A Modified Non-Isothermal Lumped Parameter Model in Porous Media for Geothermal Reservoirs

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Abstract. This paper presents a method to predict geothermal performance along production life using a lumped parameter model that has considered mass balance, heat changes, and porous media flow in geothermal reservoirs. Furthermore, the lumped model provides more information on the characteristics of geothermal reservoirs. This paper focuses on developed and combined Satman’s model on mass balance and Schilthuis’s model on material balance for oil reservoirs. This paper can calculate heat and mass balance for the non-isothermal condition with pressure and temperature changes, unlike previously published papers. Besides, this paper also includes Darcy’s equation to change the “tank” concept of lumped to be porous media as an actual reservoir condition. Thus the production mass rate can be calculated. The model developed can be used for performing history matching, “quick count” of numerical simulation due to there is calculation well by well, if those combined, can determine an entire reservoir with a simple calculation. On the other hand, this method reduces the complexity of numerical calculation. Therefore, new lumped is expected to be an alternative for application in geothermal reservoirs.

1. Introduction

Many studies on the mass balance reservoir in Geothermal, such as [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14]. Previously developed material by Schilthuis for oil & gas. In principle, the Geothermal reservoir mass balance is the same as the material balance. The difference is that the material balance is well known in oil and gas with the volume unit, while the mass balance is the mass unit.

Geothermal reservoir has unique characteristics where reservoir temperature is the main factor in affecting the reservoir, followed by reservoir permeability and pressure. A decrease in temperature will result in a decrease in enthalpy, which affects the well’s capacity. Reservoir pressure is one of the parameters that need to be maintained to not drop dramatically by controlling the mass balance [6, 7, 8, 11, 12]. However, the mass balance equation that exists so far has not considered the effect of porous media. It is then necessary to consider the porous media factor in the equation with the advantage of predicting changes that occur in the reservoir quickly and simply compared to numerical simulation, which has high complexity.
2. Reservoir Mechanism

2.1. Mass Balance
Mass balance’s basic concept shows the equilibrium of mass in, mass out, and accumulated mass [11]. Some fundamental factors considered are thermodynamics and fluid properties. Generally, the mass balance equation for geothermal [11] can be described as follows:

\[ W_{wp} + W_{vp} = V \frac{d}{dt}(1 - S_v - S_{we}) \phi \rho_w + V \frac{d}{dt}(1 - S_w - S_{we}) \phi \rho_v + W_r + W_{ri} \]  

(1)

Where \( V \) is a reservoir volume that can be assumed as a cylindrical reservoir volume (single well) and recognizing that:

\[ V = Ah = \pi r^2 h \]  

(2)

2.2. Heat Balance
Besides mass balance, in the geothermal, energy balance is essential, indicated by heat balance. The equation is similar to mass balance, only multiplied by enthalpy (can use internal energy if the fluid is assumed to be static). Also, heat source and heat loss are included. The generalized material balance equation is:

\[ W_{wp}H + W_{vp}H + Q_{loss} = V \frac{d}{dt}(1 - S_v - S_{we}) \phi \rho_w H + V \frac{d}{dt}(1 - S_w - S_{we}) \phi \rho_v H + W_r H + W_{ri} H + Q_{hs} \]  

(3)

Further, the schematic of heat balance can be modelled in the following (Figure 1):

![Figure 1. Heat balance in geothermal reservoirs [11].](image)

2.3. Porous Media
Geothermal water and steam flow through porous media following Darcian flow due to pressure difference (\( \Delta P \)). Some important equations in deciding fluid mechanism in porous media (pseudo-steady state) can be described as follows:
\[ w_{wp} = \frac{k_p k_h (P - P_{wp})}{1.612 \times 10^9 \mu_r \left[ \ln \left( \frac{r_c}{r_w} \right) - 0.75 + S \right]} \rho_w \]  

