

## **Spray-Cooled™ Technology A Proven Alternative**

Troy Ward  
*Systems Spray-Cooled, Inc.*  
311 Plus Park Blvd.  
Nashville, TN 37217  
Tel.: 615-366-7772  
Fax: 615-366-7755  
E-mail: tward@tsg.bz

### **Introduction**

From the outset, the goal was to develop a system that reduced downtime and maintenance costs associated with conventional water-cooled systems, cooled with greater efficiency and was safer to operate, and lowered the overall cost per ton.

UCAR International, Inc. began working on the Spray-Cooled™ Technology with the inventors in 1984. In January of 1985, a prototype Spray-Cooled™ roof was installed on an EAF. It was a 14'-0" diameter roof on a 13'-6" diameter furnace with a 20 MVA transformer.

After the prototype design and performance were evaluated, the first Spray-Cooled™ roof was built and installed under a developmental agreement in September of 1986 at The Timken Company's Harrison Steel Plant in Canton, Ohio. It was a 20'-6" diameter roof on a 20'-0" diameter 100 ton AC EAF with a 30 MVA transformer and 20" electrodes. For the next 13 years, additional applications were identified and converted and the patented Spray-Cooled™ concept expanded worldwide.

In June 1999, Systems Contracting Corporation of El Dorado, Arkansas purchased the patents and associated technology for the Spray-Cooled™ Systems business from UCAR International, Inc., as a continuation of System's efforts to broaden the extent of both services and expertise that it offers industry, particularly in primary metals. Now a proven alternative to conventional pressurized cooling of electric arc furnace equipment, the Spray-Cooled™ Technology has been successfully employed in EAF steel making for the past 19 years. Spray-Cooled™ equipment realizes increased life resulting from prescription management of thermal fatigue cracking, increased maintainability due to carbon steel plate construction and repair procedures, greater cooling efficiency due to variable water distribution techniques, improved operational safety due to the elimination of high pressure, high volume water leaks, and lower maintenance costs resulting from the reduced cost to rebuild versus alternative equipment replacement.

### **Downtime and Maintenance**

The patented Spray-Cooled™ Technology has brought increased life and equipment availability to EAF roofs, sidewalls and sumps, DES roof elbows, off gas ducts, LMF roofs, BOF hoods and most recently to Consteel® furnace connecting cars and pre-heater hoods. Distinct to the spray-cooled process, a spray system incorporating overlapping sprays creates a high degree of water turbulence at atmospheric pressure on the cooled surface. Droplet impingement turbulence results in efficient cooling yielding heat transfer coefficients on the order of ten times greater than for laminar flow. Water distribution rates are varied with varying nozzle populations to match known heat load demands affecting system efficiency and reliability.

Thin-walled plate construction of the independent hot plate incorporating minimal welds, rounded or chamfered corners, and mechanical forming make Spray-Cooled™ equipment less susceptible to thermal induced stress fatigue cracking – a common nemesis of this type of equipment. Stress concentration

points are taken into account. Welded corners present a point of high potential for the initiation of thermal stress fatigue cracking. Corners are allowed to expand and contract freely by being unrestrained by their geometry or by nearby welds, reinforcements or attachments. Rounding or chamfering is employed as an effective means of minimizing stress concentration at corners. The hot plate is in direct contact with the 3300°F furnace environment. A minimal amount of constraint is built into the hot plate, which undergoes cyclic thermal expansion and contraction due to this exposure. Hot plate seam welds are kept to a minimum when forming the hot plate and weld seam intersections are avoided if possible. Combined with a plate thickness optimized based on known heat loads, the construction methods employed serve to minimize thermal fatigue cracking.

The primary material used for the hot plate of Spray-Cooled™ equipment is carbon steel; pressure vessel quality ASTM A-516 Grade 70 plate. Properties such as thermal conductivity, allowable stress, workability and cost have made this grade of steel the material of choice. This plate grade is readily available, weldable, formable, and machinable. Spray-Cooled™ equipment is designed for maintainability. The hot plate wears out, but can be replaced in whole or in part. Since there are minimal attachments from the outer shell or the spray system to the hot plate, replacement is quick and inexpensive. The hot plate is simply cut free, removed and replaced. The outer shell and spray system, allowing for normal wear and tear should last indefinitely.

Thickness of the hot plate is a function of two considerations. One thickness will be considered based on its effectiveness in minimizing thermal stress fatigue cracking. Another thickness will be considered based on its effectiveness in resisting heat/corrosion oxidation erosive wear.

