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Low Pressure Wells Generation on Steam Dominated Field

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ABSTRACT

Geothermal field should have monitoring wells that are used for reservoir monitoring. Some wells were originally intended as production wells but had non-commercial production test results, partly because the wellhead pressures were below operational pressure. These well were potential to become commercial using different power plants.

This study will discuss low pressure category wells and the generation capability of each well. Observations were made on several steam domination wells beginning with the selection of a stable pressure in the production test activity and followed with data processing, output curve construction and the calculation of generation capacity. The result indicates that wells in low pressure category can be used as a solution to increase generation capacity by utilizing excess monitoring wells that already exist in the field.

1. INTRODUCTION

Kamojang Geothermal Field is located in Ibun District with a distance of about 45 km to the Southeast of Bandung City at an altitude of around 1500 MASL. This field is the oldest geothermal field in Indonesia and is currently being operated by PT. Pertamina Geothermal Energy with a total generation capacity of 235 MW. The field concession pattern has two schemes: a steam purchase agreement for units 1, 2, and 3; and an electricity purchase agreement for units 4 and 5. The steam or electricity that has been produced will then be handed over to the national electricity company based on the sales contract agreement.

The main objective of this study is to determine the generation capacity of wells with low operating wellhead pressure. These wells were originally intended as production wells, but the production test results indicated that these wells could not be transferred to the turbines with the existing inlet turbine pressure values because the wellhead pressure values were below the operational pressure values in the area (below 13 bar), therefore in the end these wells were converted as monitoring wells.

If a special low-pressure line is provided, these wells have a potential to increase field generation capacity therefore the expensive costs incurred for constructing new wells to increase the amount of steam supply to the turbine can be minimized. The author will compare the three calculation conditions: backpressure turbine, condensing turbine, and binary conditions. This study will also look at the effect of superheated steam that occurs in the well and its effect on the resulting generation value.

2. WELL CHARACTERISTIC

Two wells will be examined in this study: KMJ-A and KMJ-B, which were subjected to a re-conducted production test in 2022.

The KMJ-A and KMJ-B wells are steam-dominated wells that are located in the same cluster but have different well trajectories. Well-A is aiming for the Ciwelirang Fault-3 NW-SE as its production zone, while well-B is aiming for the Laksana Fault-3 NE-SW as its reservoir fluid production path.

Based on the PTS under flowing condition data, the percentage value of the feedzone contribution from the KMJ-A and KMJ-B wells at each depth is summarized in the following table.

Table 1: Feedzone Contribution KMJ-A & KMJ-B

No	Depth KMJ-A (mMD)	Feedzone Contribution KMJ-A (%)	Depth KMJ-B (mMD)	Feedzone Contribution KMJ-B (%)
1	705	16	875	14
2	785	19	1350	11
3	900 - 1323	52	1425	21
4	1420	6	1525	27
5	1446	7	1875	8

No	Depth KMJ-A (mMD)	Feedzone Contribution KMJ-A (%)	Depth KMJ-B (mMD)	Feedzone Contribution KMJ-B (%)
6	-	-	2775	19

The following pictures are the PT profiles of the KMJ-A and KMJ-B wells.

