

SPRAY COOLING TECHNOLOGY: BEYOND THE ROOF

Scott Ferguson, William Emling



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Spray Cooling Technology: Beyond the Roof

Abstract

The many advantages of the spray cooling technology from Systems Spray-Cooled for electric arc furnace (EAF) sidewalls and roofs have been well documented in technical papers, conference proceedings and patents. Steelmakers have come to recognize enhanced safety and environmental performance, improved productivity, reduced maintenance and operating costs. While the application of this technology on the furnace itself has been the focus of many publications, the extension of Systems' expertise beyond the furnace roof is the subject of this paper. Specifically, the fixed and moving elbows connected to the "fourth hole" of the EAF, the down coming duct, combustion chamber and the water-cooled duct portion of the fume treatment plant will be discussed. Continuous improvement and engineering developments in these areas will be reviewed. Together with the on-furnace equipment, a complete Systems Spray-Cooled system results in the safest, "greenest" and lowest total cost of ownership for EAF melt shops.

Introduction

The upper shell of an electric arc furnace is positioned atop the lower shell and provides additional volume for scrap charging and provides capacity for both metal and slag formation. It also accommodates slag foaming using oxygen and carbon injection. The foamed slag covers the arc to protect the refractories and limit nitrogen and NO_x formation. Historically, the upper shell (or "sidewall") is either comprised of

refractory material or is water cooled with high pressure (e.g. more than 60 psi or 4.1 bar) welded tubular cooling panels arranged in an external support/water supply structure, or "spider". Since the upper shell is exposed to severe heat loads, tubular cooling is sometimes done using high alloy material or copper.

With the development of ultra-high powered EAFs and the associated increased use of chemical heating, heat loads have been substantially increased in recent years. Refractory roofs and sidewalls are no longer used for these types of furnaces. Welded tubular cooling systems have been replaced in some furnaces by spray cooling, first installed by Systems at Timken Steel in 1986. Spray cooling utilizes tiny droplets of water spray to effectively and efficiently cool a steel plate exposed to the furnace interior. The result is safer and more reliable cooling. Figure 1 shows a picture of the spray cooling, which is contained within a steel enclosure.

The roof of an EAF contains the emissions generated from the process and serves to funnel them into the fourth hole. From there, an elbow directs the gases into the Direct Evacuation Control (DEC) system. Flat roofs have been replaced by higher pitched roofs to accommodate increased scrap loading and to reduce shell warpage caused by the increased heat loads. Like the sidewall history, refractory roofs have typically been replaced by water cooled designs.

Authors

Scott Ferguson

Systems Spray Cooled Inc.
Smyrna, TN
Phone: 615-366-7772
Email: sferguson@tsg.bz

William Emling

Emling Metallurgical Services, LLC
Cranberry Township, PA
Phone: 412-915-9448
Email: emlingms@gmail.com



These have traditionally been welded tubular pipes. In recent years several steelmakers have converted to spray cooling designs for the same safety and reliability reasons as with the sidewalls.

While the literature contains several references to the adoption of spray cooled technology on the furnace itself,¹⁻⁸ the focus of this paper is on the application of similar technology to the balance of the EAF operation. Several distinct benefits and opportunities will be presented.

Figure 1



Spray Cooling inside the Systems Design

BRIEF REVIEW OF ON-FURNACE APPLICATIONS

Sidewall Applications

As mentioned above, EAF heat loads have increased in recent years, as furnaces have become more productive. This has created an additional need for more efficient cooling to prevent warpage of the upper shell. While holes can be created in any steel structure due to events like arc flares or oxygen burner blowbacks, welded tubular pipes can also experience thermal fatigue failures of the welds. These failures often result in cracks, which originate in the heat-affected zones of the welds. Water leaks are thus much more of an issue with the welded tubular pipes. Because of the presence of high pressure water within the pipes, even small leaks can result in significant volumes of water entering

the furnace and lead to hydrogen explosions. Immediate corrective action must be taken to repair any cracks, which requires putting people inside the hot furnace to make the weld repairs.

Operators routinely monitor temperature sensors in the sidewalls to identify hot spots as indications of water leaks. Unfortunately, this is oftentimes not a reliable method of identifying such leaks. Various off-gas monitoring systems have also been developed in recent years to detect water presence in the off gas system. These systems can be helpful to the operator, but even small leaks of water at high pressure can be a real safety concern. By the time a hot spot is detected, or an off-gas sensor detects water, it might be too late. Once the furnace is tilted, if a large volume of water has entered inside the furnace, an explosion may occur.

