Case Study of the PureCycle 280 Organic Rankine Cycle Machine Installed in Cordova, Alaska

By John Venables, ACEP Intern

Table of Contents

Objective:

This case study investigates the first cold climate use of an Organic Rankine Cycle (ORC) machine coupled with a diesel generator as integrated by the Cordova Electric Cooperative. The goal was to generate extra electricity from waste heat from a diesel generator in order to increase the fuel efficiency of the generator by generating extra electrical power.

Background:

The Organic Rankine Cycle is designed to take waste heat and turn it into useful electricity. Similar to the Rankine cycle, the ORC is supplied by an external heat source and this heat is then applied to a working fluid, causing the fluid to evaporate. The vapor is then passed through an expander, in this case a turbine, which spins a generator. The vapor is then sent through a condenser, which is connected to a cooling tower, where heat is transferred from the vapor to the water in the cooling line, returning the vapor to a liquid state. This liquid is then pumped back through the evaporator and the cycle begins again. When coupled with a diesel generator, the hot liquid resource is the glycol/water cooling mixture from the generator. The ORC cycle is shown in Figure 1.

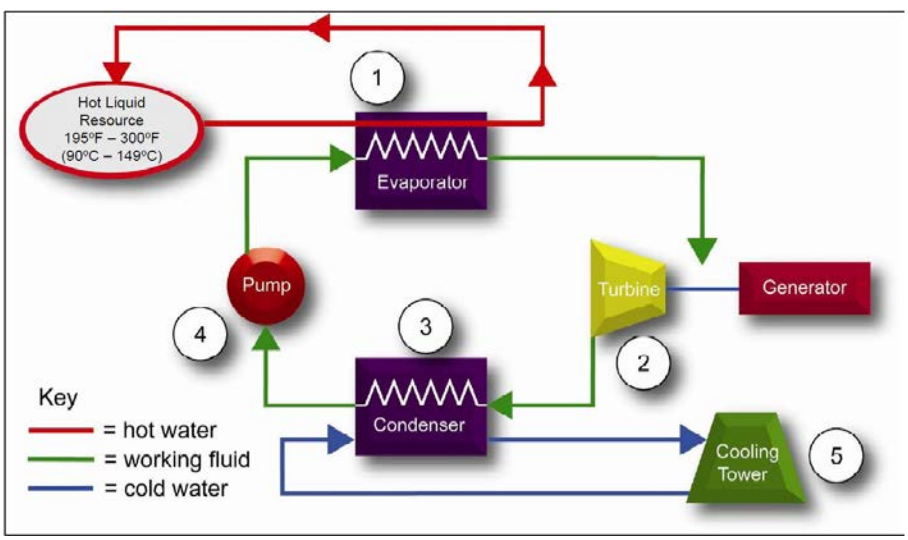

Figure 1: PureCycle ORC Schematic from Product Data and Application Guide

The Rankine cycle is the basis for all steam engines which are used today, however the heat required to change water to steam is much too high for waste heat applications. The ORC takes advantage of an organic working fluid with a phase change at a much lower temperature than a system that uses water as its working fluid. This allows the ORC to be used in applications such as waste heat recovery, biomass power plants, geothermal plants and even solar thermal applications.

Project:

The Cordova Electric Cooperative (CEC) chose to install a PureCycle Model 280 manufactured by Pratt & Whitney Power Systems, Inc. The PureCycle ORC was coupled to an Electro-Motive Division (General Motors) model 710-G4CT2, 3.7 megawatt (MW) diesel generator.

Technical Data for PureCycle 280 ORC:

Working Fluid:

The Pratt & Whitney PureCycle Model 280 Organic Rankine Cycle machine uses R245fa, a hydrofluorocarbon called pentafluoropropane, as its working fluid. R245fa is often used as a foam-blowing agent in the insulation industry and is also used as a new type of refrigerant for centrifugal chillers. Because it is lacking chlorine and doesn't have a flash point, R245fa will not deplete the ozone and is also nonflammable. The normal charge for the PureCycle is approximately 3,200 lbs (1450 kg), and only Genetron®® 245fa is acceptable for use in the ORC. The ORC should be stored above 60°F (15.5°C) to prevent any non-condensable gas, such as air and oxygen, from getting into the system.

Hot Liquid Resource:

The hot liquid resource required by the ORC ranges between 195°F (90°C) and 300°F (149°C) with a cold water source for cooling at a temperature less than 85°F (30°C). The greater the temperature difference between the heating and cooling sides of the ORC, the more power will be produced. The hot resource flow rate must also be between 180 and 1100 gallons per minute (gpm), with higher fluid rate required for lower hot liquid resource temperature.