**Fatigue Life:**

Following is a sample determination of the proper material thickness considerate of heat load and thermal stress:

Given Information:

- Existing cooling water flow rate = 3000 gpm
- Water temperature in = 80°F
- Water temperature out = 160°F
- Surface area = 617 ft<sup>2</sup>
- Plate Coefficient of Thermal Expansion = 6.33 x 10<sup>-6</sup> in / in x °F
- Plate Modulus of Elasticity = 30 x 10<sup>6</sup> lb / in<sup>2</sup>
- Plate Poisson's Ratio = 0.303
- Plate Thermal Conductivity = 25 Btu/hr x ft x °F

Analysis:

$$\text{Heat Flux} = \frac{\text{Mass Flow Rate} \times \text{Specific Heat} \times \text{Delta Temperature}}{\text{Area}}$$

$$\text{Plate Differential Temperature} = \frac{\text{Heat Flux} \times \text{Plate Thickness}}{\text{Plate Thermal Conductivity}}$$

$$\text{Stress} = \frac{\text{Plate Coefficient of Thermal Expansion} \times \text{Plate Modulus of Elasticity} \times \text{Plate Differential Temperature}}{2 \times (1 - \text{Plate Poisson's Ratio})}$$

**Combining the last two equations produces the following relationship:**

$$\text{Stress} = \frac{\text{Plate Coefficient of Thermal Expansion} \times \text{Plate Modulus of Elasticity} \times \text{Heat Flux} \times \text{Plate Thickness}}{2 \times (1 - \text{Plate Poisson's Ratio}) \times \text{Plate Thermal Conductivity}}$$

Heat Flux:

$$\text{Heat Flux} = \frac{3000 \text{ gal/min} \times 8.33 \text{ lb/gal} \times 60 \text{ min/hr} \times 1 \text{ Btu/lb} \times 80^\circ\text{F}}{617 \text{ ft}^2}$$

$$\text{Heat Flux} = 194,490 \text{ Btu/hr} \times \text{ft}^2$$

Stress:

$$\text{(For 0.50" Plate) Stress} = \frac{6.33 \times 10^{-6} \text{ in/in} \times 30 \times 10^6 \text{ lb/in}^2 \times 194,490 \text{ Btu/hr} \times \text{ft}^2 \times 0.50/12 \text{ ft}}{2 \times (1-0.303) \times 25 \text{ Btu/hr} \times \text{ft} \times 80^\circ\text{F}}$$

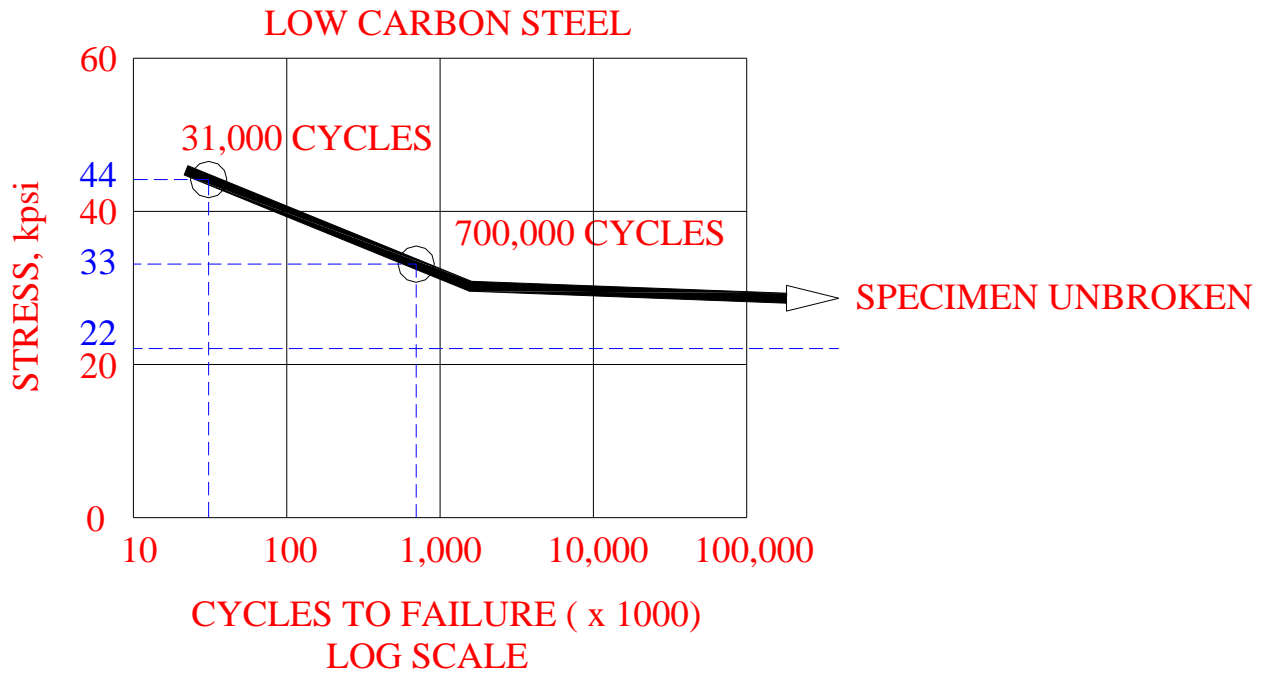
$$\text{Stress} = 44,158 \text{ lb/in}^2$$

