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Applications and Benefits of BOILERWATCH® Acoustic Gas Temperature Measurement Systems In Fossil Fueled Power Boilers

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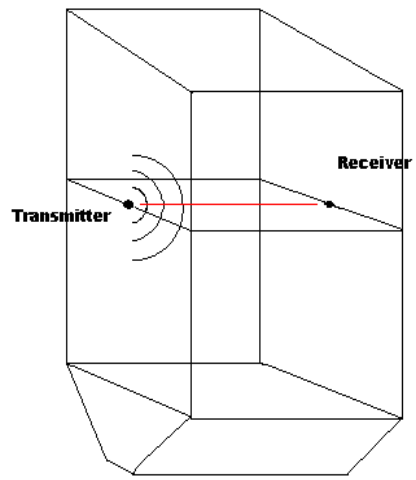
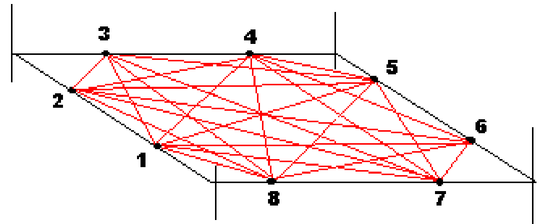
Gas temperature is one of the most important pieces of information required in operating and testing the performance of steam generating units. An acoustic pyrometer provides a practical and cost-effective solution for on-line continuous measurement of gas temperatures within hostile furnace and boiler environments. Combustion gas temperatures inside a modern power boiler furnace can reach nearly 3000 °F (1650 °C), rendering conventional thermocouple and water-cooled thermal probe methods effectively useless. The acoustic pyrometer is the only instrument that can offer reliable, accurate, and repeatable measurement of high furnace gas temperatures on an automatic unattended basis.

The patented BOILERWATCH® acoustic pyrometer instrument is based on the principal that the speed of sound in a gas is proportional to the gas temperature. By precisely measuring the transit time of a sound signal traveling a known distance through a gas volume, the average temperature of the gas along a straight-line path between the sound source and receiver can be accurately determined. In its simplest form, this fundamental acoustic pyrometer configuration is known as a stand-alone or "independent path" measurement. Modern acoustic pyrometer technology has been developed to provide this automatic non-intrusive gas temperature reading every few seconds; a measurement that in the past would have required a test crew with an HVT thermocouple probe several hours to obtain. The simplicity and automation of a previously labor-intensive and costly information gathering process opens the door to a multitude of cost-saving applications.



Single Path Acoustic Pyrometer

In addition to the fundamental single independent path temperature measurement, a number of acoustic sound sources and receivers can be placed around the perimeter of a furnace to obtain an array of path temperatures. This array contains side-to-side, front-to-back, and diagonal paths within the planar area of the furnace. From this array of path temperatures, a computer can construct a two-dimensional spatial profile of the gas temperature distribution within the plane area. This profile is automatically updated every minute or so, to provide an automatic real-time view of furnace temperature changes.



Eight-Transceiver Mapping Array

Acoustic pyrometers are now in use throughout the world on all types of fossil, chemical, and bio-mass fired units, providing improvements in operating efficiency, service life extension, reduced maintenance cost, and decreased atmospheric emissions. This document summarizes details of the most popular applications of this exciting instrumentation technology.

THERMAL PROBE REPLACEMENT

In a reheat steam generator, from light-off to synchronization, the unit must be fired at a rate to produce gas temperatures necessary to develop the proper superheat temperature. During this process, the gas temperature at the first section of reheater is limited to approximately 1000 °F (538 °C) until steam flow through the reheater is established. Fatigue life of the reheater tubes are greatly reduced if the tube metallurgy is exposed to temperatures much over 1000 °F. Careful monitoring of the gas temperature in front of the reheater is critical to insure that gas over-temperature conditions do not occur and cause damage to the reheater.

Once the turbine is rolled, steam is passed from the high temperature turbine exhaust to the reheater. Without saturated steam, the reheater outlet temperature would rapidly approach the gas temperature. Applying such high temperature steam to the cooler intermediate pressure turbine would cause high thermal stresses resulting in possible decreased service life of the turbine.

