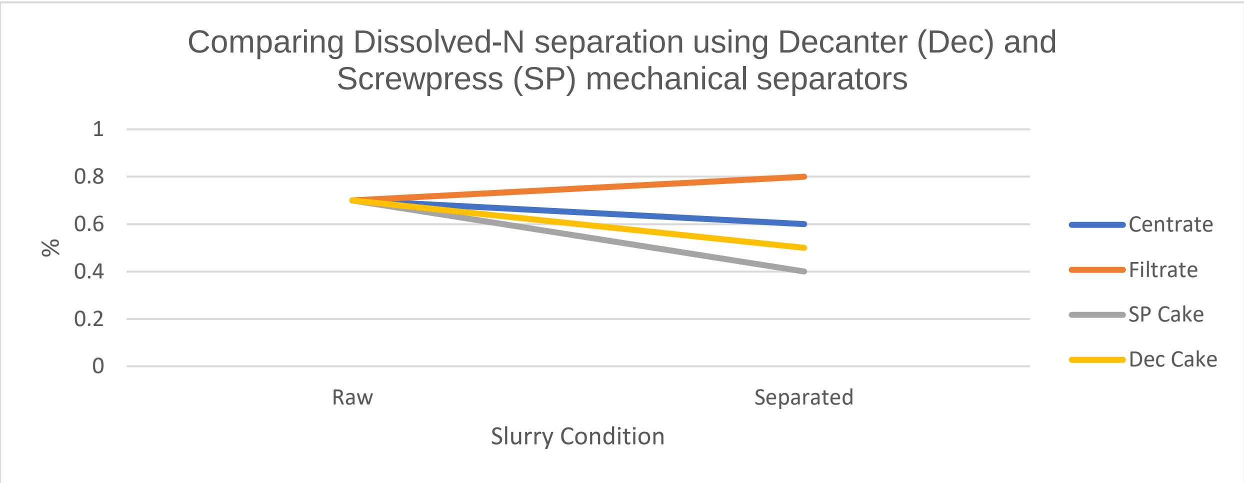
Determinant		Raw Slurry	Decanter Centrate	Screwpress Filtrate	Screwpress Cake	Decanter Cake
Phosphorus	**mg/kg**	441	265	423	416	1120
Ortho Phosphate	**mg/kg**	60	60	60	70	70
Potassium	**mg/kg**	3300	3560	3590	2900	2930
Total Nitrogen	**%**	2.6	4	2.9	1.4	1.5
Dissolved Nitrogen	**%**	0.7	0.6	0.8	0.4	0.5
Total Solids	**%**	9.5	4.2	5.5	20	24.5
Suspended Solids	**%**	7.5	1.8	3.6	N/A	N/A

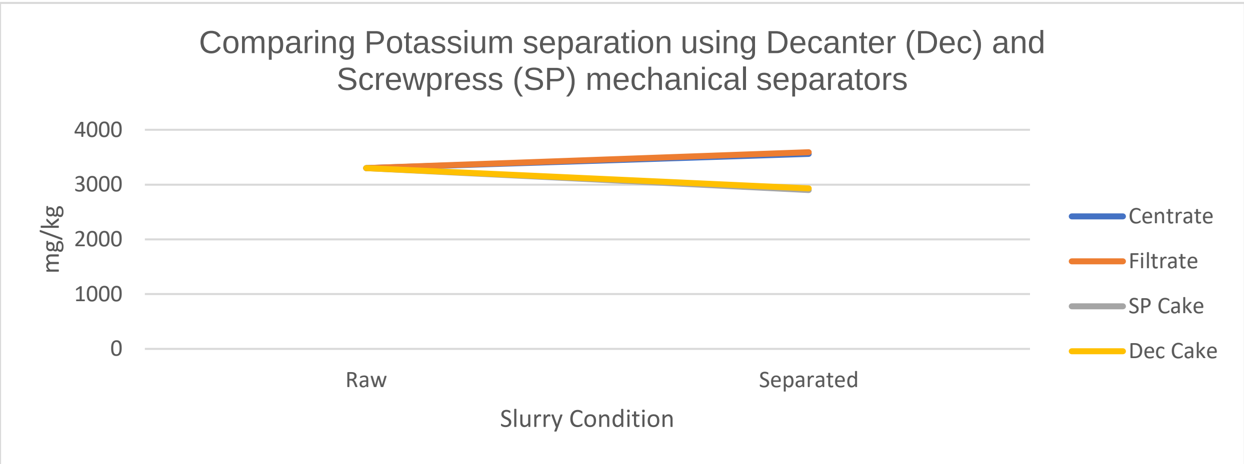
Charts 22-28: Front-end Separator Comparison Trial - Sample Analysis Results

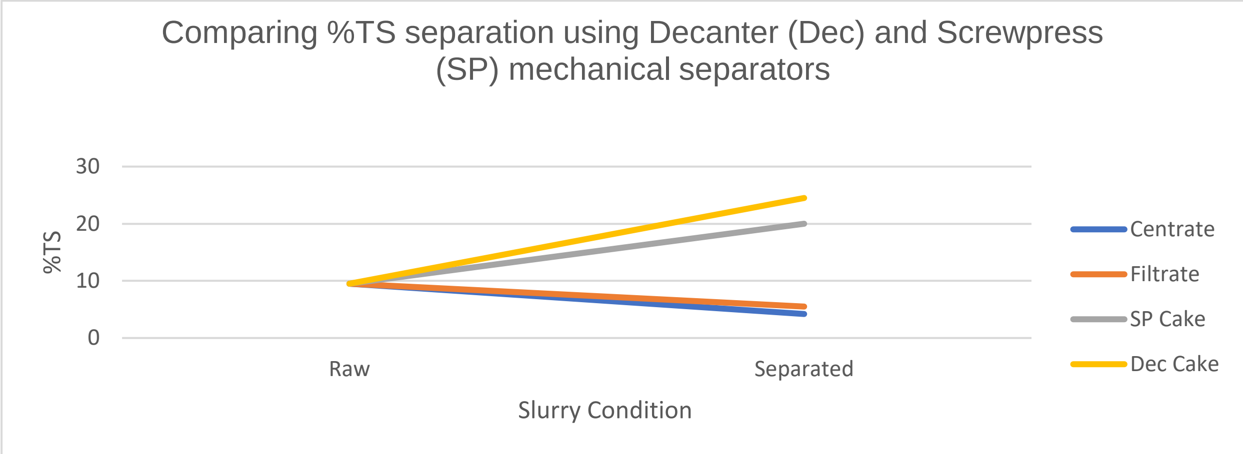


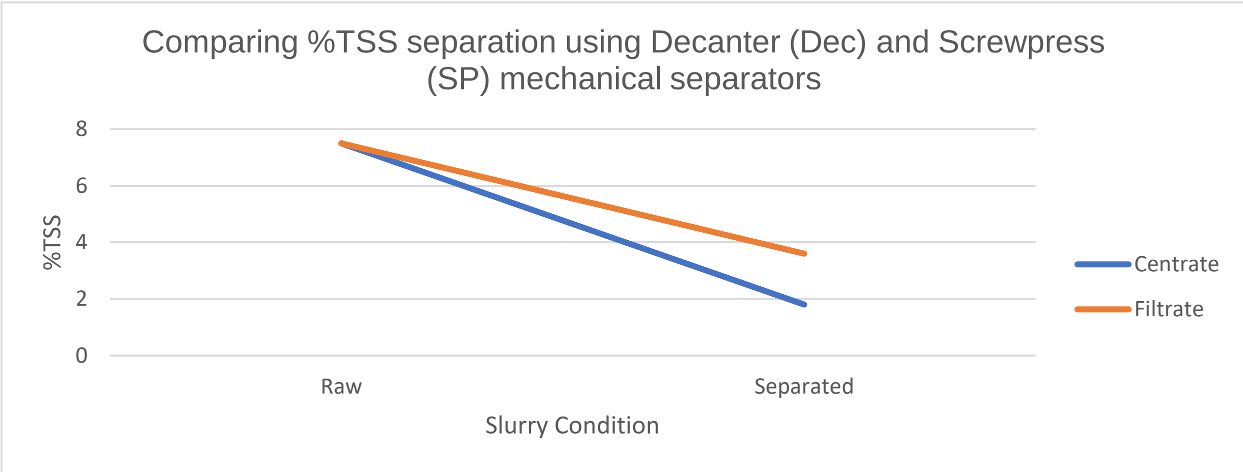



Comparing Total-N separation using Decanter (Dec) and Screwpress (SP) mechanical separators
%
5
4
3
2
1
0
Raw
Separated
Slurry Condition
Centrate
Filtrate
SP Cake
Dec Cake


Comparing Dissolved-N separation using Decanter (Dec) and Screwpress (SP) mechanical separators
%
1
0.8
0.6
0.4
0.2
0
Raw
Separated
Slurry Condition
Centrate
Filtrate
SP Cake
Dec Cake


Comparing Potassium separation using Decanter (Dec) and Screwpress (SP) mechanical separators
mg/kg
4000
3000
2000
1000
0
Raw
Separated
Slurry Condition
Centrate
Filtrate
SP Cake
Dec Cake





Nutrient Analysis Results Discussion

Total Phosphorus
The screwpress separator data showed that total-P is separated equally between the liquid and solid fractions. The decanter showed an increased concentration of total-P in the solid fraction of 253% whilst the liquid fraction contained 60% of the original concentration found in the raw slurry sample.

Ortho Phosphate
The results suggest that there was very little difference between the performance of the screwpress and decanter in terms of ortho-P separation in the solid and liquid fractions. The cake has a slightly higher concentration of Ortho-P than the liquid fraction for both screwpress and decanter.

Potassium
There seems to be very little to choose from in terms of the separation of potassium between the two separators, with a higher concentration seen in the liquid fraction of both screwpress and decanter.

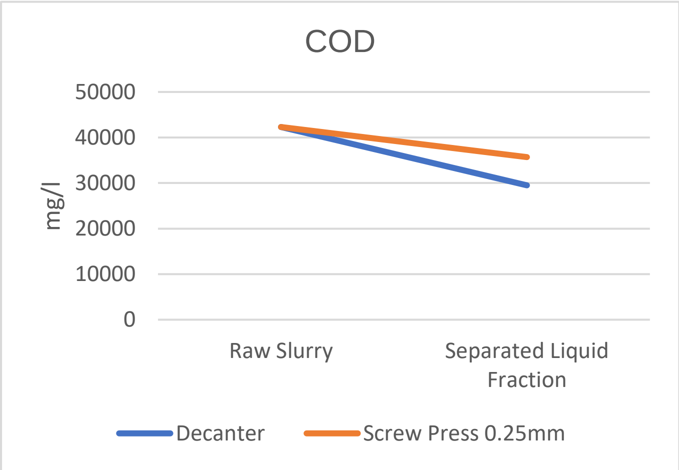
Nitrogen
An increase in % concentration of total–N is seen in the liquid fractions of both separators and a decrease in the solids. The highest % concentration is seen in the decanter centrate at 4% compared to 2.6% in the raw slurry. However, dissolved-N is reduced in the centrate, whilst a corresponding increase was seen in the filtrate.

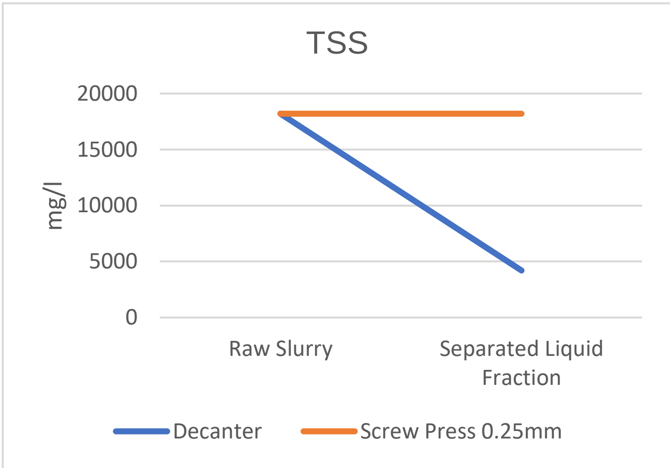
Decanter versus screw-press (0.25mm screen installed).

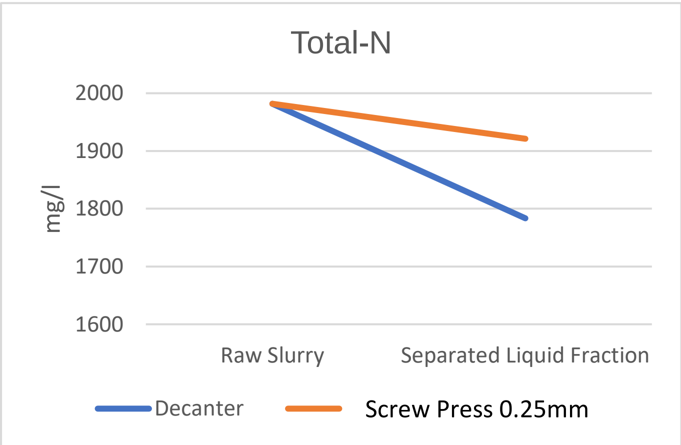
Table 3: Front-end Separator Comparison Sample Analysis Results

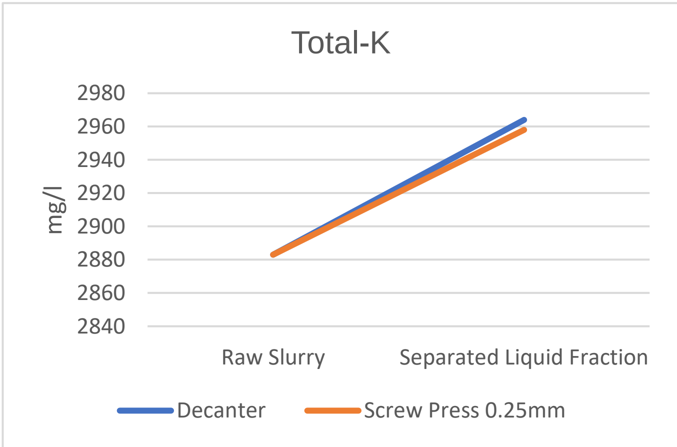
Determinant	Sample Name			Reduction Against Raw Slurry	
	Raw Slurry	Dec Centrate	SP Filtrate	Dec Centrate	SP Filtrate
	mg/l	mg/l	mg/l	%	%
Chemical Oxygen Demand (COD)	42300	29500	35700	30.3	15.6
Total Suspended Solids (TSS)	18200	4200	18200	76.9	0.0
Orthophosphate	133.34	121.76	142.07	8.7	-6.5
Total Nitrogen (TN)	1981.8	1783.5	1921.2	10.0	3.1
Total Phosphate (TP)	435.6	248.7	320.8	42.9	26.4
Total Potassium	2883	2964	2958	-2.81	-2.60

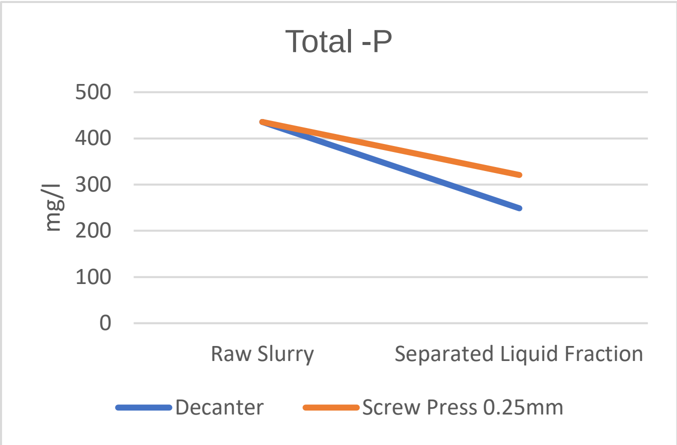
Charts 29-37: Front-end Separator Comparison Sample Analysis Results

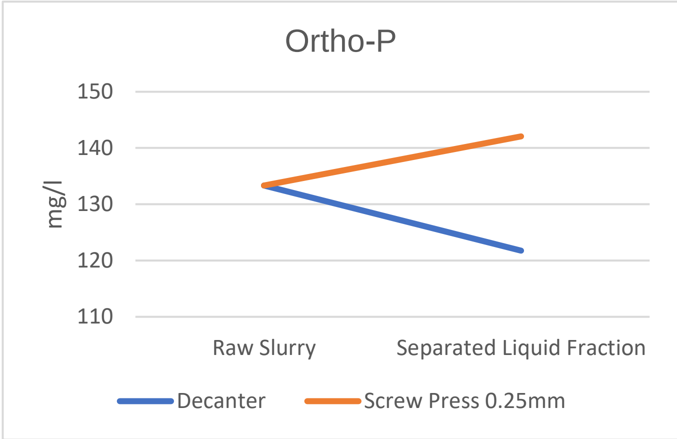


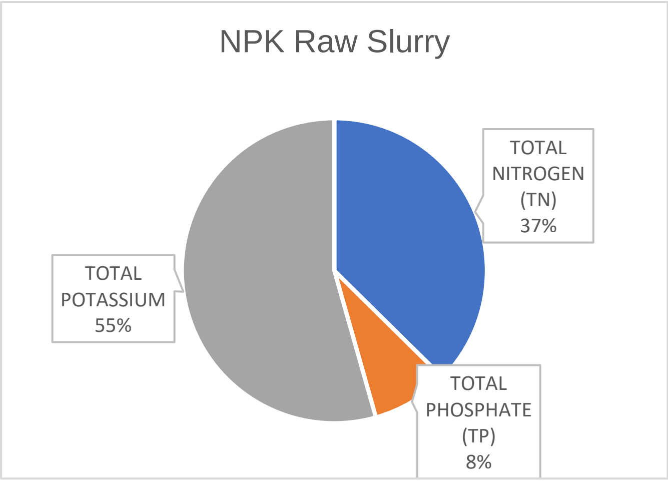


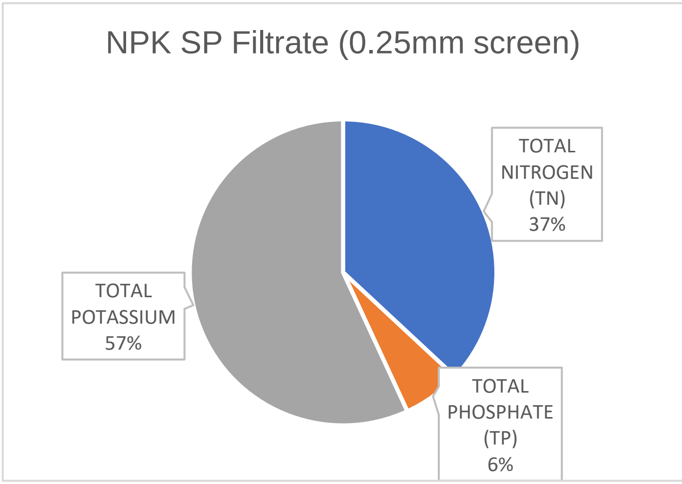


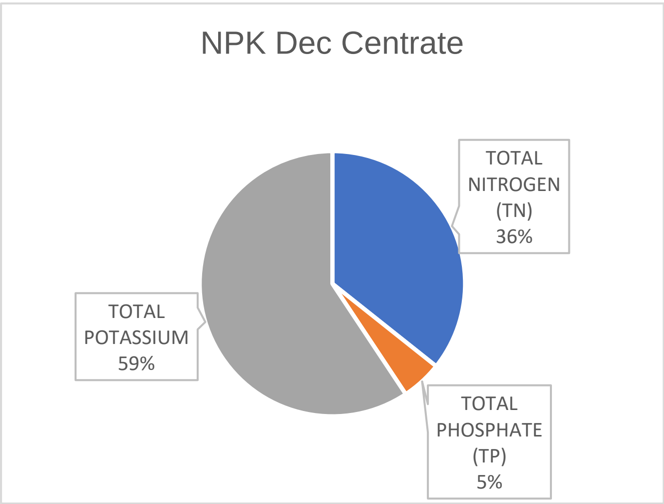












Test results clearly show that the decanter displays higher reduction rates in all but one of the determinants (Total Potassium), where the result showed a marginal increase.

