

Heat-Recovery Device Lowers Fuel Consumption for Gas-Turbine Engines

A gas turbine recuperator that can operate at higher temperatures than conventional recuperators and is manufactured from standard commercial stainless-steel tube and sheet is under development by Proe Power Systems. Incorporating such a recuperator with a turbine engine cuts the fuel consumption rate almost in half. As shown in Figure 1, a recuperator allows some of the heat in the turbine exhaust to be recovered ahead of the combustor to reduce the amount of fuel needed to heat the compressed gas to the expander turbine inlet temperature.

Current recuperators are typically based on a plate-fin heat-exchanger construction. These recuperators have high initial tooling costs; and, since recuperators operate at temperatures where creep strength is low, pressure and thermal stresses can cause the thin plates to distort or the highly stressed plate joints to leak.

The Proe 90™ (U.S. Patent #6,390,185 issued May 21, 2002) recuperator concept has been developed with the objective of overcoming these disadvantages while still maintaining high heat recovery with minimal flow restriction. The Proe 90 recuperator, shown in Figure 2, overcomes the flat-plate material limitations by having all high-pressure surfaces either curved or braced so that they can maintain increased strength and creep resistance. Furthermore, thermal stresses

are negligible because the recuperator is able to expand and contract freely. These reduced pressures and thermal stresses allow it to operate at higher temperatures (815°C) and thus at greater efficiency than conventional recuperators. The higher operating temperature results in increased engine efficiency, reduced fuel consumption, and a corresponding reduction in emissions.

Because it is constructed from commercially available stainless-steel tube and sheet stock, the Proe 90 recuperator is relatively simple to manufacture and thus requires very little specialized tooling; therefore, initial nonrecurring costs are low. Orbital welding techniques developed for shell and tube fabrication further assure low per-unit production costs, although it is not a shell and tube heat exchanger. Proe Power Systems is working with leading automatic orbital welding firms including Arc Machines Inc., Liburdi-Dimetrics, and Pro-Fusion to develop high-production rate welding with reasonable initial costs. Furnace brazing is also being evaluated to further lower per-unit production cost.

Opportunities

The company is seeking partners for joint development and licensing.

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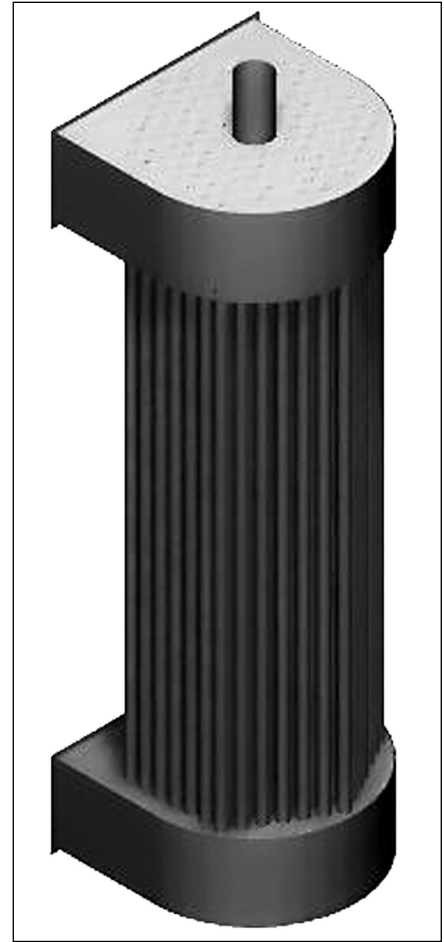


Figure 2. A Proe 90™ gas-turbine engine recuperator.

