Advancements with Regenerative Airheater Design, Performance and Reliability

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Introduction

Serving as the last heat trap for the boiler system, a regenerative airheater typically accounts for over 10% of a plants thermal efficiency on a typical steam generator. Considering this, when evaluating the performance of an airheater one should take into account all of the process variables. Along with the advancement with air pollution control equipment and soot blower technology, the U.S. Power industry has become more "*fuels flexible*", but subjected to greater reliability challenges. Fuel blends with challenging mineral ash constituents, de-activated SCR catalysts, NH_3 slip and/or sorbent injections for SO_3 control can accelerate common issues that often include fouling, plugging and/or corrosion of the airheater.

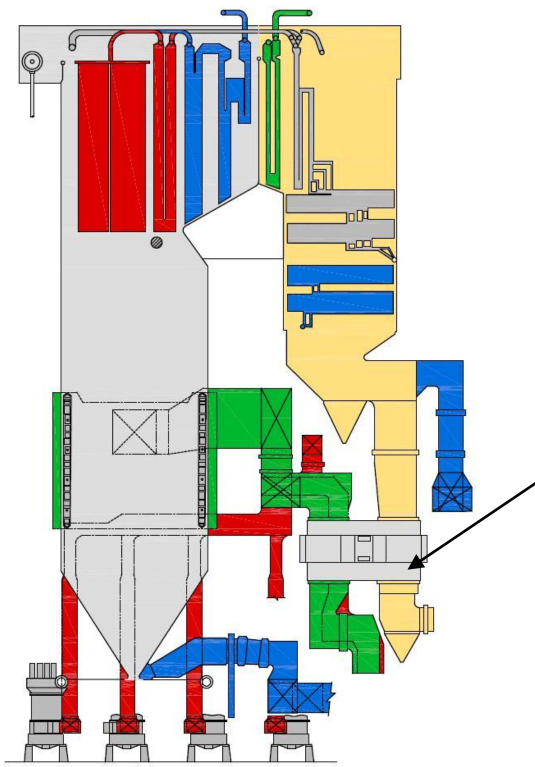
Regenerative airheaters serve as a heat exchanger which allows for proper preheating of combustion air allowing for more efficient combustion. If non-optimal performance is present not only is unit efficiency in jeopardy but so also unit availability and/or the performance of the air pollution control equipment. Airheater problems can lead to unit de-rates which result from fan capacity issues, improper combustion temperature and/or unacceptable gas temperatures entering the stack. Higher than desirable air heater gas outlet temperatures can reduce the collection efficiency of electrostatic precipitators and have negative effects on the reliability of baghouses. Considering this, the purpose of this paper is to review recent advancements in process evaluation and research and development being completed to help achieve improved air heater and overall unit efficiency, while simultaneously reducing forced outages related to the airheater.

Topics covered within this paper include:

1) Operational and Maintenance Considerations
2) Mechanical Component Considerations
3) Element material and coating considerations

Operational and Maintenance Considerations

Both air heater leakage and upstream air in-leakage from a boilers penthouse can significantly impact the thermal performance of a regenerative airheater. Air heater leakage occurs on the hot and cold ends of a regenerative air. However, often it is conceived that most of the leakage occurs on the cold end, where corrosion is more likely to occur due to the low air and gas temperatures result in larger clearances between the sealing surfaces. However, it's also important to understand that air in-leakage upstream of the airheater can temper the incoming flue gas temperature, while also increasing the volume of gas going through the airheater on a balanced draft unit. It's also important to understand the major importance of the airheater. Just for example, the following is a typical unit and the available heat transfer surface of a relatively small amount of area as compared to the overall boiler size. However, the amount of heating surface contained within a regenerative airheater is often two to three times more in actual surface heating area.



Location	Typical Heat Transfer (Area – Ft^2)
Water walls	36,000ft^2
Super heater	266,000 ft^2
Re heater	53,000 ft^2
Economizer	171,000 ft^2
Total Boiler	526,000 ft^2
Regenerative Airheater	**1,750,000**ft^2

Figure 1, typical heating surface comparison for a large utility boiler

Most regenerative airheaters were originally designed for 6-10% air heater leakage and account for more than 10% of a unit's overall thermal efficiency.

When calculating boiler efficiency, the dry gas losses represent the largest single thermal penalty. Basically this is a percent penalty based on the heat being released to the atmosphere that the boiler cannot make use of. However, this also includes a few smaller considerations as well. Any increase in gas outlet temperature over the air inlet temperature contributes to this loss.

