NEW BURNER TECHNOLOGY FOR INDIRECT FIRING CONTINUOUS ANNEALING FURNACES

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OVERVIEW

The technology for radiant tube furnaces with controlled atmospheres fired with fossil fuels has been part of standard furnace design for at least 60 years and maybe longer. Trinks and Mawhinney discuss the application in their 1955 edition of Industrial Furnaces, and our company has been producing burners for radiant tubes since at least the early 50's. Electrically heated tubes probably were used before gas fired tubes and are also widely used, but that is not part of the scope of this discussion. Problems with fossil fuel fired tubes then as well as today have been the low heat utilization of the combustion products, the protection of the furnace atmosphere from POC's entering following tube failures and the ability to get good tube uniformity. Fast mixing burners can generate high thermal gradients on the tube causing premature tube failures. Slow mixing burners can result in very high CO concentrations in the exhaust, or require high excess air to complete combustion.

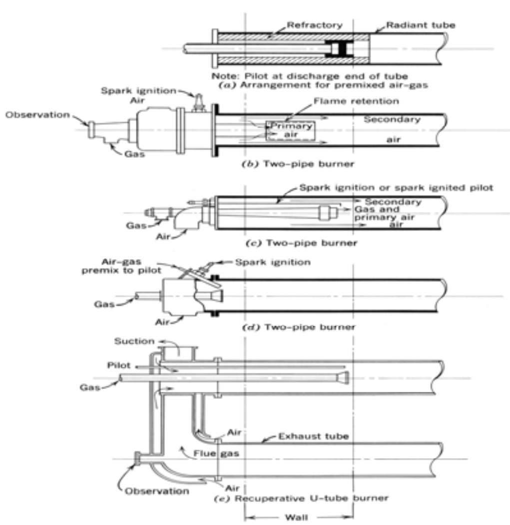

Fig. 1. Traditional Radiant Tube Burners.

Fig 2. Oil/Gas fired Burner, RTD

To the list of problems today we can add NOx emissions and the cost of fuel. But the good news is that there is a lot of new technologies coming on stream that can help solve these problems and provide furnace designers with more options.

HEAT TRANSFER AND FLUX RATES FROM RADIANT TUBES

To begin our discussion, we need to look at how radiant tubes perform their functions in an indirect fired furnace. The primary mode of heat transfer is, of course, by direct radiation from the tubes to the load and from the tubes to the furnace walls and then to the load. Sometimes, particularly in smaller lower temperature batch furnaces, convection heating utilizing high volume circulating fans can also be one of the modes of heat transfer.

Heat transfer from a radiant tube is the result of two processes – heat transfer from the products of combustion to the tube, and the radiant heat flux from the tube itself. Using new computer technology developed by my company we can easily calculate the level of magnitude from these processes. The program is called "E-Solutions for

Combustion" and is available from any of our sales offices.

Let's use an example of a 6-inch diameter steel tube inside a furnace wall with a width of 7-feet. Total surface area of the tube is 1583 sq. in. Using the radiant heat model of a flame inside a tube with the tube temperature at 1800 ^{0}F and the gases in the tube at an average of 2500 ^{0}F, the heat flux through the tube calculates to 6582.1 Btu/hr/sq.ft., or 45.7 Btu/hr/sq.in.

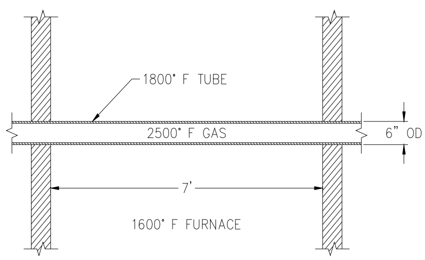

Fig 3. View across the furnace

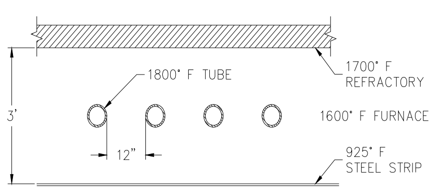

Fig. 4. View along the furnace

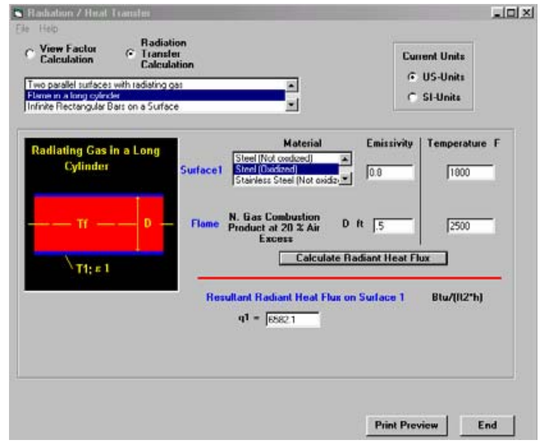

Fig. 5. Heat Transfer inside a tube.

