Thermoeconomic Analysis of Hybrid Power Plant Concepts for Geothermal Combined Heat and Power Generation

Mr.U.Nagulmeera
Asst.Professor,EEE,SBIT
Khammam,TS,India
urimallalaxmikumari62@gmail.com

Mr.M.Srinivas
Asst.Professor,EEE,SBIT
Khammam,TS,India
madala_srinivas245@yahoo.co.in

Mr.J.Kotaiah
Asst.Professor,EEE,SBIT
Khammam,TS,India
jupellikotaiah@gmail.com.

Abstract:

In this paper, we propose a thermo-economic study of a low-temperature Organic Rankine Cycle (ORC) for CHP purposes. The geothermal resource and the biogas engine exhaust gases combine to supply the thermal energy input for the hybrid power plant. Parameters such as ORC working fluid, supply temperature of the heating network, and geothermal water temperature are used to make a comparison to other geothermal CHP ideas. Hybrid power plants are more efficient than traditional CHP models or using the energy sources individually, according to both the second law of thermodynamics and economic criteria.

Key words :

CHP (Combined Heat and Power) and geothermal energy are two examples of hybrid power plants.

Introduction

Binary power plants, such as the Organic Rankine Cycle (ORC) or the Kalina Cycle (KC), are optimal for low-enthalpy geothermal resources [1,2]. An attractive strategy to enhance the economic circumstances for geothermal energy production is combined heat and power generation (CHP). Different layouts of power plants have the potential to produce an augmented heat supply. Power and heat may be generated in either a serial or parallel circuit [3]. Hybrid power plants are one example of a potential new idea that might improve thermodynamic and economic efficiency. To do this, geothermal power plants are often combined with other forms of energy production, such as solar thermal panels, solid biomass, biogas cogeneration units, or fossil fuels. fuels [4-11]. A hybrid power plant using geothermal heat and a biogas engine seems to be an appropriate idea in climate zones where solar thermal systems are not viable but renewable CHP is still preferred. Different ORC-technology hybrid power plant designs are compared in this article to both traditional geothermal CHP and independent utilization of the energy sources. The yearly power production, second law efficiency, and economic factors are all figured up at geothermal water temperatures of 120 °C. ORC working fluid, heating network supply temperature, and geothermal conditions are also subject to sensitivity assessments.

Methodology

Quasi-steady-state considerations, including simulations of the ORC process and an estimate of the yearly duration curve of the heat demand, are used to determine the annual power production for the CHP ideas under examination. The best power plant layouts are determined by taking into account the second law of thermodynamics, the internal rate of return, and the cumulative cashflow. Consequently, we may specify thermodynamic and economic boundary conditions.

Modelling the Process

Geothermal combined heat and power (CHP) systems using low-enthalpy resources are studied in both parallel and serial power unit and heat generating configurations. Figure 1 depicts a schematic of both types of power plants. In the event of high supply temperatures of the heating network or low ambient temperatures, a bypass pipe supplies appropriate geothermal water temperatures for the serial circuit.

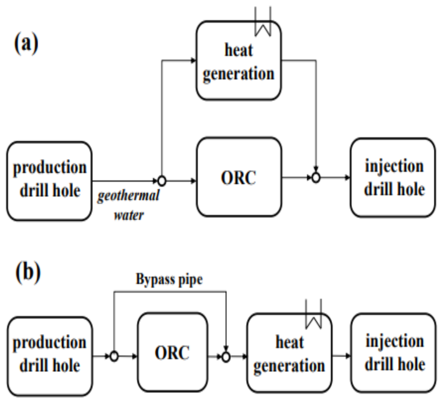

Figure 1. (a) Scheme of geothermal CHP in parallel circuit; (b) Scheme of geothermal CHP in serial circuit with bypass pipe.

A hybrid power plant for CHP is also feasible in parallel and serial configuration. Figure 2 shows the parallel power unit and heat generation circuit. According to heat demand the geothermal water mass flow is split and the ORC operates under partial load. A higher geothermal water temperature at the inlet of the ORC-unit is obtained by utilizing the exhaust gases of the gas engine. The engine coolant provides heat for the heating network in a first step. If necessary, a higher amount of heat or higher supply temperatures are obtained in a second heat exchanger. The serial configuration of the hybrid power plant is analogue to the serial geothermal CHP in Figure 1b. Finally, a separate use of geothermal heat source and biogas cogeneration unit is examined. In this case, the exhaust gases of the gas engine are simply used for heat generation instead of coupling with the geothermal water.