Measuring Dry Gas Loss *(using Airheater Leakage and corrected gas temperatures)*

The generic form of the equation to calculate Dry gas loss is:

$$\text{Dry Gas Loss} = \text{lb of dry flue gas per lb of as fired fuel} \times 0.24 \times (T_G - T_A) \times \text{Fuel HHV}$$

Where

0.24 = typical specific heat of air and flue gas
T_G = temperature of the outlet flue gas*
T_A = temperature of the inlet air
Fuel HHV = (Higher Heating Value) the Btu content of the fuel

* *This temperature is corrected to represent the temperature of the outlet flue gas if there were no air in-leakage through the air heater (PTC-4). Below, we will take this one step further to account for any air in-leakage that may occur between the furnace exit and the air pre-heater inlet (as the existing ASME Code assumes)*

Percent leakage across an airheater or ductwork can be calculated by the following:

$$\text{Percent Leakage} = \frac{\%O_2 \text{ Entering} - \%O_2 \text{Leaving}}{\%O_2 \text{Leaving} - 20.9\%} \times 90$$

Once the leakage across the airheater is calculated, the outlet temperature can be corrected* to indicate what the temperature would be if there were no leakage.

Air Heater Corrected* Exit Gas Temperature =

$$\frac{\text{Air Heater Leakage} \times Cp_{Air} \times (T_{Gas\ Out} - T_{Air\ In})}{100 \times Cp_{Gas}} + T_{Gas\ Out}$$

Where:

Cp = Specific Heat

**Note: This is a correction for air in-leakage. Note, most airheater terminology considers the diluted and or lower temperature as the "corrected for leakage" gas temperature. However, Corrected exit gas temperature as noted is referencing the "corrected to no leakage gas temperature).*

To further correct the outlet temperature, the inlet gas temperature needs to be corrected.

Airheater Inlet Gas Temperature Corrected =

$$\frac{\text{Ductwork Leakage Before APH} \times Cp_{Air} \times (T_{Gas\ In} - T_{Air\ In})}{100 \times Cp_{Gas}} + T_{Gas\ In}$$

Airheater Inlet Heat Loss =

$$\left(T_{\text{Gas Inlet Corrected}} - T_{\text{Gas Inlet Measured}}\right) \times Cp_{Gas} \times \text{lb flue gas per lb of as fired fuel}$$

To use this to correct the air pre-heater outlet temperature (*already corrected for APH leakage*):

Air Pre-Heater Exit Gas Temperature, Corrected for Total Leakage =

$$\left(T_{\text{Gas Inlet Corrected}} - T_{\text{Gas Inlet Measured}}\right) + T_{\text{APH Gas Outlet Corrected}}$$

Where:

$T_{\text{APH Gas Outlet Corrected}}$ = Temperature of the APH gas at the outlet corrected only for APH leakage

Once the previous are calculated, the total enthalpy drop for the gas and the enthalpy rise for the air should be calculated to determine the heat transfer efficiency. Dividing the enthalpy rise of the air by the enthalpy drop of the gas will give you the overall heat transfer efficiency for the air heater.

$$HeatTransferEfficiency = \frac{\text{Cp}_{\text{Air}} \text{ x } (\text{T}_{\text{Air-Out}} - T_{Air-In}) AirMassFlow}{\text{Cp}_{\text{Gas}} x (T_{GasIn} - T_{GasOutCorrected}) xGasMassFlowLessLeakage}$$

It should be noted that the most commonly used measure of air heater "efficiency" is the calculation of ***Gas Side Efficiency.*** Gas Side Efficiency is an efficiency measurement that utilizes only air and gas temperature changes in the air heater and does not take into account the specific heats of the fluids nor the mass flow rates (i.e. enthalpy). To accurately determine how well the air heater is performing, the ***Heat Transfer Efficiency*** calculation – which includes an enthalpy balance, must be used.

Further, all of the traditional methods for calculating the effect of leakage on the thermal performance of the unit make the assumption that all of the leakage occurs on the cold end of the air heater, and the temperature corrections are traditionally calculated using that assumption. In reality, a good portion of the measured leakage will actually occur on the hot end of the air heater. Because there is no practical way to measure the split between hot side and cold side air heater leakage, the calculated air heater efficiencies, regardless of method used, will always contain a small degree of error.

An air heater in poor condition will typically yield air in-leakage in excess of 15-20%. Considering this, correction of the gas outlet temperatures is required to determine the "no-leakage" gas outlet temperature. As previously noted, the airheater is responsible for a large portion of a unit's thermal efficiency. On a typical unit, each 30˚F is worth ~1% in unit efficiency (*See Figure 2*).

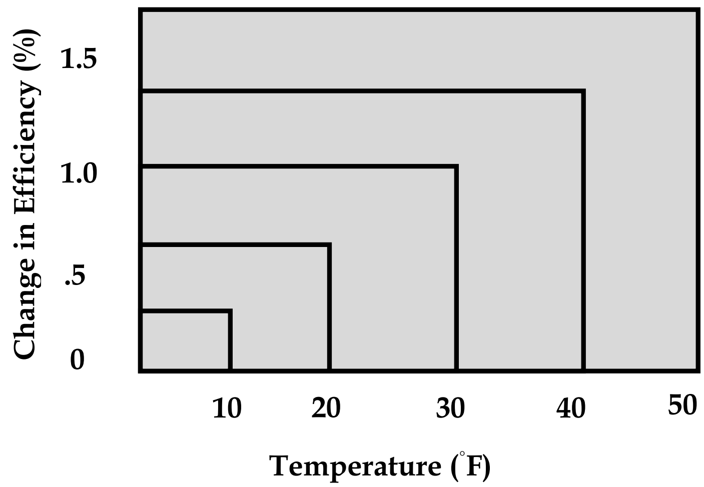


Figure 2, Airheater exit gas temperature change vs. impact on Unit efficiency *(Typical)*

