

Sludge Management in the City of Orlando— It's Supercritical!

David S. Sloan, Roy A. Pelletier, and Michael Modell

The Challenge

What to do with sludge? This is a key question in Orlando, as well as many other municipalities around the country and much of the world. For more than 25 years, the city has produced and land applied Class B residuals, but we know the future will require a change away from our reliance on this method of disposal.

Numerous issues are currently impacting the city's land application program:

- 1) A lack of reliable wet weather application sites.
- 2) Restrictive local permitting requirements and new fees related to land application sites.
- 3) A dwindling availability of qualified, responsive contract haulers.
- 4) A significant decrease in Class B land application sites in rural agricultural communities surrounding Orlando, similar to many regions across the country.

The curtain is falling on land application of Class B residuals; we all need to prepare for the inevitable! This article focuses on a new, innovative sludge oxidation process currently being refined and improved at the city's Iron Bridge Regional Water Reclamation Facility: *supercritical water oxidation*. It includes analysis of the

costs and benefits of alternatives considered by the city and reasons why the process was selected. Objectives of the full-scale demonstration project are described, along with our progress to date. The information shared is intended to help the many organizations facing the common problems of sludge disposal.

The City's Wastewater Collection & Treatment Process

Orlando is a medium-sized city that owns and operates three water reclamation facilities generating an average of about one ton of dry solids (sludge) per million gallons of wastewater treated. The largest of these is the Iron Bridge Regional Facility, with a design capacity of 40 million gallons per day (mgd), treating an annual average flow rate of about 25 mgd. Our medium facility is Water Conserv II, which has a design capacity of 25 mgd and treats an annual average flow rate of about 16 mgd. Our smallest facility is Water Conserv I, which has a design capacity of 7.5 mgd and treats an annual average flow rate of about 4.5 mgd.

Flow is collected throughout the service area in a network consisting of 918 miles of sewer lines and 210 lift stations. Since the Central Florida area is under an Orange

David S. Sloan is director of environmental services for the city of Orlando. Roy A. Pelletier is a wastewater project consultant for the city. Michael Modell, Ph.D., is the chief technical officer for SuperWater Systems LLC. This article was presented as a technical paper at the 2008 Florida Water Resources Conference in May.

County mandate for zero discharge, the city has a 100 percent reclaimed water (reuse) program, requiring compliance with stringent effluent standards.

The Iron Bridge plant is a five-stage Bardenpho biological nutrient removal process attaining effluent parameters of CBOD₅ less than 1 mg/L, TSS less than 1 mg/L, total nitrogen of about 1.5 mg/L, and total phosphorus of about 0.3 mg/L. Solids handling at the Iron Bridge facility consists of lime stabilization, processing and land applying about 125 to 150 wet tons per day (wtpd).

Solids handling at the Water Conserv II facility consists of anaerobic digestion, processing and land applying about 75 to 90 wtpd. The Conserv I facility thickens waste-activated sludge with a gravity belt thickener (GBT) and hauls about 20,000 gpd of the unstabilized liquid solids for disposal in the closest lift station within the Iron Bridge collection system service area.

The cost of operation for all solids handling operation and maintenance in the city is shown in the four tables on page 47.

Why is Change Required in the Solids Handling Process?

What Do We Presently Do With Sludge Cake?

At Iron Bridge, sludge cake is "stabilized" (the concentration of biological organisms is reduced) to comply with federal and state regulations by the addition of lime, chemically elevating the pH to 12. Stabilized sludge cake is hauled off site for land application on cattle ranches in Osceola County near Holopaw.

Ranchers accept sludge cake because it contains organics that will enhance soil moisture holding capacity, provides fertilizer value (nitrogen and phosphorus), and has essential plant minerals. Sludge helps grass grow!

Currently, costs associated with our lime

stabilization/land application sludge management program are \$362 per dry ton. A significant portion of this cost is to pay a contract hauler to transport and spread the dewatered sludge cake on contracted sludge sites.

Two years ago when we began the SCWO Project, our lime stabilization/land application costs were \$264 per dry ton. Over the two-year period, operating costs have increased \$856,538!

Why Change?

