

## Aqua Critox®

### Phosphorus Recovery From Sewage Sludge Using the Aquacritox Supercritical Water Oxidation Process

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#### **Abstract**

Sewage sludge is a potential source of energy. A kilogram of dried sewage sludge contains approximately 20,000 BTU's of energy. The challenge with releasing this energy is that sewage sludge, when collected from the bottom of a clarifier is 99% water. In order to release the energy present through gasification, pyrolysis or incineration, the water must be removed before oxidation in air can occur. This requires thickening mechanical dewatering and thermal drying. Supercritical water oxidation offers the potential to release all of the energy present in sludge, without first having to dewater the sewage sludge.

Sewage sludge also contains phosphorus. Every person produces approximately 1.2kg/annum of phosphorous. This is typically conveyed to a wastewater treatment plant. In the United Kingdom, the annual phosphorus load from human sources which is present in wastewater is therefore approximately 72,000 tonnes. This paper examines how the Aquacritox sludge to energy process could be used in combination with Biological phosphorus removal & a fluidised bed phosphorus recovery process to recover 70% of the total influent phosphorus load to the treatment plant. The paper provides a simulated case study at a 500K PE Biological phosphorus removal plant illustrating how this could be implemented. The paper also provides mass balance and cost estimates for the Aquacritox process.

#### **Introduction**

The Aqua Critox® process is a patented Super Critical Water Oxidation process developed to completely destroy the organic fraction of sewage sludge with no harmful emissions to air or water. The process uses the unique properties of supercritical water to completely destroy through oxidation all organic contaminants from sewage sludge.

The solids are mineralized within the Aqua Critox® process into sterile inert inorganic clay, carbon dioxide and nitrogen. The inorganic clay material can be used as a construction material. This inorganic clay like material can also be further processed to recover either or both phosphorous and coagulant.

As the oxidation process is exothermic the process generates significant amounts of surplus heat which can be recovered for heat applications or for the generation of electricity.

Because super critical water reactions do not necessitate the evaporation of water the process has a high thermal efficiency.

Super critical water oxidation is able to achieve high organic destruction rates (99.99 %+ ) without the requirement for expensive dewatering equipment upstream. Due to the unique properties of super critical water, SCWO achieves greater destruction efficiencies than incineration or wet air oxidation with the advantage in larger plants of excess electricity production over and above that required to run the process i.e. positive energy balance.

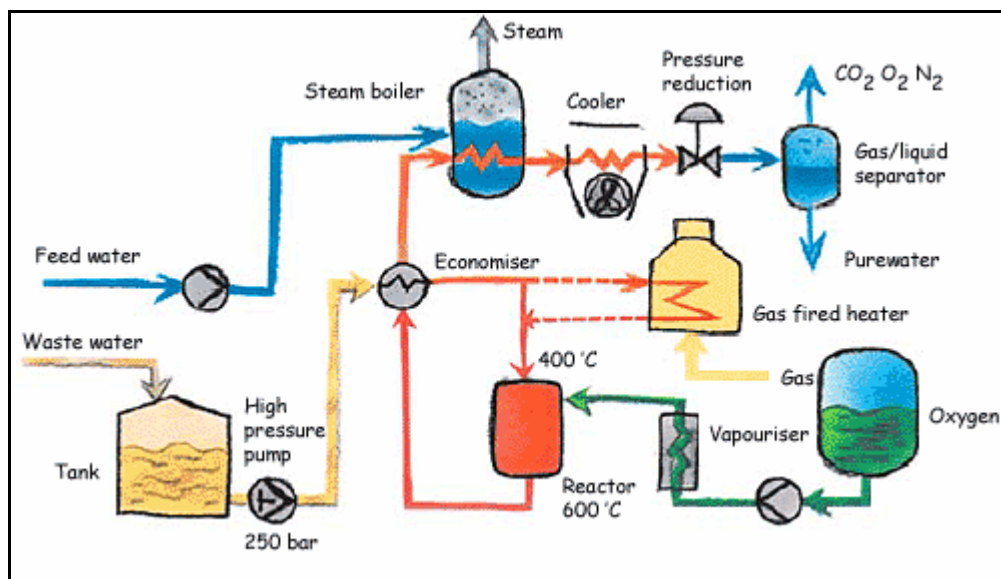
### The Aqua Critox® Process

The Aqua Critox® process is a patented process that utilises water and oxygen at elevated temperature and pressure to completely destroy the organic fraction of sewage sludge, with no harmful emissions to air or water. The process is totally enclosed and can achieve destruction efficiencies of close to 99.99%+ in less than 60secs residence time.