Retractable gas temperature probes consisting of water-cooled thermocouples have been traditionally used to monitor gas temperature upstream of the reheater tubes. However, since these probes are intrusive into the hot gas stream, they are inherently unreliable, and prone to frequent failure. Since the operating temperature range of most probes is limited to about 1200 °F, the probe must be retracted out of the furnace before the gas temperature increases as the unit is ramped-up in load. Maintenance costs are high not only for the temperature sensing elements themselves, but also for the cooling water plumbing and pumps, probe drive mechanism, and physical support apparatus.

The acoustic pyrometer, on the other hand, is completely non-intrusive, and thus far more reliable, as no part of the system is exposed to hot furnace gases. No insertion/retraction drive mechanism is required, and maintenance is drastically reduced. But probably the most important feature of the acoustic system applied as a replacement for thermal probes is it's ability to operate and provide temperature measurement continuously over the full load range of the boiler. BOILERWATCH® can accurately and reliably measure gas temperatures up to 3500 °F (1927 °C), which is in excess of even the highest gas temperatures likely to be encountered in most fossil-fired power boiler furnaces. During load swings, it is possible to overfire and overheat expensive superheat and/or reheat elements. It is well known that exposing tube element metallurgy to even small amounts of over-temperature can result in drastic reduction in tube service life. By knowing the gas temperature immediately upstream of these tube banks, operators can better judge the correct number of burners and firing rate, or with tilt burners, better determine the tilt angles needed to achieve the proper firing rate and gas temperature.

A BOILERWATCH® single path system configuration is ideal for thermal probe replacement. An acoustic transceiver is typically located on each side of the furnace, approximately one to two meters below the reheater tube bank. In some units, depending on design, the acoustic path can also be located 1-2 meters directly in front of the reheater.

INCREASE OPERATING EFFICIENCY

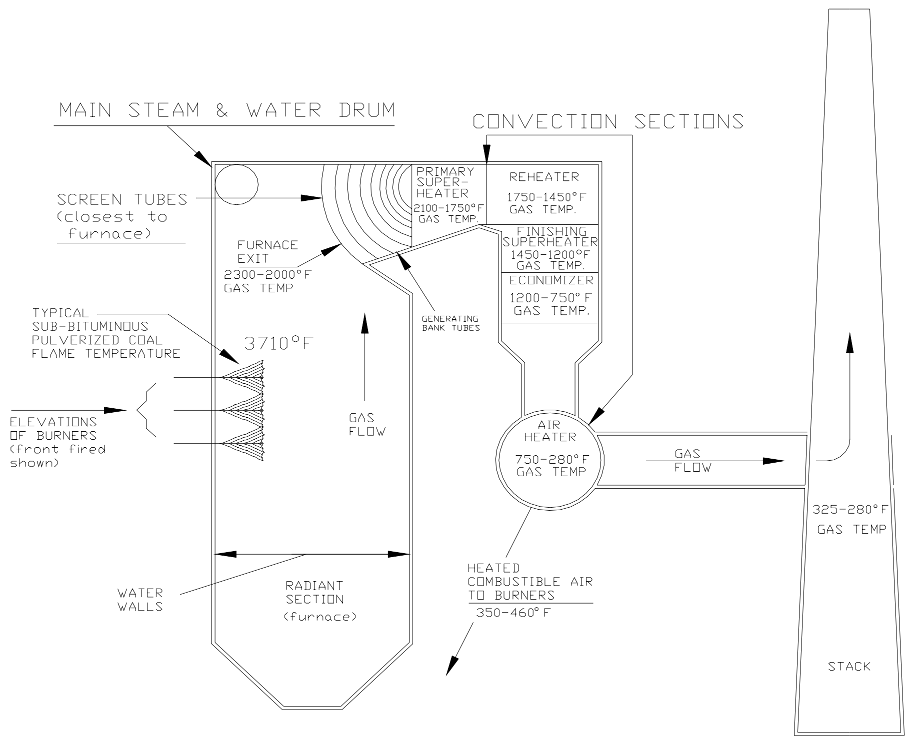
Overall operating efficiency of a large complex boiler/furnace system is effected by many factors, too numerous to mention here. There are, however, several ways in which the information provided by timely gas temperature measurements can significantly aid in the improvement of unit operation.

