AIR FLOTATION COOLERS….A USER'S PERSPECTIVE

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Presented at the Galvanizer's Association 91st Meeting

October 24 – 27, 1999

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Abstract

Today's galvanizers face an ever increasing requirement for production of sophisticated products with a variety of functional surface coatings. The move towards higher "value added" products has resulted in the requirement for advanced cooling configurations and non-contact strip handling systems.

Advances in cooling and strip handling technologies have brought forth a myriad of configuration possibilities not thought possible with older generation equipment. These possibilities are still emerging and some new layouts have emerged as a direct result of the new technology.

National Galvanizing of Monroe, Michigan recently upgraded their galvanizing line that included the replacement of the existing "after-pot" air cooling. This paper will provide an overview of National Galvanizing cooling requirements and experience since making the modifications in 1997. Topics will include a synopsis of the rebuild project, a discussion on both traditional and advanced cooling methods including evaporative cooling, strip stabilization using air flotation and details of the equipment operating performance.

Having a thorough understanding of the cooling process, application requirements and available technology will be beneficial for galvanizers contemplating a possible upgrade of their facilities.

Key words: galvanize strip air cooling, evaporative cooling, stabilization, cooling configurations.

Introduction

In 1997 National Galvanizing (Figure 1) embarked on a line rebuild which involved upgrading the existing furnace capabilities that also necessitated an increase to the corresponding cooling capabilities. Along with producing higher quality galvanized steel, the rebuild enabled National Galvanizing to increase production from 225,000 tons per year to 300,000 tons per year or an increase of 33%.

The additional production requirements required the company to review the strip cooling arrangement as part of the line rebuild program. It was evident that the existing cooling arrangement would not handle the new requirements and that the company needed to add cooling capacity. How to do this in the existing "tight" space confines was a matter of considerable discussion since more traditional arrangements would not have enough cooling capacity.

The traditional method of cooling is to subject the traveling strip to an air cooler system which imparts a large volume of ambient air at the coated strip. A considerable number of operations worldwide have this type of configuration which has been mainly supplied via major line builder companies and more recently by several smaller specialist companies.

Figure 1 National Galvanizing L.P., Monroe, Michigan

It is important to realize that space considerations prevalent in existing galvanizing lines pose a difficult challenge, which requires new and innovative layouts to be considered. This is precisely the situation that confronted National Galvanizing early in the rebuild planning stages. Over the course of six months, the company thoroughly reviewed various alternative cooling technologies, including both air flotation and evaporative water mist systems.

The competitive global market requires a re-thinking of traditional operational practices for companies engaged in galvanizing operations. What we did yesterday may not be applicable for today's requirements. New technology and refinements of existing technology should not be overlooked when considering modifications to existing operations. Many times the new technology being offered can give a marginal operation a competitive edge in the marketplace.

National Galvanizing's Rebuild Program

Located in Monroe, Michigan just 30 minutes south of Detroit and 20 minutes north of Toledo, Ohio, National Galvanizing operates as a toll processor that pickles, galvanizes, and slits hot band materials for U.S. and Canadian mills. The company coats hot roll and coils fully annealed, cold rolled steel from 0.060 to 0.250 inches, particularly high strength, low alloy grades on the galvanizing line. A later retrofit added the capability of galvannealing in response to requests by the nearby Detroit automotive companies. About 65% of the steel processed goes into a variety of suspension and other components from the automotive industry. The balance goes into agricultural and construction applications.

Starting from a “Greenfield” situation, National Galvanizing started production during 1985. In the following years, the company continued to upgrade the production capabilities in response to changing market requirements. To achieve this, the company made the following changes on the existing galvanizing line during the course of 18 days of downtime.

- Increased cooling capacity
- Added 27 feet to the furnace center
- Installed radiant tube section
- Furnace section electrical rebuild/computerization
- Replaced DC drives
- Added a bridle and entry looper

While there were many challenges for the National Galvanizing team, adding additional cooling in the confines of the existing space available was a challenge. The addition of more traditional cooling like what was already in place was not an option due to the space constraints. Raising the top turning roll was not economically feasible either. To produce a quality product, the company had to find a way of cooling the coated strip from 850^{o}F (450^{o}C) to less than 600^{o}F (315^{o}C) when galvanizing and from 1050^{o}F (565^{o}C) to less than 600^{o}F (315^{o}C) when producing galvanneal products. The space allocated to cooling was just over 20 feet in the upward leg from the zinc pot. The lack of space made the cooling side of this upgrade a very high priority and one that needed to be solved very early in the planning of the rebuild.

Traditional Methods of Strip Cooling

Strip cooling is not commonly discussed due to the wide familiarity of the requirement to properly cool the strip prior to any contact with the top turning roll and downstream operations. Figure 2 (Ref. 1) describes three different cooling technologies, air, roll and water spray systems which can be employed depending on the requirements and application. Each technique has a different cost impact (capital and operating) and operating performance as illustrated in the figure.

COOLING COMPARISON			
	Air Cooler	**Cooling Rolls**	**Water Quench**
Cooling Technique	Blowing ambient or chilled air onto the material surface	Running strip over water cooled rolls	Spraying cooled water onto material surface
Use	Coating can not be touched by a roll before being cooled AND coating can not be water cooled	Coating can be touched by a roll before being cooled OR second dry cooling after air cooler	Coating can be cooled with water
Cooling Curve	Soft cooling	Relatively intensive cooling	Intensive cooling
Cooling Time	Long	Short	Very Short
Investment Cost	Medium (if chiller is not needed)	High (expensive rolls)	Low (if cooling water is available)
Operation Cost	Low (if chiller is not needed)	Medium	Medium

Figure 2 (Ref. 1) Cooling Comparison

The common practice is to use air cooling as a means of reducing the strip temperature prior to the top turning roll since the strip can not be “touched” until the surface temperature is below 600°F (315°C). These air coolers blow ambient air with enough velocity at both sides of the traveling strip to lower the strip temperature sufficiently to prevent quality problems from occurring as the strip turns via a turning roll from a vertical orientation to horizontal.

