WHY COMPOSITE RADIANT TUBES?

The superior material characteristics of silicon carbide make it an ideal radiant tube material.

Michael C. Kasprzyk*
Schunk-INEX Corp.,
Holland, New York

Nonmetallic composite radiant tubes are fast gaining acceptance in atmosphere heat treat furnaces for a very simple reason: They save money. Composite tubes made of silicon and silicon carbide particles were originally introduced as a way to avoid downtime and to eliminate both labor and material costs associated with metal tube replacement. More recently, especially with the introduction of composite U-tubes, furnace operators have also discovered that significant productivity gains are routinely achieved.

In this article, specific case studies demonstrate how the higher heat fluxes possible with silicon carbide composite tubes can shorten cycle times. Real world examples for both batch and continuous furnaces are presented, along with economic analyses.

Furnace downtime

Indirectly heated atmosphere-controlled industrial furnaces incur downtime for a variety of reasons, but the most common is metal alloy tube failure. When the radiant tube fails, atmosphere control is lost and the furnace must be purged or emptied, and then cooled down, so that the failed tube can be replaced. The simple fact is that every alloy tube eventually fails.

Surveys of commercial heat treaters in the United States have shown a wide range of metal tube life, with over 50% replaced within 24 months (Fig. 1). These results are similar to those reported in both Asia and Europe.

Of course, many heat treaters replace the metal tubes before they fail, scheduling downtime on a regular basis to prevent an unplanned shut-down. Predicting tube life is not a simple matter, as it depends on many factors, such as the alloy type, whether the tubes are cast or fabricated, and the specific type of heat treating process. However, the most important factor is tube and furnace temperature. High temperatures accelerate the rate of creep deformation and hasten failure. Creep deformation is the principal reason for alloy tube failure. Other reasons include corrosion and carburization (embrittlement).

The cost of tube failure is much more than the tube replacement cost. Depending on the furnace type and size, it can reach hundreds of dollars

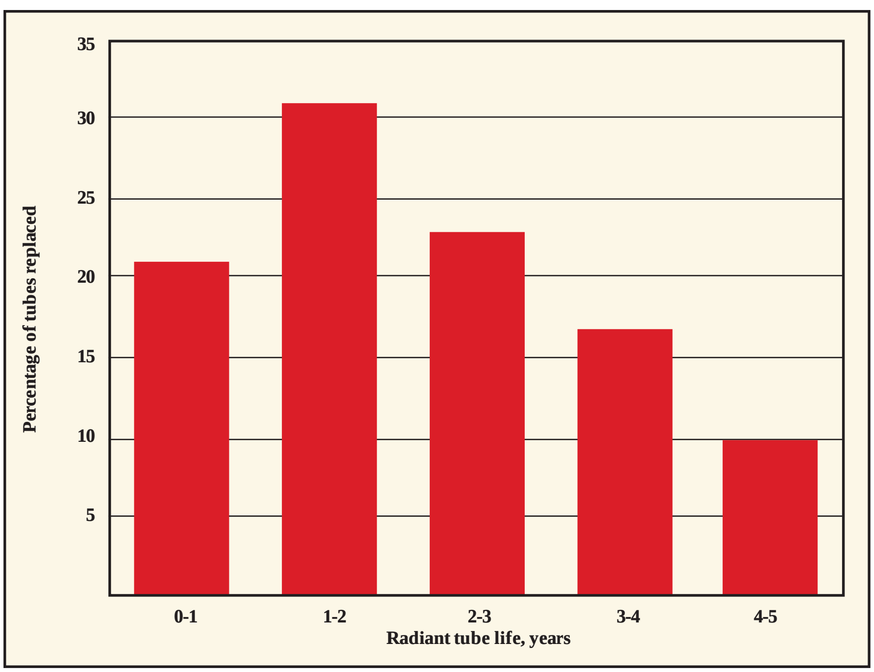

Fig. 1 — Radiant tube life distribution for metal alloy tubes. Source: Gas Research Institute internal report, Aug. 1984

*Member of the ASM Heat Treating Society per hour. The following is a list of factors that must be evaluated when determining the true cost.