Regenerative airheater design features, air to gas ratios and air to gas pressure variations have a major impact on regenerative airheater performance. Considering this, it must be noted that the mechanical condition of the airheater and minimization of air to gas leakage is vital for the health and overall plant performance. Any flue gas diluted with air leakage on the cold end of the airheater will lower the overall gas outlet temperature as well as change the temperature gradients downstream from airheater outlet. Furthermore, it must be understood high air in-leakage results in lower gas outlet temperatures and when combined with $S0_3$, accelerated corrosion is likely to occur.

There are numerous boiler operational parameters that can influence SO_3 formation. These variables are fuel sulfur content, ash content and composition, convective pass surface area, gas and tube surface temperature distributions, excess air level, firing mechanism and coal fineness. SO_3 combines with flue gas moisture to form vapor-phase sulfuric acid at temperatures below about 600°F. Therefore, any sulfuric acid in the flue gas can lead to power plant operating problems. These problems can include boiler air heater plugging and fouling, corrosion in the air heater and downstream ductwork / equipment. To prevent the condensation of the SO_3 (and thus limit formation of sulfuric acid) the exit gas temperature coming from the air heaters must be kept above the dew point of the sulfuric acid. The higher required exit gas temperatures translate directly into a loss of system efficiency, which imposes a significant heat rate penalty. However, the more SO_3 formed, the higher the dew point. The sulfuric acid dew point temperature depends on the SO_3 and water vapor concentrations in the flue gas higher concentration of either species raises the acid dew point temperature.

Leakage control in conjunction with the control of sulfuric acid (H_2SO_4) is especially important when managing flue gas that is a byproduct of high sulfur fuels. This is considering that when SO_2 is oxidized into SO_3, the SO_3 readily combines with water vapor to form H_2SO_4 (sulfuric acid). Oxidation of the SO_2 will occur from contact with heat transfer surfaces – the metal in the boiler acts as a catalyst – and also from contact with the catalyst in selective catalytic reduction (SCR) systems.

While a significant portion of the SO_3 will condense on ash particles and be collected along with the fly ash, the non-condensed SO_3 can have significant side effects. Excess SO_3 leaving the stack can result in a noticeable "blue plume", which consists primarily of sulfuric acid that has condensed into tiny droplets. Those same droplets may also condense on the cold end of the airheater, or in the downstream ductwork causing corrosion and plugging. In addition, excess SO_3 can combine with ammonia slip from an SCR system to form ammonium bisulfate (ABS) which has a notorious reputation for plugging air heater heat transfer element. Essentially, the excess ammonia combines with excess SO_3 and water vapor which starts to condense on the air heater element surfaces at temperatures below about 450˚F (230˚C).

$$NH_3 + SO_3 + H_2O \rightarrow NH_4HSO_4$$

This ABS plugging also impacts the distribution of the air and flue gas while also elevating air to gas differentials and leakage (*as a result of the elevated pressure drop across the airheater*).

In an effort to remove excess SO_3, dry powder or water slurry mixes of alkaline sorbents (ie. hydrated lime, limestone, magnesium oxide, sodium bisulfate and Trona) are sometimes injected upstream or downstream of regenerative airheaters. While these chemicals are quite effective in adsorbing excess SO_3 and reducing blue plume and corrosion, the effect of these sorbent on the air heater and its operation are still being evaluated. As a hypothetical example, if injection of a sorbent downstream of the air heater would require an elevated gas outlet temperature for maximum effectiveness, there it would be a boiler efficiency penalty associated with the reduced air heater efficiency that would be needed to provide the elevated temperature. However, it might also be possible to achieve the required elevated temperature without a heat rate penalty by simply reducing air heater leakage – thereby reducing the dilution air which acts to cool the gasses downstream of the air heater.

Considering these challenges, in conjunction with fuel changes or the modernization and refurbishment of aging units, a thorough performance evaluation of a utility boiler and regenerative airheater is crucial. This is especially true when taking into account reliability and performance of a regenerative airheater

Advancements today demand increased focus on the operational and performance variables as well as the mechanical design considerations before applying refurbishment to the heating element or sealing solution on a regenerative airheater. Furthermore, it's absolutely imperative that the proper materials used in a specification match the process and operational requirements. As a pre-requisite to any advancement with Regenerative Airheater technologies, fundamental and current performance values must be assessed.