Now look at the model of a bank of radiant tubes operating in a refractory lined furnace with the steel strip 3-ft from the wall. The 6-in diameter tubes are now spaced at a distance of 12-in apart. When the load temperature is about 925 ^{0}F, the total flux from the tube is again around 45.1 Btu/hr/sq.in. The heat flux to the steel is 9607 Btu/hr/sq.ft. It is through calculations like these that the furnace and combustion engineers are able to size the tubes and the burners for a specific performance.

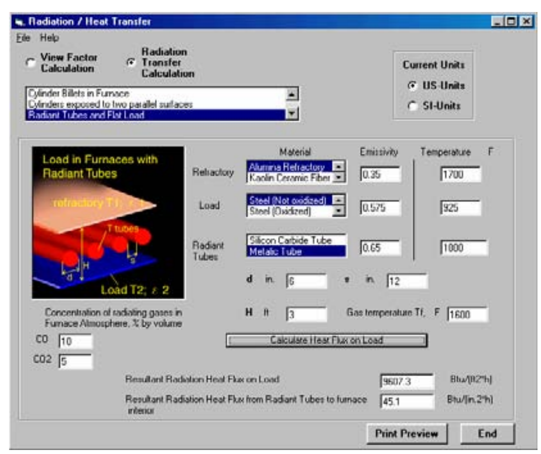

Fig 6. E-Solutions, Radiation Model

Today we can also use the powerful Computational Fluid Dynamics (CFD) programs to help understand the heat transfer mechanisms in a furnace. The example shown is a calculation done recently to evaluate the resultant heat transfer to a strip for a replacement burner technology. The flux pattern from the new burners was different from the existing burners, so this analysis was made to determine a new firing rate to achieve the same furnace throughput.

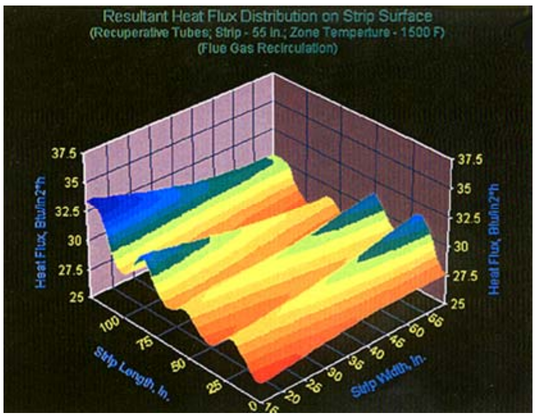

Fig. 7. Heat Flux on a sheet from radiant tubes.

With those basic concepts in mind, we can now examine the various tube configurations and applicable burner technologies.

STRAIGHT THROUGH TUBES

Straight through tubes are usually found in older furnaces with relatively narrow widths of around 5 to 7-ft. Tube diameters can vary from 5-in to 7-in with a burner firing in one end and an exhaust at the opposite end. If tubes are operating on both sides of the strip, to offset temperature uniformity problems, upper and lower burners fire from opposite sides of the furnace. An example is a 6'-6" long by 7" diameter tube operating in a 1450^0F zone with a flux requirement of approximately 48 Btu/hr/sq.in. With a total surface area of 1715 sq.in., the heat output from the tube is about 83,500 Btu/hr.

Fig 8. Straight tubes in a furnace.

This is a very tight combustion space, and many older burners must operate with as much as 5% O2 in the exhaust in order to get clean combustion – no CO. With a tube exhaust temperature of as much as 1800 ^{0}F, the 28% excess air represented by the 5% O2, results in combustion efficiency of only about 42%. The firing rate to achieve the required flux is then 196,000 Btu/hr. Tube uniformity (the difference between the highest and lowest temperature on the tube surface) will generally be less than 100 ^{0}F. The resultant combustion intensity (input/ tube volume) will be very high at 121,700 Btu/hr/cu.ft., and very difficult to achieve complete combustion in the tube even at 5% O2.

