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Organic Rankine Cycle (ORC) in geothermal power plants

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Abstract. Organic Rankine Cycle is a technology that convert low-temperature heat sources into a mechanical energy, and it can be used to produce electrical energy in a closed system. The heat sources can be derived from renewable energy such as geothermal, solar, and biomass. Furthermore, the ORC system can also be used to increase energy efficiency in the industry by utilizing the waste heat produced. Therefore, there are two classification of the ORC system, namely a heat recovery system and binary power plant. Recently, the ORC system has made a thrive in the geothermal power plant. The ORC system can be applied to resources with low to medium temperature characteristics (<90°C - 150°C). This paper will present an overview of the implementation, model, and innovation of ORC system technology in geothermal resources.

1. Introduction

Geothermal resources are one of renewable energy sourced from the earth's core with a depth of about 6500 km [1]. These geothermal resources can be classified based on the temperature characteristics and their constituents. The classifications of geothermal resources include deep hydrothermal, low temperature, geopressurized, magma energy, and Hot Dry Rock (HDR)/Enhanced Geothermal System (EGS) [2]. Based on this classification, hydrothermal is a type of geothermal resource that is generally used for geothermal power plants [1]. The hydrothermal system is divided into two types, which are vapor-dominated and water-dominated [3].

Direct steam power plant is a system used in hydrothermal resources with vapor-dominated characteristics at high temperatures, this system has an efficiency of up to 50% - 70% [1,4]. Hydrothermal resources with water-dominated characteristics generally use flash steam power plants, both in single-stage or multi-stage cycles [1,5].multi-stage systems are capable of producing a power output of 15% to 20% more than a single-stage cycle with the same geothermal fluid conditions [6]. In geothermal resources that have low temperature quality, binary power plants that use low boiling working fluids are more suitable to use under these conditions [4,7].

Based on the principle of the Rankine cycle, there are two thermodynamic cycle technologies that use working fluids in a closed system, namely the Organic Rankine Cycle (ORC) and Kalina Cycle (KC) systems [8]. Through comparative thermodynamic analysis between the ORC and KC systems, it shows

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that the ORC system has better cost-effectiveness and work to utilize waste heat at medium temperatures (90°C - 150°C) [9]. Basically, the ORC system work principle has similarities with the Steam Rankine Cycle (SRC), the difference is that this ORC system uses organic working fluids that have a lower boiling point and vapor pressure higher than water [10]. The ORC system began to develop as heat recovery which can utilize heat from renewable energy sources such as geothermal, solar thermal, and low quality biomass (<100°C) directly to produce electricity or increase energy efficiency in an industrial process [11,12].

2. Method

The design of this paper is a case study of the Organic Rankine Cycle (ORC) system in a geothermal power plant. This study examines further the development of the ORC system in utilizing geothermal resources globally. A review from the results of research conducted on the ORC system in the geothermal power plant is shown to be a consideration in developing subsequent research.

3. Results and discussion

3.1. Implementation of ORC in geothermal power plant

In 2016 the total capacity of the ORC system installed worldwide is 2701 MW, spread over 705 power plant projects and 1754 units of ORC systems Figure 1 and Figure 2. Geothermal is the most used resource in of ORC, there are several companies with a total of 337 ORC systems installed Figure 1 [11].

Globally, each ORC system has different work models and characteristics. The difference is determined by working conditions and geothermal heat sources. In addition, overall mechanical or electrical efficiency also depends on the compatibility between expander characteristics, working fluid properties, and thermodynamic cycle parameters [13].

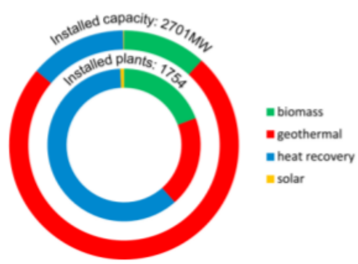

Figure 1. Total installed capacity per application of ORC [11].

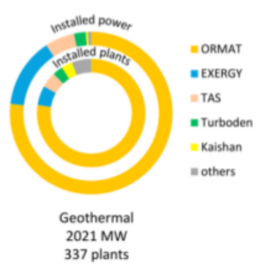

Figure 2. Market share per manufacturer of ORC [11]

3.2. Model of ORC unit

The use of ORC technology to geothermal resources can be applied with a binary power plant system, this was first tested by ORMAT in the early 1980s. Until now, the binary power plant system was substantially more identical to the ORC system [14]. The ORC system can also be applied to geothermal power plants that use a flash system by utilizing waste brine from the separator [15]. This join flash-binary geothermal power plant combines the advantages of both systems (Figure 3 and Figure 4), creating more ideal cycle [1]. However, the application of ORC technology to this system needs more attention on several parameters, such as the choice of cycle type, working fluids, condensation temperature and pressure, cooling media, and selection of expander technology that will be used [14]. In selecting the right ORC system, it is necessary to consider the capabilities of the available geothermal resources. In addition, to obtain a suitable system or to improve the efficiency of the system, be aware of the selection of working fluid and expander that is suitable for the ORC system.