With a spray-cooled system, water leaks are significantly less problematic, because there are less welds exposed to high temperatures. The Systems design utilizes a thin carbon steel plate for the exposed hot face. There are inherently less induced stresses from roll forming and welding the plate compared to a tubular pipe design. Minimal welds are utilized between the plates, and those are cooled from behind with strategically placed sprays. Should a hot face hole be caused by an arc flare or blow-back, the amount of water released from the cooling system is much less as there is no pressure from the sprays forcing water into the furnace. A nominal 50 mm (2") hole in a tubular system operating at 4.1 bar (60 psi) results in a leak of 1,007 liters per minute (266 gallons per minute). The same 50 mm (2") hole in an atmospheric non-pressurized spray cooled furnace results in 0.2 liters per minute (8 oz/min).

Steelmakers have also discovered that slag generated during the heat cycle can attach to the inner surfaces of the sidewalls and provide an insulating layer to keep the heat inside of the furnace and protect the tubular panels from heat damage.

While slag coating is effective, it can easily be removed by high temperatures if not held in place with an effective retainer system of some sort. A sidewall panel comprised of tubes has proven to be more difficult to keep coated than the Systems design, which utilizes proprietary slag cups.

The Systems design is a double-walled construction, with an inner carbon steel liner, called the hot face plate, and an outer cover that incorporates the structural elements of the sidewall. The open annulus between the hot face plate and dust cover contains the spray system. Typical thickness of the spray-cooled sidewall from hot face plate to dust cover is in the 15"-18" (350-500mm) range, although this can be reduced for tight clearance areas, such as around the gantry turret. The Systems double wall design thickness is roughly the same as a tubular panel/spider envelope, so space and clearance constraints are the same for either system.

Because the Systems design utilizes an enclosed chamber where the patented spray bars and nozzles are located, there are other advantages of this system.

- Maintenance and repairs can be done from outside of the furnace. Access hatches are provided, to enable access for inspection or spray bar adjustments.
- The sidewall is delivered on a single piece, incorporating sump area coverage as well.
- Panel to panel gaps are eliminated, thus minimizing flame and fume emissions and air infiltration. A tighter furnace.
- Advanced engineering, including FEA, results in more dimensional stability and less warpage.
- The hot face plate is the only wear item in the sidewall supply.
- The sidewall can be customized for different burner designs and brick protection methods.
- Water management uses existing non-contact water, so no additional chemical treatment is required; and there is no evaporation of the water.
- There are significantly fewer external pipes and hoses with this design, and there is obviously no need to change panels on a hot furnace.

- Custom slag doors can be incorporated into the design of the sidewall.

Roof Applications

Several steelmakers have also incorporated Systems spray cooling for the EAF roof, primarily for the same safety and operational reasons as discussed above. Roof leaks can be just as dangerous as sidewall leaks. But there are other advantages to the technological developments in this area of the furnace.

The DEC systems in EAFs are crucial for managing emissions and maintaining air quality. These systems work by maintaining negative pressure within the EAF, which helps to capture and duct emissions directly from the furnace to pollution control systems. They are designed to capture high-caloric exhaust gases and corrosive components produced during the steelmaking process, helping to reduce the release of harmful pollutants into the atmosphere. These systems are essential for complying with environmental regulations and ensuring the sustainability of steelmaking operations. With the Systems designed roof, being of similar construction as the sidewalls, the furnace is tighter, resulting in less gas leakage both into and out of the furnace. The benefits of a tighter furnace are less electrode consumption, less refractory erosion and lower NO_x formation.

Systems' steep conical roof design can result in increased life due to less heat damage, improved drainage of cooling water, better gas evacuation, less abrasive wear and increased delta life with the enclosed water sprays directed towards the delta.

Various OEM (Original Equipment Manufacturer) roof designs can be accommodated:

- Lifting of the roof using a single-point cantilever or multi-point gantry have been successfully adopted
- The fourth hole in the roof can be round, obround or oval, depending on the volumes of off gas generated
- The roof can be designed to accommodate either a spray cooled or tubular fixed fume elbow

With either the sidewall or roof design cooling water amounts can be adjusted in different areas. The size and/or quantity of the nozzles can be chosen based on temperature monitoring. Because of this flexibility, operational changes or upgrades can easily be managed. Welded tubular roofs and sidewalls utilize a uniform cooling flow over the entire system, so any adjustments needs are to the system as a whole and cannot be localized.