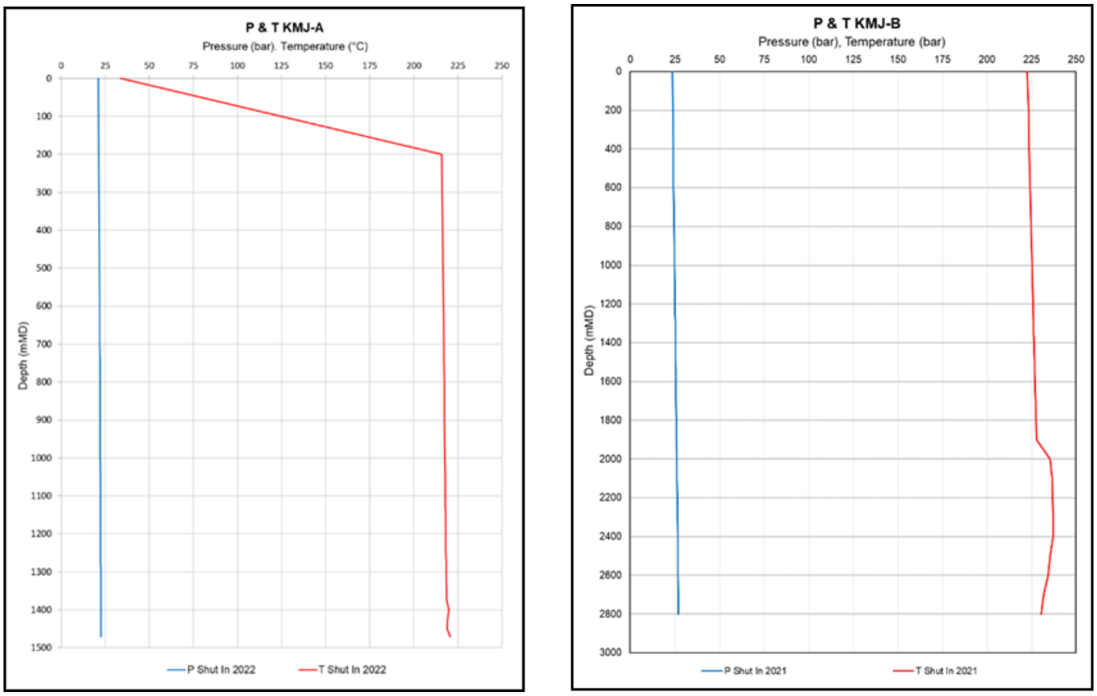

Figure 1: PT KMJ-A & KMJ-B

The latest PT data from KMJ-A shows the wellhead pressure value is 21 bar. At the same depth of 1470 mMD, the maximum temperature and pressure are 220.6 °C and 22.6 bar, respectively.

While KMJ-B, shows 23.5 bar of wellhead pressure value, the maximum temperature value is at a depth of 2300 mMD with a value of 237.2 °C, and the highest pressure is at a depth of 2800 mMD with a value of 27 bar.

3. PRODUCTION TEST & ELECTRICITY POWER CALCULATION

The data processing of production test results begins with the selection of a stable pressure range in the production profile at each tested opening. After obtaining stable test points, an output curve is then made to match the stable test points. The operational pressure in the low-pressure well is then selected to calculate the mass flow as the input for the generation capacities of KMJ-A and KMJ-B based on the matching graph.

In this study, three methods will be compared to calculate the generation capacity of the well. Those are the low-pressure turbine methods with backpressure, condensing, and binary types. As a result, the method with the highest generating capacity will be selected.

3.1 Production Test

Production tests were carried out on the KMJ-A and KMJ-B wells for 39 days and 25 days, respectively. The variation of the production test time was caused by the differences in each well's characteristics in order to achieve a stable pressure and steam flow rate at four different well openings.

3.1.1 Production Test Profile KMJ-A

KMJ-A well production test began in June 2022 and was completed in July 2022. The analysis was carried out by plotting the wellhead pressure and steam flow rate against the test time. The results obtained can be seen from the KMJ-A well production test profile as follows:

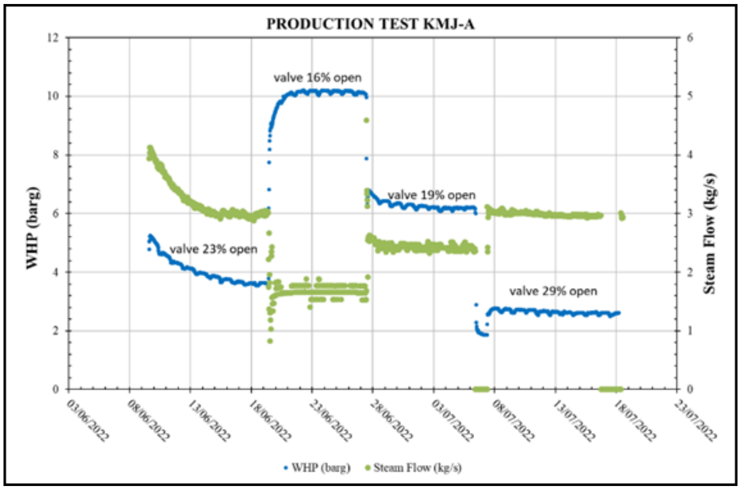

Figure 2: KMJ-A Production Test Profile

From the above production test graph, stable pressure and steam flow rate values are taken at each opening valve range. The following table is the summary from each stable point of KMJ-A.

Table 2: Summary of Stabilize Production Test Point KMJ-A

No	WHP (bara)	Steam Flow (kg/s)	TV (%)
1	4.46	2.97	23
2	11.02	1.68	16
3	7.04	2.41	19
4	3.49	2.97	29

3.1.2 Production Test Profile KMJ-B

KMJ-B well production test began in March 2022 and was completed in April 2022. The analysis was carried out by plotting the wellhead pressure and steam flow rate against the test time. The results obtained can be seen from the KMJ-B well production test profile as follows:

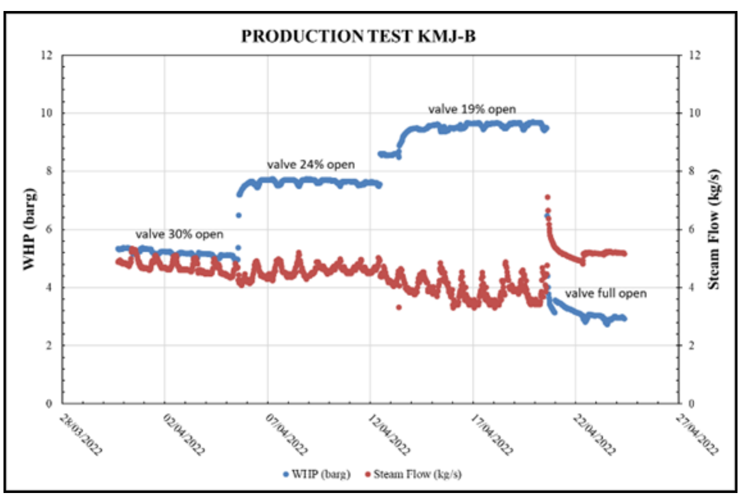

Figure 3: KMJ-B Production Test Profile

From the above production test graph, stable pressure and steam flow rate values are taken at each opening valve range. The following table is the summary from each stable point of KMJ-B.

Table 3: Summary of Stabilize Production Test Point KMJ-B

No	WHP (bara)	Steam Flow (kg/s)	TV (%)
1	5.99	4.67	30
2	8.48	4.65	24
3	10.48	3.58	19
4	3.82	5.19	100

3.2 Output Curve

Furthermore, a matching process is carried out between stable test points and the output curves of KMJ-A and KMJ-B. This matching process needs to be carried out so that it can increase the level of confidence in estimating the value of the steam flow rate from the operational pressure of the low-pressure well to be simulated.

The output curve construction uses the flow rate equation for the dry steam well:

$$M = C\ (P_r^2 - WHP^2)\verb|^|n \quad (1)$$

M (kg/s) stands for steam flow rate, C is a constant parameter, Pr (bara) shows the reservoir pressure, WHP (bara) is the wellhead pressure, and n is an exponential constant. The next step in constructing the output curve is to make a log-log plot of the difference squared between reservoir pressure and wellhead pressure against the steam flow rate. Regression could be created based on the log-log plot to determine the values of C and n.