Equation (4) is for water, while the equation for steam written as:

\[ w_{wp} = \frac{k_p k_h (P^2 - P_{wp}^2)}{9.121 \times 10^7 (T + 460) \mu_r Z \left[ \ln \left( \frac{r_c}{r_w} \right) - 0.75 + S \right]} \rho_v \]

Recognizing that the productivity index as follows:

\[ PI = \left( \frac{w}{\Delta P} \right) \]

Substituting Equation (4) into Equation (6):

\[ PI = \frac{k_p k_h}{1.612 \times 10^9 \mu_r \left[ \ln \left( \frac{r_c}{r_w} \right) - 0.75 + S \right]} \rho_w \]

Whereas for steam using pseudo pressure or \( P^2 \) square because steam is compressible so it can be described in the following equation:

\[ PI = \frac{k_p k_h}{9.121 \times 10^7 (T + 460) \mu_r Z \left[ \ln \left( \frac{r_c}{r_w} \right) - 0.75 + S \right]} \rho_v \]

Sometimes dynamic viscosity in Darcy’s equation can be changed to kinematic viscosity with the following equation:

\[ \nu = \frac{\mu}{\rho} \]

To know the correlation between steam saturation and relative permeability, we can use Corey’s correlation:

\[ k_{rv} = k_{rv}^* \left( \frac{S_v}{1 - S_{wc}} \right)^{N_v} \]

Moreover, the relationship between relative permeability and water saturation in the following:

\[ k_{rvw} = k_{rvw}^* \left( \frac{S_w - S_{wc}}{1 - S_{wc}} \right)^{N_w} \]

Relative permeability and water saturation relationship (Figure 2) are commonly determined by experiments in a laboratory using Special Core Analysis (SCAL). However, if there no data available, it can use correlations such as Corey and Honarpour. However, that relationship is difficult to calculate because geothermal water saturation is controlled by temperature, not only by pressure.
Figure 2. Chart of relative permeability vs. water saturation [15].

Suppose it is assumed that matrix or fracture shrinkage does not occur when the fluid is injected and produced, then absolute permeability is assumed to be the same between II and PI. The basic concept of how fluid flows along with the porous media to the wellbore can be illustrated by the description below:

Figure 3. Radial flow in porous media [16].

2.4. Trapezoidal Equation
Cumulative production, reinjection, and recharge \( (W) \) can be calculated as the area under the mass flow rate \( (w) \) graph \((y\)-axis\) vs. time \((x\)-axis\) so that it can be calculated as a trapezoidal area. Thus, the equation can be arranged as:

\[
W_{\text{cum}} = W_o + \frac{w_o + w_i}{2} (t_{f} - t_{i})
\]  

(12)

The next step is substituting \( k_{rw} \) and \( k_{rv} \) in Equation (4) and (5) with Equation (10) and (11), then calculating the cumulative mass of water and steam using Equation (12), and finally, the mass and heat balance can be solved by Equation (1) and Equation (3).
3. Wellbore Fluid Mechanism

Fluid movements in principle come from porous media or fractures that flow along the pore (Darcian Flow) to the wellbore with a pressure difference ($P - P_{wf}$) in the well. The fluid rises along the borehole to the surface, following the law of conservation of energy (Bernoulli’s equation). Fluid usually experiences pressure drops in which the water-dominated well is higher than the steam-dominated well. Many researchers have performed pressure drop correlations in the wellbore (wellbore modeling) to obtain wellhead pressure ($P_{wh}$) such as Lockhart Martinelli, Harrison & Freeston, Duns & Ros, Hagedorn & Brown, Orkiszewski, and Drift Flux. The total pressure drop is the sum of pressure loss due to gravity, acceleration, and friction. It can be written as:

\[
\frac{dp}{dz} = \frac{dp}{dz}_f + \frac{dp}{dz}_a + \frac{dp}{dz}_g
\]  

(13)

4. Surface Fluid Mechanism

After reaching the surface, fluid flows through the pipe from the wellhead to the separator (two-phase), then enters the turbine following the same equation as in the wellbore, Equation (13).