Burners with a slightly faster mixing rate (usually achieved with a small air/gas premix) may be able to operate in this same tube with an exhaust of only 2% O2. At the same flux rate, the burner efficiency becomes 48%, and the burner firing rate drops to 173,200 Btu/hr – a fuel savings of over 14%. More importantly, the intensity is now only 107,500 Btu/cu.ft. Temperature uniformity may be somewhat sacrificed, but good burner design can keep it close to the 100 degree differential.

The addition of a recuperator at the exhaust end of the tube can also add to the total combustion efficiency by increasing the combustion air preheat to as much as 600 ^{0}F. At the 2% O_2 and air preheat, the efficiency becomes about 56%, resulting in an additional fuel savings of 17%, and an intensity of only 91,000 Btu/cu.ft.

Fig. 9. High Alloy finned tube Recuperator

U-TUBES AND W-TUBES

At a given flux rate, to input more fuel and maintain a low O_2 in the exhaust, more combustion space is required in the tube. Return legs and bends are added to the tube design resulting in geometries that are described by their appearances – "U" and "W". Now the burner challenge is to achieve good tube temperature uniformity over 16 to 20-ft of tube length while firing at rates of 300 to 500,000 Btu/hr. These types of tubes are more prone to developing stress cracks from prolonged service, so it is also desirable to fire these systems using induced draft rather than the typical pressurized burner designs. Whereas pressurized burners operating at as high as 27-inch water air pressure are readily available up to over a million Btu/hr, induced draft systems must be designed for much lower draft pressures. Modern systems now operate at a draft pressure at the burner inlet of less than 12-inch negative water up to the 500,000 Btu/hr rating.

At these fuel inputs, recuperation is nearly mandatory. Adding a recuperator to the exhaust leg of a U or W tube is a simple procedure since the burner and recuperator are on the same side of the furnace. Several design options are used, but the newest addition to this family is the Hauck RTR-160 burner. The recuperator in this unit generates air preheats of as much as 850 ^{0}F, with thermal efficiencies in the 60 to 65 % range. Preheats this high are demanding on burner nozzle components. The outer nozzle used in the RTR is made from a reaction bonded SiC material and the gas nozzle is made from a high temperature alloy casting. A very slow mixing long flame design assures good tube temperature uniformity and a relatively low NOx emission. Measured temperature uniformity is a differential of about 75 ^{0}F.

Fig 10. U-Tube with RTR Burner.

There are older designs which incorporate an integral recuperator at the burner inlet.

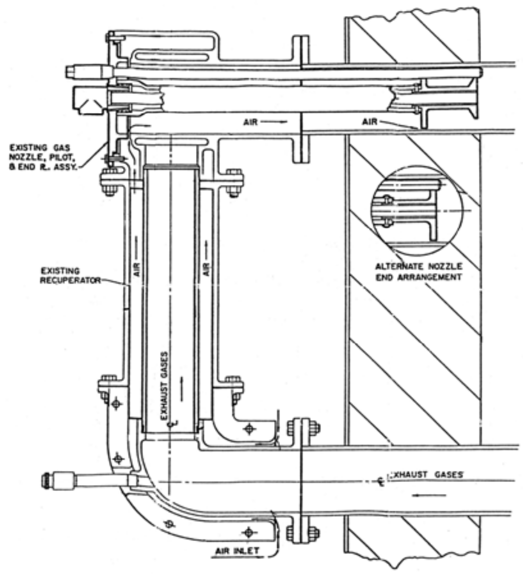

Fig. 11. Radiant tube burner with external recuperator.

A fairly recent technology is the incorporation of two regenerative burners at each end the tube. With this design, each leg of the U or W tube is fired in an alternating arrangement using a ceramic bed to capture the heat from the exhaust leg. Using this approach, tube uniformity will be much improved since there is a firing leg on each side of the tube. Thermal efficiencies are in the 70% range. This technology has been widely applied to many strip lines. However, without constant maintenance, CO and NOx emissions can be quite high.

Fig 12. Dual Regenerative burners

With high air preheats, NOx emissions go up dramatically in all recuperated radiant tube type burners. NOx reduction is accomplished in the Hauck design using Flue Gas Recirculation (FGR). Another method is to operate the unit as a push-pull system to generate the low NOx with an integral FGR pump. The Hauck RTR uses an external inducer operating at 15 psig of air to get FGR. With this design, Hauck can achieve levels of NOx emissions in the order of 0.14 lb/mmBtu.

