SUPERCRITICAL WATER OXIDATION OF SEWAGE SLUDGE – An Update

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ABSTRACT

Supercritical water oxidation (SCWO) is an innovative, economic and effective destruction method for organic wastewater and sludge and is a realistic alternative to conventional methods. From 1998 to 2007 extensive evaluations of the destruction of sewage sludge by SCWO were performed by Chematur Engineering AB on two state of the art pilot plants. These units had capacities of 250 kg/h and 1100 kg/h, respectively. The results achieved showed that the technology easily gave 99.9% destruction of the organic material in the sludge and the inorganic material left in the effluent was non leachable and is very easily settled. The very encouraging results indicated that the technology was ready to be commercialised for treatment of sewage sludge.

In 2007 SCFI Group, acquired the patented super critical water oxidation technology (Aqua Critox®) from Chematur Engineering AB of Sweden.

Further work on design capacity and energy recovery by SCFI Group has led to a reduction in over all build cost, a significant increase in processing capacity and increased energy recovery in the form of electricity generation.

SCFI Group in 2008 commissioned its 250 litre per hour demonstration Aqua Critox® super critical water oxidation demonstration plant in Cork, Ireland. Since May 2008, the plant has been subjected to continuous operation on sewage sludge to document the long term reliability of the Aqua Critox® SCWO technology.

Key words

Aqua Critox®, destruction, economic, reliable, SCWO, Sewage, Sludge.

INTRODUCTION

Oxidation of organic wastes to carbon dioxide, water, and other small molecules can effectively minimise waste volume and detoxify many hazardous compounds. Incineration in air at atmospheric pressure is the most common oxidation technique currently practised. However, incineration meets increasing opposition from the public concerned about dioxin production and toxic ash. The ash from incineration is usually treated as hazardous and therefore requires disposal at hazardous landfill. As landfill costs are increasing year on year, this places increased pressure on costs of incineration.

A Super Critical Water Oxidation System (SCWO) will oxidise aqueous streams containing organic material in relatively low concentrations. SCWO is an exothermic process and is autothermal at just three percent organic content in the waste stream. When the organic content within the waste stream is in excess of three percent, the excess energy may be utilised to generate electricity and heat. The heat can be utilised to generate steam and hot water which can find application in sludge thermal hydrolysis and or anaerobic digester heating requirements.

Waste streams do not require drying before treatment and the SCWO process produces no hazardous by-products and the inert residues are sterile, stable, non-toxic and suitable for reuse or recovery.

The first commercial SCWO plant was built in 1994 in the USA, for the Huntsman Chemical Corporation by Eco Waste Treatment (EWT). The SCWO plant design was based on the extensive research and development work EWT had carried out in conjunction with University of Texas at Austin Texas. This plant operated successfully from 1994 until 2000 when it was decommissioned.

In 1995 Chematur Engineering AB licensed the SCWO technology from EWT and in 1998 acquired EWT. Chematur built a 250 litre per hour demonstration SCWO plant in Karlskoga, Sweden in 1998. During the period 1998 to 2007 Chematur performed extensive research and development on the treatment of sewage sludge using scwo technology leading to further patented improvements in design that over came the issues relating to pumping, blockages, and fouling that had previously been seen by industry as impediments to the adoption of SCWO technology. In all this facility accumulated over eight thousand hours of operation.

SUPERCRITICAL WATER

Under normal conditions, water is seen in any of its three states: steam, liquid water, or ice. If water is heated and compressed to sufficiently high temperature and pressure, water enters a 4th state known as the super critical state. In the case of water this occurs above 374 ºC and 221 bar, (figure 1).

The reason for the efficiency of SCWO in destroying organic compounds is the unique properties of water above its critical point. Above the critical point, water has properties between those in its liquid and gas state.