Figure 2 shows both a spray cooled sidewall and roof, after fabrication in the workshop. Notice the slag retention systems for both applications. Figure 3 shows the assembly during operation.

Figure 2a



Systems Spray-Cooled Equipment After Fabrication: Roof

BEYOND THE ROOF

Fixed Fourth Hole Elbow

As mentioned in the previous section, the roof typically has a fourth hole, which provides a pathway for the process-generated off gases to exit the furnace and direct these gases to the DEC system. Attached to the fourth hole is a fixed elbow, typically incorporating a high angle to minimize slag and other particles from entering the DEC system. The fixed elbow moves with the roof and enables top scrap charging. In the operating position, this elbow mates with a movable elbow that directs the fumes away from

Figure 2b



Systems Spray-Cooled Equipment After Fabrication: Upper Shell (Sidewall)

Figure 3



Systems Spray-Cooled Upper Shell (Sidewall) and Roof in Operation

the furnace area. A variable air gap between these two elbows provides for ambient air to be introduced, to ensure that volatiles such as hydrogen, and carbon monoxide can begin to be safely combusted at this location and continue to be combusted in the dropout (also referred to as the combustion chamber).

As with the sidewall and roof applications, several steelmakers have incorporated spray cooling into the fixed elbow attached to the roof. The elbow can easily be removed from the roof. The clear safety benefits of using this technology around molten metal have been well documented. This combination is illustrated in Figure 4, where one can see the spray cooled fixed roof elbow on the left, the movable tubular elbow on the right, followed by a vertical downcomer tubular duct at the bottom of the picture. Systems Spray-Cooled has worked with several OEMs to incorporate their tubular movable elbows.

Figure 4



A Systems Spray Cooled Fixed Elbow (left) Mating With a Movable Tubular Elbow (right) and a Tubular Vertical Downcomer Duct.

Movable Fourth Hole Elbow

Lesser known and less documented are the advantages of applying spray cooling to the movable elbow and the subsequent portions of the DEC system. The movable elbow directs the off gases to a vertical downcomer duct. The combination of the movable elbow and vertical duct is often referred to as the “downcomer”.

Much like the sidewall and roof applications, thermal damage to a tubular ducting system can still occur in the movable elbow and duct (see Figure 5).

Combustion of carbon monoxide (CO) to carbon dioxide (CO₂) is an exothermic reaction, generating additional heat. Likewise, combustion of hydrogen, NO_x gases and Volatile Organic Compounds (VOCs) typically releases heat. Resultant gas temperatures in this area are still relatively high, and gas cooling has just been initiated. Figure 5 shows a thermal degradation of a movable tubular elbow. Weld failures between the tube sections can easily be seen. Escaping of CO other gases in this area is possible and could become another safety and even an environmental hazard.

Figure 5



Degradation of Movable Tubular Elbow

With the Systems spray cooled elbows, there is a double walled steel plate containment in this area. Leakage of these dangerous gases cannot occur. Figure 6 shows a furnace with both elbows utilizing the spray design. The movable elbow is articulated with rails and wheels on a trolley frame, thereby enabling variable dilution air entrainment. Lateral movement of approximately 1 meter (39.37 inches) is provided, to enable roof swings during scrap charging.

Figure 6



Systems Spray-Cooled Fixed, Movable Elbows

Large inspection hatches in the outside wall, with lift-off style doors, enable easy installation of off-gas temperature and chemical monitoring. Since the hot face exposed to the gas is smooth, buildup of abrasive particles entrained in the gas stream does not occur. This also contributes to longer service life.

The structural integrity of the spray cooled elbows has been proven to provide longer service life versus the tubular designs. Customers have reported lives up to 4 years with these elbows, and many installations have been in operation for years.

Downcomer

Directly below the movable elbow is the stationary water-cooled downcomer, which contains and cools the gas as it is directed towards the dropout (combustion) chamber. Like with the elbows, combustion of the gases can still take place within this area, so leaks could result in exothermic reactions. With a typical panelized downcomer there are gaps between the panels that do not provide for cooling.

Figure 7 shows the spray cooled design for this area. The one-piece construction eliminates panel to panel gaps, thus minimizing flame and fume

emissions. There is much tighter containment due to continuous hot face plate construction. This still impacts the ability to maintain pressure in furnace, which influences electrode consumption and refractory life.

