Trends for Radiant Tube Heated Strip Lines

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Abstract

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Introduction

After a extended period of low and stable natural gas prices, the prices have become extremely volatile in the last years. This is only one of the challenges, the operating companies of galvanizing lines are facing right now. Worldwide competition is forcing companies to produce more and more tons of strip with fewer and fewer people. Uptime of the lines must increase while the number of furnace operators and maintenance staff is reduced. In addition there are tightening emission requirements and yet unknown future carbon dioxide tariffs. All of these challenges are also related to the radiant tube heating systems of the strip line furnaces. Strip lines with outdated technology will not be competitive in the future. On the other hand, a lot of effort was put into the development of new radiant tube designs, and there is also new technology out on the market which can be adapted for strip line furnaces.

Heat Transfer in Continuous Strip Line Furnaces

Galvanizing strip processing lines include vertical of horizontal radiant tube heated furnace, where steel strip is heated to temperatures in the range of 720°C to 860°C (1330°F to 1580°F), depending on the type of material. Furnace zone temperatures of 900°C (1650°F) are typical. Heat transfer is dominantly by radiation and largely influenced by the emissivity of the strip and the temperature of the radiant tubes surface. The emissivity varies with wave length, cleanliness, oxidation state and temperature. Usually, heat up calculations are based on an emissivity of $\varepsilon = \pm 0.3$.

The maximum production rate of a strip line is limited by the:

- maximum line speed,
- or the installed heating capacity
- and in most cases by the maximum zone (radiant tube surface) temperature.

The example should illustrate the influence of emissivity (t – metric ton, ton – US ton)

Heated length:	100 m	330 ft
Zone temperatures:	880°C	1616°F
Strip width:	1524 mm	60 in
Production:	55 t/hr	60.6 ton/hr
Strip inlet temperature :	20°C	68°F
Emissivity :	0.3	
Final strip temperature:	735°C	1355°F
Emissivity:	0.4	
Final strip temperature:	810°C	1490°F

The next example demonstrates the influence of the radiant tube temperature on production:

Heated length:	100 m	330 ft
Zone temperatures:	880°C	1616°F
Strip width:	1524 mm	60 in
Final strip temperature:	850°C	1562°F
Strip inlet temperature :	20°C	68°F
Emissivity :	0.3	
Radiant Tube Temperature :	900°C	1652°F
Production:	32.5 t/hr	35.8 ton/hr
Radiant Tube Temperature :	1000°C	1652°F
Production:	67 t/hr	35.8 ton/hr

Calculations of that kind can be performed quite fast and they are a good tool to estimate the performance of a strip line and to evaluate the influence of planned changes to a furnace. For more detailed investigations, computer simulation like CFD (computational fluid dynamics) or FEM (finite element) are finding there way from academics to practical applications. Questions like:

- influence of tube spacing on the temperature distribution
- thermal stress in radiant tubes
- NO_x formation

and others can be addressed with these simulations. However, it is not yet possible, to do a complete detailed simulation of a whole strip line furnace.

Energy Efficiency

Waste heat recovery has the largest influence on the efficiency of a radiant tube heated strip line. Several different strategies for waste heat recovery can be found. In some plants, waste heat is used to preheat the strip or to use the heat in other parts of the plant. A better way of saving energy is to use the waste heat for combustion air preheating through recuperative or regenerative heat exchangers. U- and W-tubes can be equipped or retrofitted with external or plug in recuperators. Difficulties can arise from high air preheat temperatures regarding NOx-emissions and high temperatures at sealing surfaces and flanges. The hot air piping requires thorough insulation to prevent heat losses and unpleasant high temperatures around the furnace. The integration of a counter flow heat exchanger into the radiant tube eliminates these needs. One example of an integrated design is the self recuperative burner.

Regenerative systems will soon become more and more important, when energy costs will remain on a high level and when these systems have outgrown all their teething troubles. The additional complexity of regenerative systems is counterbalanced by outstanding fuel efficiency, temperature uniformity and almost cold exhaust gases.

Another factor on efficiency is caused by the fuel / air ratio, being affected by the burner and furnace control, but also depending on burner tuning and maintenance.

The following examples should show the differences of common systems and should provide some rules of thumb for a first evaluation of a furnace (please consider that some numbers are rounded).

(t – metric ton, ton – US ton):

Strip inlet temperature:	20 °C	68°F
Strip target temperature:	800°C	1490°C
Heat to load:	0.50 GJ/t	0.43 MMBTU/ton
Wall and athm. losses:	0.1 GJ/t	0.095 MMBTU/ton

Case A)
Perfect tuned regenerative system:
Total: 0.7 GJ/t (LHV) 0.7 MMBTU/ton (HHV)

Case B)
Well tuned recuperative system:
Total: 0.85 GJ/t (LHV) 0.85 MMBTU/ton (HHV)

Case C)
Reasonably well adjusted system with plug in recuperators:
Total: **1 GJ/t** (LHV) **1 MMBTU/ton** (HHV)

Case D)
Poorly adjusted system with no heat recovery:
Total: > 1.4 GJ/t (LHV) > 1.4 MMBTU/ton (HHV)

Fuel cost example for case C:
Production per year: 500,000 ton
Fuel price: 5 $/MMBTU
Fuel costs: $ 2,500,000.00

The examples show, that fuel costs for a large strip line can vary by several hundred thousand dollars, depending on the combustion system.