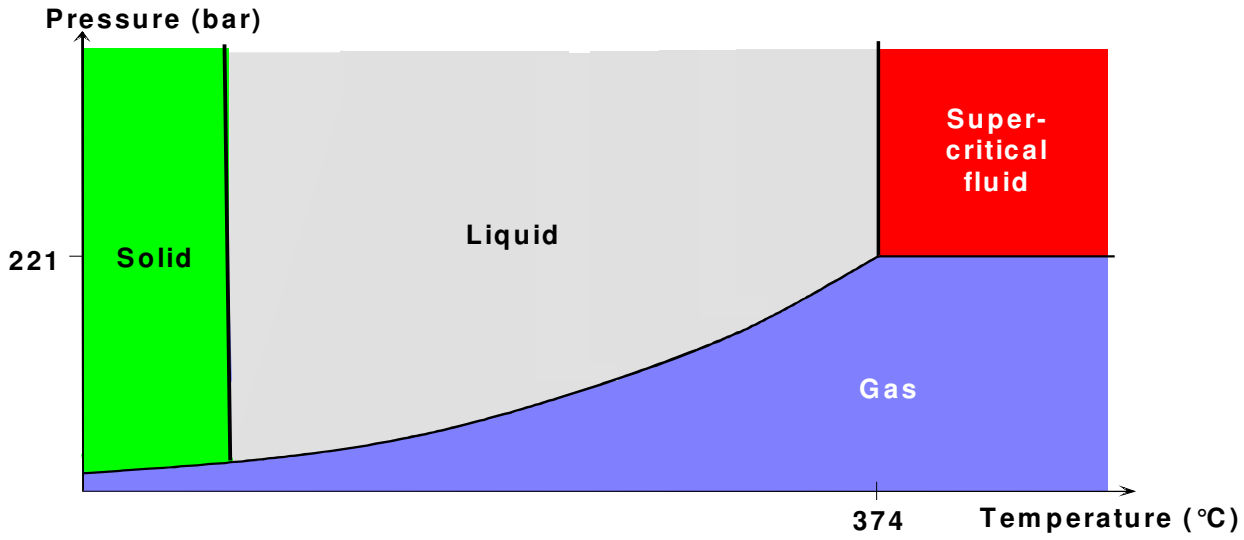

Figure 1: A simplified phase diagram of water

The density of supercritical water (SCW) is comparable with liquid water densities, and high enough for reasonable throughputs in a process. On the other hand the viscosity and diffusivity in the supercritical region are more like that of a gas. Due to the low dielectric constant of water in the super critical state, the solubility of organic compounds and gases is high. This together with the high diffusivity means there is an insignificant mass transfer resistance thus enabling very fast reaction rates.

	Liquid	SCW	Gas
Density (kg/m^3)	**10^3**	**$3x10^2$**	**1**
Viscosity (Pa s)	**10^{-3}**	**10^{-5}**	**10^{-5}**
Diffusivity (m^2/s)	**10^{-10}**	**10^{-7}**	**10^{-5}**

Figure 2: Physical properties of Super Critical Water.

Destruction of Organic Molecules in SCWO

SCWO destroys all organic wastes containing any combination of elements. Low biodegradability or high toxicity has no effect on suitability for treatment by SCWO.

Higher molecular weight organic compound are destroyed or transformed almost immediately, smaller molecules such as acetic acid and are generally slower and are typically the rate controlling compounds in the process. Never the less reaction time is extremely fast, at typically less than 60 seconds. Nitrogen containing compounds will revert to elemental nitrogen with out production of NOx. The process does not produce dioxins.

Process Description

Following some limited pre-treatment (agitation and heating for viscosity control and milling to control particle size) a high pressure pump is used to raise the pressure of the stream to 250 barg. Feed enters the economiser where it is heated to supercritical temperature by the reactor effluent. After leaving the economiser the feed enters the reactor. At start-up, or if the organic concentration is less than 3%, the feed is heated at the reactor by external booster heaters.

In the reactor oxygen is injected to start the oxidation reaction. The reaction is exothermic and temperatures increase as the reaction progresses.

After passing through the reactor the effluent flows through the economiser where it heats the incoming stream. In larger plants the heat of reaction can be recovered via a steam generator for power generation. District heating is also an option depending on the plants location.

Following any heat recovery the effluent is cooled to its exit temperature by a cooler prior to passing through the pressure reduction system where the pressure is lowered to <10 barg. The effluent then passes to a gas /liquid separator where the CO_2, N_2 and residual O_2 are separated from the liquid stream.

The inorganic residue is removed from the liquid stream. This stream has a COD of <5mg/ltr. The inorganics are inert and suitable for use a building material, non-hazardous landfill, or, depending on the components can be further treated for recovery of the phosphorous and other valuable compounds.