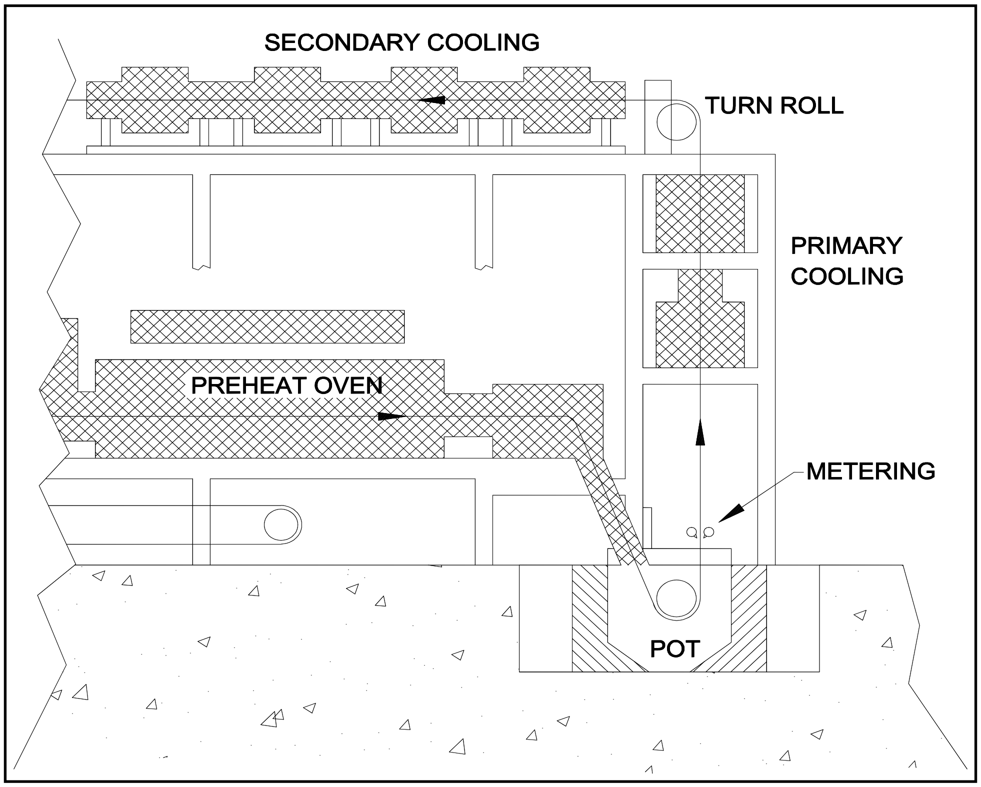

Figure 3 Typical Galvanizing Line

Figure 3 shows a diagram of a typical hot dip metal coating or galvanizing line which shows the use of air cooling in the "up-leg" vertical run and the horizontal run following the turning roll. In conventional galvanizing systems like the one shown, the strip would typically leave the zinc pot around 850°F (450°C) and would need to be air cooled to less than 600°F (315°C) to "set" the coating prior to contact with any transfer or turning rolls.

The freshly coated strip surface is very prone to damage by physical contact and great care is required to avoid surface defects being caused by coating disturbances or zinc pick-off when the strip is turned on the "top" turning roll surface. To avoid this problem, the coated strip needs to be rapidly cooled in a non-contact manner before the strip contacts any surface such as the top turning roll.

Traditionally, strip cooling is done with a combination of air coolers in the up-leg, horizontal and down-leg positions as shown in Figure 4. As mentioned, cooling the coated strip to temperatures below 600°F (315°C) prevents operational problems from developing and provides a suitable temperature in which to handle the strip without the usual problems associated with high strip temperatures.

The role of the galvanizing cooling section is to efficiently and economically decrease the strip temperature by 250 to 600°F (120 to 315°C) without damaging the coated surface and within the minimum space available. A galvanneal operation poses an even greater challenge due to the higher temperatures involved.

Having the requirement for non-contact cooling naturally led most manufacturers to offer an air cooler arrangement like the one shown in Figure 5. This arrangement uses large volumes of ambient air to cool the strip traveling between the two halves and was similar to the unit at National Galvanizers. Before the rebuild.

This system is like most coolers in operation today and consists of a fixed position plenum section on each side of the traveling strip with a series of round holes randomly placed throughout the surface (Figure 6). A fan system supplies the plenum sections with a volume of ambient air at a particular static pressure that exits the plenum via the round hole "nozzles". These nozzles impart a velocity component to the plenum leaving air stream.

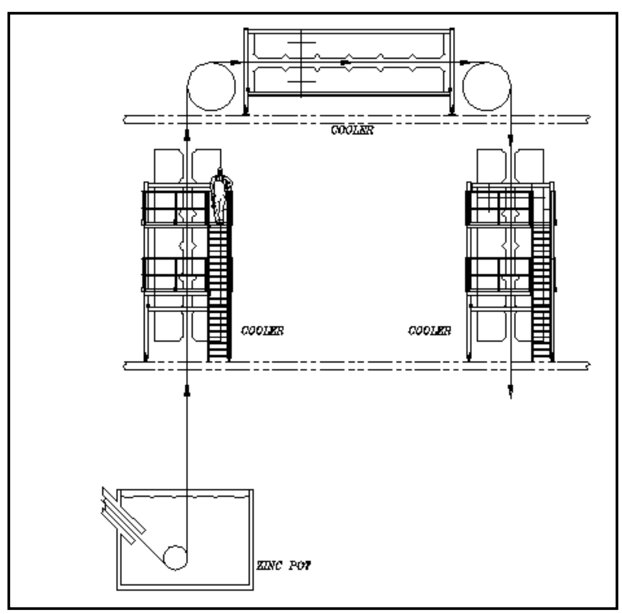

Figure 4 After-Pot Strip Cooling

To accommodate strip shape abnormalities and to facilitate ease of threading, these air coolers are typically located some 6 inches from the strip centerline leaving a distance of 12 inches between the plenums on each side of the strip.