Downtime costs

1. Tube replacement (purchase price)
2. Labor
   a. Remove the old
   b. Replace the new
3. Energy to reheat
4. Atmosphere replacement
5. Lost production time
   a. Cool down
   b. Actual remove / replace
   c. Heat up

Silicon carbide composite tubes

During the mid 1980's, silicon carbide or composite tubes began to be substituted for metal alloy tubes, especially in high-temperature or high-heat-flux applications. However, their high cost and lack of performance history prevented widespread acceptance. Recent advances have made these tubes much more affordable, and now they have a history of proven performance and durability. It is not unreasonable to expect tube life of 10 to 15 years, based on real world experience. In fact, many tubes installed in the late 1980's are still in service.

The reason these silicon carbide materials provide long life is that they possess material characteristics ideal for radiant tubes. Below is the list of the attributes of silicon / silicon carbide composites:

- Excellent creep resistance
- Excellent thermal shock resistance
- High emissivity
- High thermal conductivity
- Chemical inertness
- High-temperature capability

Specific properties vary somewhat from one manufacturer to another, but it is accurate to say that all provide the superior attributes listed above. However, these are ceramic-based materials, and as such have limited fracture toughness. Applications in which mechanical impact is likely should be avoided, and care is required during handling and installation.

The photo in Fig. 2 shows the results of high-temperature creep testing. The tube on the left is a silicon / silicon carbide tube, and it shows no deformation in compressive creep testing. The Alloy 600 tube on the right shows the deformation at loads replicating the weight of the tube. Because creep is the principal mode of failure for alloy tubes, it is easily apparent that significant downtime reductions are attainable with composite tubes.

Improving productivity

Recently, more heat treaters have become concerned with improving productivity. Classic theoretical economists have many complicated definitions for productivity. This author likes to think of improving productivity as simply completing *more work in less time.*

If heat treat furnaces equipped with radiant tubes are to do more work, or do the same work in less time, or even do both, more heat is required. Comparison of the heat transfer capability of alloy tubes compared with silicon carbide tubes shows how productivity can be improved.

Alloy tubes are traditionally limited to 55 Btu per square inch of surface per hour. This is a function of their upper temperature limit. Heat transfer by radiation is calculated as follows:

$$Q = \sigma e\,(T^4_{Tube} - T^4_{Chamber}) \times A, \text{ where}$$

Q = heat transfer (Btu/h)
e = emissivity
T = temperature (Rankin)
σ = Stefan-Boltzmann constant
A = area

Alloy tubes can be forced to run hotter and therefore transfer more heat, but this is not practical because high temperatures result in faster creep deformation, and faster creep deformation results in shorter tube life.

If higher productivity is needed and that requires more heat, and if alloy tubes cannot be operated at higher temperature, only one option remains: Add surface area. Surface area can be increased in two ways, by using larger tubes or by adding more tubes.

- *Larger tubes:* Surface area can be raised with larger tubes. These are usually much more expensive and often require extensive burner and furnace modifications.
- *More tubes:* The second option is to add more tubes and burners. This too, is an expensive option, and often there is simply not enough room for additional tubes. Some heat treaters have actually added preheat sections to their furnaces to get more heat.

Composite tubes

An alternative is ceramic composite tubes. The heat transfer from the tube is a function of the tube temperature to the fourth power. Therefore, a tube that can be operated at higher temperatures (without premature failure) can transfer much higher heat flux.

Higher heat flux in turn means that the recovery time portion of the heat treat cycle can be shortened. This is true with both batch and continuous furnaces. Composite tubes are routinely operated at flux rates of 90 to 95 Btu / in.^{2} / hour.

Tables 1 and 2 show the productivity improvements possible with

Fig. 2 — Results of high-temperature creep testing. The tube on the left is a silicon/silicon carbide tube, and the Alloy 600 tube on the right shows the deformation at loads replicating the weight of the tube. Test by High Tech Ceramics, Alfred, New York.

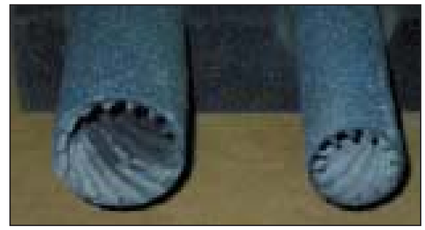

Fig. 3 — Finned silicon/silicon carbide composite radiant tubes have been proven to reduce fuel consumption.

Table 1 — Batch furnace case study

Batch furnace conversion		
Before:		
Four cast alloy U-tubes, 6 in. OD		
Open atmospheric burners (No recuperator)		
5000 pound gross load		
1650°F operating temperature		
Recovery time 3.0 hours		
Cycle time (total) 6.5 hours		
Tube life 30 months		
Results:		
Property	**Before**	**After**
Tube life	30 months	15+ years ??
Loading	5000 lb	5000 lb
Temperature	1650°F	1650°F
-	-	-
Recovery	3.0 hours	1.5 hours
Total Cycle	6.5 hours	5.0 hours

these higher heat-flux tubes in batch and continuous furnaces. Table 1 shows the result of upgrading a four U-tube batch furnace.

