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Research on a Coupled Total-Flow and Single-Flash (TF-SF) System for Power and Freshwater Generation from Geothermal Source

Guopeng Yu and Zhibin Yu *

School of Engineering, University of Glasgow, Glasgow G12 8QQ, UK; guopeng.yu@glasgow.ac.uk
* Correspondence: Zhibin.Yu@glasgow.ac.uk; Tel.: +44-(0)141-330-2530

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Abstract: In response to the twin development challenges of energy shortage and water-scarcity in worldwide arid to semi-arid regions with geothermal resources, a new combined power and freshwater generation system is proposed for geothermal energy utilization. In this system, a total-flow turbine (TF) is employed to be coupled with the traditional single-flash (SF) system and thereafter the coupled TF-SF system is investigated in this work. In addition to power generation, the exhaust steam from turbines are recovered to produce freshwater through condensation. Based on the novel designed system, the production of both power and water are studied under variable wellhead conditions, including variable wellhead pressures, temperatures, mass flowrates, and vapor qualities. The temperature of the separating point at which the total-flow expansion ends and the steam expansion starts is studied for optimal system output. In addition, the efficiency effects of the total-flow turbine on performance of the combined system is also investigated. The power generation comparison shows good power potential of the proposed TF-SF combined system. An effective total-flow turbine with an average efficiency of 65% can lead to an optimal power capacity, exceeding the traditional single-flash (SF) system by 23.7%. Moreover, more than 1/3 of total wellhead discharge can be recovered as desalinated freshwater by the naturally equipped condensation process of the power plant, showing extra benefit from geothermal energy utilization.

Keywords: geothermal energy; total-flow and single-flash (TF-SF) system; combine power and freshwater generation; parametric distributions; system performance and comparison

1. Introduction

As a renewable and sustainable resource, the geothermal energy can be well utilised for human activity and industry. Though existed worldwide, the high-temperature geothermal energy that is needed to drive electric generation stations is found in relatively few places [1,2]. In regions like Aluto Langano of Ethiopia, a great amount of geothermal energy has been detected with diverse temperatures, yet most of them are under-utilized [3].

As the most common power plant, the single-flash plant is always installed at a newly developed liquid-dominated geothermal. However, the irreversibilities associated with the flashing processes are inevitable [4,5]. Better energy utilization would be achieved if the energy-waste flashing process is reformed to be an energy-utilization one. Based on this consideration, the total-flow expansion concept, in which the wellhead geofluid is utilized in a two-phase expander/turbine for direct power generation [6–8] can be integrated to replace the flashing process in the single-flash plant. Extensive experimental and analytical studies were carried out on the total-flow expander/turbine [9,10] and most focus has been placed on screw expanders for its steady intermittent processes [11–13]. To date, no commercially successful total flow system is available to replace the traditional entire single flash system in geothermal application. However, the idea of replacing only the energy-waste flashing process with a total-flow expander shows promising potentials [14].

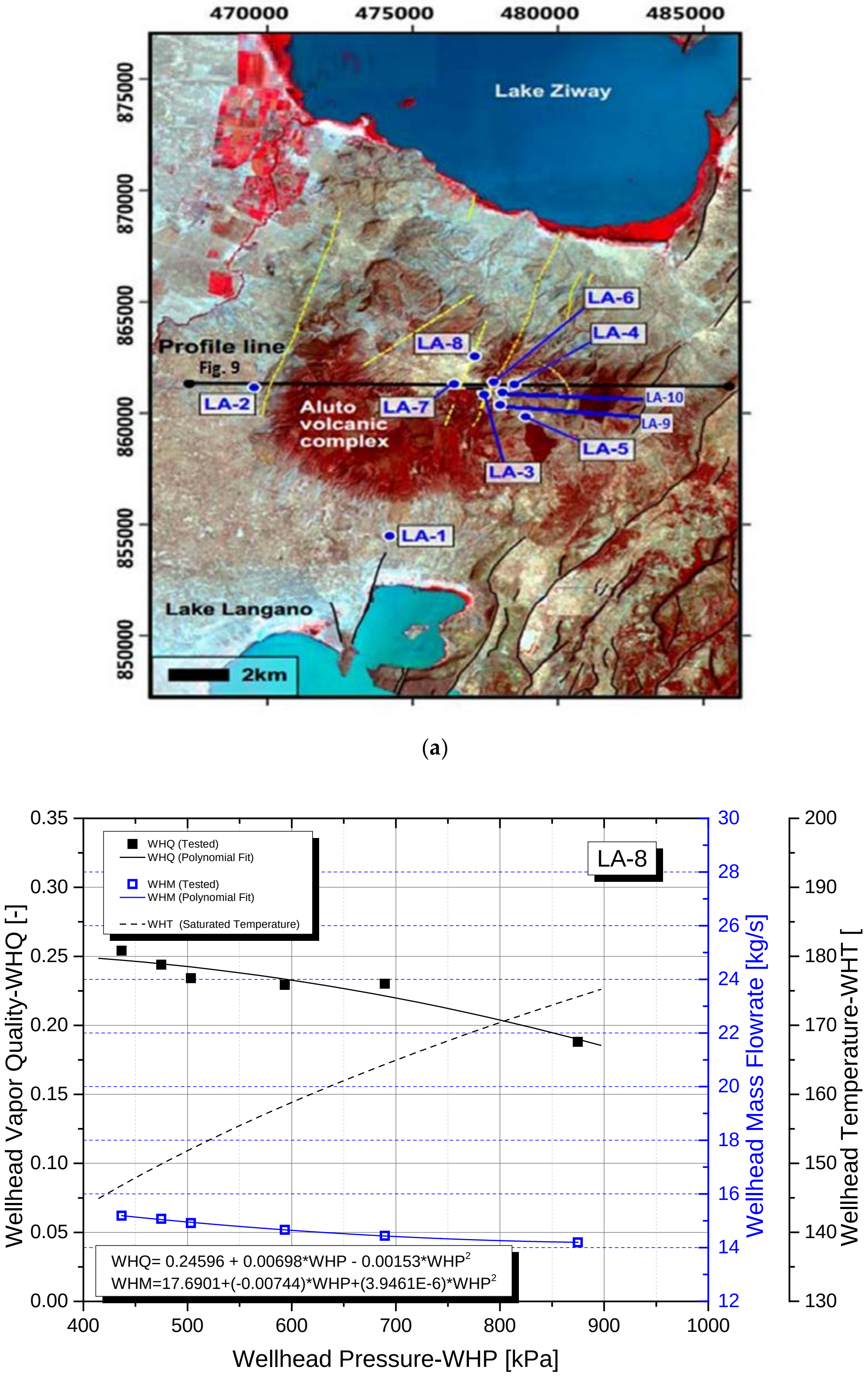
On the other hand, initiatives to address the concurrent water and power energy issues are largely being pursued separately in geothermal field. Traditionally, most of the high-temperature geothermal energy is exploited through power plant, while low-temperature geothermal energy can be optionally used for desalination and freshwater generation [15]. However, besides of generating power, the high-temperature geothermal flow can be further utilized for freshwater generation by condensing the steam after expansion. Based on this idea, a novel combined power and freshwater generation scheme is proposed. As to the freshwater generation in the geothermal energy field, extra desalination devices and processes are normally needed, which requires mechanical power or electricity consumption [16–18]. The proposed design in this work aims at eliminating these extra consumptions. The design was previously investigated by Akbarzadeh et al. [19,20] on a combined power generation and desalination system using saline water as heat resource. They started by proposing a system for simultaneous desalination and power generation based on trilateral flash cycle (TFC). Comparing to traditional power cycles, trilateral flash cycle can more effectively utilize most of the energy available in low/medium grade heat sources. Steam after expansion is condensed into freshwater and stored instead of being abandoned. By upgrading the expansion device from two-arm rotor to reaction turbines, the performance of the system has been improved significantly, demonstrating a good potential of the combined TFC and water generation concept [21].