Screw-Press Filtrate Settlement Tests

In order to determine the settleability of suspended solids in screw press filtrate, measurements were taken after a 10-day retention time. The filtrate was left to settle in IBC (1000l) for 10 days prior to sampling. The IBC was drained from the bottom with samples taken every 100 litres and analysed for % Total Solids.

Volume sampled (L)		%TS
100	Bottom	5.6
200		5.59
300		5.56
400		5.61
500		5.56
600		5.59
700		5.56
800		5.5
900		5.48
1000	Top	5.51

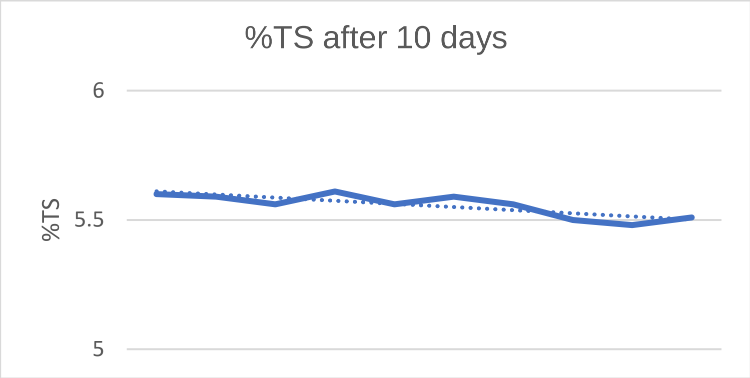


Chart 38: SP Filtrate Settlement Test Analysis

The results indicate that the separated liquid fraction remains fairly homogenous over a period of 10 days at ambient temperature. This would allow for the filtrate to be stored for this period without causing feed inconsistencies and therefore potential treatment inconsistencies through the treatment plant.

Separating the raw slurry into its solid and liquid fractions by screw filtration, prior to treatment and subsequent removal of the coagulated solids using a decanter centrifuge is seen as a method of consistently achieving desired levels of treatment in a constant flow process scenario.

Removing the bulky insoluble course material in the screw press filter allows increased contact between the coagulant and the dissolved material we wish to precipitate. This newly coagulated material can be made to bind together further using a chemical flocculator, allowing the decanter centrifuge the best opportunity of removing the vast majority of the remaining suspended solids.

Soneco© - Sono-electrochemistry

Power and Water's Soneco© units are patented electrochemical reactors with combined power-ultrasound, leading the field in contemporary water treatment. This innovative treatment method removes clays, fines, nutrients, colloids and metals and has been successfully proven in other waste water treatment sectors.

By adding electrons to water instead of liquid chemicals, the Soneco© range of products have low environmental impact, offering unrivalled environmental performance when compared to more traditional chemical based waste water treatment processes.

The modular reactors are able to be installed as a stand-alone system or can be easily integrated into existing processes.

Fig 7. Soneco© DB2 Reactor

Disk Stack Centrifuge (GEA OSE 40-01-037)

Photo 6: Disk Stack Centrifuge

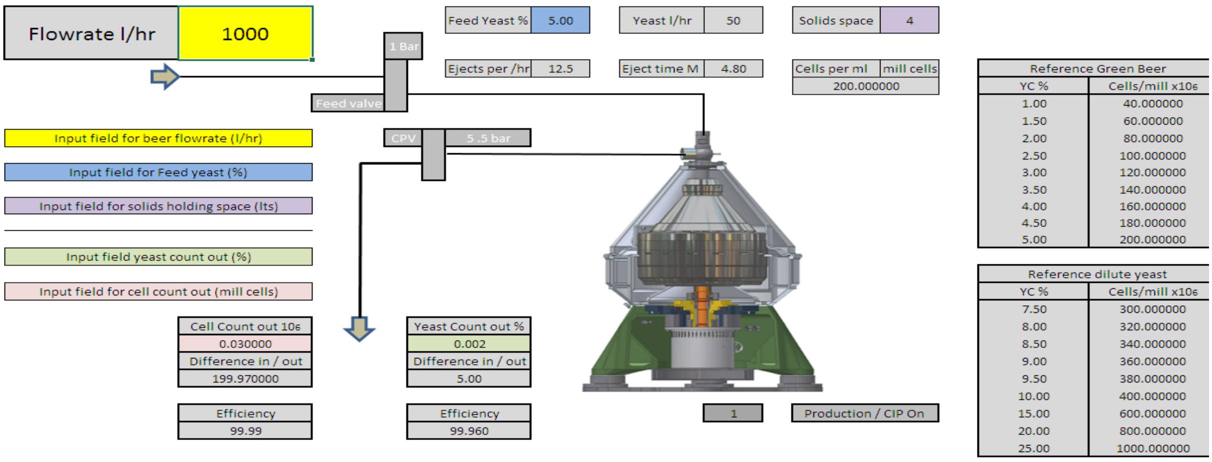
Designed and utilised to remove fine particles from the liquid effluent stream. The initial intention was that this would remove the particulate solids generated in the Soneco© electro-coagulation reactor, which had not already been separated by the Dissolved Air Flotation (DAF) unit.

The separated sludge (solids containing high nutrient values) would be re-combined with the solids generated at the primary separation stage. This would mean retaining as much of the nutrients as possible for use on the farm when appropriate.

Disk Stack Solids Loading

A solids loading calculator developed by GEA was used to determine the control parameters required according to the suspended solids present in the influent. This allowed, the feed flow, back pressure, separation time and ejection time to be regulated accordingly.

Figure 7. Disk Stack Centrifuge Loading Calculator (courtesy of GEA)



Disk Stack Back Pressure

The back-pressure parameter effectively determines how long the effluent remains in the bowl and therefore separation time. The higher the pressure the slower the throughput of effluent through the separator. As part of the commissioning it was necessary to determine which pressure resulted in the best separation characteristics. The disk stack was run at varying back pressures as follows:

Table 4. Disk Stack settings for Back pressure Trial

Feed Flow (m3/h)	Back Pressure (Bar)	Separation Time (sec)
1.0	6.0	400
1.0	6.5	400
1.0	7.0	400
1.0	7.5	400
1.0	8.0	400

Each setting was run through two discharge cycles, with the sample being collected at 200sec separation time (centrate) and immediately after solids ejection (sludge)

Table 5. Disk Stack Back Pressure Trial Results

RESULTS	Sample Name:	Raw Slurry	Dec Cent	DS 6Bar	DS 6.5Bar	DS 7Bar	DS 7.5Bar	DS 8Bar
Type of analysis:		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Chemical Oxygen Demand (COD)		26700	14600	11900	12800	13000	13200	12900
Total Suspended Solids (TSS)		9200	2825	475	625	725	625	750
Orthophosphate		139.86	64.02	27.88	30.3	29.63	28.41	28.02
Total Nitrogen (TN)		1502.77	1046.94	884.42	901.17	937.92	926.21	970.15
Total Phosphate (TP)		252.85	127.63	66.24	71.02	74.88	73.16	72.56
Total Potassium		1637	1699	1623	1727	1765	1768	1779

The results of the disk stack back pressure trial indicated that separation occurred best at a back pressure of 6.0Bar as highlighted in the results table above. This pressure setting also improved the flow through the separator as the retention time in the bowl was reduced. At the higher pressures it is thought that some suspended solid may enter back into solution. It is also possible that the bowl overflowed when the back pressure was set too high (i.e. 8Bar) resulting in poorer separation performance.

Soneco© - Advanced Oxidation Process (AOP)

Generically, these processes rely on generating hydroxyl free radicals (OH*) which are powerful oxidants capable of mineralizing pollutants found in wastewater. The hydroxyl radical is a highly reactive chemical species with a high oxidation potential, which has the potential to degrade recalcitrant organics. There are a number of different means of generating OH*. Here we aimed to produce them electrochemically at the anode (using mixed metal oxide MMO electrode material), but also by irradiation with ultrasound. This radical readily reacts with pollutants in wastewater, however it can also react with radical scavengers such as bicarbonates, causing the reduction in the process efficiency.

AOP can be used to target effluents polluted with organic species which are either toxic or refractory to biological treatments and with a concentration range within 1,000-20,000mg/l COD.

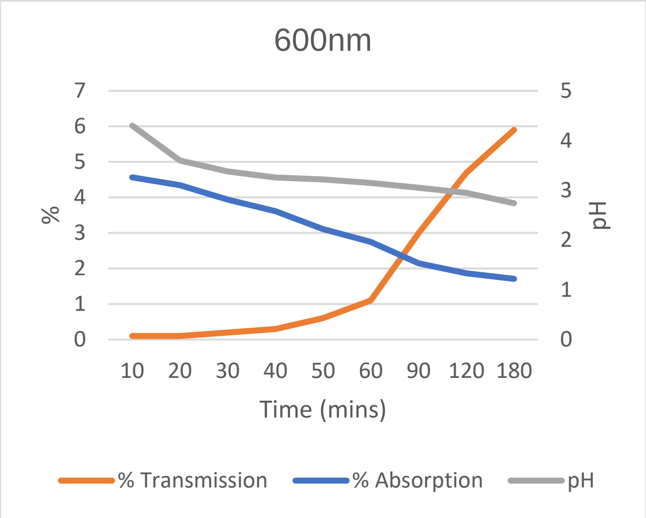
Advanced Oxidation of Azo Dye

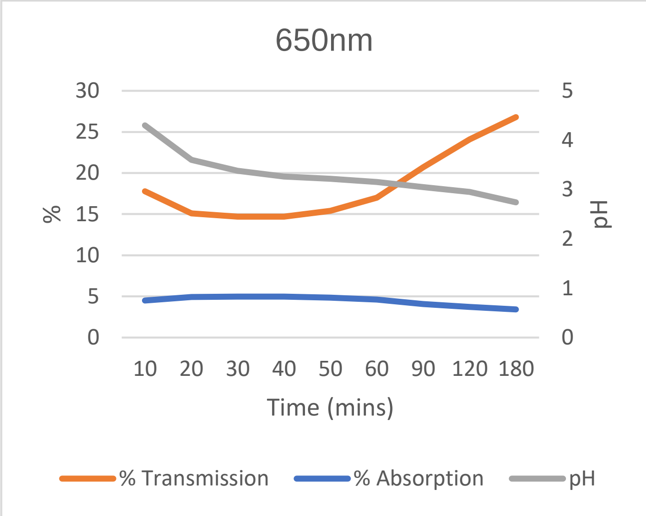
To test the efficacy of the Mixed Metal Oxide electrodes in generating OH* in the laboratory, 0.1g Azorubine red dye Carmoisine Cl14720 was diluted with 200ml de-ionised water before being subjected to AOP treatment.

Azo dyes contain di-nitrogen bonds (N=N). If the MMO electrodes generate enough OH*, these should react with the molecule causing the bonds to break, resulting in the dissipation of colour. The treated sample absorbance and % transmission can then be measured and recorded against a control sample.

Samples were taken at fixed times intervals and analysed on HACH DR3900 spectrophotometer at 600nm and 650nm.

Charts 39-40: Azo-Dye Trial Spectrophotometer Results





Preliminary laboratory results indicated that the sample absorbance is reduced whilst transmission is increased with treatment time. This shows that the means for oxidising waste water using MMO electrodes has the potential to work on plant scale albeit the mechanism for doing may be two-fold.

As well as direct oxidation by OH*, the resulting decrease in pH with treatment time may be the result of the formation of hydrogen peroxide (a weak acid) from two reacting hydroxyl radicals.

$OH^* + OH^* \longrightarrow H_2O_2$

H_2O_2 is also an oxidising agent and may be a secondary cause of the oxidation of the azo molecule.

Potentially this change in pH would need to be corrected before the treated water could be discharged safely.

Advanced Electro Oxidation Processes generally show great potential for use in the treatment of wastewater streams. However, the Soneco© AOP unit installed as part of the treatment process at Gelli Aur College Farm and based on MMO electrode material alone did not seem to produce the desired results effectively or efficiently. This is true of ProsiectSlyri Project – where a current of 400Amp at a current density of 17.17mA/cm^2 over a treatment period of 24hrs was shown to produce very limited results. Modification of the reactor would need to be made in order to increase the current density further, either through increasing the available current flowing through the system, or by means of reducing the surface area of the anode.

Effluents intended for treatment with AOP require testing for TOC, carbonates and bicarbonates to better understand the presence of any OH* scavengers present. The higher the concentration of these compounds, the lower the treatment rate is likely to be.

4.0 Analytical Results of Plant Treatment Performance

Trials using the Soneco© electro-coagulation reactor were eventually halted when it was shown that the performance was being impacted by the level of percentage total solids remaining in the reactor feed from the decanter centrifuge. The electro-generated coagulant would initially perform its intended task of coalescing colloid particles as well as precipitating the desired dissolved elements of the separated slurry matrix. However, upon precipitation, the now suspended solids would result in additional adsorption to the surface of the electrodes, building up a surface layer of caked material. The power ultrasound system designed into the reactor and employed to prevent this from occurring was not able to deal with the level of suspended solids seen post coagulation phase. This resulted in the eventual loss of electrical current flowing across the electrodes and therefore the dissolution of metal coagulant - and the treatment would eventually stop. In order to continue treatment, the electrodes had to be removed from the reactor and cleaned before re-inserting and the current re-applied. This is not practical on a day-to-day basis.

Liquid Chemical Conditioning

Switching to using liquid chemical conditioners was trialled with varying degrees of success. As a result, varying chemical combinations were tested by Aquatreat (a water treatment supplies company), before settling on the use of Poly Aluminium Chloride - PAC **OR** Ferric Chloride as a coagulant and Polyacrylamide - PAM (a cationic polyelectrolyte) as a flocculant.

Liquid chemical coagulants are widely used in industrial and municipal wastewater treatment plants.

However, at times, due to the relatively high concentrations of solids exiting the screw-press separator it became necessary to dilute the plant feed using ‘dirty water’. This dirty water may be sourced either from the dirty water storage tank on the farm or from water exiting the plant. Blending the raw feed with the dirty water to achieve a total solids content of around 1-2% would allow the chemical to interact better with the dissolved and colloidal particles, requiring less chemical to achieve desired results. Theoretically, the higher the solids content, the less space there is for the chemical to interact with the target molecules and more of the chemical interacts with the already suspended solid particulate.

Operating Expenditure (OPEX) Costs

The following OPEX costs are based on the use of the liquid chemical additives Poly Aluminium Chloride (PAC) 18% **OR** Ferric Chloride 40% as the coagulant and Polyacrylamide (PAM) 0.2% active as a flocculant. Simple cost calculations are based on a feed flow of 1m3 slurry per hour.

Table 6: OPEX costs of current plant configuration based on 1m3/hour of treated slurry

Chemical	Dose rate/m3 slurry (l)	Costs/m3 slurry (£)	Total/m3 slurry (£)	Total/100 cows (£)
PAC (18%)	5	5		
Ferric Chloride (40%)	5	5		
PAM (0.2% active)	50	0.87		
Sub Total Costs			5.87	12,186
Power Consumption @15p/kWh		Costs/hour (£)	Total/m3 slurry (£)	
Feed Pump		0.45		
Screw-Press		0.75		
Decanter		1.20		
Disk Stack		1.20		
Ancilliaries		0.6		
Sub Total Costs			4.20	8,719
Total Costs			**10.07**	**20,905**

Note: Chemical Dosing only requires the use of either PAC **OR** Ferric Chloride and this is reflected in the calculated costs

The total associated operation expenditure costs can be set against potential savings due to better nutrient use – estimated to be in the region of £8,454 per annum. An additional saving of £7,694 per annum may also be attributed to water use (£5,694) and diesel and spreading costs (£2,000). This would mean overall nutrient management costs would equate to £4,757 per annum for a 100-cow farm.

These costs are based on a small volume of chemical purchased for the purpose of the project. Bulk purchase costs of chemicals were obtained and adjusted treatment costs are summarised in the table below:

Table 7: OPEX costs when bulk purchasing chemicals

Chemical	Dose rate/m3 slurry (l)	Costs/m3 slurry (£)	Total/m3 slurry (£)	Total/100 cows (£)
PAC (18%)	5	4.10		
Ferric Chloride (40%)	5	2.45		
PAM (0.2% active)	50	0.87		
Sub Total Costs				
using PAC			4.97	10,317
using Ferric Chloride			3.32	6,892
Power Consumption @15p/kWh			4.20	8,719
Total Costs				
using PAC			**9.17**	**19,036**
using Ferric Chloride			**7.52**	**15,611**

Note: Chemical Dosing only requires the use of either PAC **OR** Ferric Chloride and this is reflected in the calculated costs

Using chemicals purchased in bulk (1,000l) equates to the potential overall nutrient management saving of £537 per annum for a 100-cow farm.