To assure compliance with federal, state and local regulations, water reclamation facilities must have a reliable way to remove excess biological mass (sludge) from the treatment process. Our present land application program presents both short-term and long-term problems.

For the short term, plant staff has an almost daily challenge to get the contract hauler to perform. Approximately 220 cubic yards of Class B lime stabilized sludge cake is produced daily at the Iron Bridge facility. The sludge contractor is responsible to haul and spread 10 to 12 trailer loads (20 cubic yards per trailer), seven days per week.

Problems include contract drivers not reporting to work, vehicle/equipment breakdowns, and weather-related closure of the application fields. These problems individually, and sometimes collectively, have a significant impact on the removal of sludge and threaten to cause violations of the city's federal and state permit.

To illustrate the potential magnitude of the problem, during the wet summer of 2006, almost 5 million gallons of thickened waste sludge were diverted to off-line tanks for temporary holding because the contractor had fallen far behind in removing the required 10 to 12 loads per day.

The contractor's application sites were often too wet to receive sludge, so the sludge had to be stored in open tanks at the plant while new land application sites were located. During that period, numerous odor complaints were received from the residential communities near the plant; the city was threatened with lawsuits and regulatory involvement if off-site odors were not quickly reduced.

Long term, planned changes in state regulations are expected to discourage the practice of land application of Class B lime stabilized sludge cake within two to five years. Local county ordinances also threaten our current program. As Central Florida continues to grow in population, agricultural operations will be impacted by the arrival of new residential neighbors, who are less familiar or accepting of typical agricultural practices.

Spreading manure and sludge to
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Water Conserv I WRF ... About \$370 per day

Process Area	Annual Costs	Cost per Wet Ton	Cost per Dry Ton
GBT Thickening	\$66,205	\$3.63	\$90.69
Haul & Dispose	\$69,432	\$3.80	\$95.11
O&M Total	\$135,637	\$7.43	\$185.80

Water Conserv II WRF ... About \$3,300 per day

Process Area	Annual Costs	Cost per Wet Ton	Cost per Dry Ton
GBT Thickening	\$161,887	\$1.77	\$31.68
Anaerobic Digestion	\$334,141	\$3.66	\$65.38
BFP Dewatering	\$324,518	\$13.85	\$115.47
Haul & Dispose	\$399,866	\$17.06	\$142.27
O&M Total	\$1,220,412	\$36.34	\$354.80

Iron Bridge Regional WRF ... About \$8,682 per day

Process Area	Annual Costs	Cost per Wet Ton	Cost per Dry Ton
GBT Thickening	\$331,579	\$5.68	\$37.85
BFP Dewatering	\$660,406	\$11.31	\$75.39
Lime Stabilization	\$440,221	\$7.54	50.25
Haul & Dispose	\$1,737,006	\$28.06	\$198.29
O&M Total	\$3,169,213	\$54.27	\$361.78

Sludge Management Total Costs for all Facilities ... About \$12,397 per day

Process Area	Annual Costs
Thickening	\$559,671
Stabilization	\$774,362
Dewatering	\$984,924
Haul & Dispose	\$2,206,304
Annual O&M Total	\$4,525,261
Average @ \$364 per Dry Ton	

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Spreading manure and sludge to enhance soil characteristics and provide fertilizer value, while important to the ranchers, is considered offensive and unhealthy by new homeowners. Frequently, local governments in rural areas are pressured to create zoning or local permitting requirements that discourage or completely eliminate land application of Class B sludge cake.

Changes to sludge management programs require long-term planning and significant capital investment. Given the issues faced with our present land application program, our staff issued an RFQ for consulting services to evaluate and recommend a long-term option to meet our growing sludge management needs. Supercritical Water Oxidation was recommended by Boyle Engineering, in cooperation with Black & Veatch, after completing a technology feasibility/cost evaluation.

Options for Disposal

Bury: Landfill

The availability of landfills that will accept sludge, as well as the cost to dispose of sludge in a landfill, varies greatly across the country. The cost (tip fee) to put sludge in a landfill varies from a nationwide low in Texas of \$15-\$20 per wet ton; (\$100 to \$133 per dry ton), to a high of \$100 per wet ton in New Jersey (\$666 per dry ton).

