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Development of Successful Poultry Litter-to-Energy Furnace

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Abstract. *Excessive land application of poultry litter has resulted in nutrient over-loading in regional watersheds. Poultry litter to Energy has been shown to be a viable, renewable energy solution. A poultry litter to energy furnace has been developed that consists of a modified Multiple Hearth Furnace (MHF), a technology that has been used for almost a century to burn sewer sludge. Circle Slot Jets are a new, patent pending method of introducing combustion air into the MHF furnace to create high turbulence and increased air-to-fuel mixing inside the furnace, increasing control and combustion efficiency and reducing CO and hydrocarbons emissions. The poultry litter is burned in a controlled environment at temperatures high enough to allow complete combustion, but low enough to avoid agglomeration and slagging in the ash and exhaust. Because of the controlled combustion process, the resultant ash is converted to a concentrated fertilizer, high in phosphorous, potassium, calcium, magnesium and other valuable micronutrients. Wet scrubber performance efficiency for emissions reductions is 95 – 99.99% for HCl, Cl_2,SO_2, HF, and particulates. This creates a very clean exhaust that meets all relevant EPA standards. This poultry litter to energy furnace provides a high value alternative to land application and helps to control rising energy costs.*

Keywords. Poultry litter, energy, combustion, poultry litter furnace, renewable energy

Introduction

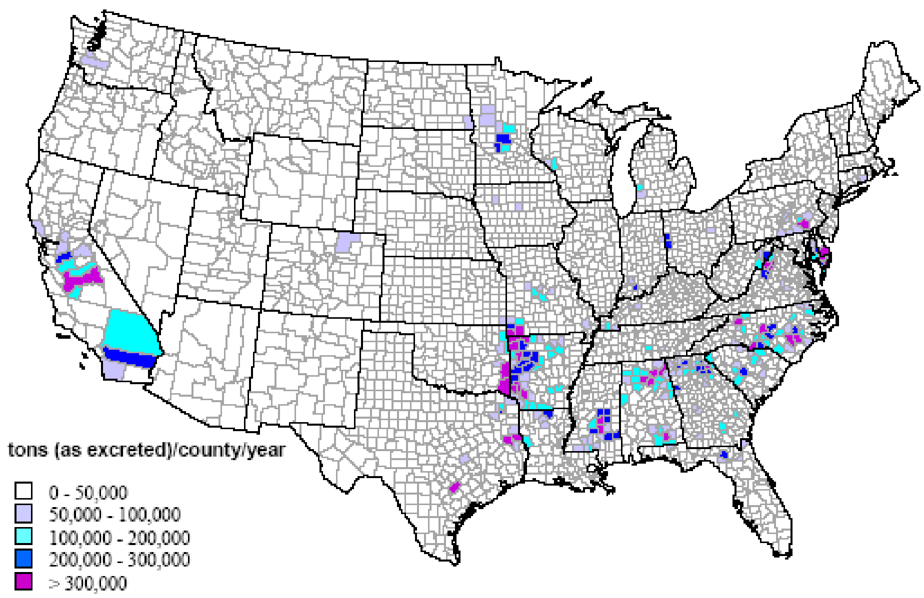
Major poultry production in the United States tends to be concentrated in regions as shown in Figure 1 (Wimberly, 2002). Though poultry litter is an excellent fertilizer and soil amendment, excessive land application has resulted in nutrient over-loading in area watersheds. In these regions, poultry litter as a fertilizer is simply too much of a good thing.

> Chicken litter, (Jim) Wimberly (of the Foundation for Organic Resources Management) points out, contains many important plant nutrients, carbon and even microbes that enhance any soil to which it is added. The problem, he adds, is that we produce too much of it. More correctly, too much is produced in concentrated areas where there isn't enough open land to use it properly. So scientists and poultry industry leaders are being challenged to find alternative ways of managing poultry litter (Deterling, 2002).

Many possible alternatives have been investigated and attempted. All have some merit. One very good solution is utilizing excess poultry litter as a fuel to generate clean, renewable energy (Martin, 2000). Waste-to-energy is an excellent solution, and ultimately solves two problems:

- Provides high value alternate use of poultry litter to reduce excessive land application
- Provides valuable and renewable energy to help offset high energy costs

Figure 1: Poultry Manure Production in the Continental United States (Wimberly, 2002)



Poultry Litter Thermodynamics

Poultry litter has been shown to be a viable, renewable biomass fuel. The heating value averages around 4100 Btu/lb (9550 kJ/kg) (Mukhtar, 2002; MES, 1999), and is usually quite dry, around 25% moisture content, when compared to other biomass sources. The stoichiometric combustion of poultry litter would result in an adiabatic flame temperature of approximately 2000˚F - 2100˚F, which is more than adequate to prove the viability of poultry litter as a thermal energy source.