Both raw and digested sludge can be treated at 6% – 22 % dry solids, providing the option of reducing dewatering requirements earlier in the treatment process.

A general arrangement for an Aquacritox Plant is provided as **Figure 1** below.

**Figure 1** General Arrangement for Aquacritox Plant



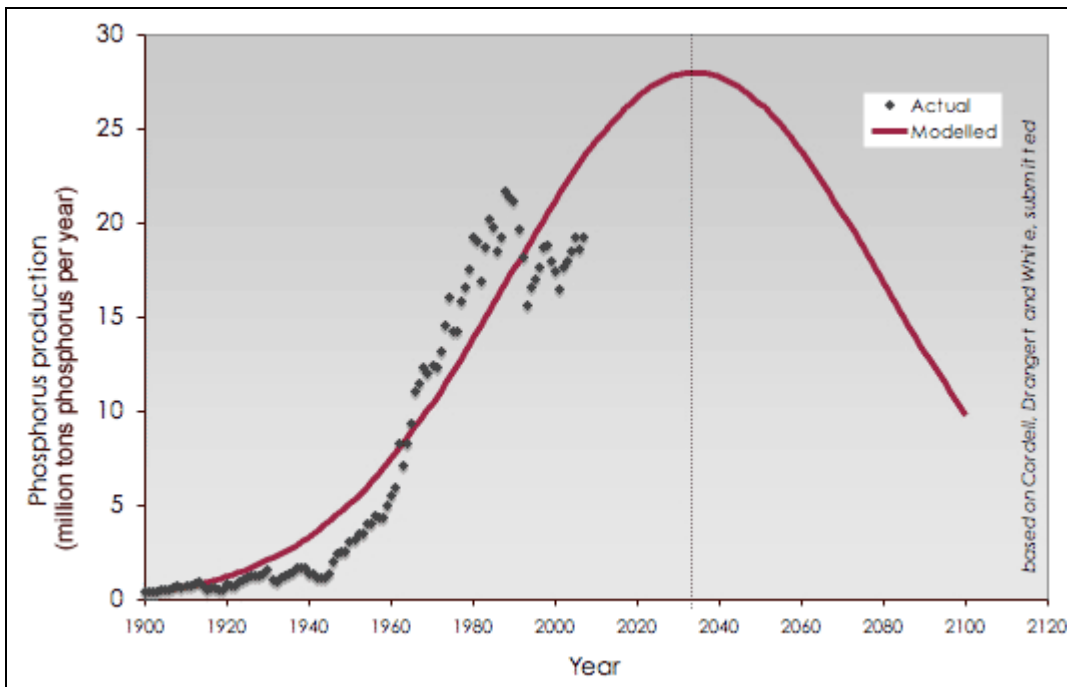
## **Phosphorus Recovery**

Phosphorus is a non renewable resource for which there is no substitute. While it is possible to substitute renewable energy for fossil fuels, no other mineral can take the place of phosphorus

Our ability to provide enough food to feed the human population is dependent on the use of artificial fertilizers, which contain phosphorus, nitrogen and potassium. While nitrogen is abundant in the atmosphere (- it just requires the use of large amounts of natural gas to capture it), phosphorus is mined at just a handful of locations worldwide, primarily, the United States, China and Morocco. (Hong et al. 2005). Today, Florida produces 25% of world's phosphate which makes the United States the world's largest producer of phosphate rock.

While the timing for “Peak Phosphorus” may be fifty, or even one hundred, years out, as with peak oil, it is not a question of if, but when. There are some indications that production has already peaked in terms of the readily available resources while other estimates put this 20-30 years out as is illustrated in **Figure 2**.

### **Figure 2      Estimates of Timeline for Peak in Phosphorus Production**



This is leading to increased interest in phosphorus recovery in a re-usable form (**Berg, U & SchaumC., 2005**). This is particularly evident in Europe where rock phosphate deposits are negligible. In 2006, 87% of the phosphorus used in EU fertilizers was from imported phosphorus, with only 13% coming from mined resources.

