Wet Air Oxidation of Municipal Sludge: Return Experience of the North Brussels Waste Water Treatment Plant

J. Chauzy*, JC. Martin**, D. Cretenot*, JP Rosiere***

*Veolia Water Technical Department, 1 rue GB Pirelli, 94410 Saint-Maurice, France (E-mail: julien.chauzy@veoliaeau.fr; didier.cretenot@veoliaeau.fr)
**Aquiris, 450 avenue de Vilvorde, 1130 Brussels, Belgium, (E-mail: jean-claude.martin@aquiris.be)
***Ministère de la Région de Bruxelles-Capitale. A.E.D. - Direction de l’Eau, Brussels, Belgium

Abstract: For large cities which cannot afford to sustain land disposal of sludge, Wet Air Oxidation appears to be an interesting option, perceived as environmentally friendly to a public opinion some times reluctant toward conventional incineration. However, due to significant investment costs, it is relevant to reduce upstream the amount of sludge by anaerobic digestion. This paper presents the North Brussels WWTP (1.1 Million pe), which was started-up in 2006. The sludge treatment consists of thermal hydrolysis of dewatered sludge followed by high load mesophilic anaerobic digestion and Wet Air Oxidation. The Wet Air Oxidation final product is then dewatered and dried to over 90% solids content, prior to being disposed as a cover product for landfills.

Keywords: Sludge, wet air oxidation, Athos™, thermal hydrolysis, mesophilic anaerobic digestion

INTRODUCTION

Biosolids management and treatment has become a significant consideration as far as waste management is concerned. In the environs of the European Union approximately 8 million tonnes of dry solids are currently produced per year (OTV, 1997), with the continued expansion of the EU and improved implementation of the European Union’s Urban Waste Water Treatment Directive, this production and associated volume will continue to drastically increase. Major cities are facing today a common challenge dealing with sludge disposal. New treatments have to be sustainable, meaning a minimal impact on environment and a recycling of both energy and material. It is clear that most of them cannot cope with conventional land application, due to long distance to available fields, complexity of logistic and tracing procedures, the management of a long and branched sewer network for which accidental pollution are difficult to prevent, impairing the agricultural use from time to time.

In this context Veolia Water Solutions & Technologies (VWS) have developed a Wet Air Oxidation (WAO) process, Athos™, as an alternative minimisation and oxidation technique to Incineration. The main principle of WAO is the thermal oxidation of the biosolid residuals in the liquid phase. Ideally, to reduce the oxygen demand these materials should be digested to reduce the volatile matter loading and chemical oxygen demand (COD), prior to their minimisation. The effluents from the process are a solid mineral complex, a liquid effluent (containing the easy biodegradable residual COD not converted by the process) and a controlled gas release to atmosphere. The system utilises pure oxygen as the oxidising agent and minimises the release of off-gas.

Athos™ Wet Air Oxidation was installed at the North Brussels Waste Water Treatment Plant (WWTP) and started-up in 2007. The required WWTP discharge limits are 125 mgCOD/L, 10 mgN/L, 35 mgSS/L, 25 mgBOD/L and 1 mgP/L. It is one of the five actual Athos™ references in Europe (Table 1), Toulouse was the full-scale prototype. WAO is the final step of a long sludge treatment line including gravity thickener, dynamic concentration by centrifuge to reach 16% dryness, Thermal Hydrolysis Process (THP) prior to turbo Mesophilic Anaerobic Digestion (MAD), following by WAO and to finish dryer plate filter. This sludge treatment line is unique over the world and is detailed here after.

THE PRINCIPLE OF WET AIR OXIDATION

Wet Air Oxidation (WAO) or Wet Oxidation is a well-established technique (Zimmermann, 1958; Foussard, 1989) for wastewater treatment particularly toxic, highly organic wastewater and sludge. Contrary to incineration which realises oxidation in gaseous phase, wet air oxidation is a process whereby the oxidation of the wastewater sludge’s organic material, which can be oxidised, occurs in the liquid phase. This is achieved at moderate temperatures 125°-320°C and pressures in the range from 5 to 200 bar to prevent the water from
The solubility of oxygen at these temperature and pressure enhances the kinetics of oxidation reactions which are realised in the liquid phase because of the pressure applied, higher than the saturated vapour pressure (Seiler, 1987). The degree of oxidation achieved is a function of temperature, oxygen partial pressure, residence time and oxidizability of the various organic species in the municipal wastewater sludge. Due to the environment within the process vessel, chemical oxidation reactions of mineral components occur together with oxidation of the organic material.

