Proceedings of NAWTEC16
16th Annual North American Waste-to-Energy Conference
May 19-21, 2008, Philadelphia, Pennsylvania, USA

NAWTEC16-1918

Advanced Technologies Provide New Insights for Assisting Energy from Waste (EfW) Boiler Combustion Monitoring, Operations and Maintenance.

Author: Stephen G. Deduck, P.E.
Principle Operations Engineer
Covanta Energy, Inc.
sdeduck@covantaenergy.com

Co-Author: David Suplicki
Sales Manager
Enertechnix, Inc.
dave.s@enertechnix.com

1 Abstract

This paper focuses on recent advancements in the areas of imaging technology and flue gas temperature measurement which are providing new insights for plant engineers into combustion conditions and operation in Energy-from-Waste (EfW) facilities. The paper describes how Covanta Energy, an operator of over 30 EfW facilities and Enertechnix, a manufacturer of advanced combustion products and services, are developing new technologies in these following areas:

Infra-red (IR) imaging using a mobile camera to provide active viewing of the boiler and combustion conditions
Digital recording of images of slagging, waste stream movement, and refractory inspection
Online inspection in back pass convection areas with a video camera that extends up to 20 feet into boiler.
Furnace Exit Gas Temperature (FEGT) measurement integrating proven acoustic pyrometer technology to replace inherently inaccurate contact temperature methods such as thermocouples.

The paper examines how each of these technologies is being introduced into EfW facilities operated by Covanta Energy.

Actual results are used to evaluate the potential these new methods have for improving combustion, reducing maintenance costs and providing plant operators with useful tools for operating EfW facilities. Video images of the furnace and convection sections will be provided and discussed.

FEGT data from comparative technologies is presented. The data is interpreted in order to compare the accuracy of the acoustic pyrometer measurement against other methods. Potential and determined benefits are presented and outlined. The paper attempts to provide a framework to help facilities understand the importance and impact of accurate FEGT measurement in the combustion process.

2 Company Backgrounds

2.1 Covanta

Covanta is the largest operator of Energy from Waste (EfW) facilities in the United States. Covanta's 34 EfW plants are located across the four corners of the country from Massachusetts to Florida, to Hawaii to Oregon, with over 90 heat recovery boilers processing 15 million tons of MSW a year. Covanta also has established EfW operating relationships in Europe and China.

On the road to becoming the largest EfW operator, in 2005, Covanta acquired and merged with another large EfW company, American Refuel. The six Ref-Fuel plants process almost 40% of the total waste delivered to Covanta.

The combined knowledge and focus on growth of the two companies created substantial business opportunities and an increase in research and development. With 11 combustion technologies and numerous emissions control technologies in the new Covanta, better insight into stoker/boiler/APC operation was sought out in order to achieve company goals. A survey of the state-of-the-art instrumentation technology led to the line of equipment offered by Enertechnix. The Covanta/Enertechnix relationship quickly developed into a mutually beneficial one in order to customize existing instrumentation offered by Enertechnix and develop new instrumentation based on Covanta's needs and EfW needs in general.

The instruments and their uses described in this paper represent existing technologies used in a new way as well as new technologies. Together, they have demonstrated significant potential to help Covanta achieve new goals for combustion optimization and emissions reduction.

2.2 Enertechnix

Enertechnix is a technology company that provides products and services for a wide range of industries, and commercial markets. Since 1995, the company has engineered and deployed process sensor solutions for measuring gas temperatures for boilers, mid-IR imaging systems for visual monitoring in high temperature, particle-laden environments and offers a full compliment of software solutions to help provide seamless integration into the latest plant control systems. Entertechnix' core competency is built on an extensive broad program of continued research and development activities that are focused on expanding products and services for its customers.

3 Technologies

3.1 *Acoustic Pyrometry*

Acoustic Pyrometry is a non-contact method based on the relationship of between the speed of sound and the density of the medium through which it travels. It is well known that the speed of sound varies with the temperature of the medium through which it travels and that changes in speed sound can therefore provide a direct measurement of the medium's temperature.

The relationship is based on the Ideal Gas Law:

$$p = \rho R T$$

where p is the pressure, ρ, is the density, R is the specific universal gas constant, T is the temperature,

And on the relationship between the speed of sound and the ratio of the pressure to the density given by:

$$c^2 = \gamma\, p/\rho$$

where c is the speed of sound and γ is the ratio of the specific heats at constant pressure and volume, respectively.

Combining these two relationships yields

$$c = (\gamma R T)^{1/2}$$

which is the basic relationship between the speed of sound and the temperature.

These relationships imply that all that is required for the temperature measurement is a transmitter to produce a sound wave at a specific time, and a receiver at a known distance to measure the arrival time of the sound wave, determine the sound speed, and compute the temperature. The technique has several important advantages over traditional contact or radiation pyrometers.