Dosing Ratios (Stoichiometric Equivalents)

The term 'stoichiometric equivalents refers to the quantity of one substance that reacts with a quantity of another. The reaction of chemical coagulant in relation to Total Phosphorus present is given below:

Poly Aluminium Chloride (18% or 180,000mg/l) : Total-P =1.3

Ferric Chloride (40% or 400,000mg/l) : Total-P = 2.88

Typical Sample Analysis

Sample analysis results for chemical dosing trial where:
Chemical (5l **PAC** -18%)
Pit %TS = 9.22%
Screw press filtrate = 6.01%TS
Decanter Centrate (from diluted screw press filtrate) = 1.86%TS
DS Centrate = 0.8%TS
DS Sludge = 0.97%TS
Flow rate 1m3/hr

Dilute screw-press filtrate was chemically dosed prior to solid/liquid separation in the decanter

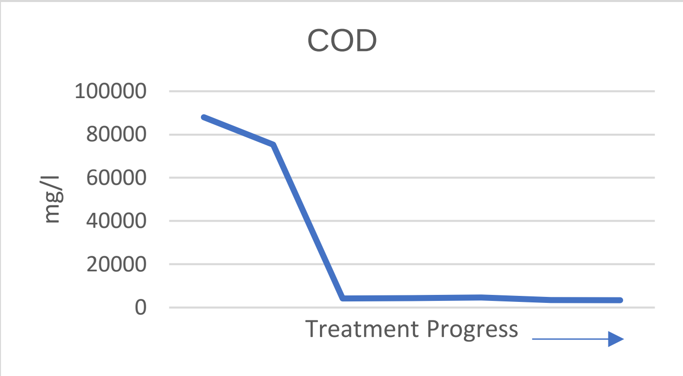
Table 8. Typical Laboratory Analysis Results

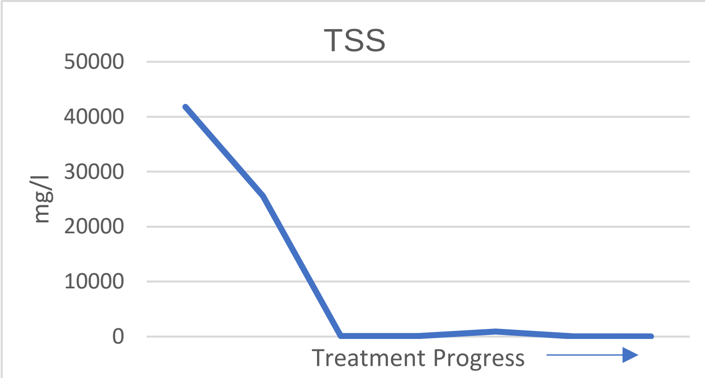
	Sample Name (mg/l)					Removal Rate*
Analysis Required	**Raw Slurry**	**SP Filtrate**	**Dec Cent**	**DS Cent**	**DS Sludge**	**%**
COD	88000	75400	4175	3400	5075	96.13
TSS	41800	25600	80	33	3580	99.92
ORTHO-P	268.21	242.34	<0.5	0.5	<0.5	99.81
TOTAL -N	1399.17	1377.7	1.22	0.42	10.35	99.96
TOTAL -P	519.52	555.3	1.45	0.74	12.14	99.85
TOTAL -K	4407	4479	1127	981	884	77.74
TOTAL-Al	75.9	61.3	0.92	2.17	751	98.78

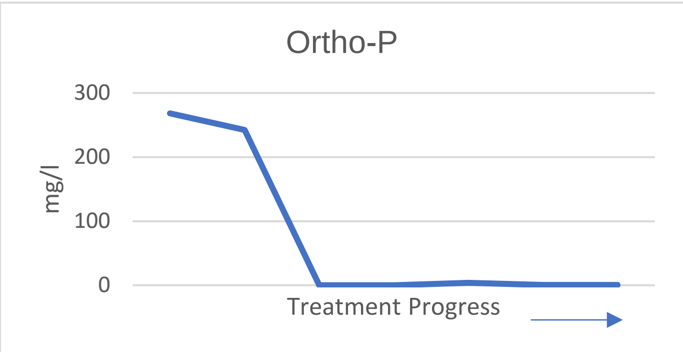
COD (Chemical Oxygen demand); TSS (Total Suspended Solids); Ortho-P (Ortho Phosphate); Total-N (Total Nitrogen; Total-P (Total Phosphorus); Total-K (Total Potassium); Total-Al (Total Aluminium).
*Removal rate calculated based on either Dec Centrate **OR** Disk Stack (DS) Centrate (whichever is the lowest) when compared with Raw Slurry.

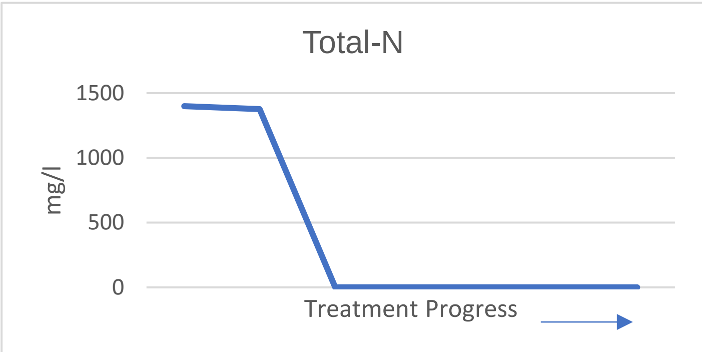
Photos 7-8: Samples taken (from left to right) - raw slurry, primary separated liquor, treated liquor and secondary separated liquor

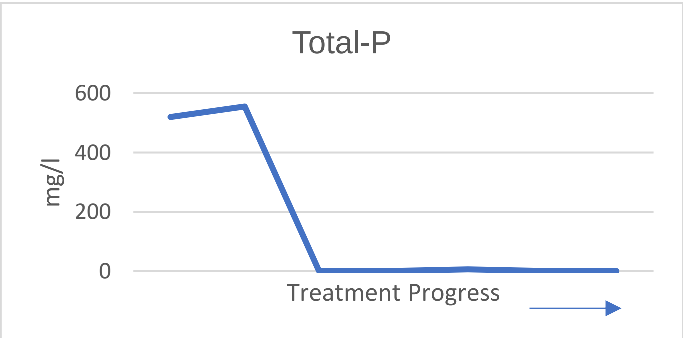
Charts 41-56: Laboratory Analysis Results Charts for Chemical Dosing Trials

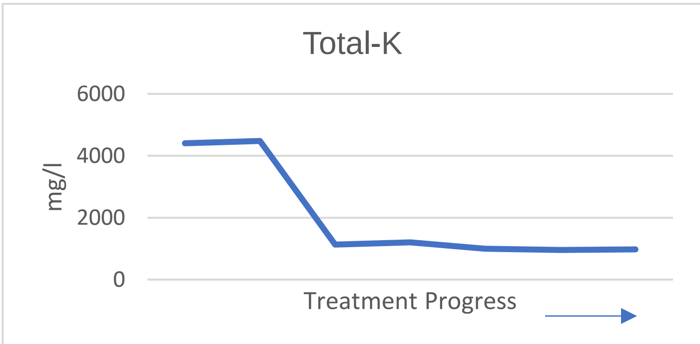


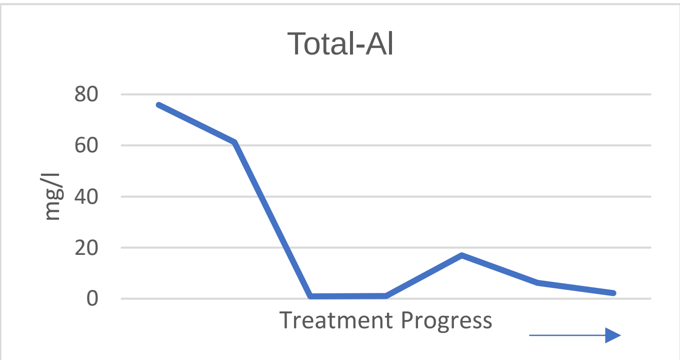


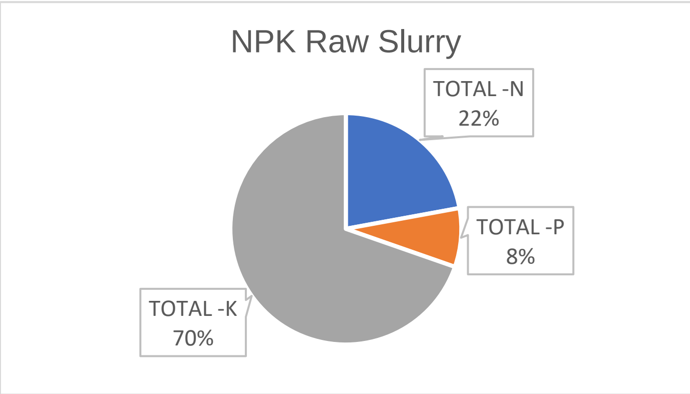


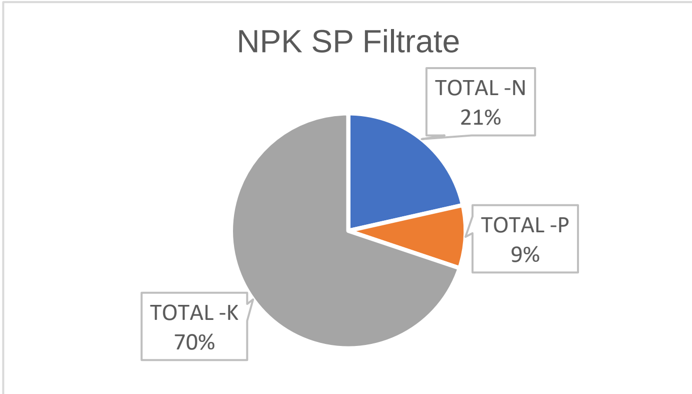


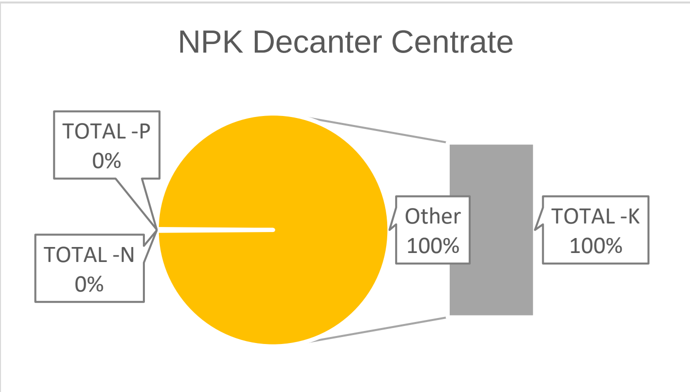


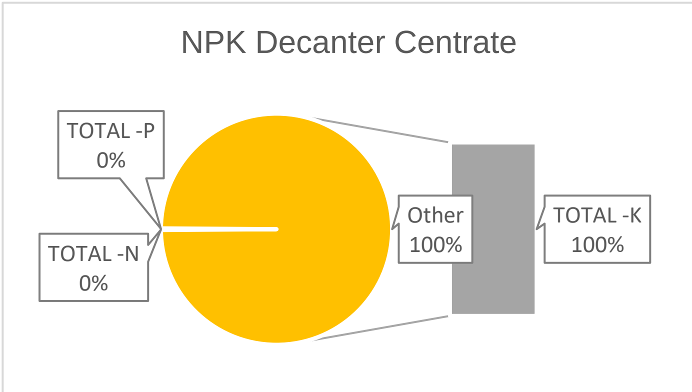


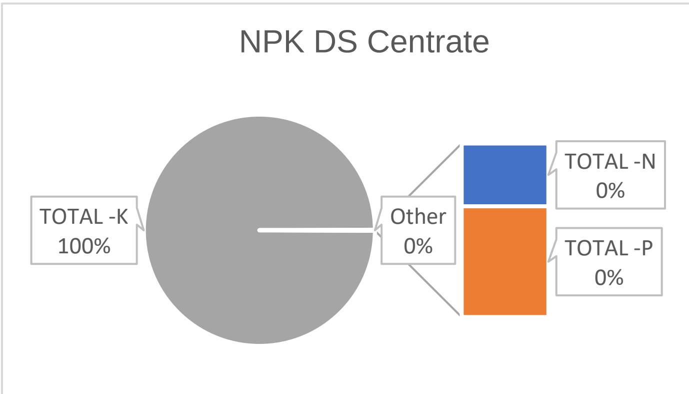


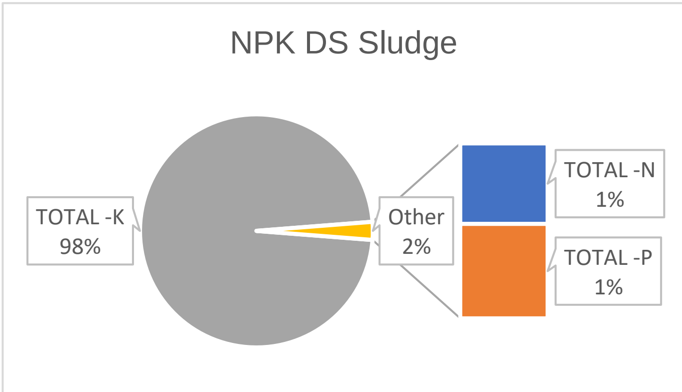

NPK Raw Slurry
TOTAL -N 22%
TOTAL -P 8%
TOTAL -K 70%

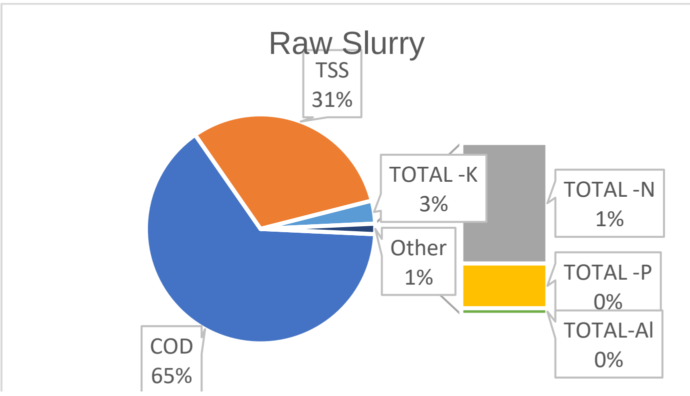

NPK SP Filtrate
TOTAL -N 21%
TOTAL -P 9%
TOTAL -K 70%

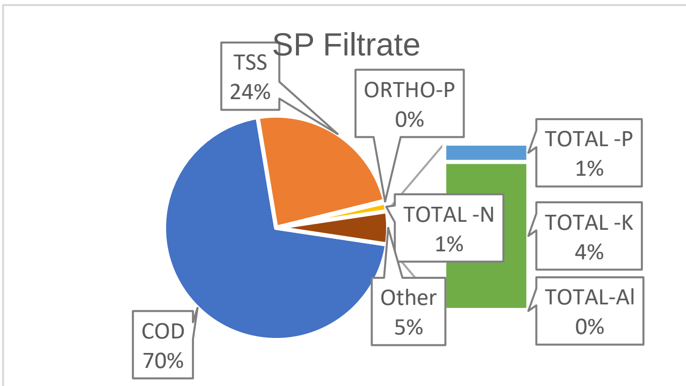

NPK Decanter Centrate
TOTAL -P 0%
TOTAL -N 0%
Other 100%
TOTAL -K 100%

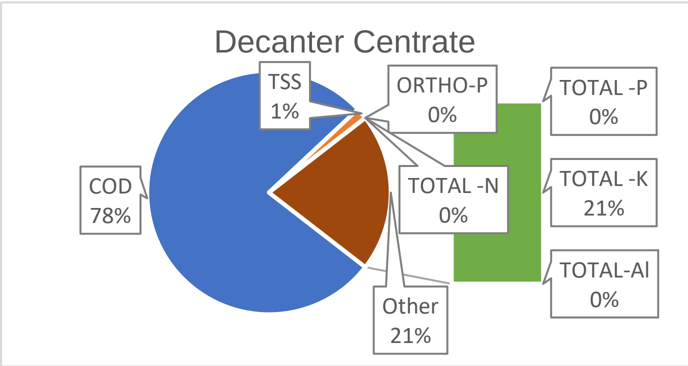

NPK Decanter Centrate
TOTAL -P 0%
TOTAL -N 0%
Other 100%
TOTAL -K 100%

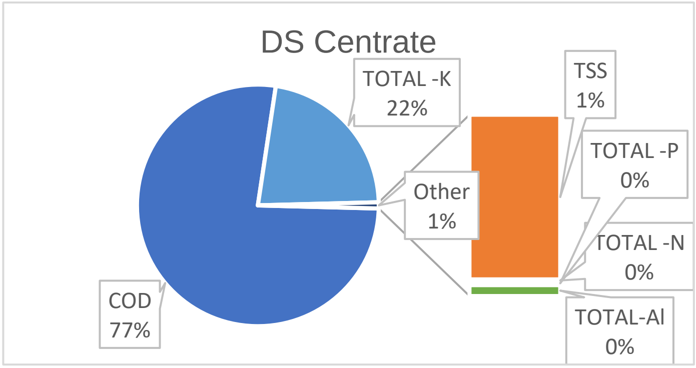

NPK DS Centrate
TOTAL -K 100%
Other 0%
TOTAL -N 0%
TOTAL -P 0%


NPK DS Sludge
TOTAL -K 98%
Other 2%
TOTAL -N 1%
TOTAL -P 1%


Raw Slurry
TSS 31%
TOTAL -K 3%
Other 1%
TOTAL -N 1%
TOTAL -P 0%
TOTAL-Al 0%
COD 65%


SP Filtrate
TSS 24%
ORTHO-P 0%
TOTAL -P 1%
TOTAL -N 1%
TOTAL -K 4%
Other 5%
TOTAL-Al 0%
COD 70%





Compliance Limits For Use Of Chemicals In Treatment

Table 9: Determinant Concentration Standards

Determinant	Standard
Chlorine	5ug/l MAC as Total Available Chlorine
Aluminium	The standard is 1mg/l (total) MAC EQS but subject to a maximum concentration in the discharge of 10mg/l (dissolved) EMISSION STD if 1:10 dilution
Cationic Polyelectrolytes (polymer)	EQS will be 0.1 x 24h LC50 for appropriate fish species, as 95pc.Dilutions <x30 require case specific consideration
Anionic and Non-ionic Polyelectrolytes (polymer)	7.5mg/l 95pc, EQS OR 0.1 x 24h LC50 for appropriate fish species, if this is known.
Suspended Solids	100mg/l EMISSION STD OR Case-specific std.
Iron	1mg/l dissolved AA EQS 5mg/l total MAC EQS Where the environmental needs of the RESERVOIR are compromised by iron particle deposition you can apply an MAC of 90mg/kg Fe, dry weight in sediment

AA = annual average
95pc = 95 percentile
MAC = maximum allowable concentration
EQS = Environmental Quality Standard

Source: www.naturalresources.wales

Table 10: Receiving Water Quality Standards

Determinant	Receiving Water Quality	
	pH<6.0 (lower 95pc) $CaCO_3$ <20mg/l AA	pH<6.0 (lower 95pc) $CaCO_3$ 20mg/l AA
Chlorine	5ug/l MAC as Total Available Chlorine	5ug/l MAC as Total Available Chlorine
Aluminium (Dissolved) (Total)	75ug/l 95pc EQS 100ug/l MAC EQS 500ug/l EMISSION STD	500ug/l 95pc EQS 1mg/l MAC EQS 1mg/l EMISSION STD
Cationic Polyelectrolytes	Adopt a case specific approach while analytical detection limit remains greater than 0.1 x fish 24h LC50	

Anionic and Non-ionic Polyelectrolytes	3.5mg/l EMISSION STD OR 0.05 x 24h LC50 for fish, if this is known as 95pc EQS	7.5mg/l EMISSION STD OR 0.1 x 24h LC50 for fish, if this is known as 95pc EQS
Suspended Solids	100mg/l EMISSION STD OR Case-specific std	
Iron (Dissolved) (Total)	0.5mg/l AA EQS 2mg/l MAC EQS	1mg/l AA EQS 5mg/l MAC EQS
	Where the environmental needs of a RESERVOIR are compromised by iron particle deposition, apply an MAC of 90mg/kg dry weight.	