Electrical System:

The ORC has a maximum gross output of 280 kW, a maximum net output of 260 kW and is designed to shut down if the gross output power decreases below 80 kW. The turbine spins a two-pole induction generator that is designed to produce three-phase AC power at 480 volts and 60 hertz. The ORC can also be setup to supply 380, 400, or 415 volts at 50 hertz as the application requires. The power factor of the ORC is also greater than 0.95 lagging.

Remote Monitoring System (RMS):

The ORC comes with remote monitoring capability which provides operators with both local and remote control of the ORC through the internet. The RMS provides communication between the operator and the equipment, for enhanced troubleshooting and remote software updates, logging of all system alarms, remote monitoring of the ORC, data storage for historical performance data, and remote startup and shutdown. The ORC can also be wired into already existing Supervisory Control and Data Acquisition (SCADA) systems that are on-site.

Additional Details:

The ORC is designed to operate in ambient temperatures between -22° and 122° F (-30° and 50° C) and produces 78 audible decibels at a distance of 33 feet. The ORC also has a design life of 20 years.

Cordova Experience:

Timeline and Funding:

In 2008, the Cordova Electric Cooperative submitted an application for project funding to the Alaska Energy Authority (AEA), and installation planning and design started in 2010. The building to house the ORC was constructed in the summer 2010, along with the purchase of the cooling tower. The ORC was installed in fall of 2012, and after a lengthy installation, was first run on March 20th, 2013. However, the ORC was only run until May 5th, 2013 before it became evident that it was not economical to continue running the ORC in its current design. The AEA supplied partial funding for the project and CEC covered much of the costs themselves. In total, the cost of the project is estimated to be just over a million dollars.

Installation:

The ORC was only connected to the main 3.7 MW diesel generator which runs year round and, in the winter time, carries the majority of the plant's load. CEC investigated attaching the ORC to multiple diesel engines, however this was deemed to not be worthwhile due to the fact that the smaller generators are only run during the summer time. Interconnecting glycol loops from multiple diesel engines is also not a favorable idea since a single pipe failure could cause all the generators to shut down. Another issue with interconnecting generators is that different diesel engines are often designed for a specific operating temperature which may vary by manufacturer. Figure 2 shows the ORC being installed in its building.

Figure 2: PureCycle 280 Being Installed

Cooling Tower:

A Baltimore Aircoil Company (BAC) cooling tower was chosen as the most economically reasonable way to cool the cold water side of the ORC condenser. The other option considered was water cooling, both in nearby Orca Inlet or in the town's water tanks at higher elevation than the power plant, however, the cost of laying pipes and purchasing pumps large enough to pump the cooling fluid to the location of the heat exchanger was not feasible. There were also other concerns such as the effects of a hot spot being created in the ocean due to the heat exchanger or the possibility of a glycol leak inside the city's water supply. The extra power needed by the larger pumps would also add extra parasitic load to the system, lowering the net output of the ORC. Figure 3 shows the cooling tower installed at the Cordova site.

Figure 3: BAC Cooling Tower Used by CEC

Performance Analysis:

The ORC was only operated during a period of 46 days in the spring of 2013 before the project was shut down. The turbine was run for a total of 381.9 hours and generated approximately 51,302 kWh of electricity, for an average power generation of 134 kW per hour. Canary Labs trending software was used to monitor 19 operational parameters which enhanced the ORC performance data analysis. The fuel efficiency of the EMD 710 diesel generator without the ORC running was 13.82 kWh/gal, and when the ORC was running it was improved to 14.32 kWh/gal. This is a 3.6 % increase in fuel efficiency for the generator or 10 – 12 gallons of fuel saved per hour. The expected efficiency of the ORC was between 5 – 7 percent, however the maximum that was achieved by CEC was just under 5 %. The average hot liquid resource temperature entering the evaporator from the generator was 188° F, while the cold inlet of the condenser was around 47 degrees. The highest power generation that was achieved under varying flow rates and temperatures was 160 kW. Since the ORC is supposed to produce 280 kW gross output, this is only 57 % of the expected output. The parasitic loads from the hot and cold fluid pumps and the cooling tower fans further reduced the net output dramatically. The estimated project payback at this rate was about 45 years, while the design life of the ORC is only 20 years.

