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The Exergy and Energy Analysis of Change Phase Steam in Patuha Geothermal Well Production

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Abstract—A Geothermal Power Plant Company in West Java Indonesia have capacity around 55MW. It company have increased the well production quality to keep up the Indonesia's energy demands. The power plant has been operated around ten years, it has ten geothermal production wells and two injection wells. The either of it wells has an abnormality. It wells has water dominated condition so, the separator equipment is required to separate the steam from water and vapor. Previous study indicated that subsurface water entering the broken reservoir pipe. That leaks in reservoir pipe was repaired in 2020. The impact after the pipe have been repaired it made the fluid characteristic of reservoir be vapor dominated. After that a separator as a steam separator is no longer required. The study compares the value energy and exergy power of the power plant. The calculations are performed from the well reservoir and all power plant equipment. According to the results of the energy study, the plant's energy efficiency after the transformation increased by 0.03%, from 19.48% to 19.52%. The exergy value of the brine in either wells (separated steam cycle) is also known to be 2.512,52 kW, beyond which the value will become zero

Keywords—geothermal; anomaly reservoir; exergy efficiency; energy efficiency

I. INTRODUCTION

Patuha Geothermal is a power plant that has a capacity of 55 MW and is in the working area of the Pangalengan geothermal field. The geothermal work areas of Patuha Geothermal include Mount Patuha, Ciwidey Crater, and Cibuni Crater. Patuha Geothermal's geothermal potential reaches 210 MWe [1]. The reservoir of this power plant has two-phase characteristics, with the dominance of steam controlled by a structure that has an area of up to 20 km^2 [2]. To maintain the quality of generation and national energy security, continuous improvement efforts are needed. One way is to evaluate the performance of generating equipment using thermodynamic analysis. The combination of thermal and exergy analysis is the most appropriate method to determine energy changes, energy efficiency, and energy quality [3]. Both analyses include changes in energy quality, irreversibilities, and losses from each stage, so that it can be identified which parts need to be optimized [4]. This method has been widely used by previous researchers to perform thermodynamic analysis in the geothermal sector with a variety of steam conversion technologies. A review of the analysis with single geothermal flash technology conducted by Pambudi et al. led the first energy analysis and optimization at Dieng Geothermal Power Plant in 2014, which resulted in the value of the entire production well with an estimate of 59.52 MW and an exergy efficiency of 36.84% by optimizing the pressure of the separator [4]. In addition to research elsewhere, optimization against condensers that have the highest irreversibility in Kamojang Geothermal by dead state analysis the temperature on energy efficiency [5]. The influence of wellhead pressure can alter the energy efficiency and net power output generated by the dry steam power plant [6]. Several research projects on the technology of two-phase steam mixed energy or purely one-phase geothermal dry steam have been frequently carried out. However, in the case study in this study, in particular Patuha Geothermal, which has two-phase anomalies of separated steam cycle changes, one-phase direct dry steam is a renewable intersection. Because it's almost uncommon for a power plant to change its steam distribution system. The application of thermodynamic analysis is a strategic step to identify the value of energy efficiency and exergy against such anomalies.

II. METHOD

2.1. Power Plant Describtion

Patuha Geothermal currently has a capacity of 60 MW and is operated by a special mission vehicle company under the Indonesian Ministry of Finance. The plant has ten production wells and two injection wells with a steam capacity of 373 tons per hour at a pressure of 7.1 bar [7]. Figure 1 and Figure 2 show The steam flow distribution from the well-pad north well and south well to the steam gathering system.