In the Orlando area, the closest landfill that will accept sludge is near Lake Okeechobee. Transportation and tip fees alone could approach \$60 to \$70 per wet ton (\$466 per dry ton). Total sludge program operational costs could exceed \$629 per dry ton when thickening, dewatering, and lime stabilization costs are included. Unless a city owns a landfill and chooses to allow water into that landfill, landfilling of sludge is an expensive, short-term option at best.

Burn: Incineration

Incineration has been practiced for years in big cities in the colder northern climates. Incineration is costly, consumes significant volumes of a valuable natural resource (gas or fuel oil), and discharges an exhaust emission containing numerous pollutants.

Complying with stringent air-quality standards has driven the cost of incineration to exceed \$600-\$700 per dry ton. Any city trying to permit a "new incinerator" (not replacing an old incinerator) will find it almost impossible to obtain state and federal air permits. Citizens (environmental groups) tend to strongly protest the issuance of these permits and most often completely derail the permitting process.

Spread: Land Spreading

Land application has been around since the beginning of time. Often, in third world countries, the only forms of fertilizer available are human and animal wastes. Human wastes are treasured and applied one ladle at a time to fertilize small family vegetable plots.

In industrialized nations, given dense population centers, human wastes are collected and processed in wastewater treatment facilities, producing thousands of tons of sludge to be land applied daily. In cold northern climates, frozen or snow-covered fields rule out land application much of the year. In the Midwest, sludge can be applied to fields only when crops are not growing. As mentioned previously, new homes are being constructed in many once-rural agricultural areas, and the odors associated with sludge spreading cause odor complaints from residents, often bringing an end to the practice.

Land spreading may continue in cities surrounded by large agricultural areas because of the low costs associated with land application—\$200 to \$300 per dry ton if application sites are in close proximity—but for most communities, land application is

not a viable, long-term option.

For Orlando, the regulations currently being developed at the state level would seem to make land application of lime stabilized Class B sludge a short-term option: two to five years remaining at best.

Dry: Pellets (Milorganite)

With the addition of lots of heat, sludge cake can be dried to 96-98 percent solids content and shaped into pellets. The pellets are organic and contain nitrogen and phosphorus. The percentage of nitrogen and phosphorus depends on the contributors to the sewer system. In Milwaukee, because of the high percentage of brewery wastes discharged to the sewer system, pellets may contain up to 6 percent nitrogen and 6 percent phosphorous content.

In Orlando our pellets would be closer to 2 to 3 percent nitrogen and 4 to 5 percent phosphorus content. Our pellets would be worth less, based on fertilizer value, than Milwaukee's sludge.

Pellet plants are being built by many communities in Florida. Costs to produce and market pellets can range from \$400-\$800 per dry ton. Many cities wind up landfilling a portion of the pellets they produce because of the limited market demand. Every year more communities are investigating pelletization plants to comply with current and future federal and state regulations. Every year the market will have more pellets available, decreasing demand and value.

Blend: Compost

Pick up any garden magazine and it will extol the benefits of gardening with compost to build the soil structure and provide nutrition to the plants. Good compost will do just that, but good compost requires the approach to be based upon blending ingredients that will result in a high-quality product.

When composting sewage sludge, the objective is disposal of a waste as quickly as possible because of the volumes involved. Compost on a farm results from straw and animal wastes decaying over an entire year. Compost at a treatment plant is typically produced, using woodchips and human wastes, in less than 60 days.

The blend ratio typically requires two to three cubic yards of wood waste to be mixed with each cubic yard of sludge cake, which can increase volumes to handle and haul 200 to 300 percent. Good soup requires proper ingredients; compost is the same.

Compost costs can range from \$400 per dry ton (open air/no odor control) to \$700 per dry ton for an in-vessel, odor-controlled system. Composting relies on finding end users who can reliably use the entire quantity produced.

Options for Disposal

Option	How?	Still Legal?
Bury	Landfill	Yes, but not available in Central Florida
Burn	Incinerate	Yes, but very difficult to get an air permit (maybe impossible)
Sink	Ocean Disposal	No longer an option
Hide	Deep Well Injection	Not an option in Florida
Spread	Land Application	Yes, but may only be for short term for Class B Stabilization
Dry	Fertilizer Pellets	Yes, flooded pellet market! High Capital and O&M costs
Blend	Compost	Yes, increases volume to dispose of /often unacceptable on-site odors!
Oxidize	Supercritical Water Oxidation	Yes, City of Orlando will be 1 st !

