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Low-Temperature Geothermal Power Generation ; Organic Rankine Cycle (ORC) : A Review

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ABSTRACT

In the present scenario of growing population and their increase in the consumption of energy, it is wise to explore and establish alternatives and clean sources of energy. Crude petroleum is a primary resource that fulfils the need of the ever growing population, but its exploration cannot be in same rate with the increasing consumption and volatile prices. The geothermal power industry has been experiencing steady growth and support around the world with governments keen to find a cheap and sustainable source of abundant energy. This support could see the geothermal industry take off during the upcoming decade in the same way as the wind and solar industries boomed in the last decade. Geothermal power emits virtually no CO_2 or pollutants which catches the eye of the world. Therefore it is considered as an ideal alternative energy source. Such a source of geothermal energy can be best harnessed using Organic Rankine Cycle (ORC). ORC is the standard process for low temperature energy conversion .India is lacking experience in the design and manufacturing of low temperature geothermal ORC plants. One proposed method to develop this experience is to understand the design process of existing low temperature geothermal ORCs. A qualitative and a thematic analysis of ORC projects around the world can highlight the common steps involved in their development and patterns in data, which could help to identify the common processes involved in these projects. The research material available from CEGE and the various companies which are providing service in parts to ORC will be organized into: prospecting, conceptual design and plant feasibility, detailed design, and construction. These steps are the important stages in ORC development, based on the research till now. The outcome of this analysis will help to establish a guideline for developing ORCs. The number of case studies required to develop robust guidelines is unknown; however, once clear patterns and similar steps emerge from a number of case studies that should be sufficient to finalise the proposed guidelines. The focus of the present article is to develop an ORC in Indian Climatic Condition. The goal of the project is to provide electricity in rural areas and developing countries with this system. This system can be manufactured locally Centre of Excellence for Geothermal Energy (CEGE) at the Gujarat-based Pandit Deendayal Petroleum University (PDPU) has found success by drilling the state's first geothermal bore well in Dholera Hot water up to 50 degrees Celsius to 55 degrees Celsius temperature gushing out from 272m deep drilled well at an unexpected flow rate of five liters a second, which can be used to harness electricity using ORC. So, the final objective is to generate possible electricity and develop a guideline that industries will adopt for their own ORC projects and eventually encourage development of the low temperature geothermal design standard.

Keywords : PDPU, CEGE, Organic Rankine Cycle, Carnot Efficiency, Twin Screw Expander

I. INTRODUCTION

Organic Rankine Cycle:

An Organic Rankine Cycle (ORC) is an instrument which uses an organic working fluid that has a boiling point less than that of water to convert low-temperature heat into mechanical work. The mechanical work that is generated can then be converted into electricity (Quoilin et al., 2013). The ORC cycle has a higher overall energy efficiency than conventional based Rankine Cycle.

Heat Engine:

Heat engine is a simple engine that converts thermal heat into mechanical work. A heat engine operates by extracting heat from hot reservoir and moving it over to a cold reservoir, generating energy in the process. A drawing of a basic heat engine is shown below:

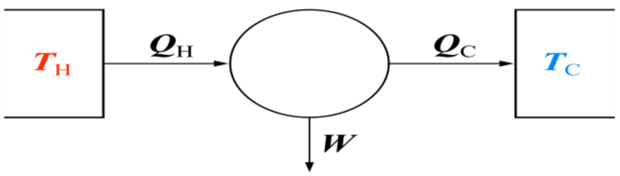

Figure.1: Schematic of Heat Engine

In order to maximize the amount of work a heat engine can produce, the temperature of the hot reservoir needs to be increased as much as possible, whereas the temperature of the cold reservoir needs to be reduced.

Carnot Efficiency:

An ideal heat engine operates at the Carnot efficiency. The Carnot efficiency is the maximum possible efficiency that any engine can achieve, regardless of size, complexity, money spent or the amount of time allowed for the engine to perform work. Carnot efficiency can be calculated by the expression:

$$\eta = WQ = 1 - T_C/T_H$$

Where:

W is energy exiting the system as work, or in our case, electricity.

Q is heat put into the system.

T_C is the absolute temperature of the cold reservoir (the cooling source temperature).

T_H is the absolute temperature of the hot reservoir (the hot water supply temperature)

Carnot efficiency is a theoretical efficiency that cannot be accomplished in reality. In reality, the efficiency of any heat engine is reduced by various factors such as heat loss, pressure drops, and frictional losses.

What is Organic Rankine Cycle?

ORC is heat-to-power generating system that captures waste heat to generate up to MW of energy of fuel-free, emission-free electricity. ORC technology allows for the sustainable production of electricity as long as an appropriate thermal heat source is available. The minimum temperature required for generation of electricity from ORC unit is 77^0 C.

Appropriate waste energy sources for the ORC are small, distributed hot water sources such as stationary engine jacket water, biomass boilers, and solar thermal and geothermal fluids. ORCs in general have many advantages over conventional Rankine cycle. it is known that the working fluid in ORCs have higher molecular weight than water and this will increase the masss flow rate of the selected organic working fluid for the same size of turbine (Drescher and Bruggemann, 2007). If this can be done, it will give better turbine efficiencies with less turbine losses (The diagram below shows examples of different heating and cooling sources that can be used with the ORC.