AA = annual average
95p = 95 percentile
MAC = maximum allowable concentration
EQS = Environmental Quality Standard

Source: www.naturalresources.wales

Iron is generally considered as being associated with suspended solids and investigations carried out by Severn-Trent Water suggest a relationship ratio of 1:7 between total iron and suspended solids as outlined in the table below:

Table 11: Iron Standards

Effluent Suspended Solids (mg/l)	**Effluent Iron Concentration (mg/l) Total Fe as Max Allowable Conc.**
7	1
14	2
21	3
28	4
35	5

Source: www.naturalresources.wales

6.0 Discussion

Primary Separators

The project aimed to compare and contrast the performance of 2 differing mechanical separator technologies – a screw press filter and a decanter centrifuge. Whilst the screw press may be more familiar to farmers, the decanter – although used in other sectors, is not common place in the agricultural sector.

Although solid/liquid separation occurs by means of different mechanisms, they are both primarily designed to achieve as dry a cake as possible. This application however, requires low solid in the liquid fraction and therefore high solid capture rates. Where both machines are capable of producing a stackable cake, the solids capture rate is seen to be significantly higher with the decanter (52% compared with 17% for the screw press). As a consequence, it follows that the removal rates for other determinants are also higher with the decanter. This has a positive impact on the level of downstream processing required i.e. the more solid captured at the primary separation stage the lower the cost of secondary stage treatment.

Although the capital outlay is significantly higher for the decanter and it is also more expensive to operate, the improvement in performance is such that it is highly recommended and plant treatment would fail without.

The screw press does have added benefit of ease of use against the decanter but cannot compete with separation performance in the liquid fraction and it is therefore only viable to separate raw slurry straight from the yard (what it was designed to do) prior to a coagulation/flocculation stage followed by decanter separation of the additional solids.

Pumping SPS filtrate to an empty slurry store would allow it to equilibrate prior to use. Separated screw-press filtrate does not stratify as quickly as raw slurry and the size and volume of the store would ensure that any changes in concentration e.g. due to rainfall episodes, would be kept to a minimum. This would remove any ambiguity and uncertainty surrounding concentrations experienced in the reception pit and therefore, separator performance. This could then be further separated in the decanter, producing a more consistent liquid centrate low in suspended solids.

Soneco© Sono-electrocoagulation reactor

Using the Soneco© reactors to electro-generate the coagulant in order to treat the separated slurry proved problematic. The issue arose from the level of precipitated solids seen. Dissolved solids in the separated slurry could reach 70%. When this was precipitated during the coagulation phase the solids would migrate in the liquid and adsorb to the surface of the electrode. This had been anticipated to happen during the design stage, with ultrasound incorporated in to the design to help keep the electrodes free of fouling. However, the solid particle migration was due in part to both electronic charge and the effects of the ultrasonic waves. It became evident that the ultrasonic cleaning was not able to cope with the level of suspended solids. This resulted in a drop in electrical current across the electrodes and subsequent loss of treatment.

The level of dissolved solids in the slurry became the primary reason why the Soneco© electro-coagulation reactor became unsuitable for the treatment of separated slurry.

The electro-treatment required was proportional to the concentration of nutrients present in the centrate. Therefore, from a process point of view, it would be advantageous to have as much nutrient as possible removed from the centrate and bound in the solid cake.

The % Total Solids (%TS) also has a negative effect on the treatment efficiency at the electro-coagulation stage, impacting on the electrode performance.
These initial results suggest that in order for the nutrients to be captured in the solid cake at a higher percentage – a lower bowl speed works best. The converse seems true of the % Total Solids, where a higher bowl speed is favourable. The difference in %TS however seems only slight at 0.16% when comparing maximum and minimum bowl speeds.

Electro-generating enough coagulant to react with the dissolved solids, enabling a high reduction in Ortho-Phosphate was also problematic for the same reason. Not enough coagulant could be generated quickly enough to allow for a constant flow process at a level that would be acceptable to working dairy farms. Larger power supplies would have been required with an associated increase in CAPEX and OPEX resulting in the process becoming commercially unviable on farms.

Switching to liquid chemical coagulants and flocculants resolves the issue of electrode fouling. It is noted that chemical-based treatment systems in other industries have drawbacks of their own, namely cost and safety, but also chemical transport. However, from a treatment perspective, the results were much improved, with a higher percentage of phosphorus removal than that seen with the Soneco© unit for the reasons outlined above.

Soneco© AOP reactor
An Advanced Oxidation Process is associated with the generation of free radicals and in particular, hydroxyl free radicals (OH*). These are highly reactive chemical species and are used in water treatment to oxidise re-calcitrant contaminants to more environmentally friendly products.

The Soneco© AOP incorporates power ultrasound, intended for both maintaining electrode efficiency by preventing anode fouling and also generating reactive free radicals through the process of cavitation.

The effect of the ultrasonic wave is two-fold:

1. The wave acts on nucleation sites (cavities) within the liquid, increasing their size until they can no longer sustain themselves. These rapidly collapse (cavitation) generating very high local temperatures and pressures. These cavitation events can result in the formation of hydroxyl free radicals.
2. The action of the wave causes mass transfer of particles to the electrode surface from the bulk liquid where further hydroxyl free radicals are formed at or very near the surface of the electrode.

The Soneco© unit deployed on site was unable to oxidise the liquid in its current state of development and further work needs to be undertaken in order to find ways of increasing the level of OH* generated and removing as much of both the targeted and untargeted contaminant molecules prior to entering the reactor. This will give the reactor the best chance of success in treating the residual contaminants and possibly allow consented discharge or re-use of the water.

Dissolved Air Flotation (DAF)

A DAF unit was hired by Power and Water for a period of 3 months to trial its effect on the liquid going through the electro-coagulant reactor. Removing as much of the suspended solid prior to entering the reactor would have potentially been of great benefit. The DAF was placed in between the decanter centrifuge and the reactor in order to remove any remaining suspended solids that came through in the centrate. Total Solids (%TS) analysis indicated at this time that the centrate was consistently too high in %TS for the DAF to be effective (>1.5%TS) and it was removed.

Later, it was discovered that the dissolved solids in the liquid entering the reactor was proving to also be problematic. The combination of dissolved and suspended solids (Total Solids) was simply too high for the Soneco© electro-coagulation reactor to cope with.

Analysis Results

The PSDA compares the separation performance of the 3 mechanical separators employed at ProsiectSlyri. Direct comparisons can be drawn between the screw press and decanter centrifuge, as these are both employed as primary separators, designed to remove the course solids. The disk stack on the other hand is designed more to remove the fine solids and was used in this instance as a secondary mechanical separator.

The results indicate that during this trial, the screw press (fitted with a 0.5mm filter screen) was less able to remove suspended solids than the decanter centrifuge, with 47% solids seen in the filtrate, but only 9% seen in the decanter centrate. Also, the particle size percentage shows that the decanter was able to provide a centrate with 63% of the solids being in the order 0-10µm, compared to 18% for the screw press.

Further, the disk stack centrifuge provided a centrate with 74% of the solids in the order 0-10um with only 1.43% suspended solids seen in the supernatant

Note: the disk stack relies on an influent of decanter centrate to achieve these results.

Therefore, these results show the importance of the decanter centrifuge in providing a much-improved separation performance against the screw press.

Note: The screw press was also trialled using a smaller 0.25mm filter screen. However, this resulted in a higher proportion of the suspended solids being forced through in the liquid filtrate. This was due to the increased pressure subjected on the slurry at the screen surface by means of increased resistance at the point of separation.

The results from the chemical dosing trials showed the treatment to be effective at removing 99% of each total phosphorus, ortho-phosphate, total nitrogen and total suspended solids and the majority of COD (96%) and total potassium (78%).

During these trials it became apparent that diluting the slurry at times of high levels of total solids would be necessary. In order to achieve acceptable treatment levels using the equipment available a maximum total solids concentration of 2.0% entering the decanter (post coagulation stage) was necessary. Anything above this level would require higher chemical dosing rates and increased contact times than currently available, due to chemical competition between the already suspended particulate and the dissolved solids, where dissolved solids can account up to 75% of the total solid concentration.

When appropriate dilution factors are used, the removal rates seen in the analysis results show that the condition of the water exiting the plant to be low in all determinants (and therefore meet the discharge criteria) other than COD, which remains stubbornly above the discharge threshold. Improving the performance of the AOP or utilising other technologies such as forced air reedbeds should decrease COD levels to below the discharge consent of 125mg/l. Although total Aluminium exiting the disk stack centrifuge is higher than permitted levels, that exiting the decanter is shown to be lower. This is potentially the result of disk stack operation, whereby a proportion of the solid particulate is re-dissolved in the centrate.

A BOD:COD ratio was determined, but only as a snapshot analysis. This indicated a ratio = 0.25, which puts it in the biodegradable zone. A biodegradable zone means the limit of organic matter that can be decomposed by microbes in natural and man-made treatment conditions. This zone may be divided into several levels such as low, moderate and high biodegradability. Due to the number of samples required to determine an accurate BOD:COD ratio over a given period of time (e.g. 1 year), this snapshot result has little value on its own and would require further study.

A change in effluent pH must be considered when using Ferric Chloride. A pH4.2 was measured in the separated liquor (down from pH7.2 in the feed), which should be corrected before discharging into the local watercourse (the cost of pH correction has not been applied to OPEX cost analysis). This is less of a concern when using PAC, where the pH remained relatively stable at the dosing rates used.

Residual aluminium and iron in the treated water was measured at 2.4mg/l and 53mg/l respectively. These levels must be lowered below 1mg/l to achieve environmental discharge consent. More efficient chemical usage and improved mixing and contact time should aid this.

Treatment plant operation costs, although seem high, are reduced considerably when better use of available nutrients is taken in to account, resulting in an additional cost of only £4,757 for a 100-cow farm. This is was further reduced when considering the bulk purchase of chemicals, where economies of scale have a positive impact, whereby an overall calculated cost saving of £537 was potentially achievable.

Capital expenditure on the project was high, but the proposed treatment regime going forward could be reduced significantly by subtracting the costs of the Soneco© electro-coagulation and DAF unit - and subject to contamination level monitoring, also the disk stack centrifuge, saving in the order of £100,000.

Due to restrictions to the project during the last quarter of 2019 and most of 2020 (see footnote), these results signify only a small number of trials using liquid chemical dosing. As a consequence, this highlights only a somewhat brief snapshot and further work would be required in order to generate a larger data set before firm conclusions can be drawn on treatment efficacy and overall OPEX costs.

Overall, the project achieved the main goal of separating the solids from the liquid and reducing nutrient levels, but:

- The treated water is yet to reach the quality needed for discharge consent. Further reducing COD levels would be required.
- Further development is needed on the AOP to increase the oxidation potential through the generation of hydroxyl free radicals. This would theoretically decrease COD levels and allow for the water to be discharged.
- Additional treatment application technologies are seen as key to maximise the re-use of the separated water.

Managing the amount of nutrient reaching the watercourse was the key to taking this project to the next logical step for protecting the environment and creating sustainable, profitable farming practices.

7.0 Conclusions

During the cattle housed periods, the separated liquid produced by both types of primary separator was too high in % solids to be used as a direct feed to the treatment plant when the feed was taken directly from the collecting pit.

The separated liquid fraction would need to be less concentrated in order to allow for consistent and applicable down-stream processing. One way to achieve this was to dilute with farm dirty water for a final concentration of between 1-2%TS.

The decanter centrifuge consistently produced the lowest % total solids in the separated liquid fraction when compared to the screw-press separator.

Both primary separation equipment suppliers highly recommended providing a continuous homogenous feed to reduce severe changes in feed consistency and therefore separator performance. These changes influenced the effective treatment of the separated liquid fraction down-stream and we were not able to therefore achieve constant, effective, treatment rates.

Feed

Paper bedding	5.37%ds
Saw dust bedding	7.43%ds (though has dropped off recently)

Screw Filter

Removal rate	Circa 15% TSS removal.
Filtrate	Circa 5% but fluctuates based on feed

Decanter

Removal rate	Circa 50% TSS removal.
Filtrate	Circa 3% but fluctuates based on feed

Although the Soneco© reactor has proved successful in removing contaminants from other industrial and municipal waste water treatment sectors, this project was aimed at using the technology to try and treat separated farm slurry. Preliminary laboratory analysis indicated that the potential existed for successful deployment of this technology on dairy farms across Wales and beyond.

The Soneco© reactor unit worked by initially re-circulating the effluent over the electrode surface, building up a level of coagulant that was calculated to be appropriate for the removal of phosphate. With limited power supply, this could take a number of hours as the phosphate levels experienced were very high. During this time – and because of the high solids loading, the electrodes would slowly become coated in solid particulates, which would cause the flow of current to decrease and eventually stop. The in-built power ultrasound system, designed to prevent this from happening proved unsuccessful due to the high solid content.

The decision to switch to liquid chemical dosing as a treatment regime was made necessary due to the Soneco© units failure to cope with the high solid concentrations seen, becoming overloaded.

The use of chemical conditioners in wastewater treatment is well understood and is currently a cornerstone of municipal waste water treatment plants. Farmers have the space required, handling capabilities and experience of utilising other chemicals on the farm which require special care and consideration in their use and would therefore not be overly concerned about using chemical for the treatment of their slurry.

Lessons Learned

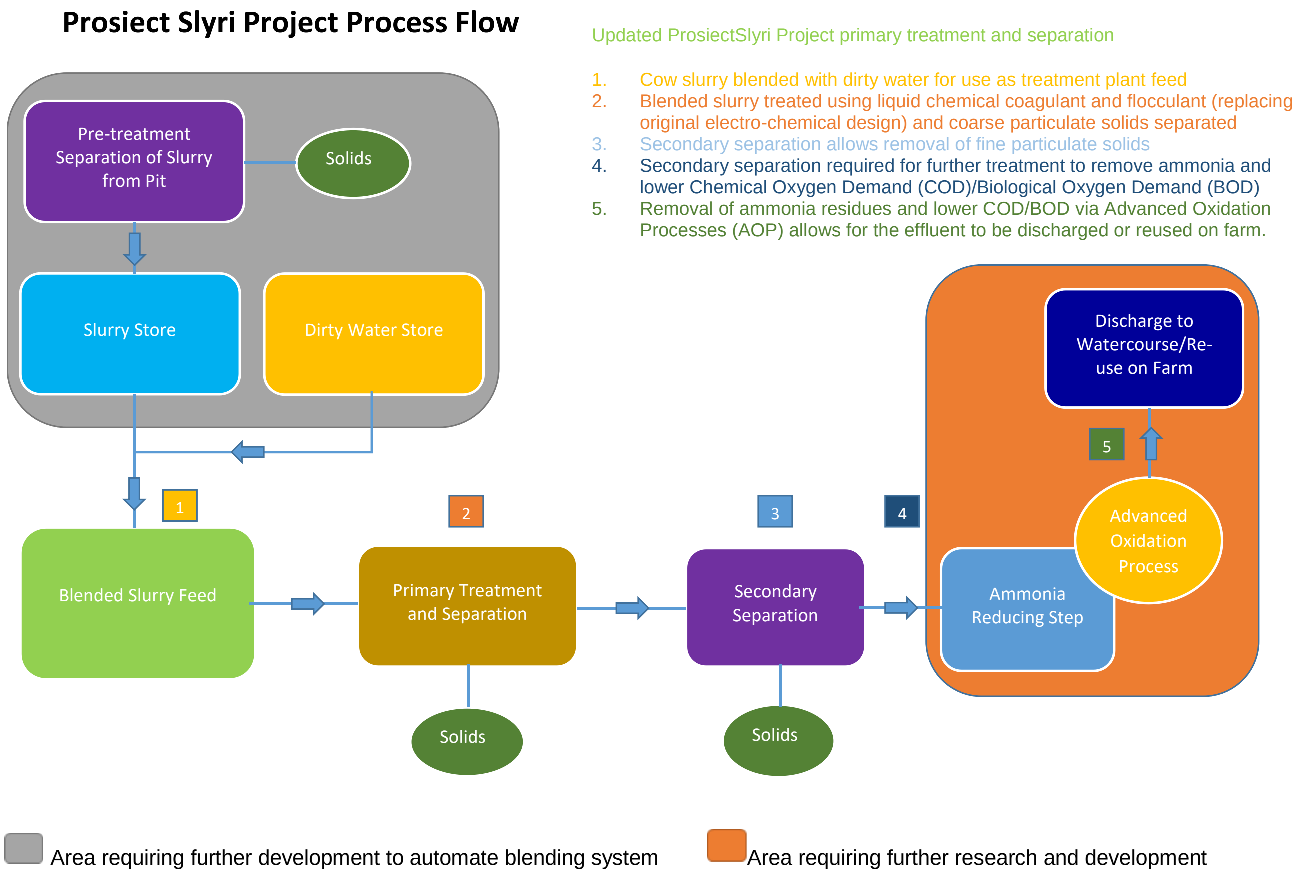
- Slurry separators are designed primarily to produce as dry a cake as possible, where the treatment plant requires a liquor which is as low in solids as possible.
- Fluctuations in slurry feed need to be accounted for in future
- Up to 70% of the total solids in slurry can be dissolved
- Enhanced removal rates seen using GEA Decanter when compared to Cri-man Screw-Press
- High solids loadings prevent adequate coagulation and flocculation of dissolved and colloidal particulates.
- Mechanical separation and removal of enough of the solids can prove problematic and may require blending with a ‘dirty water’ source to achieve treatment targets.
- Soneco© sono-electrocoagulation is currently not suitable for use on farms as a slurry treatment technology.
- The technical aspects of operating the disk stack centrifuge may become prohibitive for use on farms and it may be possible to omit this technology from the treatment plant.
- The Soneco© AOP reactor did not perform as intended. Further work must be done to adapt current design in order to increase oxidation potential.