Some of the operational variables that must be considered are as follows:

- Thermal Efficiency
- Fuel Analysis (S, N, H_2O)
- Mineral Ash Analyses
- Air Pollution Control (APC) equipment
    - SNCR or SCR Performance (NH_3 Slip)
    - Sorbent Injections (upstream and downstream of the airheater)
    - APC equipment specifications downstream of the Airheater
- SO_3
- Flue Gas distribution
- Velocity and temperature gradients
- Flue Gas volume

In addition to the previous, some air heater specific variables that must also be considered are as follows:

Hot End	**Intermediate | Cold-End**
1. Incoming gas temperature 2. Upstream Air in-leakage 3. Hot end differential Pressure (air / gas) 4. Incoming flue gas volume and velocity 5. Gas Inlet Temperature 6. Wind box to Furnace Differential 7. Element Design, Gauge, Weight, Depth 8. Incoming flue gas oxygen (%)	1. Average cold-end operating temperature 2. Desired flue gas exit temperature (*Corrected for Leakage*) 3. Cold end differential pressure (air / gas) 4. Inlet air Temperature 5. Element Design, Gauge, Weight, Depth 6. Exiting flue gas oxygen

Whether you are referencing burner performance, boiler performance, airheater performance and/or the APC equipment, all of these components are influenced by their inputs with regard to their operational efficiency. Variables such as the airheater gas outlet temperatures and velocity gradients, leakage/mass flow, coal fineness, sorbent particle sizing & distribution, excess air setting, calcium-to SO_3 molar ratio, ash content and ash resistivity can have a significant impact on the air pollution control equipment.

Considering the previous, when evaluating the basic flow paths of a regenerative airheater (figure 3), it's important that the comprehensive inter-relationships of all the previously noted variables be considered.

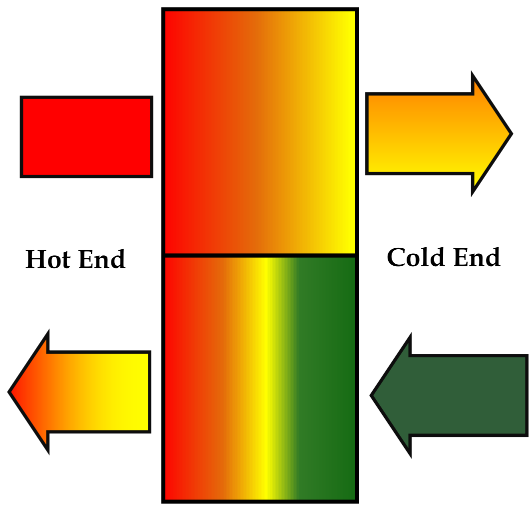


Figure 3, Regenerative Air Heater (*basic flow diagram*)

To properly assess air heater performance, the temperatures in and out of both sides of the air heater need to be known as well as the oxygen concentrations before and after the gas side of the air heater. Velocity heads need to be measured as feasible to determine if there are any significant flow stratifications in the ducts. If so, the temperature and oxygen should be normalized on a flow weighted basis. Furthermore, to perform a proper thermal heat balance, the air and gas flows before and after the air heater also need to be measured. This can be calculated as a function of static pressure, temperature and velocity head measurement at each of the airheater inlet and outlet ducts.

Mechanical Considerations

There are many different options when it comes to choosing a heat exchange element design for an airheater. Each configuration has its own unique pressure drop and heat transfer characteristics. For example, an element configuration that is designed to achieve maximum heat transfer in a limited amount of space (depth) may also have a higher overall pressure drop than an element design that requires a greater depth to achieve the equivalent heat transfer. Typically, the configurations with the lowest pressure drop per inch of depth also have a lower heat transfer rate per inch and require a greater depth of element for equal thermal performance. While the end result of some element configurations can be an overall lower pressure drop while achieving the same amount of heat transfer, not all airheaters can accommodate the additional element depth that may be required without extensive modifications to the rotor. Considering this, when evaluating heating element types, all variables must be considered.

Just as an example, the following graph (*Figure No. 4*) illustrates varying element configurations options vs. the theoretical gas temperature using a minimum and maximum variation of depths.

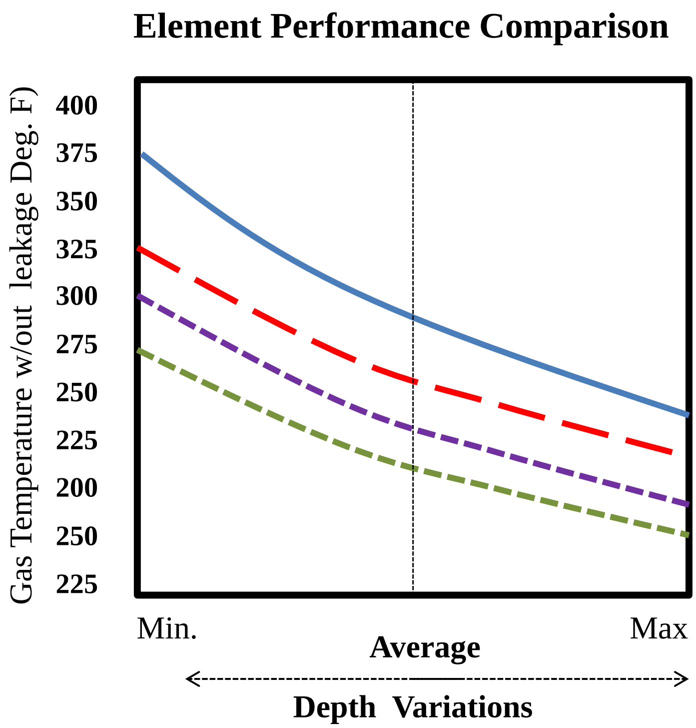


Figure No. 4, varying element configurations (*for example only*)

