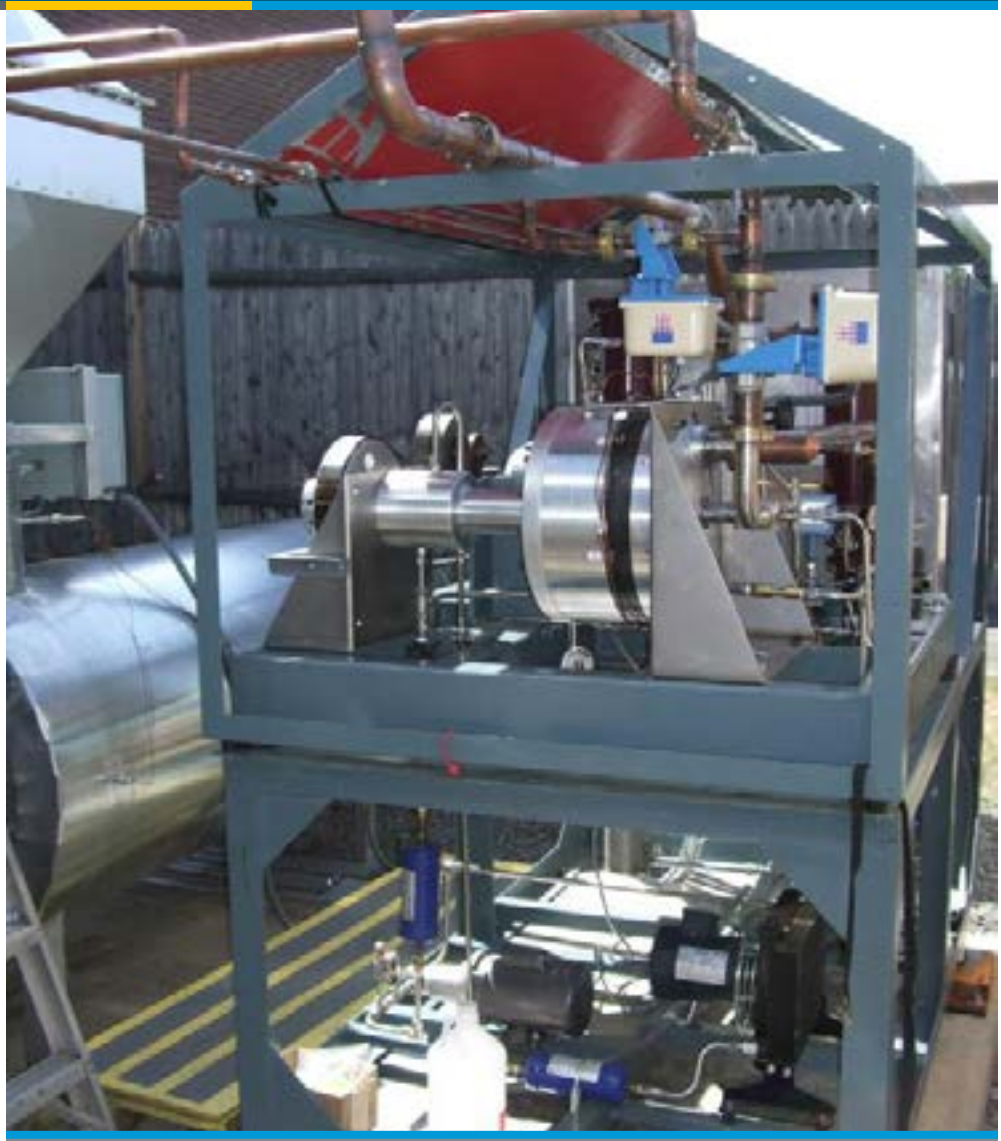
Scroll Expander for Organic Rankine Bottoming Cycle Waste Heat-to-Power System

Efficient, Cost-Effective System to Recover Medium-Grade Industrial Waste Heat

Developed Scroll Expander System is Suitable for Smaller Industrial Facilities.

There is a significant opportunity to recover waste heat that is exhausted in various manufacturing industries, including food processing. A large portion of unrecovered industrial waste heat is in the low and medium temperature range (below 800°F), which has less recovery value than high-temperature waste heat. Despite the lower recovery value, there is an opportunity for large energy savings if cost-effective technologies can be developed to recover and reuse this low- and medium-temperature waste heat.