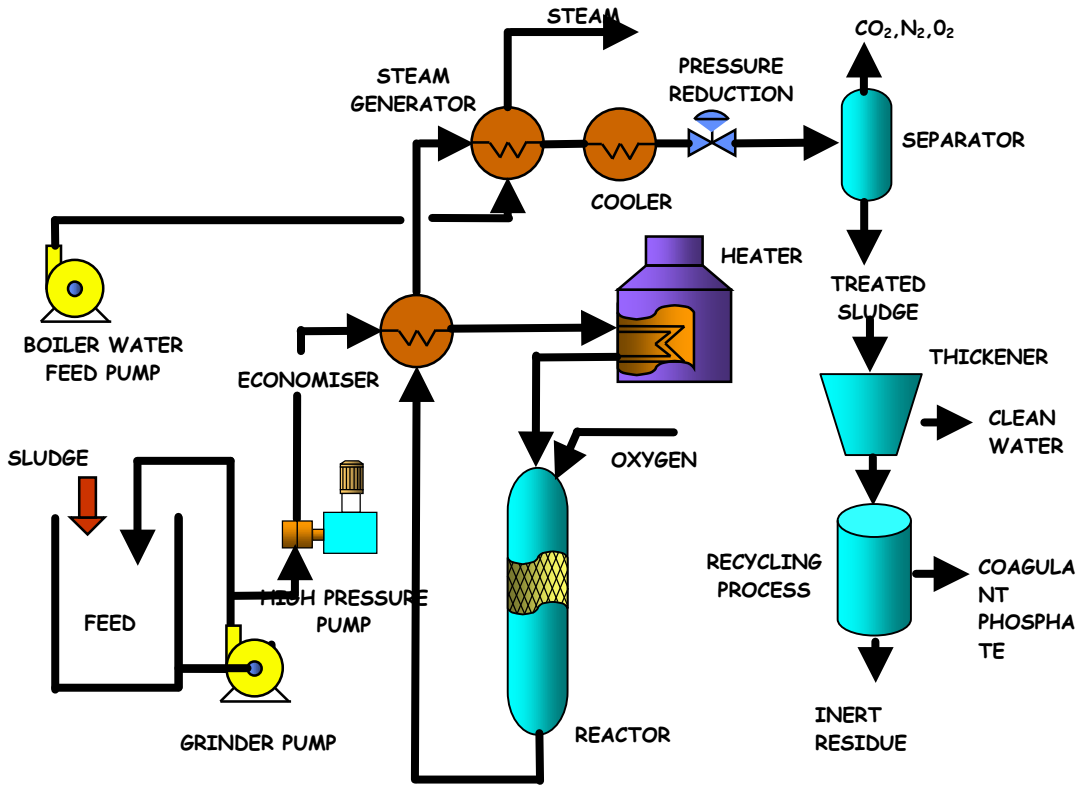

Figure 3: Aqua Critox® process schematic.

DESIGN CONSIDERATIONS

In order to ensure an efficient, economical and reliable process the properties of the sludge to be treated must be understood at the start of the design process. SCFI therefore carry out full chemical and physical analysis and pilot assessment utilising our demonstration Aqua Critox® plant before proceeding to detailed engineering.

The SCFI SCWO process, marketed as AquaCritox® has been designed to maximise efficiency and throughput while minimising downtime for maintenance and cleaning.

Maintenance of a constant feed to the high pressure pumps is essential. The AquaCritox® process includes, where required, milling of the incoming feed to ensure consistent feed which also helps prevent blockages. Agitated and heated holding tanks prevent sedimentation and thus control viscosity and the solids concentration. The waste is recirculated around these tanks and the high pressure pump is fed from this recirculation line thus maintaining constant feed pressure.

A high pressure pump designed for the handling of sludge is important. Extensive work has been carried out in the selection of suitable pumps. This work was carried out to allow for consistent pumping of particulate containing sewage sludge over extended periods. Certain materials which commonly cause difficulty in high pressure pumping of sewage sludge are hair and plastic fragments from items such as Q-tips. Generally for sewage sludge a piston diaphragm pump is used. This type of pump is particularly suitable as the sludge does not come into contact with moving parts which may be plugged. The pumps are sized to give sufficient velocity in the system to minimise fouling and blockages.

The Economiser and Reactor design are protected by patents. The economiser is a tube in tube type heat exchanger to minimise any risk of blockages. The reactor is a plug flow reactor designed to give the highest efficiency at minimum volume.

The design of the pressure reduction system is also critical and protected by patents. Although possible, the use of a single valve for pressure reduction is not recommended. A single valve would result in extremely high velocities, severe erosion and noise issues. The AquaCritox® demonstration plant uses a patented capillary system, where pressure drop is achieved by distributing flow over a number of long capillaries. Accurate adjustment of pressure is achieved by selection of the number of tubes to be used together with the controlled addition of choke water. Larger plants may employ this system or a series of nozzles, depending on the design.