The idea of Poultry Litter to Energy (PLE) is not new, but, surprisingly, PLE projects have rarely been successful. The litter burns easily enough, but the high concentrations of potassium, phosphorous, magnesium, calcium, manganese and other materials cause problems in both the exhaust and the ash. The low fusion temperature of these alkalis and alkali metals results in softening, or melting, of the materials during combustion. When the ash is cooled, these materials agglomerate, or re-freeze, forming a very hard, porous, lava rock-like substance called “slag”. A small portion of the low melting point materials, in the form of dust and particles, are carried with the exhaust gases. When these melted particles come in contact with the heat exchanger, they re-solidify on the exchanger surfaces and eventually form a layer of slag. This slag acts as an insulator and significantly limits the effectiveness of the heat exchanger. Cleaning of the tubes can be a painstaking process where the slag, or scale, must be scraped off, or chipped off in some cases, to remove (MES, 1999).

A Poultry Litter to Energy Furnace Developed

Fortunately, a solution has been developed to coax the valuable thermal energy out of poultry litter that is technically, environmentally, and economically viable. It builds on technology that has been used for almost a century to burn sewer sludge – the Multiple Hearth Furnace (MHF). The poultry litter is burned in a controlled environment at temperatures high enough to allow complete combustion, but below the fusion temperature of the ash in the bed and the dust in the exhaust. This allows the heat to be collected in fairly standard waste-heat-boilers (WHB) to generate steam that can be used for process steam, electricity generation, or both. The process described herein is not the only solution for poultry litter-to-energy, but is unique in that it is based on the use of biosolids burning technologies and not based on coal or wood-burning equipment.

The Multiple Hearth Furnace (MHF)

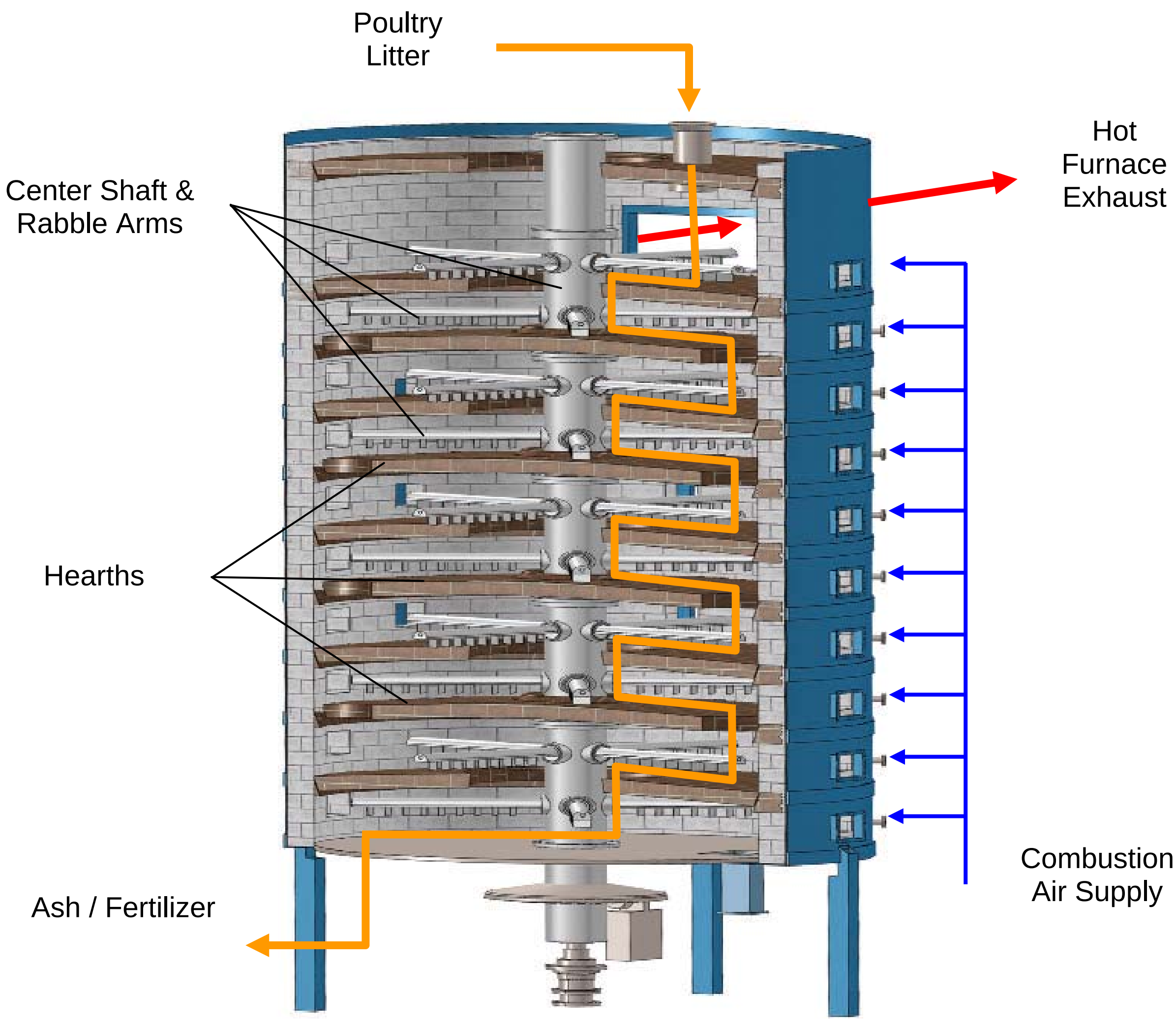
The poultry litter to energy solution developed by American Heat and Power consists of a modified multiple hearth furnace (MHF). MHFs are very robust furnaces that have been used successfully for almost a century in the United States to burn municipal wastewater sludge, as well as other industrial furnace applications. In fact, MHFs installed in the Detroit wastewater treatment plant in 1938 are still in operation today; that’s 68 years of continuous operation!

