

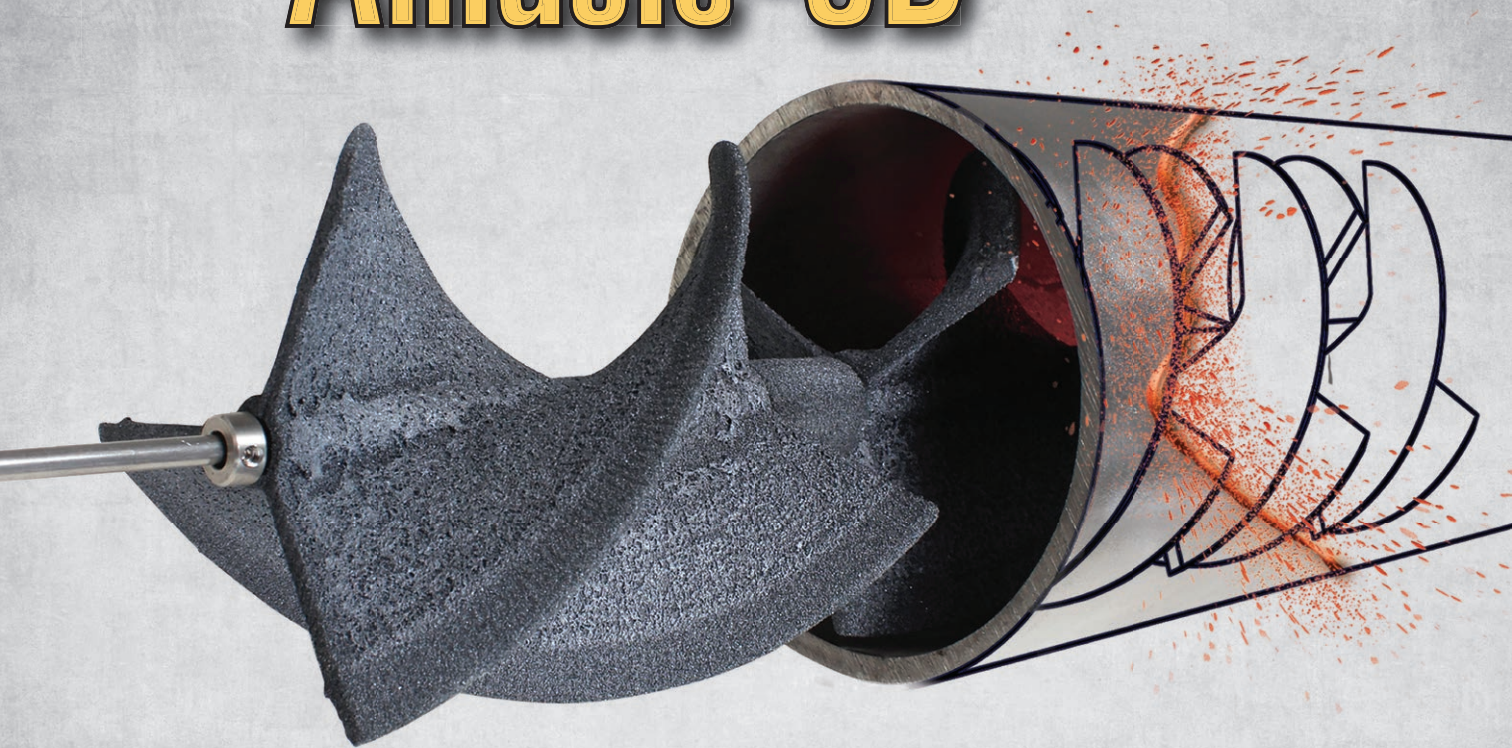
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## SpyroCor™ and Amasic-3D™



Additive Manufacturing  
for Energy Efficiency in  
Automotive Heat Treating

**Tom Briselden –**  
**Saint-Gobain; Northeast, Pa.**



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# Additive Manufacturing for Energy Efficiency in Automotive Heat Treating

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Industrial heating continues to be challenged with processing new exotic materials for the automotive, aerospace and steel industries.