In order to maintain efficient use of oxygen and to maintain process efficiencies and plant safety, the AquaCritox® plant is supplied with a sophisticated control system which limits the amount of manual intervention required by plant operators. The control system monitors and controls plant temperatures and pressures, oxygen supply and residual oxygen in the off gasses. Off gas make up is constantly monitored as is effluent water quality. The system allows for automatic switchover to standby exchangers and cleaning preventing blockages and down time.

In larger plants the configuration of the system, and the exothermic nature of the reaction, means that there is significant waste heat available for recovery. The AquaCritox® process includes a provision for recovery of this heat in the form of electricity generation. Depending on the size of the plant, sufficient power can be generated to power the plant and have residual power for export to the national grid. There is also an option for recovery of the low grade heat from smaller plants either for heating options earlier in the waste treatment process or for district heating.

The residual inorganic fraction of the sludge exits the process as a very fine inert material. The material contains phosphorous and iron which may be recovered as phosphoric acid and an iron coagulant if required.
Alternatively the material is attractive as a construction or filler material.
SCFI are currently researching further uses of this material that exploits its particle size.

Evaluation of scwo for the complete oxidation of sewage sludge

Chematur Engineering and more recently SCFI have performed a series of evaluations with undigested and digested primary and secondary sewage sludges. The tests were performed at the Chematur and SCFI demonstration plants, which were designed as described above, excluding the steam boiler. Both dewatered sludge and sludge “as received” have been used.

The influence of temperature and concentration on the efficiency of the process has been monitored. The evaluations confirmed that all organic material was easily destroyed but that a minimum temperature was required to ensure all nitrogen containing compounds were completely broken down. This temperature of 540 ^{o}C is easily achieved with in the SCWO process.

Variation on feed concentration led to no significant variation in final COD; however a minimum concentration is required to eliminate the need for booster heating of the process. SCFI have determined that organic concentrations of 3 to 10% with a total solid content not greater than 20% is the most efficient range for treatment. This in effect means that SCWO can be utilised to process liquid or dewatered sludges

The destruction efficiency of the organic material using SCWO is significantly higher than that achieved with wet air oxidation and other process operating below the critical point. A number of such plants are used to treat sewage sludge and they typically reduce the organic load by approximately 70%. A long residence time is required for this. This compares to a 60 second residence time in the reactor for a 99.99% reduction using SCWO.

During the test work CEAB and SCFI have shown that the off gasses contain no NO_x or SOx were detected. These results form the basis of a long scale demonstration currently in progress at the SCFI pilot plant facility in Cork, Ireland

Economics

SCFI Group are confident that the process is economically competitive, not just with incineration, but also with land spreading, when the costs of pre-treatment and transport are taken into account. The most significant operating cost for SCWO is oxygen. For large scale Aqua Critox® plants liquid oxygen (LOX) is the chosen oxidant. Where bulk LOX supply is not available at competitive costs we provide on site generation.

For smaller applications we can operate the Aqua Critox® system using air as the oxidant.

Every sludge producer's sludge will have many variables such as volume, percentage dry solids, percentage inorganic, calorific content and salt content. SCFI evaluate each enquiry by performing an initial desktop study and then making a business case to the sludge producer. It is our objective to provide a secure long term sludge solution for our customers.

Cost of sludge treatment will normally be in the region of £30- £60 GBP per tonne of sludge cake. This cost is based on SCFI designing, financing , building, owning and operating an Aqua Critox® SCWO plant to treat sewage sludge at the sewage works.

Conclusions

The results obtained in the original pilot trials and subsequent evaluation studies by SCFI Group show that SCWO is a viable alternative for the treatment of swage sludge. The reaction is exothermic giving an opportunity to recover the heat gained, either as electricity, in larger plants, or as low grade process heating in smaller plants. Waste heat can also be recovered for district heating and other uses depending on the site set-up. The process offers complete mineralisation of sewage sludge, the potential for renewable energy generation, and has the potential to significantly reduce the carbon foot print of the STW.

AquaCritox® offers a further benefit in that there are no further toxic/hazardous residues requiring disposal and offers the option of recovery of phosphorous and coagulant from the inert residue.

The process is robust. There are few moving parts and the equipment has been designed specifically for the variation in feed experienced in a standard sewage treatment plant.

SCFI Group can offer a Design, Finance, Build, Own, Operate and Maintain service using the AquaCritox® process for sludge treatment thus giving the customer a long term, secure sludge disposal solution with long term visibility on costs.
For further information contact info@scfi.eu or visit our web site www.aquacritox.ie

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