Wastewater and sewage sludge represents a significant potential source of phosphorus. If all of the phosphorus available in sewage sludge in the EU was recycled, this could provide for 28% of the EU's total phosphorus requirements. Sweden for example has mandated that 60% of phosphorus must be recovered at its wastewater treatment plants by 2015 (**Levlin, E, 2003**).

The concentration of phosphorus in municipal wastewater is approximately 6-8mg/l with each person contributing approximately 3.28 grams of Phosphorus per day. This is a consistent and predictable source of phosphorus.

Every person produces approximately 1.2kg/annum of phosphorus. This is typically conveyed to a wastewater treatment plant. In the United Kingdom, the annual phosphorus load from human sources which is present in wastewater is therefore approximately 72,000 tonnes. This would be equivalent to 336,000 tonnes of Phosphorus pentoxide, which at a typical value of US\$500 per tonne, would be worth US\$168M per annum. This does not include any additional phosphorus present in wastewater from commercial or industrial sources.

Currently there are two ways in which this Phosphorus can leave a wastewater treatment plant: In the treated wastewater, or in the sludge stream.

In the absence of specific phosphorus removal methods, approximately 75% of the phosphorus which comes into the treatment plant in the raw wastewater leaves in the treated wastewater, and approximately 25% leaves the plant in the biosolids or sludge stream. Where specific phosphorus removal mechanisms are employed (Chemical / Biological), in excess of 85% phosphorus removal can be achieved. In this scenario, 15% of the phosphorus which was present in the raw wastewater

leaves the plant in the treated wastewater and 85% leaves the plant in the sludge stream (where chemical phosphorus dosing was employed it leaves the plant as an iron or alum precipitate, where Biological phosphorus removal is used it leaves the plant as poly-phosphate within the biomass).

Currently the only method to recycle the phosphorus present in wastewater is by applying sludge to land. In certain jurisdictions the application of biosolids to land is not practiced and this is leading to interest in alternative methods of recovering and recycling phosphorus from sewage sludge.

### **The Aquacritox Process as a Potential Means of Phosphorus Recovery**

The Aquacritox process presents an opportunity to recover both energy and phosphorus from sewage sludge.

The Aquacritox process is a supercritical water oxidation process in which sludge is heated to between 370° C and 500° C at 220bar of pressure in the presence of oxygen. All of the organic matter is completely oxidized in an exothermic reaction. The energy released is used to generate heat and electricity. The process produces an ash like product and a supernatant, which is essentially water with COD levels less than 5mg/l.

Any soluble or Ortho-P which was present in the sludge is present as soluble Phosphorus in the sludge supernatant. This phosphorus can then be readily precipitated as Calcium Phosphate or Ammonium Magnesium Phosphate using crystallization processes such as the DHV Crystallator process or the Ostara PEARL process (Britton A. et al 2005).

Where required, phosphorus can also be recovered from the residual **inert** solid stream. Phosphorus is extracted by leaching the residuals with HCl, H<sub>2</sub>SO<sub>4</sub> or NaOH. Leaching the residuals with 1% NaOH solution at a temperature between 80-90°C for 75 to 90 minutes, can extract 65% to 90% of the phosphorus. Extraction efficiencies are higher with acid. Once extracted, the phosphate can be precipitated as Calcium Phosphate by the addition of lime.

### **Case Study:**

**Phosphorus Mass Balance at a Biological Phosphorus Removal Plant with and without Aquacritox.**

### **Methods**

A mass balance study has been carried out to illustrate how an Aquacritox plant could be used at a 500,000 PE Biological Phosphorus Removal plant to treat the sludge and also recover the phosphorus present. This is a simulated study based on data gathered at a number of actual biological phosphorus removal wastewater facilities.

Two scenarios are examined. The first is Biological phosphorus removal with anaerobic digestion, followed by sludge dewatering and sludge haulage off-site. The second is the same Biological phosphorus removal plant, but with an Aquacritox system in place of the Anaerobic digestion and sludge dewatering system.

Typical values for influent phosphorus loading have been used and a phosphorus removal efficiency of 85% is assumed.