BURNER CONTROL AND OPTIMIZATION

The most common methods of firing large fossil fueled power boilers involve either horizontal firing with fixed burners (including cyclones), or tangential firing with tilt air/fuel nozzles.

In <u>horizontally fired systems</u>, burners are located in rows, either on the front wall alone or on both front and rear walls (opposed firing). Also, several rows of burners may be located at different elevations in the lower furnace area. In these units, selective furnace utilization and steam temperature control may be accomplished by controlling individual burners or by controlling rows of burners, depending on the design of the particular unit. The fundamental principal here is that by raising and lowering the flame inside the furnace, the elevation of heat absorption can be controlled as well as heat absorption in the superheat and reheat sections. Of particular interest in controlling the elevation of heat absorption is furnace exit gas temperature (FEGT).

Measurement of FEGT with one or more independent paths provides an indication of the furnace heat absorption for a given burner utilization and degree of ash deposits on furnace walls. Increasing FEGT under identical burner utilization and firing rate indicate build-up of ash deposits and hence lower furnace wall heat absorption. Also, under conditions of constant furnace wall ash deposits, changes in burner utilization and hence the elevation of furnace heat absorption are reflected in the FEGT measurement. In addition, continuous measurement of FEGT can provide the operator with advance warning of eventual secondary superheater fouling, since at constant load, an increase in FEGT indicates a reduction of furnace heat absorption due to ash deposits or slagging.



GENERAL ARRANGMENT SECTIONAL ELEVATION OF SUB-CRITICAL PRESSURE STEAM GENERATOR SHOWING RADIANT & CONVECTION SECTIONS, AND TYPICAL GAS PATH TEMPERATURES FROM FLAME TO STACK EXIT GAS.

In addition to the above benefits, measurement of FEGT with a BOILERWATCH® temperature mapping system configuration shows the gas temperature balance as a function of location on the two-dimensional horizontal furnace exit plane. This presentation can show previously hard-to-detect conditions such as malfunctioning burners, improper burner balance, incorrectly set or malfunctioning air dampers, and unbalanced heat distribution along superheat and reheat banks. In response to the visual indication of temperature distribution, operators can exercise control of available burners to compensate for burner problems, or to eliminate burner or air/fuel imbalances.

Tangentially fired systems are based on the concept of a single flame envelope. The fuel and air are admitted from the furnace corners in vertical layers. Dampers control the air to each compartment, making it possible to vary the distribution of air over the height of the windbox. Fuel and air nozzles tilt in unison to raise and lower the flame in the furnace to control furnace heat absorption and thus heat absorption in the superheater and reheater sections. In addition to controlling the FEGT for variations in load, the tilts on coal-fired units can also compensate to some degree for the effects of ash deposits on furnace wall heat absorption.

As wall blowers clean ash deposits from the furnace walls, the FEGT tends to decrease due to better overall furnace heat absorption. By tilting the windbox nozzles upward at the proper rate, combustion is completed higher in the furnace, which effectively reduces the absorption in the lower furnace and increases the FEGT to maintain steam at design temperatures. Conversely, as furnace walls are again gradually covered with ash deposits and furnace heat absorption goes down due to the insulating effects of the ash, the tilts are gradually lowered and combustion is completed lower in the furnace. This exposes the hot gases to a greater proportion of the furnace wall surface and affects FEGT and steam temperature until ash is again removed from the furnace walls.

As in horizontally fired units, the use of BOILERWATCH® MMP independent path and temperature mapping configurations provide indications of the elevation of furnace heat absorption, detection of over-firing conditions, and with mapping capability, the ability to detect imbalance of the flame envelope and non-uniform heat distribution along superheat and reheat tube banks.

Another very important benefit available from BOILERWATCH® MMP temperature mapping lies in keeping the fireball off of the furnace walls to prevent excess thermal stress and corrosion of the fireside wall tubes. Over time, reduction of water wall flame impingement results in decreased maintenance cost and increased unit availability. Even a small improvement in plant availability can lead to large cost savings, as discussed later in this paper.