3.2.1 Output Curve KMJ-A

The reservoir pressure from KMJ-A is 23.4 bara. The graph between log (Pr^2-WHP^2) and log (M) can be obtained based on the stable production test points from KMJ-A

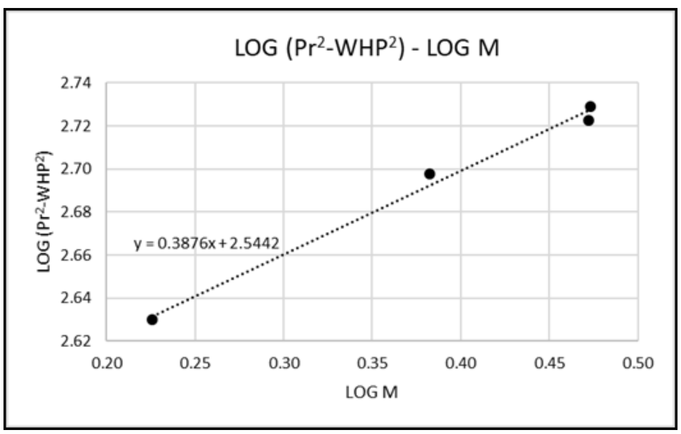

Figure 4: Log(Pr2-WHP2) - Log(M) KMJ-A

The value of C and n from KMJ-A are 2.7E-07 and 2.58, respectively. The output curve graph resulting from the two values can match the KMJ-A test points with the results shown in the following table and graph.

Table 4: Wellhead Pressure & Flowrate Simulation KMJ-A

WHP (bara)	M (kg/s)	M (t/h)
0	3.17	11.41
2	3.11	11.20
4	2.94	10.57
5	2.81	10.12

WHP (bara)	M (kg/s)	M (t/h)
6	2.66	9.58
8	2.30	8.28
10	1.88	6.78
12	1.44	5.19

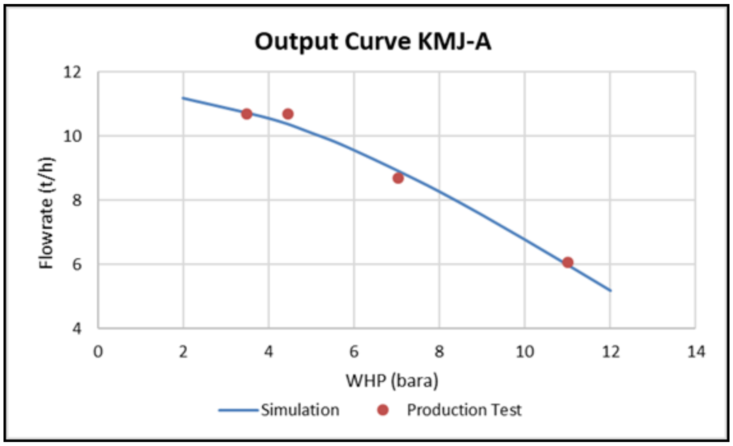

Figure 5: Output Curve KMJ-A

3.2.2 Output Curve KMJ-B

The reservoir pressure from KMJ-B is 24.4 bara. The graph between log (Pr^2-WHP^2) and log (M) can be obtained based on the stable production test points from KMJ-B

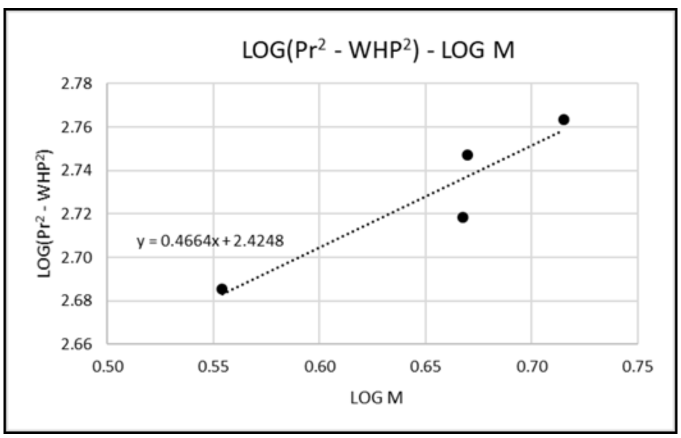

Figure 6: Log(Pr2-WHP2) - Log(M) KMJ-B

The value of C and n from KMJ-B are 6.2E-06 and 2.14, respectively. The output curve graph resulting from the two values can match the KMJ-B test points with the results shown in the following table and graph.