Recommendations

- Remove inconsistencies with slurry feed by continuously mixing without greatly reducing the particle size (i.e. gently stirring).

- Blend separated slurry with 'dirty water' when required for a final pre-treatment feed =1.5-2.0%TS
- Optimise decanter centrifuge parameters for use with liquid chemical
- Adapt AOP in order to increase oxidation potential

Figure 8: Adapted Process Flow



Disruption to Project

During the course of the project there were a number of occasions that the plant was not operational. The most obvious of these was the Covid-19 pandemic, where non-essential personnel were not permitted on the college campus grounds during the UK national lockdown (23rd March – 20th July 2020). Prior to this time an electrical issue meant that the plant operations had to be halted until a replacement component could be installed. In addition, a faulty HMI screen on the decanter centrifuge meant that trials had to be suspended until a new HMI could be sourced and installed by trained technicians. A second lockdown in Wales (23rd October – 9th November) prevented operations at this time also.

The project used NRW Analytical Services to provide the sample analysis. Due to laboratory HVAC refurbishment there was a period (totalling approximately 3 months) when the laboratory wasn't available for commercial sample testing. Additionally, due to the covid-19 pandemic, NRW were also unable to accept and analyse any commercial samples until November 2020. Any samples analysed at the Power and Water in-house laboratory could not be verified as the laboratory is not UKAS accredited.

Sample Testing

Sample testing was primarily conducted by NRW Analytical Services. However, other UKAS accredited laboratories were also utilised from time to time to conduct analyses not offered by NRW, as well as the Power and Water in-house laboratory.

APPENDICES

Chart 1. PDSA of Raw Shed Slurry

TEST REPORT
PARTICLE SIZE DISTRIBUTION ANALYSIS
BS 1377:Part 2:1990: Clause 9.2 / 9.4

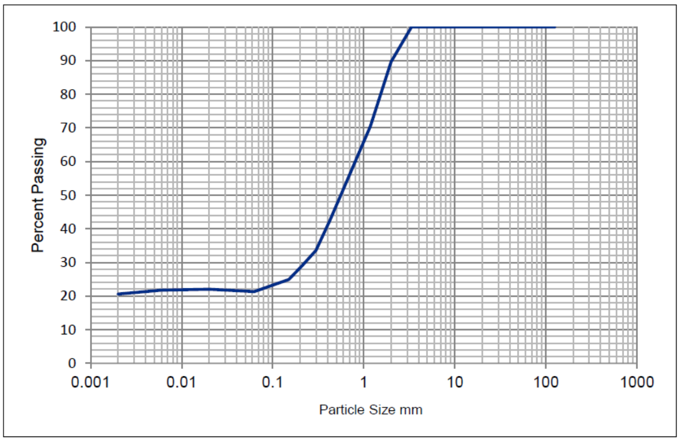
Project No:	D9215-19	**Client:**	Power & Water
Project Name:	Cow Slurry Testing	**Address:**	Unit C10 Ashmount Business Park Swansea SA6 8QR
ATS Sample No:	18347		

Site Ref / Hole ID:	Shed Slurry	**Depth (m):**	
Sample No:	N/A	**Sample Type:**	Bulk
Sampling Certificate Received:	No	**Material Description:**	Cow Slurry
Location in Works:	Shed	**Material Source:**	N/A
Date Sampled:	Unknown	**Material Supplier:**	Client
Sampled By:	Client	**Specification:**	BS 1377
Date Received:	21 June 2019	**Date Tested:**	01 June 2019

Test Results

Sieving	
Particle Size mm	% Passing
125	100
90	100
75	100
63	100
50	100
37.5	100
28	100
20	100
14	100
10	100
6.3	100
5.0	100
3.35	100
2.00	90
1.18	70
0.600	52
0.425	42
0.300	34
0.212	29
0.150	25
0.063	21

Preparation / Pretreatment	
Sieve:	Pre dried
Pipette:	as BS1377



Sedimentation	
Particle Size mm	% Passing
0.0201	22
0.0060	22
0.0020	21

Sample Portions	
Cobbles / Boulders	0
Gravel	10
Sand	68
Silt	1
Clay	21

Particle Density Mg/m3	
N/A	assumed
Dry mass of sample, kg	
0.01	

Uniformity Coefficient
D_{60} / D_{10}

Remarks:

QA Ref.	**Apex Testing Solutions**	Approver	Date	Fig
BS1377 - 2 Rev 3.0	Sturmi Way, Village Farm Industrial Est, Pyle, Bridgend, CF33 6BZ Tel: 01656 746762 Fax: 01656 749096 7771	A Grogan A Grogan, Laboratory Manager	01/07/2019	PSD

Chart 2. PDSA of Slurry in the Treatment Plant Feed Line

TEST REPORT
PARTICLE SIZE DISTRIBUTION ANALYSIS
BS 1377:Part 2:1990: Clause 9.2 / 9.4

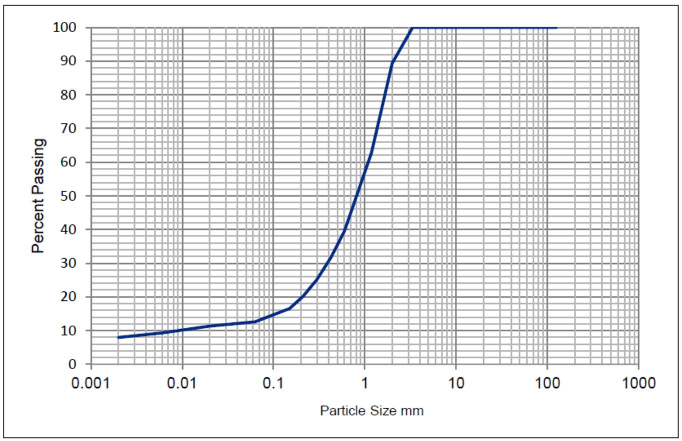
Project No:	D9215-19	**Client:**	Power & Water
Project Name:	Cow Slurry Testing	**Address:**	Unit C10 Ashmount Business Park Swansea SA6 8QR
ATS Sample No:	18348		

Site Ref / Hole ID:	Feed Line Slurry	**Depth (m):**	
Sample No:	N/A	**Sample Type:**	Bulk
Sampling Certificate Received:	No	**Material Description:**	Cow Slurry
Location in Works:	Feed Line	**Material Source:**	N/A
Date Sampled:	Unknown	**Material Supplier:**	Client
Sampled By:	Client	**Specification:**	BS 1377
Date Received:	21 June 2019	**Date Tested:**	01 July 2019

Test Results

Sieving	
Particle Size mm	% Passing
125	100
90	100
75	100
63	100
50	100
37.5	100
28	100
20	100
14	100
10	100
6.3	100
5.0	100
3.35	100
2.00	89
1.18	63
0.600	39
0.425	32
0.300	25
0.212	20
0.150	17
0.063	13

Preparation / Pretreatment	
Sieve:	Pre dried
Pipette:	as BS1377



Sedimentation	
Particle Size mm	% Passing
0.0201	11
0.0060	9
0.0020	8

Sample Portions	
Cobbles / Boulders	0
Gravel	11
Sand	77
Silt	5
Clay	8

Particle Density Mg/m3	
N/A	assumed
Dry mass of sample, kg	
0.02	

Uniformity Coefficient
D_{60} / D_{10}

Remarks:

QA Ref. BS1377 - 2 Rev 3.0	**Apex Testing Solutions** Sturmi Way, Village Farm Industrial Est, Pyle, Bridgend, CF33 6BZ Tel: 01656 746762 Fax: 01656 749096	7771	Approver *A Grogan* A Grogan, Laboratory Manager	Date 01/07/2019	Fig **PSD**

Chart 3. PSDA of the Decanter Centrifuge Centrate

TEST REPORT

PARTICLE SIZE DISTRIBUTION ANALYSIS

BS 1377:Part 2:1990: Clause 9.2 / 9.4

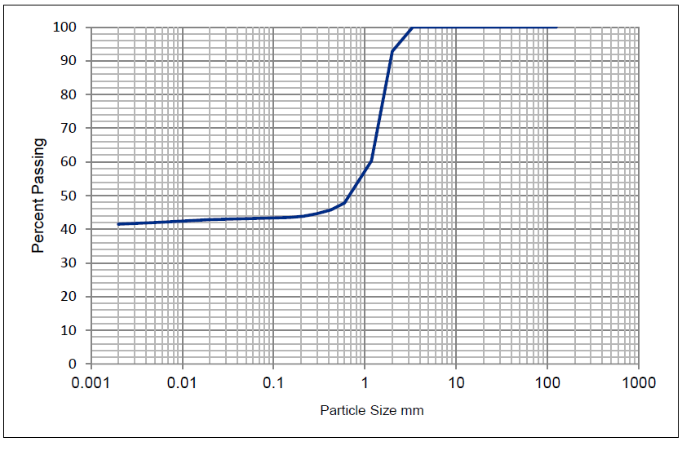
Project No:	D9215-19	**Client:**	Power & Water
Project Name:	Cow Slurry Testing	**Address:**	Unit C10 Ashmount Business Park Swansea SA6 8QR
ATS Sample No:	18346		

Site Ref / Hole ID:	Decanter Centrate	**Depth (m):**	
Sample No:	N/A	**Sample Type:**	Bulk
Sampling Certificate Received:	No	**Material Description:**	Cow Slurry
Location in Works:	Decanter Centrate	**Material Source:**	N/A
Date Sampled:	Unknown	**Material Supplier:**	Client
Sampled By:	Client	**Specification:**	BS 1377
Date Received:	21 June 2019	**Date Tested:**	01 July 2019

Test Results

Sieving	
Particle Size mm	% Passing
125	100
90	100
75	100
63	100
50	100
37.5	100
28	100
20	100
14	100
10	100
6.3	100
5.0	100
3.35	100
2.00	93
1.18	60
0.600	48
0.425	46
0.300	45
0.212	44
0.150	44
0.063	43

Preparation / Pretreatment	
Sieve:	Pre dried
Pipette:	as BS1377



Sedimentation	
Particle Size mm	% Passing
0.0201	43
0.0060	42
0.0020	42

Sample Portions	
Cobbles / Boulders	0
Gravel	7
Sand	50
Silt	2
Clay	42

Particle Density Mg/m3	
N/A	assumed
Dry mass of sample, kg	
0.03	

Uniformity Coefficient
D_{60} / D_{10}

Remarks:

QA Ref.	Apex Testing Solutions	Approver	Date	Fig
BS1377 - 2 Rev 3.0	Sturmi Way, Village Farm Industrial Est, Pyle, Bridgend, CF33 6BZ Tel: 01656 746762 Fax: 01656 749096 7771	A Grogan A Grogan, Laboratory Manager	01/07/2019	PSD

Chart 4. PSDA of the Disk Stack Centrifuge Centrate

TEST REPORT

PARTICLE SIZE DISTRIBUTION ANALYSIS

BS 1377:Part 2:1990: Clause 9.2 / 9.4

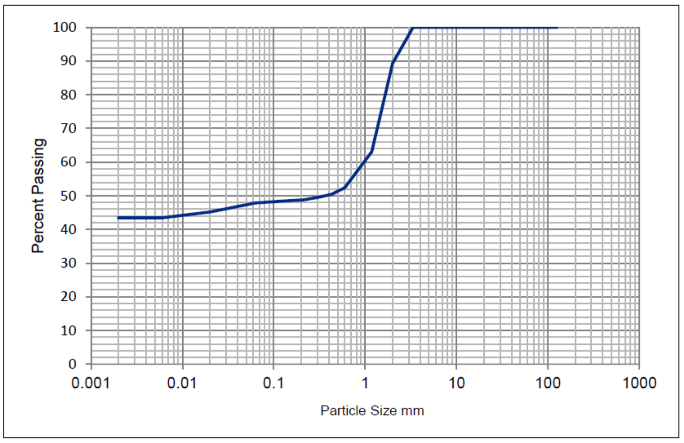
Project No:	D9215-19	**Client:**	Power & Water
Project Name:	Cow Slurry Testing	**Address:**	Unit C10 Ashmount Business Park Swansea SA6 8QR
ATS Sample No:	18345		

Site Ref / Hole ID:	Disk Stack	**Depth (m):**	
Sample No:	N/A	**Sample Type:**	Bulk
Sampling Certificate Received:	No	**Material Description:**	Cow Slurry
Location in Works:	Disk Stack	**Material Source:**	N/A
Date Sampled:	Unknown	**Material Supplier:**	Client
Sampled By:	Client	**Specification:**	BS 1377
Date Received:	21 June 2019	**Date Tested:**	01 July 2019

Test Results

Sieving	
Particle Size mm	% Passing
125	100
90	100
75	100
63	100
50	100
37.5	100
28	100
20	100
14	100
10	100
6.3	100
5.0	100
3.35	100
2.00	89
1.18	63
0.600	52
0.425	50
0.300	49
0.212	49
0.150	49
0.063	48

Preparation / Pretreatment	
Sieve:	Pre dried
Pipette:	as BS1377



Sedimentation	
Particle Size mm	% Passing
0.0201	45
0.0060	43
0.0020	43

Sample Portions	
Cobbles / Boulders	0
Gravel	11
Sand	41
Silt	4
Clay	43

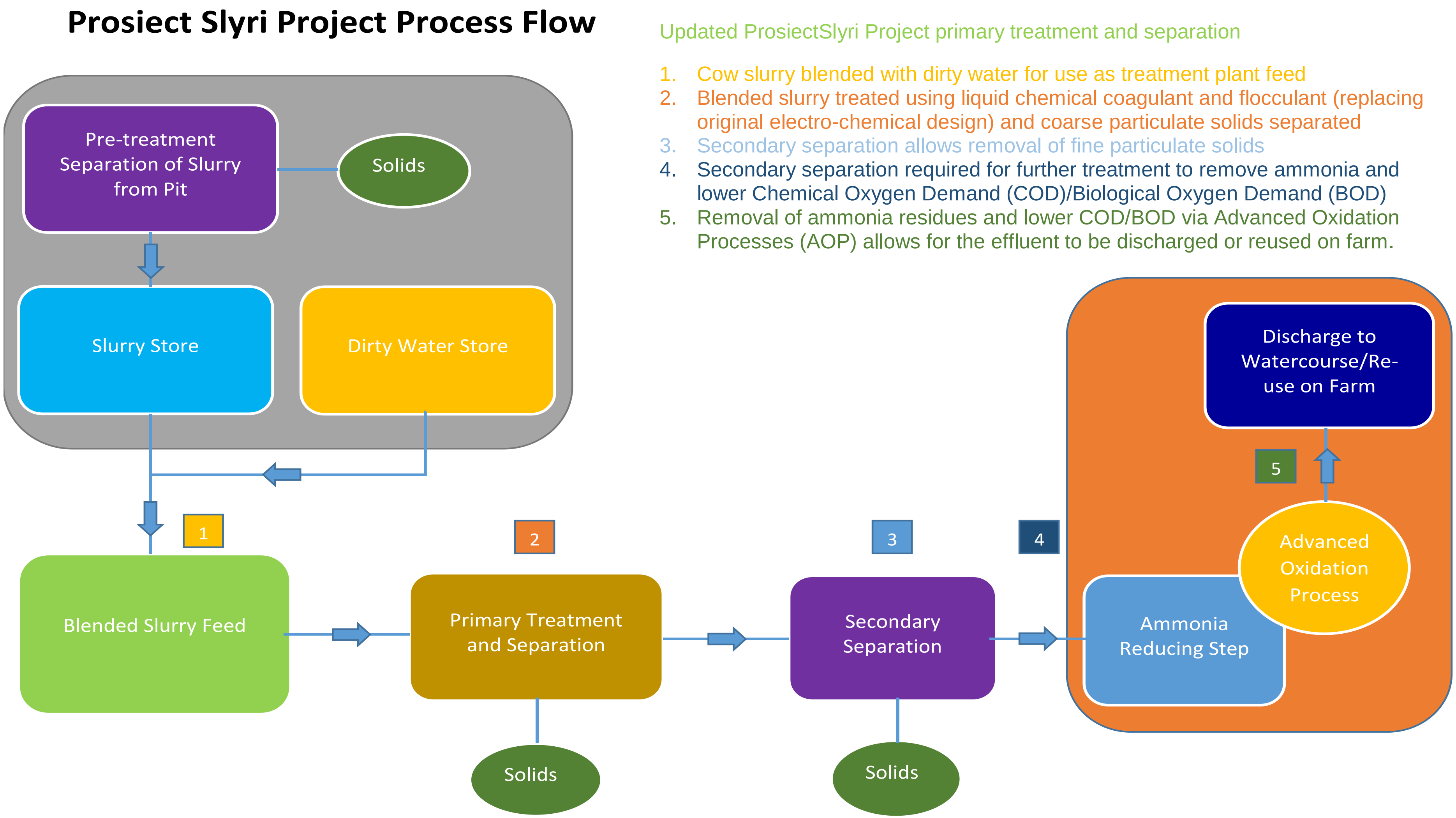
Particle Density Mg/m3	
N/A	assumed
Dry mass of sample, kg	
0.02	

Uniformity Coefficient
D_{60} / D_{10}

Remarks:

QA Ref. BS1377 - 2 Rev 3.0	ATS	**Apex Testing Solutions** Sturmi Way, Village Farm Industrial Est, Pyle, Bridgend, CF33 6BZ Tel: 01656 746762 Fax: 01656 749096	7771	Approver A Grogan A Grogan, Laboratory Manager	Date 01/07/2019
					Fig **PSD**

Chart 5: Change to original treatment process flow



Updated ProsiectSlyri Project primary treatment and separation

1. Cow slurry blended with dirty water for use as treatment plant feed
2. Blended slurry treated using liquid chemical coagulant and flocculant (replacing original electro-chemical design) and coarse particulate solids separated
3. Secondary separation allows removal of fine particulate solids
4. Secondary separation required for further treatment to remove ammonia and lower Chemical Oxygen Demand (COD)/Biological Oxygen Demand (BOD)
5. Removal of ammonia residues and lower COD/BOD via Advanced Oxidation Processes (AOP) allows for the effluent to be discharged or reused on farm.