INCREASED HEAT ABSORPTION BY REDUCED SLAGGING

In addition to using FEGT measurements to indicate the heat absorption condition within the furnace, a BOILERWATCH® system that continuously monitors gas temperatures upstream and downstream of superheater and reheater tube banks over the full operating load range can help provide a significant improvement in efficiency. By locating one BOILERWATCH® independent path upstream of the tube bank and another downstream of the bank, input/output differential gas temperature is indicated. A decrease in this temperature differential is indicative of reduced heat absorption by the tube bank due to fouling or slag coated tube surfaces.

The temperature differential can be input to a DCS or soot blower control system for use as a set-point with which to activate soot blowers. This approach is more efficient than conventional soot blower control based on time schedule sequencing, as blowers in the superheat and reheat areas are used only when needed. Significant cost savings can be achieved by lowering the use of soot blowers on tube banks. These savings come from using less steam and parasitic power, increased service life of tubes from reduced thermal stress and fireside pitting/corrosion, and better unit availability because of fewer tube failures.

EMISSIONS REDUCTION

Among today's more serious environmental problems are acid rain and the emissions of SO_2 and NO_x, particularly from coal-fired plants. The cost impact of applying conventional emissions control approaches such as wet scrubbers and electro-static precipitators is significant, and has caused utilities to look for less costly solutions to reduce the problem. Recent trends have focused heavily on retrofits of low-NOx burners and other changes to firing systems for reducing NOx production at the source. While low-NOx burners themselves have produced good results in the effort to cut emissions, other tools can be used along with burner upgrades to further optimize the firing system performance relative to lower NOx production.

Early steam generator firing systems produced great turbulence to achieve rapid mixing of the reactants and high energy release during the early stages of combustion. A significant problem with these systems is high levels of NOx formation. Contemporary firing systems are designed to produce a slower burning rate which reduces the peak flame temperature and thus serves to curtail the thermal NOx production in the latter stages of combustion.

Conditions that increase production of NOx can be detected by gas temperature measurement, since high gas temperatures are the fundamental indicator of excess flame temperatures. A BOILERWATCH® MMP temperature mapping system at the furnace exit plane will clearly show excess gas temperatures and regions of temperature peaks at the furnace outlet. With this information, the operator can control the combustion process by selective burner and air control to achieve furnace exit temperatures that produce less NOx. In addition, regions of temperature peaks (or hot-spots) can be eliminated to produce a more uniform temperature distribution entering the superheat and reheat areas.

This not only reduces NOx formation, but reduces thermal stress on the upper furnace and convection pass components.

Sorbent Injection is another approach to the reduction of both SO_2 and NO_x emissions. This process basically involves injecting a lime-urea hydrate into the combustion gas stream in the upper furnace region of the boiler. To be effective, this process requires that the hydrate be introduced within a critical temperature range, depending on the specific composition of the hydrate. With a given hydrate composition at an injection temperature of 950°C, for example, SO_2 and NO_x removals of 50% are achievable, making the process a viable alternative.

Since the effectiveness of hydrate injection is highly dependent on the gas temperature in the region of introduction, the efficiency and cost effectiveness of the process can be greatly improved and optimized if accurate real-time gas temperature information is available to the injection control system.

SEI's BOILERWATCH® MMP temperature mapping system is ideally suited to provide the real-time temperature information required by efficient sorbent injection controls. The BOILERWATCH® MMP and SEI's TMS-2000 temperature mapping software for Windows have built-in features which provide easy integration with injection controllers. One key feature of TMS-2000 software is the ability to compute the average gas temperature within each of up to 16 user-defined sub-zones within the map planar area. These rectangular zones can be of any size and may be placed at any location within the plane. It is even possible to define non-adjacent or overlapping zone areas. Since the gas temperature in the upper furnace region can vary significantly as a function of position relative to the range needed for optimized effectiveness of the injection process, partitioning the mapping plane into smaller areas (or zones) provides the ability to control the injection process with a much greater degree of resolution. The zone temperature readings are then used to control specific injectors, insuring that the hydrate is applied only if and when the gas temperature in that region is within the necessary range.