$$\text{(For 0.375" Plate) Stress} = \frac{6.33 \times 10^{-6} \text{ in/in} \times 30 \times 10^6 \text{ lb/in}^2 \times 194,490 \text{ Btu/hr} \times \text{ft}^2 \times 0.375/12 \text{ ft}}{2 \times (1-0.303) \times 25 \text{ Btu/hr} \times \text{ft} \times 80^\circ\text{F}}$$

$$\text{Stress} = 33,118 \text{ lb/in}^2$$

$$\text{(For 0.25" Plate) Stress} = \frac{6.33 \times 10^{-6} \text{ in/in} \times 30 \times 10^6 \text{ lb/in}^2 \times 194,490 \text{ Btu/hr} \times \text{ft}^2 \times 0.25/12 \text{ ft}}{2 \times (1-0.303) \times 25 \text{ Btu/hr} \times \text{ft} \times 80^\circ\text{F}}$$

$$\text{Stress} = 22,079 \text{ lb/in}^2$$



**Figure 1**

If a large number of specimens are tested to failure at different values of stress amplitude and plotted versus cycles to failure, the resulting plot is called the S-N diagram. For carbon steels, it is usually found that above 1,000,000 cycles to failure the plot levels off (i.e. there is a value of stress amplitude below which fatigue failure does not occur). This is known as the endurance limit or fatigue limit for the material.

In Figure 1, the cycles to failure for the sample with a 0.50" thick hot plate (44,158 psi stress) is approximately 31,000 cycles. The cycles to failure for the sample with a 0.375" thick hot plate (33,118 psi stress) is approximately 700,000 cycles. A 0.25" thick hot plate (22,079 psi stress) would have a fatigue life that would exceed 100 million cycles. Note that for the same heat load, the stress amplitude is directly proportional to the sample thickness. If based solely on fatigue life expectancy, the recommended thickness for the carbon steel hot plate would be 0.25".

**Wear:**

Corrosive deposit and/or heat oxidation, and the repetitive formation and removal of the complex, less adherent oxides scales by off gas stream entrained particles can accelerate metal removal or thinning of the hot plate. This chemical/physical attack, resulting from the presence of impurity elements, heat, and the gas stream velocity, can accelerate wear and effectively reduce the number of cycles to hot plate failure. The exposed surface of the Spray-Cooled™ equipment hot plate is smooth and its topography offers no residence to the corrosion causing gas stream components. However, should oxidation/corrosion erosional wear be identified as the predominant mode of premature failure, life can be extended directly proportional to an increase in plate thickness. All other things being equal, doubling the plate thickness should double the life expectancy.

**Repairs:**

A *temporary* repair of a burned hole, made during the production cycle, is typically performed by first cutting out the damaged material. Remove material to the extent sufficient to assure the hot plate where

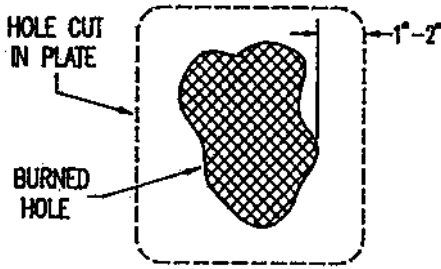


Figure 2

the patch is being installed is at its original base metal thickness, usually cutting 1"-2" outside of the hole (Figure 2). Use the cut out piece as a template for fabricating the patch. Using the best available grade of carbon steel, make the patch slightly larger than the

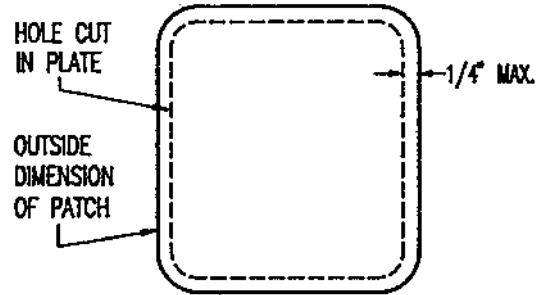


Figure 3

removed piece being careful not to exceed 1/4" on any side (Figure 3). Position the prepared patch over the hole and attach with a 1/4" fillet weld. Replace slag retainers if originally present.

Cracks are repaired by first arc gouging the entire length of the crack plus 1" beyond on each end to remove the damaged material (Figure 4). Beveled weld preparations are made to the sides of the crack to

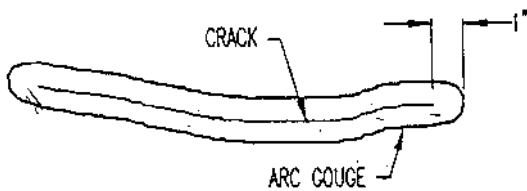


Figure 4

ready the joint for welding (Figure 5). The joint is then welded using a stringer bead process for the entire thickness of the base metal. Temporary work can be accomplished by cutting in through the outer shell or utilizing nearby access hatches. Cutting-your way-in and welding-your way-out is another Spray-Cooled™ equipment distinction that improves maintainability. The affected area is isolated from the cooling water by the temporary removal of a spray bar.