Area requiring further development to automate blending system

Area requiring further research and development

Chart 6: PSDA Results for Mechanical Separators

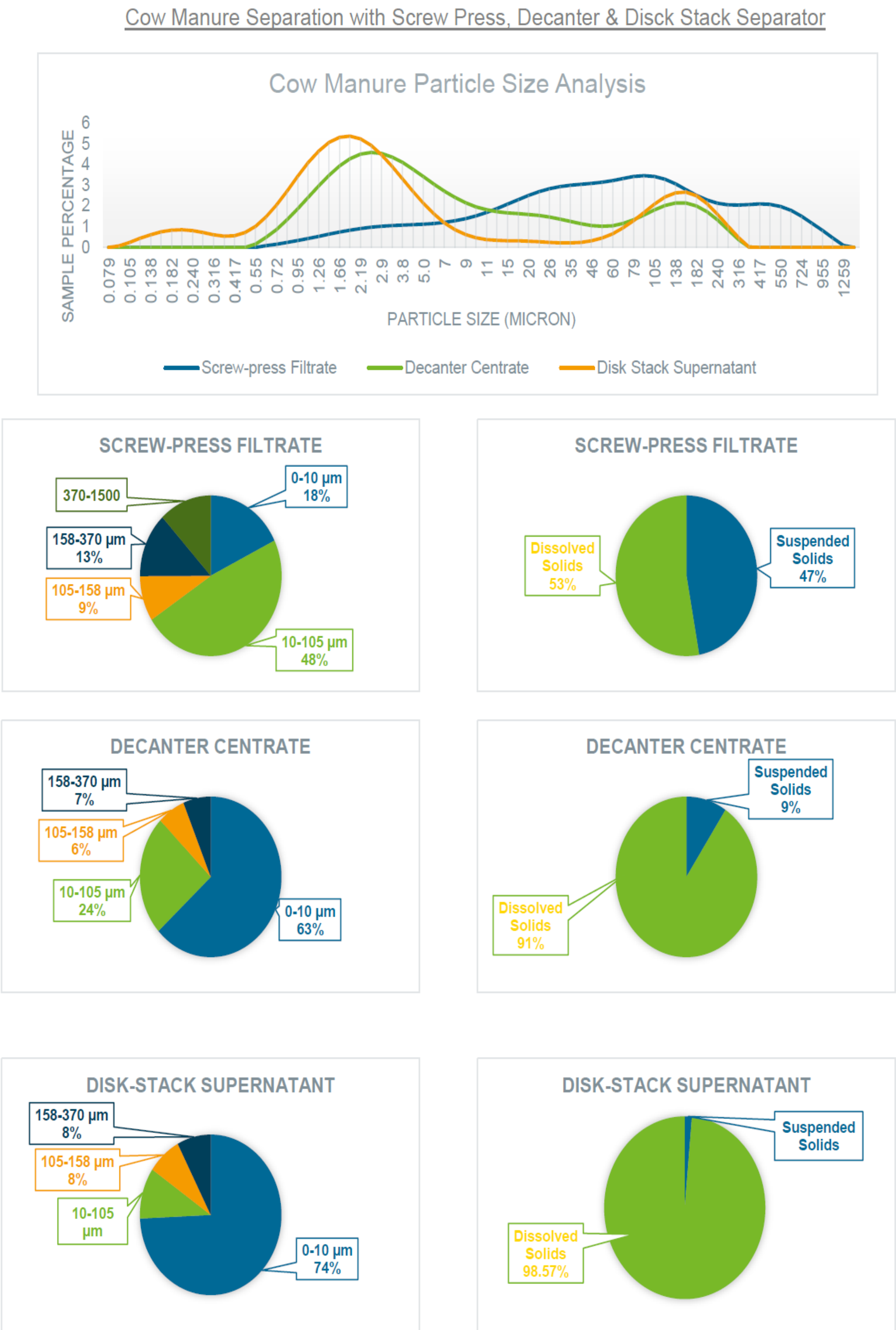


Figure 1. Disk Stack Centrifuge Solids Ejection Time Calculator

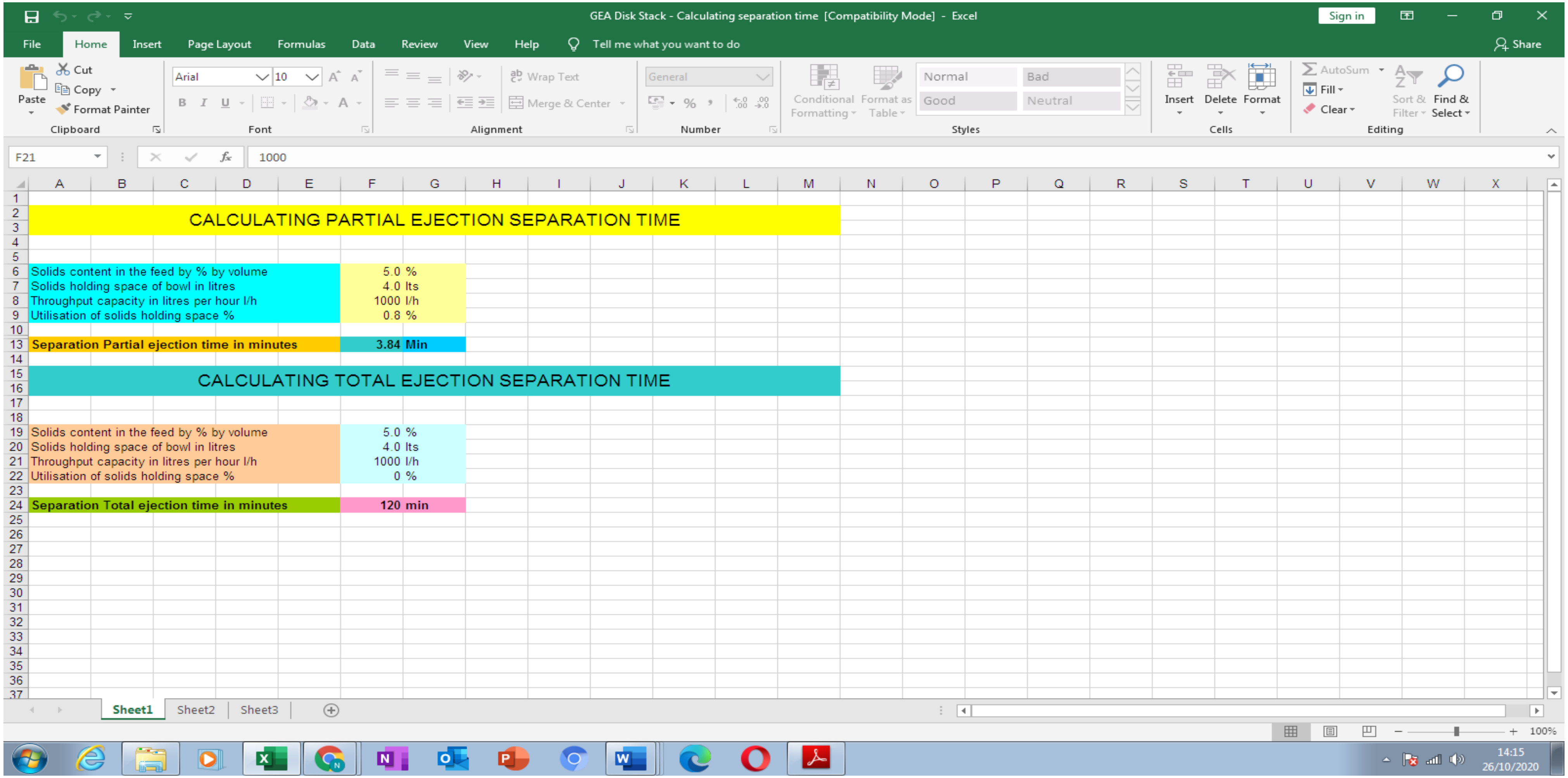


Table 1: Analysis Results for Separated Decanter Cake

KINGSHAY FARMING AND
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BRIDGE FARM
WEST BRADLEY
GLASTONBURY
SOMERSET BA6 8LU

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JOHN OWEN
COLEGSIRGAR
GELLIAUR COLLEGE FARM
CARMARTHERN
SA32 8NJ
DECANTER CAKE

CAKE ANALYSIS RESULTS

Sample Reference :

DECANTER CAKE

Sample Matrix : CAKE

Laboratory References	
Report Number	31248
Sample Number	118261

Date Received	19-NOV-2020
Date Reported	27-NOV-2020

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

ANALYTICAL RESULTS *on 'dry matter' basis.*

Determinand	Value	Units
Oven Dry Matter	20.2	%
Total Nitrogen	3.51	% w/w
Nitrate Nitrogen	<10	mg/kg
Ammonium Nitrogen	4802	mg/kg
Total Phosphorus (P)	7484	mg/kg
Total Potassium (K)	13670	mg/kg
Total Magnesium (Mg)	3404	mg/kg
Total Copper (Cu)	64.2	mg/kg
Total Zinc (Zn)	259	mg/kg
Total Sulphur (S)	4746	mg/kg

Released by *Myles Nicholson* Date *27/11/20*

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KINGSHAY FARMING AND CONSERVATION LTD BRIDGE FARM WEST BRADLEY GLASTONBURY SOMERSET BA6 8LU	JOHN OWEN COLEGSIRGAR GELLIAUR COLLEGE FARM CARMARTHERN SA32 8NJ DECANTER CAKE

H 91

Please quote above code for all enquiries

CAKE ANALYSIS RESULTS

Laboratory References	
Report Number	31248
Sample Number	118261

Sample Reference :

DECANTER CAKE

Sample Matrix : CAKE

Date Received	19-NOV-2020
Date Reported	27-NOV-2020

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

ANALYTICAL RESULTS *on 'dry matter' basis.*

Determinand	Value	Units
Total Calcium (Ca)	38809	mg/kg
Total Sodium (Na)	2783	mg/kg
pH 1:6 [Fresh]	7.26	

Released by Myles Nicholson Date 27/11/20

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Please quote above code for all enquiries

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GELLIAUR COLLEGE FARM
CARMARTHERN
SA32 8NJ
DECANTER CAKE

CAKE ANALYSIS RESULTS (Metric Units)

Sample Reference : DECANTER CAKE

Sample Matrix : CAKE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	31248
Sample Number	118261

Date Received	19-NOV-2020
Date Reported	27-NOV-2020

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result	Amount per fresh tonne	Amount applied at an equivalent total Nitrogen application of 250 kg N/ha	Units
pH 1:6 [Fresh]		7.26			
Oven Dry Matter	%	20.2	202.00	7123	kg DM
Total Nitrogen	% w/w	3.51	7.09	250	kg N
Ammonium Nitrogen	mg/kg	4797	0.97	34.17	kg NH4-N
Nitrate Nitrogen	mg/kg	<10	< 0.01		kg NO3-N
Total Phosphorus (P)	% w/w	0.748	3.46	122.00	kg P2O5
Total Potassium (K)	% w/w	1.37	3.32	117.09	kg K2O
Total Magnesium (Mg)	% w/w	0.340	1.14	40.20	kg MgO
Total Sulphur (S)	% w/w	0.475	2.40	84.58	kg SO3
Total Copper (Cu)	mg/kg	64.2	0.01	0.46	kg Cu
Total Zinc (Zn)	mg/kg	259	0.05	1.84	kg Zn
Total Sodium (Na)	% w/w	0.278	0.76	26.69	kg Na2O
Total Calcium (Ca)	mg/kg	38809	7.84	276.42	kg Ca
Equivalent field application rate		——	1.00	35.26	tonnes/ha

The above equivalent field application rate for total nitrogen of 250 kg/ha has been provided purely for guidance purposes only. Organic manures should be used in accordance with the Defra Code of Good Agricultural Practice and where required within the specific regulatory guidance for the spreading of that material to land. To get the most benefit from your organic manures it is recommended that you follow the principles as set out in Defra's Fertiliser Manual (RB209) or as directed by a FACTS qualified adviser.

Released by *Myles Nicholson* Date *27/11/20*

How does your sample analysis compare with the 'standard' figures for organic manures?

Farmyard Manure	Dry Matter (% DM)	Total Nitrogen (Kg N/t)	Total Phosphate (Kg P2O5/t)	Total Potash (Kg K2O/t)	Total Sulphur (Kg SO3/t)	Total Magnesium (Kg MgO/t)
Cattle FYM	25	6.0	3.2	9.4	2.4	1.8
Pig FYM	25	7.0	6.0	8.0	3.4	1.8
Sheep FYM	25	7.0	3.2	8.0	4.0	2.8
Duck FYM	25	6.5	5.5	7.5	2.6	2.4
Horse FYM	25	5.0	5.0	6.0	1.6	1.5
Goat FYM	40	9.5	4.5	12.0	2.8	1.8

Notes: The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 60% & 90% respectively.

Poultry Manure	Dry Matter (% DM)	Total Nitrogen (Kg N/t)	Total Phosphate (Kg P2O5/t)	Total Potash (Kg K2O/t)	Total Sulphur (Kg SO3/t)	Total Magnesium (Kg MgO/t)
	20	9.4	8.0	8.5	3.0	2.7
	40	19.0	12.0	15.0	5.6	4.3
	60	28.0	17.0	21.0	8.2	5.9
	80	37.0	21.0	27.0	11.0	7.5

Notes: The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 60% & 90% respectively.

Cattle & Pig Slurries	Dry Matter (% DM)	Total Nitrogen (Kg N/m3)	Total Phosphate (Kg P2O5/m3)	Total Potash (Kg K2O/m3)	Total Sulphur (Kg SO3/m3)	Total Magnesium (Kg MgO/m3)
Cattle slurry	6.0	2.6	1.2	2.5	0.7	0.6
Dirty water (from cattle)	0.5	0.5	0.1	1.0	0.1	0.1
Separated cattle slurries						
- strainer box liquid	1.5	1.5	0.3	1.5	ND	ND
- weeping wall liquid	3.0	2.0	0.5	2.3	ND	ND
- mechanically separated liquid	4.0	3.0	1.2	2.8	ND	ND
- solid portion after separation	20.0	4.0	2.0	3.3	ND	ND
Pig slurry	4.0	3.6	1.5	2.2	0.7	0.7
Separated pig slurry - liquid	3.0	3.6	1.1	2.0	ND	ND
Separated pig slurry - solid	20.0	5.0	3.7	2.0	ND	ND

Notes: ND = no data.
The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 50% & 90% respectively (50% & 100% for dirty water).

Biosolids	Dry Matter (% DM)	Total Nitrogen (Kg N/t)	Total Phosphate (Kg P2O5/t)	Total Potash (Kg K2O/t)	Total Sulphur (Kg SO3/t)	Total Magnesium (Kg MgO/t)
Digested cake	25	11.0	11.0	0.6	8.2	1.6
Thermally dried	95	40.0	55.0	2.0	23.0	6.0
Lime stablised	25	8.5	7.0	0.8	7.4	2.4
Composted	40	11.0	10.0	3.0	6.1	2.0

Notes: The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 50% & 90% respectively.

Other Organic Manures	Dry Matter	Total Nitrogen	Total Phosphate	Total Potash	Total Sulphur	Total Magnesium
Composts	(% DM)	(Kg N/t)	(Kg P2O5/t)	(Kg K2O/t)	(Kg SO3/t)	(Kg MgO/t)
Green compost	60	7.5	3.0	6.8	3.4	3.4
Green/food compost	60	11.0	4.9	8.0	5.1	3.4
Mushroom compost	35	6.0	5.0	9.0	ND	ND
Digestates						
Food-based whole	4.1	4.8	1.1	2.4	0.7	0.2
Food-based separated liquor	3.8	4.5	1.0	2.8	1.0	0.2
Food-based separated fibre	27.0	8.9	10.2	3.0	4.0	2.2
Farm-sourced whole	5.5	3.6	1.7	4.0	0.8	0.6
Farm-sourced separated liquor	3.0	1.9	0.6	2.5	<0.1	0.4
Farm-sourced separated fibre	24.0	5.6	4.7	6.0	1.2	1.8
Paper Crumble						
Chemically / physically treated	40	2.0	0.4	0.2	0.6	1.4
Biologically treated	30	7.5	3.8	0.4	2.4	1.0
Water Treatment Cake						
Water treatment cake	25	2.4	3.4	0.4	5.5	0.8
Food industry 'wastes'	(% DM)	(Kg N/m3)	(Kg P2O5/m3)	(Kg K2O/m3)	(Kg SO3/m3)	(Kg MgO/m3)
Dairy waste	4	1.0	0.8	0.2	ND	ND
Soft drinks waste	4	0.3	0.2	Trace	ND	ND
Brewing waste	7	2.0	0.8	0.2	ND	ND
General food waste	5	1.6	0.7	0.2	ND	ND

Notes: ND = no data.

The 'standard' figures for the above organic manures have been taken from Defra's Fertiliser Manual 2017 (RB209) 9th edition and the corresponding PLANET version 3 software. Further information on fertiliser recommendations for organic manures can be obtained from the Fertiliser Manual or from a FACTS qualified adviser.