(i) It is a non-contact technique providing real-time measurements
(ii) It provides an integral measurement along the entire line of flight
(iii) It is capable of excellent accuracy and precision
(iv) Accuracy is not affected by uncertainty in emissivity
(v) It can be applied over an extremely wide-range of temperatures – from below room temperature to several thousands of degrees, allowing it to track startup and shutdown operations.

3.2 *Infrared Cameras*

Infrared imaging permits direct observation of important phenomena normally not visible due to insufficient light or obstruction by flames or clouds of suspended particles. Enertechnix personnel have pioneered new advancements in the use of infrared imaging to obtain and process useful images in combustion environments which are especially effective for the EfW boiler conditions.

By combining patented filtration methods with new high performance lens equipment, multiple infrared imaging solutions can be incorporated to monitor crucial boiler conditions. Areas of inspection can include refractory tile conditions, burner management, fuel feed movement and impact, and chemical injection effectiveness. Infrared imaging can look through the fire ball at full load conditions in order to provide real time evaluations of boiler operations.

Additional capabilities can be incorporated with the infrared imaging modules that include thermal temperature pyrometry, 'dual' fixed and mobile functionality to limit the need for multiple cameras and reduce costs, image archiving for historical evaluation of boiler conditions over time, and new wireless solutions which can provide seamless access to in-house viewing of images across a company network system (intranet).

3.3 *Boiler Inspection Cameras*

Covanta had been aware of variable length, (up to 20 feet long), air-cooled, video cameras that were available using a miniature camera at the tip, rather than having a lens tube with a camera at the outer end. Covanta recognized that the portability and extendibility of such a camera could have many uses in boiler, scrubber and bag house inspection, for both online operation and offline condition.

Enertechnix informed Covanta that they were also working on the development of such as camera and asked Covanta to use their boilers in this development. Covanta agreed and after several trials and improvements, purchased a camera.

Covanta still considers the long camera to be in a developmental stage, but is excited and optimistic that minor early obstacles can be overcome and make this inspection tool valuable and affordable enough for expanded use throughout its system of plants.

4 Acoustic Pyrometer

4.1 *Brief History of Acoustic Pyrometry*

Applying the acoustic pyrometry technique to measure hot gases in large furnaces can be quite challenging. Limitations had existed in controlling a high intensity sound source in noisy boiler environments. Combined with robust signal detection and microprocessor speed, the acoustic pyrometry deployment was considered difficult to justify economically.

A primary technical challenge that had hindered widespread commercial application of acoustic pyrometers, particularly in large, utility boilers has been to reliability generate sound signals loud enough to be detected in the presence of considerable background noise. However, this hurdle has been overcome with the development of patented technology with a practical sharp, high intensity pneumatic sound generator, coupled with an advanced signal detection algorithms.

The system produces high-energy sound wave (over 170db) using a unique pneumatic device. The sound wave has a distinctive sharp leading edge that is propagated concentrically from the generator, and enables the pyrometer to accurately measure temperatures to within ±1 percent over a range of 0 to 3500°F, even in the presence of considerable noise.

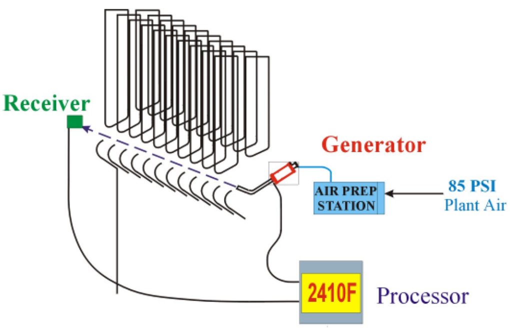
The new sound source permits the use of long pipes to deliver the sound to desired measurement location. This permits mounting arrangements through windboxes, and/or around obstructions without affecting the quality of the resultant measurement.

The high-energy sound wave also enables the use of smaller and more sophisticated receivers that can be readily installed through furnace walls using ½" slots. This has a major impact on reducing installation costs by eliminating the need for large expensive boiler wall penetrations.

4.2 *Covanta's Background with Acoustic Pyrometry*

Acoustic pyrometry with a combined transmitter/ receiver is well-established in the utility industry and was well known to Covanta. However, the relatively high costs could not be justified in the EfW industry. Enertechnix improved the design by splitting the combined transmitter/receiver into separate components. A combined transmitter/receiver requires two tube bends for installation, but the smaller stand-alone Enertechnix transmitter only requires a single boiler tube bend, significantly decreasing installation costs. Additionally, the relatively very low-cost receivers could now actually fit in a small hole in the membrane between the tubes, without requiring any tube bends. More importantly though, a matrix of multiple receivers can be linked to a single transmitter. All these new design features combined mean that a multiple path acoustic pyrometry system can be installed for a cost that could now be justified in some of Covanta's EfW boilers.