*Permanent* repairs to the hot plate can be postponed until the end of a production cycle or when downtime is scheduled for maintenance on other equipment to minimize unscheduled downtime. A permanent repair is done similarly, but entails removal of damaged material and replacement with a new

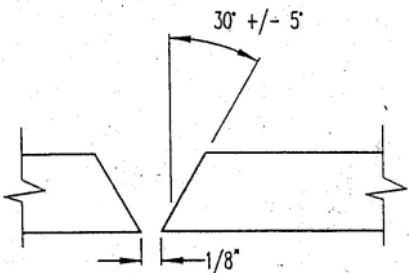


Figure 5

original base metal (A516 Grade 70) patch material installed flush in the cutout (Figure 5). Steps are taken to ensure that a full penetration weld is achieved by using a root pass weld and dye checking it before finishing the weld with stringer beads.

Operator awareness is equally important in maintaining spray-cooled equipment. As usual, production personnel play a vital role in maintaining their equipment. Inspection and emergency action plans are all aspects of operation that have significant effect on the overall reliability and performance of the equipment.

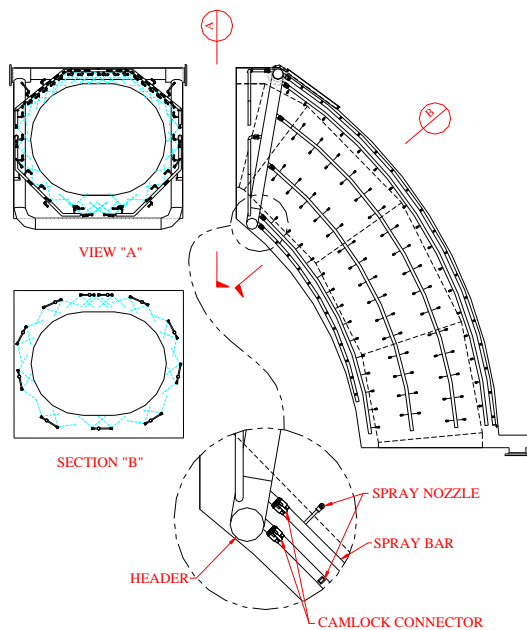
This information is intended to be used only as a guide in providing general information with respect to the maintenance of Spray-Cooled™ equipment and should only be practiced by persons trained and experienced in the operation and maintenance of related steel making furnace systems. Because the operator's specific use, application and conditions of use are all outside of the control of SYSTEMS Spray-Cooled™, Inc., same makes no warranty or representation regarding the results which

may be obtained by the operator in using this information. It shall instead be the responsibility of the operator to determine the suitability of any of the maintenance methods discussed for the operator's specific application.

### Cooling Efficiency and Operational Safety

#### Cooling System:

The spray system (Figure 6) is an arrangement of non-corrosive piping and nozzles. Spray nozzles are removable by means of detachable spray bars that connect to a water supply header using camlocks. A single inlet feeds the header. The entire piping network is attached to the outer shell so that the hot plate may be replaced without affecting the spray system.



**Figure 6**

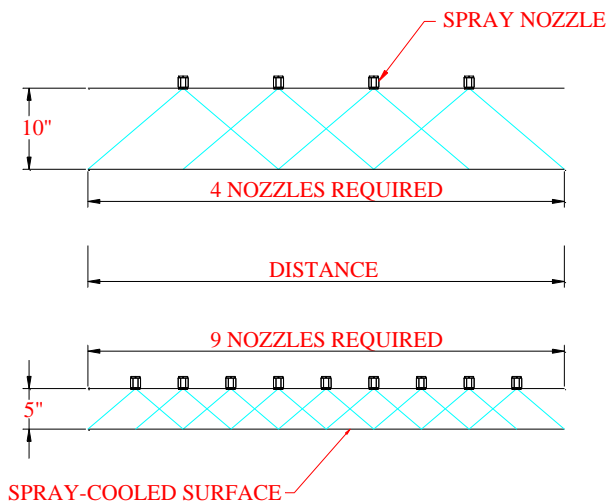


The amount of water distributed in a particular area of the equipment is determined by the size of the nozzle used, the quantity of nozzles and the pressure at which the water is supplied. The resulting water distribution (i.e. gpm/ft<sup>2</sup>) affects the system efficiency and reliability.

Droplet impingement produced by the spray nozzles rather than water velocity typical for pressurized tubular cooling provides the turbulence required for optimal heat transfer. Liquid droplet spray and jet impingement cooling have been widely used in the metal making industry and have been shown capable of high heat removal rates. Very effective heat transfer can thereby be obtained at virtually any flow rate. Cooling water is distributed according to the varying heat load demands identified; cool spots – less water, hot spots – more water. Cooling water is supplied at the same supply inlet temperature throughout the equipment. Available water is thereby used most efficiently.

Cooling capacity can also be readily increased. Camlock connectors facilitate spray bar removal. Either replacing existing nozzles with larger capacity nozzles or adding more nozzles will supply additional water and corresponding cooling.

