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Introductory Chapter: ORC Power Generation Technology Using Low-Temperature Geothermal Energy Resources: A Conceptual Case Study

Basel I. Ismail

1. Introduction

The term “Geothermal Energy” refers to the Earth’s natural heat energy. The continual heat energy flux coming from the Earth’s core to the surface is the source of geothermal energy. The Earth’s geothermal resources are huge; for example, the portion of geothermal energy stored at a depth of 3 km is estimated to be 1,194,444,444 TWh, which is substantially more than the total energy equivalent of all fossil fuel resources combined, which is estimated to be 1,010,361 TWh [1]. Geothermal energy is regarded as an environmentally beneficial clean energy source that, when used to generate electrical power, has the potential to considerably reduce GHG emissions. It is reported that global net electrical power demand will rise by nearly 85% between 2004 and 2030, increasing to 30,364 TWh in 2030 from 16,424 TWh in 2004, making the use of geothermal energy for electricity generation an appealing solution, especially with advances being made in innovative technological methods of drilling and power generation schemes. Geothermal energy resources differ regionally based on the temperature and depth of the resource, the availability of ground water, and the chemical composition of the rock [2]. It is distinct from other conventional and renewable energy sources in that it is always accessible, steady throughout the year, regardless of weather conditions, and has an inherent storage potential. The temperature of geothermal energy resources typically ranges approximately from 50 to 350°C. Geothermal resources near volcanic regions and island chains tend to have a high resource temperature with temperature typically greater than 200°C. Medium-temperature, ranging from 150 to 200°C, and low-temperature geothermal resources of less than 150°C are typically found widely in most continental regions and considered to be the most commonly available geothermal energy resources [3]. The geothermal binary cycle technology known as the Organic Rankine Cycle (ORC) technology can successfully generate power from medium- and low-temperature geothermal energy (LTGE) resources. LTGE-ORC technology emits almost no greenhouse gases into the environment and is an appealing technology because of its simplicity and small number of components, all of which are common and commercially accessible. More information related to a number of past and existing successful ORC binary power plants can be found in Refs. [1–4]. In this introductory chapter, the fundamental concept of ORC binary fluid power technology using LTGE geothermal resources is introduced with a detailed numerical example, as an illustration of its thermodynamic performance.

2. Fundamental concept of a binary fluid ORC system using LTGE resources

Figure 1 depicts a schematic representation of an ORC binary fluid system utilized for electric power generation using LTGE resource.

The initial (main) fluid collected from the LTGE resource *via* the production well is the geo-fluid. The geo-fluid transports heat from the liquid-dominated LTGE resource (being the heat carrier) and effectively transfers this heat to the low-boiling point organic-based working fluid (the secondary fluid) through an efficient heat exchanger. Typical ORC organic fluids may include pure hydrocarbons (e.g., pentane, butane, propane), refrigerants (e.g., R134a, R218, R123, R113, R125), or organic mixtures. More details about the selection criteria of these ORC organic fluids for optimal performance can be found in Refs. [1–4]. The ORC is a thermodynamic Rankine cycle that uses the organic working fluid instead of steam (water). In this binary fluid ORC LTGE system, the low-boiling point organic liquid absorbs the heat which is transferred by the geo-fluid and boils at a relatively much lower temperature (compared to water) and as a result develops significant vapor pressure sufficient to drive the axial-flow or radial-inflow turbine. The turbine is coupled to an electric generator, which converts the turbine mechanical shaft power into electrical power. The organic working fluid expands across the turbine and then is cooled and condensed in the condenser before it is pumped back as a saturated liquid to the heat exchanger using a condensate pump to be re-evaporated, and the power cycle repeats itself.

Figure 1. A schematic showing the fundamental concept of an ORC binary fluid technology utilizing LTGE resource for power generation.

3. Thermodynamic analysis of an ORC system utilizing a low-temperature geothermal energy resource: A case study with numerical illustration

A small-scale modular binary fluid ORC geothermal power generation system is proposed for design and installation in Vancouver, BC Canada, near a site characterized by a low-temperature geothermal energy resource. The production well in this resource is capable of supplying hot geo-fluid (mainly liquid water) at a temperature of 90°C (see **state a**, **Figure 1**). The proposed ORC system utilizes R-134a as a working fluid. In this ORC system shown in **Figure 1**, it is required to provide R-134a at a mass flow rate $\dot{m}_R$ of 6.25 kg/s as saturated vapor at 85°C to an inflow radial turbine (**state 3**). The ORC condenser operates at constant pressure with a constant phase-change temperature of 40°C. R-134 then enters an ideal ORC-pump as a saturated liquid (**state 1**, **Figure 1**). The density of the geo-fluid is assumed to be constant at approximately 1000 kg/m³. The geo-fluid liquid exits the ORC-evaporator (**state b**, **Figure 1**) to be re-injected into the geothermal resource at 35°C with constant specific heat capacity $C_{p,Geo} = 4.185$ kJ/kg.°C.

Thermal design constraints: The ORC-evaporator (counter flow-HEX) effectiveness $\varepsilon_{Evap,ORC} = 90\%$; the turbine isentropic efficiency $\eta_T = 100\%$; negligible pressure drops in the ORC-piping systems.

Electric generator specification: $\eta_{EG} = 92\%$.

Electricity-driven pump efficiency = 100%.