Based on these ideas, an optimized energy system for geothermal energy utilization is proposed and studied in this paper. A total-flow process is used to replace the flashing process to get more power output. Based on the novel designed system, the production of both power and water are studied under variable wellhead conditions, including variable wellhead pressures, temperatures, mass flowrates and vapor qualities. The temperature of the separating point at which the total-flow expansion ends and the steam expansion starts is studied for optimal output. In addition, the efficiency effects of the total-flow turbine on performance of the combined system is also investigated.

2. Geothermal Well Analysis

The geothermal well under investigation in this work is located in the Aluto Langano geothermal field of Ethiopia, which is recognized as a high-temperature liquid-dominated geothermal field in eastern Africa. One typical and active geothermal well (i.e., LA8) is chosen as heat source for the proposed system. It produces two-phase, fluid-dominated wellhead discharge, and the discharge data from wellhead tests are gathered and analysed in Figure 1. Wellhead vapor quality (WHQ) and wellhead mass flowrate (WHM) are tested in situ [3]. Polynomial curves are fitted to the test points to correlate the well flow data to corresponding wellhead pressures to show better the discharging tendencies. Correlation formulas of wellhead vapor qualities and wellhead mass flowrates are developed as shown in Figure 1. Moreover, the wellhead temperature is calculated based on the pure water properties in REFPROP, ignoring the contained chemicals [22].

Wellhead vapor quality and flowrate are keeping reducing as the head pressure adds up. The vapor quality of LA-8 is mostly within 0.19–0.25 range. In comparison to other active wells in the same field, LA-8 possesses a relatively higher vapor quality, making it less liquid-dominated [3]. The wellhead mass flowrate (WHM) discharged from LA-8 decreasing slightly from 15.4 kg/s to 14.2 kg/s, indicating that LA-8 has a rather steady discharging, with no high sensitivity to wellhead pressure change.



(**a**)

(**b**)

Figure 1. Wellhead information of Aluto Langano (**a**) geothermal field geothermal and (**b**) well LA-8.

3. System Description

3.1. Total Flow Expansion

The total-flow expansion concept is to use the geofluid directly as it emerges from the well in the prime mover, be it a turbine or some other specially designed device, and significant savings would be achieved since no flashing processes or separation processes are needed as in traditional geothermal power systems. There have been major development efforts aimed at producing such a system, but no product is commercially available yet since there are still crucial issues to be scientifically understood. In this project, a total-flow turbine has been designed and investigated with promising progress [23]. It is a curved-nozzle total flow reaction turbine for two phase expansion. Flash boiling and power generation process has been comprehensively investigated. Reasonable total-flow efficiencies will be adopted in this work based on ongoing research when applying the total-flow turbine to the following system simulations.

3.2. Combined Total Flow and Single Flash (TF-SF) System

As described above, the total-flow turbine with curved nozzle is able to accomplish both the flashing and power generating tasks, it is designed to be coupled with the single flash system by replacing the flashing process. Further, in comparison with previous geothermal energy usage, instead of directly reinjecting the condensed water to geothermal reservoirs or discharging it to the environment in the form of co-produced brine and/or uncondensed steam, the desalinized freshwater during condensation is wholly recovered in the proposed three systems.