Spray nozzles are available in a variety of capacities. The nozzles most commonly employed in Spray-Cooled™ equipment today range in capacity between 2.6 and 9.0 gpm per nozzle @ 30 psig and have a 120° full cone spray pattern. Nozzle orientation angle, nozzle capacity and the distance the nozzle is away from the cooled surface determine the cooling water flow rate per unit area (gpm/ft<sup>2</sup>) and the amount of overlapping coverage. Figure 7 shows the effect of nozzle distance away from the Spray-Cooled™ surface.



**Figure 7**

Heat loads dictate the cooling water requirements for Spray-Cooled™ equipment. The amount of water required is inversely proportional to the allowable water temperature rise between the inlet and outlet of the equipment for an identified heat load. Lower water temperature rises require usage of higher volumes of cooling water. Higher water temperature rises permit usage of lower volumes of cooling water.

There is however, a limitation that must be respected. Cooling water must be supplied at a rate sufficient to minimize film boiling. Water exposed to atmospheric pressure boils at approximately 212°F. Evaporative cooling is undesirable. Boiling begins as water on the heated surface is superheated slightly, and subsequently evaporates. Bubbles begin to form on the surface during nucleate boiling. As the temperature continues to rise, rapidly forming bubbles blind the heated surface preventing replenishment with fresh liquid. A vapor film, which covers the surface, forms as the bubbles coalesce. Heat must then be conducted through the film before it can again be exposed to the cooling water. This thermal resistance causes a reduction in heat transfer and conditions become very unstable. Film boiling occurs. The surface must dissipate the heat flux, or its temperature will rise catastrophically above the melting temperature of the metal. For this reason, outlet temperatures are limited to at or around 160°F ensuring that sufficient cooling water is available for the normal heat flux and providing ample margin to accommodate transient heat loads that are likely present. Nozzle spray pattern overlap provides additional protection against this phenomenon. Should a nozzle somehow become restricted, adjacent nozzles will provide back-up cooling to the affected area.

Accumulative run-off water forms a cascading film that bonds to the hot plate by surface tension and flows along the surface to assist the cooling process by offering reserve cooling capacity.



Water quality requirements are comparable to requirements of water used in other water-cooled equipment throughout the plant. Keeping water temperatures low by not reusing cooling water in adjoining equipment and distributing the water through non-corrosive piping lessens water quality requirements. Water with a *ph*, which is neutral to slightly alkaline (7 to 8), has *total hardness* not greater than 200 ppm, has an *alkalinity* not greater than 150 ppm, has *total dissolved solids* not greater than 400 ppm, has *largest particulate size* not greater than 0.030 in. and at a *temperature* not greater than 110°F is optimal. Properly functioning spray nozzles are a

key factor in the successful operation of Spray-Cooled™ equipment. Nozzle blockage is minimized by the installation of a mechanical strainer through which all cooling water must pass in route to the equipment inlet. A strainer screen opening of 1/32" to 1/16" maximum is recommended.

#### **Safety:**

Operation at atmospheric pressure reduces the amount of water that escapes the equipment when there is a leak. A typical Spray-Cooled™ furnace component operating at 6 gallons per minute per square foot would dispense only 5 gallons per hour through a 2 square inch hole. In contrast, a typical tubular water-cooled furnace component operating at 60 psi would discharge more than 16,000 gallons per hour through the same size hole.

#### **Operation:**

Cooling water is supplied to Spray-Cooled™ equipment through non-corrosive piping circuits as simplified in Figure 8. A supply line carries water to the equipment. A strainer is installed in close proximity of the Spray-Cooled™ equipment. Auxiliary equipment strainers are employed to minimize the likelihood of plugged nozzles. Consistent with other process auxiliary equipment, periodic inspection and maintenance are required. On a regular basis, observe the pressure drop across the strainer and perform necessary maintenance and/or cleaning if the pressure differential across the strainer exceeds the recommended setting. Inspect for holes or tears in the baskets or screens. Non-corrosive piping downstream of the strainer ensures against contamination by rust.

A flow measurement device located between the strainer and the equipment is used to monitor low and high flow conditions. An orifice plate, a simple device installed in a straight run of pipe supplying the equipment is recommended. The orifice plate contains a hole smaller than the pipe diameter. The flow constricts, experiences a pressure drop, and then the differential pressure across the plate can be correlated to the flow.



Remote submersible temperature transmitters located at the discharge outlet(s) of the equipment monitor discharge water temperatures. Flow and temperature monitors are connected to an alarm panel or Programmable Logic Controller.

