Two-Stage Thermal oxidization: A Cost-Effective, Environmentally Sound Alternative for BioEnergy Recovery from Multiple Hearth Furnaces

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Abstract

Incineration or Thermal Oxidization of wastewater biosolids is a proven, cost-effective, and environmentally sound practice. Air pollution control device technology is available to comply with US EPA 40 CFR Part 60, Subparts LLLL and MMMM, and 40 CFR Part 62, Subpart LLL, commonly referred to as the SSI Rule.

This paper will discuss an overview of biological and thermal bioenergy recovery potentials and pathways. The focus of the paper is energy recovery from a Multiple Hearth Furnace (MHF) based thermal oxidization system at the Delaware Regional Water quality Control Authority (DELCORA), Chester, PA. Operational results from this recent MHF bioenergy recovery project are included.

Key Words

Two Stage Oxidization, Multiple Hearth Furnace (MHF), Zero Hearth Afterburner, Autogenous Combustion, Last Gas Contact Temperature, Quench, Packed Bed Scrubber, Multi-Venturi Scrubber, Wet Electrostatic Precipitator (WESP), Regenerative Thermal Oxidizer (RTO), Bioenergy, 40 CFR Parts 503, 60 and 62 (US EPA MACT Standards, also called SSI Rule)(1), Rankine Cycle.

History

The MHF has been used for biosolids incineration since 1935. The Fluidized Bed Combustor (FBC) since 1965. There were approximately 250 operating MHF for applications biosolids in 2009 in the US. (2)

The useful life expectancy of a MHF or a Fluidized Bed Combustor (FBC) can exceed 50 years. The intervals of refractory rehabilitation are about the same for a new or an existing incinerator. Scrubber life varies with use and regulatory mandates. Many scrubber systems have been in continuous operation for 20 years or more.

Bioenergy Recovery Potentials – Overview

Bioenergy recovery pathways from Wastewater Treatment is site specific and recovery technologies vary. Two commonly used processes are: Biological Oxidization (Anaerobic Digestion) and Thermal Oxidization (MHF or FBC).

<u>Biological Oxidization</u>:

Biological oxidization of volatile wastewater solids is a tried and proven technology. In a well-designed, well-operated anaerobic digester, about 60% to 70% of the Volatile Solids (VS) are converted to gas phase constituents and water. About 16 ft^3 of biogas is produced per pound of VS converted (3). The gas-phase biogas contains about 600 to 700 BTU/ft^3 (3,4). A simplified bioenergy potential calculation in per ton of VS converted is presented in Equation 1.

Equation 1

$$(2000 \text{ lbs VS x } 0.65_{\text{dest, eff.}}) \text{ X } (16 \text{ ft}^3 \text{ biogas/lb VS destroyed}) \text{ X } (650 \text{ BTU/ft}^3) = 13.5 \text{ Million BTU/ton VS}$$

Recovery of the Bioenergy potential from biogas utilization can employ various prime movers. An Internal Combustion Engine (IC) will produce about 40% to 43% gross electrical recovery potential, about 32% to 35% net electrical efficiency, In an IC based Combined Heat and Power (CHP) system about 40% to 45% of usable heat be can recover. The combined heat and power efficiency can be as much 80% to 85% of the input energy on a gross energy output basis, net about 65% to 70%.

Other prime movers including: Micro-turbines, Steam / ORC turbines, sterling engines, fuel cells and other prime movers must be evaluated on a site-specific basis.

<u>Thermal Oxidization:</u>

In a thermal oxidization system (MHF or FBC) about 100% of the VS are converted into gas-phase constituents. The calorific value of VS can be measure as "High Heating Value" and averages 8,000 to 12,000 BTU/lb[2,5]. Equation 2 estimates the bioenergy potential per ton of VS converted.

Equation 2

(2000 lbs VS) X (100% VS converted) X (10,000 BTU/lb.) = 20 Million BTU/ton VS oxidized

Recent reviews and new projects in Europe prove that incineration is still a modern and robust concept for wastewater solids handling.[6]

Recovery of the bioenergy potential from thermal oxidization can take a variety of pathways, some of the common pathways are; return waste heat to Incinerator; employ Waste Heat Recovery Boiler (WHRB) followed by steam turbine, Organic Rankin Cycle turbine, or other use such as building heat or elevating the temperature liquid sludge to enhance dewatering characteristics.