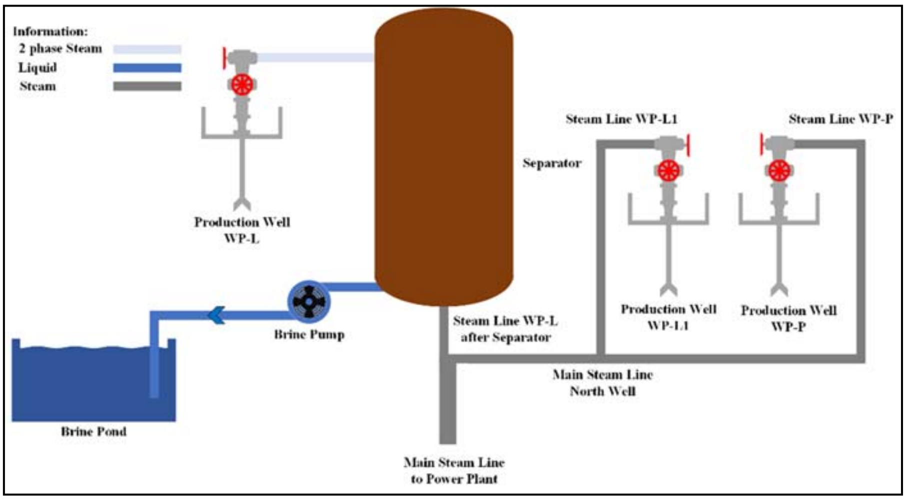


Fig. 1. Distribution Steam WP-L in Separated Steam Cycle

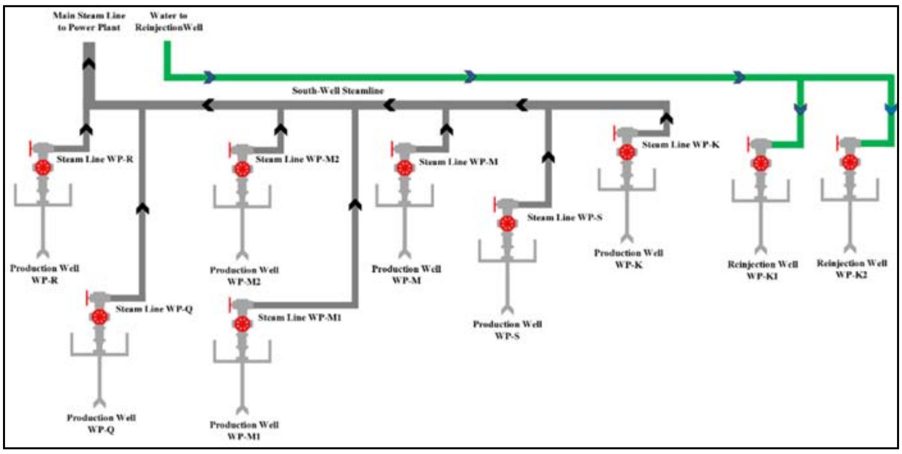


Fig. 2. Distribution Steam WP-L in Separated Steam Cycle

2.2. Novel Anomaly of One Well-Pad and Transfiguration System in Patuha Geothermal

The fact that the initial hypothesis for the WP-L well is that it has a fraction of wet steam is not derived from the characteristics of its reservoir. Based on the work of the workover in 2020 at WP-L, leakage was found in the 12 inch and 13-3/8inch reservoir pipe casings at a depth of 163 m subsea. The water comes from the surface water flow, so it goes underneath the reservoir pipe that's in it. Characteristics of WP-L are steam-dominated reservoirs at the top and an underlying liquid-dominated reservoir [8]. After sealing the leak using the cementing method, the WP-L steam line initially used separator equipment as a method of separating the wet fraction, then a tie-back engineering method was carried out (closing the direction of the steam line from WP-L to the Separator and directing it directly to the main steam line north well). Changing the steam line system from a separated steam cycle to direct dry steam is a rare and unique condition in generator operation.

2.3. Power Plant System Power Plant Schematic

Patuha geothermal has two main steam distribution lines, namely the south well and the north well. An anomaly production wells happened on WP-L, on WP-L occurred in the steam distribution line's north well. Of the ten production wells that use the separated steam cycle system only on WP-L, nine use the direct dry steam system. The percentage of WP-L's contribution to the amount of steam production in the steam gathering system is only 9% of the total production capacity. So to identify state 1, it is in the steam gathering system (inlet demister). The initiation of each state in Patuha Geothermal is shown in Figure 3. In this state, all the steam from the entire production well is gathered into one, with a fraction of 98–99.8% dominated by dry steam. State 2 is an outlet demister resulting from steam separation, with pollutants carried when distributed from the well-pad to the steam gathering system. The flow from the demister outlet will lead directly to the turbine. Whereas the pollutants and water remaining in the demister will be drained through the flow drain demister to the condensate pond. State 3 is a fluid when entering a turbine in which there are several flow divisions, namely turbine gland steam, motive steam NCG removable system, and inlet turbines A and B. In addition, steam-line fluids from the outlet demister to the inlet of the turbine undergo a decrease in pressure and mass flow. It's because of the rock muffler and the condensate steam trap. Based on the referenced production data, the value of steam passed from the well-pad to the inlet of the turbine has been reduced by 3%. State 4 is a state condenser turbine output; the compression flow from the condenser will be pumped to the cooling tower with a pump of 550 kW capacity. The fluid driven by the HWP is assumed to be isentropic without any variation in the entropy value. While state 12 is a condensate flow that is directed towards a spray cooling tower like a nozzle. State 6 is the output of a glad steam turbine that enters the inter-condenser, whereas state 5 is an ejector output that comes from the NCG inside the condenser and is then pulled by the steam state 3 motive. Inside the inter-condenser, the liquid fluid will flow to the condenser. While in the inter-condenser, there is a process of condensation of the water spray from the ACWP that comes from the cooling tower (state 10). The remaining NCGs in the inter-condenser will be divided by LRVP with a power of 500 kW (state 7) towards the after-condenser; inside the after-condenser there is a water spray process from the ACWP. The NCG will flow out towards the cooling tower for the spray process from the HWP water pump. (state 9). The flow from the after-condenser will flow to the condenser in state 8. After the drain demister is initiated at state 13, the condensate flow will be directed toward the pond. While the blowdown flow of HWP and steam trap inlet turbines will be ignored. The Reinjection Pump will pump condensate water into the reinjection well using a 350 kW pump with a pipe distance of 3.8km.