Figure 5 Typical Strip Cooler

Having a large distance from the "hole" nozzles to the traveling strip does present some operational and efficiency problems for the galvanizer. It is well known that the effectiveness of a round hole as a nozzle is dependent on the distance the material to be cooled is from the nozzle. Good design practices state that for a hole nozzle to be effective the substrate should be no more than three hole diameters from hole nozzle or in the case of 1 inch holes three inches away from the nozzle. Since most existing hole nozzle configurations are 6 to 12 inches or more away the overall strip, cooling capability is diminished from optimum conditions. The actual cooling performance of this type of cooler falls off as the distance is increased away from the round hole and is dependent on the hole diameter used and the distance away from the strip as shown in Figure 7. For example, a half inch diameter hole system loses 32% of the effective cooling capacity as you move from 3 to 6 inches away from the strip. At 12 inches the loss grows to 73%.

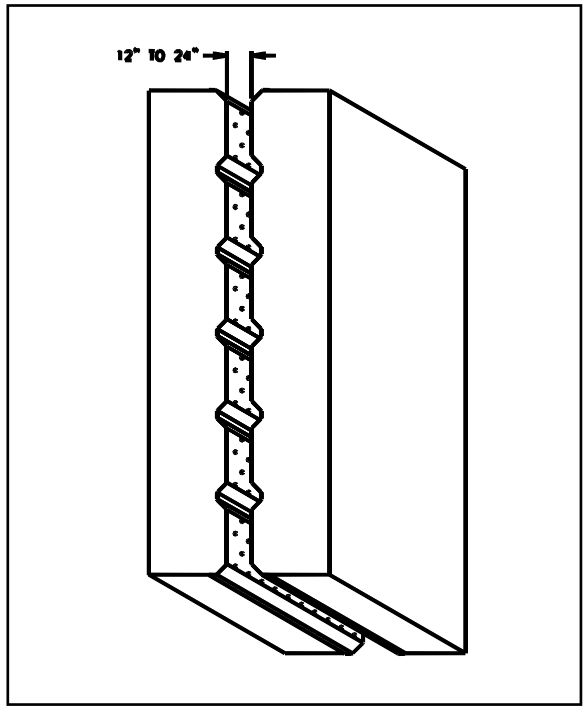

Figure 6 “Round Hole” Cooler

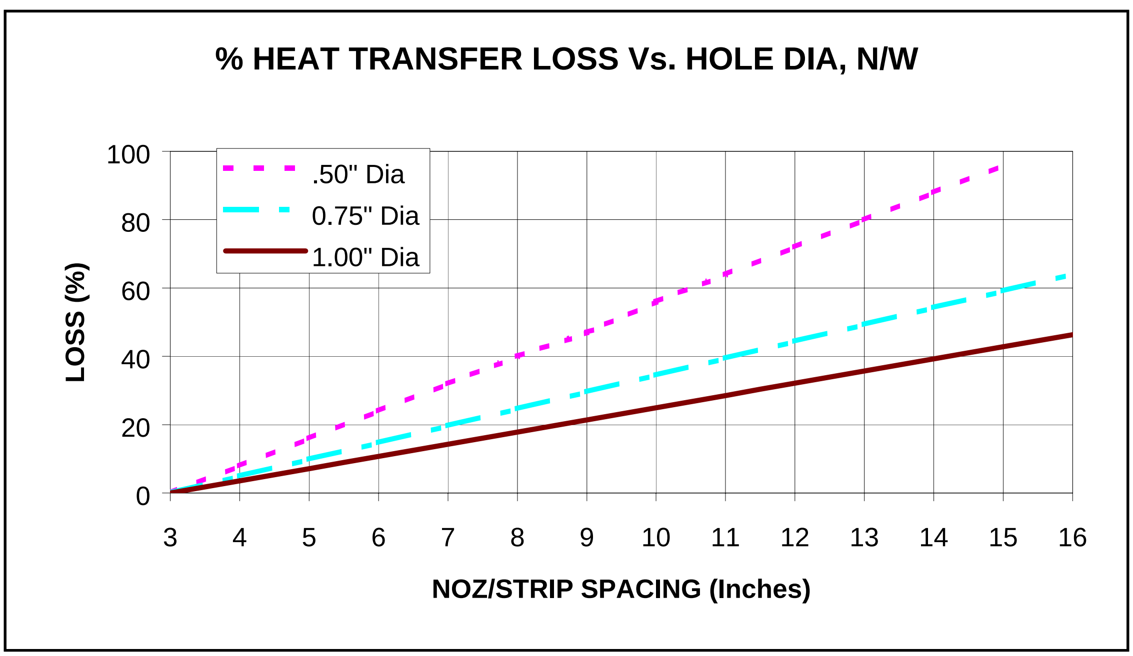

Figure 7 Heat Transfer Loss vs. Hole Diameter

Another approach was to attach a length of tube the diameter of a round hole in an effort to extend or place the actual nozzle, now the end of the tube, closer to coated strip. Like the hole bar arrangement discussed above, this configuration was also constrained by being effective within a particular number of diameters beyond the end of the tube.

With both of these systems the coated strip still had stability problems that can cause operational problems due to the inability to either system to effectively hold the strip in one position. This primarily is due to the random nature of the exhaust air streams on both sides of each system as shown in Figure 8. As cooling air is delivered and exhausted randomly from both sides, the strip is free to move about as it expands and contracts due to differential cooling.