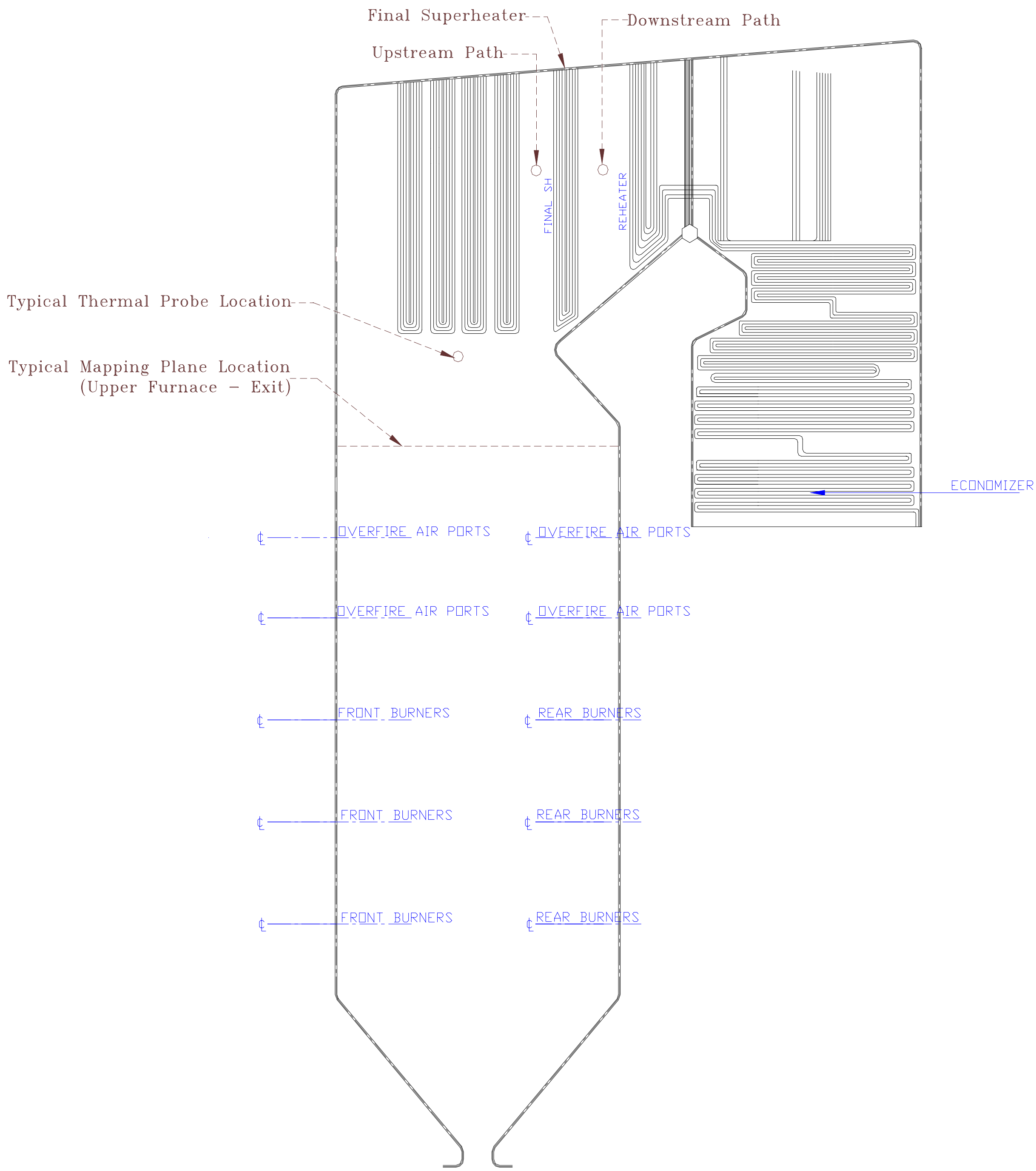
SEI offers as optional equipment for the BOILERWATCH® mapping system the TMS-AIU Analog Interface Unit, which provides 4-20 ma current loop output signals from the mapping computer to the injection controller. Up to 16 output channels are available from the AIU, one channel corresponding to each of the sixteen possible zones. This BOILERWATCH® system configuration allows optimal control of the injection system in a fully automatic and unattended mode.