Systems that utilize the Organic Rankine cycle (ORC) can convert medium-temperature waste heat into electric power. Typically, barriers to the development and deployment of small-scale waste heat recovery systems in manufacturing include payback period, lack of engineering resources, and impact on production and product quality. A proprietary scroll expander technology, developed by TIAX LLC, will help reduce the size, cost, and complexity of the waste heat recovery system that uses an ORC while also increasing efficiency compared to conventional bottoming cycle expander concepts. Medium-grade waste heat streams—between 400°F and 800°F—could be utilized effectively by an efficient, mechanically sound scroll expander that operates at an optimal power range. Scroll expander technology has already been successfully demonstrated with carbon dioxide expanders.



A field test unit of the Organic Rankine cycle waste heat-to-power system with a scroll expander being assembled. *Photo credit TIAX LLC.*

In the basic operation of the scroll expander-based ORC, working fluid is pumped through a recuperator and vaporized in a boiler, where it absorbs the waste heat. This vapor then leaves the boiler and enters the scroll expander, where the motion is converted to shaft power and drives an electric generator. After the working fluid is exhausted from the scroll expander, it again passes through the recuperator to be cooled, then to the condenser before being pumped back through the recuperator to the boiler. The design flexibility of the scroll expander allows for it to match the temperature availability of a specific waste heat stream. The scroll expander can also be scaled to a specific capacity and can accommodate a variety of organic and inorganic working fluids. In addition, the volume ratio can be varied to match the pressure ratio.

Benefits for Our Industry and Our Nation

The scroll expander-based ORC system could generate large energy benefits by enabling waste heat recovery from medium-grade waste heat streams that occur in a variety of industries. Applying

the scroll expander technology will improve the performance and reduce the cost of ORC in smaller-scale waste heat recovery applications. Even in batch operations (e.g., those found in food processing), which have more limited potential savings, between 5% and 30% of input energy could potentially be recovered. Waste heat recovery would also provide environmental benefits. If successfully commercialized, a fleet of only 300 scroll-powered waste heat-to-energy units could generate 60 million kilowatt hours of electricity, saving a total of 0.6 trillion British thermal units (Btu) and avoiding 66 million pounds of carbon dioxide emissions.

Applications in Our Nation's Industry

The scroll expander technology can be used in food processing applications such as coffee roasting, bakery operations, breweries, pet food production, dry roasting of nuts, and cocoa/chocolate processing, along with other industries such as textiles, plastics, fabricated metals, and foundries. Specifically, it will be compatible with industrial processes that exhaust moderate-quality waste heat between 400°F and 800°F.

Project Description

The project objective was to develop a scroll expander for ORC systems to be used in industrial and commercial medium-grade waste heat recovery applications, and to validate and quantify the benefits of the prototype system compared to other waste heat recovery technologies.

Barriers

- Limiting internal leakage losses in the expander and feed pump which would result in excess flow for the expander and an insufficient pressure rise in the pump.
- Limiting friction losses from the initial bearing and pressure balance configuration, which would reduce efficiency.
- Degradation of lubrication and/or working fluid in the boiler.
- Time variation in temperature or flow of waste heat stream.

Pathways

The ORC design was refined and the performance analyzed in order to ensure that it could be implemented as an efficient, cost-effective, and adaptable package. After the ORC design was completed, a more detailed design of the scroll expander was developed. Following bench test planning and design, the waste heat recovery system was assembled and tested in a laboratory environment. The scroll expander was then installed and demonstrated in a complete ORC system.

Milestones

This project began in 2013 and was completed in 2017.

- Completion of overall design of the waste heat recovery system, including the scroll expander and major ORC components, and analysis/modeling of system performance.
- Bench test system design, identification and purchase of specific parts, fabrication of components, and assembly of the bench test system.
- Laboratory testing of the bench test system performed over a range of conditions and speeds.
- Completion of the design of the field test system and testing of the ORC system at TIAX.

Accomplishments

- The scroll expander was demonstrated in a bench-scale set-up to have isentropic efficiency of more than 70%.
- When installed in a complete ORC system driven by a medium-grade waste heat source, the scroll expander generated 4-6 kilowatts of electrical power.

Commercialization

Before the developed scroll expander technology can enter the market, further testing, product development, and a host site demonstration are needed. The overall commercialization strategy is the end user pull model. A host site demonstration of the technology is expected to generate end user interest, which will enable TIAX to partner with waste heat recovery system suppliers to make, sell, and support ORC systems based on the scroll expander technology.

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Project final report available at www.osti.gov/scitech: *OSTI Identifier 1360148* ■