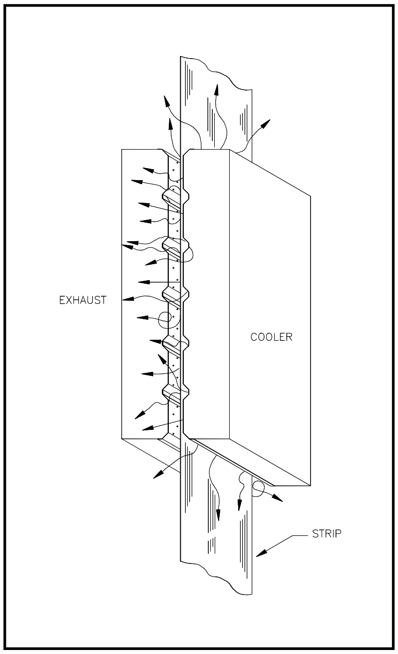

Figure 8 Exhaust Air Flows

Advanced Cooling Methods

Very early in the expansion plans, National Galvanizing realized that the existing up-leg air cooler would not be adequate for the new production requirements. Since the company would now have the capability for both galvanizing and galvanneal operations, being able to cool the strip prior to the top turning roll was of major concern. Simply just adding another section of cooling was not an alternative due to space considerations. Consequently, the company needed to look at alternative cooling systems that could do the job yet fit into the tight confines of the existing space.

One alternative explored was the use of a combination of air flotation cooling coupled with a section of evaporative cooling. This section will explore how each of these systems work and the features and benefits of each.

The commercial development of air flotation drying technology in the 1960's provides today's galvanizing/galvanneal operations with a proven method of non-contact strip cooling and strip handling technology. Using ambient or chilled air, instead of heated air as would be the case in a drying application, allows this same arrangement that has proven so effective in drying applications be used to effectively cool a strip.

Figure 9 Typical Air Flotation Cooler

A traditional flotation dryer system uses heated supply air via a gas burner or a steam coil while in an air cooler we eliminate the heat source and use ambient air. Figure 9 is a photograph of a typical flotation cooler arrangement as assembled just prior to shipment.

The operation of this arrangement as a flotation cooler is quite simple. This arrangement uses a header/plenum configuration to deliver ambient air to the nozzles or air bars above and below the strip as shown in Figure 10. Arranged in a staggered configuration, the nozzles create a pressure pad that supports the strip as it passes through the dryer.

The critical area of any air flotation system is the design of the air bars. Air bar or nozzle designs have evolved over the years and have resulted in a number of configurations. For galvanizing and coated steel operations, the predominate design is a two slot pressure pad air bar.

The design of this air bar consists of two slots separated by a flat support area between slots. To improve the performance, a set of holes is located on each side of the air bar center as shown. Air exiting the slots converges toward the center of the support area between the slots creating a pressure pad along the top of the air bar as shown in Figure 11.

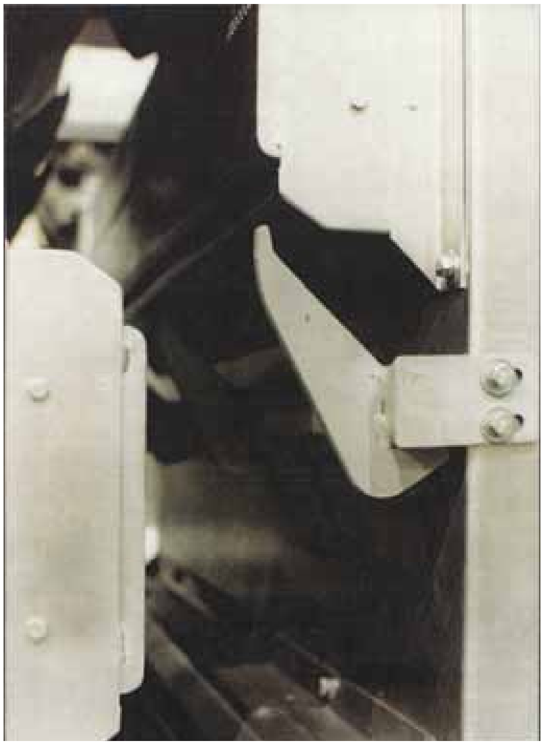

Figure 10 Air Flotation Nozzle

A good dual slot air bar will convert as much as 40% of the nozzle supply pressure to cushion pressure that is used to create the supporting pressure pad. It should be noted that not all air bar designs are equal since some have reduced heat transfer capabilities and excessive fan power requirements (Figure 11).

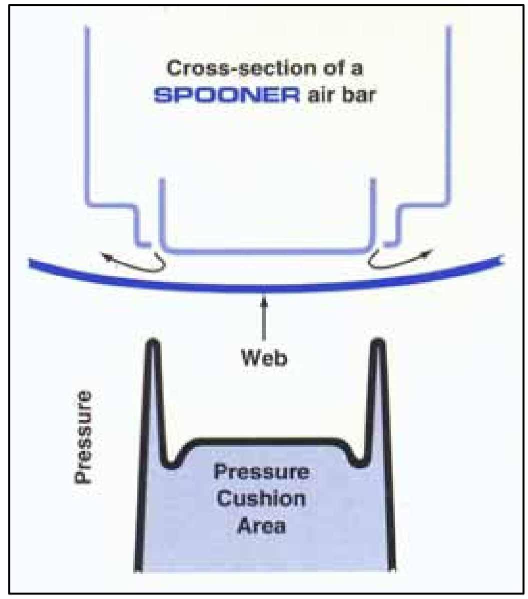

Figure 11 Nozzle Pressure Pad

The primary criteria for designing a good nozzle system lies in having the arrangement that provides superior strip handling and cooling characteristics. The nozzle system needs to maintain adequate clearance to prevent contact while the strip is traveling through the cooler. Also important is the nozzle's jet stability to prevent jet flip flop which exhibits itself as a condition where all the air exits only one of the slots. Typical operating nozzle velocities range from 10,000 fpm to 15,000 fpm (50 m/sec to 75 m/sec).

The staggered position of the air bars provide a beam of stable pressure on which to support the processed strip as it glides over the developed air cushion across the full width of the strip. (Figure 12)

Figure 13 illustrates how the staggered air bar configuration imparts "beam" strength to the strip as it passes through the flotation cooler. Each of the air bars pushes the strip in opposite directions as shown.

Figure 14 shows how a flotation air bar will handle a crowned or bowed strip. As the strip approaches the air bars, the generated pressure cushion will exert maximum pressure that will tend to straighten the strip as it passes through the air cooler.

