Modifications and Optimization of the Organic Rankine Cycle

Improving Recovery of Waste Heat in Industrial Processes

This project developed and demonstrated a direct evaporator for an Organic Rankine Cycle (ORC) system that utilizes waste heat from a reciprocating engine or gas turbine.

Introduction

Waste heat from turbines and engines used in industrial applications along with waste heat from industrial processes are exceptionally abundant sources of energy. If even a fraction of this waste heat could be economically converted to useful electricity, it would have a tangible and very positive impact on the economic health, energy consumption, and carbon emissions in the U.S. manufacturing sector. The current waste heat recovery technologies, including ORC systems and thermoelectrics, are technically feasible but in many cases economically unattractive. This limits their current use to a small number of niche applications.

ORC technologies operate by transferring heat from the source through an evaporator to boil a fluid and create vapor that is expanded across a turbine or other work extraction device. This creates shaft power that can be easily turned into electrical power through a generator. Current limitations in ORC technologies have led to inefficient systems that offer only marginal economic benefits. These limitations stem from the use of a secondary heat transfer loop in most commercial systems to offset safety risks. This secondary loop creates additional costs for each unit, increases the opportunity for component failure, and reduces the conversion efficiency of the system.

To address these problems, researchers are working to develop advanced and cost-effective ORC systems. In this project, the research team leveraged previous work in advanced ORC technologies to develop a new direct evaporator solution that will reduce the ORC system cost by up to 15%, enabling more rapid adoption of the technology for industrial engines and turbines.

Benefits for Our Industry and Our Nation

GE has more than 1,800 simple cycle gas turbines installed in North America and Europe that cumulatively generate more than 60 GW of electrical power. If 20% of this installed base were retrofitted with the proposed ORC technology, 3 GW of additional electrical power could be produced, which would effectively utilize 90 trillion Btu of waste heat per year. These energy savings represent CO_2 emission savings of 4.8 million metric tons, and economic savings of $630 million. An anticipated additional economic benefit of this research effort is a reduction in the costs of ORC technology, which will provide greater returns on investment than previous ORC systems.

The direct evaporator and supporting equipment installed at the GE test facility. *Photo courtesy of Idaho National Laboratory.*

Applications in Our Nation's Industry

This technology will be initially retrofitted for waste heat recovery in reciprocating engines and gas turbines. ORC systems can be used in waste heat recovery applications for a broad range of industries, including metals and minerals manufacturing, refineries, chemical processing plants, concrete plants, iron smelters, and an array of other industrial processes.

Project Description

This project optimized the ORC for the conversion of low-temperature waste heat from gas turbine or reciprocating engine exhaust to electricity. The work entailed detailed design and modeling of a direct evaporator concept that improves efficiency by eliminating the usual secondary heat exchanger loop. Thermal decomposition and flammability analyses of the organic working fluid were performed to maximize system performance and minimize safety risks. A prototype test facility was designed and constructed to evaluate the operation of the direct evaporator. The result of these efforts was a safe, economically feasible direct evaporator design to be manufactured with the gas turbine or reciprocating engine as a single package that is easy for customers to install and operate.

Barriers

- Most commercial ORC systems use a flammable hydrocarbon working fluid. If the evaporator were to develop a leak, the flammable working fluid would leak into the hot exhaust stream and create a potential fire hazard. Additionally, an evaporator placed directly in the exhaust stream poses the risk of heating up the working fluid to the point that it rapidly decomposes, forming decomposition byproducts. This can reduce cycle efficiency and cause potential fouling of the heat exchanger tubing.
- It is common for ORC systems to cost $2,500/kW and above. At this cost, most of the available waste heat recovery opportunities are not economically viable.

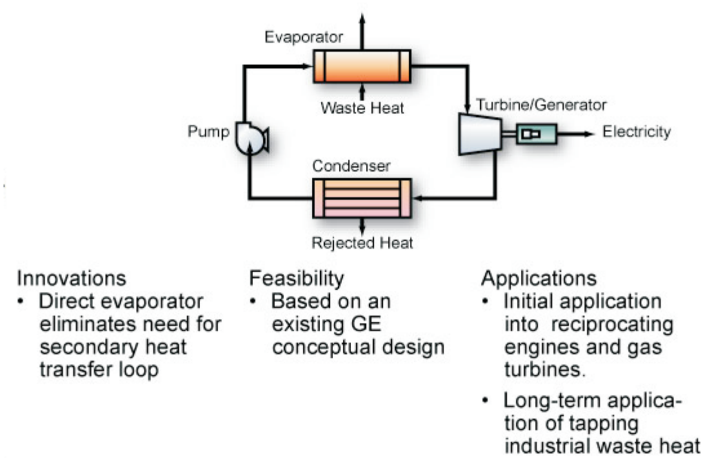
Pathways

To eliminate the limitations caused by the secondary heat transfer loop, researchers developed an advanced ORC system by using a novel direct evaporator approach, which was based on conceptual designs that had been developed by GE. This research effort accelerated the development of the technology through research in flammability, two-phase heat transfer, and experimental validation.

Milestones

This project started in 2008 and concluded in 2013.

- Detailed design and modeling of evaporator
- Design and construction of partial prototype test facility
- Working fluid decomposition chemical analyses
- Test-bed heat transfer evaluation
- Design, build, and test prototype evaporator in ORC cycle



Concept schematic of a direct evaporator for an Organic Rankine Cycle system. *Illustration courtesy of Idaho National Laboratory.*

Accomplishments

- A prototype ORC system using direct evaporation technology was fabricated and tested
- A process to evaluate and select an optimal ORC working fluid was developed
- Safety risks associated with the direct evaporator design were evaluated and mitigation strategies developed

Commercialization

GE will initially focus on pairing the developed direct evaporator ORC technology with existing GE turbines and engines; specifically the small-frame gas turbines offered by GE Oil and Gas operations, and the natural gas reciprocating engines offered by its Jenbacher operations.

After GE has evaluated and proven the reliability of its ORC cycle in a sizable installed base of GE engines and gas turbines, it will then be able to adapt this ORC technology to a broader range of applications, especially those utilizing industrial sources of heat.

Project Partners

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Project final report available at
www.osti.gov/scitech: *OSTI Identifier 1116747*

DOE/EE-0463 • Updated June 2017