Air Leakage and Performance

The main advantage of the regenerative air heater is that it is probably the least expensive heat recovery device that is able to operate reasonably well in the harsh environment of the flue gas exhaust stream from a fossil fired boiler. A major drawback of the regenerative air heater is the undesired leakages that are inherent to the design of the device.
It's extremely difficult to seal these types of heaters due to the large temperature difference between their hot and cold ends (about 400˚F), coupled with the large diameter of the rotors. These opposing temperature gradients work together to produce a significant radial thermal expansion difference between the hot and cold sides of the air heater's rotor after unit start up.

Due to this inherent thermal distortion, it's not uncommon for the outer edges of a large air heater at operating temperature to experience a significant "droop" (or "*turn down*"). The distortion caused by this thermal turndown (which can be as much as 4 inches on some rotors) changes the gaps between the seals and the sealing surfaces as the rotor warms to operating temperature, and is the most significant contributor to air heater leakage. This phenomenon must be accounted for when setting the seals at a cold state.

A considerable amount of additional air heater leakage can occur around the perimeter of the air heater through the bypass/circumferential seals. The following 3-D diagram (*Figure 5*) is a good representation of the various leakage paths through the air heater. In this diagram, the leakage through the circumferential seals (*also may be referred to as peripheral seals or bypass seals*) is depicted at the bottom.

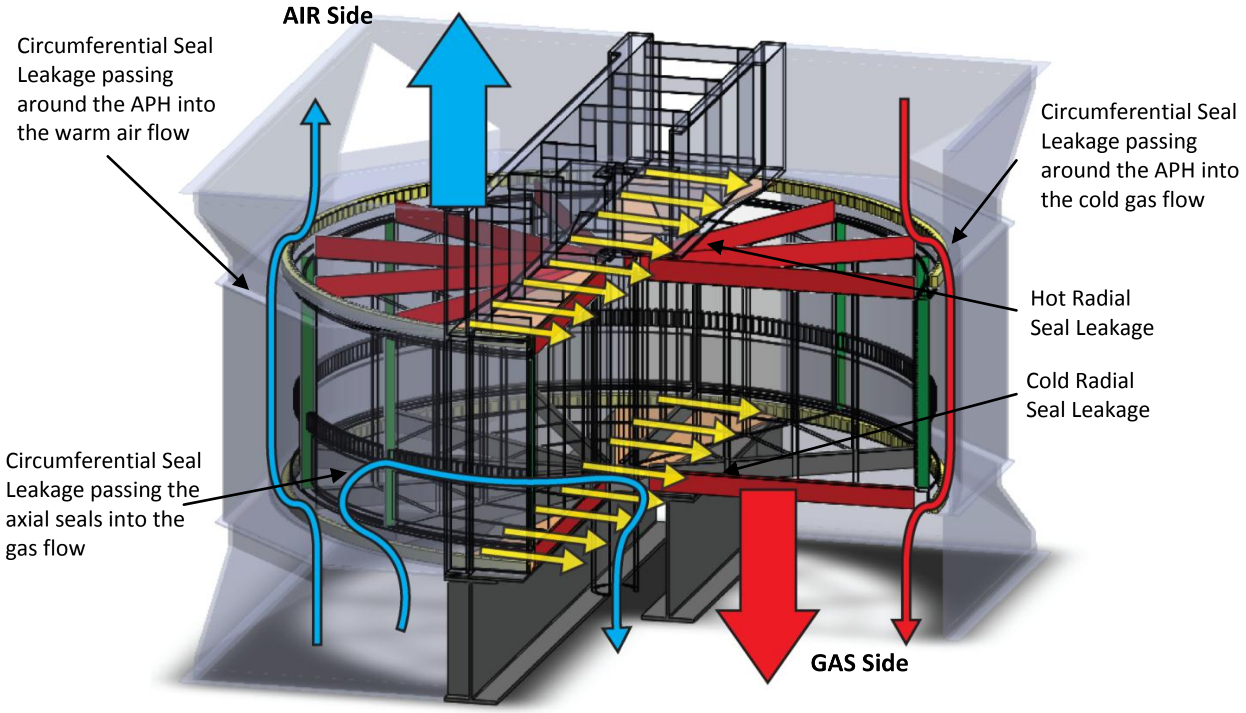


Figure 5 –Circumferential leakage through an air heater

Circumferential seals are located on the entire circumference of the air heater rotor, on both the hot end and cold end of the air heater. On the flue gas side of the air heater, all of the leakage through the inlet side circumferential seals will short circuit around the air heater (*bypassing the heat transfer element*) and exit through the downstream circumferential seals. This leakage results in a loss of enthalpy transfer into the element bundle, and increases the temperature (*and therefore the actual volume*) of gas entering the ID fans. On the air side of the air heater the volume of leakage through the first set of circumferential seals, will enter the annulus around the perimeter of the rotor, where the leakage will split in two directions. The volume in each direction depends on the differential pressures between points of exit. A portion of the flow will continue in a straight path and exit through the second set of circumferential seals. The remainder of the flow will be directed around the perimeter of the rotor and exit into the exhaust gas stream (*through the axial seals*) and that volume will, in turn, exit the air heater through the gas side-cold end circumferential seals.