### **Influent Parameters:**

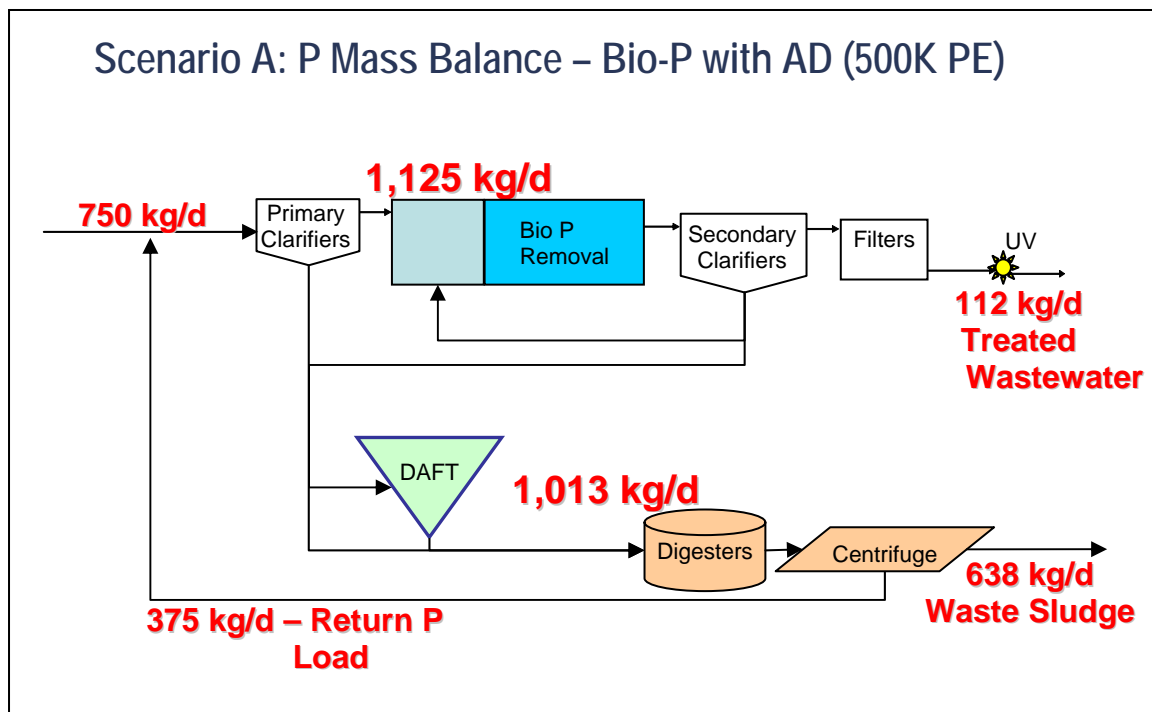
Flow: 125,000m<sup>3</sup>/day

Raw Influent Phosphorus Concentration: 6mg/l  
 Final Effluent Phosphorus Concentration: <1mg/l

Scenario A: Biological Phosphorus removal with Anaerobic Digestion

In Scenario A, (Figure 3) the total phosphorus mass loading into the plant is 750kg/day. There are two ways in which phosphorus leaves the plant: the sludge stream and the treated wastewater. The sludge stream will contain 85% of the phosphorus and the treated effluent will contain 15% of the phosphorus. As with all Biological phosphorus removal plants with Anaerobic digestion, some of the phosphorus taken up by the sludge is released in the Anaerobic Digester and is returned back to the headworks of the plant with the sludge dewatering liquors. This ‘dead load’ of phosphorus which is recycled would typically be in the region of 375kg/d.

**Figure 3 Scenario A: Mass Balance for Bio-P Removal with Anaerobic Digestion at a 500K PE WWTP**



*Scenario B: Biological Phosphorous Removal with Aquacritox and phosphorus recovery*

In Scenario B, (Figure 4) the Aquacritox process replaces the Anaerobic digester and sludge centrifuge. All of the energy present in the sludge is released and used to generate heat and power. The phosphorus which comes into the plant as Ortho-Phosphate is released from the sludge during the Aquacritox treatment step and is present in the supernatant.

