ACEP

Alaska Center for Energy and Power

Fostering development of innovative solutions to Alaska's energy challenges.

The Green Machine: A Possible Means for Increasing Diesel Engine Efficiency in Alaska

Research Briefing

This report looks at whether an organic Rankine cycle device can be added to Alaska's rural power plants to economically generate additional electricity from excess heat from diesel generators.

Project Introduction

The isolated rural villages in Alaska annually consume about 370,000 MWh of electrical energy, which comes from individual diesel-fired generator sets. Because the generators must be sized for the maximum usage a village will need, the generators are running at less than full capacity during off-peak times; the ratio of electrical power produced to fuel energy consumed is generally less than 40%. The rest of the fuel energy is lost as heat. While some power plants utilize a portion of this for other heating needs, such as space and water heating, the majority of this energy in Alaska is wasted.

The goal of adding organic Rankine cycle (ORC) products to an existing power cycle is to reclaim some of this heat to generate a bit more power, increasing the overall fuel efficiency of the power plant. While this technology is mature for larger-scale power generation, the products for smaller-capacity generator sets, appropriate for the typical size of Alaska village power plants, are still new to the market or in prototype phase. Many villages are being approached by these product developers to invest in this new technology, so ACEP, in partnership with its funding partners, the Denali Commission and the Alaska Energy Authority, set out to test its viability in Alaska.

ElectraTherm's "Green Machine" was identified as one of the devices with the highest potential for success. The Green Machine is designed to generate up to 50 kW of power using the organic Rankine cycle, which is a process used to obtain energy from lower-value (lower temperature) heat sources than are commonly used for power generation.

The Alaska Center for Energy and Power (ACEP) is an applied energy research group housed under the Institute of Northern Engineering at the University of Alaska Fairbanks.

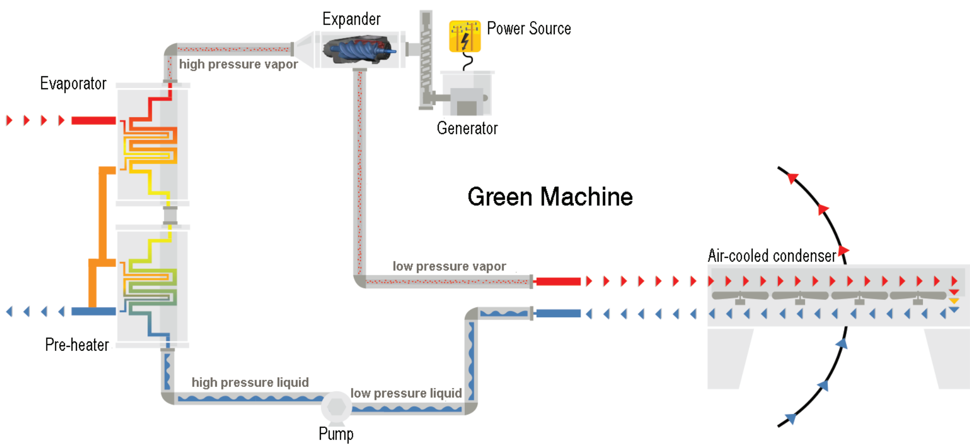
Mechanical engineering doctoral student Vamshi Avadhanula operates the controls of the Green Machine. In addition to the technical aspects of the study, researchers are assessing whether operations and maintenance of the device would impose a significant burden on rural power plant operators.

UAF photo by Todd Paris

ACEP and Tanana Chiefs Conference

In 2010, the Alaska Center for Energy and Power (ACEP) partnered with Tanana Chiefs Conference (TCC), a nonprofit consortium of 42 communities in Interior Alaska, to obtain and test a 50 kW Green Machine. ACEP tested the Green Machine for 600 hours at the University of Alaska Fairbanks (UAF) power plant and collected and analyzed the data, finding promising results. In the meantime, TCC facilitated communication between ACEP and the villages to help select an Alaska community whose power company would be willing to field test the Green Machine. Tok was selected by TCC, and the Green Machine will be installed in the Tok power plant in the summer of 2013.

