Organic Rankine Cycle Waste Heat Solutions And Opportunities In Natural Gas Compression > The renewable energy source you already have

BY JOHN FOX

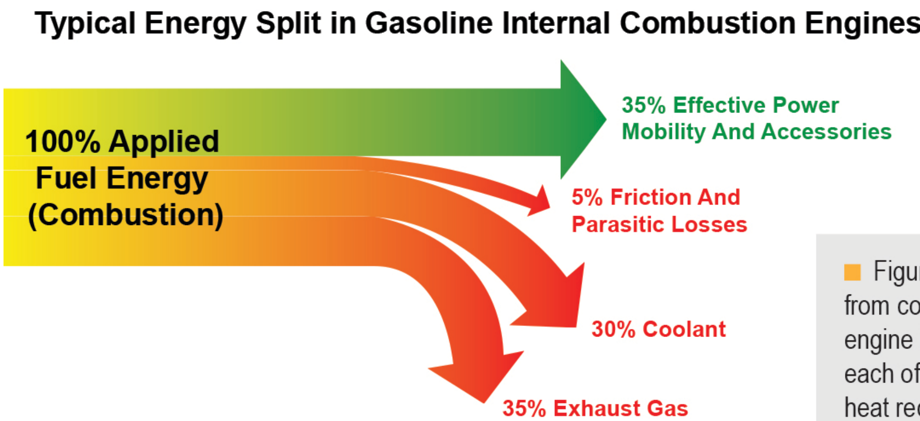

Figure 1. The majority of the heat resulting from combustion in an internal combustion engine is lost in the coolant and exhaust, each of which represents an opportunity for heat recovery.

It takes a significant amount of energy to transport the ever-growing supply of natural gas in the United States from where it is produced to where it is consumed. At each natural gas compression station there are multiple opportunities to convert the existing waste heat streams to additional electricity for the site and potentially more horsepower for increased compression and plant throughput. The existing waste heat streams can be converted to more power with no added fuel or emissions, using technology that is proven and established worldwide.

Organic Rankine Cycle (ORC) technology has been around for decades, but only recently established itself as a proven source of power generation from low-temperature waste heat streams. Such heat streams are commonly found on reciprocating engines, where an ORC generator can increase engine performance and decrease fuel consumption by converting the engine's jacket water and/or exhaust into additional electricity for the site. The typical engine runs at approximately 35% efficiency, resulting in considerable waste heat from the jacket water and the exhaust.

Engine applications include prime power production in remote areas, island and developing nations, biogas gen-sets such as landfill and wastewater treatment plants, and renewable biofuels. The thousands of natural gas compression engines across the globe provide a great opportunity for waste-heat-to-power. The abundance of waste heat in its many forms provides for the renewable you already have.

Because ORC generators work as cooling devices, they can act as the engine's radiator, essentially working as a "radiator with a payback." For all engine applications, there is an associated cost of cooling the engine, either in horsepower provided by the engine or in electricity purchased from the grid. By adding an ORC to an engine installation, the parasitic load of cooling the engine can be greatly reduced or even eliminated. The ORC turns the cost of cooling into the payback of cooling.

Excess heat abounds

Most industrial processes, though designed with efficiency in mind, shed excess/unused heat in some form and in significant amounts. Heat may originate from boilers, engines, furnaces, incinerators, etc., or it may originate from other processes, including gas compression, chemical reactions and more.

The majority of the heat resulting from the combustion of fuel in an internal combustion engine is lost in the coolant and exhaust, each of which represents an opportunity for heat recovery (Figure 1). This level of heat rejection is common to diesel, gas, or biomass-powered reciprocating engines. Exhaust stack gases from virtually all combustion processes (ovens,