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Summary Table of Issues

Technology	Cost Range per dry ton	Environmental Issues	Market Issues	Costs Highly Site Specific	Annual Est. Orlando Costs*
Landfill	\$400-700	X	O	X	4,818,000
Incineration	\$600-700	X	O	O	5,694,000
Land Application	\$300-400	X	O	X	3,066,000
Pellets	\$400-800	O	X	X	5,256,000
Compost	\$400-700	X	X	X	4,818,000
SCWO	\$150-400	O	O	O	2,409,000

Note: X = Applies to that technology
 O = Does not apply to that technology
 * Based on 8,760 dtpy.

Patents Issued For SCWO References Cited - U.S. Patent Documents

Patent Number	Date Granted	Patent Holder
3,876,497	4/1975	Hoffman
3,876,536	4/1975	Pradt et al
3,977,966	8/1976	Pradt et al
4,100,730	7/1978	Pradt
4,113,446	9/1978	Modell et al *
4,141,829	2/1979	Thiel et al
4,174,280	11/1979	Pradt et al
4,241,722	12/1980	Dickinson
4,284,015	8/1981	Dickinson
4,292,953	10/1981	Dickinson
4,338,199	6/1982	Modell *
4,543,190	9/1985	Modell *
4,564,458	1/1986	Burleson
4,692,252	9/1987	Atwood et al
4,713,177	12/1987	Atwood et al
4,822,497	4/1989	Hong et al
4,869,833	9/1989	Binning et al
5,100,560	3/1992	Huang
?	7/1992	Rufer et al
5,252,224	11/1993	Modell *

*** Denotes Patents held by Michael Modell**

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Oxidize: Supercritical Water Oxidation

The concept behind supercritical water oxidation (SCWO) was invented and patented by Dr. Michael Modell while he was a tenured professor of chemical engineering at the Massachusetts Institute of Technology. During the 1970s, he advised NASA on waste treatment in space. In that work, he saw the need for the complete recycling of water, oxygen, and waste materials for a space colony and concluded that the same principles would apply to better protect the environ-

ment on earth.

SCWO is based on the principle that when water is heated to 600 degrees C under high pressure, it becomes a supercritical fluid, a form of matter between the liquid and gaseous states. Organic materials (food, bacteria, hazardous chemicals, etc.) are insoluble in normal water, but when mixed with supercritical water, organics rapidly dissolve and reform into simple molecules such as hydrocarbon gases and alcohols. When oxygen is added, the reformed organics are fully oxidized; they bind with oxygen to form carbon dioxide and pure water. Inorganic matter (minerals, salts, metals, etc.)

form metal oxides and salt.

The primary product of SCWO—clean water—can be reused or safely released into a receiving body of water. Other byproducts of SCWO are purified to become commercial-grade carbon dioxide, clean sand, and recovered metals, which can be sold into established markets.

The most desirable end products of SCWO waste treatment are carbon dioxide (CO₂) and water (from the organics) and minerals and metals (from the inorganics), all of which are reusable. The process also generates a significant amount of heat energy, which can be captured and used to generate electricity.

Because the process operates at temperatures and pressures that far exceed previous temperature/pressure-based systems, 99.9 percent of the organics contained within the waste flow entering the reactor are destroyed. The need for downstream dewatering, odorous decant tanks, and problems that hindered previous wet oxidation processes are eliminated.

SCWO holds significant promise as the next generation of sludge treatment technology. Cost estimates for treatment via SCWO range from \$300-\$400 per dry ton without energy recovery or capture of CO₂. With energy recovery and capture/sale of CO₂, cost estimates range from \$150-\$200 per dry ton.

Anyone Else Pursuing SCWO?

Lots of folks have been working on SCWO for a long time. Numerous patents have been issued since 1975 for various approaches to destroy/oxidize wastes using SCWO.