American Heat and Power has modified the existing MHF by adding a patent pending air injection system and modern control technologies. The new air injection technology, called ‘Circle Slot Jets’, significantly increases the convective transport properties at the interface of the air and the “fuel” inside the furnace. This technology will be discussed in more detail later. The important benefit is that the increased air-fuel mixing greatly improves the combustion process, reduces the formation of thermal nitrogen oxides (NOx) and decreases the emissions of carbon monoxide (CO).

A cut-away view of a standard Multiple Hearth Furnace is shown in Figure 2. The multiple hearth furnace is made up of several hearths stacked vertically, with space between them. The hearths have alternating in, and then out hearths; meaning the ‘drop holes’ in the hearth are alternating between inside, near the center shaft, and outside near the outer wall of the furnace. The poultry litter (or other solid biomass fuels or materials) are plowed, or “rabbled”, through each hearth by means of a rotating center shaft to which are connected rabble arms with angled plow blades, or “teeth”.

The plow blades rabble the material along the floor of the hearth in a spiral pattern either from the outside toward the center (in-hearth) or from the center toward the outside (out-hearth). As the litter drops downward progressively through the furnace drop holes, the combustion air supply and exhaust gases move upward through the furnace, passing through the same drop holes, but in the opposite direction.

Figure 2. Cut-Away of a Multiple Hearth Furnace (Courtesy Industrial Furnace Company, Inc.)