The proposed geothermally sourced combined power and freshwater generation TF-SF system is configured and shown in the left half of Figure 2, and corresponding temperature-entropy diagrams of the system are is shown in the right half of Figure 2. Firstly, the wellhead geofluid is introduced to the total-flow turbine for two phase expansion (point 1–point 2). Secondly, the vapor (point 3) and liquid (point 4) at the outlet of total-flow turbine is separated, and the vapor is introduced into the steam turbine of the original single-flash system to go through the second stage expansion (point 4–point 5). Finally, the whole fluid at turbine outlet of point 5 will be fully condensed (point 5–point 6) and recovered as freshwater because no other chemicals are contained.

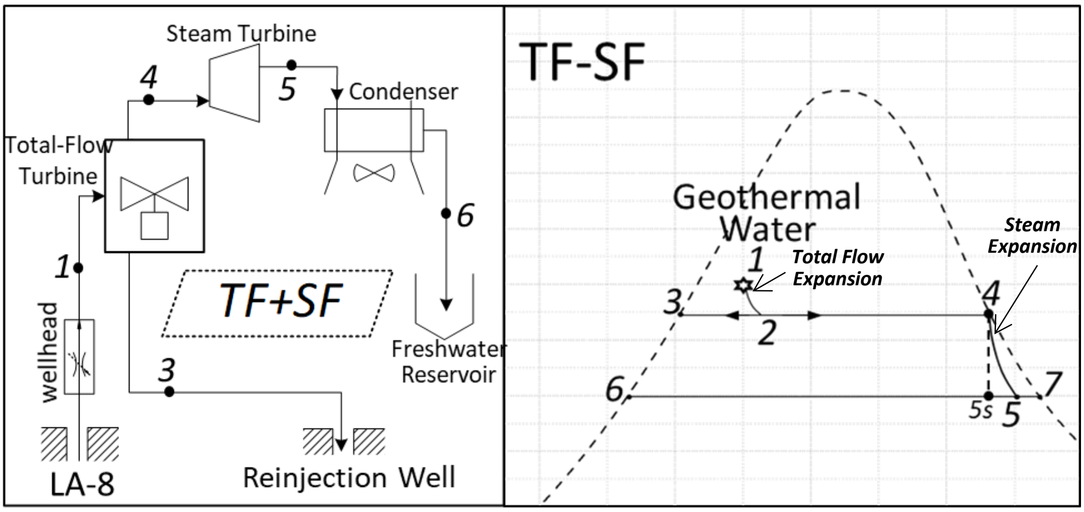


Figure 2. Configurations and temperature-entropy diagrams of TF-SF system.

4. Modelling Assumptions

Assumptions are needed before the system modelling:

At the end of total-flow expansion, a separation process is modelled as an isobaric process with constant pressure;

Any change in the kinetic or potential energy of the fluid is neglected as it undergoes a flashing process or an expansion process through the turbine;

Heat loss from the turbines are neglected.

5. Modelling

Step 1: Power generation calculation of the total-flow (TF) expansion stage.

As to the combined total flow and single flash (TF-SF) system, modelling of the total-flow part system is straightforward since an average turbine efficiency is pre-set as constant. The power output (P_{TF}, kW) in TF part from point 1 to point 2 comes from the multiplication of the enthalpy difference (h, kJ/kg) and mass flowrate (WHM, kg/s),

$$P_{TF} = WHM \times (h_1 - h_2) \tag{1}$$

The turbine efficiency is used to get the vapor quality of point 2 and the enthalpy of this point is thereafter gotten from REFPROP.

Step 2: Wet efficiency calculation of steam turbine in the single flash (SF) stage.

As to the single flash part modelling, the key process is the expansion process taking place in the steam turbine, i.e., from point 4 to 5 as shown in Figure 2. According to the Baumann rule [4], a 1% average moisture causes roughly a 1% drop in turbine efficiency. Although the inlet flow is saturated vapor, the steam turbine operates mostly in the wet region, degradation in performance caused by moisture should be taken into account. Adopting the Baumann rule, the turbine efficiency η_t is given by

$$\eta_t = \eta_{td} \times (x_4 + x_5)/2, \tag{2}$$

where η_{td} is the dry turbine efficiency which is conservatively assumed to be constant at 85%; x_4 (=1) and x_5 denote the vapor qualities of inlet and outlet flows of the steam turbine.

To get the thermodynamic state of point 5, which is in return determined by turbine efficiency as shown in Figure 2, fluid properties at state 5 s, i.e., the ideal turbine outlet state would be used,

$$\eta_t = (h_4 - h_5)/(h_4 - h_{5s}), \tag{3}$$

where h_{4s} is enthalpy of state 4, which is easily calculated from the known pressure and entropy values ($s_{5s} = s_4$).

$$h_{5s} = h_6 + (h_7 - h_6) \times [\frac{s_{5s} - s_6}{s_7 - s_6}] \tag{4}$$

Adopting the Baumann rule, enthalpy of the turbine outlet state 4 can be obtained as

$$h_5 = \frac{h_4 - \left(\frac{\eta_{td}}{2}\right) \times (h_4 - h_{5s}) \times \left(1 - \frac{h_6}{h_7 - h_6}\right)}{1 + \left(\frac{\eta_{td}}{2}\right) \times (h_7 - h_6) \times (h_4 - h_{5s})} \tag{5}$$

Then the vapor quality x_5 is obtained from the condensing pressure and entropy value h_5.