The composition of all municipal sludges vary and even sludges from a similar treatment train, but from different sewer collection systems may present different wet oxidation kinetics depending on the sludge pre-treatment or production processes (Belkhodja, 2000). Residence times may range from 15 to 120 minutes depending on temperature and degree of treatment required. The reduction or removal of COD may be typically 75% to 90%. Insoluble organic matter is converted to simpler soluble organic compounds, which are in turn, oxidised and eventually converted to carbon dioxide and water if their oxidation reaction is permitted to complete, without the emissions of nitrogen oxides (NOx), sulphur dioxide (SO2), hydrogen chloride (HCl), dioxins, furans and fly ash etc. The operating process conditions selected depend mainly on the treatment objectives.

THE PARTICULARITIES OF WAO REALISED BY THE ATHOS™ PROCESS
The Athos™ Process (Luck et al., 1999, 2000) is a wet oxidation system dedicated for oxidation of residual sludge from municipal wastewater treatment. It operates at mild (mid range) pressure 54 bar, using if needed homogeneous copper(II) ion (copper sulphate) as a catalyst and pure oxygen as the oxidising agent for a high mineralisation of the sludge. The benefit of the catalyst is to lower the oxidation temperature while keeping the process performances. The use of a catalyst enables the operating temperature to be reduced by circa 50°C with a shorter retention period and the consequent reduction in the energy requirements. The hydraulic retention time at 250°C, which is the nominal temperature condition, is close to 1 hour and the solids retention is almost double by the use of a recirculation of settled mineralised solids ahead of the reactor feeding. 75 to 90% COD mineralisation is achieved and a solids volume reduction of 90 to 95% can be achieved. Heat recovery is realised by using a closed loop of superheated water to ensure auto-thermal conditions. This heat circuit uses shell and tube heat exchangers.

The main particularities of WAO done by Athos™ compare to other processes is that the reactor is a perfectly mixed reactor by using an external recirculation loop instead of plug flow reactor, pure oxygen instead of air, and heat exchangers working with a closed loop of superheated water instead of sludge/sludge heat exchangers.

DESCRIPTION OF THE SLUDGE TREATMENT AT NORTH BRUSSELS WWTP
The large capacity of the plant (1.1 million population equivalent) raised several issues to be handled in order to get a sustainable and cost effective sludge treatment and disposal or reuse
An innovative sludge treatment train was selected (Figure 1), including the Athos™ WAO process. The objective was to maximise waste sludge volume reduction using a thermal oxidation process with optimised overall energy recovery. Sludge incineration may be a solution, but incineration was forbidden in the tender.

The sludge treatment train of the North Brussels plant has a capacity of 77 tDS/day. It is including a gravity thickening step followed by a dewatering step using centrifuges which thicken the sludge up to 15-16% dryness. Dewatered sludge are fed into thermal hydrolysis process operating at 165°C before entering into high load mesophilic anaerobic digestion (Panter et al., 2005). The Athos™ process is then treating digested sludge and the final mineral residue is dewatered up to 90-95% by using a dryer press-filter. The North Brussels wastewater treatment plant was started-up by the year 2006.

Figure 1: North Brussels sludge treatment train.

Thermal Hydrolysis Process and Mesophilic Anaerobic Digestion

Thermal sludge hydrolysis into solubilised inorganic and mainly organic matter is realised by injecting 190°C and 12 bar steam into 16% dewatered sludge in order to maintain the sludge at 165°C during approximately 30 minutes. The objective of THP is the improvement of sludge biodegradability for maximising organic matter reduction and biogas production in the further mesophilic digestion step. The thermal hydrolysis process, provided by Cambi, is composed of three main vessels described in Figure 2: the pulper is the first tank in which 16% dryness sludge is pre-heated at approximately 85-90°C by using recycling steam coming from flash-tank. The pre-heated sludge is then heated up to 165°C in one of the 5 reactors operating in batch mode, by live steam injection at 190°C and 12 bar. After 30 minutes at almost 165°C, the sludge is flashed in the reactor for recycling flash steam in the pulper. Flash steam release will finish in the flash-tank to recycle steam in pulper and also to cool down hydrolysed sludge at 105-110°C. Finally, a tube in tube heat exchanger is used to decrease the temperature of sludge down to 45-50°C before entering into mesophilic anaerobic digestion.