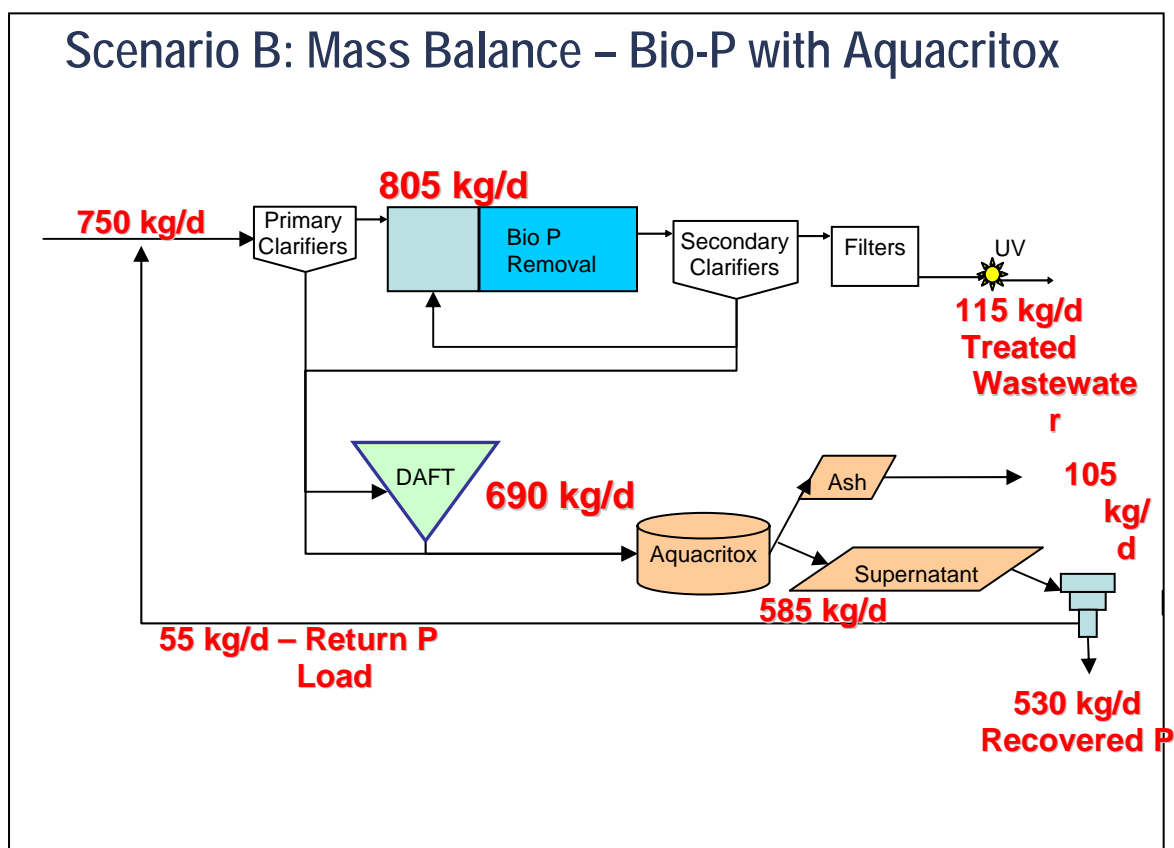
The expected phosphorus concentration in the supernatant in this scenario will be 847.8 mg/l. This is based on 250m<sup>3</sup>/day of sludge at 12% solids going through the Aquacritox plant.

The mass of phosphorus present in the supernatant will be 585kg/day representing 78% of the total influent phosphorus load to the plant. It would typically be possible to recover at least 90% of this phosphorus from the supernatant using commercially available fluidised bed crystallisation

technologies. This would result in a recovery of 530 kg P per day, which would represent a phosphorus recovery rate of 70%.

The soluble phosphorus present in the supernatant is an ideal feedstock stream for phosphorus recovery in a fluidized bed crystallization reactor. There are a number of companies which have commercially available fluidized bed crystallization systems such as the PEARL system offered by Ostara Nutrient Recovery Technologies Inc and the Crystallactor developed by DHV. These systems recover phosphorus as a precipitate such as Magnesium Ammonium Phosphate (struvite) or Calcium Phosphate (Berg U. & Knoll G, 2005)

**Figure 4 Scenario B: Mass Balance for Bio-P Removal with Aqua Crotix® at a 500K PE WWTP**



### Conclusions and Recommendations

This case study showed that sewage sludge can be successfully treated on an on-going basis under stable operating conditions. The results confirm that complete oxidation of organic matter is achievable. Analysis on the supernatant confirms that the water produced could be discharged safely without further treatment. Analysis of the inorganic residue produced confirms that the residual material is inert and is predominantly silica.

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