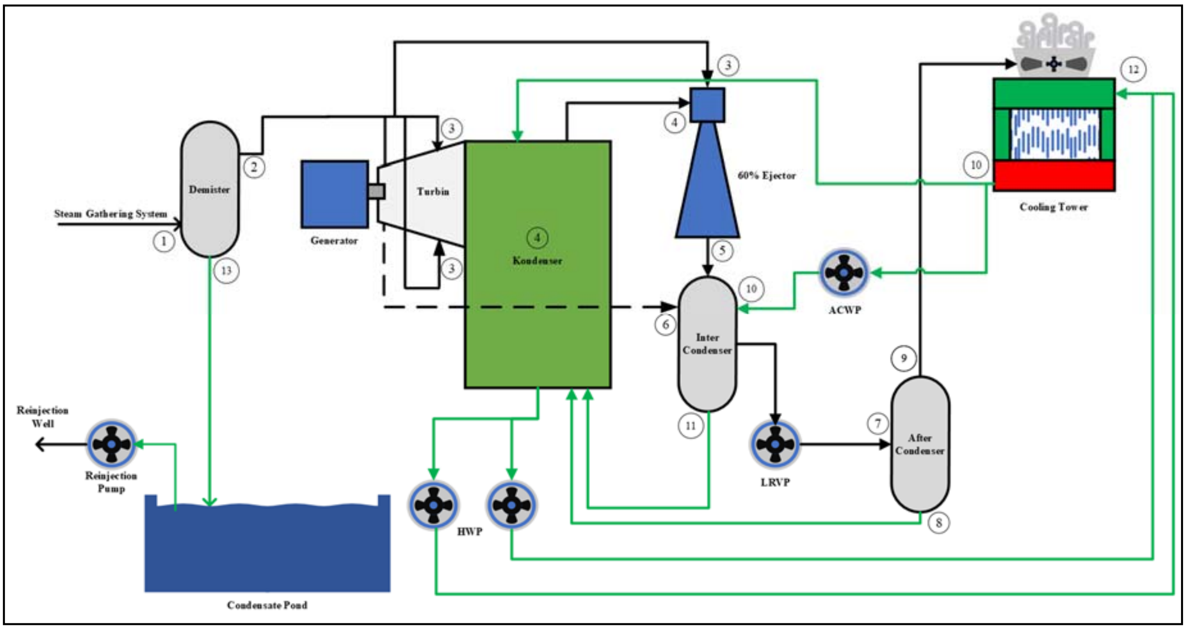


Fig. 3. Initiate State of The System

2.4. Power Plant System Power Plant Schematic

Data compilation is divided into two categories: before and after transfiguration. Data classification before transfiguration is from February 2020 to August 2020. Then the post-transfiguration data from September 2020 to the end of March 2021 The pressure, mass flow, temperature state, and environmental data will be averaged for each month. Then the calculation and data modeling in this study use computing from MS Excel. As for enthalpy and entropic calculations, each uses the International Standard Unit Table A-4. The Steam Table Excel Macros IF-97 by Magnus Holmgren is used as a validation test for entalpic and entropic values. Thus, the calculation of thermodynamic properties is known.

2.5. Energy Analysis

In energy analysis, it is necessary to identify each state in addition to the energy balance of each equipment [9]. he calculation of the energy balance of each piece of equipment is loaded on Table 1, taking into account the energy entering the system and the energy coming out of the system [10]. The analysis coverage of this study ranges from the environmental side (dead state) to the outlet spray cooling tower and demister. Energy calculations per state or piece of equipment are loaded in Equation 1 [11]. Then the efficiency of the plant can be calculated using the comparison of the output energy with the input energy loaded in Equation 2 [11].

$$E_{n\,state} = \dot{m_{state}}\ x\ (h_{state}) \qquad (1)$$

$$\eta\ \text{Plant} = \frac{W_{output}}{Q_{input}}\ x\ 100\%, \qquad (2)$$

TABLE I. ENERGY BALANCE

Equipment	Energy Equation
Steam Gathering System	$\dot{E}n_1 = \dot{m}_1 . h_1$
Demister	$\dot{E}n_{Dem} = \dot{E}n_1 - (\dot{E}n_2 + \dot{E}n_{13})$
Turbine	$\dot{E}n_{Turbine} = \dot{E}n_3 - \dot{E}n_4$

Main Condenser	$\dot{E}n_{Condenser} = (\dot{E}n_4 + \dot{E}n_{10} + \dot{E}n_{11} + \dot{E}n_8) - (\dot{E}n_{4ej} + \dot{E}n_{12})$
60% Steam Ejector	$\dot{E}n_{Ejector} = (\dot{E}n_3 + \dot{E}n_{4ej}) - \dot{E}n_5$
Inter-Condenser	$\dot{E}n_{ITC} = (\dot{E}_5 + \dot{E}_6 + \dot{E}_{10}) - (\dot{E}_{11} + \dot{E}_7)$
Seal Water Separator	$\dot{E}n_{SWS} = (\dot{E}_7 - (\dot{E}_9 + \dot{E}_8)$
Cooling Tower	$\dot{E}n_{CT} = (\dot{E}_{12} + \dot{E}_9) - \dot{E}_{10}$

2.6. Exergy Analysis

Exergy is the development of the second law of thermodynamics, which calculates the value of the quality of the irreversibility and efficiency values of exergy in a thermal power plant [10]. Just like energy analysis, this analysis starts from the dead state to the final state of production, the cooling tower. The value of exergy efficiency from each well to the steam gathering system is considered the same. The great enthalpy and entropic values of each state will affect the exergy efficiency of the system [3]. The calculation of the exergy value of the state is formulated in Equation 3 [11]. While the exergy value of irreversibility is loaded in Table 2. Calculation of exergy efficiency values for each state or piece of equipment loaded in Equation 4 and 5 [3] [4].