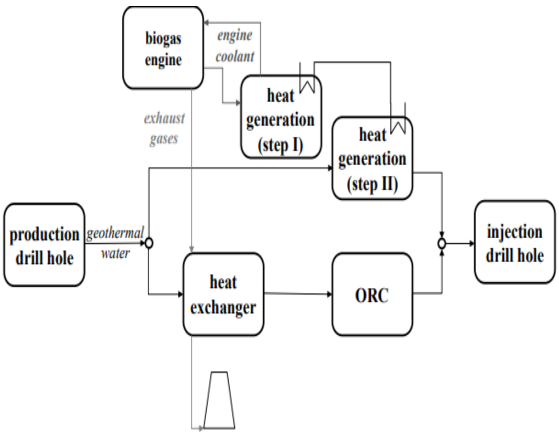

Figure 2. Scheme of geothermal hybrid power plant in parallel circuit.

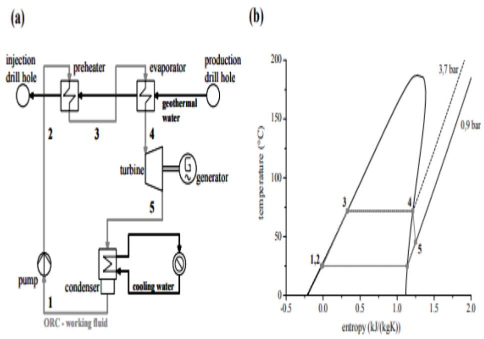

Figure 3. Scheme of ORC-unit (a) and corresponding T,s-diagram for ORC with the working fluid isopentane (b).

Table 1. Boundary conditions for the ORC power plant

Parameter	Unit	
Isentropic efficiency of the ORC-turbine $\eta_{i,T}$	%	80
Generator efficiency η_G	%	95
Isentropic efficiency of the ORC-pump $\eta_{i,P}$	%	75
$\Delta T_{PP,EVP}$	K	5
$T_{CW,in}$	°C	15
ΔT_{CW}	K	5

Table 2. Operational parameters of the biogas cogeneration unit (JMS 620 GS-B.L.).

Parameter	Unit	
Electrical power output P_{el}	kW	2717
Thermal power output $\dot{Q}$	kW	1315
Engine coolant outlet temperature $T_{CW,out}$	°C	87.8
Engine coolant inlet temperature $T_{CW,in}$	°C	65.5
Engine coolant mass flow rate $\dot{m}_{CW}$	kg/s	19.9
Exhaust gas outlet temperature $T_{EG,out}$	°C	463.9
Exhaust gas mass flow rate $\dot{m}_{EG}$	kg/s	4.35

In terms of heating, we take into account a heating system that serves a community of 8,000 people. It is projected that there will be 30% single-family homes and 70% multi-family dwellings. Using load profiles for normal weather conditions (zone 13), VDI 4655 [14] determines the required heating capacity for each dwelling unit. A peak load boiler is evaluated for thermal powers more than 6000 kW. There is a total of 23.9 GWh of thermal energy tied to the heating system. The yearly duration curve is approximated by 10 load steps that correspond to the average ambient temperature of the usual climatic patterns (see Figure 4), allowing for a quasi-steady-state estimate of power and heat production. The heating network's supply and return temperatures are also considered to be linearly dependent on the ambient temperature between 14 and 16 degrees Celsius. Supply temperatures range between 90 and 60 degrees Celsius. The supply-return temperature differential is kept at a constant 20 K.

Discussion and Results

The typical example for geothermal fluid assumes a mass flow rate of 100 kg/s and a temperature of 120 °C. This is consistent with what you'd expect to see in the Molasse Basin, which is located south of Munich, Germany. The working fluid for the ORC is R245fa. Depending on the load step, the thermodynamic values include both the thermal and electric power of the units. In addition, the second law efficiency and the total yearly quantity of power produced are shown. The cashflow and IRR for the various power plant designs are compared.

Finally, we explore the monetary impact of changing a few key border conditions.

Thermodynamic Outcomes

The heating system for a CHP that uses geothermal energy must be completely fed by the geothermal water in a parallel circuit configuration. In a hybrid power plant, the engine coolant might satisfy some of the building's heating needs. Increasing the temperature of the geothermal water by connecting it with the exhaust gases of the gas engine also improves the efficiency of the ORC-unit's power production. Figure 5a depicts the electric power of the ORC-unit Pel,ORC and the total thermal power of the heating network Pth,HN as a function of the estimated load steps for a geothermal CHP operating in parallel circuit. In addition, Q Geo highlighted the percentage of thermal power provided by geothermal water. The geothermal fluid in a combined heat and power plant provides all of the required heat. It follows that Pth,HN and Q Geo both have values of 1 in Figure 5a. At increasing loads, the heating network's thermal power drops and more heat is transferred to the ORC. This results in a higher output of electricity from the ORC. Parameters for a parallel-circuit hybrid power plant are shown in Figure 5b; this plant receives some of its thermal power from the engine coolant Q EC and some from the electric power of the gas engine Pel,GE. The hybrid power plant's biogas engine can produce 2717 kW of electricity and run for 8,000 hours a year. For higher load steps, which correspond to higher ambient temperatures and reduced heat demand, the ORC-unit's electrical output rises. For all load stages, the engine coolant contributes a portion of the heating network's energy needs. In the end, the engine coolant supplies 100% of the heating network's needs at load stages 8 through 10, or 2952 h/a. During this time, there is no need to use geothermal water to produce heat. As a result, the ORC-unit may be connected to the full geothermal mass flow rate to produce electricity. In the case of a hybrid power plant, the temperature of the geothermal water is raised as well. This allows the ORC to operate at greater process pressures and boosts the ORC-unit's efficiency by around 3%. Condensation and evaporation ORC pressure values for the geothermal CHP and the hybrid power plant are shown in Table 4.