How the Organic Rankine Cycle (ORC) Works



Step 1: Heat is captured by the evaporator and boils the working fluid into pressurized vapor.

Step 2: The vapor flows through the twin screw expander, spinning an electric generator to produce power.

Step 3: The vapor is cooled and condensed back into liquid in the condenser.

Step 4: The working fluid is pumped to higher pressure and returned to the evaporator to repeat the cycle.

Courtesy of ElectraTherm, Inc.

Is the Green Machine Right for Alaska?

The goal of the Green Machine project in Alaska is to determine whether the device is an economical way to utilize waste heat from rural power plants, taking excess heat from the first power cycle and using it as the input to the organic Rankine cycle, wringing out a bit more power before finally discharging the lowest-temperature exhaust heat into the environment. In rural villages, where diesel is flown in and costs from \$5 to \$20 a gallon, to effectively increase the overall efficiency of the power generator makes economic and practical sense. The Green Machine is estimated to increase overall fuel efficiency by 3% to 4% and reduce CO_2 emissions by 22.2 pounds for every gallon of diesel conserved. Using those figures, payback time for the Green Machine can be as little as two years, depending on the exact input and output temperatures and the cost of fuel.

ORC Technology

The Rankine cycle extracts energy when a working fluid, usually water, undergoes a phase transformation between liquid and steam. The working fluid is boiled by the heat source and expands into steam. This expansion powers a turbine. Once the usable energy is released through steam, it condenses back to a liquid, expelling waste heat in the process. The Rankine cycle is widely used in fossil fuel power generation and in solar thermal, biomass and nuclear power plants, generating about 90% of all electric power used worldwide today.[1]

The organic Rankine cycle operates on exactly the same principle, only it uses an organic compound specially chosen to operate at a lower working temperature as a working fluid, which enables it to extract power from lower-temperature heat sources. The organic Rankine cycle is used to power the hotel and resort at Chena Hot Springs, the lowest-temperature geothermal resource used for commercial power production in the world.[2]

Initial Product Assessment

In 2009-2010, the ORC research team at UAF performed an extensive literature and product search and found that ElectraTherm's Green Machine was the only ORC machine that was close to commercial release that would work on the small-scale and low-temperature heat output that would come from a typical village generator set. Large-scale ORC units (approximately 100 kW or more) are an established technology, but small- to mid-sized applications still need testing for feasibility and economic viability.[3] The Green Machine was also an ideal candidate because it has a simple design with routine maintenance requirements that a village power plant operator would be familiar with (for example, lubricating bearings). It also promised to be robust through potentially rough shipping, and the manufacturer was cooperative and very interested in having a field test in a harsh Alaska environment.

UAF photo by Todd Paris

ACEP Research Engineer David Light sets up the Green Machine at the UAF power plant for the first round of testing and performance evaluation. The UAF Power Plant was a main partner in this phase of the project, allowing ACEP researchers to use surrogate heat and water sources from the university's combined heat and power plant to simulate a diesel generator in a controlled setting.

Research Methods

The Green Machine ORC unit was installed at the UAF power plant in November-December 2011. After 600 hours of run time, the ORC system consistently generated 47.1 kW of net power (after accounting for parasitic power losses) when both the heating source and cooling source provided sufficient temperatures and flow rates. The test was designed to mimic the operating conditions of a village diesel generator, with temperature and flow rate of the heating source similar to that of the jacket coolant.

No major system breakdowns occurred during the test and the performance period, and every component of the system appeared consistent with the manufacturer's specifications. During the 600 hours of the reliability testing, the only flaw that was found was a defect in a pressure switch that caused an intermittent inability to restart the ORC system. The flaw was automatically detected by the ORC system software displayed on the system monitor screen. This is one of a series of safety guards to prevent the machine from overload; this defect will not affect the system's ability to operate.