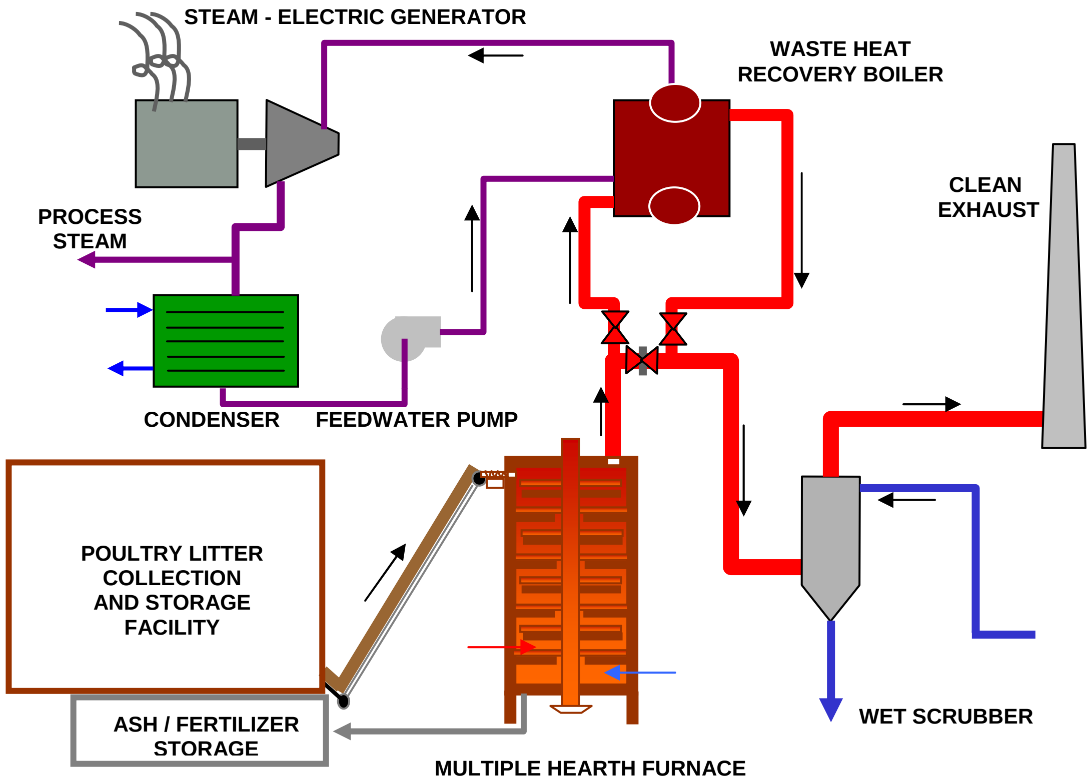


The MHF is the heart and integral part of a Poultry Litter to Energy (PLE) Facility, as shown in Figure 3. The PLE facility consists of the collection and storage facility where trucks would deliver the litter, the furnace, the waste-heat-boiler to collect the heat and generate steam from the furnace exhaust, the wet scrubber and exhaust systems. If electricity production is desired, a steam-electric generator can be installed as shown in Figure 3. The combustion air for the furnace is drawn from the storage and collection facility to help provide ventilation and odor control.

The Ash – A Concentrated Fertilizer

Because of the controlled combustion process, the resultant ash is converted to a concentrated fertilizer or fertilizer amendment, high in phosphorous, potassium, calcium, magnesium and other valuable micronutrients. The nitrogen and the organic matter are lost in the combustion process, but the value of this fertilizer amendment is estimated at $40 to $70 per ton at current values.

Figure 3. Poultry Litter to Energy with Process Steam and Electrical Generation



The ultimate analysis of the ash is shown in Table 1 (Mukthar, 2002; MES, 1999). The high content of phosphorous, potassium, calcium, and other micronutrients make this ash an excellent fertilizer or fertilizer amendment. Because of the greatly increased bulk density compared to raw litter, this concentrated fertilizer can be more economically transported to other crop producing regions of the country.

Table 1. Post combustion analysis of the Poultry Litter Ash.

	Texas A&M		Maryland
Percent by Mass ***Parameter***	**As Excreted Manure (EM)**	**Clean-out Litter (CL)**	**MES Burn Test**
Aluminum, % as AL2O3	0.79	1.23	2.52
Calcium, % as CaO	15.084	21.5	16.625
Iron, % as Fe2O3	1.484	1.06	0.9
Magnesium, % as MgO	7.472	5.9	4.05
Manganese, % as MnO	0.626	0.22	0.153
Phosphorous, % P2O5	24.798	25.12	20.425
Potassium, % as K2O	26.944	16.51	7.125
Silicone, % as SiO2	3.686	6.34	21.25
Sodium, % as Na2O	3.724	6.52	6.875
Sulfur, %SO3	8.326	7.23	4.485
Titanium, % as TiO2	0.122	0.1	0.2

Air Emissions

The exhaust gas emissions meet all relevant EPA requirements. In fact, utilizing poultry litter to replace fossil fuels (natural gas, fuel oil, coal) to generate steam and electricity actually creates a cleaner environment. The total NOx and SOx pollution is reduced in many cases by utilizing poultry litter as the fuel of choice and utilizing the wet scrubber technology to ensure a clean exhaust. AHP's high convective rate furnace technology, as well as ammonia dissociation (ammonia is inherent in the litter) work to create very low NOx emissions. These NOx emissions are often lower than that generated from the fuel oil or aging natural gas boilers that are being offset.

Odors from the storage and collection facility are controlled. The combustion air for the furnace is drawn from the collection and storage facility to provide ventilation and prevent odors from escaping the facility, which effectively provides thermal oxidation of the ventilation air before release to the atmosphere.

Wet Scrubber Technology

The wet scrubber provides an efficient method for cleaning the exhaust before release. Table 2 lists some of the by-products potentially present in the exhaust prior to the scrubber. For example, because of salts in the litter, there are chlorines in the exhausts. This potentially creates HCl (hydrochloric acid) in the exhaust. There are also sulfur compounds and particulates. Dry scrubber technology can reduce the HCL and SO_2 by as much 90%. AHP does not think this is the best solution. Wet scrubbers' standard performance efficiency for emissions reductions is 95 to 99.99% for HCl, Cl_2,SO_2, HF, and particulates. This creates a very clean exhaust that meets all relevant EPA standards.

The scrubber water is slightly acidic due to the effectiveness in capturing the HCL and SO_2 . The scrubber water can be readily pH balanced with a lime or a sodium bicarbonate additive before final treatment and subsequent reuse or release.