Step 3: Optimal separating temperature of the two stage TF-SF system. For a traditional single flash system designed for a saturated liquid heat source, there's a 'rule of thumb' about the optimal temperature of state 2 which determines the separation temperature as well as the inlet flow state of turbine [4]. However, calculations show that this rule is no longer applicable with two-phase heat source as studied in this paper [24]. In order to reasonably determine the exit temperature at which the total-flow expansion ends and the steam turbine starts to work, a segmenting modelling method is applied by decreasing the separating temperature of state 2 from wellhead temperature to condensing temperature by small temperature steps, and the optimal separation temperature and system performance is therefore accurately obtained.

Step 4: System performance. The power output (P_{SF}, kW) in single flash part from point 4 to point 5 also comes from the multiplication of the enthalpy difference and mass flowrate,

$$P_{SF} = WHM \times x_2 \times (h_4 - h_5) \tag{6}$$

Therefore, total power generation P is the sum of power of both the TF and SF parts. In addition, since the freshwater comes entirely from the final condensation process, i.e., the total flow introduced to the steam turbine, the generation of freshwater (m_{FW}, kg/s) is gotten by

$$m_{FW} = WHM \times x_2 \tag{7}$$

6. Results and Discussions

6.1. System Performance

As the wellhead condition varies, both the wellhead pressure and temperature vary correspondingly. The power production of the proposed TF-SF system under variable wellhead conditions and different separating temperatures are firstly investigated, since the power capacity is the primary objective of power plants in geothermal fields. And the freshwater production is analysed thereafter as extra benefits of this new design. During this simulation, the total-flow turbine efficiency has been conservatively pre-set as 35%.

Figure 3 presents the power generation of TF-SF system against the wellhead pressure and separating temperature. As the figure shows, system power output is less sensitive to the wellhead pressure than to the separating temperature. When the wellhead pressure is lower than 650 kPa, system power capacity keeps increasing as the separating temperature gradually increases towards wellhead temperature. This means that, under low wellhead pressure conditions with lower temperature but higher vapor quality, the best power generation occurs when the vapor and liquid is separated directly after being discharged from wellhead, and no flash/total-flow process is actually needed. In this way, the best solution for high power performance is to change the system to a traditional steam system in which the vapor separated from wellhead is introduced to steam turbine directly.

However, as the wellhead pressure increases above 650 kPa, the optimal separating temperature occurs since the power increases first and then decreases, indicating the TF-SF system's superior to the direct steam system under these conditions in terms of power generation. As wellhead pressure increases from 650 kPa to 940 kPa, the optimal separating temperature slightly increases from 162.3 °C to 177.2 °C, and the optimal power output decreases from 851.1 kW to 812.4 kW. Overall, the maximum power capacity of the TF-SF system among the LA-8 wellhead conditions is 851.1 kW when the average total-flow turbine efficiency is only pre-set as 35%.

The tendency of system power capacity in Figure 3 can be illustrated better by separating the power generation of the total-flow expansion part (TF) and the single-flash and expansion part (SF), as shown in Figure 4. Basically, power generation of the SF part significantly outweigh that of the TF part when the separating temperature is higher than 120 °C, meaning that the single flash part dominates the power capacity under given conditions. However, the power generation advantage of the single flash part over the total flow part shows a decreasing trend as wellhead pressure adds up. The reason is that higher wellhead pressure and temperature causes higher TF turbine inlet enthalpy, even though the wellhead vapor quality and mass flowrate are reduced. Consequently, the power generation of TF part increases along with the wellhead pressure increment. However, the lower vapor quality and flowrate of the heat source would reduce the SFS turbine inlet enthalpy, causing a reduction in SF power generation. When the separating temperature becomes lower than 120 °C, power capacity of the TF part overtakes the SF part, but the total power generation of the system would become lower than 629.6 kW. The analysis above indicates that, under LA-8 wellhead conditions, a high separating temperature is recommended to achieve high power generation.

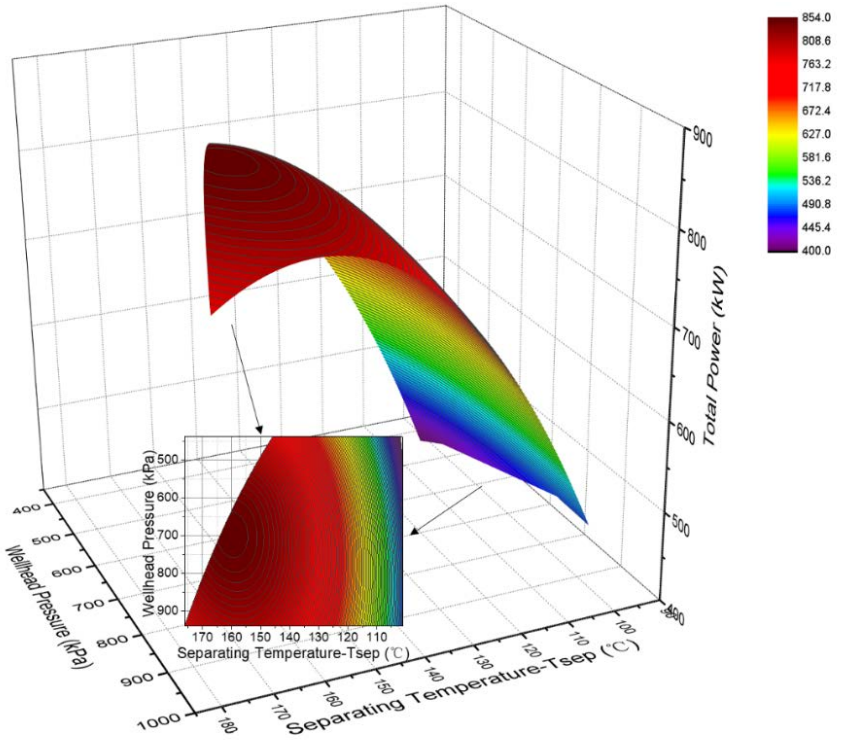


Figure 3. Distribution of system power generation against wellhead pressure and separating temperature.