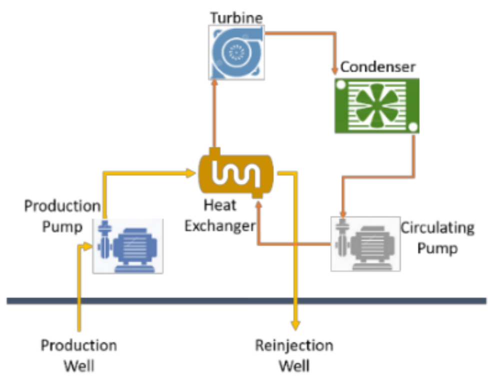

Figure 3. Binary geothermal power plant and combined flash-binary power plant [1].

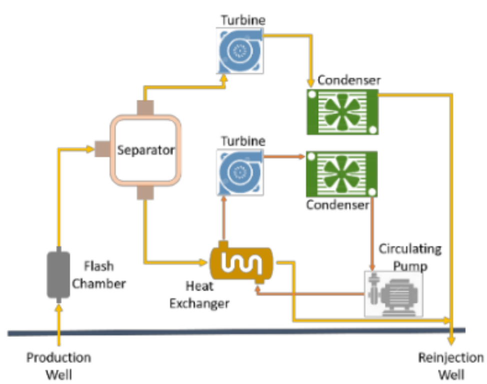

Figure 4. Combined flash-binary power plant [1].

3.3. Innovation of ORC system

3.3.1. Working fluids. The use of organic working fluid in the Rankine cycle is to use heat at low to medium temperatures (<90 °C-150 °C) [16]. Organic working fluids are used in the ORC system because they have low boiling points, critical temperatures, and pressures that are much lower than water [17]. In comparison with water, the higher molecular mass has a used fluid that is used in the ORC. This allows compact designs, greater mass flow, and higher turbine efficiency (around 80% to 85%) [10]. Table 1 shows some organic working fluids that have the potential to work in the ORC system along with their thermodynamic characteristics and properties.

Table 1. Properties of working fluids that possible for the ORC system [18].

Substance	Molecular formula	Physical data				Environmental data		
		Molecular mass [kg/kmol]	P_{crit}[a] [MPa]	T_{crit}[b] [K]	T_{bp}[c] [K]	ALT[d] [yr]	ODP[e]	GWP[f] [100yr]
R143a[w]	$C_2H_3F_3$	84.04	3.76	345.88	225.91	n.a.	0	n.a.
R32[w]	CH_2F_2	52.02	5.78	351.26	221.51	4.9	0	675
R22[w]	$CHClF_2$	86.47	4.99	369.32	232.35	n.a.	0	n.a.
R290[w]	C_3H_8	44.10	4.25	369.84	231.15	n.a.	0	3
R134a[w]	$C_2H_2F_4$	102.03	4.06	374.18	247.08	14	0	1430
R227ea[d]	C_3HF_7	170.02	2.93	374.89	256.81	n.a.	n.a.	n.a.
R152a[w]	$C_2H_4F_2$	66.05	4.50	386.65	249.13	1.4	0	124
R124[i]	C_2HClF_4	136.48	3.62	395.43	261.15	n.a.	n.a.	n.a.
CF_3I[w]	CF_3I	195.91	3.95	396.44	251.30	n.a.	n.a.	n.a.
R236fa[d]	$C_3H_2F_6$	152.04	3.20	398.72	271.75	n.a.	n.a.	n.a.
R600a[i]	C_4H_{10}	58.12	3.64	407.85	261.41	0.019	0	~20
R142b[i]	$C_2H_3ClF_2$	100.49	4.12	410.35	263.85	19.5	0.065	2400
R236ea[d]	$C_3H_2F_6$	152.04	3.41	412.37	279.25	8	0	710
Iso-butene[i]	C_4H_8	56.11	4.01	418.05	266.25	n.a.	n.a.	n.a.
Butene[i]	C_4H_8	56.11	4.01	419.25	266.85	n.a.	n.a.	n.a.
R600[d]	C_4H_{10}	58.12	3.80	425.15	272.63	0.018	0	~20
R245fa[d]	$C_3H_3F_5$	134.05	3.64	427.210	288.29	8.8	0	820
Neo-pentane[d]	C_5H_{12}	72.15	3.19	433.75	282.65	n.a.	n.a.	n.a.
R245ca[d]	$C_3H_3F_5$	134.05	3.93	447.57	298.28	6.6	0	560
R21[w]	$CHCl_2F$	102.92	5.18	451.48	282.05	n.a.	n.a.	n.a.
R123[i]	$C_2HCl_2F_3$	152.93	3.67	456.85	300.95	1.3	0.012	77
R365mfc[d]	$C_4H_5F_5$	148.07	3.27	460.01	313.15	n.a.	n.a.	n.a.
R601a[d]	C_5H_{12}	72.15	3.39	460.35	300.95	0.01	0	~20
R601[d]	C_5H_{12}	72.15	3.37	469.65	309.15	0.01	0	~20
R141b[i]	$C_2H_3Cl_2F$	116.95	4.25	477.65	305.20	9.4	0.11	630