Table 2. Averaged Exhaust Gas Emissions Results at MES Test Burn (without scrubber)

	lb/DSCF	lb/MMBtu
Particulate Matter*	2.40E-04	5.3
Hydrogen Chloride	2.70E-05	0.6
Ammonia	<6.3E-8	<.002
Sulfur Dioxide	1.30E-05	0.3
Nitrogen Oxides(as NO2)	3.51E-05	0.7
Carbon Monoxide	2.20E-06	0.05
VOCs **	5.00E-07	0.01

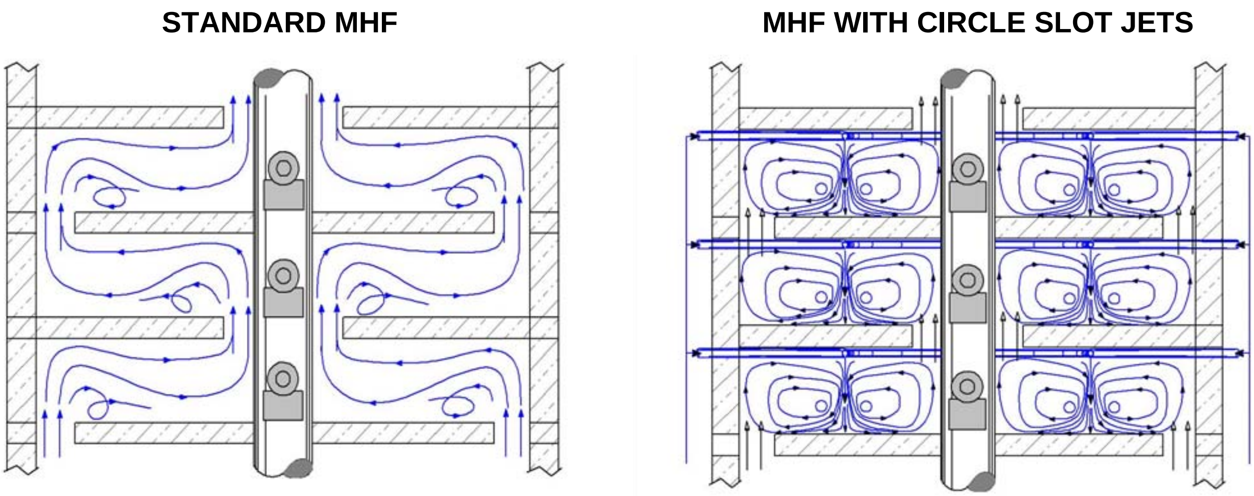
*Particulate matter results represent uncontrolled emissions, upstream of the dust collector.
** VOCs are total hydrocarbons as CH4.

Circle Slot Jets (CSJs) - The Secret of Success

Without Circle Slot Jets: The fundamental limitation of a standard Multiple Hearth Furnace (without Circle Slot Jets (CSJs)) is the poor air-fuel mixing. The air, exhaust gases, and other airborne materials (dust, ash, volatiles, etc.) travel through the path of least resistance, which is the large space between the floor and the ceiling. This flow is not very conducive to mixing of the air as the gases pass mostly through the center of the hearth chamber while the solid fuel remains on the floor of the hearth. A cross-section of this flow pattern is shown on the left in Figure 5. The result is very poor convection rates, low turbulence, and poor mixing of the fuel and air, which all lead to inefficient combustion, as indicated by high CO and unburned hydrocarbons in the exhaust, difficult furnace control, and unburned carbon in the ash.

With Circle Slot Jets: The Circle Slot Jets are a method of introducing combustion air into the furnace. It consists of a circular pipe hung from the ceiling, with a series of holes, or slots, that produce downward jets in a circle centered around the center shaft. The air is forced down to the floor with a high velocity adequate to cause shear mixing and entrainment of the air, and high convective mixing of the air and the solid fuel along the floor due to the high local velocities at the interface of the solids and air. The ring of downward air flow creates a circular impingement region on the floor of the hearth, and induces a second circular recirculating vortex region; one inside and one outside of the impingement ring. We call this a “dual-donut” vortex flow pattern. This highly turbulent flow pattern significantly increases the convection rates in the furnace, which increases combustion efficiency and effectiveness. This is highly advantageous for producing good combustion properties in the furnace. The levels of carbon monoxide (CO) and unburned hydrocarbons are reduced to near zero. The authors have a patent pending on the Circle Slot Jets.

Figure 4. Comparison of the cross-section of air flow in a standard Multiple Hearth Furnace (left), versus a MHF with Circle Slot Jets (CSJ) (right). With CSJs, the flow is forced to mix repeatedly with the ‘fuel’ on the floor of the furnace.



Poultry Litter To Energy – Furnace Performance Testing

American Heat and Power and IFCO conducted initial poultry litter test burns utilizing Industrial Furnace Company’s (IFCO’s) bench scale multiple hearth furnace. The furnace is 3 foot by 4 hearths and located at their manufacturing facility in Rochester, New York. AHP modified the existing bench scale MHF unit by installing specially designed and constructed Circle Slot Jets into hearths 2 and 3, and tested the system by burning poultry litter as a fuel in the furnace.