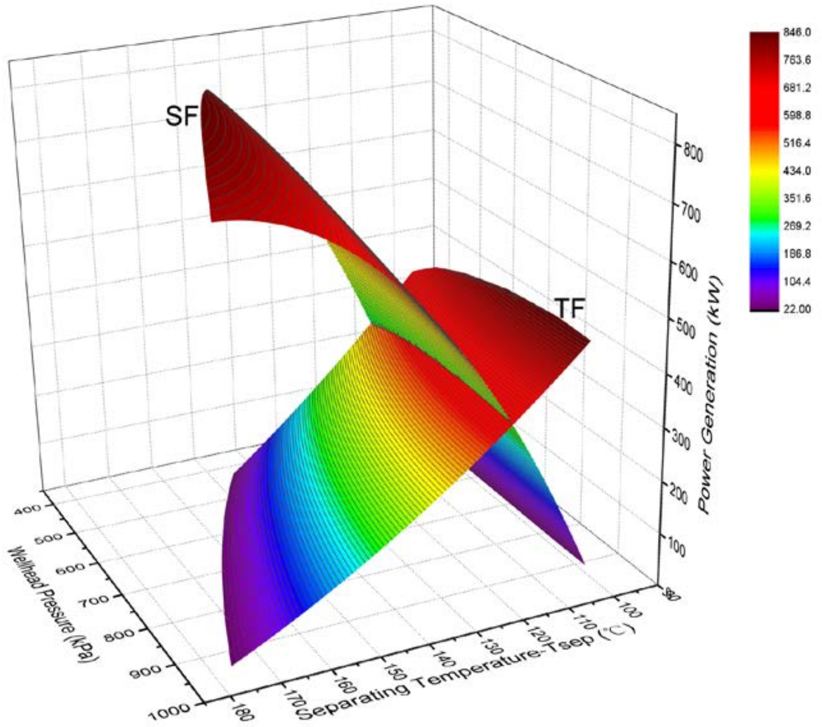


Figure 4. Distribution of TF and SF perspective power generation.

As designed, a condensation process is integrated with the TF-SF system to get freshwater as extra benefits to help address the local water scarcity problem. The production of freshwater generation against wellhead conditions and system parameters are presented in Figure 5. A lower wellhead pressure and lower separating temperature lead to a higher freshwater generation. The reason is that steam is condensed to become freshwater after exhausting from the SF steam turbine, and the steam is originated from the vapor at the outlet of TF turbine. In this way, lower wellhead pressure means higher vapor quality of the geothermal water, which would increase the vapor quality at TF turbine outlet. On the other hand, lower separating temperature also leads to higher vapor fraction at the outlet of TF turbine, revealing that freshwater generation is an advantage of total-flow expansion system. Freshwater of the TF-SF system is thus increased by the combination of these two factors. For example, a low wellhead pressure of 436.9 kPa can lead to a higher freshwater amount of 4.7 kg/s, which accounts for 30.8% of the total wellhead flowrate, but at higher wellhead pressure of 940.5 kPa, a low freshwater amount of 2.5 kg/s would be reached, which only accounts for 17.9% of the total wellhead flowrate.

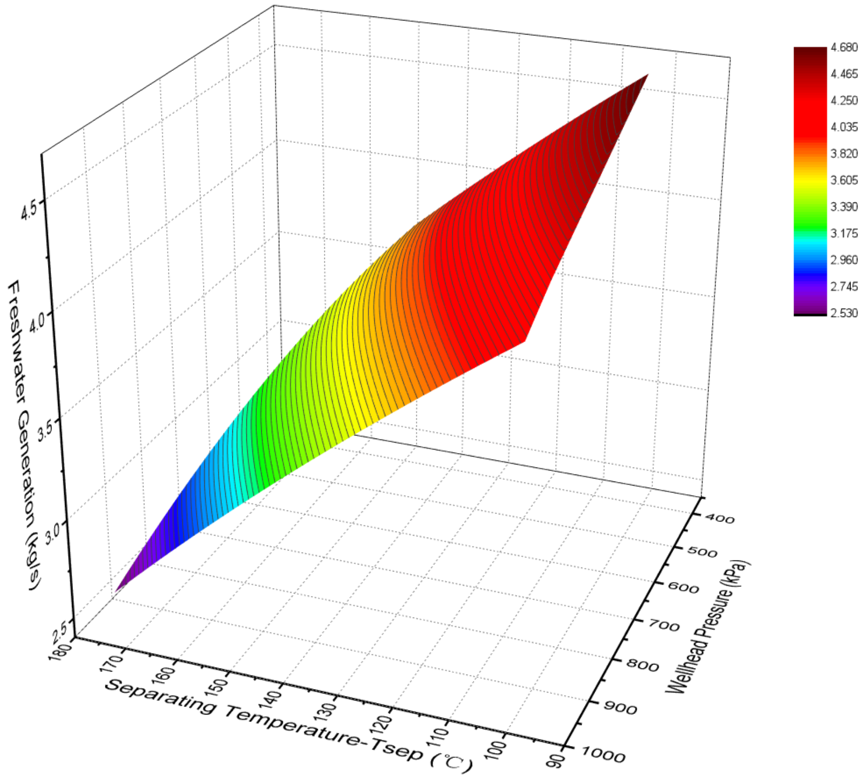


Figure 5. Distribution of freshwater generation against wellhead pressure and separating temperature.