Figure 7

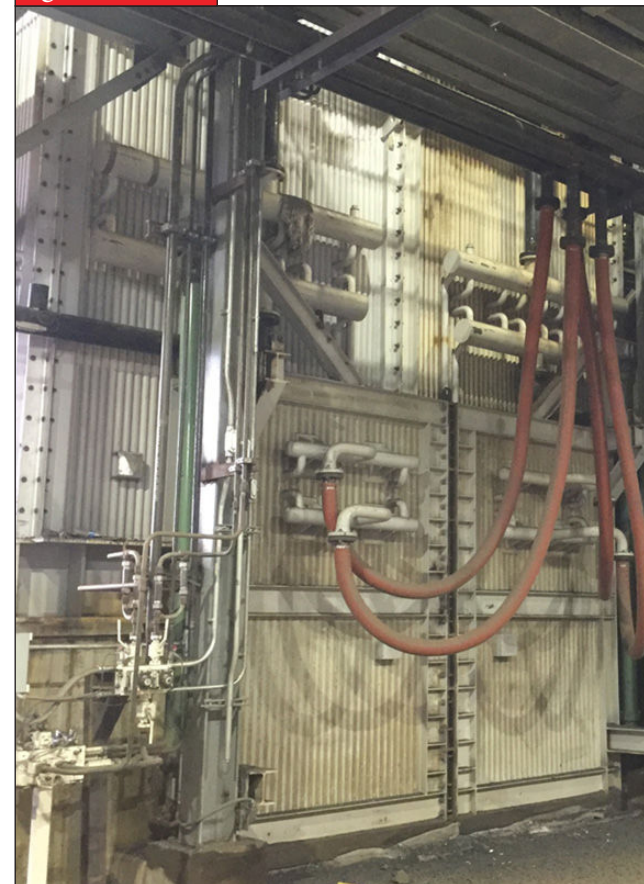


Systems Spray-Cooled Downcomer

Dropout Chamber (“Combustion Chamber”)

As the hot gases descend through the downcomer area, they eventually enter the dropout/combustion chamber (DOC). Carbon monoxide and hydrogen generated in the furnace are destroyed, and cooling of the gases continues. Unlike on-furnace, where keeping the heat in the furnace is of prime importance, slag buildup on the walls is not important. The goal becomes cooling of the gas. The DOC, mounted onto a concrete base, allows for settling of large abrasive particles, entrained in the gas, to prevent settling in the downstream ductwork. It also allows for additional residence time for combustion. The chamber needs to be periodically cleaned and is accessed by mobile equipment through water cooled barn doors. Figure 8 shows an example of a tubular cooled DOC.

Figure 8



Typical Tubular Panelized Drop Out Chamber

Although infrequent, dropout chamber or downcomer explosions have been reported within the industry, caused when liquid steel from an EAF lower shell breaks out and impinges on tubular panels with high pressure internal water cooling. Damage and resultant repairs are extensive. Similar EAF lower shell accidents have occurred in operations having spray cooled equipment, with little to no damage being reported.

The Systems designed dropout chamber (see in Figure 9) is comprised of several panelized sections, incorporating double wall design with internal nozzles and spray bars. Note the smooth inside walls, to ensure that dust and debris can drop to the bottom of the chamber for easy and safe cleanout. This is an important distinction, since solid particles cannot adhere and accumulate to the walls, causing corrosion/erosion and dangerous build-ups. Potential “cave-ins”, when the particles are released,

also cannot occur. The safety of those accessing the DOC for clean out or inspection is thus ensured.

As with other areas, lift-off style hatch doors are provided for inspection and spray bar modifications.

Figure 9



Systems Spray-Cooled Drop Out Chamber, Showing the Interior Walls

Conversion to a spray cooled downcomer and DOC has been accomplished with several customers, through custom engineering to match existing infrastructure. The size of the DOC can be optimized (also considering existing EAF and platform support structures) by Systems engineers to minimize baghouse problems (e.g. high temperatures and fires damaging bags).

Downstream Hot Ductwork

Emerging from the DOC, often from an elevation above the cleanout doors, the downstream water-cooled ductwork further cools the gas, until gas temperatures reach the point where forced cooling is no longer required. This is typically 30 to 45 meters (100-150 ft.) in length. Figure 10 shows a tubular cooled duct that has square sections, which can be supported with structural beams. Round sections can also be used, but structural support may be more complicated.