$$E_i = \dot{m}_i . [(h_i - h_0) - T_0(S_i - S_0) \quad (1)$$

$$\eta_{\text{Exsergy state}} = \left[1 - \left(\frac{\dot{I}}{\dot{E}_{input}}\right)\right] x100\% \quad (2)$$

$$\eta_{\text{EksPlant}} = \frac{\dot{W}_{out}}{\dot{E}_{in}} x100\% \quad (3)$$

TABLE II. EXERGY BALANCE

Equipment	**Irreveribility Equation**
Demister	$I_{dem} = \dot{E}_1 - (\dot{E}_2 + \dot{E}_{13})$
Turbine	$I_{Turbine} = \dot{E}_3 - \dot{E}_4$
Main Condenser	$I_{Condenser} = (\dot{E}_4 + \dot{E}_{10} + \dot{W}_{mACWP} + \dot{E}_{11} + \dot{E}_8) - (\dot{E}_{4ej} + \dot{E}_{12} + \dot{W}_{mHWP})$
60% Steam Ejector	$I_{Ejector} = (\dot{E}_3 + \dot{E}_{4ej}) - \dot{E}_5$
Inter-Condenser	$I_{ITC} = (\dot{E}_5 + \dot{E}_6 + \dot{E}_{10}) - (\dot{E}_{11} + \dot{E}_7)$
Seal Water Separator	$I_{SWS} = (\dot{E}_7 - (\dot{E}_9 + \dot{E}_8)$
Cooling Tower	$I_{CT} = (\dot{E}_{12} + \dot{E}_9) - \dot{E}_{10}$
Brine	$I_{Brine\,WP-L} = \dot{E}_{Brine\,WP-L} + \dot{W}_{Brine\,Pump}$

III. RESULT AND DISCUSSION

3.1. Energy and Exergy Balance

The calculation of the energy balance is used to facilitate the identification of inputs and outputs in the system [9]. In this study, the energy balance is loaded from the steam gathering system to the cooling tower. The energy balance of this study is loaded into Table 1. Based on Table 1, the mass flow value of the steam gathering system is obtained from the amount of steam accumulation that will enter the input demister; the enthalpy value at this point will be affected by the accumulated steam fraction. The values of the steam fraction on the turbine inlet vary in the range of 98–99%. Based on comparison from Table 3 and Table 4, it is known that the value of the energy flow rate on the demister before transfiguration was the highest energy value, reaching 16.974.49 kW, whereas the lowest energy value only reached 455.62 kW. The smaller the energy value in the component demister, the higher the thermal efficiency value. When compared with after transfiguration (Table 4), the energy flow rate value of the demister is influenced by the energy emitted in the flow drain demister. This is very logical because when the equipment separator has been removed, there will be some fluids from WP-L carrying the water mixture, but the fraction value is not lower than 97-98%. While main condenser and cooling tower equipment have large energy releases before and after transfiguration, they tend to fluctuate with values ranging from 218.641.85 kW to 232.576.45 kW. The energy released to the environment by the cooling tower is in the form of condensate and NCG. the system is circulating the condensate water in the cooling tower will be circulated back into the main-condenser with of earth's gravity.

TABLE III. ENERGY FLOW RATE FOR EACH EQUIPMENT (SEPARATED STEAM CYCLE) IN KW

No	Equipment	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20
1	Demister	16.974,49	17.453,98	10.471,04	455,62	5.871,98	5.689,10	5.357,04
2	Turbine	64.035,31	62.871,50	62.081,89	62.310,76	61.047,59	61.945,94	61.085,31
3	Main Condenser	158.067,02	158.099,80	152.067,83	156.578,16	156.858,67	158.223,57	147.585,43
4	Ejector 60%	16.806,43	16.889,93	16.822,41	16.941,71	16.924,08	16.873,69	16.911,51
5	Inter Condenser	20.539,17	20.338,01	20.431,18	20.052,68	20.624,94	21.167,07	20.994,26
6	Seal Water Separator	26.596,20	26.601,99	26.604,24	26.615,49	26.579,90	26.549,21	26.559,18
7	Cooling Tower	232.576,45	231.420,07	224.416,59	229.083,82	228.387,63	230.782,11	218.641,85

TABLE IV. ENERGY FLOW RATE FOR EACH EQUIPMENT (DIRECT DRY STEAM) IN KW

No	Equipment	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21
1	Demister	688,82	1.426,23	7.347,11	9.989,79	6.170,96	7.809,62	10.823,96
2	Turbine	60.072,40	58.692,89	57.917,02	61.333,47	61.818,09	61.446,49	61.655,90
3	Main Condenser	144.722,36	143.246,77	136.281,34	168.487,23	172.034,78	166.276,87	168.781,21
4	Ejector 60%	16.932,25	17.060,19	17.135,26	17.070,98	17.066,44	17.041,45	17.051,57
5	Inter Condenser	21.042,28	20.604,14	21.000,94	20.390,58	20.320,21	19.670,54	20.025,28
6	Seal Water Separator	26.554,25	26.577,25	26.547,28	26.585,57	26.590,15	26.636,00	26.612,12
7	Cooling Tower	214.617,46	211.403,64	205.253,53	241.062,78	245.202,72	238.490,12	241.461,00