6.2. *Influence of Total-Flow Turbine*

As illustrated above, the crucial factor of the proposed TF-SF system is the efficiency of the total-flow turbine. In order to study the sensitivity of system performance to TF turbine efficiency, four reasonable efficiencies covering from 20% to 65% are assumed and compared. As to the wellhead condition chosen in this simulation, the pressure/temperature/mass flowrate/vapor quality are 655.7 kPa/162.3 °C/14.5 kg/s/0.23. An optimum system power of 851.1 kW would be reached under this condition when the TF turbine efficiency is 35%, as shown in Figure 3.

As shown in Figure 6, power capacity of the SF part is only slightly influenced by the variable total-flow turbine efficiency (η_{tf}). The increment of total-flow turbine efficiency (η_{tf}) would slightly decrease the vapor quality at turbine outlet, meaning that slightly less vapor would go through the steam turbine in the SF part to generate power. The biggest decrement of SF power capacity is only 5.5%.

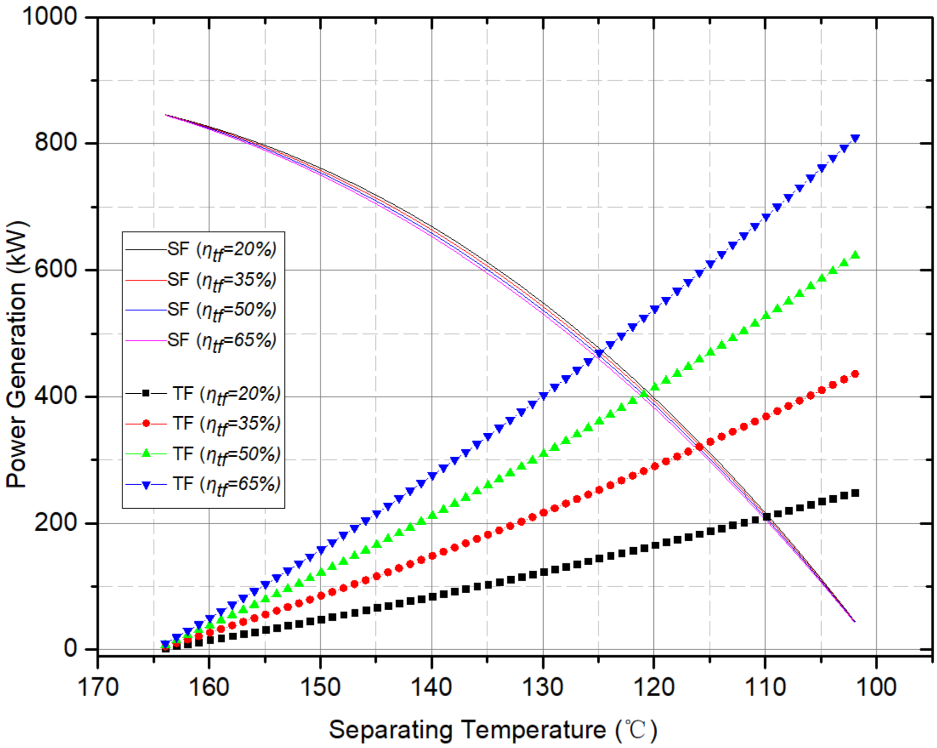


Figure 6. Effects of total-flow turbine efficiency (η_{tf}) on power capacities of TF and SF.

However, a more efficient total-flow turbine can significantly improve the power capacity of the TF part. During the reduction of separating temperature from wellhead condition to condensation condition, the TF part's power can only exceed the SF part's as the separating temperature is lower than 110 °C when the total-flow turbine efficiency is pre-set as 20%. However, a separating temperature of 125 °C is enough for the TF part to exceed SF regarding power capacity when the total-flow turbine efficiency can reach 65%, in which case the TF part is comparable to the SF part in terms of power generation.

The effects that total-flow turbine efficiency (η_{tf}) has on TF-SF system performance, including power generation and freshwater generation, are shown in Figure 7. As a comparison, power capacity of a single-flash-only power system is also added, as the black dash lines represents. Firstly, the power generation comparison shows clearly higher power production of the proposed TF-SF combined system. When the total-flow turbine efficiency (η_{tf}) reaches to a value of 50%, an optimal power capacity can reach up to 875.8 kW at the separating temperature of 147.9 °C, exceeding that of SF-Only system by 16.1%. Furthermore, a more effective total-flow turbine with an efficiency (η_{tf}) of 65% has an optimal power capacity of 933.0 kW at the separating temperature of 131.9 °C, higher than that of SF-Only system by 23.7%.

As for the freshwater generation capacity, higher total-flow turbine efficiency leads to slightly lower system freshwater output because it leads to smaller amount of steam flowing into the following steam turbine. However, the biggest reduction regarding the freshwater production within the efficiency range is only 0.2 kg/s (<5%), making it ignorable. On average, one fourth to one third of wellhead flow is recoverable by the system. During the condensation of the steam, the produced freshwater is to a certain extent desalinated and good for application in human activity, such as industrial water supply, plants irrigation, daily washing consumption. This extra benefit helps address the local water scarcity problem.