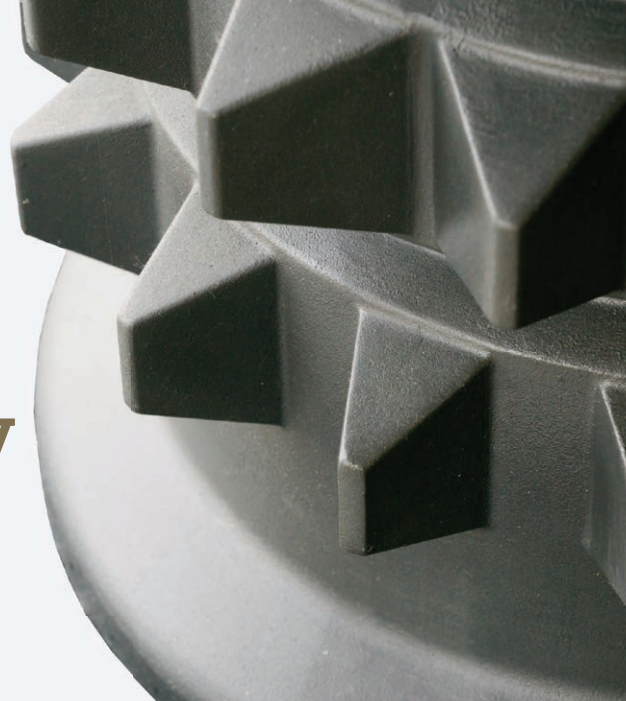
**N**ew materials push the envelope of furnace temperature and environments that result in lower throughput and efficiency, higher emissions and more-frequent maintenance. Ceramic materials fill a critical gap in allowing furnace components to operate in these extreme environments. However, traditional ceramic materials are limited to simple tube, fin and nozzle designs. Thus, their wide-scale adoption and impact on sustainability are low.

## Energy Consumption Trends

The ability to improve thermal efficiencies from 70-85%, operate at temperatures exceeding 1200°C (2192°F) and incorporate advanced low-emission burner designs requires the use of ceramic materials that can be formed with optimized geometries. These include twisted tapes, twisted channels and complex hole configurations impossible with current manufacturing platforms. The introduction of additive-manufactured (AM) advanced silicon carbide (SiC), including 3D-printed shapes, opens up a new window of opportunity for end-users, designers and manufacturers of high-temperature heating equipment.

The combined energy consumption of all manufacturing sectors in the U.S. is over 14 quads, generating over 500 million tons of CO<sub>2</sub> (U.S. DOE, Energetics-2010). This accounts for 18% of the world's energy and emissions. The manufacturing and assembly of a typical motor vehicle consumes between 25 and 30 GJ (23-28 MMBTUs) of energy and generates over 1 ton of CO<sub>2</sub> emissions (Argonne National Labs, September 2010).

Process heating is the single-largest source of waste energy generated from a typical manufacturing plant. With over 3,000,000 automobiles produced in the U.S. and 75 TBTUs of energy consumed each year, the reduction of waste heat and emissions due to process heating is critical to the long-term sustainability and reduction of environmental impact.



**Fig. 6. Previous-generation ceramic heat-exchanger geometry for plug recuperators**

## Counteracting Reduced Efficiency at Elevated Temperatures

Indirect-heated “atmosphere” furnaces account for a significant portion of high-temperature (>700°C, 1292°F) processes in the automobile manufacturing industry. Single-ended and U-type gas-fired radiant tubes are commonly used as the heating source with a thermal efficiency approaching 70%<sub>LHV</sub>. With a typical atmosphere composition containing hydrogen, nitrogen, carbon and oxygen, the selection of radiant-tube material becomes a critical component in maintaining a gas-tight furnace.

When furnace temperatures approach 900-1000°C (1650-1830°F), efficiency is decreased and emissions are increased. As an example, one such process is hot stamping steel sheets coated with aluminum and silicon. The sheets are heated in the furnace to 900°C and are then hot pressed to shape. An Al-Si-Fe coating is formed on the surface of the part that provides strength and corrosion resistance. The higher temperatures required for this type of processing reduces combustion thermal efficiency and available heat to the furnace by more than 10%. Thus, throughput is reduced and energy consumption increased. The higher operating temperatures also have the potential to increase NO<sub>x</sub> generation and reduce component life.