The results of the thermal efficiency calculations for each condition are loaded in Tables 5 and 6. The equipment with the highest energy efficiency is the demister, which is above 90%. It is influenced by the conditions of the demisters, which have very small enthalpy and entropic differences. While the lowest energy efficiency values occur in the inter-condensers and seal water separators, which reach 28–29%. Within both equipment, there are entropy and fraction changes in some fluids, including steam, non-condensable gas (NCG), and water. The fluid has different enthalpy and entropic values, as well as energy values in the carried mass, so that the insenthalpy and isentropic phases occur inside the nucleus. Energy efficiency reviews on demister equipment tend to range from 94% to 99%. After transfiguration, the efficiency values tend to be stable at 96–97%. If reviewed from the perspective of energy analysis, turbine efficiency values tend to undergo very significant changes after transfiguration into direct dry steam. The turbine's highest energy efficiency will be in December 2020, reaching over 88%, a 2% difference compared to the previous transfiguration of a maximum of 84–86%. The low energy efficiency value of a system is influenced by a number of conditions, including the content and quality of the steam fluid that is flowing from the reservoir to the vapor gathering system. The low value of the steam fraction affects its efficiency. When steam distribution lines still rely on an operator to separate water contaminants from the WP-L, there is a release of brine energy and electricity to operate the brine pump. In addition, according to the reference from the production book at Patuha Geothermal, the efficiency value of the steam distribution process from the wellhead to the turbine inlet reached 3%. Such losses occur on condensate drain pots, steam traps, rock mufflers, and pipes. [7].

TABLE V. ENERGY EFFICIENCY FOR EACH EQUIPMENT (SEPARATED STEAM CYCLE) IN PERCENT (%)

No	Equipment	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20
1	Demister	94,37	94,11	96,35	99,87	97,88	97,97	98,02
2	Turbine	85,49	86,43	85,37	86,94	88,10	87,30	84,12
3	Main Condenser	66,81	66,78	67,59	67,08	66,59	66,15	67,68
4	Ejector 60%	77,43	74,75	72,76	73,71	70,21	75,27	68,15
5	Inter Condenser	28,72	28,44	28,57	28,04	28,84	29,60	29,35
6	Seal Water Separator	29,72	29,72	29,71	29,71	29,73	29,76	29,75
7	Cooling Tower	48,90	48,69	47,88	48,23	48,70	49,44	47,93

TABLE VI. ENERGY EFFICIENCY FOR EACH EQUIPMENT (DIRECT DRY STEAM) IN PERCENT (%)

No	Equipment	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21
1	Demister	99,98	99,67	97,30	96,54	97,89	97,31	96,26
2	Turbine	82,77	82,65	80,75	88,41	88,63	88,16	88,02
3	Main Condenser	67,98	68,32	69,13	65,12	64,74	65,93	65,37
4	Ejector 60%	63,96	58,44	49,04	79,68	80,76	79,22	75,54
5	Inter Condenser	29,42	28,81	29,36	28,51	28,41	27,50	28,00
6	Seal Water Separator	29,75	29,74	29,76	29,73	29,73	29,69	29,71
7	Cooling Tower	47,55	46,81	46,54	49,96	50,31	48,92	49,59

3.2. Exergy Analysis

An exergy balance differs from an energy balance in that several work parameters of the system are taken into account in one equilibrium. Energy that leaves the system and cannot be used again is irreversibility. Table 2 contains the calculation of the irreversibility value of each component in Patuha Geothermal. The irreversibility value of the main condenser considers the work value of the auxiliary Cooling Water Pump (ACWP) and Hot Well Pump (HWP) motors because the main condenser system requires work from both motors. The calculation of the exergy value of each component is presented in Tables 7 and Table 8. The exergy value of the steam gathering system that enters the inlet demister before transfiguration has the highest value of

281.170.25 kW. This value does not include the reduction of the brine exergy value in WP-L. The exergy loss that occurs in the demister is caused by the quality of the steam. If the steam produced by the demister is not dry and dirty, it can cause vibration, erosion, and scale formation in the turbine, causing losses. The state that has the lowest exergy value is the turbine gland steam, this is influenced by the very small amount of mass flow that is being streamed. The exergy value in NCG released to the cooling tower only reaches 417-458 kW. If seen from the exergy value generated by the turbine before transfiguration, the exergy value ranges from 80,523.01 kW to 84,797.62 kW. This is influenced by the quality and mass flow of steam.