continued on page 34

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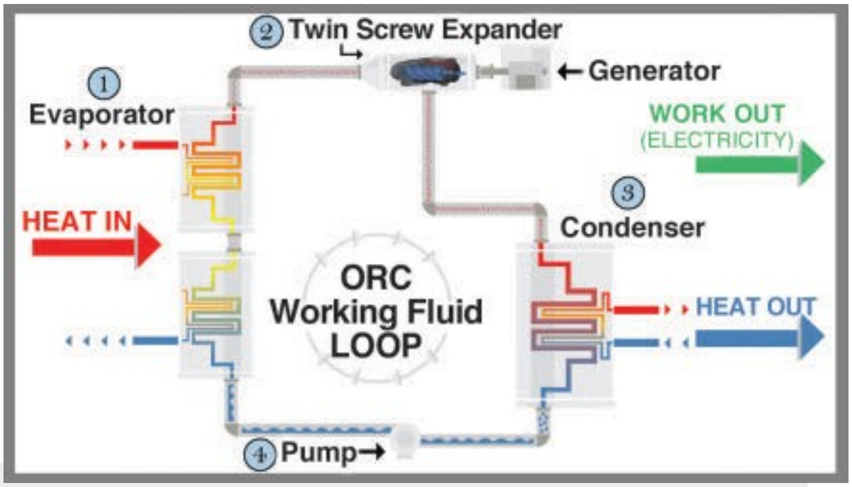

Figure 2. The Organic Rankine Cycle (ORC) has much in common with both the steam engine and a refrigerator. It is a thermodynamic device (an engine) to convert thermal and mechanical energy.

kilns, furnaces, incinerators, thermal oxidizers and boilers) contain a large fraction of the original energy of the fuel consumed.

In addition to industrial processes, waste heat is available in alternative energy applications such as geothermal, biogas, solar, biomass, and oil field geothermally heated co-produced fluids.

Historically low-grade waste heat has been ignored for several reasons:

- Low-temperature waste heat cannot drive conventional heat engines such as water-based Rankine cycle systems (steam-turbine power plants). A lower-temperature method of converting a fraction of this heat into electricity is needed.
- Although the total amount of heat can be very large, it is geographically diverse. There is insufficient heat available at individual process sites to utilize the most commonly available heat engine solutions, typically rated in megawatts. Therefore, the distribution and variation of available waste heat demands smaller, modular and distributed generation technology.
- Industries produce heat as a by-product of their primary enterprise, so they generally do not consider waste-heat-to-power as an integral part of their operations. Often sites do not have the personnel with the skills or desire to recognize a power generation opportunity, be able to design and install heat capture hardware plus ORC, and operate and maintain power station-type equipment.
- Finally, low relative energy costs, as well as the historically intangible nature of the environmental benefits associated with reduced emissions, have made the payback period of small waste-heat-to-power equipment too long. However, historically rising costs of energy — including the environmental costs of fossil fuel combustion — coupled with enabling new technology, have reduced the return on investment for waste-heat-to-electricity conversion equipment.

How it works

The ORC process follows that of the steam engine, the principle difference being the replacement of water with a working fluid with a much lower boiling point. Consider the ORC a refrigerator running in reverse, i.e., heat flow across a difference in temperature generates power. See the basic cycle in Figure 2.

Steps in the process include:

- Surplus heat is used to boil a working fluid in an evaporator.
- Under pressure, the vapor is forced through a twin-screw expander (the power block), turning it to spin an electric generator.
- The vapor is cooled and condensed back into a liquid in the condenser.
- The working fluid liquid refrigerant is pumped to higher pressure and returned to the evaporator to repeat the process.

Replacing water with alternative low boiling-point fluids allows a modified version of the traditional Rankine cycle to successfully use heat — which is typically at temperatures too low to drive a steam engine — to produce electricity. Such fluids include organic molecules, e.g., hydrocarbons like pentane, or hydrofluorocarbon refrigerants, hence the moniker ORC.

ElectraTherm's ORC waste-heat-to-power generators use a hydrofluorocarbon called R-245fa (1,1,1,3,3-pentafluoropropane), a nonflammable, nontoxic liquid with a boiling point slightly below room temperature, about 58°F (15°C).

Return on investment

To take low-temperature heat energy from the jacket water of a 1341 hp (1 MW) engine-powered generator, for example, and convert it to a valuable form of energy such as electricity, ORC technology is bound by the same laws of thermodynamics that apply to the engine itself. Heat must be rejected.

Figure 3 shows heat flowing from a high-temperature T_H through the

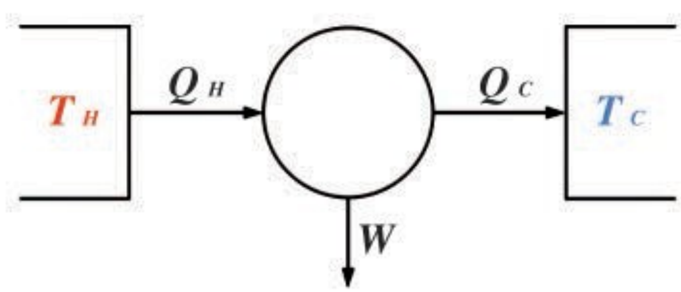

Figure 3. Heat flows from a hot source to a cold sink. Some heat is converted to useful work.