High load digestion or “turbo-digestion” is fed with hydrolysed sludge at approximately 12% dryness (after steam injection) and operates at a temperature of 38 to 40°C. This high sludge concentration at the inlet of digester is possible because of low viscosity and high biodegradability of hydrolysed sludge. Dry solids concentration is limited to 6 to 8% in conventional anaerobic digesters because of mixing difficulties. Mesophilic anaerobic digestion when combined with thermal hydrolysis has several advantages compare to conventional anaerobic digestion, such as high volatile matter removal (up to 50-55% compare to 30-35% for conventional mesophilic anaerobic digestion on biological sludge), low hydraulic retention time of around 15 days, very low volume of turbo-digestion, no need of heating system on recycling loop (temperature control of digestion is done by adjustment of inlet hydrolysed sludge temperature), high biogas production, high dewaterability of digested
sludge and minimisation of excess sludge volume. The mesophilic anaerobic digesters of North Brussels currently reached 52% Volatile Matter (VM) removal with a temperature of around 39°C and a hydraulic retention time of 15 days.

**Figure 2:** North Brussels Thermal Hydrolysis Process.

**Wet Air Oxidation**

In the next step, digested sludge is mineralized by a wet air oxidation system using the Athos™ process (Figure 3). Two Athos™ units are installed in parallel (Figure 4). Their treatment capacity represents 2x12 m³/h of digested sludge at approximately 80-90 gDS/L.

**Figure 3:** Athos™ Wet Air Oxidation Process.  
**Figure 4:** Reactors of WAO.

The Athos™ wet oxidation process operates at mild operating conditions under 54 bar and 250°C using homogeneous copper(II) ion catalyst, to lower oxidation temperature while keeping high oxidation performances, and pure oxygen as the oxidizing agent. Heat is recovered by using a closed loop of super-heated water for a real auto-thermal operation. The WAO reactor is considered as a completely stirred reactor by using a recirculation pump at an appropriate recirculation ratio. Oxygen is introduced at a controlled flow-rate in the recirculation loop using a sludge-ejector.
Detailed description of Athos™ device: the soluble oxidation catalyst is added in the stirred feeding tank, which also collects the recycled mineralized sludge, in order to increase the solid retention time, and digested sludge. A high pressure pump (Figure 5) is then used to convey the sludge through a primary heater, composed of a group of shell-and-tube heat exchangers (Figure 6), which heats the sludge up to a calculated required temperature (165-180°C) much less than oxidation reactor temperature of 250°C. Oxygen introduction at a controlled flow in a recirculation loop of mineralized sludge reacts with organics from digested sludge and exothermic oxidation reactions release heat in the reactor which permits to carry out the oxidation at a temperature of 250°C. A pressure of almost 54 bar is applied in the reactor in order to have around 16 bar of gas (except vapour) upper the saturated pressure of 38 bar at 250°C. The oxidant is pure oxygen, stored on-site under liquid form. The hydraulic retention time is 1 h. These operating conditions lead to a high COD removal with remaining acetic acid, very refractory to oxidation but very easily biodegradable. Thus acetic acid can be used within the treatments works as a carbon source to perform nutrient removal such as denitrification.

For start-up needs, steam is produced by a high pressure boiler at 25 bar using biogas produced by the digester to heat water to 200°C and sludge at almost 165-180°C for initiating WAO reactions. In start-up configuration, sludge and hot water by-pass the cooler. Once the process reaches a steady state, it becomes auto-thermal without any thermal energy input, thanks to the exothermic reaction.

The off-gas produced is treated in a thermal oxidizing unit before being discharged to the atmosphere with no dust. Both gas and liquid phases are extracted from the reactor considered as a gas/liquid separator.

The oxidized sludge is then withdrawn and cooled down in a second group of primary heat exchangers. The recovered heat is transmitted to the incoming sludge by means of a superheated water loop circulating between the two exchangers in a closed loop. After being released and cooled down in secondary heat exchanger for heat recovery, the liquid and solid phases of oxidized sludge are separated in a lamellar settler. The supernatant, mainly composed of ammonia and BOD, is sent upstream to the inlet of WWTP. A part of the concentrated sludge extracted from the settler is sent into the feeding tank in order to increase the solid retention time in Athos™ system, and another part of mineralized concentrated sludge is definitively extracted from the system and sent upstream to a dryer press-filter.