5. Power Generation

In principle, geothermal power plants are similar to steam power plants, except geothermal energy from reservoirs. The steam flowed into a turbine; the heat energy from the steam is converted to mechanical energy in the turbine; the turbine drives an electric generator; thus, electrical energy is produced. The movement of fluid from wellbore to the turbine is presented in (Figure 4). Point 1 shows the fluid condition in the well, then flashing occurs to the surface, namely the wellhead (Point 2). Furthermore, the fluid is separated in a separator (Point 3). Then the steam enters the turbine (Point 4) and leaves the turbine (Point 6) while brine (5) and condensate (9) are injected back into the injection well.

![Figure 4](image)

**Figure 4.** Chart of the phase diagram of a geothermal steam-water process [17].

The general power equation in turbine used is:

\[
W = \eta m (h_1 - h_2)
\]  

(14)

Defining that:

\[
s_4 = s_6 = s_f s_6 + x_n s_{nf6}
\]  

(15)
Rearrange Equation (15), the result in the following equation:

$$x_e = \frac{s_{k_e} - s_{f_e}}{s_{f_e}}$$  \hspace{1cm} (16)

Enthalpy of condenser can be written as:

$$h_e = h_{f_e} + x_e h_{f_e}$$  \hspace{1cm} (17)

6. Data

Five wells can be used for testing this method that is Well 1 to Well 5. The input parameter for all wells can be seen in Table 1.

| Parameter | Unit | Well 1 | Well 2 | Well 3 | Well 4 | Well 5 |
|-----------|------|--------|--------|--------|--------|--------|
| $k_a$ | md | 28 | 39 | 50 | 28 | 7 |
| $k_{rv}$ | fraction | 0 | 0 | 0 | 0 | 0 |
| $k_{rv}^*$ | | 1 | 1 | 1 | 1 | 1 |
| $k_{rc}$ | fraction | 1 | 1 | 1 | 1 | 1 |
| $k_{rc}^*$ | | 1 | 1 | 1 | 1 | 1 |
| $r_e$ | m | 500 | 500 | 500 | 500 | 500 |
| $r_w$ | m | 0.14 | 0.11 | 0.11 | 0.11 | 0.14 |
| $S_v$ | fraction | 0 | 0 | 0 | 0 | 0 |
| $S_w$ | fraction | 1 | 1 | 1 | 1 | 1 |
| $N_v$ | dimensionless | 1 | 1 | 1 | 1 | 1 |
| $N_w$ | dimensionless | 1 | 1 | 1 | 1 | 1 |
| $S_{wc}$ | fraction | 0 | 0 | 0 | 0 | 0 |
| $S$ | dimensionless | 0.01 | 0.01 | 0.01 | 0.01 | 0 |
| $A$ | m$^2$ | 785398 | 785398 | 785398 | 785398 | 785398 |
| $h$ | m | 1000 | 800 | 1000 | 1000 | 700 |
| $V$ | m$^3$ | 8.E+08 | 6.E+08 | 8.E+08 | 8.E+08 | 5.E+08 |
| $\phi$ | % | 8% | 10% | 10% | 10% | 10% |
| $T_i$ | °C | 206 | 244 | 236 | 234 | 300 |
| $P_i$ | bara | 43.0 | 28.0 | 55.0 | 55.0 | 67.0 |
| $P_{wf}$ | bara | 37.2 | 24 | 51.65 | 51.45 | 39 |
| $P_{wh}$ | bara | 6 | 7 | 8 | 8 | 14 |
| $P_{sep}$ | bara | 5.5 | 6 | 7 | 7 | 11 |
| TIP | bara | 5 | 5 | 5 | 5 | 5 |
| $\eta$ | % | 79% | 79% | 79% | 79% | 79% |
7. Result and Discussion

The developed model has been validated with the actual wells of PT. Pertamina Geothermal Energy. The sensitivity of these methods was tested by using five wells. In the first case (Well-1), several parameters change with time, such as reservoir pressure, steam and water production, water productivity index (PI steam = 0 because Sv = 0), and power. The simulation was run for 30 years. The reservoir pressure value tends to decrease with an initial pressure of 43 bara to an end pressure of 42.2 bara. If $P_{wf}$ is assumed constant at 37.2 bara, then the $P_{wh}$ is also constant (isothermal).