Standard MHF (Without Circle Slot Jets)

The initial tests were conducted to establish a benchmark in a standard MHF, i.e., without Circle Slot Jets. The burn was successful, in that the litter was burned completely. However, the burn was difficult to control due to the inherent poor air-fuel mixing in the standard furnace. The flames in the furnace were lazy, yellow and smoky. When the air flow was increased in an attempt to improve combustion by increasing airflow to reduce CO emissions, the burn temperature decreased due to excess air. When the air flow was reduced, the burn rate decreased, and the ash had unburned carbon remaining. When the air flow was adequate for complete combustion, the furnace overcooled. Trying to operate the furnace under these conditions was frustrating.

With Circle Slot Jets

After establishing the best burn possible without the Circle Slot Jets, the airflow to the CSJs was established, and the impingement and dual-donut vortex flow structure was verified with visual observations in the furnace. The furnace temperatures started to climb almost immediately. Temperature readings were recorded periodically as the various furnace parameters were modulated to determine the furnace's reaction to varying parameters with the CSJs operating.

One of the initial observations was the visible change in the appearance of the furnace flames. The furnace was no longer yellow and smoky, but now burning with a hot, clean blue flame. The color and character of the flames looked as though it were a natural gas flame – blue and orange, instead of the characteristic yellow biosolids flame. It was so startling that the natural gas supply was checked to ensure there was in fact no natural gas being burned in the furnace! There were no longer lazy yellow flames in the furnace. Without CSJs, the burning bed of poultry litter coals was somewhat ash coated and only moderately glowing orange embers. With the CSJs, the bed of coals were now an active, brilliant bright orange, some even white, burning brightly and actively as the air poured down over it from above. Some particles of glowing embers were being recirculated around the chamber, and the impingement regions and recirculation regions were visible through the inspection doors.

Figure 5 shows side-by-side photograph comparisons of this burn through the inspection port in the furnace. The left is yellow and smoky; the color on the right is almost pink; a mixture of the blue flame and the orange-hot furnace background. Streaks of glowing, burning particles can be seen in this (~0.4 second) time-lapse photograph.

This is a profound and significantly different character of fire, cleaner and more thorough than anything normally found in a multiple hearth furnace. A comparison of the average furnace temperatures shows that the addition of the Circle Slot Jets allowed the furnace to burn at over 1400˚F, whereas without the CSJs, the furnace struggle to maintain 1100˚F. Table 3 shows averages of these temperatures for each hearth for operations with and without the circle slot jets.

Figure 5. Comparison of Poultry litter Burn in MHF furnace without, and with, CSJs

STANDARD MHF **MHF WITH CIRCLE SLOT JETS**

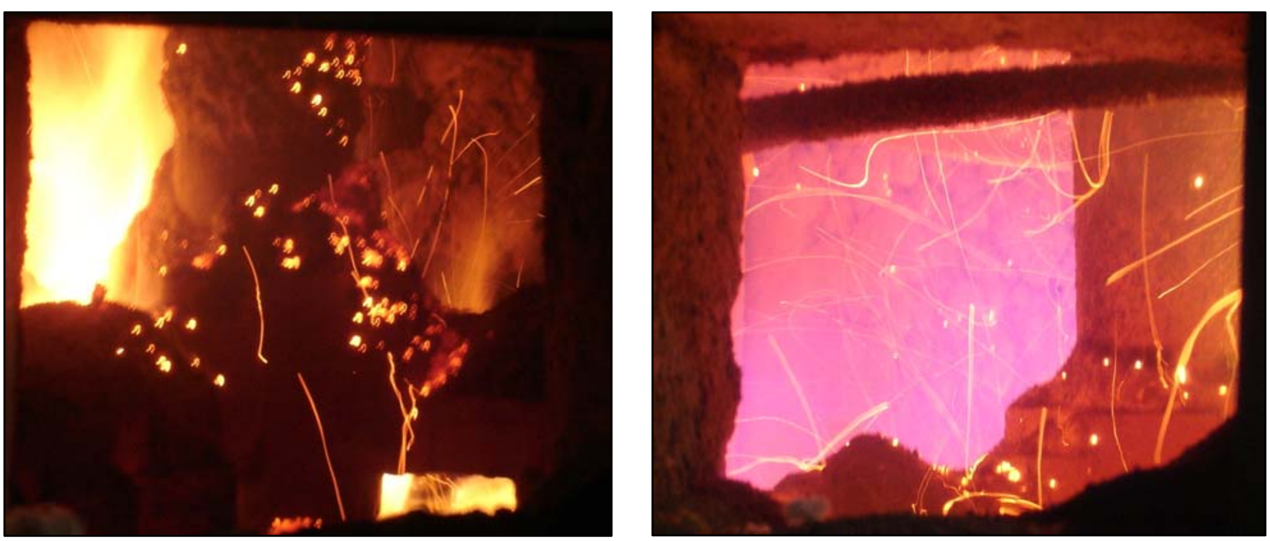


Table 3. Comparison of Hearth Temperatures for Standard (Std) Multiple Hearth Configuration and MHF with Circle Slot Jets burning Poultry Litter.