Design of supports needs to consider thermal expansion and contraction. While the duct is horizontal, section sizes can be quite long to minimize welding and connecting. Long sections may be helpful in reducing initial capital costs and original installation procedures, but replacement of large sections can be complicated, requiring the use of man-lifts and mobile cranes.

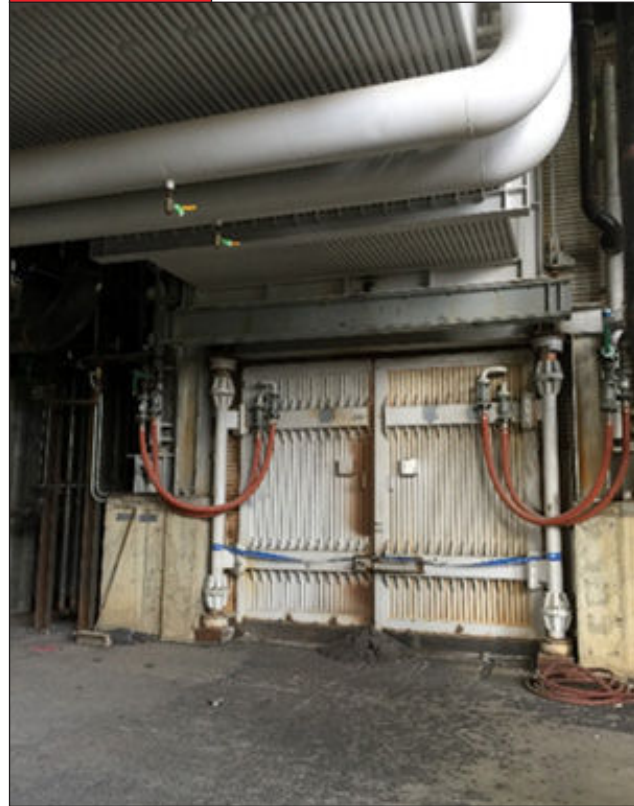
Water leaks are not very common, but when they are discovered, repairs are often difficult, resulting in lengthy down time for draining; followed by either welding or replacing of entire sections. Spare sections are usually not kept on site, and repairs must be temporary until special orders for replacement sections can be delivered.

Because tubular pipes are not drained as part of their normal function, long idle times for maintenance outages and/or unplanned outages can be problematic, especially during winter months when outside temperatures are

below freezing. Steel plants have experienced frozen water in the pipes, leading to multiple water leaks, and subsequent delays for draining and weld repair procedures.

The outer cross-section of the spray cooled ductwork is typically square, so support can be provided with structural beams. Like in the other areas, spray bars and nozzles are positioned inside of the outer steel frame, and cool the inner steel plate, which is round and has smooth inner surfaces. This surface reduces the amount of dust that can become trapped within the duct and transports more of this material to the baghouse. The circular inner duct configuration enables the most effective cooling of the gas. Figure 9 shows examples of the ductwork. Since the outer skin is near ambient temperature, there is no thermal distortion nor corrosion.

Figure 10



Typical Tubular Cooled Duct Emerging from DOC

Figure 10



Supported Duct Work

Figure 11



Systems Spray-Cooled Ductwork

Temporary repairs can be made during production. This generally consists of welding up a crack or installing a patch plate at a location where a hole has occurred. Typically, this is accomplished from the outside of the equipment by accessing the inner plate from the water side through external hatches provided or a temporary hole cut in the outer shell. Cutting-your-way-in and welding-your-way-out is another distinction that improves maintainability. The affected area can be isolated from the cooling water by the temporary removal of a spray bar and capping of the supply nipple. Several customers have had spray cooled ductwork in service for many years without replacement. Some more than 30 years of continuous operation.

In the design of the ductwork, Systems engineers ensure that minimal constraints are built into the hot face plates to allow for cyclic thermal expansion and contraction. The pressure vessel quality plate is readily weldable, formable and machinable. Plate thickness design considers corrosion and abrasive wear

(a function of gas stream velocities and entrained particles), and resistance to thermal fatigue. Designers also consider rounding and chamfering of corners to minimize stress concentration. Obviously, a round inner duct eliminates welded corner or stress risers.