Conventional "hole" bar configurations are not able to focus the air pressure force of the air stream in the manner that a well designed pressure pad air bar system can accomplish. This is the reason why a flotation cooler will stabilize the moving oscillating strip.

Design clearances are normally in the range of 1 to 3 inches measured between the processed strip and the air bar top surface. The air bar elements are fed with air from a pressure distribution chamber designed to insure even support pressures located on either side of the coated strip. Figure 15 illustrates a typical air flotation cooler arrangement.

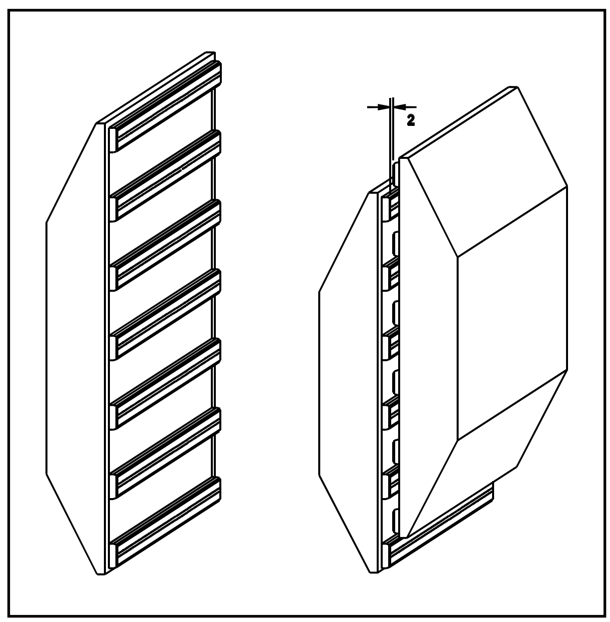

Figure 12 Alternating Nozzle Design

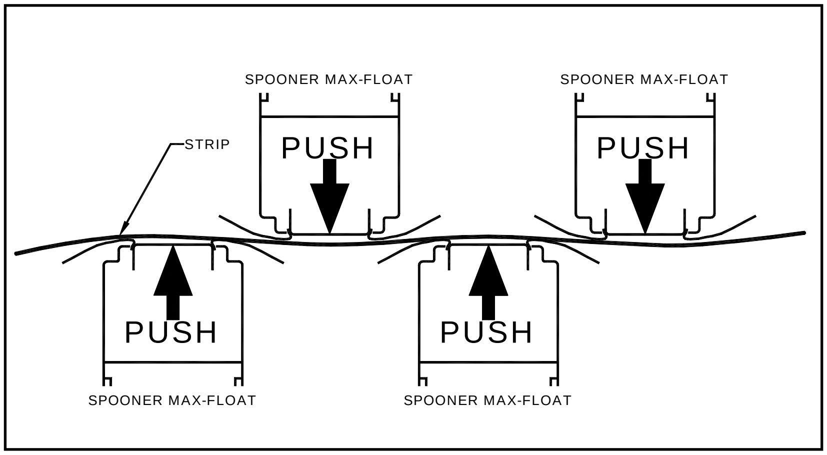

Figure 13 Nozzle Pressure – "Beam Strength"

Materials of construction are typically a combination of mild steel, aluminized steel and stainless steel. Access to the cooler internal areas and air bars is through a retraction arrangement. The common retraction system is a screw jack design that moves the two halves of the cooler away from the strip centerline. Retraction heights are typically 16 to 20 inches (400 to 500 mm).

The performance of an air flotation cooler is dependent not only on the air bar design, but also on the air velocity used in the cooling system. Adjusting the air velocity as delivered to the strip primarily controls cooling rates. The use of chilled air systems has proven only to offer marginal increases in cooling performance and is not typically considered.

Another method of cooling which if employed properly can greatly enhance the performance of the cooling arrangement is the use of evaporative or "water mist" cooling. However, proper placement of the evaporative cooling system is imperative to its successful application. Figure 16 shows a picture of the arrangement of this type of system.

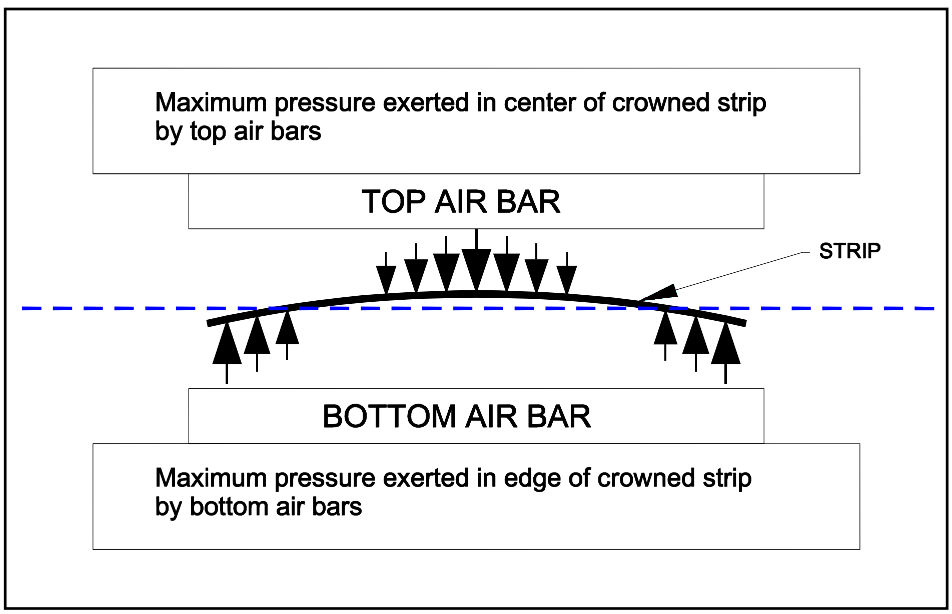

Figure 14 Handling Crowned or Bowed Strip

Water mist cooling technology is not new and has been used successfully in a number of other industries (i.e. graphic arts) over the years. This technology is based on the atomization of water by the expansion of compressed air and exhibits excellent cooling homogeneity and controllability. Typically water mist systems are located just prior to the top turning roll in both galvanizing and galvannealing lines. Cooling in this position has to not only be efficient and uniform, but also performed in such a way that there is absolutely no leakage of water downward or vapor upward. With proper design considerations it is possible to maintain water and vapor containment in the area of the water mist apparatus.