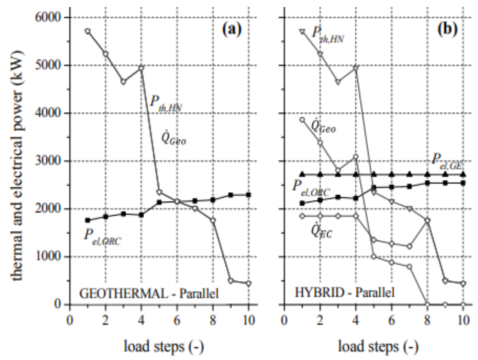

Figure 5. Electrical and thermal power of the power plant units (a) Geothermal CHP in parallel circuit; (b) Hybrid power plant in parallel circuit.

Table 4. Condensation and evaporation pressure

Parameter	R245fa-GeoCHP	R245fa-Hybrid	Isopentane-GeoCHP	Isopentane-Hybrid
p_1 (bar)	1.47	1.47	0.90	0.90
p_2 (bar)	6.53	6.94	3.67	3.85

Figure 6 displays the yearly gross energy generation for each power plant idea under consideration. There is a difference between the ORC-unit and the gas engine in the hybrid power plant. The amount of power produced by a gas engine is the same whether it is used in a hybrid configuration or independently. The maximum annual electricity production is achieved using a parallel circuit hybrid power plant. The quantity of power produced is decreased by 4.7% when geothermal water and a biogas engine are used independently. The hybrid concept's use of higher geothermal water temperatures to improve the ORC-unit's efficiency accounts for the disparity. When compared to the parallel circuit, the hybrid power plant's serial circuit generates 11% less power. The geothermal mass flow must be increased in the serial circuit to achieve the necessary supply temperature and heat load. In series circuit, 39.6 percent of the geothermal water mass flow is needed to feed the heating network during the first load phase, whereas only 18.5 percent is needed in parallel circuit. This variation exists up to load step 7, and it results in a drastically reduced amount of power produced by the serial circuit. When comparing geothermal CHP to a hybrid power plant operating in parallel, the latter may reduce energy production by as much as 23%. There is a drastic reduction since the geothermal heat source must compensate for the whole heat demand. When comparing CHP in serial and parallel circuits, the latter yields 11.3% higher efficiency.

Conclusions

The use of hybrid power plants in conjunction with geothermal combined heat and power systems is an exciting prospect. The benefits of combining a biogas engine with a geothermal resource have been shown by comparing the two to their individual usage. By raising the temperature of the geothermal water with the heat from the exhaust fumes, the ORC-unit is able to function at a greater efficiency. It's preferable to have the power and heat generators connected in parallel. Up to 8.0% more second law efficiency and 50% greater cumulative cashflow at the end of the lifespan are achieved compared to traditional geothermal CHP. The hybrid power plant is 2.1% more efficient and can produce 943,3 MWh/a more energy than when each component is used alone. Advantages in operating and maintenance expenses can contribute to substantial price variations. At the conclusion of the lifespan, the total cash flow has increased by more than a factor of three. Analyses of sensitivity reveal that the efficiency and cost characteristics of an ORC are very mildly affected by the working fluid. When the heating network's supply temperature is increased, however, the hybrid power plant's biogas-cogeneration unit is not used to its full potential, resulting in a 27.6 percentage point lower cumulated cashflow after 30 years of operation. The second law efficiency is improved by 22.9% and the cumulative cashflow is almost doubled if the geothermal water temperature is raised from 120 °C to 160 °C. Part load behaviour of the pump and turbine, as well as varying pinch points in the heat exchanger, are taken into account in the subsequent dynamic simulations.

References

[1] . Tchanche, B.F.; Lambrinos, G.; Frangoudakis, A.; Papadakis, G. Low-grade heat conversion into power using Organic Rankine Cycles—A review of various applications. Renew. Sustain. Energy Rev. 2011, 15, 3963–3979.