However, the pressure drop effect occurs in the power plant, decreasing the power from 5.7 MW to 4.9 MW at the end of the simulation. The downward trend also occurred in the water productivity index. The reservoir dryness is assumed to be 0 or a complete liquid reservoir. The mass flow rate of steam increases along the borehole and the surface pipe. The steam flowrate at the wellhead is around 10.3 kg/s, then decreases over the production time to 8.8 kg/s (see Appendix). A decrease in reservoir pressure causes this effect. The temperature is constant (isothermal) by 206°C, so the effect of the pressure drop is more dominant than temperature.

In Well-2, there is a decrease in temperature, from 244 to 236°C, which decreases the power from 6.9 MW to 5 MW. Reservoir pressure also tends to decrease from 28 to 27.2 during 30 years of production. However, the dryness remains 0, indicating that the reservoir’s fluid is 100% water (see Appendix).

![Figure 5. Chart of steam and water production of Well-2.](image-url)
Table 2. List of parameters of the Well-2 result.

| Pres  | Pwf  | t  | Res Temp | wp  | wv  | x  | wr  | wri | Qhs | Qloss | Pwh | x wh | wh | ww | wh P | Sep | x sep | Cond | SSC | Power |
|-------|------|----|----------|-----|-----|----|-----|-----|-----|-------|-----|------|----|-----|-----|-----|-------|-----|-----|-------|
| bara  | bara | year | °C | kg/s | kg/s | frac | kg/s | kg/s | kj  | kj   | kg/s | kg/s | kg/s | kg/s | bara | bara | bara | t/hr/MW | MW |
| 28.0  | 24.0 | 0.0 | 244 | 71.7 | 0.0 | 2.1 | 0.0 | 0.7 | 0.17 | 59.2 | 12.5 | 6.0 | 0.19 | 0.054 | 6.9 | 6.9 |
| 27.9  | 24.0 | 3.4 | 243 | 69.9 | 0.0 | 2.1 | 0.0 | 0.7 | 0.17 | 58.0 | 12.0 | 6.0 | 0.18 | 0.054 | 6.9 | 6.7 |
| 27.8  | 24.0 | 6.9 | 242 | 68.1 | 0.0 | 2.1 | 0.0 | 0.7 | 0.17 | 56.6 | 11.5 | 6.0 | 0.18 | 0.054 | 6.9 | 6.4 |
| 27.7  | 24.0 | 10.4| 241 | 66.3 | 0.0 | 2.1 | 0.0 | 0.7 | 0.17 | 55.3 | 11.1 | 6.0 | 0.18 | 0.054 | 6.9 | 6.2 |
| 27.6  | 24.0 | 14.1| 240 | 64.4 | 0.0 | 2.1 | 0.0 | 0.7 | 0.16 | 53.9 | 10.6 | 6.0 | 0.18 | 0.054 | 6.9 | 5.9 |
| 27.5  | 24.0 | 17.9| 239 | 62.6 | 0.0 | 2.1 | 0.0 | 0.7 | 0.16 | 52.5 | 10.2 | 6.0 | 0.17 | 0.054 | 6.9 | 5.7 |
| 27.4  | 24.0 | 21.8| 238 | 60.8 | 0.0 | 2.1 | 0.0 | 0.7 | 0.16 | 51.1 | 9.8  | 6.0 | 0.17 | 0.054 | 6.9 | 5.4 |
| 27.3  | 24.0 | 25.8| 237 | 59.0 | 0.0 | 2.1 | 0.0 | 0.7 | 0.16 | 49.7 | 9.3  | 6.0 | 0.17 | 0.054 | 6.9 | 5.2 |
| 27.2  | 24.0 | 30.0| 236 | 57.2 | 0.0 | 2.1 | 0.0 | 0.7 | 0.16 | 48.3 | 8.9  | 6.0 | 0.17 | 0.054 | 6.9 | 5.0 |