To effectively employ a water mist system in galvanizing applications, consideration needs to be given to the thermodynamic aspects of the process. The principle behind the use of a water mist spray is to use the latent heat of vaporization of water to ultimately cool the strip. What this means is that the water mist spray picks up heat energy from the hot strip and changes the state (i.e. changes to steam). The latent heat of vaporization is the heat energy that must be supplied to a liquid to transform the liquid to a vapor. For water, at standard temperature (70^{o}F) and pressure (14.7 psi), this works out to 966.6 Btu/lb water. The water applied for evaporative cooling is in the form of spherically shaped droplets.

Locating the water mist spray system down stream of the air cooler provides many advantages since the strip leaving the air cooler is around 650 to 675^{o}F (340 to 350^{o}C). A water mist system can be used achieve an additional 50 to 75^{o}F (28 to 42^{o}C) reduction in strip temperature prior to the top turning roll. The key to success for this system is to get enough water to reach the strip and this is a function of the water droplet size that is dependent on the spray nozzle used.

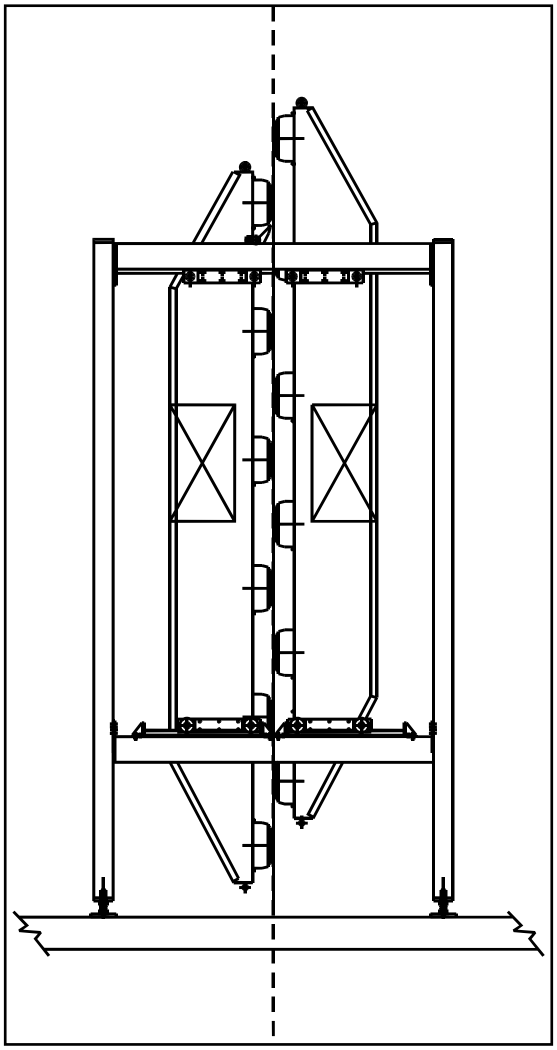

Figure 15 Typical Air Flotation Cooler Argt.

Figure 16 Typical Water Mist Cooling System

Figure 17 illustrates a combined air flotation cooler with a water mist spray system as would be used in the vertical up-leg following the zinc pot on a galvanizing line like what is employed at National Galvanizing in Monroe, Michigan.

Comparing Technologies

The best way to compare cooling technologies is to look at the performance of each alternative using the applications requirements National Galvanizing had established for the rebuild.

Upon completion of the rebuild program, National Galvanizing will run a range of strips from 0.060 to 0.250 inch thickness at 50 to 125 fpm (15 to 35 m/min). The up-leg cooler will be required to cool a 48 inch (1220 mm) strip from 1050 to 600^{o}F (565 to 315^{o}C). Due to space considerations, the new cooler will have to fit into the space vacated by the existing cooler. For design purposes, a reference strip was chosen as follows:

Reference Strip

Strip Thickness	0.187 inches
Width	48 inches
Speed	50 fpm
Entering Cooler Temp.	1050^{o}F
Leaving Cooler Temp.	600^{o}F

Since space was not available to add more cooling, National Galvanizing chose to look at an air flotation cooler in place of the existing air cooler. The new air float cooler would consist of two ten foot sections with air supplied via a 45,660 acfm New York Blower supply fan with a 250 horsepower motor. An Allen Bradley variable frequency fan drive was added to allow the adjustment of the coolers nozzle velocity. Additionally, the system includes a step retraction system which allows the operator to position the halves of the cooler to the strip at six inch, three inch and one inch intervals.