Figure 1

Typical MHF Thermal Oxidization Energy Recovery Pathways

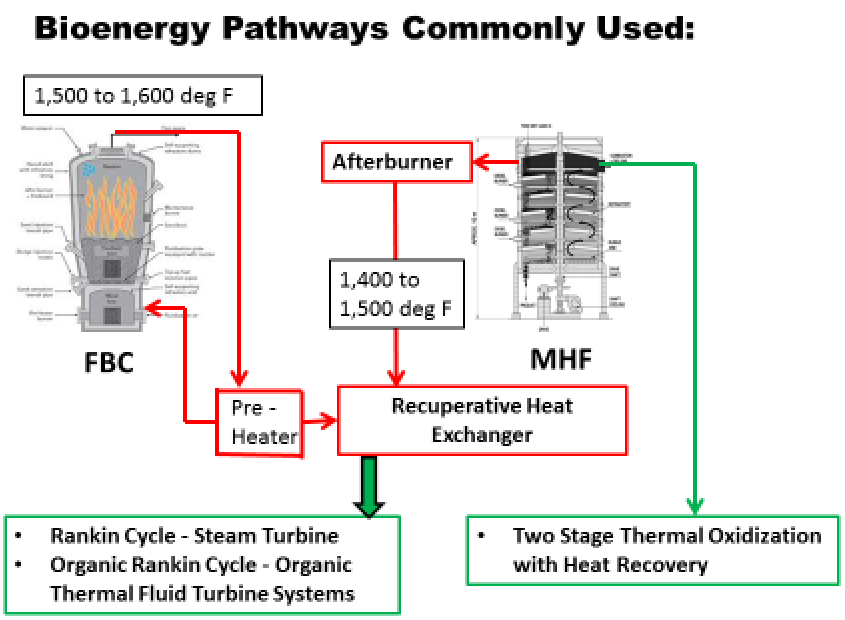
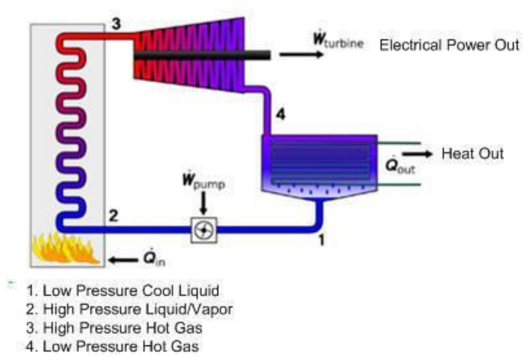


Figure 2 Rankine Cycle Energy Recovery



The simplified Rankine Cycle, depicted in Figure 2, includes; boiler to convert water to steam, a steam turbine to generate electrical power, a condenser to cool steam to water, and a pump to circulate in a closed loop system. The electrical efficiency of a steam or thermal fluid (ORC) system is about 20% to 25% gross, less net.

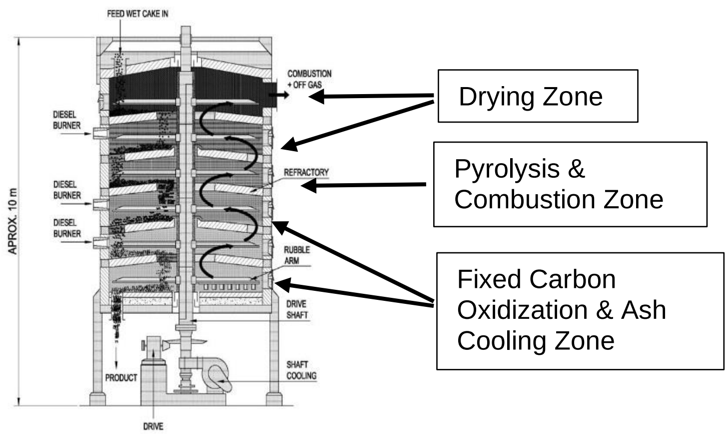
Efficiencies vary with installation and equipment utilized.

Combustion in a MHF

The MHF is an ingenious device. The MHF dries the dewatered cake solids, thermochemically converts the volatile organics to handle able off-gases, and cools the ash all in one vessel. MHF produce dry bottom ash and thereby avoids the complications of ash dewatering common to fly ash systems. Dry ash disposal costs are less because it does not include landfilling water.

The MHF has four distinct zones; Drying, Pyrolysis and Flame Combustion, Fixed Carbon Burning and Ash Cooling as shown in Figure 3..