Covanta immediately recognized these advantages and selected one of its largest and most profitable facilities to be the first plant to try the Enertechnix acoustic pyrometry system. The plant was also scheduled to undergo combustion system modifications and was looking for ways to reduce superheater corrosion.



System Components

4.3 *Initial Installation of AP System - Covanta Hempstead, NY*

One of the three boilers at Covanta's Hempstead, New York, 3,000 TPD EfW plant was selected to have an Enertechnix acoustic pyrometry system installed. The boilers are equipped with DBA roller grate, mass-burn technology. The Hempstead plant is one of Covanta's most important plants, and maintaining its year-to-year high boiler availability is a key to that success. A combustion system modification for emissions reduction was scheduled to be installed on this boiler and with a history of challenging superheater corrosion, Covanta wanted to be able to closely monitor combustion flue gas temperatures leaving the furnace/entering the superheater. The superheater extends the full height of the boiler second pass and gas temperatures leaving the furnace or first passes greatly impact superheater performance and integrity.

4.4 *Existing Furnace Arrangement and Instrumentation*

Figure (1): Sketch/drawing/schematic of upper furnace.

The existing instrumentation monitoring furnace temperature consisted of three thermocouples in the upper furnace front wall. These thermocouples extended into the furnace less than 2 feet of the 18 foot front-to-rear depth. The furnace is 24 feet wide. Access is available at the front and side walls, but the first and second passes share the rear wall, precluding access to that wall. The plant had also installed an IR pyrometer in the center of the right sidewall, approximately 20 feet below where the thermocouples are located.

4.5 *AP System Configuration*

After several design iterations to balance cost and coverage, Covanta and Enertechnix decided upon a configuration of two transmitters (signal generators) and three receivers positioned on the sidewalls, giving three beam lines (front, diagonal and rear) as shown on Figure (2). This configuration was desired to be able to show front to rear temperature differences which are key for a front-to-rear stoker fired boiler. Side-to-side temperature differences were considered to be ever-changing due to the heterogeneous nature of MSW, but front-to-rear differences would be tied to combustion system performance as the waste burns and moves down the grate from the front to the rear of the boiler/stoker. The horizontal measurement plane is in the upper furnace, just prior to the vertical furnace exit. The combustion gases must make a 90° turn to transition from the measurement plane to the furnace exit.

Acoustic Sound Generator (ASG)
Unit 2 Covanta Hempstead, NY

Acoustic Sound Receiver (ASR)
Unit 2 Covanta Hempstead, NY

4.6 *Results*

4.6.1 Without Combustion Modifications in Service

Prior to the combustion modifications mentioned above, observations showed that the flue gas flow as it traveled up the furnace was predominantly concentrated at the rear wall in a bright yellow stream. The forceful upward flow gas stream was easily identified by glowing particulate in the stream, i.e. the "fireflies". On the front wall, a darker orange stream and reverse flow or eddies were observed as fireflies floating or drifting down the front wall.

Front wall thermocouples were in the range of 1500°F, (low readings due to radiation error) with the IR at the lower elevation indicating approximately 1800°F.

The acoustic pyrometer temperature readings supported the observations, with consistent indications of 1700° F along the front wall, 1800-1850°F along the diagonal and 1900-2000°F along the rear wall.

4.6.2 With Combustion Modifications in Service

The combustion modifications were expected to even out the flue gas flow and observations confirmed this expectation. The rear gas stream was not as concentrated and consistent upward flow was now observed at the front wall.

Front wall thermocouples increased slightly, but stayed in the range of 1500°F and the IR temperature decreased to 1700°F.

The acoustic pyrometer system again supported the observations with consistent indications of 1700-1800°F along each of the three lines of measurement. Not only was the flue gas more balanced, the maximum gas temperatures entering the superheater had been shown to decrease with the acoustic pyrometer. The thermocouples taken alone actually showed a small increase in gas temperature which would have been very misleading had the acoustic pyrometer readings not been available. The IR correctly reflected the overall decrease in temperature, but since only one was installed, the reduction in temperature variations throughout the plane could not be seen.

Figure (3) shows the trends of temperature, with and without the combustion modifications in operation.

Comparison of the AP system to HVT measurements is being planned by Covanta to verify the observations and the data may be available at the time of publishing.

It should also be mentioned that a series of IR pyrometers could have been installed, but the coverage across the whole boiler width of the acoustic pyrometer was considered to be more capable of providing representative data.