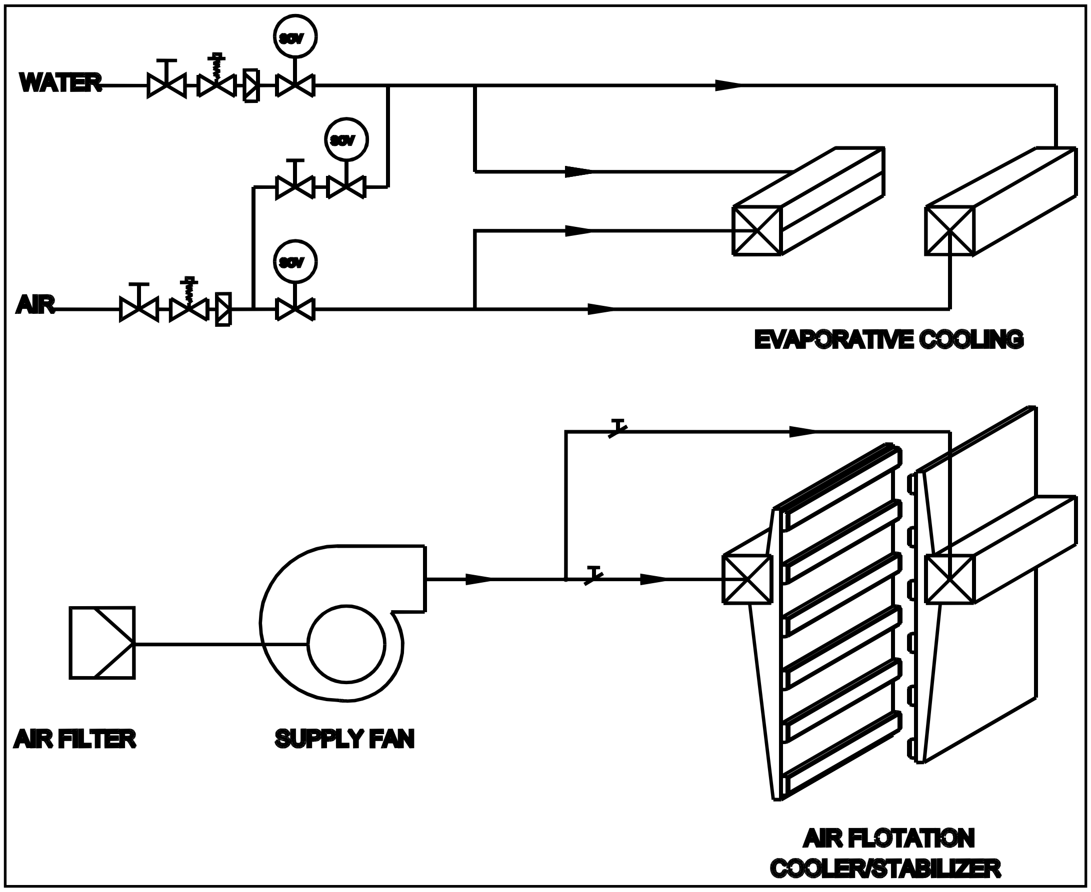

Figure 17 Combined System Schematic

Operating at the maximum nozzle velocity of 17,700 fpm (90 m/sec) and at the recommended distance from the strip, the air float cooler can cool the reference strip from 1050^{o}F (565^{o}C) to 625^{o}F (329^{o}C). At the reference conditions, the proposed air cooling system is some 25^{o}F short of the 600^{o}F (315^{o}C) benchmark before the coated strip reaches the top turning roll.

Since space is a consideration, we were not able to supply a longer cooler. Additionally, increasing the nozzle velocity beyond 17,700 fpm (90 m/sec) was not economically feasible. Using chilled air at 70^{o}F (20^{o}C) would only result in marginal cooling and require the addition of a chiller unit.

Figure 18 shows the cooling capabilities of the existing or "pre-rebuild" cooler versus the expected performance of a new air flotation cooler of equivalent length. The problem with using the existing cooler arrangement is very apparent in the galvanneal production mode since the system falls some 125^{o}F (50^{o}C) short of the required 600^{o}F (315^{o}C) strip temperature prior to the top turning roll. Granted, the company could slow the line down to achieve the required strip temperature cooling but that would negate the production increase that the company needed to achieve to justify the line rebuild.

Replacing the existing cooling arrangement with an air flotation system would increase the overall cooling allowing National Galvanizing to achieve a strip temperature of around 625^{o}F (330^{o}C) just prior to the top turning roll under the reference galvanneal production conditions. Using air flotation technology provides a strip temperature that is very close to the 600^{o}F (315^{o}C) benchmark prior to the top turning roll. While this arrangement provides a 100^{o}F (38^{o}C) improvement to the existing cooling arrangement, the strip is still above the benchmark and there is no margin of safety for unusual circumstances.

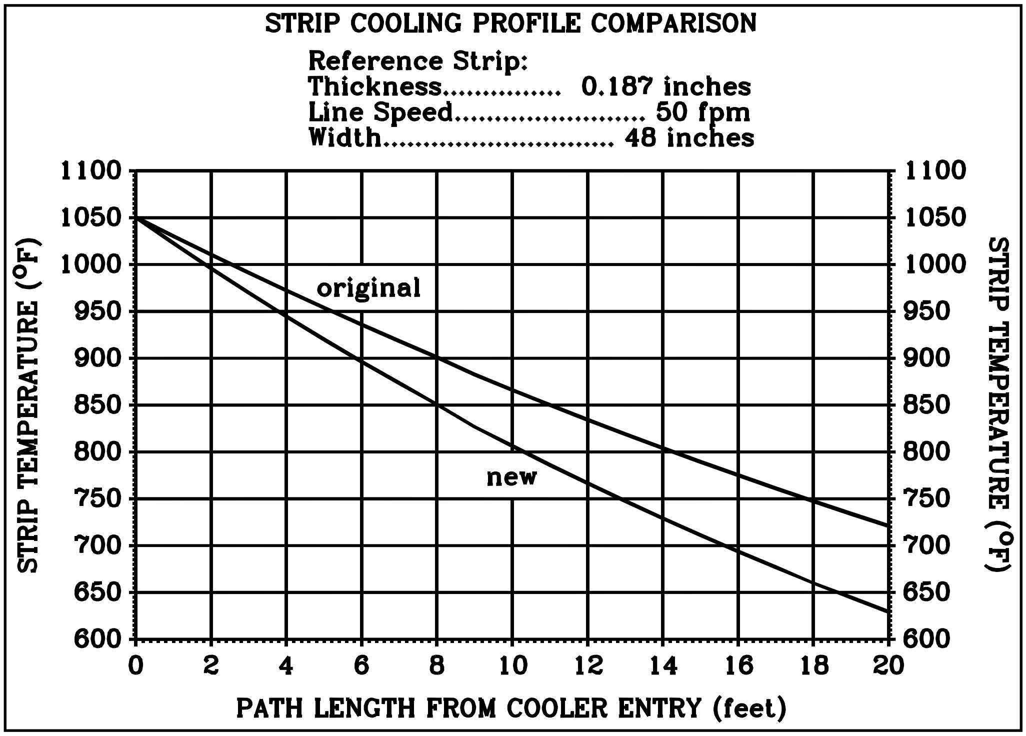

Figure 18 Cooling Performance

To obtain the additional 25°F of cooling in the remaining small available space required the use of a water spray mist evaporative cooler just prior to the top turning roll as shown in Figure 19. By using 0.83 gpm of water, the water mist system completes the cooling requirements of the reference strip and will result in a strip temperature of less than 600°F (315°C) just prior to the top turning roll. Figure 19 is a picture of one of the spray heads just prior to the turning roll.