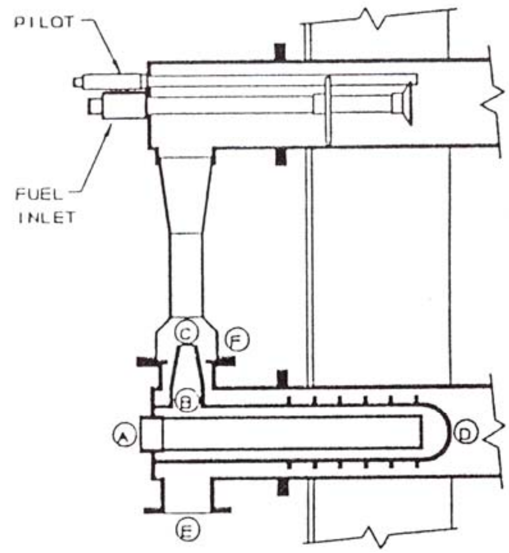

Fig. 13. Recuperator with internal FGR

Fig. 14. Hauck Patented External FGR System

SINGLE ENDED RADIANT TUBES (SER)

Back in the early ‘80’s technology came out of Europe that redesigned the radiant U-tube by bending the return leg back on the outside of the firing leg and exhausting the POC’s at the burner. The unique feature here is that a recuperator can be added at the discharge where it runs parallel to the incoming cold combustion air, thus preheating the air without any complex piping. Basically, the radiant tube becomes a tube within a tube, with the burner firing through the inner tube.

As one would envision, the inner tube must now operate at a significantly higher temperature than the outer tube in order to achieve heat transfer. The original designs were all fabricated from high temperature resistant alloys, but there have been problems with premature tube failure in higher temperature furnaces. This has made for a particularly bad reputation for SER technology in the US market.

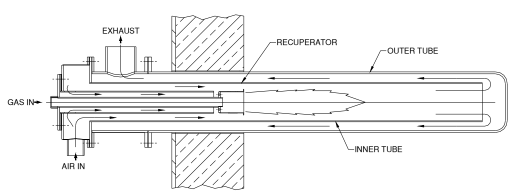

Fig. 15. Original SER concept.

The introduction of new technology for manufacturing reaction bonded silicone carbide (SiC) and metallic silicon in a matrix of SiC have opened new doors for burner manufacturers in the area of high temperature radiant tubes. Hauck in particular has introduced a new concept in SER technology called the SERamic line of burners for which patents have been applied.

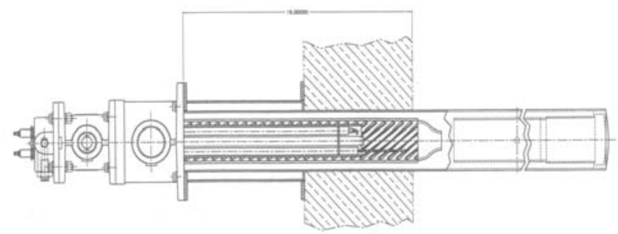

Fig 16. Hauck SER

While the outer tube can be manufactured from either alloy or SiC, all the inner parts – inner tube, air nozzle, recuperator – are manufactured from SiC materials. In strip line applications, SiC outer tubes are not practical when a break could destroy all the tubes. For this application, Hauck uses a patented flexible SiC inner tube called Sicaflex that doesn’t self destruct when a horizontally mounted metal alloy outer tube sags at temperature.

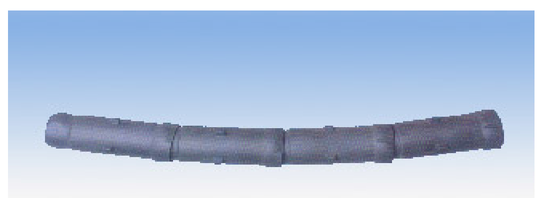

Fig. 17. Sicaflex assembly

Another feature in the SERamic burner is that the burner is not directly coupled to the inner tube as in the original SER designs. By having the combustion air exit from the burner through a high velocity SiC nozzle, and providing a gap between the nozzle and the inner tube, POC’s are entrained into the combustion gases, reducing flame temperature and NOx emissions. Combustion efficiencies run in the 60 to 65 % range, and NOx levels are in the area of 0.15 lb/mmBtu.