Required: For this conceptual ORC power generation system, the following thermodynamic performance indicators are determined:

- a. The R-134a-pumping power $\dot{W}_{Pump}$ (kW) requirement for the ORC system.
- b. The heat transfer rate input $\dot{Q}_{Evap,ORC}$ (kW) to the ORC system.
- c. The turbine supplied power $\dot{W}_{Turb}$ (kW).
- d. The electric generator power output $\dot{W}_{EG}$ (kW).
- e. The net power $\dot{W}_{net,ORC}$ (kW) delivered by the ORC system.
- f. The thermal efficiency $\eta_{th,ORC}$ (%) of the ORC system.
- g. The specific heat transfer q_{Geo} (kJ/kg) supplied by the low-temperature geothermal resource to the ORC system.
- h. The heat transfer rate $\dot{Q}_{Geo}$ (kW) supplied by the LTGE resource to the ORC system.
- i. The mass flow rate of the geo-fluid $\dot{m}_{Geo}$ (kg/s) to be extracted from the low-temperature geothermal resource.
- j. The volumetric flow rate of the geo-fluid $\dot{V}_{Geo}$ (L/min) to be extracted from the geothermal resource.
- k. The overall energy conversion efficiency η_{Geo} (%) of the low-temperature geothermal ORC power generation system.

4. Methodology, analysis, and results

Application of the steady-state energy balance, mass balance, and other thermodynamic relationships over the ORC pump (stream 1–2), turbine (stream 3–4), evaporator (stream 2–3), electric generator (EG), and the geothermal resource (stream a-b), yields the following set of model equations (Tables 1 and 2):

$$\dot{W}_{pump} = \dot{m}_R(h_2 - h_1) \tag{1}$$

$$w_{pump} = h_2 - h_1 \tag{2}$$

$$h_2 - h_1 = v_1(p_2 - p_1) \tag{3}$$

$$\dot{Q}_{Evap,ORC} = \dot{m}_R(h_3 - h_2) \tag{4}$$

$$\dot{W}_{Turb} = \dot{m}_R(h_3 - h_4) \tag{5}$$

$$\dot{W}_{EG} = \eta_{EG} \dot{W}_T \tag{6}$$

$$\dot{W}_{net,ORC} = \dot{W}_{EG} - \dot{W}_{pump} \tag{7}$$

$$\eta_{th,ORC} = \frac{\dot{W}_{net,ORC}}{\dot{Q}_{Evap,ORC}} \tag{8}$$

$$\dot{Q}_{Geo} = \dot{m}_{Geo} q_{Geo} \tag{9}$$

$$\dot{m}_{Geo} = \frac{\dot{Q}_{Geo}}{q_{Geo}} \tag{10}$$

$$\dot{V}_{Geo} = \frac{\dot{m}_{Geo}}{\rho_{Geo}} \tag{11}$$

$$\dot{Q}_{Geo} = \dot{m}_{Geo}(h_a - h_b) \tag{12}$$

$$q_{Geo} = c_{p,Geo}(T_a - T_b) \tag{13}$$

$$\dot{Q}_{Geo} = \frac{\dot{Q}_{Evap,ORC}}{\varepsilon_{Evap,ORC}} \tag{14}$$

$$\eta_{Geo} = \frac{\dot{W}_{net,ORC}}{\dot{Q}_{Geo}} \tag{15}$$

State #	T (°C)	P (kPa)	v (m ³ /kg)	h (kJ/kg)	s (kJ/kg.°C)	x (%)
1	40	1017.0	0.000873	256.54		0.0
2		2926.2		258.21		
3	85	2926.2		428.10		100
4				409.14	1.6782	93.5
a	90					
b	35					

Table 1.
Thermodynamic properties of R-134a at the given conditions.

Required	Calculated numerical value
$\dot{W}_{Pump}$ (kW)	10.42
$\dot{Q}_{Evap,ORC}$ (kW)	1061.83
$\dot{W}_{Turb}$ (kW)	118.50
$\dot{W}_{EG}$ (kW)	109.02
$\dot{W}_{net,ORC}$ (kW)	98.60
$\eta_{th,ORC}$ (%)	9.3
q_{Geo} (kJ/kg)	230.18
$\dot{Q}_{Geo}$ (kW)	1179.81
$\dot{m}_{Geo}$ (kg/s)	5.13
$\dot{V}_{Geo}$ (L/min)	307.5
η_{Geo} (%)	8.4

Table 2.
Summary of the ORC-LTGE performance results.

Author details

Basel I. Ismail
Department of Mechanical Engineering, Lakehead University, Canada

*Address all correspondence to: baseliai@gmail.com

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References

[1] Ismail BI. Chap 18: Power generation using nonconventional renewable geothermal & alternative clean energy technologies. In: Carayannis EG, editor. Planet Earth 2011 – Global Warming Challenges and Opportunities for Policy and Practice. London, UK: InTech Open Access Publishing Company; 2011

[2] Ismail BI. Advanced electrical power generation technology using renewable & clean low-enthalpy geothermal energy sources. Recent Patents on Mechanical Engineering. 2011;4(2): 168-179

[3] Ismail BI. Advances in Geothermal Energy. Rijeka, Croatia: InTech Open Access Publishing Company, 2016. 174 pages. DOI: 10.5772/60623

[4] Ismail BI. Chapter 1: Power generation using geothermal low-enthalpy resources and ORC technology. In: Ismail BI, editor. Renewable Geothermal Energy Explorations. London, UK: IntechOpen; 2019. DOI: 10.5772/intechopen.84390. Available from: <https://www.intechopen.com/chapters/66034>