Figure 3



MHF Zones

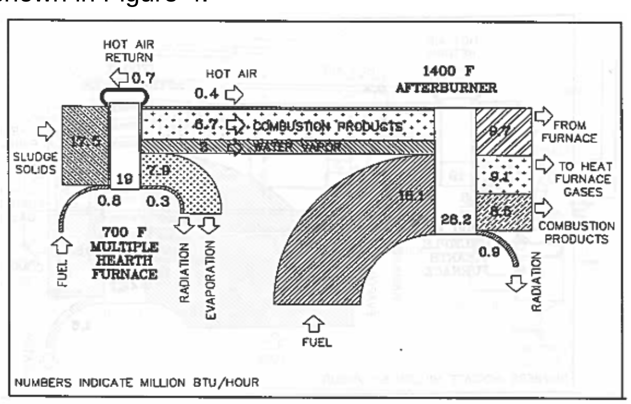
During the drying step and combustion step Volatile Organic Compounds (VOCs) and products of combustion are released into the flue gas. VOCs are regulated emissions, as surrogate parameters, of Carbon Monoxide (CO) or Total Hydrocarbons (THC). Destruction of VOCs requires elevated temperatures (1,350 to 1,500 deg F).

One solution employed to reduce VOC emissions from a MHF was to convert the top two hearths to “zero hearth” afterburners. Elevating the temperature in the zero hearths to 1,400 to 1,500 deg F has shown to reduce flue gas emissions to within regulatory limits of 100 ppmvd at 7% O_2 measured as CO or THC.[2,7]

Conversion to a zero hearth afterburner could adversely impact charging rate / furnace capacity and will result in hotter furnace operation and more auxiliary fuel. A large fraction of the zero hearth afterburner heat demand is required to evaporate water from the gas saturated drying stage. The fuel demand of a zero hearth afterburner is significant. The latent heat of vaporization heat demand alone is 970 BTU per pound water evaporated.

Fuel demand of a separate vessel afterburner is shown in Figure 4.[5]

Figure 4 Energy Diagram for Conventional Afterburner at 1,400° F



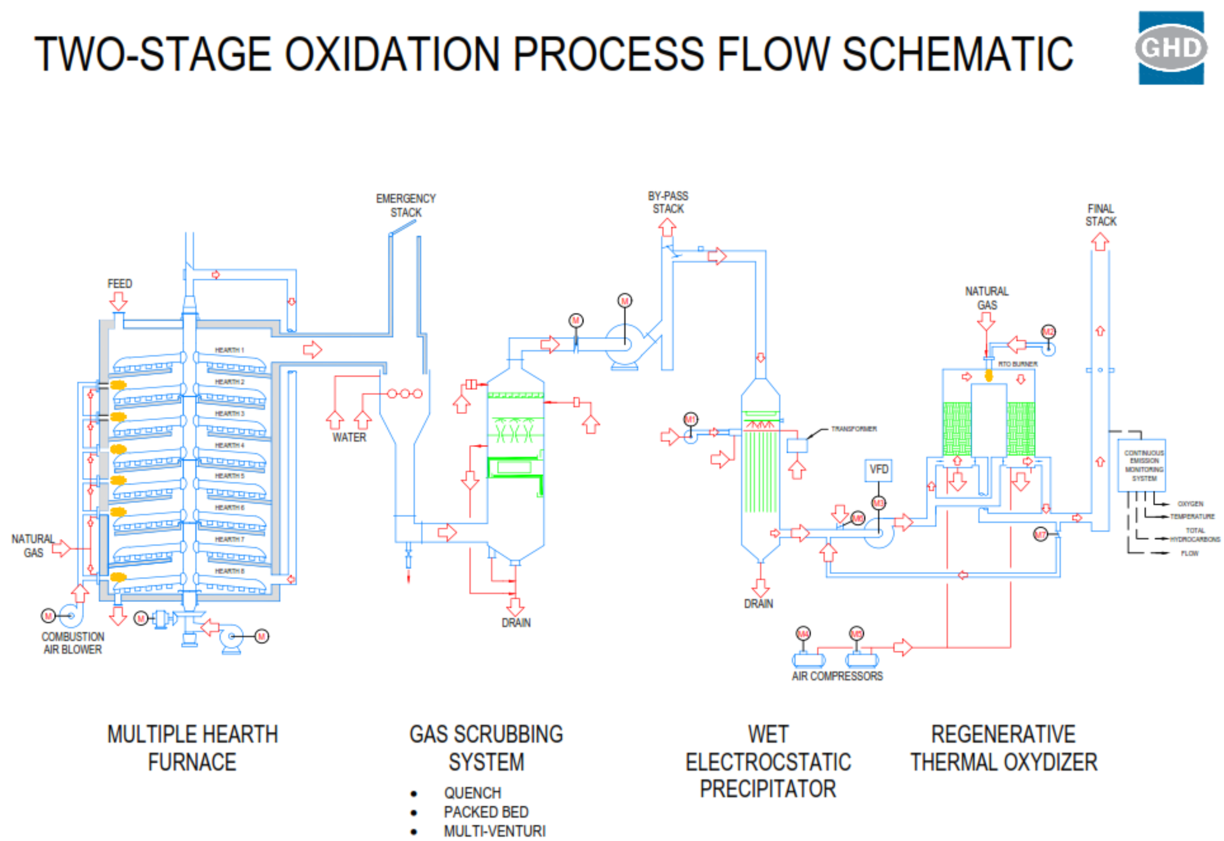
Bioenergy Recovery using Two-Stage Thermal Oxidization