Hearth Number	Standard MHF *(NO Circle Slot Jets)*	MHF WITH Circle Slot Jets
Hearth 1 (Top)	**986˚F** (530˚C)	**1338˚F** (725˚C)
Hearth 2	**1054˚F** (568˚C)	**1440˚F** (782˚C**)**
Hearth 3	**945˚F** (507˚C)	**861˚F** **(**461˚C)
Hearth 4 (Bottom)	**641˚F** (338˚C)	**510˚F** (266˚C)

Exhaust Emissions

The exhaust emissions measurements also provided positive results. The results were so much better than expected that the emissions monitoring equipment was thought to be malfunctioning, and so was recalibrated before continuing with the tests. The air emissions results showed an almost complete elimination of Carbon Monoxide (CO) and Nitrogen Oxides (NO, NOX) from the emissions. Before the CSJs were turned on, the CO production ranged from 200 to over 1500, with spikes over 2000 ppm. The total NOx ranged from 21 ppm to over 80 ppm, with occasional spikes over 200 ppm. After the CSJs were operational, the meter simply toggled between “0” and “1” for both the CO measurement and the NOx measurements. The unburned hydrocarbons also measured 0.0. Table 4 summarizes the air emissions results without, and then with the Circle Slot Jets.

The highly turbulent air-to-air and air-to-solid fuel mixing, along with the increased exhaust temperature explain the very low (even zero) CO and hydrocarbons emissions. It was also visually verified that the combustion process was more efficient and effective.

The lower NOx production is a result, at least in part, of what is termed “flame quenching”. Due to the very high convective transport rates at the solid fuel interface, the heat of combustion is quickly taken away with the moving air, reducing the amount of residence time at high temperature required for the production of thermal NOx. In addition, the higher temperatures allow a more active ammonia disassociation, which is also known to help reduce both fuel-born and thermal NOx production.

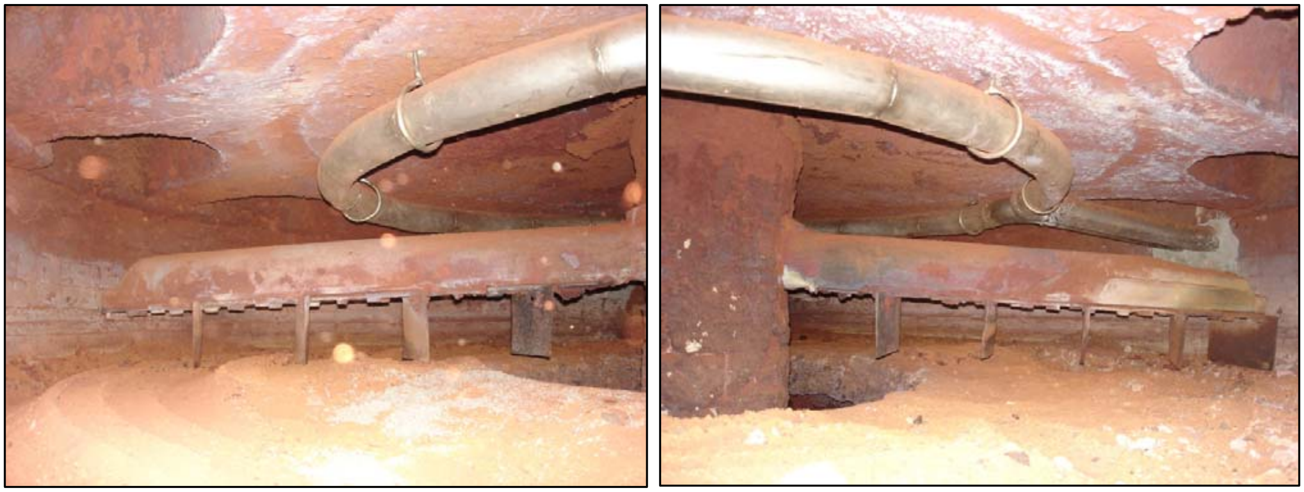
Table 4. Emissions Comparison for Multiple Hearth Furnace burning Poultry Litter with and without Circle Slot Jets.