Product Testing and Analysis

Based on data obtained from the reliability test, net efficiency of the ORC system was found to be about 7.6%, with a potential annual energy generation of about 398,500 kW-hours (assuming 363 working days and two maintenance days), and a potential annual diesel fuel saving of 28,500 gallons. The estimated annual reduction in CO_2 is 316 tons; CO, 3,075 pounds; HC, 351 pounds; PM, 88 pounds; and NO_x, 3,075 pounds. Assuming an interest rate of 10% and a diesel fuel price of $5/gallon, the payback time is about 2.4 years. With an interest rate of 0%, the estimated payback time becomes 2.1 years.

A 50-hour performance test was conducted after the reliability test was completed. The performance test measured the electrical output of the ORC system as well as the effects of varying the temperatures and flow rates of the heating and cooling sources. The results demonstrated performance consistency throughout the varying conditions. The results also showed that the efficiency for gross output of the ORC system ranges from 5.6% to 8.2% (net efficiency from 5.3% to 7.6%) for a wide range of heating source and cooling source conditions.

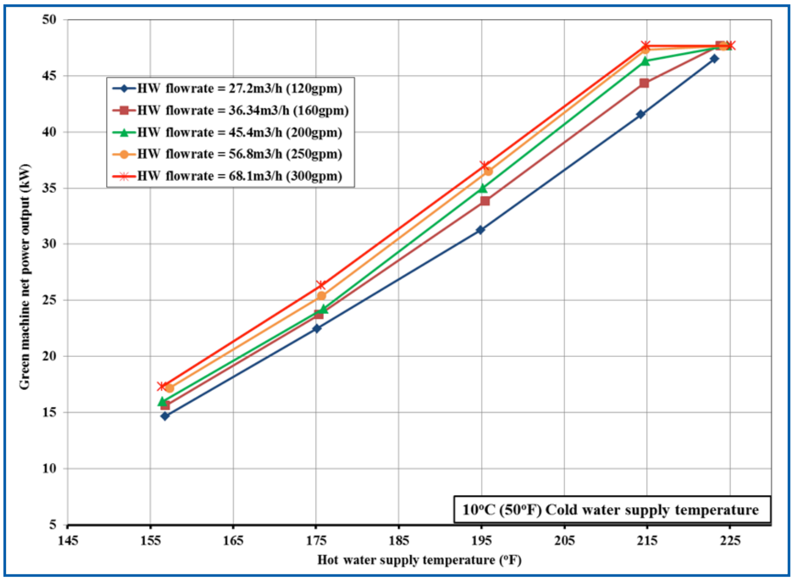
Project Findings

Findings on performance: Fuel efficiency of a diesel generator may be improved by about 4% with an ORC system, which uses waste heat from the diesel engine jacket water and exhaust.

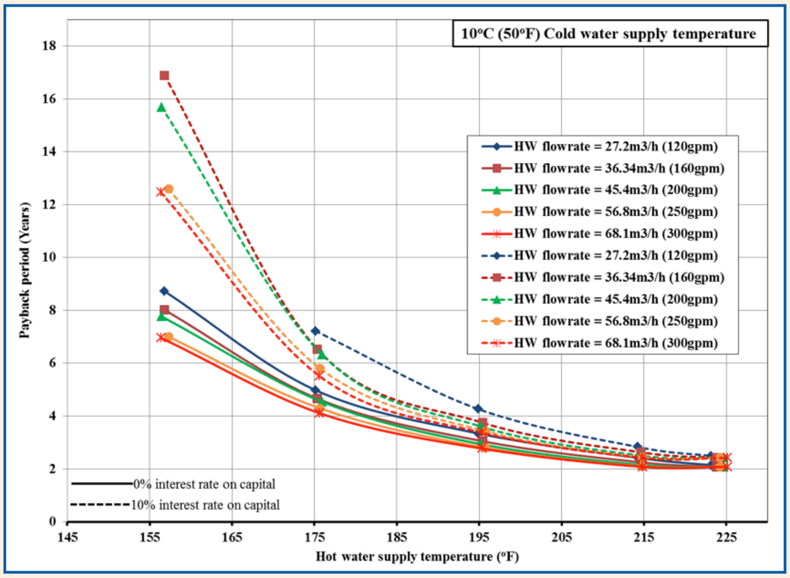
Experiments show that the maximum net efficiency experienced at a heating fluid temperature of 195°F (typical jacket water temperature) is about 7.4%. Assuming that more than 50% of fuel energy is wasted as heat (in the jacket water and exhaust), this means the potential improvement of fuel efficiency is about 3.7%, which is close to the target of a 4% improvement in fuel efficiency. In addition, if a higher-temperature heat source (such as is obtainable from exhaust) is used along with a simple retrofitting process to increase the cap of the ORC output restriction from 50kW to 65kW, then the 4% improvement in fuel efficiency seems reachable.