SERVICE LIFE EXTENSION

Adding useful service life to critical pressure parts and other furnace components is a collateral benefit to all of the applications mentioned above. The fundamental mechanism involved in lengthening the life of furnace components is the reduction of thermal stresses through monitoring and control of gas temperatures. The two salient opportunities to control and reduce thermal stress are superheater and reheater protection during start-up and firing system manipulation aimed at keeping the fireball off of furnace waterwalls. Start-up protection for superheat and reheat elements during start-up has already been discussed, so we can focus on thermal stress of furnace waterwalls.

In most furnaces, the potential exists for unbalanced firing conditions resulting from specific utilization of burners, malfunctioning burners, air damper control problems, and certain other possible causes. These problems appear as unbalanced heat distribution at various elevations in the furnace. These unbalances, if sufficiently severe, produce abnormally high gas temperatures adjacent to certain areas of furnace water walls. If undetected and allowed to persist, these conditions can place high levels of thermal stress on the wall tube metallurgy, which reduces tube life. Thermal stress is the single most common cause of tube failure. The resulting steam leak(s) necessitate the unit to be shutdown on forced outage so the leaks can be repaired. This is not only very expensive in terms of maintenance cost, but also in lost availability of the unit and often the need to purchase replacement power form other sources.

A BOILERWATCH® MMP temperature mapping system installed at the furnace exit provides immediate indication of temperature imbalance, permitting the operators to rapidly remedy the condition before tubes are seriously stressed. One BOILERWATCH® user recently reported: ***"The temperature mapping system helped us cut our incidents of tube leaks from a dozen or so, down to two per year"***. With results like this it's easy to see how these benefits result in major cost savings.



Final Superheater
Downstream Path
Upstream Path
FINAL SH
REHEATER
Typical Thermal Probe Location
Typical Mapping Plane Location
(Upper Furnace – Exit)
ECONOMIZER
OVERFIRE AIR PORTS
OVERFIRE AIR PORTS
OVERFIRE AIR PORTS
OVERFIRE AIR PORTS
FRONT BURNERS
REAR BURNERS
FRONT BURNERS
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AVAILABILITY IMPROVEMENT

The major reason for improving availability in electricity production is a matter of economics which basically relates to the high cost of constructing power generating facilities. The capital investment per KW of generating capacity has climbed steadily in recent years, and in view of environmental requirements and economic and political realities, these costs can only increase in the future. Therefore, there is little incentive for power producers to build more generating units than absolutely needed. Better plant availability will have a large effect on construction or deferment of new plants. Conversely, long-term outages from repeated boiler tube leaks, turbine blade failures, or other plant equipment problems could force a utility either to install additional generating capacity or to purchase replacement power (if available) at higher cost.

PAYBACK

The payback for improving the availability of a typical 500-MW coal-fired plant is significant. In 1981, Combustion Engineering, Inc., reported that for each 1 percent improvement in operating availability, a utility avoids coal-fired replacement power costs from less efficient generation of about US $60,000 per day. Should the replacement energy come from oil-fired capacity, the incremental costs would be substantially higher; US $180,000 to $360,000 per day. Obviously, these costs have increased significantly since these figures were reported in 1981. In addition to cost savings in replacement power, by improving it's forced outage rate, a utility can reduce the system reserve margin, which results in decreased future capital expenditures for additional generating capacity.

Even if payback is viewed conservatively and only in terms of saving the cost of replacement power, it is clear that if a fully configured BOILERWATCH® temperature mapping system helped prevent only a one (1) day forced outage, **the total cost of the BOILERWATCH® system can be recovered in one day or less.**

The conclusion is clear: one of the best alternatives available to the electric power industry for increasing generating capacity at least cost is to improve plant productivity and availability.

SEI's patented BOILERWATCH® acoustic gas pyrometer systems provide generating plant operators with important and timely information necessary to save cost through optimized operating efficiency, reduced maintenance, increased availability, and reduced need for replacement power.

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