TABLE VII. EXERGY FOR EACH EQUIPMENT (SEPARATED STEAM CYCLE) IN (KW)

No	Equipment	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20
1	Inlet Demister	281.170,25	277.199,41	268.218,60	258.835,46	258.819,60	261.156,04	256.772,83
2	Outlet Demister	265.331,82	260.883,47	258.418,83	258.504,19	253.322,29	255.867,04	251.699,24
3	Inlet Turbin	84.797,62	83.200,43	82.394,32	82.377,97	80.885,39	82.112,84	80.523,01
4	Outlet Turbin Condenser	19.794,16	19.539,97	19.285,47	19.270,36	18.655,67	18.682,55	18.079,78
5	Outlet Ejector 60%	3.842,18	3.849,24	3.848,47	3.847,03	3.908,33	3.946,30	3.962,66
6	Turbin Gland	145,59	145,78	145,62	145,95	147,70	148,75	149,01
7	Inlet Seal Water Separator	7.581,13	7.574,63	7.589,16	7.562,40	7.646,40	7.704,42	7.722,28
8	outlet Seal Water Separator	1.315,53	1.310,96	1.320,44	1.302,22	1.359,42	1.399,22	1.410,55
9	Outlet NCG SWS to CT	417,48	415,51	419,59	411,76	436,36	453,50	458,38
10	Outlet Cooling Tower	1.448,49	1.470,87	1.524,94	1.488,66	1.603,07	1.658,18	1.761,96
11	Outlet Inter-condenser	711,93	706,99	717,25	697,60	760,22	805,41	818,50
12	Outlet CDS to CT	16.766,92	15.866,18	15.357,07	15.698,12	16.006,47	16.424,81	15.539,78
13	Flow Drain Demister	15.838,43	16.315,94	9.799,77	331,28	5.497,31	5.289,00	5.073,59

The results of calculating the exergy value of each state after transfiguring the system are presented in **Erreur ! Source du renvoi introuvable.**. The exergy value entering the inlet demister system has decreased, ranging from 19,000-20,000 kW. This difference is good, because the quality value of the steam fraction distributed to the turbine inlet is dry, eliminating the need for a separator. So that the mass flow value carried by the fluid is purely dry steam dominated. The Exergy value of the flow drain demister when compared to before the transfiguration experienced significant changes tends to fluctuate, but this is better because its value tends to decrease when the transfiguration has been carried out. Reviewing the exergy value of the turbine, it only ranges from 74,335 kW to 83,420 kW, much different from before the transfiguration. The mass flow value carried by the steam fluid will affect the amount of exergy value produced. Since from September to December there is well maintenance in WP-Q, the value of the mass flow distributed to the generators is reduced.

TABLE VIII. EXERGY FOR EACH EQUIPMENT (DIRECT DRY STEAM CYCLE) IN (KW)

No	Equipment	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21
1	Inlet Demister	246.277,81	241.522,21	242.160,64	263.958,71	264.657,75	264.036,51	268.567,66
2	Outlet Demister	246.217,45	240.728,09	235.632,62	254.833,88	259.074,24	256.922,04	258.515,96
3	Inlet Turbine	77.907,15	76.167,71	74.353,29	81.324,41	83.420,05	82.215,80	82.859,20
4	Outlet Turbine Condenser	17.611,84	17.176,25	17.100,03	19.178,23	19.562,59	19.557,27	19.650,82
5	Outlet Ejector 60%	3.880,85	3.910,16	3.885,89	3.865,66	3.983,98	3.876,15	3.908,67
6	Turbine Gland	146,92	146,84	146,02	145,80	148,95	145,86	146,87
7	Inlet Seal Water Separator	7.610,22	7.626,95	7.581,05	7.557,50	7.714,35	7.580,75	7.620,76
8	outlet Seal Water Separator	1.336,78	1.346,71	1.317,86	1.300,46	1.403,79	1.313,29	1.340,90
9	Outlet NCG SWS to CT	426,62	430,89	418,48	411,00	455,47	416,52	428,39
10	Outlet Cooling Tower	1.385,94	1.530,28	1.274,91	1.354,32	1.877,01	1.632,86	1.659,34
11	Outlet Inter-condenser	735,11	746,07	714,45	695,72	810,68	709,51	739,65
12	Outlet CDS to CT	13.952,18	14.122,54	12.720,54	16.427,91	18.649,11	17.145,11	17.540,43
13	Flow Drain Demister	60,35	794,12	6.528,02	9.124,83	5.583,51	7.114,47	10.051,69

3.3. Influence of transfiguration system to irreversibility process

In a work process in a system, there will always be irreversibility. The smaller the value, the better the work in the system [12]. **Erreur ! Source du renvoi introuvable.** contains the results of exergy loss/irreversibility calculations prior to transfiguration. The result is that the highest value is found in the cooling tower; the value tends to be constant and does not change. In contrast to the demister, which experienced high irreversibility in February 2020. Meanwhile, the best exergy loss value lies in the inter-condenser, with a constant value of 607.44 kW to 758 kW. The irreversibility that occurs in the separator will add to the irreversibility of the generator. The irreversibility values of brine range from 2,320.06 kW to 2,578.18 kW. In contrast to the separated steam cycle process, in the direct dry steam distribution process, the irreversibility value of the turbine tends to decrease, meaning that the value of the turbine's exergy efficiency is getting better. Meanwhile, the value of the exergy loss that occurs in the demister tends to increase because it is influenced by the presence of the wet fraction that enters the demister system, so that the exergy loss value reaches 10,051.69 kW. When viewed from the perspective of the electrical energy generated, the value tends to increase in the range of 49,720.19 kW to 54,788.32 kW.