General Atomics (a subdivision of General Dynamics) and Chematur AB are two corporations presently pursuing commercialization of SCWO for sludge treatment. To date, neither firm has applied their technology successfully to full-scale, continuous, on-line operations. Patents held by both firms cover process equipment configurations that are different to the approach developed by Modell and covered by Modell/Modtec patents.

The industry sees the value in applying SCWO to waste disposal. None have proven capable of bringing a fully functional, cost-effective system to the market place.

SCWO: A Closer Look

Supercritical water oxidation, or SCWO, is the name given to the phenomenon of oxidizing organics in water under conditions where pure water would be a supercritical fluid. "Organics" is used here in the broadest sense, which includes biological materials, dead or alive. "Supercritical" refers to the definition used in

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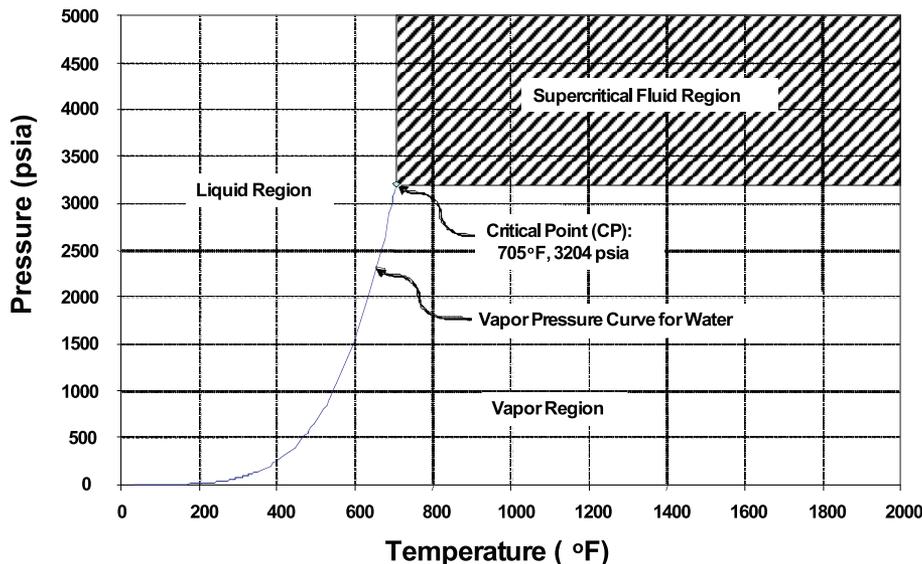


Figure 1. The vapor pressure curve for water

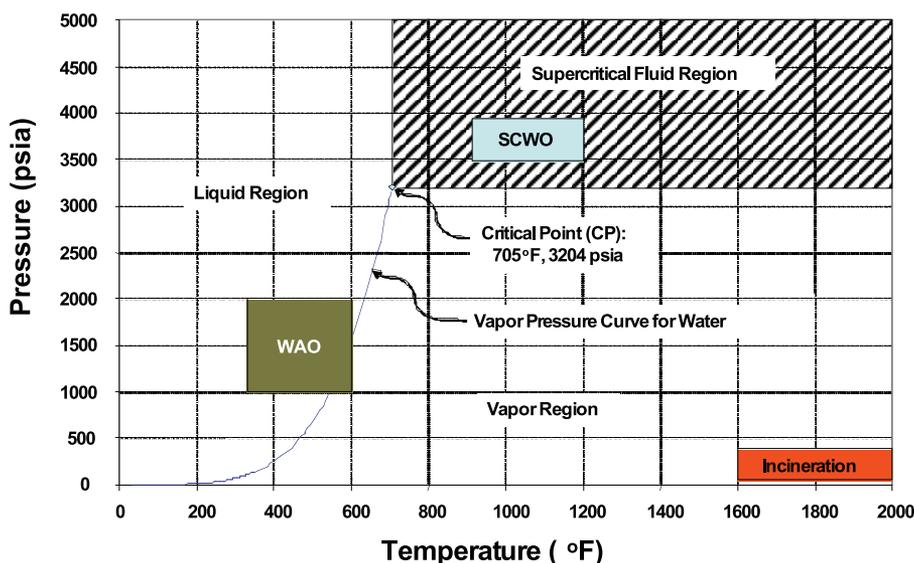


Figure 2. The temperatures and pressures of oxidation regimes

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physical chemistry: Every fluid has a critical temperature and a critical pressure, above which only a single phase exists (i.e., liquid and vapor cease to exist as separate phases); this phase is referred to as the supercritical phase, and the fluid is called a supercritical fluid.