[2]. Vélez,F.; Segovia, J.J.; Martín, M.C.; Antolín, G.; Chejne, F.; Quijano, A. A technical, economical and market review of Organic Rankine Cycles for the conversion of low-grade heat for power generation. Renew. Sustain. Energy Rev. 2012, 16, 4175–4189.

[3]. Heberle, F.; Brüggemann, D. Exergy based fluid selection for a geothermal Organic Rankine Cycle for combined heat and power generation. Appl. Therm. Eng. 2010, 30, 1326–1332.

[4]. Heberle, F.; Preißinger, M.; Brüggemann, D. Thermoeconomic evaluation of combined heat and power generation for geothermal applications. In Proceedings of the World Renewable Energy Congress, Linköping, Sweden, 8–13 May 2011; pp. 1305–1313.

[5]. Heberle, F.; Brüggemann, D. Thermoeconomic comparison of designs for geothermal combined heat and power generation. In Proceedings of the European Geothermal Congress, Pisa, Italy, 3–7 June 2013.

[6]. Tempesti, D.; Manfrida, G.; Fiaschi, D. Thermodynamic analysis of two micro CHP systems operating with geothermal and solar energy. Appl. Energy 2012, 97, 609–617.

[7]. Astolfi, M.; Xodo, L.; Romano, M.C.; Macchi, E. Technical and economical analysis of a solar-geothermal hybrid plant based on an Organic Rankine Cycle. Geothermics 2011, 40, 58–68.

[8]. Borsukiewicz-Gozdur, A. Dual-fluid-hybrid power plant co-powered by low-temperature geothermal water. Geothermics 2010, 39, 170–176.

[9]. Astina, I.M.; Pastalozi, M.; Sato, H. An improved hybrid and cogeneration cycle for enhanced geothermal systems. In Proceedings of the World Geothermal Congress, Bali, Indonesia, 25–29 April 2010.

[10]. Kohl, T.; Speck, R. Electricity production by geothermal hybrid-plants in low-enthalpy areas. In Proceedings of the 29th Workshop on Geothermal Reservoir Engineering, Stanford, CA, USA, 26–28 January 2004.

[11]. Karellas, S.; Terzis, K.; Manolakos, D. Investigation of an autonomous hybrid solar thermal ORC-PV RO desalination system. The Chalki Island case. Renew. Energy 2011, 36, 583–590.

[12]. Woudstra, N.; van der Stelt, T.P. Cycle-Tempo: A Program for the Thermodynamic Analysis and Optimization of Systems for the Production of Electricity, Heat and Refrigeration; Energy Technology Section, Delft University of Technology: Delft, The Netherlands, 2002.

[13]. Lemmon, E.W.; Huber, M.L.; McLinden, M.O. NIST Standard Reference Database 23, Version 9.1; National Institute of Standards and Technology: Boulder, CO, USA, 2013.

[14]. Verein Deutscher Ingenieure e.V. VDI Richtlinie 4655—Referenzlastprofile von Ein- und Mehrfamilienhäusern für den Einsatz von KWK-Anlagen; Springer-Verlag: Düsseldorf/Beuth, Germany, 2008. (In German)

[15]. Baehr, H.D.; Kabelac, S. Thermodynamik: Grundlagen und technische Anwendungen, 15th ed.; Springer Vieweg Verlag: Auflage/Berlin, Germany, 2012.

[16]. Quoilin, S.; Declaye, S.; Tchanche, B.F.; Lemort, V. Thermo-economic optimization of waste heat recovery Organic Rankine Cycles. Appl. Therm. Eng. 2011, 31, 2885–2893.

[17]. Preißinger, M.; Heberle, F.; Brüggemann, D. Advanced Organic Rankine Cycle for geothermal application. Int. J. Low-Carbon Technol. 2012, 8, 62–68.

[18]. Heberle, F.; Bassermann, P.; Preissinger, M.; Brüggemann, D. Exergoeconomic optimization of an Organic Rankine Cycle for low-temperature geothermal heat sources. Int. J. Thermodyn. 2012, 15, 119–126.

[19]. Görke, B.; Sievers, A. Gewinnbetrachtung von strom- und wärmegeführten Geothermie-Projekten unter Berücksichtigung der aktuellen EEG Novelle. In Kongressband Geothermiekongress, Karlsruhe, Germany, 11–13 November 2008, Geothermische Vereinigung—Bundesverband Geothermie e.V.: Geeste, Germany, 2008; pp. 147–156.

[20]. Janczik, S.; Kaltschmitt, M. Kombinierte Nutzung von Geothermie und Klärschlamm. VGB PowerTech 2010, 7, 84–91.