In a two-stage thermal oxidization system the VOCs escaping the first stage oxidization reactor in the MHF are allowed to pass through the wet scrubber. Because VOCs are not water-soluble, the bulk of VOCs escaping the furnace remain in the flue gases exiting the wet scrubber stages.

Prior to the RTO, the flue gases undergo particulate removal, acid gas reduction, and metals condensation/reduction in the wet scrubber. The flue gas temperature exiting the wet scrubber is about 38^0C (100^0F), or about ten times less than the flue gas temperature exiting the MHF of about 540^0C ($1{,}000^0$ F). This reduction in flue gas temperature has a corresponding reduction in flue gas volume and moisture holding capacity. Flue gas moisture and volume is reduced by about tenfold.

These pre-cleaned relatively dry flue gases are than directed to a second stage of combustion, using a Regenerative Thermal Oxidizer (RTO), where the VOCs are reduced to within regulatory emission standards. This two-stage oxidization configuration in depicted in Figure 5.

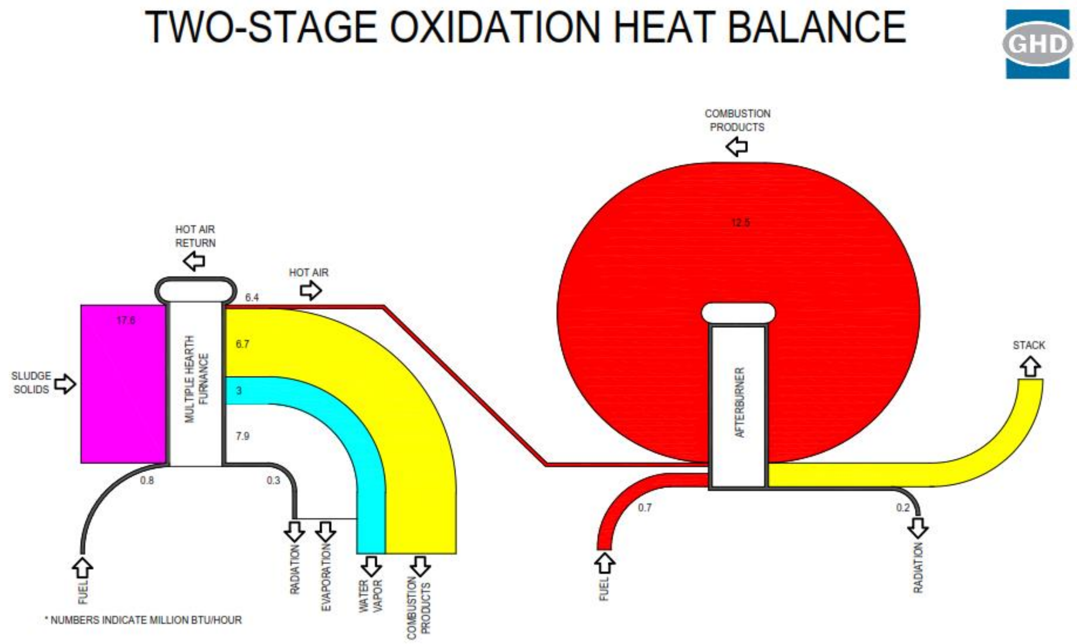
Figure 5



Heat Balance

The fuel use of a two-stage oxidization uses only about one tenth of the auxiliary fuel than that of a conventional, zero hearth or external MHF afterburner.[5,6] Contributing factors to the reduced fuel demand include the ten-fold reduction in flue gas volume and moisture content, and the excellent thermal properties of ceramic materials. A typical heat balance is presented in Figure 6.

Figure 6



In any biosolids incineration system the bulk of the input energy is derived from the combustion of VS and fixed carbon in the biosolids feedstock. If the heat energy produced by the thermal oxidization of carbon and VS is not sufficient to evaporate the water in the feedstock, then auxiliary fuel is added to the MHF or FBC incinerator. Autogenous or self-sustaining combustion has been achieved in both the MHF and FBC at about 28% to 30% Total Solids (TS) and about 75% to 80% VS.