Radial seal leakage is expressed as a percentage and basically represents the percentage of the gas flow downstream from the airheater that is the result of the mass of inlet air that leaks through the airheater seals into the gas outlet stream. It is the experience of the authors is such that radial leakage rates over 40% have been measured in some air heaters. Furthermore, leakage rates around15% to 20% are often accepted as a "normal" condition, especially in older air heaters that have experienced physical distortion, wear, and erosion over time. Leakage at this level places a significant extra burden on the boiler fans in order to move gas and air that serves no useful purpose. The burden placed on the fans is often exacerbated by the fact that, in many plants, changes in fuels and operating conditions over the years have resulted in induced draft fans operating at near capacity. Because fans become much less efficient when they operate near full capacity, a 1% increase in fan volume can actually result in as much as a 3% increase in required fan horsepower (refer to Figure 6). So, in these cases, even a small reduction in radial seal leakage can yield very large benefits considering that fan motors are one of the largest electricity users in the entire plant.

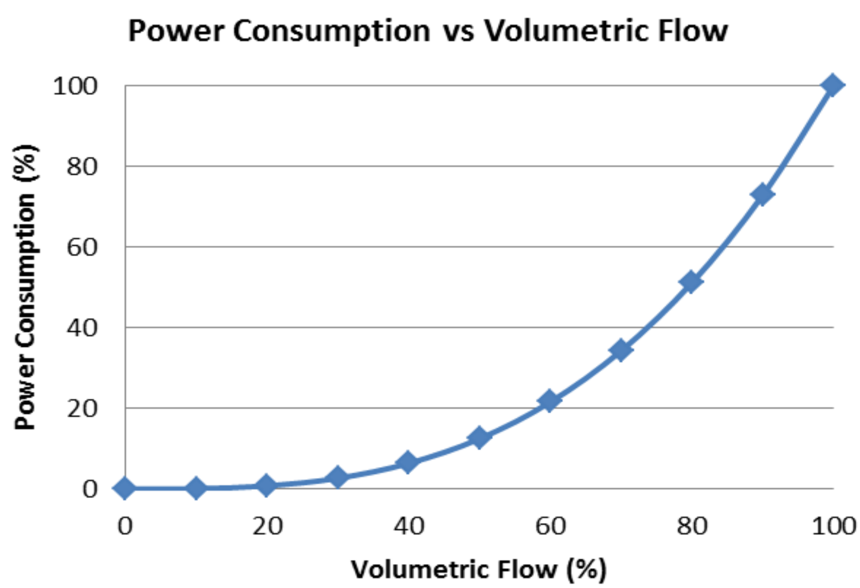


Figure 6, Flow Volume vs. Power Consumption (*Speed Control Theoretical*)

Leakage Solutions

A cost effective and simple method for reducing air heater leakage is replacement of the original equipment type air heater seals with newer design high performance full contact radial seals and progressively interlaced circumferential/bypass seals- also designed for flexibility under contact - such as those shown here (*supplied by Paragon Air Heater Technologies).* Full contact seals have demonstrated the ability to reduce air heater leakage by 50% or more from "as-is" levels in many airheaters when they have replaced original equipment type seals. An example of a high performance full contact radial seal (DuraPlus™) is shown in Figure 7.

In comparison with an original design seal, which is really a rigid "proximity" air dam, the full contact seal is constructed to maintain a continuous, but flexible contact with the sealing plate at all times, effectively eliminating the main path for radial seal leakage. These seals provide additional leakage reduction benefits because they are capable of maintaining full contact even when there is unevenness and distortion in the sealing surfaces (*sector plates*), as is commonly found in older air heaters. These "distortion gaps" can be a significant contributor to the high leakage rates found in most old air heaters.

The high performance circumferential seals (DuraFlex™) shown in Figure 8 have progressively interlaced structural design that provides both flexibility and resistance to tearing, which allows the seals to operate in contact with the perimeter sealing surface without being damaged, thus minimizing the gaps and leakage openings in comparison to original style seals.

Figure 7, DuraPlus™ High Performance Seal

Figure 8, Circumferential Seal

Improved Reliability and Heating Element Considerations

To further pursue innovative advancements in air heater performance, the cold end element layers of a regenerative airheater can be coated with state of the art enamel that is formulated with nanoparticle additives that provide unique attributes. This nanotechnology is the result of a joint 8 year development project by the University of Bologna and SMALTIFLEX S.p.A., Modena, Italy, a Paragon Air Heater Technologies partner.