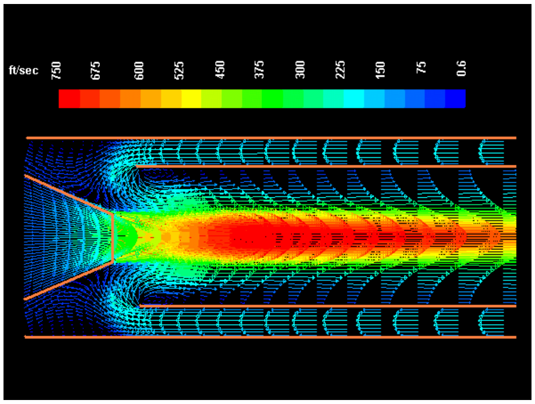

Fig 18. CFD Modeling of SER

Another interesting application of SER technology is in the firing of existing U tubes. By placing an SER in each leg with the Sicaflex inner tube arrangements, the uniform tube temperatures previously only obtainable with the dual regenerative burner technology can be obtained without the pulsing and maintenance problems. Hauck calls this technology our Gemini Tube Option (GTO), patent applied for. The Hauck Sicaflex internal tube design is used in each firing leg. Equalized pressure at the middle of the U bend reverses the flow in each leg exhausting back through the recuperator and into the exhaust header. While the basic SER is designed to operate with a pressure fan, the burners can be set up to fire a total of 300 to 400,000 Btu through two burners which will then permit a push-pull operation to create a negative pressures in the main tube at the exhaust leg.

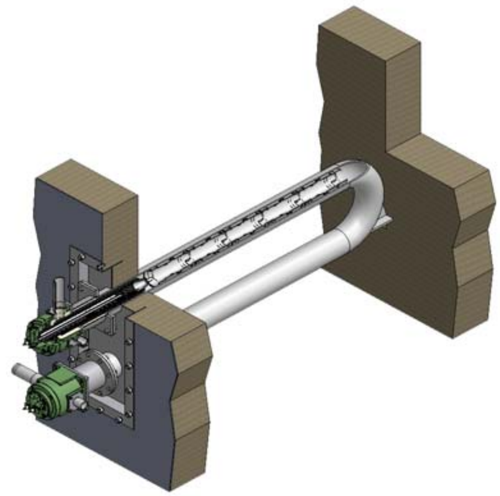

Fig.19. Hauck's Gemini Tube Option (GTO) SER Arrangement.

P-TUBES AND DOUBLE P-TUBES

In these designs a high velocity burner with a counterflow recuperator similar to an SER design is fired into the tube at a point where the return tube is re-attached to the main firing leg. The high velocity jet entrains POC's into the flame to reduce NOx while the rest of the exhaust gases flow back through the recuperator to the exhaust system.

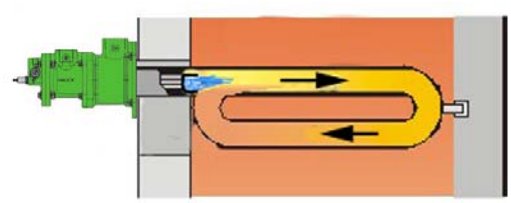

Fig. 20. P-tube design.

A double "P" has two return legs attached at this point.

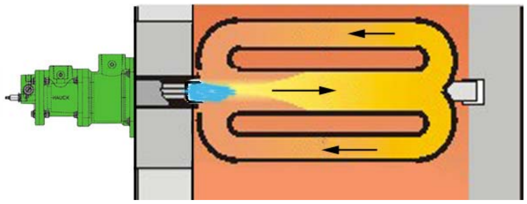

Fig. 21. Double P design

One problem with this technology that some of the early metal tube designs have had is cracking at the joints from the thermal stressing caused by high temperature gradients at the point where the cold return leg connects to the hot firing leg.

CONCLUSION

Today there is a whole catalog full of new or vastly improved radiant tube firing technologies that reduce excess air requirements for clean and stable combustion while improving fuel consumption and increasing life expectancy. New recuperator technologies using SiC components as well as high alloy castings permit long trouble free operation. NOx reduction technologies are also available that can reduce the NOx levels resulting from high temperature air preheats.