The curve in Figure 1 is the vapor pressure for pure water as a function of temperature. It terminates at the critical point (CP) of 705°F and 3,204 pounds per square inch absolute (psia). The supercritical region starts at this point and continues to higher temperatures and pressures. Every fluid has a vaporization curve, a critical point, and a supercritical fluid region.

In 1980, Dr. Modell discovered that organics in water could be oxidized very

effectively at temperatures of 900 to 1,200°F and a pressure of 3,700 psia, under conditions where pure water is a supercritical fluid (see Figure 2). Prior to that point in time, oxidation of organics in water was practiced either at lower temperatures (WAO) or higher temperatures (incineration); neither of those two processes produced clean effluents.

Subsequent R&D was directed at proving that virtually every organic could be oxidized to ultrahigh efficiencies (e.g., 99.9 to 99.9999 percent conversion of carbon to CO₂) in SCWO – without formation of NO_x and without the need for a stack. The discovery of the new phenomena was patented (Modell, 1982).

Early developments of the technology were focused on destruction of hazardous

wastes such as PCBs and dioxins (see, e.g., Thomason and Modell, 1984; Modell, 1988), but the high chlorine content of many such wastes proved to be very corrosive and greatly limited the application. By the early 1990s, it was realized that sludges from treatment of municipal and pulp mill wastewaters were ideal applications of SCWO (see e.g., Golyina and Li, 1995; and Modell et al., 1995). These wastes contain acceptable levels of chlorides (e.g., < 5000 ppm) and could be processed without the need for excessive dewatering. Although 7 to 13 percent dry weight solids (wt-%) were acceptable, inorganic solids contained in the feed or formed during oxidation settled in the reactor or heat exchangers and clogged the flow.

In 1993, Modec (predecessor company to SuperWater Systems) introduced a new reactor design that effectively eliminated clogging caused by inorganic solids. The new design used a tubular reactor with velocities high enough to keep solids in suspension (see Modell, et al, 1993).

In the past decade, several companies built pilot plants and tested them for wastewater treatment sludges. One company built a full-scale unit for Harlingen, Texas. Although high destruction efficiencies were obtained, these process designs did not follow the teachings of Modell's 1993 patent, and the efforts to commercialize the sludge application failed due to settling of inorganic solids.

The Orlando/SuperWater SCWO Process

The SCWO process now being used in the full-scale system at the Iron Bridge Regional Water Treatment Facility is based on the design principles of the 1993 Modell patent (now owned by SuperWater Systems), with several new enhancements. The flow sheet is shown in Figure 3.

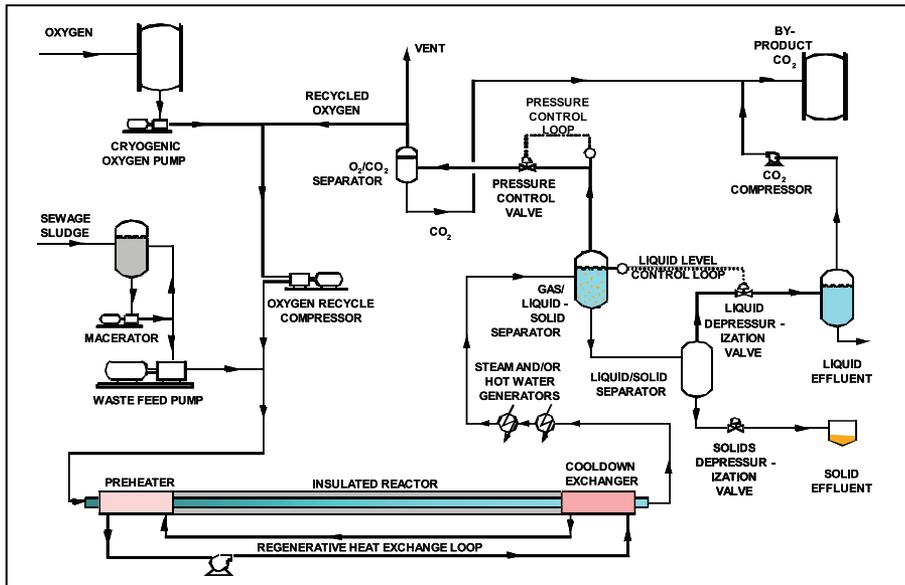
The sludge feed at 10 wt-% solids is macerated and recirculated to a holding tank. A portion of the recirculated flow is pressurized to 3,800 psia with a sludge pump. Oxygen is drawn from a storage tank, pumped to 3,800 psia, vaporized, and then mixed with the pressurized sludge feed. The combined stream is fed to a reactor assembly, which is a tubular system of constant pipe diameter that is used for the combination of preheater, reactor, and cooldown heat exchanger (Modell et al., 1996).