TABLE IX. IRREVERSIBILITY FOR EACH EQUIPMENT (DIRECT DRY STEAM) IN (KW)

No	Equipment	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21
1	Demister	60,35	794,12	6.528,02	9.124,83	5.583,51	7.114,47	10.051,69
2	Turbine	10.121,61	9.971,77	11.011,57	7.041,94	6.963,82	7.220,42	7.366,18
3	Main Condenser	5.173,28	4.703,68	5.811,00	4.134,20	2.823,25	4.043,08	3.785,35
4	Ejector 60%	2.183,64	2.198,24	2.132,32	2.381,33	2.355,46	2.354,96	2.322,27

5	Inter Condenser	688,77	705,69	733,02	767,86	659,42	772,35	733,42
6	Seal Water Separator	5.846,82	5.849,35	5.844,71	5.846,03	5.855,08	5.850,93	5.851,46
7	Cooling Tower	12.992,86	13.023,15	11.864,11	15.484,59	17.227,57	15.928,77	16.309,48
8	Electricity	49.720,19	48.509,77	46.766,04	54.226,79	54.788,32	54.172,96	54.272,49

The results of calculating the exergy efficiency of each piece of equipment can be seen in **Erreur ! Source du renvoi introuvable.** and Table**Erreur ! Source du renvoi introuvable.**. The demister efficiency value remains at 98–99% even though there has been a change in the steam distribution system. This is influenced by the quality of the steam entering the inlet demister, which is dominated by dry steam. While the value of turbine efficiency increases by 2%–3% after transfiguration. The turbine efficiency value is also affected by the value of the steam fraction that is fed into the turbine inlet. Then, the value of the condenser efficiency is better than 80%. When viewed from the perspective of the amount of steam production generated against the generated power value, the power value is more efficient compared to before the transfiguration.

TABLE X. EXERGY EFFICIENCY FOR EACH EQUIPMENT (SEPARATED STEAM CYCLE) IN PERCENT (%)

No	Equipment	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20
1	Demister	94,37	94,11	96,35	99,87	97,88	97,97	98,02
2	Turbine	85,51	86,42	85,34	86,92	88,05	87,30	84,04
3	Main Condenser	75,47	75,81	74,05	75,93	79,11	80,71	78,21
4	Ejector 60%	64,34	62,82	63,50	62,80	63,41	63,89	64,33
5	Inter Condenser	83,36	82,92	83,43	82,37	84,53	86,17	86,35
6	Seal Water Separator	22,86	22,79	22,93	22,66	23,49	24,05	24,20
7	Cooling Tower	8,43	9,03	9,67	9,24	9,75	9,82	11,01

TABLE XI. EXERGY EFFICIENCY FOR EACH EQUIPMENT (DIRECT DRY STEAM CYCLE) IN PERCENT (%)

No	Equipment	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21
1	Demister	99,98	99,67	97,30	96,54	97,89	97,31	96,26
2	Turbine	83,09	82,95	80,94	88,51	88,72	88,24	88,05
3	Main Condenser	73,38	75,42	69,09	80,25	87,11	81,26	82,57
4	Ejector 60%	63,99	64,01	64,57	61,88	62,84	62,21	62,73
5	Inter Condenser	84,08	83,86	83,03	82,18	85,29	82,23	83,27
6	Seal Water Separator	23,17	23,31	22,90	22,65	24,10	22,82	23,22
7	Cooling Tower	9,64	10,51	9,70	8,04	9,82	9,30	9,23

In February 2020, the steam production value was 109.09 kg/s, capable of producing 54.74 MW of power. Based on **Erreur ! Source du renvoi introuvable.**whereas in January 2021, steam production was 101.91 kg/s, capable of producing 54.79 MW of power. This means that the direct dry steam distribution process is more efficient when compared to the separated steam cycle process.