An industry-standard single-ended radiant tube and U-tube combustion system (Figs. 1 and 2) consists of a radiant tube, burner, recuperator and flame-tube insert. The systems operate between 25-100 kW with efficiencies approaching 70%. Ni-Cr-based fabricated radiant tubes such as 330, 600, 601 and their typically cast counterparts HT and HX are often used for material working temperatures below 1100°C (2012°F).

## Ceramic Opportunities for Radiant Tubes

Silicon-carbide radiant tubes (Fig. 3) are desired for working temperatures over 1200°C due to their greater heat release when



compared to traditional materials. An increase in heat release, measured as heat flux, permits a furnace to achieve greater temperatures with a given tube count, insulation configuration and production throughput.

These tubes must be gas-tight, have no porosity to minimize intergranular oxidation and be strong enough for both horizontal and vertical mounting. They must survive for at least three to five years in hydrogen-, nitrogen-, carbon- and oxygen-based atmospheres with contaminants such as aluminum, silicon and iron.

Significant progress has been made on manufacturing reaction-bonded SiC radiant tubes up to 300 mm (11.8 inches) in diameter and 3,000 mm (118 inches) in length. There has been limited acceptance of SiC U-tubes in the industry, however, due to the use of multicomponent designs with different coefficients of thermal expansion.

The use of a variety of joining and mounting techniques to accommodate the thermal expansion and strength issues is proven in a few applications. The ability to provide a functional, long-life ceramic U-tube continues to be a key challenge and key opportunity in high-temperature processes found in the automotive and steel industries.

### Ceramic Opportunities for Flame Tubes

Flame tubes are often used to direct flame and exhaust gases and improve temperature uniformity. In both metal- and ceramic-based radiant tubes, these components must be able to operate in a low-oxygen combustion environment at temperatures exceeding 1100°C and accommodate changes in the radiant-tube dimensions over time (ovality and slumping). Utilization of a properly designed flame tube will help improve the temperature uniformity of the tube and decrease emissions generation of NO<sub>x</sub>. This is particularly helpful at increased operational temperatures where combustion efficiency may be reduced.

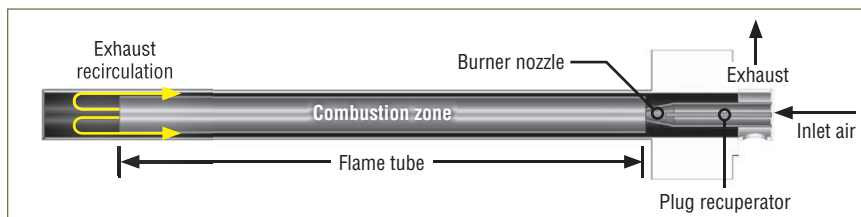


Fig. 1. Single-ended radiant-tube cross section with components

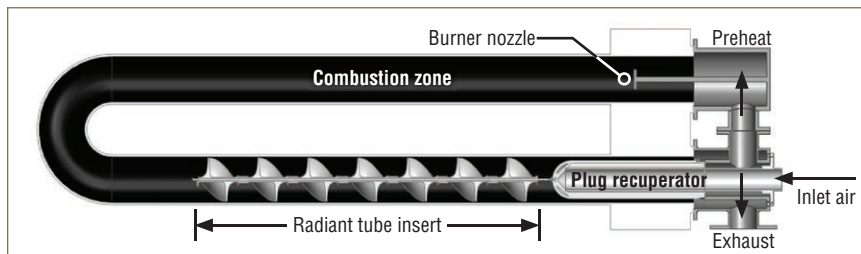


Fig. 2. Radiant U-tube cross section with components



Fig. 3. SiC radiant tube (courtesy of Elster GmbH)

### Ceramic Opportunities for Radiant-Tube Inserts

Significant acceptance of radiant-tube inserts (Fig. 4) occurred over the last 10 years with the introduction of patented siliconized SiC twisted tapes such as SpyroCor™. Current industry data indicates over 50,000 SpyroCor twisted-tape units have been installed worldwide and are saving, on an annual basis, over 2 trillion BTUs of energy. Radiant-tube inserts increase the efficiency of a radiant tube by 5-10% by enhancing the radiant heat transfer in the exhaust leg of the radiant tube. The improved efficiency increases the heat release from the tube to the material being heated.