The calorific fluid used to transfer heat from primary cooler to primary heater is superheated water entering the heater and the cooler respectively at 200°C and 80°C. Primary heater and cooler exchangers are designed in order to be switched: heater becomes cooler and vice versa, by using automatic valves. This answer to heat exchangers fouling problem has proven to
very efficient for a long sludge WAO system operation period in a full energetically self-sustaining way.

RESULTS AND PERFORMANCES
During the WAO step, 75 to 80% of inlet COD is removed at North Brussels WWTP. The off-gas, mainly composed of carbon dioxide (CO₂), residual oxygen (O₂) and ammonia (NH₃) is first going to a condenser in order to remove NH₃, and then is going into the gas treatment (oxidiser) to remove traces of carbon monoxide (CO) and volatile organic carbon (VOC). The liquid effluent coming from WAO (overflow of settler and filtrate from dryer plate filter) is going upstream to the WWTP which had been designed taking into account of the sludge treatment returns load. The characteristics of this return is 0.3–0.5 g SS/L, 3.0–3.5 g NH₄–N and 12–15 g COD/L.

Mass reduction and volume reduction
Thermal hydrolysis combined with mesophilic anaerobic digestion has an average removal of suspended solids of 45% and an average removal of totals solids of 40%, the difference between SS and TS removal is due to solubilisation of organic and mineral matter during THP and anaerobic digestion. The Wet Air Oxidation done on digested sludge reaches SS removal of 48%. Finally, the global SS removal of the North Brussels sludge treatment line is 71%. The remaining SS after WAO and plate filter is almost completely mineral.

Between the inlet of the step of centrifugation at 16% dryness and the final cake, the volume reduction factor is close to 100 (Figure 7). From the 600 400 m³/year of thickened sludge (30 g SS/L) coming from gravitary thickener, the final cake volume is 5700 m³ per year (dryness of 90%).

Figure 7: Sludge volume reduction reached with the complete sludge treatment train of North Brussels.

Final product
The mineral settled sludge coming from the lamellar settler which has a concentration of 80–90 gDS/L is dewatered and dried in combined equipment. The feed to the combined dryer plate filter is accomplished in a conventional manner and filter cakes are formed in the chambers by the pressure of the feeding pump. Once filled, hot water at approximately 80°C (obtained by heat recovery on Athos™ sludge cooling) is recirculated through filter plates, in a closed loop. At the same time the cakes are being heated, a vacuum is drawn on the chambers of the plate filter, in order to evaporate water contained in cakes at low temperature (45–50°C). The water vapour removed from the filter cake is condensed in a pre-condenser prior to reaching the vacuum pump. The cake can be dried to any desired moisture level by simply controlling the drying time.
After dewatering by dryer plate filter, the dryness of the final cake is minimum 90%. The cake is composed of 89–93% of mineral matter and the total organic carbon is 3-5%. Leaching tests show that heavy metals are immobilised into the mineral solid matrix. The 90-95% DS mineral residue is currently reused as a product for covering a landfill in Belgium. Several reuse options remain opened for consideration in the long term, such as use for secondary raw material in building and construction.

**Energy integration**

A complete scheme for energy recovery had been thought out for North Brussels WWTP. WAO uses steam (25 bar and 220°C) only during the start-up period. After this period, the process is autothermal and does not need any thermal energy input. Moreover, WAO is producing on the secondary cooler hot water (80°C) available for buildings heating or for dryer plate filter. WAO is completely integrated into the energy recovery scheme of the plant (Figure 8) which is composed of CHP (1 MW electric) and steam production (25 bar) for Thermal hydrolysis and the start-up of WAO. Both are using biogas from anaerobic digestion.

**CONCLUSION**

North Brussels WWTP is equipped with a complete sludge treatment train, a configuration unique over the world, including a step of Wet Air Oxidation realised by the Athos™ process. Wet Air Oxidation was chosen by the Ministère de la Région de Bruxelles-Capitale, among other reasons, in order to drastically reduce the quantity of dewatered sludge which have to leave every day the plant, and thus the operating costs. During the project, proposing Wet Air Oxidation on North Brussels WWTP was a real alternative, regarding operational cost and investment, to on-site fluidised bed sludge incineration which was not wished by the Ministère de la Région de Bruxelles-Capitale. Associated with anaerobic digestion, the WAO represents one interesting solution for large municipalities to get rid of sludge and to minimize environmental impact, including the possibility to recycle final mineral products and produce thermal energy.
REFERENCES