Table 2: Analysis Results for Separated Screw-Press Cake

KINGSHAY FARMING AND
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BRIDGE FARM
WEST BRADLEY
GLASTONBURY
SOMERSET BA6 8LU

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GELLI AUR COLLEGE FARM
CARMARTHEN
SA32 8NJ
SCREW CAKE

CAKE ANALYSIS RESULTS

Sample Reference :

SCREW CAKE

Sample Matrix : CAKE

Laboratory References	
Report Number	31760
Sample Number	118360

Date Received	23-NOV-2020
Date Reported	30-NOV-2020

The sample submitted was of adequate size to complete all analysis requested.
The sample will be kept as the dry ground sample for at least 1 month.

ANALYTICAL RESULTS *on 'dry matter' basis.*

Determinand	Value	Units
Oven Dry Matter	24.5	%
Total Nitrogen	1.38	% w/w
Nitrate Nitrogen	<10	mg/kg
Ammonium Nitrogen	2483	mg/kg
Total Phosphorus (P)	1821	mg/kg
Total Potassium (K)	8568	mg/kg
Total Magnesium (Mg)	3342	mg/kg
Total Copper (Cu)	60.2	mg/kg
Total Zinc (Zn)	110	mg/kg
Total Sulphur (S)	2321	mg/kg

Released by Myles Nicholson Date 30/11/20

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KINGSHAY FARMING AND CONSERVATION LTD BRIDGE FARM WEST BRADLEY GLASTONBURY SOMERSET BA6 8LU	JOHN OWEN COLEG SIR GAR GELLI AUR COLLEGE FARM CARMARTHEN SA32 8NJ SCREW CAKE

H 91

Please quote above code for all enquiries

CAKE ANALYSIS RESULTS

Laboratory References	
Report Number	31760
Sample Number	118360

Sample Reference :

SCREW CAKE

Sample Matrix : CAKE

Date Received	23-NOV-2020
Date Reported	30-NOV-2020

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

ANALYTICAL RESULTS *on 'dry matter' basis.*

Determinand	Value	Units
Total Calcium (Ca)	65727	mg/kg
Total Sodium (Na)	1810	mg/kg
pH 1:6 [Fresh]	7.48	

Released by Myles Nicholson Date 30/11/20

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GELLI AUR COLLEGE FARM
CARMARTHEN
SA32 8NJ
SCREW CAKE

CAKE ANALYSIS RESULTS (Metric Units)

Sample Reference : SCREW CAKE

Sample Matrix : CAKE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	31760
Sample Number	118360

Date Received	23-NOV-2020
Date Reported	30-NOV-2020

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result	Amount per fresh tonne	Amount applied at an equivalent total Nitrogen application of 250 kg N/ha	Units
pH 1:6 [Fresh]		7.48			
Oven Dry Matter	%	24.5	245.00	18116	kg DM
Total Nitrogen	% w/w	1.38	3.38	250	kg N
Ammonium Nitrogen	mg/kg	2482	0.61	44.96	kg NH4-N
Nitrate Nitrogen	mg/kg	<10	< 0.01		kg NO3-N
Total Phosphorus (P)	% w/w	0.182	1.02	75.50	kg P2O5
Total Potassium (K)	% w/w	0.857	2.52	186.30	kg K2O
Total Magnesium (Mg)	% w/w	0.334	1.36	100.44	kg MgO
Total Sulphur (S)	% w/w	0.232	1.42	105.07	kg SO3
Total Copper (Cu)	mg/kg	60.2	0.01	1.09	kg Cu
Total Zinc (Zn)	mg/kg	110	0.03	1.99	kg Zn
Total Sodium (Na)	% w/w	0.181	0.60	44.20	kg Na2O
Total Calcium (Ca)	mg/kg	65727	16.10	1190.71	kg Ca
Equivalent field application rate		——	1.00	73.94	tonnes/ha

The above equivalent field application rate for total nitrogen of 250 kg/ha has been provided purely for guidance purposes only. Organic manures should be used in accordance with the Defra Code of Good Agricultural Practice and where required within the specific regulatory guidance for the spreading of that material to land. To get the most benefit from your organic manures it is recommended that you follow the principles as set out in Defra's Fertiliser Manual (RB209) or as directed by a FACTS qualified adviser.

Released by *Myles Nicholson* Date *30/11/20*

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How does your sample analysis compare with the 'standard' figures for organic manures?

Farmyard Manure	Dry Matter (% DM)	Total Nitrogen (Kg N/t)	Total Phosphate (Kg P2O5/t)	Total Potash (Kg K2O/t)	Total Sulphur (Kg SO3/t)	Total Magnesium (Kg MgO/t)
Cattle FYM	25	6.0	3.2	9.4	2.4	1.8
Pig FYM	25	7.0	6.0	8.0	3.4	1.8
Sheep FYM	25	7.0	3.2	8.0	4.0	2.8
Duck FYM	25	6.5	5.5	7.5	2.6	2.4
Horse FYM	25	5.0	5.0	6.0	1.6	1.5
Goat FYM	40	9.5	4.5	12.0	2.8	1.8

Notes: The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 60% & 90% respectively.

Poultry Manure	Dry Matter (% DM)	Total Nitrogen (Kg N/t)	Total Phosphate (Kg P2O5/t)	Total Potash (Kg K2O/t)	Total Sulphur (Kg SO3/t)	Total Magnesium (Kg MgO/t)
	20	9.4	8.0	8.5	3.0	2.7
	40	19.0	12.0	15.0	5.6	4.3
	60	28.0	17.0	21.0	8.2	5.9
	80	37.0	21.0	27.0	11.0	7.5

Notes: The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 60% & 90% respectively.

Cattle & Pig Slurries	Dry Matter (% DM)	Total Nitrogen (Kg N/m3)	Total Phosphate (Kg P2O5/m3)	Total Potash (Kg K2O/m3)	Total Sulphur (Kg SO3/m3)	Total Magnesium (Kg MgO/m3)
Cattle slurry	6.0	2.6	1.2	2.5	0.7	0.6
Dirty water (from cattle)	0.5	0.5	0.1	1.0	0.1	0.1
Separated cattle slurries						
- strainer box liquid	1.5	1.5	0.3	1.5	ND	ND
- weeping wall liquid	3.0	2.0	0.5	2.3	ND	ND
- mechanically separated liquid	4.0	3.0	1.2	2.8	ND	ND
- solid portion after separation	20.0	4.0	2.0	3.3	ND	ND
Pig slurry	4.0	3.6	1.5	2.2	0.7	0.7
Separated pig slurry - liquid	3.0	3.6	1.1	2.0	ND	ND
Separated pig slurry - solid	20.0	5.0	3.7	2.0	ND	ND

Notes: ND = no data.
The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 50% & 90% respectively (50% & 100% for dirty water).

Biosolids	Dry Matter (% DM)	Total Nitrogen (Kg N/t)	Total Phosphate (Kg P2O5/t)	Total Potash (Kg K2O/t)	Total Sulphur (Kg SO3/t)	Total Magnesium (Kg MgO/t)
Digested cake	25	11.0	11.0	0.6	8.2	1.6
Thermally dried	95	40.0	55.0	2.0	23.0	6.0
Lime stablised	25	8.5	7.0	0.8	7.4	2.4
Composted	40	11.0	10.0	3.0	6.1	2.0

Notes: The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 50% & 90% respectively.

Other Organic Manures	Dry Matter	Total Nitrogen	Total Phosphate	Total Potash	Total Sulphur	Total Magnesium
Composts	(% DM)	(Kg N/t)	(Kg P2O5/t)	(Kg K2O/t)	(Kg SO3/t)	(Kg MgO/t)
Green compost	60	7.5	3.0	6.8	3.4	3.4
Green/food compost	60	11.0	4.9	8.0	5.1	3.4
Mushroom compost	35	6.0	5.0	9.0	ND	ND
Digestates						
Food-based whole	4.1	4.8	1.1	2.4	0.7	0.2
Food-based separated liquor	3.8	4.5	1.0	2.8	1.0	0.2
Food-based separated fibre	27.0	8.9	10.2	3.0	4.0	2.2
Farm-sourced whole	5.5	3.6	1.7	4.0	0.8	0.6
Farm-sourced separated liquor	3.0	1.9	0.6	2.5	<0.1	0.4
Farm-sourced separated fibre	24.0	5.6	4.7	6.0	1.2	1.8
Paper Crumble						
Chemically / physically treated	40	2.0	0.4	0.2	0.6	1.4
Biologically treated	30	7.5	3.8	0.4	2.4	1.0
Water Treatment Cake						
Water treatment cake	25	2.4	3.4	0.4	5.5	0.8
Food industry 'wastes'	(% DM)	(Kg N/m3)	(Kg P2O5/m3)	(Kg K2O/m3)	(Kg SO3/m3)	(Kg MgO/m3)
Dairy waste	4	1.0	0.8	0.2	ND	ND
Soft drinks waste	4	0.3	0.2	Trace	ND	ND
Brewing waste	7	2.0	0.8	0.2	ND	ND
General food waste	5	1.6	0.7	0.2	ND	ND

Notes: ND = no data.

The 'standard' figures for the above organic manures have been taken from Defra's Fertiliser Manual 2017 (RB209) 9th edition and the corresponding PLANET version 3 software. Further information on fertiliser recommendations for organic manures can be obtained from the Fertiliser Manual or from a FACTS qualified adviser.

Table 3: Analysis results for Composted Solids

KINGSHAY FARMING AND
CONSERVATION LTD
BRIDGE FARM
WEST BRADLEY
GLASTONBURY
SOMERSET BA6 8LU

H 91

Please quote above code for all enquiries

JOHN OWEN CSG
GELLI AUR COLLEGE FARM
CARMARTHEN
CARMARTHENSHIRE
SA32 8NJ
COMPOST

COMPOST ANALYSIS RESULTS

Sample Reference :
COMPOST

Sample Matrix : COMPOST

Laboratory References	
Report Number	31493
Sample Number	118293

Date Received	20-NOV-2020
Date Reported	27-NOV-2020

The sample submitted was of adequate size to complete all analysis requested.
The sample will be kept as the dry ground sample for at least 1 month.

ANALYTICAL RESULTS *on 'dry matter' basis.*

Determinand	Value	Units
Oven Dry Matter	23.5	%
Total Nitrogen	2.80	% w/w
Nitrate Nitrogen	660	mg/kg
Ammonium Nitrogen	106	mg/kg
Total Phosphorus (P)	4300	mg/kg
Total Potassium (K)	28154	mg/kg
Total Magnesium (Mg)	6138	mg/kg
Total Copper (Cu)	49.1	mg/kg
Total Zinc (Zn)	266	mg/kg
Total Sulphur (S)	5271	mg/kg

Released by Myles Nicholson Date 27/11/20

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Tel: +44 (0) 1344 886338 **Fax:** +44 (0) 1344 890972 **Email:** enquiries@nrm.uk.com **www**.nrm.uk.com

KINGSHAY FARMING AND
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JOHN OWEN CSG
GELLI AUR COLLEGE FARM
CARMARTHEN
CARMARTHENSHIRE
SA32 8NJ
COMPOST

COMPOST ANALYSIS RESULTS

Laboratory References	
Report Number	31493
Sample Number	118293

Sample Reference :

COMPOST

Sample Matrix : COMPOST

Date Received	20-NOV-2020
Date Reported	27-NOV-2020

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

ANALYTICAL RESULTS *on 'dry matter' basis.*

Determinand	Value	Units
Total Calcium (Ca)	26332	mg/kg
Total Sodium (Na)	4302	mg/kg
pH 1:6 [Fresh]	8.93	

Released by Myles Nicholson Date 27/11/20

NRM Coopers Bridge, Braziers Lane, Bracknell, Berkshire RG42 6NS
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KINGSHAY FARMING AND
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JOHN OWEN CSG
GELLI AUR COLLEGE FARM
CARMARTHEN
CARMARTHENSHIRE
SA32 8NJ
COMPOST

COMPOST ANALYSIS RESULTS (Metric Units)

Sample Reference : COMPOST

Sample Matrix : COMPOST

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	31493
Sample Number	118293

Date Received	20-NOV-2020
Date Reported	27-NOV-2020

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result	Amount per fresh tonne	Amount applied at an equivalent total Nitrogen application of 250 kg N/ha	Units
pH 1:6 [Fresh]		8.93			
Oven Dry Matter	%	23.5	235.00	8929	kg DM
Total Nitrogen	% w/w	2.80	6.58	250	kg N
Ammonium Nitrogen	mg/kg	106	0.02	0.95	kg NH4-N
Nitrate Nitrogen	mg/kg	660	0.16	5.89	kg NO3-N
Total Phosphorus (P)	% w/w	0.430	2.31	87.92	kg P2O5
Total Potassium (K)	% w/w	2.82	7.95	302.14	kg K2O
Total Magnesium (Mg)	% w/w	0.614	2.40	91.00	kg MgO
Total Sulphur (S)	% w/w	0.527	3.10	117.63	kg SO3
Total Copper (Cu)	mg/kg	49.1	0.01	0.44	kg Cu
Total Zinc (Zn)	mg/kg	266	0.06	2.38	kg Zn
Total Sodium (Na)	% w/w	0.430	1.36	51.75	kg Na2O
Total Calcium (Ca)	mg/kg	26332	6.19	235.11	kg Ca
Equivalent field application rate		——	1.00	37.99	tonnes/ha

The above equivalent field application rate for total nitrogen of 250 kg/ha has been provided purely for guidance purposes only. Organic manures should be used in accordance with the Defra Code of Good Agricultural Practice and where required within the specific regulatory guidance for the spreading of that material to land. To get the most benefit from your organic manures it is recommended that you follow the principles as set out in Defra's Fertiliser Manual (RB209) or as directed by a FACTS qualified adviser.

Released by *Myles Nicholson* Date *27/11/20*

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Tel: +44 (0) 1344 886338 **Fax:** +44 (0) 1344 890972 **Email:** enquiries@nrm.uk.com **www**.nrm.uk.com

How does your sample analysis compare with the 'standard' figures for organic manures?

Farmyard Manure	Dry Matter (% DM)	Total Nitrogen (Kg N/t)	Total Phosphate (Kg P2O5/t)	Total Potash (Kg K2O/t)	Total Sulphur (Kg SO3/t)	Total Magnesium (Kg MgO/t)
Cattle FYM	25	6.0	3.2	9.4	2.4	1.8
Pig FYM	25	7.0	6.0	8.0	3.4	1.8
Sheep FYM	25	7.0	3.2	8.0	4.0	2.8
Duck FYM	25	6.5	5.5	7.5	2.6	2.4
Horse FYM	25	5.0	5.0	6.0	1.6	1.5
Goat FYM	40	9.5	4.5	12.0	2.8	1.8

Notes: The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 60% & 90% respectively.

Poultry Manure	Dry Matter (% DM)	Total Nitrogen (Kg N/t)	Total Phosphate (Kg P2O5/t)	Total Potash (Kg K2O/t)	Total Sulphur (Kg SO3/t)	Total Magnesium (Kg MgO/t)
	20	9.4	8.0	8.5	3.0	2.7
	40	19.0	12.0	15.0	5.6	4.3
	60	28.0	17.0	21.0	8.2	5.9
	80	37.0	21.0	27.0	11.0	7.5

Notes: The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 60% & 90% respectively.

Cattle & Pig Slurries	Dry Matter (% DM)	Total Nitrogen (Kg N/m3)	Total Phosphate (Kg P2O5/m3)	Total Potash (Kg K2O/m3)	Total Sulphur (Kg SO3/m3)	Total Magnesium (Kg MgO/m3)
Cattle slurry	6.0	2.6	1.2	2.5	0.7	0.6
Dirty water (from cattle)	0.5	0.5	0.1	1.0	0.1	0.1
Separated cattle slurries						
- strainer box liquid	1.5	1.5	0.3	1.5	ND	ND
- weeping wall liquid	3.0	2.0	0.5	2.3	ND	ND
- mechanically separated liquid	4.0	3.0	1.2	2.8	ND	ND
- solid portion after separation	20.0	4.0	2.0	3.3	ND	ND
Pig slurry	4.0	3.6	1.5	2.2	0.7	0.7
Separated pig slurry - liquid	3.0	3.6	1.1	2.0	ND	ND
Separated pig slurry - solid	20.0	5.0	3.7	2.0	ND	ND

Notes: ND = no data.
The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 50% & 90% respectively (50% & 100% for dirty water).

Biosolids	Dry Matter (% DM)	Total Nitrogen (Kg N/t)	Total Phosphate (Kg P2O5/t)	Total Potash (Kg K2O/t)	Total Sulphur (Kg SO3/t)	Total Magnesium (Kg MgO/t)
Digested cake	25	11.0	11.0	0.6	8.2	1.6
Thermally dried	95	40.0	55.0	2.0	23.0	6.0
Lime stablised	25	8.5	7.0	0.8	7.4	2.4
Composted	40	11.0	10.0	3.0	6.1	2.0

Notes: The 'standard' phosphate & potash availability figures to the next crop grown from Defra's Fertiliser Manual are 50% & 90% respectively.

Other Organic Manures	Dry Matter	Total Nitrogen	Total Phosphate	Total Potash	Total Sulphur	Total Magnesium
Composts	(% DM)	(Kg N/t)	(Kg P2O5/t)	(Kg K2O/t)	(Kg SO3/t)	(Kg MgO/t)
Green compost	60	7.5	3.0	6.8	3.4	3.4
Green/food compost	60	11.0	4.9	8.0	5.1	3.4
Mushroom compost	35	6.0	5.0	9.0	ND	ND
Digestates						
Food-based whole	4.1	4.8	1.1	2.4	0.7	0.2
Food-based separated liquor	3.8	4.5	1.0	2.8	1.0	0.2
Food-based separated fibre	27.0	8.9	10.2	3.0	4.0	2.2
Farm-sourced whole	5.5	3.6	1.7	4.0	0.8	0.6
Farm-sourced separated liquor	3.0	1.9	0.6	2.5	<0.1	0.4
Farm-sourced separated fibre	24.0	5.6	4.7	6.0	1.2	1.8
Paper Crumble						
Chemically / physically treated	40	2.0	0.4	0.2	0.6	1.4
Biologically treated	30	7.5	3.8	0.4	2.4	1.0
Water Treatment Cake						
Water treatment cake	25	2.4	3.4	0.4	5.5	0.8
Food industry 'wastes'	(% DM)	(Kg N/m3)	(Kg P2O5/m3)	(Kg K2O/m3)	(Kg SO3/m3)	(Kg MgO/m3)
Dairy waste	4	1.0	0.8	0.2	ND	ND
Soft drinks waste	4	0.3	0.2	Trace	ND	ND
Brewing waste	7	2.0	0.8	0.2	ND	ND
General food waste	5	1.6	0.7	0.2	ND	ND

Notes: ND = no data.