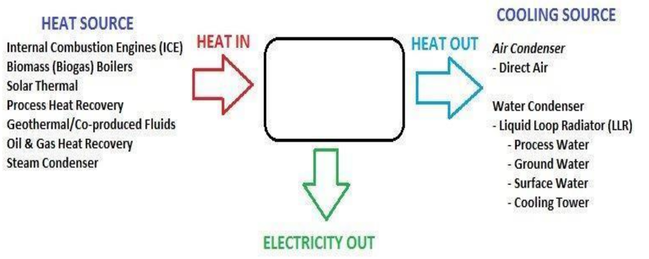

Figure 2 Sources for Electricity Generation

Important Components in ORC:

A few noteworthy components in the ORC are the twin screw expander, induction generator, and the non-toxic system working fluid.

II. METHODS AND MATERIAL

Twin Screw Expander:

ORC can be operated with a wide range of heat sources and heat sinks with satisfactory cycle efficiency. The ORC uses a twin screw expander as its power block; which effectively is a compressor operating in reverse. The twin screw expander design is robust and very simple. The operating speed of the twin screw expander is relatively low (<4500 RPM), and does not require a gearbox to drive the generator. A significant advantage of the twin screw expander is the ability to operate in two phase, or in the "wet" conditions. This two phase operation means that the refrigerant does not have to be 100% vapor. The ability to operate in a range of working fluid conditions from superheat to wet vapor allows the ORC to follow variable heat loads and produce power over a wide range of input conditions. This is particularly important when load following internal combustion engines through different speed and load conditions. The twin screw-expander

Induction Generator:

An induction generator is electro-mechanically similar to an induction motor. In the case of the ORC Generator, the induction generator is based on a 70-100 horsepower (about 50-75 kW) squirrel cage motor with some optimizations to the internal construction to make it more efficient as a generator. In the event of a loss of grid, the unit will automatically shut down, and cannot be re-started until line conditions return to normal.

Working Fluid

The choice of working fluid is key element in low temperature organic rankine cycle. The working fluid that is used in the ORC is the compound HFC-245fa (1,1,1,3,3 pentafluoropropane). HFC-245fa is a member of the hydro fluorocarbon (HFC) family of refrigerants. This non-flammable, low-toxicity, non-corrosive, environmentally-safe fluid boils at approximately 15.5°C at atmospheric pressure. HFC-245fa is ozone safe and generally safe to handle.

System Operation:

ORC system operation can be broken down into five major steps, which are represented in the diagram below. These steps are:

1. Working fluid is pumped to higher pressure and transferred to the preheater.
2. The temperature of the working fluid is increased in the preheater and sent to the evaporator.
3. Heat captured by the evaporator boils the working fluid into pressurized vapor.
4. The vapor flows through the twin screw expander, spinning an electric generator to produce power.
5. The vapor is cooled and condensed back into a liquid in the condenser to repeat the cycle.

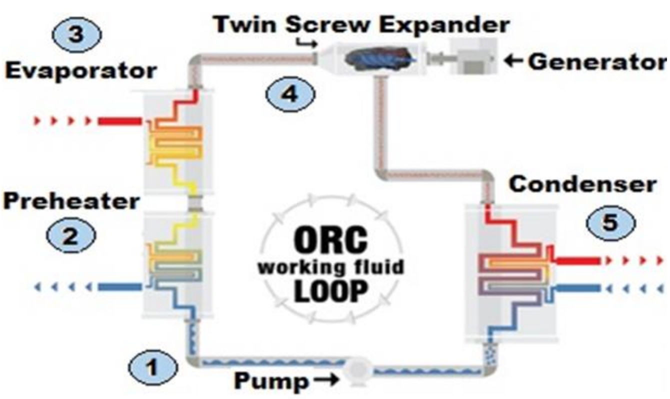

Figure 3 Flow Diagram of Organic Rankine Cycle

Heat Sources for the ORC Generator

The ORC can utilize low grade waste heat (temperatures between 77°C-122°C) from hot water sources. Waste heat from exhaust gases, thermal oils, and other liquid heat sources may also be used with deployment of a secondary heat exchange loop.

Condensing Options

The ORC offers two condensing options—air-cooled and water-cooled. The use of an air cooled condenser condenses the working fluid outside the ORC Generator. On the other hand, when a water cooled condenser is used, the working fluid is condensed in the water cooled condenser which is located inside the ORC Generator. Water cooled condensers can be utilized as cooling towers and closed liquid loop radiators.

III. RESULTS AND DISCUSSION

Performance

Site conditions, such as the system delta T (which is affected by ambient air temperature and temperature of heating/ cooling water) and available thermal heat all affect ORC performance.

System Delta T

System delta T is the ΔT temperature differential between the hot source and condensing source, and is also the primary driving force behind increased efficiency in ORC systems. The temperature ranges for TH and TC that low grade heat ORC systems typically operate in will dictate lower efficiencies than high grade heat ORC systems because of the higher heat source temperature TH. The ORC system is limited by delta T temperature because of the physical properties of liquid water.

The ORC Generator's location influences the ambient air temperature conditions. In locations with hot climates, such as India, Africa and the Equator, ORC net power output will be lower than net power outputs produced by machines that are installed in cold climate locations, such as Northern Europe, even at the same hot water input temperature. This discrepancy is due to a lower system delta T (difference between the hot water input and condensing temperature) in hot climates versus that in cold climates.

IV. CONCLUSION

The Organic Rankine Cycle (ORC) is a standard process for low temperature energy utilization, l with commercial ORCs utilizing temperatures as low as 80°C. India is lacking experience in the design and manufacturing of low temperature geothermal ORC plants and currently there are no Geothermal ORC modular setups in India. One proposed method to develop this is to understand the design process of existing low temperature geothermal ORCs around the world. The study reveals that there is a great opportunity to employ this technology in India provided we have to overcome some challenges related to component selection, finance and maintenance. But successful implementation will give boost in India energy sector.

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