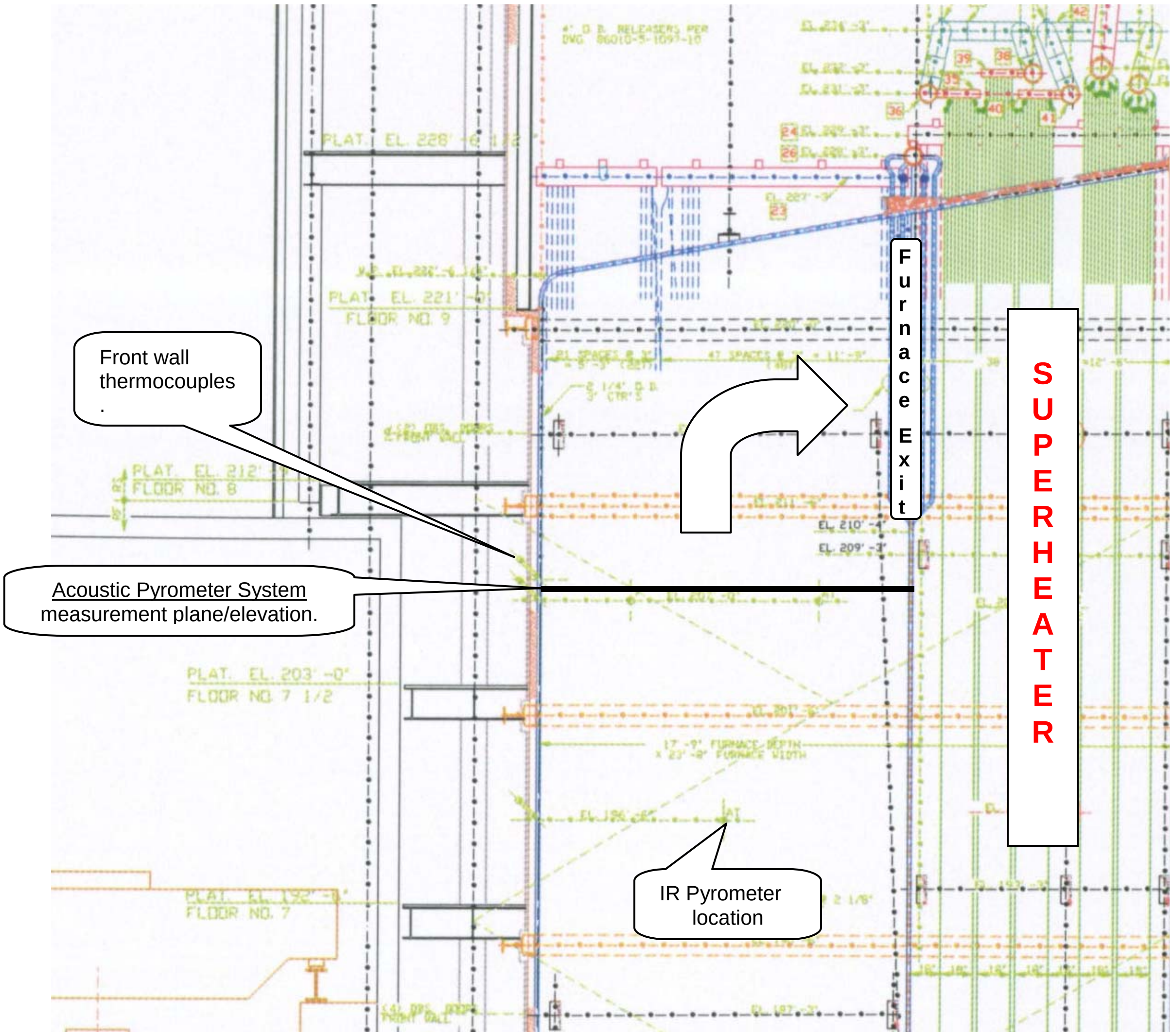


FIGURE 1
HEMPSTEAD RESOURCE RECOVERY
UPPER FURNACE SIDE VIEW

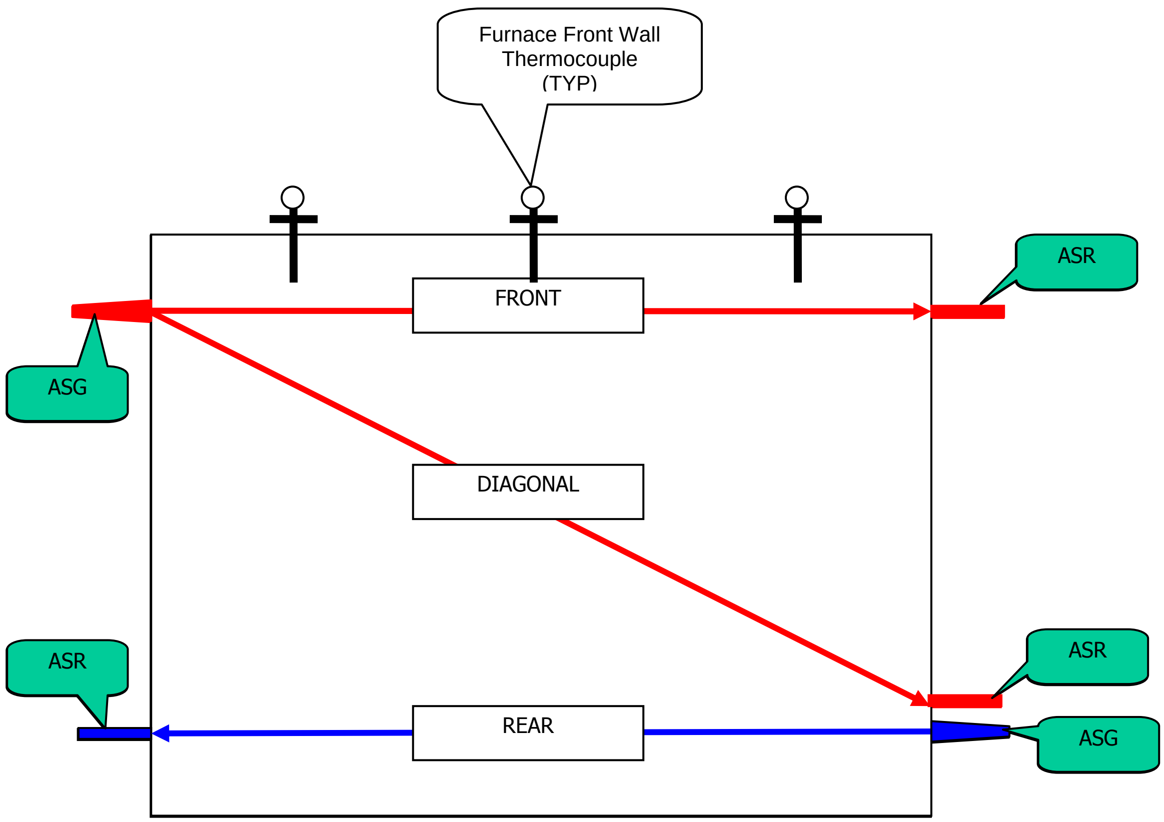


FIGURE 2
HEMPSTEAD RESOURCE RECOVERY
UPPER FURNACE PLAN VIEW

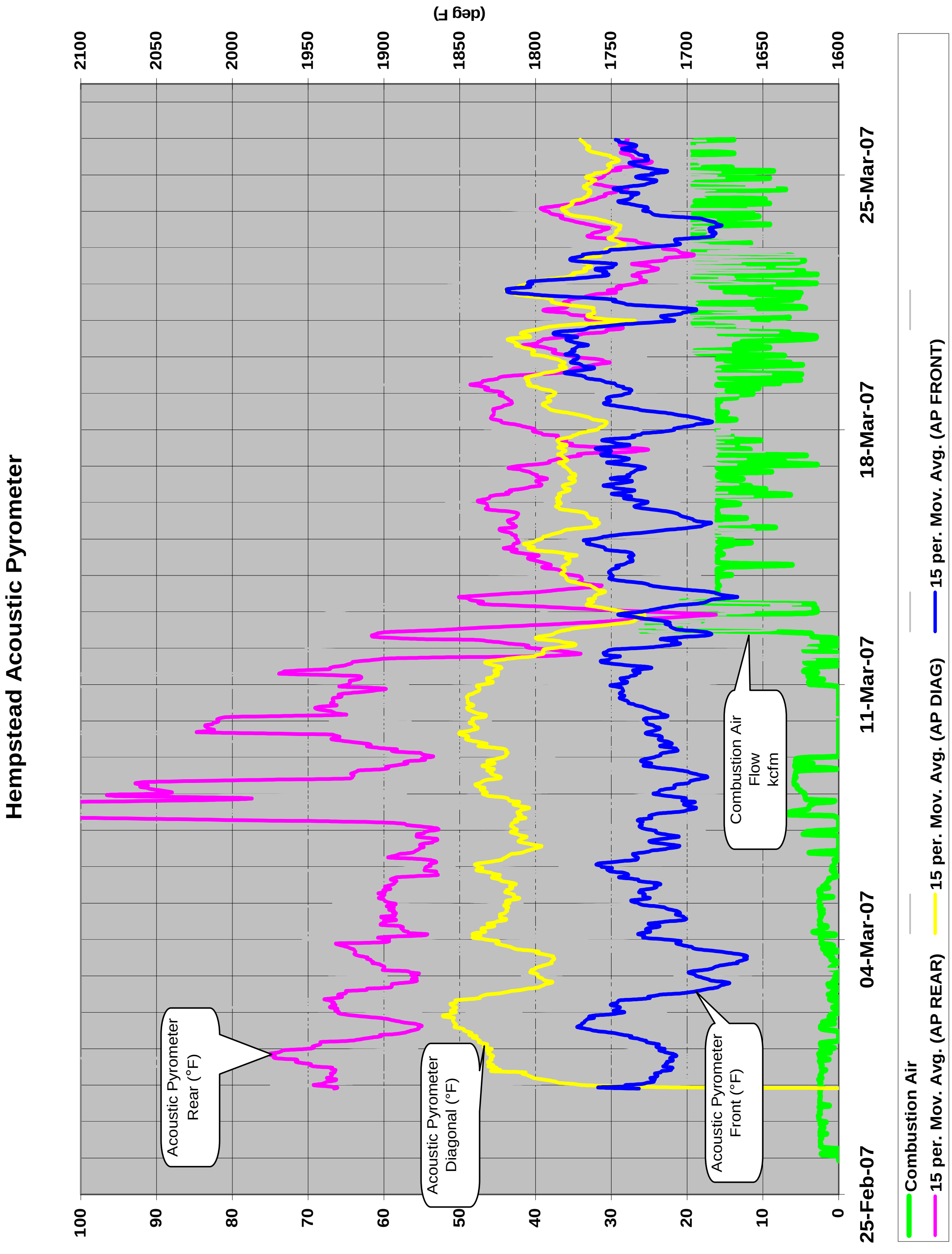


FIGURE 3
HEMPSTEAD RESOURCE RECOVERY
Acoustic Pyrometer Temperature Trends
With and without combustion modifications

4.6.3 Advantages over thermocouples & IR pyrometers

The greatest advantage that acoustic pyrometry has over other measurements such as thermocouples (T/C's) and IR is that the AP provides a true average across the furnace. When several AP lines of measurement are used, a representative average of the entire plane can be achieved. T/C's are only a single point in the measurement plane, and indicate lower than actual gas temperatures due to radiation effects. The IR is a cone of undetermined and varying length and penetration. If representative indications of the bulk average or sectional averages are desired, AP is the clear choice. IR does have the advantage of speed of measurement, so it can be a better choice when fast control is required. Comparative costs of AP and IR can be similar when the number of IR's required to provide a representative average is considered. The advantage of thermocouples is their low cost, but maintenance and radiation errors give them severe inherent limitations.

4.6.4 Reliability