Findings on usage feasibility: Based on the observations and operating experiences, the system is considered very reliable under normal operating conditions. No technical problems are foreseen at this time, and no advanced technology background is needed for operation and maintenance. Maintenance is also relatively inexpensive, requiring only inexpensive consumable materials such as filters and lube oil if the maintenance schedule is incorporated into the routine diesel generator set maintenance schedule.

Findings on payback: Based on the reliability testing results at full capacity (50 kW) of the Green Machine, the estimated payback time is 2.1 years for a 0% interest rate and 2.4 years for a 10% interest rate.



Test Results: Green Machine power output at different jacket water temperatures and flow rates



Calculated payback period for Green Machine at different jacket water temperatures and flow rates, assuming:

1. 363 working days per year with two days of maintenance
2. Stationary diesel engine specific fuel consumption of 3.7kWh/lit (14kWh/gal)
3. Diesel fuel cost of $5/gal
4. Total initial investment cost (component cost + installation cost) estimated at $280,500 (includes GM cost).
5. Estimated yearly maintenance cost of $7,600

Next Steps

Now that the Green Machine has proved promising in a controlled laboratory environment, the next step is to test it in the real-world conditions of a rural village. ElectraTherm is also interested in the performance data that ACEP will collect during the device's field deployment.

ACEP, in partnership with Tanana Chiefs Conference (TCC), which owns the Green Machine, assessed each of the 42 communities in the TCC region as appropriate testing grounds for the device based on several factors, including capacity and interest of the utility, ease of access, current configuration of the power plant and the existing use of waste heat in each community.

Based on this assessment, Tok was selected in partnership with its utility, Alaska Power and Telephone (AP&T), which manages several power plants statewide. The Green Machine was installed in AP&T's Tok power plant in the fall of 2013, and AP&T is contributing its expertise and trained manpower at the test site. Plans are in the works for the installation of three more organic Rankine cycle devices in rural Alaska.

Future Considerations

One important consideration for future installations in Alaska is how this device could impact the current uses of waste heat in communities. For instance, AP&T's Tok power plant currently uses a portion of its waste heat to heat its office and shop spaces. In winter, more waste heat is used for space heating, leaving less for the Green Machine's use. In summer, less heat is used for space heating, but the Green Machine's cooling needs will be more difficult to meet. Active cooling will draw more parasitic power and reduce the net amount of electricity that the Green Machine produces. This balance will be considered and monitored during testing to determine the most viable configuration for future installations.

Notes

[1] Wiser, Wendell H. 2000. *Energy resources: occurrence, Production, Conversion, Use*. Birkhäuser. p. 190. ISBN 978-0-387-98744-6.

[2] www.chenahotsprings.com/geothermal-power/

[3] Avadhanula, V., Lin, C., and Johnson, T., "Testing a 50kW ORC at Different Heating and Cooling Source Conditions to Map the Performance Characteristics," SAE Technical Paper 2013-01-1649, 2013, doi:10.4271/2013-01-1649.

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