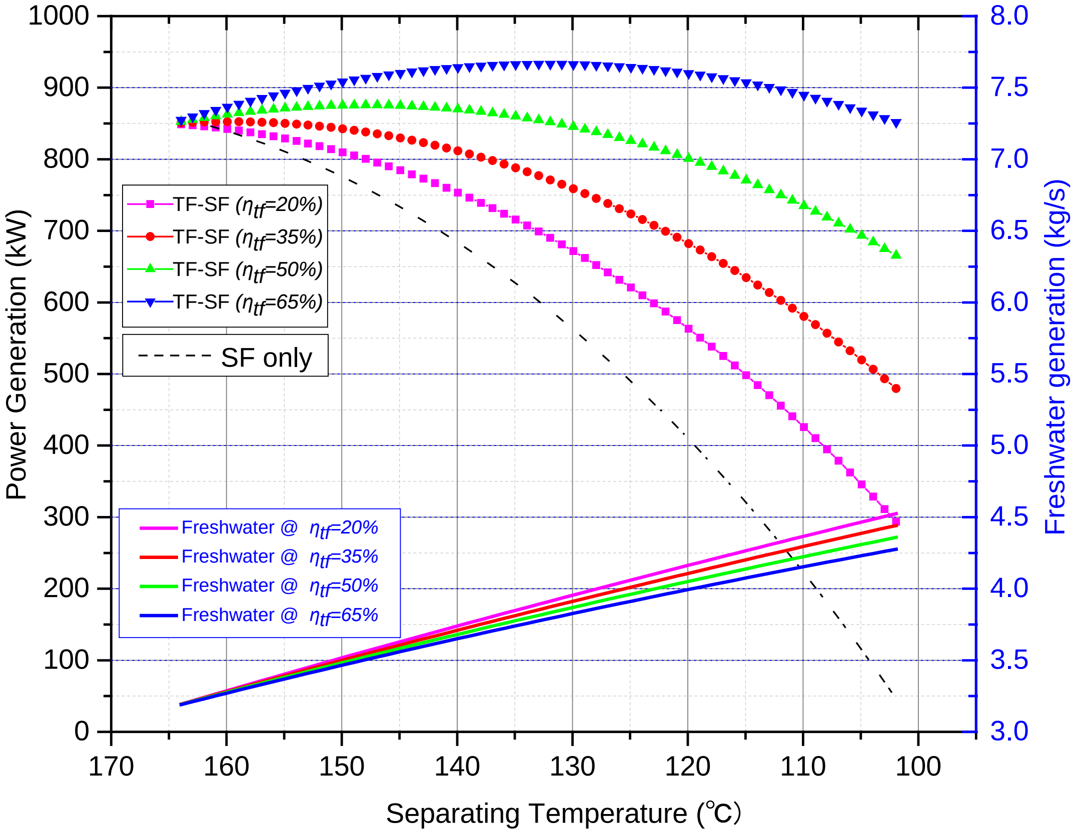


Figure 7. Effects of total-flow turbine efficiency (η_{tf}) on TF-SF system performance.

In order to maintain the sustainability of the geothermal field, the rejection strategy is a key factor to be considered. However, since the geothermal field targeted here is a two-phase, liquid-dominated one with relatively low-to-medium production enthalpy (1100 kJ/kg $< h <$ 1200 kJ/kg) [25–27], in general the pressure decline is not excessive for geothermal systems in this sort of fields. Besides, good permeability in this kind of field benefits itself with strong lateral recharge. Analyses of worldwide installed geothermal power systems indicate that, for medium- and low-enthalpy energy wells, on average, 62% and 76% of their produced mass is reinjected respectively after being utilized. Thus, the TF-SF system proposed that recovered one fourth to one third of wellhead flow is applicable without causing destruction of the field sustainability.

Furthermore, as pre-set in the modelling, the condensation is designed at atmosphere pressure to avoid vacuum and system complexity, the freshwater recovered has a near-boiling temperature of 100 °C, which qualify them to be further utilized as hot freshwater and the extra energy saving and benefit is predictable.

7. Conclusions

To solve the concurrent water and energy shortage issues hinder local economy, the abundant and under-utilized geothermal sources are exploited. A designed total-flow turbine (TF) from the sponsored project is applied to couple with the traditional single flash system (SF), and the combined TF-SF system is proposed and compared in this work. The performance of both power generation and water production are investigated, and a few remakes can be made as follows.

(1) Under the chosen wellhead conditions, the TF-SF pattern perform better than the traditional single stage system in terms of power generation. Under a wellhead condition in which the pressure, temperature, and mass flowrate are 655.7 kPa/162.3 °C/14.5 kg/s, an optimum system

power of 851.1 kW would be reached under this condition even when the TF turbine efficiency is assumed to be as low as 35%.

(2) An effective η_{tf} of 65% can lead to an optimal power capacity of 933.0 kW, exceeding the traditional SF system by 23.7%, proving a promisingly effective combination of the total flow and single flash (TF-SF) system.

(3) More than one third of total wellhead discharge can be recovered as desalinated freshwater by the naturally equipped condensation process of the power plant. This is an economical way to relieve the water shortage pressure without adding extra desalination equipment and consuming more power.

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Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

TF	Total-flow turbine/expansion
SF	Single-flash system
LA	Aluto Langano geothermal field of Ethiopia
WHP/p	Wellhead pressure (kPa)
WHT/T	Wellhead temperature (°C)
WHQ/x	Wellhead vapor quality (-)
WHM/m	Wellhead mass flowrate (kg/s)
FW	Freshwater
P	Power generation (kW)
h	Enthalpy (kJ/kg)
S	Entropy (kJ/kg.K)
H	Turbine efficiency (%)