High velocities and the smooth transitions from preheater to reactor to cooldown exchanger help to minimize settling of solids and buildup of scale in the system. Scale formation in the preheater is removed periodically by mechanical cleaning devices.

The energy required for preheating is obtained from cooling the reactor effluent.

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Figure 3. The Orlando-SuperWater SCWO process with heat and CO₂ recovery



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Pressurized pure water is used to carry the heat from the reactor effluent to the preheater. The preheater to cooldown heat exchanger encompassing the recirculating heat transfer loop approximates an adiabatic subsystem, so the fluid leaving the cooldown exchanger is near the adiabatic flame temperature of the feed-oxygen mixture. The steam and/or hot water generators shown in Figure 3 are thus capable of recovering virtually all the heating value of the feed-oxygen mixture.

The process of Figure 3 also features oxygen and carbon dioxide recovery. By cooling the reactor effluent and separating the phases before depressurization, one obtains a gas phase of CO₂, O₂, N₂, and small amounts of H₂O and N₂O.

Upon depressurizing this gas phase from 25 MPa, most of the CO₂ will be liquefied. It is possible to obtain highly purified CO₂ byproduct with a cryogenic distillation column. The overhead from the distillation is rich in O₂ and can be recycled. The recycle line will require a vent to purge N₂ and N₂O from the system.

References

1. Modell, M., "Processing Methods for the Oxidation of Organics in Supercritical Water," U.S. Patent No. 4,338,199, issued July 6, 1982.
2. Thomason, T.B. and Modell, M., "Supercritical Water Destruction of Aqueous Wastes," *Hazardous Waste*, 1 (4), 453 (1984).
3. Modell, M., "Supercritical Water Oxidation," Chapter B-11 in *Standard Handbook for Hazardous Waste Treatment and Disposal*, H. M. Freeman, ed., Hill Publishing Company, 1988.
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7. Modell, M, Mayr, S.T., and Kemna, A. "Supercritical Water Oxidation of Aqueous Wastes," *Proc. - Int. Water Conf.*, 56th p. 479-488 (1995).
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Criteria	Wet Oxidation	SCWO	Incineration
Temperature (°F)	300 to 600	900 to 1,200	1,500 to 3,000
Pressure (psia)	1,000 to 2,000	3,500 to 4,000	20 to 30
Residence time (min)	60 to 120	0.5 to 1	0.001 to 0.01
Sludge Conc. (wt-%)	3 to 8	8 to 13	25 to 35
Destruction Efficiency (%)	20 to 80	99.9 to 99.9999	98 to 99
Benefits	<p>Relatively inexpensive</p> <p>Solid effluent can be readily dewatered to 35 wt-% cake</p>	<p>Virtually complete destruction</p> <p>No stack gas scrubbing needed</p> <p>Solid effluent passes TCLP</p> <p>Sludge heating value can be recovered as steam for power generation</p> <p>CO₂ can be recovered as a liquid</p> <p>No more costly than land-application</p>	<p>Established technology</p> <p>Significant volume reduction of solids</p>
Drawbacks	<p>All effluents need further treatment, which drives up total cost</p>	<p>Unproven at commercial scale for sludge</p>	<p>Extensive dewatering required for feed preparation</p> <p>Expensive if stack requires scrubbing</p> <p>Fuel required to supplement feed</p>

Comparison of Sludge Oxidation Technologies