In a two-stage oxidization system, heat energy from the first stage (MHF) is wasted to the scrubber to gain the benefits of flue gas cleaning, volume, moisture, and acid gas reduction while retaining the heat availability of the VOCs. In the second stage combustion, the RTO heat energy is recovered in ceramic media and recycled to the incoming gases. The overall thermal efficiencies of RTOs are about 90% to 93%.

DELCORA Project

The Delaware County Regional Water Quality Control Authority (DELCORA) in Chester PA USA owns and operates two 48 dry tons/day (dt/d), 8 Hearth, Multiple Hearth Furnace (MHF) based thermal oxidization systems. DELCORA provides a service to surrounding communities by receiving truck hauled waste. DELCORA is the largest truck hauled waste receiving facility in the area.

In light of the pending EPA MACT (SSI Rule) Standards, prior stack tests showed NOx occasionally above the new SSI limit, and capacity concerns DELCORA authorized an evaluation of biosolide handling alternatives. GHD completed the biosolids handling alternatives evaluation in 2011. This study reaffirmed the advantages of combustion as a cost effective and environmentally sound biosolids handling solution and recommended the installation of the innovative two-stage thermal oxidation system.

In the improvement project, the Multiple Hearth Furnace (MHF) “zero hearth afterburner” was eliminated and approximately 50 m^2 of drying hearth area was restored. The MHF now provides more efficient drying and enables lower operating temperatures in the first stage oxidization of biosolids. Products of incomplete combustion and Volatile Organic Compounds (VOCs) formed in the combustion zone and stripped in the drying step are oxidized in the Second thermal oxidation stage, a Regenerative Thermal Oxidizer (RTO) operating after the wet-scrubber in the flus gas flow stream.

Figure 7

The Wet Scrubber, installed upstream of the RTO, was furnished by Hitachi Zosen Inova U.S.A. LLC and included a new water seal/water wall stage, quench stage, packed bed stage, multi-venturi stage, and mist eliminator.

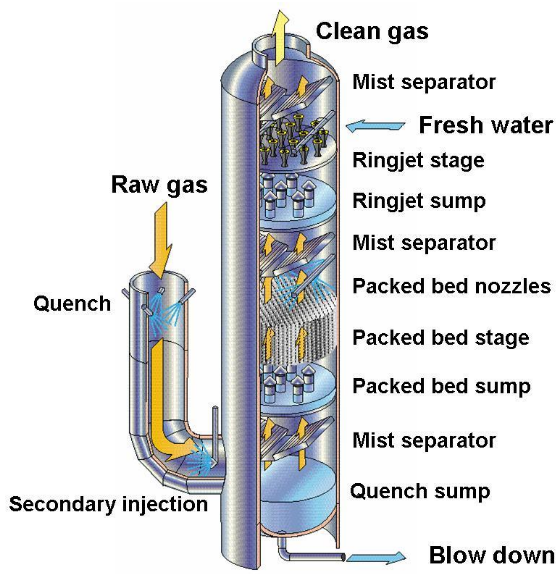
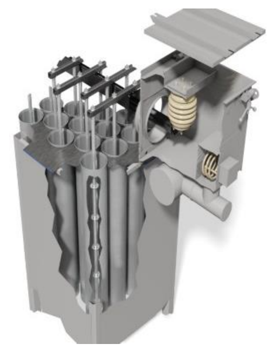


Figure 8
The Wet Electrostatic Precipitators (WESP) also upstream of the RTO, furnished by Lundberg Inc., provides enhanced particulate and metals reduction.



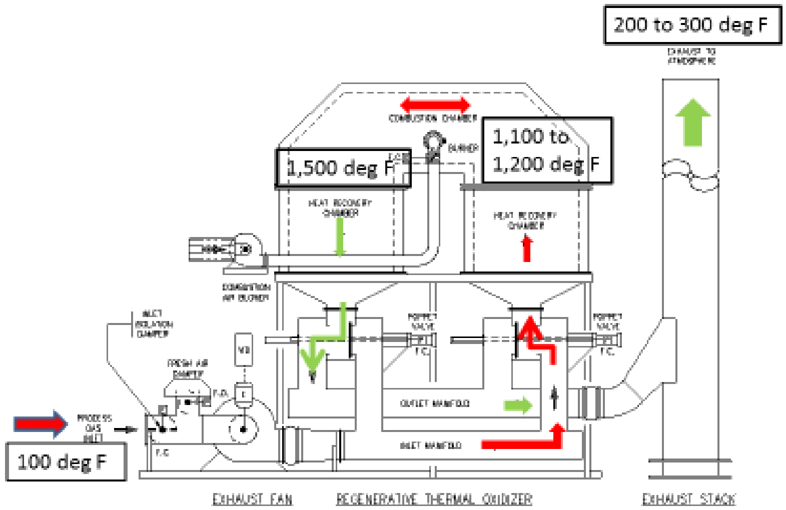
The principal design features include:
Down-Flow configuration, large circular tube collecting electrodes, large diameter charging electrodes and water flow concurrent with flue gas to minimize wet/dry area corrosion.
A low velocity mist eliminator was included at the WESP outlet.