Tube Material

Both, fabricated and cast tubes of different alloy grades are used for radiant tubes. For horizontal lines, ceramic single ended tubes become more and more popular. As shown above, the heating rate of a strip line depends largely on the radiant tube surface temperature. Allowable tube temperatures are often a limiting factor for production, but it is not in the case of ceramic radiant tubes which could be operated at tube surface temperatures > 1250°C (2300°F) what is more than wanted in a galvanizing line. The tube life of ceramic radiant tubes is no longer limited by thermal aging but more by accident from a broken strip or during tube handling. However, it has been demonstrated with dozens of strip line furnaces with thousands of tubes installed, that these matters can be handled.

Temperature uniformity

Temperature uniformity is one of the main goals in radiant tube development, not just for an even strip temperature profile but also because of tube life. Hot spots will cause tube failures by burning holes into the tube or because they are causing high thermal stresses.
A radiant tube with an even temperature distribution can provide more heat to the furnace and has a longer tube life.

Low NOx combustion

Low NO_x burners are now in every burner manufacturers portfolio. Especially when the combustion air is preheated NO_x-emissions can be extremely high if no measures are taken. Exhaust gas treatment is extremely expensive and therefore low NOx burners are always preferable. There are several techniques to reduce thermal NOx-formation, which is the predominant source for NOx when burning natural gas:

- high velocity combustion
- air staging
- fuel staging
- external recirculation
- internal recirculation

Most Low NOx burners incorporate one or more of these techniques. Other methods like reburning and steam injection are applied in large capacity firings like boilers and gas turbines only.
Recirculation of exhaust gases have proven to be very effective. External recirculation can be retrofitted to U- and W-tube systems. A drawback of external recirculation is, that the recirculated gases are passing through the heat exchanger, lowering the efficiency or causing a need for a larger heat exchanger.

Internal recirculation is a part of the concept of recirculating radiant tube designs. A special form of internal recirculation leads to a special form of combustion, called flameless oxidation, FLOX®. In contrast to 20-40% recirculation of common systems, recirculation rates of well over 100% lead to drastic reduction of NOx emissions even for very high air preheat. The FLOX® technology is a key technology to keep NO_x in check, especially in regenerative systems.

Control Concepts

Radiant tubes in strip lines are operated as:

- pull
- push or
- push pull

systems. Pull systems provide a negative tube pressure which prevents combustion products from leaking into the furnace in case of a cracked tube. For pull-only systems, there is no combustion air piping what makes this system inexpensive but burner tuning often a challenge, especially on older lines or when several radiant tubes are out of service. Push or push-pull systems are preferred now because they allow for better fuel / air ratio control.

The heat input can be controlled:
- proportional
- high / low or
- on / off

The division of a furnace into zones is either done by the piping arrangement in case of proportional zone controlled furnaces, or it is done electrically for pulse fired systems. In pulse fired systems, the burner are fired on/off in a staggered pattern which prevents pressure impulses in the air and gas manifolds. The increasing usage of field bus communication fit well with the introduction of pulse firing and individually controlled and supervised burners. There is a trend to package radiant tube systems complete with burner, heat exchanger, controls and flame safety. This makes furnace design, start up and maintenance significantly easier.

Furnace models are generally based on zone temperature measurements. Particularly in vertical furnaces, it is not easy to define a zone temperature. Well defined positioning of the thermocouples are essential for reliable control. Bad measurements or undefined thermocouple positions can lead to premature radiant tube failures. A furnace model which is based on heat input is an alternative to systems which are based on zone temperatures.

Radiant Tube Designs

Radiant tube designs can be distinguished between recirculating and non-recirculating systems. While non-recirculating tubes are still widely used, recirculating systems become more and more popular for reasons of temperature uniformity, NO_x performance, integration of waste heat recovery and easier sealing.

Non recirculating tubes are often proportionally controlled. The burner designs aims for a flame which is stretched over the first tube leg. Heat exchangers can be plug in recuperators or attached types. The tube temperature uniformity of these designs is rather poor, but can be improved with regenerative firing.

Recirculating tubes should be operated with on/off operation and with high velocity burners. P- and double-P-tubes provide good temperature uniformity, but they also depend on even temperatures to keep the thermal stress between the centre and return leg low. The combination of a recirculating tube design and regenerative air preheating leads to an A-tube design. The regenerators are arranged in both legs of the tube with flow directions changing every 10 seconds. Besides minimizing exhaust gas losses, this tube design has a superior temperature uniformity and extremely low NO_x-emissions when operating in FLOX® mode.

Conclusions

There are many different radiant tube designs in operation and on the market. The following technology trends could be observed:

- Heat recovery
  - Plug in recuperators and self recuperative systems
  - Self regenerative systems
- Low NOx
  - Internal and external recirculation
  - Flameless oxidation, FLOX®
- Material
  - Ceramic single ended radiant tubes for horizontal lines
- Controls
  - Push or push pull systems
  - Pulse firing systems
  - Direct spark ignited on/off systems
  - Flame safety
  - Field bus communication
- Tube design
  - Recirculating radiant tubes
  - Packaged systems

It is expected that energy conservation will gain further importance in the future. The NOx emissions have to be kept in mind, but advanced low NOx burner technology is available. Modern computer tools will enable further progress but this will require a lot of effort on the R&D side as well as a close cooperation of users and suppliers.