Failures and Challenges:

Not having adequate cooling for the condenser loop was the ultimate downfall of this project. Due to the fact that the 50/50 water/glycol mixture supplying heat to the ORC from the diesel generator was under 190° F, the cooling side needed to be extremely cold, which was not achievable using the cooling tower setup. The cooling tower was undersized for the project, and even with the fans running at 100 %, it was impossible to get the cooling side temperature down far enough. Ideally, the cooling water supply would need to be as close to 32 degrees Fahrenheit as possible for an ORC setup connected to a diesel generator to get the rated power from the ORC. The fact that the diesel motors are designed to run at a certain temperature for best performance means that it isn't advisable to try and raise the operating temperature of the diesel motors. The environmental requirements for the engine are also based on heat, and changing the operating temperatures can create sludge in the engine and void the warranty. Since the amount of power generated by the ORC increases as the temperature difference between the hot and cold sides of the ORC increases and the hot resource is regulated by thermostats on the diesel generator, the cold resource is the variable which must be manipulated. CEC found that increasing the temperature difference even a few degrees will quickly increase the electrical output of the ORC.

Freezing was another issue encountered with the evaporative cooling tower. When the ambient temperatures dropped below freezing, the tower was subject to freezing, and the buildup of ice on the membrane caused tearing damage to the tower. This is avoided by back-flowing the tower, which requires the ORC to be shut down and reversing the fans on the cooling tower so as to blow the ice out of the tower. This, however, was not designed to be done remotely which caused problems when the power plant was not staffed during the evening. Therefore the ORC would only be able to run during the day when the backflow procedure could be done every few hours.

Another issue that arose was the fact that the diesel generator is equipped with thermostats on the return line from the evaporator, and if the fluid coming back into the engine was below required temperature, the thermostats would close, therefore cutting off the flow of hot liquid to the ORC and causing a shutdown. This became an issue since the ORC demanded so much heat from the generator. The heat rejection of the engine and the amount of heat the ORC requires are all things that must be considered for this application.

Communication with the manufacturer was also a major difficulty for CEC. Pratt & Whitney was very reluctant to help with the interconnection of their SCADA protocols with the software that CEC uses for their plant. Pratt & Whitney Power Systems (PWPS) was also sold to Mitsubishi Heavy Industries in December 2012, which further complicated getting help from the manufacturer. The PWPS technician that came to Cordova to commission the ORC was severely underqualified and missed key elements of the system that were right in front of him.

The ORC was well built, however it had several design flaws that also needed to be fixed, including the electrical control panel that was supplied with the ORC, which had to be completely rebuilt, and several leaks that had to be addressed before the ORC could be started up. The ORC should have also had high pressure fittings in place of the low pressure fittings that were used and several PVC elbows were made out of silicon gaskets instead of PVC which seemed cheap.

Recommendations for Success:

This application is very site specific and requires a combination of higher temperature hot liquid resource and very cold cooling resource. Since the ORC requires so much heat, a hot liquid source with a temperature between 225-250° Fahrenheit would be good, however the most difficult part of this application is cooling. An evaporative cooling tower is not a good option for Alaska, especially in areas, such as the Arctic, where temperatures year round are often below freezing. Water cooling from a glacier stream, the ocean, or a city water tank would be the best option, however location is the determining factor as to how much it will cost to install this type of cooling system and environmental approval can become a major challenge to hurdle.

Available personal for the project must also be considered. The labor resource costs, both in terms of the number of personal dedicated to the project and the hours spent on the project, were huge for CEC. It is also important to research the manufacturer of the ORC and talk to other project managers about their experiences with the technology. If the manufacturer won't supply you with information about other places where there have been successful installations of their technology, something is wrong. Often times the results that the manufacturer tells you that you can achieve are not actually achievable, making communication with others that have successfully deployed the technology key to being successful yourself. It is also advisable to have a written contract with the manufacturer stating that they will supply support and replacement parts for failures for the first several years.

Conclusions:

CEC really appreciated the opportunity to test this new technology, and though they put all their effort into having the project succeed, the technology is just not viable in Alaska at this point. While they did succeed in increasing the fuel efficiency of their diesel generator, the ORC was costing extra money from the parasitic pump loads and the ORC didn’t generate the electricity that the manufacturer assured them it would. If funding became available, it may be possible to get the project going again using a water cooling system in the city’s water tanks. This would provide better cooling for the ORC condenser and heat the water in the tanks, which is a desire the town has had for a while. This, however, would be expensive to lay the pipes and buy bigger pumps to transfer the fluid up to the tanks, plus concerns over leaks into the water tanks and more power consumed by the bigger pumps. Exhaust heat recovery may be another way to increase the temperature of the hot liquid resource, however there are many emissions permits that would have to be obtained before that system could even be considered. ORC technology coupled with a diesel generator may have a future in Alaska, however the results do not justify the costs at this point in time.