Consisting of an arrangement of special spray nozzles that are capable of atomizing a stream of water to a particular droplet size that upon discharge from the nozzle can effectively reach the traveling coated strip. Too small of a droplet size will result in greatly diminished performance since the droplet does not have enough inertial to reach the coated strip. Too large of droplets will also be a problem due to the potential for dripping down to the zinc pot.

Figure 19 National Galvanizing's Water Mist System

A water mist system works by using the latent energy requirements of water to cool the strip. It is well known that liquid water requires an input of heat energy for the liquid water to change state. Having the water mist come in contact with the hot strip provides a means for the strip to transfer energy to the water droplet due to heat transfer mechanisms. The corresponding droplets eventually have enough heat transfer to allow the droplet to change phases from a liquid to a gas. The corresponding heat transfer or energy transfer between the strip and the water spray mist results in a reduction strip temperature due to this thermodynamic process. The key to a successful water mist spray system is the selection of the nozzles so that a proper size droplet is formed and delivered to the strip. Care must also be taken to shield the water mist system from the air cooler as well.

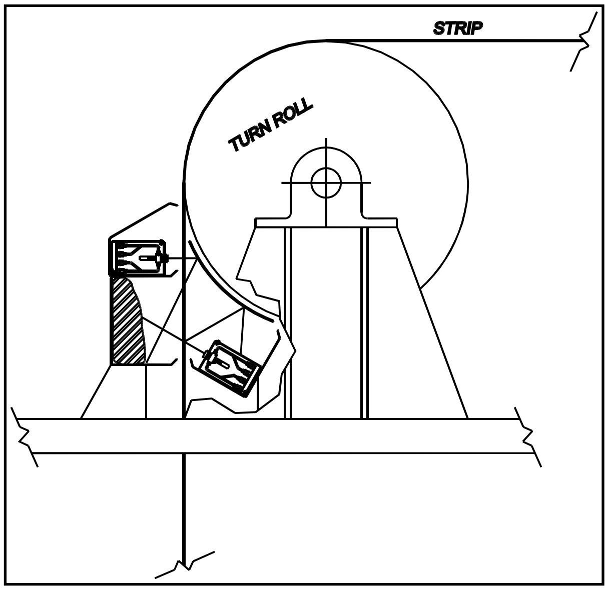

Figure 20 Schematic of Water Mist System

The schematic diagram of the water mist system supplied to National Galvanizing is shown in Figure 20. The nozzles selected have the provision to self clean by operating the piston in each nozzle. It is recommended that the water supply be chemically treated to prevent residue buildup in the nozzles.

To accommodate various strip widths, the outside nozzles can be turned off. Having a variable frequency drive on the fan allows the operator to control the nozzle velocity to accommodate various cooling requirements. Each cooling system can be operated independently from one another. The operators at the floor level control room can complete all control functions.

Installation and Operating Experience

The installation of the Spooner equipment was fairly simple since the equipment was assembled at Spooner's factory in Green Bay, Wisconsin. Once the existing cooling equipment was completely removed, the installation contractors were able to lift the two ten foot sections of cooler into position without any difficulty. National Galvanizing chose to use filtered outside air to supply the air flotation cooler. With the relative size of the supply fan and associated filter arrangement, National Galvanizing chose to construct an enclosed mezzanine adjacent to an outside wall as shown in Figure 21.

Figure 21 Outside Mezzanine at National Galvanizing

Regarding the operation of the air cooler, the biggest challenge was convincing the operators to operate the cooler nozzles close to the strip. Having a cooler that could be positioned was entirely new to the operators. The fear of having the strip touch the nozzle section was very prevalent and the operators were very reluctant to operate as we suggested. Our claims of being able to stabilize and hold the strip were not believed by the operators and it took a demonstration to all crews and willingness by management to have the operators operate the system as we suggested to finally convince them of the merits of the system.

It was natural for the operators to look at the new Spooner system and not have an understanding of the operating principles involved. Both systems use air to cool the strip. The ability of the new cooler to offer superior cooling and strip stabilization would simply need to be demonstrated and explained to gain the operator’s confidence. Over time this was accomplished but it took awhile for this to happen. The key is to train and spend time with the various operators under actual operating conditions. In this fashion the operators can see the cause and effect of operating the cooler under various conditions. Operating the nozzles within three inches of the traveling strip wasn't something that everyone felt comfortable with at the beginning.

The cooling system has performed as expected. Most of the time the operators are able to obtain a 600°F (315°C) strip temperature prior to the top turning roll with just the air flotation cooler. The system does stabilize the strip when operated as recommended and will handle some rather difficult strip contortions without touching the nozzle surface.

SUMMARY

In summary, once the operators were able to get beyond the initial learning curve, things went well. It was natural that the operators would have a reluctance to accommodate a change in operating philosophy but with on-site training this reluctance was quickly overcome. The line operators soon realized how user friendly the new system was.

Some of the benefits of the Spooner cooler arrangement that were immediately recognized was an increase in strip stability at the zinc pot, the ability to position the cooler in and out from the strip line and the ease of maintaining the system. Additionally the company looks forward to working closely with Spooner to reap the benefits of the water spray mist system which is typically used only during galvaneal operations.

Looking beyond traditional approaches allowed National Galvanizing to solve their up-leg strip cooling problem without having to resort to expensive alternatives like moving the top turning roll and achieve the production requirements targeted.

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