The RTO, furnished by Nestech, Inc., shown in Figure 9, is the first of a kind two canister RTO on a biosolids incineration system. A novel heat recirculation loop from exhaust ±120^{0}C (±250°F) to inlet, ±40^{0}C (100°F) was designed. This heat return is used to elevate the inlet flue gas temperature above dew-point, (about 5°to 10^0 C) to minimize the collection of condensable organics on the RTO media.

Figure 9

Gas Flow Through the RTO – Forced Draft

Courtesy; Nestec Inc.



DELCORA - first application of a two-canister RTO on a MHF based system

Status

The combination two-stage oxidization, four-stage gas cleaning system has reduced Particulates, Dioxins/Furans, THC, CO, NOx, SOx, HCl and other regulated emissions to fractional levels of the US EPA MACT Standards and Pennsylvania DEP Standards. (Particulate was measured at 0.014 kg/dry ton combusted versus a limit of 0.59 kg dry ton (0.03 lbs/dt versus a limit of 1.3 lbs./dt.)

The first improved MHF 1 system was placed into operation with minimal problems in June 2016 and is operating at 700°C (1,450°F) last gas contact temperature with as little as 5% to 10% of the fuel consumption of the zero hearth afterburner configuration(9). During the compliance stack test the RTO/afterburner used an average of 0.39 MMBTU/dry ton incinerated, the MHF used an average of 1.6 MMBTU/dry ton incinerated. The combined (MHF plus RTO) average fuel cost was $9.48/dry ton incinerated, at a Natural Gas commodity cost of $8.00/1000 ft^3.

The second improved MHF 2 was performance stack tested in February 2017. During the compliance stack test the RTO/afterburner used an average of 0.15 MMBTU/dry ton incinerated, the MHF used an average of 1.93 MMBTU/dry ton incinerated. The combined (MHF plus RTO) average fuel cost was $16.64/dry ton incinerated, at a Natural Gas commodity cost of $8.00/1000 ft^3.

Discussion of Project and Data Collected

During the performance stack testing of both MHF 1 and 2 the charging rate in dry tons per hour was maintained above 85% of 55 dt/d. (46.75 dt/d). One objective of the project was to increase the permitted charging rate of each MHF from 48 dt/d to 55 dt/d.

Table 1 - Key Operating Parameters During Perfprmance Stack Testing						
Parameter	**Units**	**MHF 1 Tested Aug. 2016 21-Test Run Average (Each run 1 to 4 hrs)**	**MHF 2 Tested Feb. 2017 21-Test Run Average (Each run 1 to 4 hrs)**	**English Units**	**MHF 1 Tested Feb. 2017 21-Test Run Average (Each run 1 to 4 hrs)**	**MHF 2 Tested Feb. 2017 21-Test Run Average (Each run 1 to 4 hrs)**
MHF Feed Solids						
TS	%	25	24	%	25	24
Charging Rate	tone/day	43.1	42.6	ton/day	47.42	46.81
VS	kg/hr	1,347	1,418	lbs/hr	2,964	3,120
VS/TS	%	75	80	%	75	80
MHF						
Comb. Zone	deg C	780	811	deg F	1,450	1,492
Outlet	deg C	510	650	deg F	950	1,200
RTO						
Inlet	deg C	32	32	deg F	90	90
Comb. Zone	deg C	780	811	deg F	1,450	1,492
Outlet	deg C	123	127	deg F	254	260
N.G Fuel	m3/dry tonne	9	4.5	ft3/dry Ton	316	156
Venturi Δ P	mm	356	377	Inches wc	13.95	14.86

Each MHF emissions performance stack testing was conducted per PA DEP/US EPA approved protocol. Dioxin/Furan runs were mandated to be 4-hour duration. The 3-run test average emission for each regulated emission is shown in Tables 2 and 3. These tables also show, in the last column, a comparison to the regulated emission standards. Graphs 2 and 3 below show fuel demand during the test periods.