Emissions components	Standard MHF *(NO Circle Slot Jets)*	MHF WITH Circle Slot Jets
CO (ppm)	980	< 1.0
NO_X (ppm)	49	< 1.0
O_2 (%)	16.3%	12.2%
C_XH_X (%)	1.0%	0.0%

Circle Slot Jets – The First Commercial Installation

The first commercial installation of the patent pending “Circle Slot Jets”, or CSJs, was completed in February 2006 in one of the two 14 foot diameter by 7 hearths multiple hearth furnaces located at a wastewater treatment plant on the East Coast. The furnaces burn roughly 14 dry tons per day of sewage sludge generated at the plant. The two furnaces at the plant are identical, and CSJs were installed into two hearths in only one of the two furnaces. Figure 6 shows the installation of the 3 inch stainless steel CSJ pipe hung from the ceiling in hearth 2. The small holes are just visible in the bottom part of the circular pipe. Also visible in the photograph are the furnace's drop holes from out-hearth above, the centershaft with rabbling arms and teeth, and the drop hole in center of the lower hearth.

Figure 6. First Commercial Installation of Circle Slot Jets in WWTP Biosolids Furnace.



The side by side, identical furnaces were started and brought up to normal operating conditions while being fed sludge from the same source, which was split into two equal feedrates into each furnace. The furnaces were allowed to reach steady state, and adjusted to provide conditions as similar as possible, with the circle slot jets being the only intentional difference between them. Photographs were taken on hearth 4 of each furnace. The burn on the left (no CSJs) is characterized by low convection, lazy yellow flames, and some visible smoke, which all indicate a poor fuel-air mixing condition. The same hearth (hearth 4) under identical conditions in Furnace #2 with circle slots is very different. The bed is much more active, burning bright orange and even white in places, with aggressive wisps of flames appearing sporadically. Here, the furnace air flow is very turbulent, and the combustion process is efficient and effective. Observations showed that the sludge was consumed (burned) faster in the hearth with CSJs.

Figure 7. Side by side comparison of identical Biosolids Multiple Hearth Furnaces operating without (left) and with (right) circle slot jets. The three inch circle slot jet pipes can be seen in the photograph on the left.

STANDARD MHF **MHF WITH CIRCLE SLOT JETS**

Conclusions and Recommendations

The Multiple Hearth Furnace with Circle Slot Jets provides a technically and environmentally viable Poultry Litter to Energy solution to deal with nutrient overloading and rising energy costs. Testing has shown the furnace allows poultry litter to be burned in a controlled manner that allows complete combustion, but avoids agglomeration and slagging of the ash. This Poultry Litter to Energy technology provides a cost effective means of dealing with nutrient overloading in poultry producing regions. Heat energy from the furnace can be collected without fouling and with limited corrosion due to the dry, slag fee nature of the exhaust. The heat can be used to generate steam for electricity generation and/or for process steam. The process steam can be used to offset steam currently generated with natural gas or fuel oil boilers at large poultry rendering plants or other facilities with high energy requirements.

One of the recommended applications for the MHF PLE technology is to replace fossil fuels used to meet the high steam load requirements of poultry rendering plants. These plants are conveniently located in or near the regions of highest poultry production, by design. This minimizes transportation costs of the litter. In addition, the energy requirements for steam relative to the amount of electricity of these processing plants match extremely well with the energy generated from Poultry Litter to Energy furnace systems, which permits a high total efficiency of the Poultry Litter to Energy plant. These Poultry Litter to Energy plants can solve serious environmental concerns, while providing millions of dollars in energy savings to poultry producers each year.

References

Deterling, Del, Mid-Jan 2002, Chicken Litter Logic, Progressive Farmer.

Environmental Resources Management, July 2000, Report on Eastern Correctional Institution Cogeneration Facility Full-Scale Poultry Litter Test Burn - November 1999, under direction of Diane Brown, Power Plant Research Program, Annapolis, MD.

Martin, Jr., Ph.D, John, Lefcort, Sc.D., Malcolm D., September 2000, An Analysis of the Feasibility of Using Broiler Litter as a Fuel, Paper presented to the Seventeenth Annual International Pittsburgh Coal Conference, Pittsburgh, PA.

Maryland Environmental Service (MES) Report, November 1999, ECI Cogeneration Facility, Full-Scale Poultry Litter Test Burn, Ref: Air Nova, Inc. “Maryland Environmental Service Poultry Litter Test Burn Emission Evaluation Test Program”, December 1999.

Mukhtar, Saqib, Annamalai, Kalyan, 2002, Co-Firing of Coal and Broiler Litter (BL) Fuels for Power Generation: BL Fuel Quality and Characteristics, ASAE Paper No. 024189, Chicago, Illinois, St. Joseph, Michigan: ASABE

Priyadarsan, S., Anamalai, K., J.M. Sweeten, M.T. Holtzapple, S. Mukhtar, 2002, Waste to Energy: Fixed Bed Gasification of Feedlot and Chicken Litter Biomass, ASAE Paper No. 034135, Las Vegas, Nevada, St. Joseph, Michigan: ASABE.

Wimberly, Jim, September 2002, Converting Poultry Litter into Energy in the United States – A Status Report, Map derived from the USDA 1997 Agricultural Census data, Foundation for Organic Resources Management, available at: http://www.organix.org.