References

1. DiPippo, R. Geothermal Power Plants, Chapter 1—Geology of Geothermal Regions. In *Geothermal Power Plants*, 4th ed.; Butterworth-Heinemann: Oxford, UK, 2016; pp. 3–22.
2. Brandoni, C.; Marchetti, B.; Ciriachi, G.; Polonara, F.; Leporini, M. The impact of renewable energy systems on local sustainability. *Int. J. Prod. Qual. Manag.* **2016**, *18*, 385–402. [CrossRef]
3. Geremew, H. *A Study of Thermodynamic Modelling and Gas Extraction System Design for Aluto Langano Geothermal Power Plant in Ethiopia*; Geothermal Training Programme: Reykjavik, Iceland, 2012.
4. DiPippo, R. Chapter 5—Single-Flash Steam Power Plants. In *Geothermal Power Plants*, 4th ed.; Butterworth-Heinemann: Oxford, UK, 2016; pp. 107–142.
5. Cerci, Y. Performance evaluation of a single-flash geothermal power plant in Denizli, Turkey. *Energy* **2003**, *28*, 27–35. [CrossRef]
6. DiPippo, R. *Geothermal Power Generation: Developments and Innovation*; Woodhead Publishing Series in Energy: Number 97; Woodhead Publishing: Sawston, UK, 2016.
7. Fabris, G. Two phase turbine for cogeneration, geothermal, solar and other applications. *FAS Eng.* **2006**.
8. Rane, S.; He, L. Two-Phase Flow Analysis and Design of Geothermal Energy Turbine. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *604*, 012043. [CrossRef]
9. Akagawa, K.; Fujii, T.; Ohta, J.; Takagi, S. Cycle performance of total flow turbine systems (2nd report, utilization of wet steam). *Trans. JSME* **1988**, *54*, 1509–1515. [CrossRef]
10. Fabris, G. Two-Phase Flow Turbine for Cogeneration, Geothermal, Solar and Other Applications. In *Energy Innovations Small Grant (EISG) Program*; 2005.

11. Rubio, J.L.G.; Illescas, F. Test of a total flow helical rotor screw expander at Cerro Prieto, Mexico. *Trans. Geotherm. Resour. Counc.* **1981**, *5*, 425–427.
12. Smith, I.K.; Stosic, N.; Kovacevic, A. *An Improved System for Power Recovery from Higher Enthalpy Liquid-Dominated Fields*; Geothermal Resources Council: Davis, CA, USA, 2004; Volume 28.
13. Smith, I.K. Development of the Trilateral Flash Cycle System: Part 1: Fundamental Considerations. *Proc. Inst. Mech. Eng. Part A J. Power Energy* **1993**, *207*, 179–194. [CrossRef]
14. Smith, I.K.; Stosic, N.; Kovacevic, A. *Power Recovery from Low Grade Heat by Means of Screw Expanders*, 2nd ed.; Chandos Publishing: Oxford, UK, 2014; pp. 127–184.
15. Grasby, S.E.; Allen, D.M.; Bell, S.; Chen, Z.; Ferguson, G.; Jessop, A.; Raymond, J. *Geothermal Energy: An Important Resource*; Geological Society of America: Boulder, CO, USA, 2019; Volume 519.
16. Caldera, U.; Bogdanov, D.; Breyer, C. Renewable Energy Powered Desalination Handbook: Chapter 8—Desalination Costs Using Renewable Energy Technologies. In *Renewable Energy Powered Desalination Handbook*; Gude, V.G., Ed.; Butterworth-Heinemann: Oxford, UK, 2018; pp. 287–329.
17. Missimer, T.M.; Choon Ng, K.; Thuw, K.; Wakil Shahzad, M. Geothermal electricity generation and desalination: An integrated process design to conserve latent heat with operational improvements. *Desalin. Water Treat.* **2016**, *57*, 23110–23118. [CrossRef]
18. Lund, J.W.; Boyd, T.L. Direct utilization of geothermal energy 2015 worldwide review. *Geothermics* **2016**, *60*, 66–93. [CrossRef]
19. Date, A.; Date, A.; Akbarzadeh, A. Investigating the potential for using a simple water reaction turbine for power production from low head hydro resources. *Energy Convers. Manag.* **2013**, *66*, 257–270. [CrossRef]
20. Date, A.; Khaghani, A.; Andrews, J.; Akbarzadeh, A. Performance of a rotating two-phase turbine for combined power generation and desalination. *Appl. Therm. Eng.* **2015**, *76*, 9–17. [CrossRef]
21. Zhao, Y.; Akbarzadeh, A.; Andrews, J. Simultaneous desalination and power generation using solar energy. *Renew. Energy* **2009**, *34*, 401–408. [CrossRef]
22. NIST Reference Fluid Thermodynamic and Transport Properties Database, REFPROP Version 9.0. Available online: https://www.nist.gov/srd/refprop (accessed on 12 April 2020).
23. Sham, R.; Li, H.; Haiteng, M. CFD modelling and analysis of Two-Phase Geothermal Energy Turbine. In Proceedings of the International Conference on Innovative Applied Energy, IAPE '19, Oxford, UK, 14–15 March 2019.
24. Yu, G.; Yu, Z. Investigation of Geothermally Sourced Combined Power and Freshwater Generation Systems. In Proceedings of the Energy Procedia 2018, 10th International Conference on Applied Energy (ICAE2018), Hong Kong, China, 22–25 August 2018.
25. Alexandre, R.D.; Eylem, K.; Sadiq, J.Z. Reinjection in geothermal fields—A worldwide review update. *Renew. Sustain. Energy Rev.* **2016**, *53*, 105–162.
26. Valgar-đur, S. Geothermal reinjection experience. *Geothermics* **1997**, *26*, 99–139.
27. Eylem, K.; Sadiq, J.Z.; Michael, O. Reinjection in geothermal fields: A review of worldwide experience. *Renew. Sustain. Energy Rev.* **2011**, *15*, 47–68.