The Enertechnix acoustic pyrometer system has been in operation at the Covanta Hempstead facility since January of 2007. Reliability has been very good, with only minor, occasional plugging of furnace penetrations and minor corrosion of tubing. These issues are very manageable at the upper furnace location, but it is suspected that they would become more problematic if used in the lower furnace. Currently, Covanta has no plans to use the AP system in the lower furnace.

4.6.5 Limitations

The only limitation encountered with the AP system is that the sampling frequency is relatively long at approximately 20-40 seconds per sample. The frequency is dependent on how fast the plant air system can recharge the signal generators and how many generators are in the system. For this reason, the AP system is not being contemplated for use in fast control applications.

4.6.6 Future –

Because the EfW furnaces are relatively shallow in size (i.e. front-to-rear dimension) when compared to Enertechnix's primary market of utility sized furnaces, Enertechnix has supplied Covanta with a new design configuration of multiple transmitter locations from one signal generator. This new arrangement decreases the system cost significantly further, allowing consideration of installation into additional facilities. Covanta is currently considering several facilities for a trial installation of this new configuration.

5 Infrared (IR) Through-Flame (TF) Video Camera

5.1 Background of Infrared Technology used by Covanta

Covanta, like many companies, has been using infra-red technology in non-combustion tasks for many years. Identifying external insulation heat losses and electrical system inspection are two examples of IR's many beneficial uses. Recently though, Covanta became aware of IR, at a specific wavelength, being used in the boiler inspection field to actually see through flames. To the naked eye, this area of the boiler is just an opaque "ball of fire". Being able to see through the flames in the lower furnace has several important benefits such as being better able to evaluate the stoker fuel-feeding process and online inspection of the lower furnace wall protection materials, e.g. refractory, tile etc. Covanta looked at different ways this technology was applied by different vendors and after several field demonstrations, chose to purchase the Enertechnix IR camera for several of the features that Enertechnix incorporates.

5.2 Advantages of Enertechnix TF IR over other brands

Covanta ultimately decided to purchase the Enertechnix through-flame infrared camera for several reasons. The strongest reason was that the Enertechnix camera used lens tubes that could be inserted into the boiler observation windows/doors and manipulated, rather than just looking through the windows from the outside.