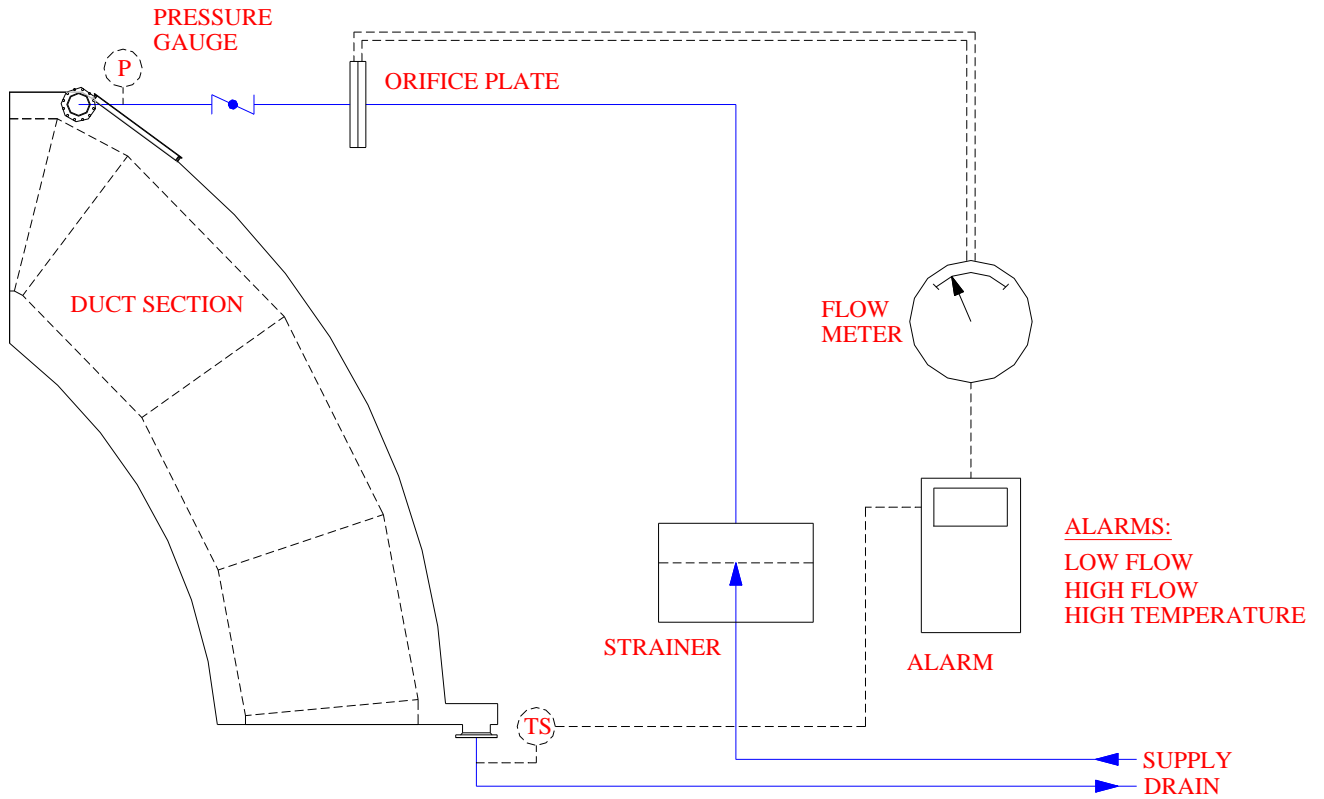


Figure 8

Instrumentation, ensuring vital operations are functioning properly is employed to assist with monitoring Spray-Cooled™ equipment. In addition to the routine inspection of the various components, an alarm system alerts operators of too low or too high cooling water supply conditions, too large pressure differential across the strainer, and discharge water too high temperature signaling a potential system upset condition.

The critical component of Spray-Cooled™ equipment is the carbon steel hot plate. Proper maintenance begins with recognizing the importance of protecting the hot plate and understanding the operating functions of the equipment providing the protection. Same as for all other water-cooled equipment, an uninterrupted supply of cooling water to the heat affected area is essential. This water is supplied from nozzles in Spray-Cooled™ equipment making this particular function easily verifiable through inspection openings present in the equipment outer shell. United States Patent No. 6,092,742 describes the patented nozzles incorporated in Spray-Cooled™ equipment for this purpose. A lack of water or an irregular spray pattern suggests attention to the nozzle is needed and is correctible by cleaning or replacing the nozzle. Occasional inspection of the spray nozzles reduces the potential for burn-through and premature degradation of the carbon steel hot plate.

Periodically, the interior of the equipment should be examined to verify properly functioning nozzles and the absence of mineral deposits on the spray surface. No sign of deposits suggests the system is operating correctly. Deposits on the surface of a noted area suggest an operational hot spot or a plugged nozzle.

### Lower Cost Per Ton

To this point, this discussion has dealt briefly with distinct Spray-Cooled™ benefits that promote reduced downtime and increased maintainability and greater cooling efficiency and operational safety. These and other benefits can be substantiated by years of consistently good performance in EAF and BOF steel making applications.

Lower maintenance costs is another goal of Spray-Cooled™ Technology. Whether it's periodic maintenance or complete hot plate rebuilds, spray cooling has afforded its users lower maintenance costs resulting from the reduced cost to rebuild versus replacement of alternative equipment.

In September 2001, Nucor Yamato Steel in Blytheville, Arkansas installed 2,032 SF of Spray-Cooled™ off-gas duct during conversion of their D1, D2 and D3 duct sections on both furnaces to spray cooling.