Table 2

MHF 1 Stack Test results August 2016

Emission	***Units (All Results at 7% O2)***	***Three Run Average***	***SSI Rule Limit***	***Title V Permit Limit***	***% of Limit***
Particulate Matter	*mg/dscm*	0.95	80		**1.2**
	lbs/dry ton	0.065		1.3	**1.3**
Total Hydrocarbons (THC)	*ppmvd*	< 10	100	100	**10**
Carbon Monoxide (CO)	*ppmvd*	43.5	3,800	100	**44**
Oxidizes of Nitrogen (NOx)	*ppmvd*	151	220		**69**
Sulfur Dioxide (SO2)	ppmvd	1.05	26		**4**
Hydrogen Chloride (HCl)	ppmvd	0.95	1.2		**79**
PCDD/PCDF (TMB)	ng/dscm	0.23	5		**4.6**
PCDD/PCDF (TEQ))	ng/dscm	0.0034	0.32		**1.1**
Cadmium	mg/dscm	0.0003	0.095		**0.3**
Lead	mg/dscm	0.0011	0.3		**0.4**
Total Mercury	mg/dscm	0.0037	0.28		**1.3**

Auxiliary fuel demand was very low during the five (5) consecutive day stack testing of MHF 1. Extended periods of autogenous combustion conditions were experienced during the test period. RTO fuel demand remained steady throughout testing period. Fuel demand per stack test run is presented in Graph 1.