As a result of these changes, this particular furnace had an increased capacity of 390 more batches per year, based on 24/7 and 50 weeks. Or, translated to pounds of capacity, the ability to process 1,950,000 more pounds per year.

Similar dramatic productivity improvements are possible with continuous furnaces. Table 2 is an example based on a conversion of a mesh belt furnace, which had ten metallic Single Ended Recuperator burners in Zone 1. These burners were converted to use composite tubes and the results are shown.

When considering such changes, it is important to remember these cautions.

First, furnace operators must make sure that the work can accommodate faster heat-up rates without adverse metallurgical or dimensional effects. Usually this is not a problem.

Second, in particular with continuous furnaces, care must be taken to analyze the whole system for the effects of increased capacity. Specifically, can the transfer mechanism withstand the increased loading, and is quench capacity sufficient?

Table 2 — Continuous furnace case study

Continuous furnace conversion results		
Parameter	**Before**	**After**
Tube life	1.5 years	15+ years ??
Temperature	1750°F	1750°F
Production rate	1500 lb per hour	2500 lb per hour
1000 pounds / hour more, or 66% productivity improvement		

Table 3 — Finned tube case study

Finned tubes
Furnace rated at 600,000 Btu / hour
Duty cycle: 60% high fire
Gas usage: 60% x 600 cubic feet = 360 ft^3 / hour
Gas savings: 10.4% x 360 ft^3 / hour = 37.4 ft^3 / hour
Annualized savings : 37.4 ft^3 / hour x 24 x 7 x 50 = 314,000 ft^3 314,000 ft^3 x \$5.00 / 1000 ft^3 = \$ 1,570.00

Energy conservation

A new awareness of fuel costs is causing many operators to explore new technologies to reduce energy consumption. New burner technologies such as Single Ended Recuperator Burners (tube within a tube) have been widely accepted in countries with high fuel costs. These advanced burners are now gaining acceptance world wide. More efficient recuperators to recover waste heat are also gaining in popularity.

Inserts to extract more heat within the tube are also growing in favor, with many new and novel products being offered. Another approach is internally finned tubes, designed to cause turbulence that eliminates laminar gas flow near the inside tube wall. The turbulence also produces more complete combustion. The fins themselves provide increased surface area to capture the heat in the combustion gas stream.

The photo in Fig. 3 shows composite tubes with spiraled internal fins. Although relatively new to the industry, these tubes have been proven to reduce fuel consumption.

Few heat treaters have individually metered furnaces, therefore hard data is not always available. However, one manufacturer of powertrain components was able to document savings of 10.4% in a batch furnace with open ended tubes. Table 3 illustrates these savings based on current gas prices. Others have reported similar savings, with specific amounts saved depending on the size of loads and hours of production.

What is available

Various manufacturers of silicon carbide tubes have in recent years expanded their offerings to include different shapes and larger diameters and lengths. As a result, many more furnaces can now be converted to these new composite tubes. Table 4 lists the commonly available silicon carbide composite radiant tubes.

Some furnaces currently use alloy tubes with shapes not listed above, such as "Trident", "W", "P", and "O" tubes. Furnace operators with these shaped tubes are advised that these shapes are not likely to be available in the near future. Those seeking longer tube life and/or productivity improvements are advised to convert to U-tubes. Usually this is a straight forward furnace modification.

The superior material characteristics of silicon carbide make it an ideal radiant tube material. Widely accepted in Europe, this material is rapidly gaining acceptance in the rest of the world due to its long life and high heat flux capacity. Bottom-line savings due to reduced tube replacement costs and improved furnace throughput are readily attainable. ■

Table 4 — Composite tube product availability

Composite material availability (silicon/silicon carbide)
Open ended
SER tubes: Closed ended and flanged
Internal fins
U-tubes
Burner nozzles
Recuperators
Segmented tubes

For more information: Michael C. Kasprzyk, Schunk-INEX Corp., 9229 Olean Road, Holland, NY 14080; tel: 716/537-2270; fax: 716/537-3218; e-mail: inex@buffnet.net; Web site: www.schunk-inex.com.

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