Figure 11a



Tubular

In many steel plants, the horizontal duct sections give way to a vertical tower, prior to the end of the forced cooling process. Figure 11 shows such transition for both tubular and spray cooled designs. To transition from horizontal to vertical, and to accommodate various building constraints and/or material handling operational needs, elbow sections and other complex shapes are necessary. With tubular designs, the welded pipes are formed during manufacturing to achieve these geometries. Imparted stresses need to be relieved, to minimize potential weld cracking. Tubular curved sections at the base of a tower can also become a collection point for water impurities.

Figure 11b



Systems Spray-Cooled Ductwork Prior to Mixing with Canopy Ductwork

Because steel plates are not constrained by the bending radii, there are less geometrical limitations. Complex shapes can be fabricated that are much easier to install. Since water is drained as part of the spray process, collection of impurities is not an issue. Like in other spray cooled areas, large hatches allow for inspection. Figure 12 shows an example of a complex spray cooled section in another application

Figure 12



Complex Shapes Designed for Spray-Cooled Sections Hot Ductwork

Considerations After Hot Ductwork

At the end of a water-cooled ductwork, gases from the building canopy and other secondary emission sources are mixed with the cooled gas and transported to the baghouse via non-water-cooled sections of ductwork. These other gases are low enough in temperature to allow the mixing. Careful calculation and engineering of both the cooled and non-water-cooled duct lengths must be done in concert, to ensure that harmful dioxin and furan formation does not occur. Temperatures of non-contained gases must avoid 200-450°C (392 -842°F). Incoming baghouse temperatures must also be controlled to avoid high temperature alarms and/or baghouse fires.

In many countries EAF dust is considered a hazardous waste. In the United States, for example, the Environmental Protection Agency (EPA) classifies this dust under the Resource Conservation and Recovery Act (RCRA) with waste code K061. This is due to the presence of toxic materials such as lead, cadmium and chromium.

Dust must be collected and transported to either a disposal site or another facility for recycling operations. Hence dust handling/collecting, both inside the baghouse and when transferring to a collection silo after the baghouse, is very critical. The dust must remain dry throughout these steps. Several plants operating with tubular ductwork have reported difficulties caused by water leakage from the welded pipes resulting in dust agglomeration and “caking”; thereby requiring immediate intervention. No such anomalies have been reported with a spray cooled duct system.

OPPORTUNITIES

Based on years of experience working closely with customers, and continuously upgrading designs and features, many enhancements have been made to the Systems installations. Opportunities for further improvement to the spray cooled technology have recently been suggested:

- For new installations, more efficient cooling can mean a shorter length of water cooled ductwork, lowering installation costs for piping, electrical and foundation work. Pump sizes can also be reduced due to the need for lower water pressures.
- For existing operations utilizing spray cooling, advanced instrumentation coupled with machine learning digitalization could provide opportunities to optimize water flow rates and resultant heat transfer. For example, if certain circuits have water temperature differentials (delta-T's) that are low, water flows could be reduced, or water could be recirculated without passing through cooling towers. Pumps with variable speed drives could be incorporated to lower electrical and water consumption.
- Customers with existing plants, operating with welded tubular cooling but considering conversion to spray cooling, can now utilize technologies like laser scanning and 3-D engineering. Scans of the existing support structure and potential obstructions can enable optimized routing of spray cool piping, motors and ductwork.

CONCLUSIONS

The many on-furnace advantages of spray cooling can be extended when considering this technology beyond the roof. While the risk of hydrogen explosions is inherently less when away from liquid metal, catastrophic events in elbows, downcomers and dropout chambers have still been reported in the industry. Spray cooled implementation beyond the furnace roof can help mitigate such events.

Regarding environmental sustainability, there are other advantages to consider. For each area,

the one-piece framed construction and continuous hot face plate eliminate potential air gaps, reducing gas exfiltration into the environment and unplanned exothermic ambient air infiltration. The double walled system enables more effective gas leak monitoring and detection, and the smooth surface decreases build-up of dust and degradation of gas stream containment over the ductwork lifetime.

Operating and maintenance reliability is greatly enhanced throughout the process. By relying upon water droplet impingement cooling at atmospheric pressure, the spray cooling technology from Systems Spray-Cooled provides water cooling at a greater efficiency than conventional welded tubular methods. Positive extraction of spent cooling water reduces the amount of water present within the equipment and in the baghouse environment.

Systems technology has directly led to improved EAF shop reliability while decreasing and easing maintenance requirements, safer working conditions in a cleaner environment, reduced spare part inventories while extending the service life of the equipment, and provides for more production with less energy consumption. The “rebuild rather than replace” concept also contributes to the lowest total cost of ownership.

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