This facility in Arkansas has two 22 ft., 120 ton AC furnaces equipped with a 90 MVA transformer, a 1,100 volt secondary, 24" electrodes turns 40 minute heats. The melt shop has produced an averaged 2.4 million tons per year since 2000. Table I is a summary of the furnace operating parameters.

**Table I - Furnace Operating Parameters**

<b>Furnace No.</b>	<b>Average Power</b>	<b>Average Power Factor</b>	<b>Average Secondary Current</b>
1	80 MW	0.83	60,000 amps
2	79 MW	0.83	61,500 amps
<ul style="list-style-type: none"> <li>• Average Tap-Tap Time . . . . . 39.9 Minutes</li> <li>• Average Tap Tons . . . . . 121.3 Tons</li> <li>• KWH/Ton . . . . . 335.0</li> <li>• Oxygen Usage . . . . . 1,440 SCF/Ton</li> <li>• Electrode Consumption . . . . . 2.78 Lbs./Ton</li> </ul>			

In 2001, the decision to replace the water-cooled tubular duct sections was two-fold. Recurring pipe stress cracking and the accompanying high-pressure water leaks bore mandatory maintenance and downtime and threatened safe operation while compliance to off gas emissions permits was another driving force. Nucor was already an experienced Spray-Cooled™ equipment user and had knowledge of successes with Spray-Cooled™ ductwork at their Birmingham, Alabama; Plymouth, Utah and Berkeley County, South Carolina facilities. They were already familiar with the improved safety aspects offered by the non-pressurized Spray-Cooled™ technology and anticipated the same reduced downtime and maintenance costs they had experienced after conversion of their roofs and roof elbows, sidewalls and sumps and LMF roofs. Based on their earlier experiences with spray cooling, hopes were equally as high that the results would be the same as they expanded their use of the technology into the off-gas ducts. Table II is a summary of their conversions to spray cooling in chronological order.

---

**Table II - Conversion To Spray Cooling**

---

<u>Date</u>	<u>Furnace No.</u>	<u>Equipment</u>
July '88	1	Roof and DES Elbow
August '88	2	Roof and DES Elbow
June '91	2	Sidewall and Sump
July '91	LMF I	Roof
June '92	1	Sidewall and Sump
January '94	1,2	Roof
May '99	1,2	DES Elbow
September '00	LMF II	Roof
April '01	1,2	Roof
April '01	1,2	DES Elbow
April '01	1,2	Sidewall and Sump
<b>September '01</b>	<b>1,2</b>	<b>D1/D2 Duct</b>
<b>September '01</b>	<b>1,2</b>	<b>D3 Duct</b>
<b>December '01</b>	<b>1,2</b>	<b>D1/D2 Duct</b>
<b>December '01</b>	<b>1,2</b>	<b>D3 Duct</b>

---

Table III is a summary of the duct section design and operating parameters. The duct cross-section is oblong round to provide adequate coverage of the fume elbow translation as the EAF is tilted slightly to tap or to slag during a heat. The average weight of subject sections is 18,500 lbs., approximately 1/3<sup>rd</sup> the weight of comparable sized conventional water-cooled tubular paneled ducts. Cooling water is supplied at 20 psig through 911 nozzles and the weighted average water temperature rise is 32°F. An average heat flux of approximately 97,000 Btu/hr x ft<sup>2</sup> can be calculated, resulting in thermally induced stresses approaching 11,000 psi. Stress fatigue cracking should only occur where considerably higher localized transient heat loads occur in the presence of insufficient cooling and the stress amplitude is allowed to exceed the endurance limit of the carbon steel plate. Over time, these areas will be identified and adjustments to water distribution rates can be made to improve performance.

**Table III - Duct Design Parameters**

---

- Diameter D1/D2 ..... 10'-0" x 7'-9" I.D.
- Weight ..... 22,000 Lbs.
- Nozzles ..... 551
- Supply Water Flow ..... 3,149 GPM
- Supply Water Pressure ..... 20 PSIG
- **Maximum Temperature Rise** ..... 40°F
- Diameter D3 ..... 10'-8" x 8'-5" I.D.
- Weight ..... 15,000 Lbs.
- Nozzles ..... 360
- Supply Water Flow ..... 2,058 GPM
- Supply Water Pressure ..... 20 PSIG
- **Maximum Temperature Rise** ..... 20°F

---

The normal operating schedule at this facility is 7 days/week, 24 hours/day with scheduled shutdown(s) twice a year for maintenance - one in March and one in September. While initial expectations were for vast improvement, as a part of the initial learning experience the duct sections were taken out of service at 6-month intervals coincidental with scheduled shutdowns for inspection and evaluation of performance until March 2003. Hot plates were repaired and/or replaced as needed, taking advantage of the opportunity afforded during the pre-scheduled shutdowns so that maintenance procedures and performance expectations could be established. Between March 2002 and March 2003, the spray-cooled duct sections saw 9,350 heats experiencing only one *minor* incident resulting in minimal lost production time. In March of 2003 the duct sections were removed and replaced during a semi-annual shutdown. The decision was made to replace the hot plates due to metal thinning. This was done with no loss in production.