Graph 1

MHF and RTO Fuel Demand; MHF 1 Performance Test

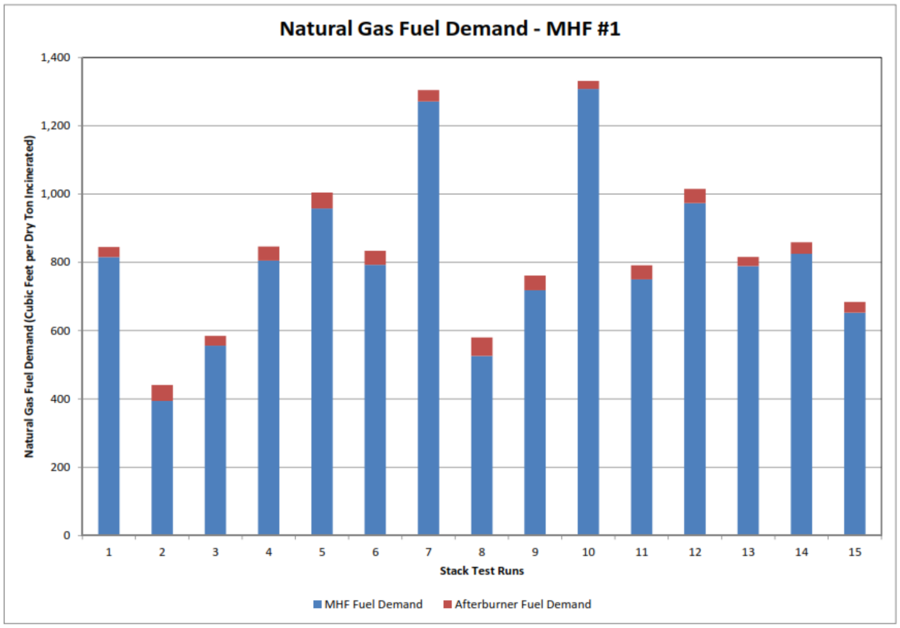


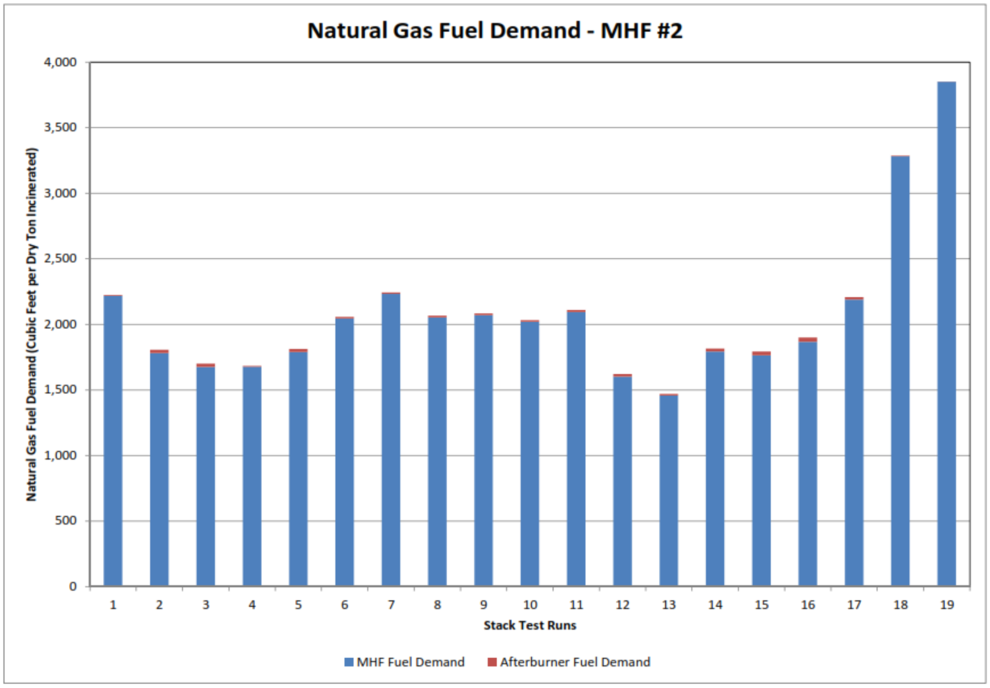
Table 3

MHF 2 Stack Test results, February 2017

Emission	*Units (All Results at 7% O2)*	*Three Run Average*	*SSI Rule Limit*	*Title V Permit Limit*	*% of Limit*
Particulate Matter	*mg/dscm*	3.61	80		**4.5**
	lbs/dry ton	0.034		1.3	**5.0**
Total Hydrocarbons (THC)	*ppmvd*	< 10	100	100	**10**
Carbon Monoxide (CO)	*ppmvd*	56.2	3,800	100	**56**
Oxidizes of Nitrogen (NOx)	*ppmvd*	103	220		**47**
Sulfur Dioxide (SO2)	ppmvd	0.27	26		**1**
Hydrogen Chloride (HCl)	ppmvd	0.77	1.2		**64**
PCDD/PCDF (TMB)	ng/dscm	0.4	5		**0.8**
PCDD/PCDF (TEQ))	ng/dscm	0.0155	0.32		**4.8**
Cadmium	mg/dscm	0.0001	0.095		**0.1**
Lead	mg/dscm	0.0047	0.3		**1.5**
Total Mercury	mg/dscm	0.00002	0.28		**0.007**

Graph 2

MHF and RTO Fuel Demand; MHF 2 Performance Test



Unique Design Features

- First of a kind, to the best of my knowledge, application of a two canister RTO on a MHF. A two canister RTO reduces both capital and operating expense compared to three canister RTOs. PA DEP mandated testing of VOC destruction efficiency across the RTO. Both RTO 1 and 2 showed VOC destruction efficiencies above 90% at variable VOC loading to the RTO.

- An RTO heat recirculation loop was designed to minimize the formation of condensable organics fouling on the RTO media.

- The exhaust gas from the RTO is ideally suited for add-on mercury reduction if mandated by future regulator standards for mercury emissions from MHF based systems. Since the RTO exhaust is well above dew point, no reheating of the flue gas is required and condensation on the carbon media is not a concern.

Sealing of the MHF sludge inlet.

- As an adjunct to the project, reciprocating piston pumps (Schwing) replace a belt/screw conveyor sludge feed system to the MHF. By sealing the furnace inlet for the pipe only penetration a surprising reduction in flue gas volume from MHF was realized. The flue gas volume at the stack with the large inlet hole was about 14,000 ACFM. After the inlet was sealed, for the pipe only penetration the flue gas volume dropped to about 9,500 ACFM as recorded by the CEM system.

- Use of a single flue final stack was approved by PA DEP thus allowing a single CEM probe/analyzer system. Cleaned exhaust from both RTOs enter a single stack fitted with

Continuous Emission Monitoring System (CEMS) probe assemblies. Only one CEMS probe assembly/analyzer of each type is required for monitoring. Two complete CEMS are installed, one as standby for backup.

Conclusion

Project objectives and goals were achieved using an innovative, first of a kind, two canister Regenerative Thermal Oxidizer operating in a post-scrubber afterburner configuration.

The project demonstrated compliance with EPA MACT and PA DEP air emission standards at a significant decrease in auxiliary fuel use, an increase in furnace capacity (from 48 to 55 dt/d), replacement of aging equipment, and reduction of inordinate furnace maintenance cost/downtime due to lower furnace operating temperatures.

Final approval from Pa DEP / EPA to increase furnace capacity (from 48 to 55 dt/d) is pending PA DEP/EPA review of MHF 2 stack test reports submitted to PA DEP in June 2017.

The performance of the system is comparable to that of a Fluidized Bed Combustor in terms of fuel use and air emission compliance.

Thermal Oxidization is a cost-effective biosolids handling alternative. WEF reports(2) typical incineration facilities experience annual operation cost of $155 to $310 per dry ton.

Acknowledgements;
GHD wishes to express appreciation to the many people who provided support for the success of the DELCORA facility, especially, Bill Karch, co-author, project and construction manager for DELCORA, the directors of DELCORA who accepted the challenge of new technology and the plant personnel who make it work.

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