n.a.: none-available, w: wet, d: dry, i: isentropic.
[a] *Pcrit*: critical pressure.
[b] *Tcrit*: critical temperature.
[c] *Tbp*: normal boiling point.
[d] ALT: atmospheric life time.
[e] ODP: ozone depletion potential, relative to R11.
[f] GWP: global warming potential, relative to CO_2.

In the selection of working fluids, factors such as safety problems (non-flammable, non-corrosive), health (non-toxic) and environmental impacts (low ODP and GWP) must also be considered [17]. Several types of working fluids that allow them to be applied to the ORC system have fulfilled the safety, security, and environmental impacts they caused, in addition to the reliability of the thermodynamic properties of the working fluid will be used on this system.

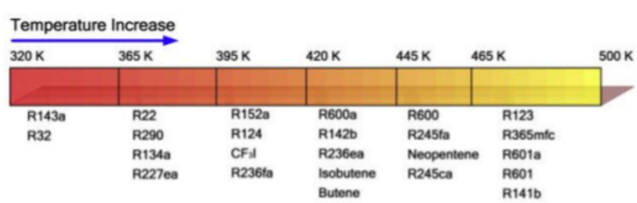

Figure 5. Optimal selections of working fluids corresponding to the heat source temperature level [19].

Selecting the right working fluid in the ORC system is influenced by the temperature range of the ORC system which will operate as shown in Figure 5. This occurs due to thermodynamic properties of fluid will affect the efficiency of the cycle at certain temperatures [10]. However, overall mechanical or electrical efficiency in the ORC system depends on the compatibility between expander characteristics, working fluid properties, and thermodynamic cycle parameters [13].

3.3.2. Expander. The choice of expander in the ORC system must consider many factors, such as power capacity, isentropic efficiency, cost and complexity [20]. In general, expander types can be categorized into two types, namely the type of speed and the type of volumetric according to Figure 6 [21]. The volumetric type expander has a lower flow rate, a higher pressure ratio, and a much lower rotational speed than the speed type expander [22]. The volumetric type expander is more suitable to use at a power output of 50 kWh or below, while a speed type expander is more suitable for power output above 50 kWh [23]. Basically, a geothermal power plant that has a large capacity uses a speed (axial / radial) type expander to be able to produce large power (> 50 kWh).

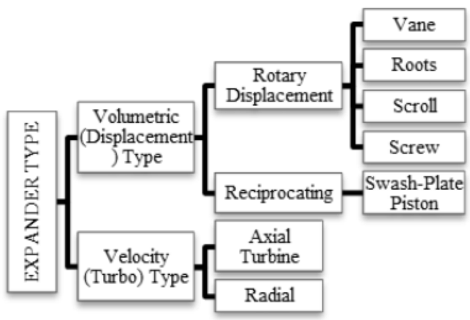

Figure 6. Classification of ORC expander [21].

4. Conclusion
The ORC system in this geothermal power plant technology can be classified into two types, namely as a binary power plant and combined flash-binary power plant. In the application of this system, working fluid selection, expander use, and suitability between systems and working conditions are the main things that can affect the efficiency and work effectiveness of the system. The choice of a working fluid that is safe, environmentally friendly, has reliable thermodynamic characteristics, and that is suitable for a certain temperature range need to be noticed to obtain the most optimal work cycle. In addition, the expander selection in accordance with the working characteristics of the ORC system is also an important factor in achieving high mechanical and electrical efficiency.

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