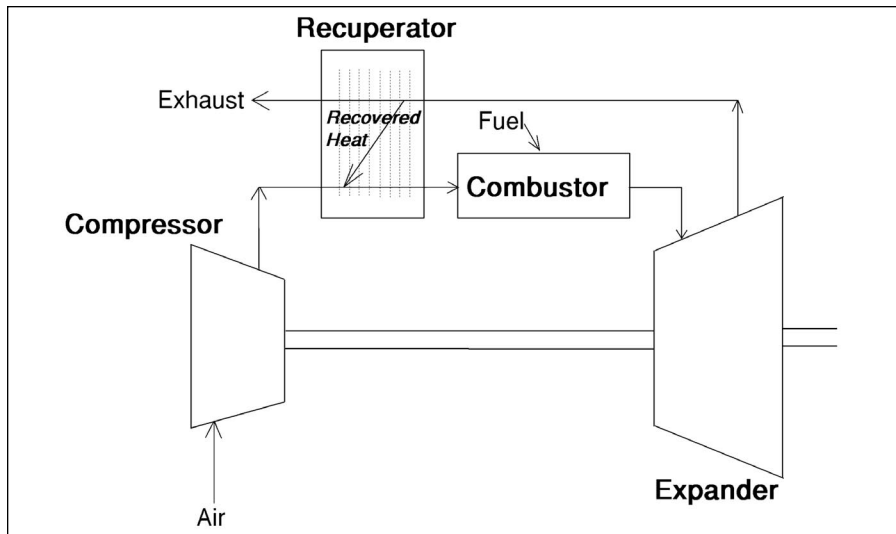


Figure 1. Schematic of a recuperated gas-turbine engine.

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In Situ Rapid Densification with Low-Viscosity Impregnant Reduces Processing Time to Produce Uniform Density Carbon–Carbon Composites

High-performance carbon–carbon (C–C) composites possess a set of properties that make them desirable materials for high-temperature structural uses such as in rocket propulsion components, hypersonic vehicles, and aircraft brakes. They are stronger and stiffer than steel and less dense than aluminum. In addition, they maintain their mechanical properties to temperatures above 3000°C, and their properties improve with heating as the nonordered carbon is converted to the ordered graphite structure (the process of graphitization). Despite these properties, however, the use of C–C composites has been limited both because of their high cost and their oxidation at elevated temperatures. A recent development in composite processing at the Air Force Research Laboratory (AFRL), Edwards, California—called *in situ* rapid densification—greatly reduces their processing time and thus their cost.

For ~30 years, C–C composites have been manufactured principally by two processes that use different means to combine the matrix and fibers and to densify the composite. One process involves impregnating the fiber preform with a liquid hydrocarbon such as pitch or a resin followed by carbonization, which removes all noncarbon atoms. The other process involves infiltrating the composite preform with a hydrocarbon gas. Both processes are followed by graphitization in which the partially densified composite is heated to temperatures above 2400°C to enhance its mechanical properties.

After the composite is graphitized, these processes require machining the outside of the partially densified composite to remove material. This step is required because both processes preferentially densify the outside of the composite, which blocks the surface pores so that additional densification cannot occur. Because of this shortcoming, the infiltration/impregnation-carbonization-graphitization-machining cycle must be repeated at least three times. Since each cycle requires 3–4 weeks, densification is time-consuming and costly. By understanding the reasons for the shortcomings of current commercial processing, the *in situ* rapid densification process is able to avoid inhomogeneous densification and reduce the time required from many months to less than two weeks, thereby markedly decreasing



Figure 1. Components fabricated by the *in situ* rapid densification process include brakes, nozzles, pistons, hypersonic leading edges, heating elements, and structural components.

ing the production cost.

This novel process rapidly densifies the composite uniformly because it addresses the opposing requirements of the impregnant’s low viscosity and good wettability on the one hand and the need for a high-char-yield carbon precursor on the other. This improvement is accomplished by using a low-viscosity impregnant, such as naphthalene, that wets the fiber preform surface and is then absorbed into the fiber perform, like water into a sponge, completely and uniformly filling the preform. Thus, this process gives a uniform density and eliminates the need for machining after densification. After the impregnant has filled the preform, the impregnant is polymerized into a carbon-matrix precursor, which is then pyrolyzed to produce a uniform, dense carbon matrix. Since the carbon-matrix precursor has a high carbon yield, fewer cycles are needed to bring the composite to final density.

Such a uniformly densified composite can be produced from any type of fiber preform (e.g., woven, braided, one-dimensional to *n*-dimensional, felt). Furthermore, in contrast to other processes, there does not appear to be a size limitation; preforms with diameters up to 45 cm and lengths up to 183 cm have been uniformly densified. An additional advantage of this technology is the ability to join C–C parts with a mechanically strong, seamless

joint. Some of the products produced by this process can be seen in Figure 1.

In this process, it is not necessary to graphitize the composites, thus saving time and energy. Even without graphitization, the ablation and erosion performance of the C–C composite produced by this process equals that of commercially produced composites that are exposed to the exhaust of liquid rocket engines or of solid rocket motors. In most applications, it is not necessary to graphitize the material. However, when it is exposed to temperatures above 2000°C, a highly graphitic material with high thermal conductivity is produced. The significance of this result is that it is possible to use the low-cost liquid phase process to produce C–C composites with the properties of composites produced by a gas-phase process. The likely decrease in processing costs associated with this process will result in many new applications for this material.

Opportunities

The AFRL High Temperature Components Group welcomes inquiries in cooperative research and development.

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