Well-3 shows the reservoir pressure decreases from 55 to 54.2 bara throughout 30 years of production. The reservoir temperature is constant (236°C). The value of well flowing pressure is assumed constant at 51.65 bara; thus, the $P_{wh}$ is also constant at 8 bara. The decline of reservoir pressure occurs on power generation, the decline of power from 8.6 MW to 6.6 MW at the end of production time (Appendix). The decline trend also occurs for the productivity index of water, from 31.73 to 31.67 kg/s/bara. The dryness in the reservoir is assumed as 100% water. The mass flow rate of steam increases along with wellbore and surface piping because of dryness. The steam flowrate at wellhead about 15.4 kg/s and then decline along with production life to 11.7 kg/s. The decline of reservoir pressure causes this effect.

Well-4 shows the reservoir pressure decreases from 55 to 54.2 bara throughout 30 years of production. The reservoir temperature is constant (236°C). The steam flowrate at wellhead about 8.9 kg/s and then decline along with production life to 6.9 kg/s. The decline of reservoir pressure occurs on power generation, the decline of power from 5 MW to 3.8 MW at the end of production time. The declining trend also occurs for the productivity index of water, from 17.79 to 17.75 kg/s/bara (see Appendix). The value of well flowing pressure is assumed constant at 51.45 bara; thus, the $P_{wh}$ is also constant at 8 bara.

Calculation of Well-5 data shows reservoir pressure decreased from 67 to 63 bara along with the production. The reservoir temperature tends to decrease, from 300°C to 284°C. The well flowing pressure is assumed constant at 39 bara. The decline in power is from 14 MW to 10 MW at the final calculation (see Appendix). Compared with the four previous well samples, Well-5 is well with the most significant production even though it has the lowest permeability. This well has the advantage of having the highest temperature compared to other wells. A downward trend also occurred for the water productivity index, from 3.51 to 3.47 kg/s/bara. The mass flow rate of steam increases with the wellbore and surface piping due to increased drought. The steam discharge at the wellhead is around 25.8 kg/s then decreases with the production life to 18.2 kg/s. The decrease in reservoir pressure contributes to this decline.

8. Conclusion

The conclusions of this study are a non-isothermal lumped parameter has been developed, and it can be applied for evaluating geothermal reservoirs. The new equation has considered many aspects that affect fluid mechanism from a reservoir to power generation such as mass and heat balance, Darcian flow in porous media, fluid mechanism equation to know pressure drop in a wellbore, from bottom hole to wellhead, the pressure drop in the pipeline and can calculate power generation (MW) of production. It is also applicable to consider mass re-injection, re-charge, heat loss, and heat source. Furthermore, it provides a simple equation for an independent user to simulate the reservoir and predict the production.
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Nomenclature