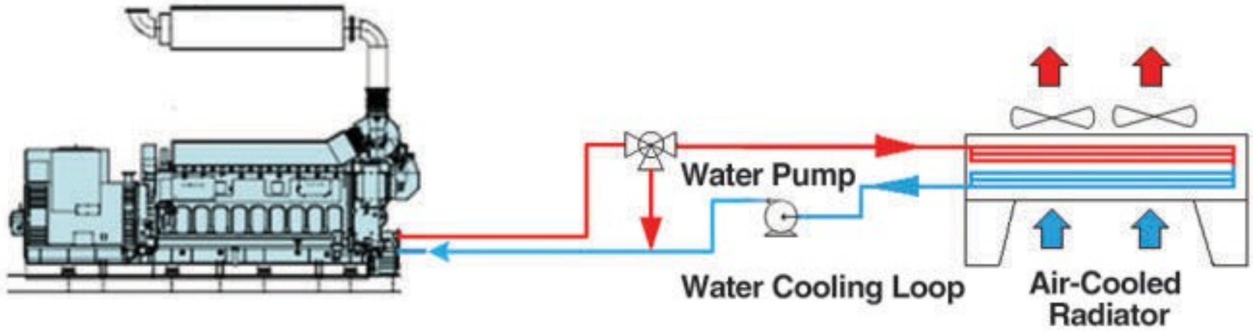

Figure 4. One single cooling device for engine/ORC combination — the engine radiator is eliminated in the lower configuration.

working fluid of the ORC and into the cold sink T_C, forcing the working substance to do mechanical work, in this case on a generator.

The fraction of heat that is theoretically recoverable is limited by the Carnot efficiency equation, given as:

$1 - (T_H / T_C)$

provided that temperatures are measured in Kelvin or Rankine degrees. Thermal efficiencies range between 6 and 12%. Although the numbers seems small, since the heat is already going to waste, the fuel source is essentially free.

The heat from the condenser can be reused, though not for generating more electricity because of its low temperature, but in applications for low-temperature heat, such as district heating, greenhouses, aquaculture, domestic hot water preheating, radiant heating, swimming pools, de-icing, etc.

ORC efficiency R&D

ElectraTherm, a manufacturer of low-temperature ORC generators, in working with the U.S. Department of Defense (DoD), researched ORC efficiencies and output, and discovered the possibility of replacing the engine radiator completely.

The company began its first project with the DoD to simulate various U.S. Navy-owned engine models and ORC integration schemes, and fully test those configurations on ElectraTherm's test cell. A matrix was developed consisting of five engine models and two-engine configurations over different ambient conditions for waste heat capture: jacket water only and jacket water boosted

continued on page 36

The skidded ORC unit includes a combined radiator for the both the engine and the ORC.

with exhaust energy. Navy personnel visited ElectraTherm several times during the first project for training and inspection of the test cell and facilities. At the conclusion of the project a favorable report was issued by the Navy and is available for U.S. Government employees upon request.

The next project, which is underway, is the development of a higher output, fully integrated ORC specific to a Cummins KTA-50 1475 hp (1.1 MW) engine for DoD deployment. The ORC and balance of plant are packaged in ISO shipping containers for ease of deployment and mobility throughout the world. Funding for this second project came from DoD's Environmental Security Technology Certification Program (ESTCP) through Southern Research Institute (SRI), which is independently monitoring the performance and fuel efficiency gains.

Replace the engine radiator

This project forced the ElectraTherm engineering team to look hard at the question, "Do we need both the engine radiator and ORC radiator?" All ORCs need condensing and all engines need cooling. Could it be done with one radiator, eliminating approximately $75,000 in capital cost for an engine this size?

The answer was a clear "yes." Advanced engine cooling with a payback was born, accomplished with an intermediate heat exchanger to optimize the return temperature to the engine and a bypass to ensure the engine cooling remained operating if the ORC is not running. The impact to the overall installed cost for an ORC can now be reduced by 20 to 30%.