The 'standard' figures for the above organic manures have been taken from Defra's Fertiliser Manual 2017 (RB209) 9th edition and the corresponding PLANET version 3 software. Further information on fertiliser recommendations for organic manures can be obtained from the Fertiliser Manual or from a FACTS qualified adviser.

Table 4: Analysis Results for Field Trial Plots 2020

Contact : KINGSHAY FARMING AND CONSERVATION LTD BRIDGE FARM WEST BRADLEY GLASTONBURY SOMERSET BA6 8LU Tel. : 01458 851555	Client : JOHN OWEN COLEGSIRGAR GELLIAUR COLLEGE FARM CARMARTHERN SA32 8NJ

H 91

Please quote the above code for all enquiries

Sample Matrix : Agricultural Soil

Laboratory Reference

Card Number 17347/20

Date Received 16-Nov-20

Date Reported 17-Nov-20

SOIL ANALYSIS REPORT

Laboratory Sample Reference	Field Details		Soil pH	Index			mg/l (Available)		
	No.	Name or O.S. Reference with Cropping Details		P	K	Mg	P	K	Mg
74747/20	1	**PLOT1** *Grassland into Grassland*	**5.9**	**2**	**1**	**2**	**23.6**	**66**	**82**
74748/20	2	**PLOT2** *Grassland into Grassland*	**5.9**	**3**	**0**	**3**	**25.6**	**58**	**105**
74749/20	3	**PLOT3** *Grassland into Grassland*	**5.9**	**3**	**1**	**3**	**33.0**	**80**	**132**
74750/20	4	**PLOT4** *Grassland into Grassland*	**5.7**	**3**	**1**	**3**	**29.0**	**73**	**103**
74751/20	5	**PLOT5** *Grassland into Gooseberries Established*	**5.7**	**3**	**1**	**3**	**32.6**	**79**	**102**
74752/20	6	**PLOT6** *Grassland into Gooseberries Established*	**5.9**	**3**	**1**	**3**	**31.6**	**98**	**127**

If general fertiliser and lime recommendations have been requested, these are given on the following sheets.
The analytical methods used are as described in DEFRA Reference Book 427
The index values are determined from the AHDB Fertiliser Recommendations RB209 9th Edition.

Released by Gina Graham On behalf of NRM Ltd Date 17/11/20

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MICRO NUTRIENT REPORT

DATE **17th November 2020**

SAMPLES FROM **JOHN OWEN, COLEGSIRGAR, GELLIAUR COLLEGE FARM**

KINGSHAY FARMING AND
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BRIDGE FARM
WEST BRADLEY
GLASTONBURY
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Reference: **17347/74747/20** Field Name: **PLOT1**	Result	(*)	Deficient	Marginal	Target	Marginal	Excessive
Organic matter (LOI) %	7.4	1					

Reference: **17347/74748/20** Field Name: **PLOT2**	Result	(*)	Deficient	Marginal	Target	Marginal	Excessive
Organic matter (LOI) %	6.2	1					

Reference: **17347/74749/20** Field Name: **PLOT3**	Result	(*)	Deficient	Marginal	Target	Marginal	Excessive
Organic matter (LOI) %	6.4	1					

Reference: **17347/74750/20** Field Name: **PLOT4**	Result	(*)	Deficient	Marginal	Target	Marginal	Excessive
Organic matter (LOI) %	6.5	1					

Reference: **17347/74751/20** Field Name: **PLOT5**	Result	(*)	Deficient	Marginal	Target	Marginal	Excessive
Organic matter (LOI) %	6.7	1					

Reference: **17347/74752/20** Field Name: **PLOT6**	Result	(*)	Deficient	Marginal	Target	Marginal	Excessive
Organic matter (LOI) %	13.0	1					

Notes (*)

(1) The levels of organic matter in this soil are good. This should help to retain moisture and plant nutrients. NRM considers Organic soils to contain between 10-20% organic material with Peaty soils containing over 20% . The optimum ranges for Organic Matter which have been set are dependent on the soil type and the cropping but these must be viewed as guidance values only.

DATE 17th November 2020
SAMPLES FROM JOHN OWEN, COLEGSIRGAR, GELLIAUR COLLEGE FARM

SAMPLED BY

Report reference 17347/20

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BRIDGE FARM
WEST BRADLEY
GLASTONBURY
SOMERSET BA6 8LU
Tel: 01458 851555
Fax: 01458 851444

Fertiliser Recommendations

The phosphate and potash recommendations shown below, are those required to replace the offtake and maintain target soil indices. The larger recommended applications for soils below target index will allow the soil to build up to this target index over a number of years. Not applying fertiliser to soils which are above target index will allow the soil to run down over a number of years to the target index.
The recommendation should be increased or decreased where yields are substantially more or less than that specified. The amount to apply can be calculated using the expected yield and values for the offtake of phosphate and potash per tonne of yield given in the RB209 9th edition.
All recommendations are given for the mid-point of each Index.
Where a soil analysis value (as given by the laboratory) is close to the range of an adjacent Index, the recommendation may be reduced or increased slightly taking account of the recommendation given for the adjacent Index. Small adjustments of less than 10 kg/ha are generally not justified.
Efficient use of P and K is most likly to be achieved on soils that are well structured and enable good rooting.
For visual evaluation of soil structure (VESS), a score on 1 or 2 would be considered adequate.
Don't forget to deduct nutrients applied as organic manures.
For Nitrogen recommendations please refer to the RB209 9th edition or seek advice from an FACTS qualified adviser.
Target Indices:
Arable, Forage, Grassland and Potato Crops: P Index 2, K Index 2-
(In rotations where most crops are Autumn-sown, soils are in good condition and P is applied annually, high index 1 can be an adequate target.)
Vegetables and Bulbs: P Index 3, K Index 2+
(If vegetables are only grown occasionally as part of an arable rotation, it would be most economic to target index 2 for arable and forage crops.)
Fruit Vines and Hops: P Index 2, K Index 2, Mg Index 2
(Note: Cider apples respond to K Index 3, Mg Index 3)
A lime recommendation is usually for a 20cm depth of cultivated soil or a 15cm depth of grassland soil. Where soil is acid below 20 cm and soils are ploughed for arable crops, a proportionately larger quantity of lime should be applied. However, if more than 10 t/ha is needed, half should be deeply cultivated into the soil and ploughed down, with the remainder applied to the surface and worked in.
For established grassland or other situations where there is no, or only minimal soil cultivation, no more than 7.5 t/ha of lime should be applied in one application.
In these situations, applications of lime change the pH below the surface very slowly. Consequently, the underlying soil should not be allowed to become too acidic because this will affect the root growth and thus limit nutrient and water uptake, which will adversely affect yield.
The exception is the protocol for liming for planting fruit, vines and hops because acidity problems occur in patches and acidity can develop rapidly when herbicides are used. Thus the whole of the plough layer should be limed to maintain a pH value of 6.5 in the early years of fruit or hops. It will be impossible to correct any acidity at depth by later lime incorporation so the quantity of lime applied before planting should be calculated to correct the pH of the top 40cm of soil.
Where lime is needed to correct acidity in the subsoil, it should be ploughed down. Where sampling has only been carried out to 15cm depth, the lime requirement using this pH result should be doubled. If the total lime requirement is more than 7.5 t/ha, half should be deeply cultivated into the soil and ploughed down, with the remainder applied and worked in after ploughing. If less the 7.5 t/ha of lime is needed, the whole requirement should be applied after ploughing and cultivated in.
For Fruit, Vines and Hops:
Most fruit crops are tolerant of slight acidity and grow best at around pH 6.0 to 6.5. (6.5-6.8 before planting). Soil pH levels below about 5.5 can give rise to manganese toxicity, causing measley bark in apples and purple veining in some strawberry varieties. Blackcurrants are more susceptible to soil acidity and a pH of at least 6.5 should be maintained.
Blueberries are an exception to other fruit as they require a soil pH 4.5-5.5.
Mature hops can tolerate a considerable degree of soil acidity but some varieties may suffer from manganese toxicity if the soil becomes too acid. Young hop plants are more sensitive to acidity. It is important that soils used for fruit, vines and hops are not over limed as this may lead to micronutrient deficiencies such as iron and manganese.
Fruit crops are not generally thought to respond to sulphur. However, atmospheric sulphur emissions have declined significantly and a yield response to sulphur is possible in some circumstances. Where sulphur deficiency has been recognised or is expected, apply 15-25 kg/ha SO3. Sulphur should be applied as a sulphate containing fertiliser in the spring. Crops are most at risk of sulphur deficiency where they are grown on light sandy soils, soils with a low organic matter content, and in high rainfall areas.

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
PLOT1	**Grassland / Grassland**	*Units/Acre*				*T/Ac*	**0.6**
074747 / Medium		*Kg/Ha*				*Te/Ha*	**1.6**

In the first season after Autumn or Spring sowing, deduct the amount of phosphate and potash applied to the seedbed from the recommendations.

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
PLOT2	**Grassland / Grassland**	*Units/Acre*				*T/Ac*	**0.6**
074748 / Medium		*Kg/Ha*				*Te/Ha*	**1.6**

Fertiliser recommendations are based on **AHDB RB209 (Ninth Edition).** If a nutrient is deficient and no recommendation is given, either no recommendation is given in RB209 or we have insufficient data to give a recommendation. Apply Lime to the nearest half Ton / Tonne.
NRM is a UKAS accredited laboratory to ISO/IEC 17025

Report continued.......

DATE	17th November 2020
SAMPLES FROM	JOHN OWEN, COLEGSIRGAR, GELLIAUR COLLEGE FARM
SAMPLED BY	
Report reference	17347/20

KINGSHAY FARMING AND
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Tel: 01458 851555
Fax: 01458 851444

Fertiliser Recommendations

Please see previous sample for crop specific notes.

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
PLOT3	**Grassland / Grassland**	*Units/Acre*				*T/Ac*	**0.6**
074749 / Medium		*Kg/Ha*				*Te/Ha*	**1.6**

Please see previous sample for crop specific notes.

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
PLOT4	**Grassland / Grassland**	*Units/Acre*				*T/Ac*	**1.1**
074750 / Medium		*Kg/Ha*				*Te/Ha*	**2.6**

Please see previous sample for crop specific notes.

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
PLOT5	**Grassland / Gsbry Est**	*Units/Acre*	**32**	**144**	**0**	*T/Ac*	**1.4**
074751 / Medium		*Kg/Ha*	**40**	**180**	**0**	*Te/Ha*	**3.5**

For established crops, the timing of phosphate, potash and magnesium applications is not critical.
Sulphate of potash should be used for raspberries, redcurrants and gooseberries where more than 120 kg K2O/ha is applied.
To avoid inducing magnesium deficiency, the soil K: Mg ratio (based on soil mg/litre K and Mg) should be no greater than 3: 1.

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
PLOT6	**Grassland / Gsbry Est**	*Units/Acre*	**32**	**144**	**0**	*T/Ac*	**1.0**
074752 / Organ.		*Kg/Ha*	**40**	**180**	**0**	*Te/Ha*	**2.4**

Please see previous sample for crop specific notes.

Fertiliser recommendations are based on **AHDB RB209 (Ninth Edition).** If a nutrient is deficient and no recommendation is given, either no recommendation is given in RB209 or we have insufficient data to give a recommendation. Apply Lime to the nearest half Ton / Tonne.
NRM is a UKAS accredited laboratory to ISO/IEC 17025

Table 5: Analysis Results for Field Trial Plots 2019

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Client : JOHN OWEN
COLEG SIR GAR
PROSIECTSLYRI
GELLI AUR COLLEGE FARM
CARMARTHENSHIRE
SA32 8NJ

Sample Matrix : Agricultural Soil

Laboratory Reference
Card Number 07582/19

Date Received 01-Apr-19
Date Reported 17-Apr-19

SOIL ANALYSIS REPORT

Laboratory Sample Reference	Field Details		Soil pH	Index			mg/l (Available)		
	No.	Name or O.S. Reference with Cropping Details		P	K	Mg	P	K	Mg
34096/19	1	01 *Grassland into Grassland*	5.7	2	1	2	23.4	95	96
34097/19	2	02 *Grassland into Grassland*	6.1	2	2-	3	24.8	139	113
34098/19	3	03 *Grassland into Grassland*	5.8	2	2-	3	22.2	143	112
34099/19	4	04 *Grassland into Grassland*	5.9	3	2-	3	25.8	123	107
34100/19	5	05 *Grassland into Grassland*	6.0	3	2-	3	26.6	125	113
34101/19	6	06 *Grassland into Grassland*	6.0	3	2+	3	26.4	183	133

If general fertiliser and lime recommendations have been requested, these are given on the following sheets.
The analytical methods used are as described in DEFRA Reference Book 427
The index values are determined from the DEFRA Fertiliser Recommendations RB209 9th Edition.

Released by Joe Cherrie On behalf of NRM Ltd Date 17/04/19

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Registered Number: 05655711

PAAG
Professional Agricultural Analysis Group

DATE 17th April 2019
SAMPLES FROM JOHN OWEN, COLEG SIR GAR, PROSIECTSLYRI

SAMPLED BY

Report reference 07582/19

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Fertiliser Recommendations

The phosphate and potash recommendations shown below, are those required to replace the offtake and maintain target soil indices. The larger recommended applications for soils below target index will allow the soil to build up to this target index over a number of years. Not applying fertiliser to soils which are above target index will allow the soil to run down over a number of years to the target index.
The recommendation should be increased or decreased where yields are substantially more or less than that specified. The amount to apply can be calculated using the expected yield and values for the offtake of phosphate and potash per tonne of yield given in the RB209 9th edition.
All recommendations are given for the mid-point of each Index.
Where a soil analysis value (as given by the laboratory) is close to the range of an adjacent Index, the recommendation may be reduced or increased slightly taking account of the recommendation given for the adjacent Index. Small adjustments of less than 10 kg/ha are generally not justified.
Don't forget to deduct nutrients applied as organic manures.
For Nitrogen recommendations please refer to the RB209 9th edition or seek advice from an FACTS qualified adviser.
Target Indices:
Arable, Forage, Grassland and Potato Crops: P Index 2, K Index 2-
Vegetables and Bulbs: P Index 3, K Index 2+
Fruit Vines and Hops: P Index 2, K Index 2, Mg Index 2
(Note: Cider apples respond to K Index 3, Mg Index 3)
A lime recommendation is usually for a 20cm depth of cultivated soil or a 15cm depth of grassland soil. Where soil is acid below 20 cm and soils are ploughed for arable crops, a proportionately larger quantity of lime should be applied. However, if more than 10 t/ha is needed, half should be deeply cultivated into the soil and ploughed down, with the remainder applied to the surface and worked in.
For established grassland or other situations where there is no, or only minimal soil cultivation, no more than 7.5 t/ha of lime should be applied in one application.
In these situations, applications of lime change the pH below the surface very slowly. Consequently, the underlying soil should not be allowed to become too acidic because this will affect the root growth and thus limit nutrient and water uptake, which will adversely affect yield.
Fertiliser recommendations are based on DEFRA RB209 (Ninth Edition - 2017). If a nutrient is deficient and no recommendation is given, either no recommendation is given in RB209 or we have insufficient data to give a recommendation. Apply Lime to the nearest Ton / Tonne.
NRM is a UKAS accredited laboratory to ISO/IEC 17025:2005

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
01	**Grassland / Grassland**	*Units/Acre*				*T/Ac*	**1.1**
034096 / Medium		*Kg/Ha*				*Te/Ha*	**2.6**

In the first season after Autumn or Spring sowing, deduct the amount of phosphate and potash applied to the seedbed from the recommendations.

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
02	**Grassland / Grassland**	*Units/Acre*				*T/Ac*	**0**
034097 / Medium		*Kg/Ha*				*Te/Ha*	**0**

Please see previous sample for crop specific notes.

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
03	**Grassland / Grassland**	*Units/Acre*				*T/Ac*	**0.8**
034098 / Medium		*Kg/Ha*				*Te/Ha*	**2.1**

Please see previous sample for crop specific notes.

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
04	**Grassland / Grassland**	*Units/Acre*				*T/Ac*	**0.6**
034099 / Medium		*Kg/Ha*				*Te/Ha*	**1.6**

Please see previous sample for crop specific notes.

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
05	**Grassland / Grassland**	*Units/Acre*				*T/Ac*	**0**
034100 / Medium		*Kg/Ha*				*Te/Ha*	**0**

Fertiliser recommendations are based on **DEFRA RB209 (Ninth Edition - 2017)**. If a nutrient is deficient and no recommendation is given, either no recommendation is given in RB209 or we have insufficient data to give a recommendation. Apply Lime to the nearest half Ton / Tonne.
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Report continued.......

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PAAG Professional Agricultural Analysis Group

DATE	17th April 2019	
SAMPLES FROM	JOHN OWEN, COLEG SIR GAR, PROSIECTSLYRI	
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Report reference	07582/19	

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Fertiliser Recommendations

Please see previous sample for crop specific notes.

Field Name / Ref / Soil Type	*Last Crop / Next Crop*		*P2O5*	*K2O*	*MgO*		*Lime*
06	**Grassland / Grassland**	*Units/Acre*				*T/Ac*	**0**
034101 / Medium		*Kg/Ha*				*Te/Ha*	**0**

Please see previous sample for crop specific notes.

Fertiliser recommendations are based on **(Ninth Edition - 2017).** If a nutrient is deficient and no recommendation is given, either no recommendation is given in RB209 or we have insufficient data to give a recommendation. Apply Lime to the nearest half Ton / Tonne.
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Ignasi Sirés1, Enric Brillas1, Mehmet A. Oturan2, Manuel A. Rodrigo3, Marco
Panizza4*

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Review on BOD, COD and BOD/COD ratio: a triangle zone for toxic, biodegradable
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