\[ A = \text{drainage Area, m}^2 \]
\[ c_f = \text{rock compressibility, bara}^{-1} \]
\[ h = \text{feed thickness, m} \]
\[ k_a = \text{absolute permeability, md} \]
\[ k_r = \text{relative permeability, fraction} \]
\[ k_{rv} = \text{relative permeability to steam, fraction} \]
\[ k_{rw} = \text{relative permeability to water, fraction} \]
\[ k_{rv}^* = \text{relative permeability to steam at end point, fraction} \]
\[ k_{rw}^* = \text{relative permeability to water at end point, fraction} \]
\( n = \) incremental superscript, dimensionless
\( N_{c} = \) Corey steam exponent, dimensionless
\( N_{w} = \) Corey water exponent, dimensionless
\( P = \) current reservoir pressure, bara
\( P_{i} = \) initial reservoir pressure, bara
\( P_{wf} = \) bottom hole pressure, bara
\( Q_{ri} = \) heat of reinjection, J/s
\( Q_{r} = \) heat of recharge, J/s
\( Q_{loss} = \) Heat of loss, J/s
\( H = \) enthalpy, kJ/kg
\( s = \) entropy, kJ/kg.K
\( r_{e} = \) external radius, m
\( r_{w} = \) well radius, m
\( S = \) skin, dimensionless
\( S_{c} = \) steam saturation, fraction
\( S_{w} = \) water saturation, fraction
\( S_{wc} = \) immobile fluid saturation, fraction
\( T = \) reservoir temperature, °C,
\( T_{i} = \) initial reservoir temperature, °C
\( t = \) time, s
\( V = \) bulk volume, m³
\( w_{v} = \) steam mass rate, kg/s
\( w_{w} = \) water mass rate, kg/s
\( W_{vp} = \) cumulative mass steam production, kg
\( W_{wp} = \) cumulative mass steam production, kg
\( W_{ri} = \) cumulative mass of reinjection, kg
\( W_{r} = \) cumulative mass of recharge, kg
\( W_{i} = \) initial cumulative mass, kg
\( W_{c} = \) current cumulative mass, kg
\( W_{p} = \) cumulative mass production, kg
\( Z = \) steam compressibility factor, dimensionless
\( \mu_{v} = \) steam viscosity, Pa.s
\( \mu_{w} = \) water viscosity, Pa.s
\( \rho_{s} = \) steam density, kg/m³
\( \rho_{w} = \) water density, kg/m³
\( \rho_{m} = \) rock density, kg/m³
\( \phi = \) porosity, fraction
Appendix

**Figure A1.** Chart of steam and water production of Well-1.

**Figure A2.** Chart of steam and water production of Well-3.
Figure A3. Chart of steam and water production of Well-4.

Figure A4. Chart of steam and water production of Well-5.
Table A1. List of parameters of the Well-1 result.

| Pres bara | Pwf bara | t year | Res Temp °C | wp kg/s | wv kg/s | wv x frac | x wr | wri kg/s | Qhs kj | Qloss Pwh kj | x wh | ww kg/s | wh kg/s | P Sep bara | x sep frac | P Cond bara | SCC | Power t/hr/MW | MW |
|-----------|----------|--------|-------------|---------|---------|-----------|------|----------|--------|-------------|------|---------|---------|-----------|------------|-------------|------|--------------|-----|
| 43.0 37.2 0.0 | 206 102.5 0 0 0 0 0 0 6 0.10 | 92.2 10.3 5.5 0.11 | 0.054 | 6.9 | 5.7 |
| 42.9 37.2 3.5 | 206 100.7 0 0 0 0 0 0 6 0.10 | 90.7 10.1 5.5 0.11 | 0.054 | 6.9 | 5.6 |
| 42.8 37.2 7.1 | 206 98.9 0 0 0 0 0 0 6 0.10 | 89.0 9.9 5.5 0.11 | 0.054 | 6.9 | 5.5 |
| 42.7 37.2 10.7 | 206 97.1 0 0 0 0 0 0 6 0.10 | 87.4 9.7 5.5 0.11 | 0.054 | 6.9 | 5.4 |
| 42.6 37.2 14.4 | 206 95.3 0 0 0 0 0 0 6 0.10 | 85.8 9.6 5.5 0.11 | 0.054 | 6.9 | 5.3 |
| 42.5 37.2 18.2 | 206 93.5 0 0 0 0 0 0 6 0.10 | 84.2 9.4 5.5 0.11 | 0.054 | 6.9 | 5.2 |
| 42.4 37.2 22.1 | 206 91.7 0 0 0 0 0 0 6 0.10 | 82.6 9.2 5.5 0.11 | 0.054 | 6.9 | 5.1 |
| 42.3 37.2 26.0 | 206 89.9 0 0 0 0 0 0 6 0.10 | 81.0 9.0 5.5 0.11 | 0.054 | 6.9 | 5.0 |
| 42.2 37.2 30.0 | 206 88.1 0 0 0 0 0 0 6 0.10 | 79.4 8.8 5.5 0.11 | 0.054 | 6.9 | 4.9 |