Mobile Infra Red Camera Inspection Unit 2 Covanta Hempstead, NY

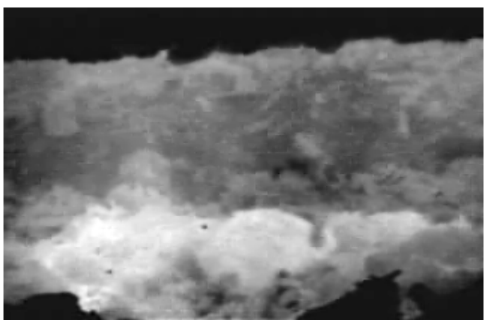
The ability to insert a lens tube greatly expands the areas that can be observed. In addition, Enertechnix offers a variety of lens tubes from direct view with different width field of views to a right-angle or 90° lens tube that can be easily rotated while inside the boiler to achieve a 360° view. The lens tubes can be easily changed and with proper cooling air flow, can be inserted into the hottest parts of the furnace.

Covanta's decision on the Enertechnix camera was solidified based on trials at two locations in one boiler. One, viewing the fuel feed process and the second viewing lower furnace refractory and tile.

5.3 *IR Camera Uses*

5.3.1 Fuel Feed

The Enertechnix IR TF camera was inserted through the lower stoker view ports, looking up the stoker at the flames. The camera provided a clear view through the flame basket and showed the MSW falling off the feed table onto the grates. The flames were barely noticeable; we refer to them as "ghost" flames. This first-time perspective to Covanta engineers and combustion specialists will be highly valuable in providing insight into and enabling the evaluation and trouble-shooting of fuel feed problems.



View looking up the grate through the flames

5.3.2 Lower furnace inspection

The camera was then inserted through furnace sidewall view ports approximately halfway up the furnace. The camera was pointed down toward the lower furnace tiles above the stoker fuel bed, directly into the normally blinding flame basket. Again, the flames all but disappeared and the outlines of the individual tiles were clearly seen.

After purchase of a TF-IR camera, Covanta used it at the Hempstead plant to inspect lower furnace refractory, attempting to detect any damage prior to a scheduled outage. Online inspection without bringing the boiler down was another key contributor to maintaining high availability at this key plant.

View of Refractory Tiles

5.3.3 Limitations

Covanta has used the TF-IR camera as a portable inspection tool, so time at temperature is the determining factor as to how long and where the camera lens tube can be inserted. In the hottest parts of the lower furnace, the camera/lens tube can still be inserted, provided the maximum required cooling air pressure of 80 psig is maintained, but needs to be removed after several minutes to cool after which time it can be reinserted. At cooler parts of the stoker exit and upper furnace, the camera/lens tube can be held in place for much longer continuous periods.

It was also found through use, that when attempting to look through the flame basket, side-to-side across the wider parts of the lower furnace, the view was somewhat limited as opposed to looking through the flame basket across the shorter front-to-rear furnace dimension.

6 Remote Inspection Video Camera

6.1 *Design*

The remote inspection camera ("RIC") is designed with an intent to inspect crucial boiler areas that have limited visible light conditions, harsh environment and remote areas of the boiler unreachable by conventional camera systems.

The RIC is constructed for rugged and reliable usage for harsh boiler and adverse particle-laden conditions. The RIC design consists of a combined integrated CCD video camera and light source for optimal viewing with no 'glow' back conditions from commonly associated when viewing dust filled environments - therefore, eliminating the need for additional lighting equipment.

The RIC has a proprietary air cooling design which eliminates the need for water cooling typical of older and bulkier video equipment. This important feature combined with the ability to add sections of pipe to obtain an overall length of up to 20 ft gives the camera both portability and flexibility. Minimum access for insertion is 3 inches. The user has flexibility while maintaining a safe work environment when conducting inspections and viewing.

Video images are viewed via a remote monitoring station. The remote monitor has outputs for video recording, wireless or direct video monitoring onto a plant network, and a ‘heads up’ option which allows the operator to view the inspection process via safety glasses with a video monitor incorporated into the glasses.

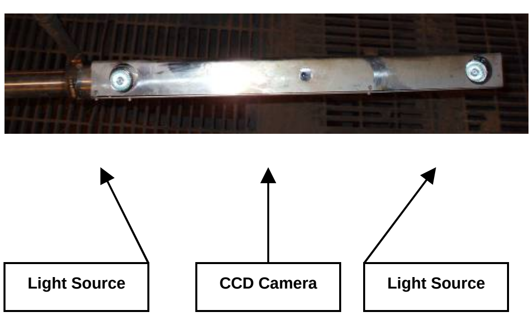
RIC inserted through Access Door

6.1.1 Separated lights

The RIC assembly has an integrated light source. The light source has a dimming capability to allow for changing light conditions based on the inspection area environment.

The light source (two bulbs) is designed to certain angles for illumination and optimizes the viewing in areas where particle flows are present.