Engineering materials, including coatings and in particular enamel coatings, often have a limited lifespan due to unavoidable degradation and unexpected damage from stress and strain. In order to overcome these issues, research in the field of self-healing materials, defined as a ‘‘material where damage automates a healing response,’’ is currently an active field of study. This research is driven by the possibility that future materials may not have to be replaced, which would result in cost and efficiency savings in many applications. Vitreous enamel coatings are one of the materials which benefit from these research activities and are being used for high performance applications.

Vitreous enamel coating are a special class of ceramic-glass material used as coating for metal substrate. Vitreous enamel coatings are characterized by high corrosion resistance (that can be 10 times higher than conventional stainless steel) and high value of superficial hardness (from 600 HV to 800 HV), nevertheless they are brittle in nature and spalling phenomena can affect their in-service performance.

The concept of developing a self-repair enamel coating has been driven by the need for enhanced mechanical performance when subjected to external loads that can be static or dynamic (fatigue or impact). Different strategies are being proposed to achieve self-repair effects in case of mechanically loaded components made by metals, ceramics, polymers, cements and, even more, composite materials. In case of polymer materials two main strategies have been considered and developed: one consider the possibility to induce a self-repair mechanism in polymeric matrix when a polymer chain is broken, a second strategy, inspired by the tissue self-healing capability, is based on the introduction of an healing agent into the polymeric matrix. In particular, in the last case, healing agents can be introduced in a polymeric matrix within microcapsules. The healing agent is released when cracks are able to open such capsules. After doing so, the interaction between the agent and particles of a catalyst are introduced in the matrix and can give rise to local polymerisation effects suitable to bond the crack surfaces and stem the crack propagation [6]. A similar approach has been followed by introducing hollow glass fibres in a polymer-matrix composite: an agent stored within the hollow fibres outflows where fibres are broken allowing both damage detection and in situ restoring effects [7,8]. Based on these principles several materials and coatings have been developed, nevertheless no one of them is a vitreous material and, in particular, no one of them is a vitreous coating for metal substrate. Several problems have been accounted and solved to develop a self-repair vitreous material. Among these problems the most relevant is the intrinsic brittleness of the vitreous matrix. More than this and considering the particular case of the vitreous enamel coating, the second aspect that has to be accounted is the coating adhesion to the substrate. These problems have been overcome by means of a proper combination of different material manipulation at the nanoscale. In particular the joined research collaboration of SMALTIFLEX with the Bologna University have determined the means for modification of enamel coatings through the addition of two metal oxides nanoparticles and one sub-micrometric repairing agent to the enamel material.

Figure 9 illustrates an example of a stress-strain curve comparing standard and the self-repair enameled steel commonly used for heating elements. From this diagram it can be seen that the self-repair enamel exhibits a superior mechanical performance with respect to the stress and the strain. In particular the research demonstrates that the strain of self-repair enamel is 2.4 times greater than a standard one and that the stress of self-repair enamel is 2.7 times greater than standard.

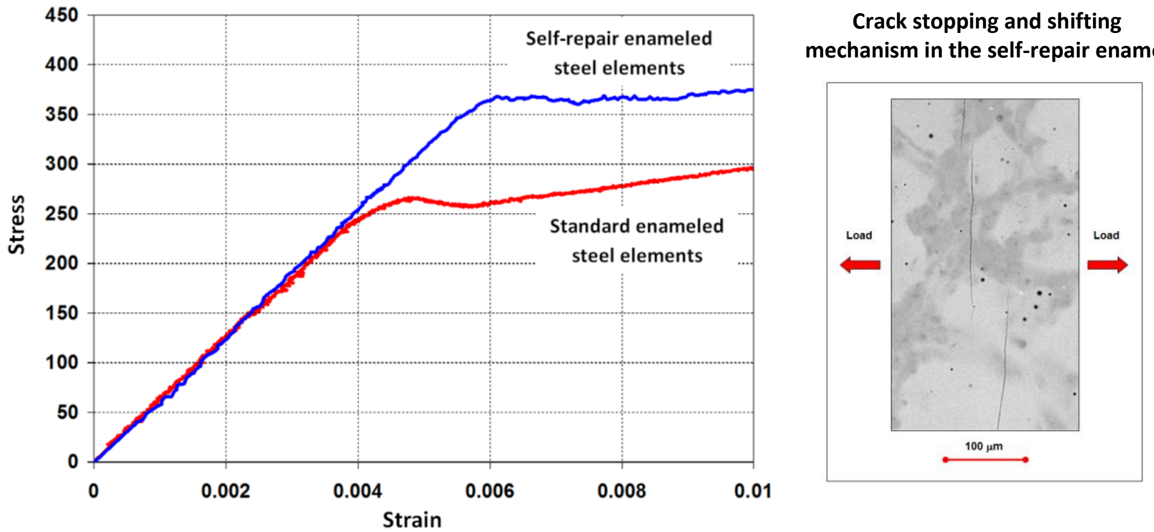


Figure 9: example of stress-strain diagram in the case of standard and self-repair enamel; and an SEM image of the crack stopping process that characterizes the self-repair enamel.