**Summary**

Based on newfound experience, Nucor Yamato Steel maintains that the Spray-Cooled™ duct will operate reliably with practically zero downtime during a 12-month production cycle. When a stress crack occurred, the amount of water that leaked from the duct was minimal and was another testimony to the improved safety of the non-pressurized cooling system. In addition, repairs were quick and generally scheduled around furnace downtime for unrelated reasons. With over 30 months of operation at Nucor Yamato, there was not a single incident of a *major* water leak or downtime with this system. Table IV is a summary of the duct section performance. The 65 LF of off-gas duct averaged 9,380 heats per 12-month campaign requiring minimal maintenance.

**Table IV - Duct Performance As Of March 31, 2004**

---

<u>Duct No.</u>	<u>Service Ending</u>	<u>Total No. Of Heats</u>	<u>Maintenance To Date</u>
D1/D2	March '03	9,350	-
D3	March '03	9,350	-
D1/D2 (Spare)	March '04	9,410	10 Hrs.
D3 (Spare)	March '04	9,410	20 Hrs.

---

Table V is a comparison of downtime and performance since converting to Spray-Cooled™ off-gas ducts. Furnace downtime and maintenance man-hours were greatly reduced or eliminated entirely. Average hourly production rate increases were also realized.

<b>Table V – Duct Downtime And Performance Comparison</b>		
<b><u>Topic</u></b>	<b><u>Prior To Spray Cooling</u></b>	<b><u>After Spray Cooling</u></b>
• Avg. Downtime Per Month Due To Water Leaks	40 Hrs./Mo./Fce.	0 Hrs./Mo./Fce.
• Avg. Maintenance Per Month Replacing Panels; Repairing Hose Leaks; Patching Inner Liner; Plugged Nozzles	64 Man-Hours/Mo.	2.5 Man-Hours/Mo.
	335	335
• KWH/Ton		
• Tons Produced	180 Tons/Hr.	190 Tons/Hr.

Table VI is a replace or rebuild cost comparison of the last three years prior to spray cooling to the performance since conversion to spray cooling in 2001. The life-cycle replacement cost of conventional water-cooled tubular off-gas duct panels had averaged \$550,000 per year prior to spray cooling. Based on the documented cost of repairing/rebuilding the Spray-Cooled™ off-gas duct sections averaging \$110,000 per year and a continuing annual production of 2.2M tons, an annual maintenance cost savings of \$440,000 is projected.

<b>Table VI - Replace Or Rebuild Cost Comparison</b>		
<b><u>Event</u></b>	<b><u>Cost Prior To Spray Cooling</u></b>	<b><u>Cost After Spray Cooling</u></b>
• Replace Panels, etc.; Reline Entire Section, etc.	\$ 0.25/Ton	\$ 0.05/Ton
• Replace Panels, etc.; Reline Entire Section, etc.	\$ 1,650,000/Previous 3 Years (2.2M Tons/Yr.)	\$ 333,000/Projected 3 Years (2.2M Tons/Yr.)

Similarly, Nucor Yamato Steel has realized maintenance cost savings attributable to their conversion to Spray-Cooled™ Technology on their EAF roofs and furnace upper shells. Reported maintenance costs are \$0.13 per ton and \$0.17 per ton respectively, on their roofs and furnace upper shells.

United States Steel - Gary Works reports reduced downtime resulting from a reduction from 416 hours per year of weld repairs on tubular panels to 52 hours per year of weld repairs on converted Spray-Cooled™ BOF hoods. This equates to 364 additional hours of furnace up time.

## **Conclusion**

Spray-Cooled™ equipment incorporates features that minimize or completely eliminate many of the problems typical of conventional water-cooled equipment. As discussed herein, these benefits promote reduced downtime due to prescription management of thermal fatigue cracking, increased maintainability due to carbon steel plate construction and repair procedures, greater cooling efficiency due to variable water distribution techniques, improved operational safety due to the elimination of high pressure, high volume water leaks, and lower maintenance costs resulting from the reduced cost to rebuild versus alternative equipment replacement. These and other benefits can be substantiated by years of consistently good performance in electric arc and basic oxygen furnace steel making worldwide.

## **Acknowledgements**

The author is grateful to Nucor Yamato Steel of Blytheville, Arkansas and United States Steel of Gary, Indiana. The author would also like to specifically thank Jerry Vassar, Mechanical Maintenance Supervisor, Nucor Yamato Steel; Dick Ostertag, Project Engineer United States Steel and others who have contributed their input to this subject.

## **References**

1. E. A. Avallone, T. Baumeister III, "Mark's Standard Handbook for Mechanical Engineers", 10<sup>th</sup> edition, McGraw-Hill Book Company 1996, pp 5-9, Figure 5.1.17.
2. D. A. Lehr, "Features of UCAR Spray Cooling That Prolong BOF Hood Life", UCAR Carbon Company, Inc.
3. Holman, J. P.: *Heat Transfer*, 5<sup>th</sup> edition, McGraw-Hill Book Company 1981