Figure 4 shows how the engine radiator is replaced by the ORC and its condenser, a liquid loop radiator. In the lower schematic, the ORC is capturing both the engine jacket water and exhaust for maximum electrical output. The preheater of the ORC is specifically sized to the engine model to remove most of the engine cooling duty — reducing parasitic loads at existing sites with engine radiators or completely eliminating the engine radiator on greenfield sites or where radiators are being replaced or upgraded. A secondary loop configured between the engine and the condenser for the ORC controls the return temperature of the jacket water to the engine. The ORC condenser is sized for 100% heat rejection for the engine, and the ORC and the engine cooling operate seamlessly whether the ORC is on or off.

If integrating at a site with a shaft-driven radiator, the radiator can be decoupled and additional horsepower freed up for compression. In effect, the engine's waste heat becomes a source of cost savings by displacing the radiator's capital cost, reducing or eliminating the associated parasitic load on the engine and producing electricity for the site.

Figure 5 shows the configuration that will deploy later this year, comprised of two 40 ft. (12.2 m) ISO (International Standards Organization) shipping containers. The Cummins gen-set, engine controls, switch gear and exhaust-gas heat exchanger are housed in a combined heat and power (CHP) module packaged under ElectraTherm's direction by Cummins Rocky Mountain, located in Denver, Colorado.

The ORC module will contain the ORC and associated controls, liquid loop radiator (the combined radiator for the engine and ORC), and the corresponding balance of plant, including piping, pumps and expansion tank, etc. The system will be tested first at ElectraTherm's facility, and then shipped to the field for a full year of performance monitoring and fuel savings validation.

Waste heat to additional compression

ElectraTherm's experience with gen-set integration has included single and multiple engines utilizing jacket water heat alone as well as jacket water combined with exhaust heat. ElectraTherm's ORC has been integrated with engine models from Jenbacher, Deutz and MWM in Europe, and CAT and Waukesha engines in North America. The ElectraTherm product line consists of ORCs sized from 47 hp (35 kW), 87 hp (65 kW) to 147 hp (110 kW). These fit well with ~700 hp (~500 kW), ~1000 hp (~800 kW) and ~1500 hp (~1000 kW) engines, respectively.

As ORC technology continues to grow in varying applications and geographies, new opportunities will bring value to the marketplace. The large number of stationary engines associated with natural gas compression provide ample waste heat.

One prospective customer is investigating the potential of removing the

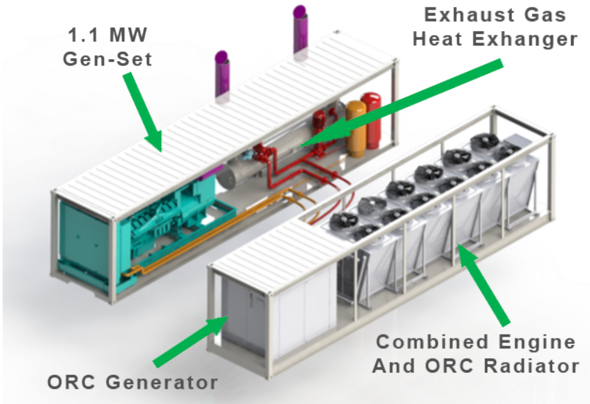

Figure 5. Containerized prime power with ORC integration and complete engine radiator replacement.

shaft-driven radiators from their existing gas compression engines. In doing so, approximately 75 hp (56 kW) of parasitic load from the engine will be removed, freeing up horsepower for additional compression. Plus, the ORC-generated electricity can be converted to more compression via an additional electric compressor. More compression means more gas throughput, which equates to increased revenue.

Converting the existing waste heat streams to more compression without increased emissions can be of particular interest in emissions-capped (nonattainment) areas where another engine cannot be added easily. An ORC is a unique approach for increasing plant throughput without additional emissions, thereby keeping the station under existing permitted levels.

Distributed waste-heat-to-power systems for stationary engines are not yet widely known or mainstream, but the technology is field-proven, and the economics and improved site performance can be attractive. New genset applications, or plants looking to replace an existing radiator, may consider ORC technology as a "radiator with a payback." Plants seeking more compression capacity should consider using the waste-heat resource already available to improve site throughput. CT2

ElectraTherm's Organic Rankine Cycle (ORC) unit converts waste heat to usable power.