The second improvement that has been studied and developed to enhance the functionality of the enamel for the heating elements is the no-stick effect that can reduce the risk of plugging. The no stick enamel is characterized by a reduced contact angle between a liquid drop and the enamel surface. In the table and figure 10 below are reported the main results obtained by the measurements of the contact angle. From such results it is evident the reduced wet-ability that is exhibited by the no-stick enamel respect to the standard one.

Contact angle (°)	**Standard enamel**		**No-stick enamel**	
	M.V,	S.D.	M.V,	S.D.
Water	30	1.0	65	1.5
Acid solution + ash	40	1.2	72	1.2

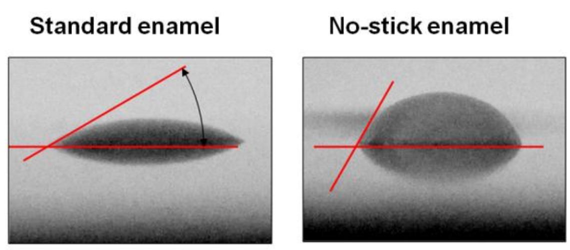


Figure 10, Standard enamel vs. No-stick enamel

In figure 11 it is reported an example of NF6 elements profile that has been enameled respectively by the no-stick enamel and by the standard enamel. By lab scale test it was proven that the no-stick enamel is less prone to plugging phenomena with respect to the standard one.

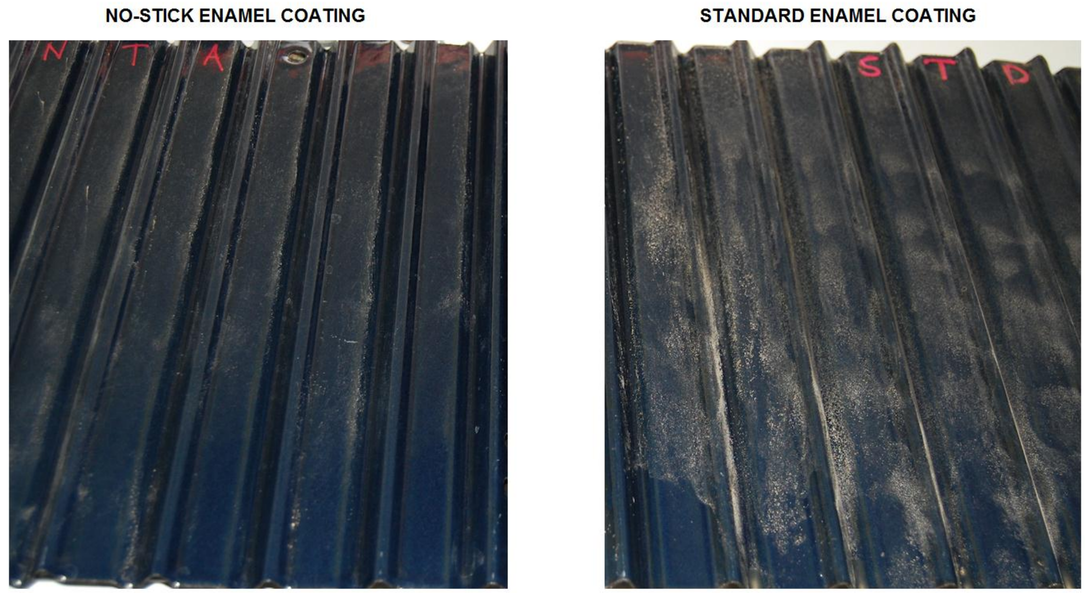


Figure 11: an example of lab scale test of heating elements that have been coated respectively by means of the no-stick enamel and the standard one.

It is anticipated that this innovation will result in further operational improvements, fewer outages for water washing elements, lower long term pressure drop in regenerative air heaters, and extended element life. Below is a photograph of a recent shipment of vitreous enamel coated elements / baskets prior to installation at one of Paragon Airheater customers at HECO, Kahe Point (USA).

Figure 12: Vitreous Enamel Coated elements/baskets supplied to HECO, Kahe Point

Conclusions

From the standpoint of the thermal efficiency of a power plant, the air heater is a critical piece of equipment. Even a small deterioration in air heater performance can result in efficiency losses resulting wasted fuel and unnecessary CO_2 emissions, not to mention the load limitations due to fan losses associated with air heater leakage. As with any improvement, the key is to understand, evaluate, optimize and consistently improve the process through lessons learned and consistently attending to the details when working to sustain performance for the long-term.

This process and the components mentioned within this paper have been proven and validated with previous case studies on product technology published. Therefore, the goal of this paper was to provide a summary and review today's advancements with regenerative airheaters in regards to design, performance and reliability.

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