Table A2. List of parameters of Well-3 result.

| Pres bara | Pwf bara | t year | Res Temp °C | wp kg/s | wv kg/s | wv x frac | x wr | wri kg/s | Qhs kj | Qloss Pwh kj | x wh | ww kg/s | wh kg/s | P Sep bara | x sep frac | P Cond bara | SCC | Power t/hr/MW | MW |
|-----------|----------|--------|-------------|---------|---------|-----------|------|----------|--------|-------------|------|---------|---------|-----------|------------|-------------|------|--------------|-----|
| 55.0 51.7 0.0 | 236 106.3 0 0 0 0 0 0 8 0.15 | 90.8 15.4 7 0.16 | 0.054 | 6.9 | 8.6 |
| 54.9 51.7 3.3 | 236 103.1 0 0 0 0 0 0 8 0.15 | 88.1 15.0 7 0.16 | 0.054 | 6.9 | 8.4 |
| 54.8 51.7 6.8 | 236 99.9 0 0 0 0 0 0 8 0.15 | 85.4 14.5 7 0.16 | 0.054 | 6.9 | 8.1 |
| 54.7 51.7 10.3 | 236 96.7 0 0 0 0 0 0 8 0.15 | 82.7 14.1 7 0.16 | 0.054 | 6.9 | 7.8 |
| 54.6 51.7 14.0 | 236 93.5 0 0 0 0 0 0 8 0.15 | 80.0 13.6 7 0.16 | 0.054 | 6.9 | 7.6 |
| 54.5 51.7 17.8 | 236 90.3 0 0 0 0 0 0 8 0.15 | 77.2 13.1 7 0.16 | 0.054 | 6.9 | 7.3 |
| 54.4 51.7 21.7 | 236 87.1 0 0 0 0 0 0 8 0.15 | 74.5 12.7 7 0.16 | 0.054 | 6.9 | 7.1 |
| 54.3 51.7 25.8 | 236 83.9 0 0 0 0 0 0 8 0.15 | 71.8 12.2 7 0.16 | 0.054 | 6.9 | 6.8 |
| 54.2 51.7 30.0 | 236 80.7 0 0 0 0 0 0 8 0.15 | 69.0 11.7 7 0.16 | 0.054 | 6.9 | 6.6 |

Table A3. List of parameters of the Well-4 result.