To optimize the heat release in the exhaust leg of the radiant tube, the length, diameter and twist rate of the insert are customized for each installation using computational fluid dynamics (CFD) modeling. Typical results reported from industry are a 2-5% throughput improvement, 5-20% energy savings and NO<sub>x</sub> reduction, and improved temperature uniformity.

### Ceramic Opportunities for Twisted-Channel Recuperators

The largest impact on a combustion system's efficiency can be realized in the design of the waste-heat recovery system. Traditional metallic-based, plug-type heat exchangers are inserted into the exhaust leg of the radiant tube. High-temperature

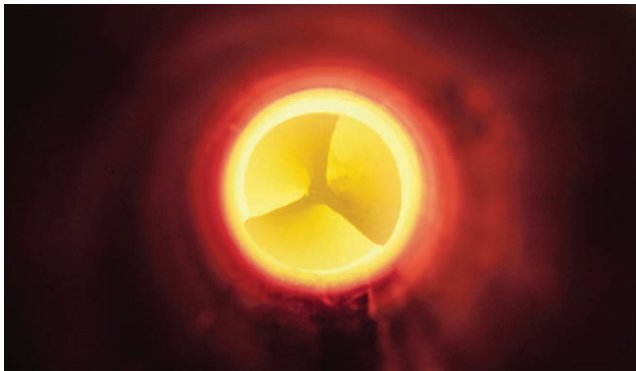


Fig. 4. Radiating tube insert

waste heat is used to preheat combustion air entering the burner. Limitations in current material and burner designs limit the resulting preheat air temperatures to less than 425°C (800°F).

Some high-performance regenerative systems can have a significant impact on efficiency. However, these systems require two burners and two heat-exchange beds as compared to the traditional single-burner and recuperator configuration. While high-performance regenerative systems are more efficient than a metal-based plug recuperator, they are much more costly to design, install and maintain. Therefore, a technology gap (Fig. 5) exists for plug recuperators to generate over 500°C (932°F) preheat air temperature and achieve the efficiency of a regenerator. Both metallic and ceramic designs are limited to simple shapes, namely straight tubes with the option to enhance the surface with fins or dimples (Fig. 6). Typical efficiencies approaching 70% are realized.

The introduction of twisted-channel heat exchangers (Fig. 7) made from Amasic-3D™ Additive Manufactured Advanced Silicon Carbide provides one means for bridging the technology gap and achieving efficiencies approaching 85-90%. The patented twisted-channel design increases the surface area of a heat exchanger by three to six times. The twisted flow path of inlet air and exhaust gas increase the heat-transfer coefficients



Fig. 7. Next-generation ceramic heat-exchanger geometry for plug recuperator

Waste heat temperature ↓	Preheat air temperature →						
	Temperature °C (°F)	315° (600°)	426° (800°)	538° (1000°)	649° (1200°)	760° (1400°)	871° (1600°)
	538° (1000°)		18%				
	649° (1200)	14%		23%			
	760° (1400°)	15%	20%		20%		
	871° (1600)	17%	22%				
	982° (1800)	18%	24%				40%
	1093° (2000)						43%
	1204° (2200°)						47%
	1315° (2400°)						
■ Standard alloy HX		■ Advanced alloy HX		■ Regenerator			

Fig. 5. Technology gap for high preheat air temperature with high-percentage efficiency

within the channel by two times. Siliconized SiC allows for operating temperatures up to 1350°C (2460°F). By optimizing the twist rate, number of channels and length, preheat temperatures exceeding 1000°C are achieved.

### Energy: The Primary Resource

Energy is the primary resource used to extract value from all other resources. Energy is being consumed at a substantial rate and generating a corresponding increase in NOx and carbon emissions. The demand for lighter and stronger material in the automotive, aerospace and steel industries is challenging a plant operator's ability to maintain sustainable, cost-effective operations.

Current, industry-standard combustion systems are disadvantageous in the consumption of energy and the generation of emissions. The use of additive-manufactured SiC components is mature to a point where these high-temperature components can be integrated into a system to promote saving time, energy, emissions and maintenance costs in industrial heating processes.

The impact of these advanced components will reduce the net energy consumed in the production of each automobile. For automobile component suppliers, the impact is twofold.

- The increase in throughput will positively impact profitability.
- The cost savings from energy-efficiency improvements will help to offset the price pressure consistently applied to this market. 🇨🇦

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