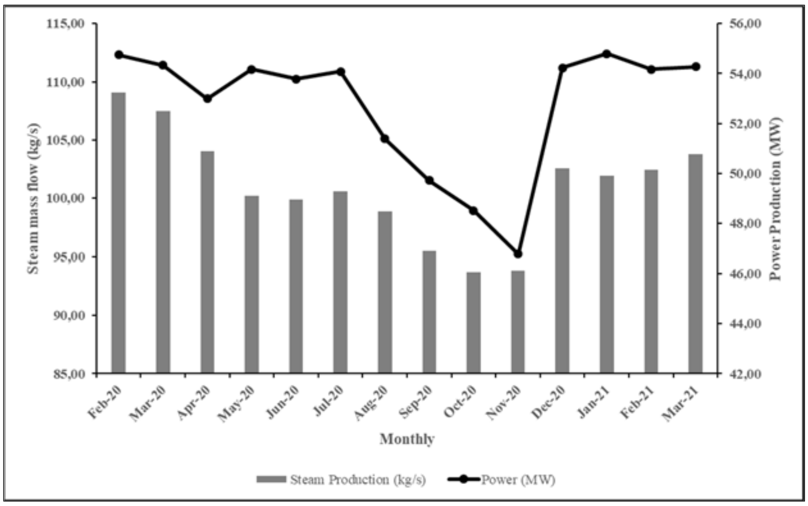
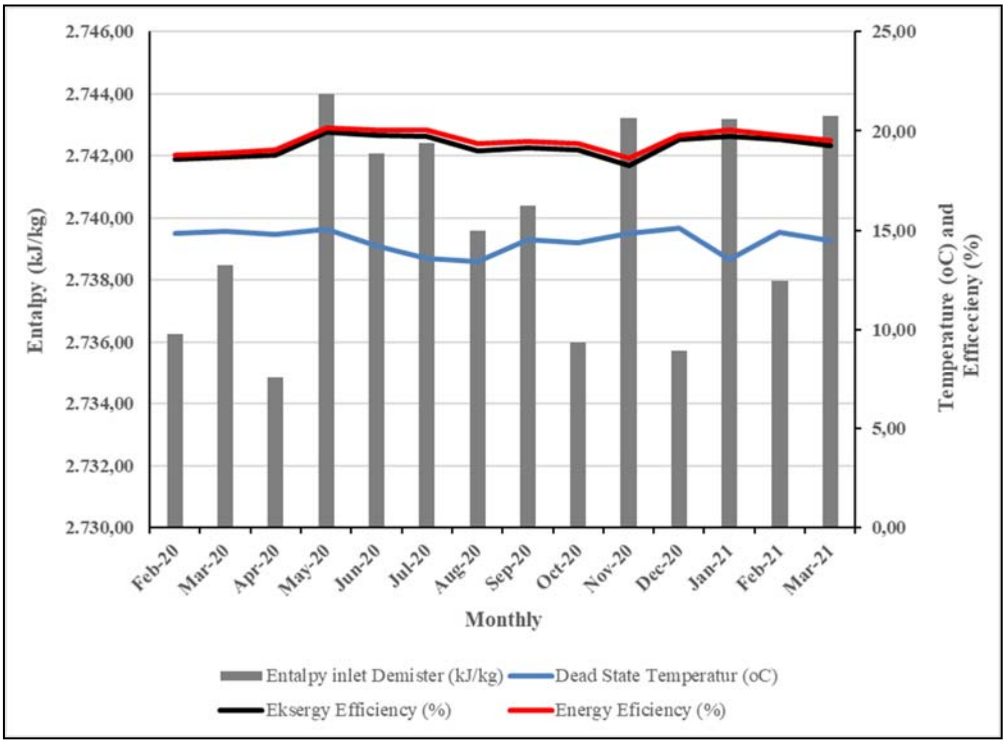


Fig. 4. Steam and Power Production Graph

The lowest generation occurred in November 2020; this was affected by the non-operation of one of the wells, namely WP-Q, which was undergoing a workover. Based on **Erreur ! Source du renvoi introuvable.** The effect of the temperature value in the environment (dead state) will be inversely proportional to the energy efficiency and exergy, the lower the food temperature value, the greater the energy efficiency and exergy values. The higher the temperature value in the environment, the lower the energy efficiency and exergy of the generator. The temperature value will affect the vacuum in the condenser. When compared before transfiguration with after transfiguration, the value of exergy efficiency is smaller because there is a brine pump used to pump brine out of the separator. The increase in exergy efficiency from Patuha Geothermal is only 2% after transfiguration. This value is large considering that the contribution of WP-L steam production to total steam is 9%.



The Influence of dead state temperature and entalpi to Energy dan Exergy Efficiency

IV. Conclusion

The effect of the transfiguration of steam distribution from the separated steam cycle to direct dry steam at Patuha Geothermal can be seen from the steam fraction, energy efficiency, and exergy efficiency. In this study, the value of the steam production contribution of the WP-L well that experienced an anomaly was only 9% of the system. Based on the energy analysis as a whole, the average efficiency value did not change much, which only increased by 0.03% from 19.48% (separated steam cycle) to 19.52% (direct dry steam). This is because in energy analysis calculations, it only calculates the value of the thermal and work energy of the system. Whereas in the calculation of exergy analysis, it is more visible at the locations of the exergy losses from the system, namely the cooling tower, steam turbine, seal water separator, and main condenser. Meanwhile, the loss of brine waste is only 0.97% (separated steam cycle), and the value becomes zero after being transfigured into a direct dry steam cycle. With exergy analysis, it can be concluded that:

1. The average total exergy available in the steam gathering system from all wells in Patuha Geothermal before the transfiguration was 266,024.60 kW and after the transformation was 267,486.93 kW. There is a difference of 1,462.33 kW between before and after the transformation.
2. The average exergy value of steam flowing into the power plant is 257,718.13kW in the form of steam, while 8,306.47kW is in the form of brine in the flow drain demister, which is flowed to the condensate pond.
3. The highest exergy efficiency value of the equipment is demister, with 96.94% before transfiguration and increasing to 97.85% after changing to direct dry steam.
4. The cooling tower has the lowest exergy efficiency value of 9.57%, which drops 0.1% to 9.47% after transfiguration.
5. The exergy value of brine in WP-L was 2,512.52 kW before transfiguration, and after transfiguration, it was zero.
6. The largest value of exergy loss occurred in the cooling tower at 14,816.54kW before transfiguration and decreased to 14,690.07kW.

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