| Pres bara | Pwf bara | t year °C | wp kg/s | wv kg/s | wv x frac | x wr | wri kg/s | Qhs kj | Qloss Pwh kj | x wh | ww kg/s | wh kg/s | P Sep bara | x sep frac | P Cond bara | SCC | Power t/hr/MW | MW |
|-----------|----------|--------|---------|---------|-----------|------|----------|--------|-------------|------|---------|---------|-----------|------------|-------------|------|--------------|-----|
| 55.0 51.5 0.0 | 234 63.1 0 0 0 0 0 0 8 0.14 | 54.3 8.9 7 0.15 | 0.054 | 6.9 | 5.0 |
| 54.9 51.5 3.4 | 234 61.3 0 0 0 0 0 0 8 0.14 | 52.7 8.6 7 0.15 | 0.054 | 6.9 | 4.8 |
| 54.8 51.5 6.8 | 234 59.6 0 0 0 0 0 0 8 0.14 | 51.2 8.4 7 0.15 | 0.054 | 6.9 | 4.7 |
| 54.7 51.5 10.4 | 234 57.8 0 0 0 0 0 0 8 0.14 | 49.7 8.1 7 0.15 | 0.054 | 6.9 | 4.5 |
| 54.6 51.5 14.0 | 234 56.0 0 0 0 0 0 0 8 0.14 | 48.1 7.9 7 0.15 | 0.054 | 6.9 | 4.4 |
| 54.5 51.5 17.8 | 234 54.2 0 0 0 0 0 0 8 0.14 | 46.6 7.6 7 0.15 | 0.054 | 6.9 | 4.3 |
| 54.4 51.5 21.7 | 234 52.4 0 0 0 0 0 0 8 0.14 | 45.1 7.4 7 0.15 | 0.054 | 6.9 | 4.1 |
| 54.3 51.5 25.8 | 234 50.6 0 0 0 0 0 0 8 0.14 | 43.5 7.1 7 0.15 | 0.054 | 6.9 | 4.0 |
| 54.2 51.5 30.0 | 234 48.8 0 0 0 0 0 0 8 0.14 | 42.0 6.9 7 0.15 | 0.054 | 6.9 | 3.8 |
Table A4. List of parameters of Well-5 result.

| Pres bara | Pwf bara | t year | Res Temp °C | wp kg/s | wy kg/s frac | x frac | wr kg/s | wri kg/s | Qhs kw | Qloss kw | Pwh bara | x frac | wh kg/s | P Sep bara | x frac | P Cond bara | SSC t/hr | Power MW |
|-----------|----------|--------|--------------|---------|---------------|--------|---------|----------|-------|---------|----------|--------|---------|----------|--------|------------|---------|---------|
| 67.0      | 39       | 0.0    | 300          | 98.3    | 0              | 0      | 0       | 0        | 14    | 0.26    | 72.5     | 25.8   | 11      | 0.28     | 0.10   | 7.1      | 14.0     |
| 66.5      | 39       | 3.5    | 298          | 96.4    | 0              | 0      | 0       | 0        | 14    | 0.26    | 71.7     | 24.8   | 11      | 0.28     | 0.10   | 7.1      | 13.4     |
| 66.0      | 39       | 7.0    | 296          | 94.5    | 0              | 0      | 0       | 0        | 14    | 0.25    | 70.8     | 23.8   | 11      | 0.27     | 0.10   | 7.1      | 12.9     |
| 65.5      | 39       | 10.7   | 294          | 92.7    | 0              | 0      | 0       | 0        | 14    | 0.25    | 69.9     | 22.8   | 11      | 0.27     | 0.10   | 7.1      | 12.4     |
| 65.0      | 39       | 14.4   | 292          | 90.8    | 0              | 0      | 0       | 0        | 14    | 0.24    | 69.0     | 21.8   | 11      | 0.26     | 0.10   | 7.1      | 11.9     |
| 64.5      | 39       | 18.2   | 290          | 88.9    | 0              | 0      | 0       | 0        | 14    | 0.23    | 68.1     | 20.9   | 11      | 0.25     | 0.10   | 7.1      | 11.4     |
| 64.0      | 39       | 22.0   | 288          | 87.1    | 0              | 0      | 0       | 0        | 14    | 0.23    | 67.2     | 20.0   | 11      | 0.25     | 0.10   | 7.1      | 10.9     |
| 63.5      | 39       | 26.0   | 286          | 85.2    | 0              | 0      | 0       | 0        | 14    | 0.22    | 66.2     | 19.1   | 11      | 0.24     | 0.10   | 7.1      | 10.5     |
| 63.0      | 39       | 30.0   | 284          | 83.4    | 0              | 0      | 0       | 0        | 14    | 0.22    | 65.2     | 18.2   | 11      | 0.24     | 0.10   | 7.1      | 10.0     |