Remote Inspection Camera Head



6.1.2 Video recording

The RIC is designed and cabled to the remote monitoring station. The remote monitor allows for independent viewing and video recording capability.

The remote monitoring station is designed with a 4” LCD Monitor which allows direct viewing of the RIC images taken during its operation. The remote monitor station has two output connectors. These connectors can be utilized for simultaneous digital recording and used for the optional ‘heads up’ display for the video monitor eye glasses.

The remote monitor comes equipped with a digital temperature display which is used to monitor the temperature of the camera head assembly during operation. The camera head temperature is monitored during usage so that camera assembly does not overheat and fail during operation.

The latest standard of digital recording equipment can be used in conjunction with remote monitoring station. The device used at Covanta is a Panasonic AV50 video recorder. It records directly to an SD-card which then can be uploaded any pc-based media player for viewing or archiving.

The digital video files can then be reviewed with media software to analyze views taken during the inspection.

Remote Display Monitor And Digital Recording

6.1.3 Easily extendable

The RIC design allows extending up to 20 feet in length. The special proprietary pipe sections come in 4’ or 6’ lengths and are fastened together to meet any the required inspection length for operation.

The flexible length pipe sections allow for easy and mobile capability when conducting inspections throughout the plant.

Once the length is determined, the main cabling is secured within pipe sections and a final connection is made RIC head assembly. The other connection is made to the remote monitor station. Once assembled to the air cooling assembly, the total weight of the assembly is less than 100lbs.

Remote Inspection Assembly
5 – Four (4) Ft. Configuration

6.1.3.1 Connection at front end

The RIC is cooled via standard plant air. A single hose and minimum of 80 psi is required. The plant connection is made to a specially designed air filtration manifold / hub and then split into two hose output connections. The two output hoses connect to the air intake assembly which is fastened to the end of the RIC camera pipe sections. This provides the necessary cooling for the RIC operation.

6.2 *Limitations of time & temperature*

The RIC is designed to operate in harsh and high temperature areas in and around the boiler. The limitation of time is directly related to the temperature of the RIC assembly during operation.

The RIC has a temperature monitor designed within the assembly. During the operation of the RIC camera, the temperature is displayed on the remote monitor station. The user must monitor the temperature of the camera. The design allows for the RIC camera to withstand a temperature of 120 degrees F or more.

During inspection operations conducted at Covanta, the RIC was used in environments from 600 to 1500 Degrees F. In nearly all the cases, the RIC temperature stayed under the 120 Degree F design threshold. Inspections and video recordings lasted from 2 to 10 minutes.

Different boiler environments may present conditions that may limit the time the RIC camera is in use. Management of the inspection activity and areas of importance will allow for ample time to conduct inspection and video recordings.

6.2.1 Online

The RIC is capable of functioning during online boiler conditions. Plant safety standards always apply when utilizing the camera. The camera can be inserted into an access port (minimum of 3" clearance) or access door. Covanta conducted inspections in multiple locations. Areas included 2^{nd} and 3^{rd} convection passes and the superheater entrance.

In each case, the temperature of the RIC camera must be monitored during any inspection process.

6.2.2 Offline – no scaffolding needed

The RIC extended length capability allows one to conduct inspections in hard-to-reach locations, such as tube lanes and upper furnace tube conditions when there is not sufficient time or money to install scaffolding.

Since the boiler is offline, there is no limitation on its usage due to temperature constraints and air cooling requirements.

6.3 *Potential Uses*

Some of the potential uses where Covanta is planning to test and develop uses for the RIC are

- Inspecting sootblowers, both online and offline and also during actual sootblower operation with steam
- Inspecting superheater, steam generating and economizer tube banks for fouling and plugging and evaluate the effectiveness of online water washing of those areas
- Observing flue gas flow patterns through these same banks in operation to help evaluate tube shield and tube arrangement designs

Inspection Prior to Wash Water Cleaning

Same Inspection Post Wash Water Cleaning

6.3.1 Flue gas flow pattern observations - video

6.3.2 Tube shield condition - video

- Covanta will also plans on testing the RIC in the dry scrubbers to see if atomizer spray patterns can be viewed online and wall build-up online or offline.

7 Summary

The expanding Energy from Waste market along with company growth has thrust Covanta into a position where good-enough is not good-enough anymore. The EfW industry requires continuous monitoring and evaluation to achieve and maintain high levels of performance. Combustion and operation must be optimized, emissions minimized and financial return maximized. The naked eye and typical instrumentation are now not good enough. State-of-the art, high-technology devices can provide engineers better insight and perspective to make the evaluations and modifications that help achieve these lofty goals. Enertechnix has not only provided the instruments, but also the scientific know-how along with a cooperative development approach to adapt existing instrumentation and develop new instrumentation to fit EfW and Covanta's needs.