Table 5: Wellhead Pressure & Flowrate Simulation KMJ-B

WHP (bara)	M (kg/s)	M (t/h)
0	5.49	19.75
2	5.41	19.47

WHP (bara)	M (kg/s)	M (t/h)
4	5.18	18.63
5	5.00	18.02
6	4.80	17.28
8	4.30	15.48
10	3.70	13.32
12	3.03	10.91

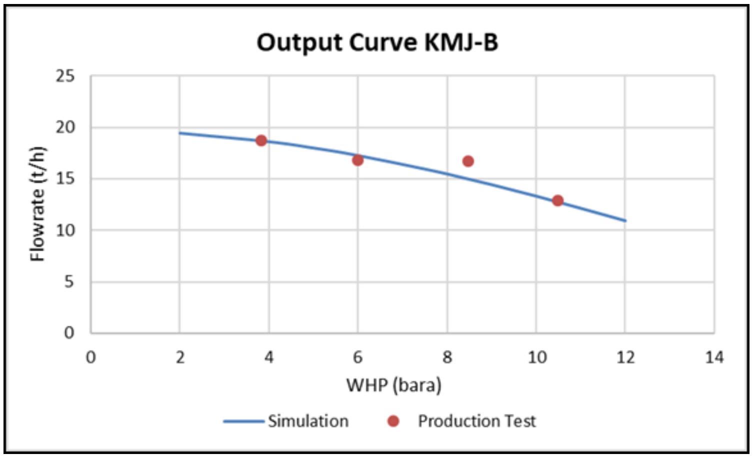

Figure 7: Output Curve KMJ-B

3.3 Electricity Generation

Based on the output curve simulation results, the estimated flowrate values of the KMJ-A and KMJ-B wells at an operational pressure of 5 bara are 10.12 tph and 18 tph, respectively. These two values will be used as input calculations for the three methods tested: Backpressure, Condensing, and Binary.

For the calculation using the backpressure turbine method, the atmospheric pressure at an elevation of 1500 MASL, which has a value of 0.86 bara, is being used. For the condensing turbine method, the values of turbine inlet pressure and condenser pressure are 2.45 bara and 0.079 bara, respectively. These data are based on low-pressure turbine data from Nga Awa Purua Field in New Zealand (Azhari, 2018). The other assumptions that are being used are the isentropic process between the turbine and condenser, and the electricity generation efficiency is 80%.

KMJ-A and KMJ-B have the flowline temperature 175 °C and 184 °C, respectively. Both of these value have values above the saturation temperature.

$$T > Tsat \quad (2)$$

Since the flowline temperature has a bigger value than the saturation temperature, the fluids that flow through the flowline towards the turbine are in the superheated steam condition.

Entropy calculation uses the following equation:

$$S = S_l + x.S_{ls} \quad (3)$$

Where S (kJ/kg.K) stands for fluid flowing entropy, S_l (kJ/kg.K) is liquid entropy, x (%) is dryness, and S_{ls} (kJ/kg.K) shows the different value between steam and liquid entropy.

Enthalpy calculations uses the following equation:

$$H = H_l + x.H_{ls} \quad (4)$$

Where H (kJ/kg) stands for fluid flowing enthalpy, H_l (kJ/kg) is liquid enthalpy, x (%) is dryness, and H_{ls} (kJ/kg) shows the different value between steam and liquid enthalpy.

The electricity generation calculation uses the following equation:

$$W = m\eta\Delta H \quad (5)$$

Where W (kW) is the turbine power, m (kg/s) stands for steam flow rate,·η(%) is turbine efficiency, and ΔH (kJ/kg) shows the different value between turbine and condenser enthalpy.

The author uses 14% thermal efficiency value for the calculation using binary method. This value is based on the thermal efficiency value from the OEC brine unit in Sarulla Geothermal Field (Doddy, 2020 from Saptadji 2018).

The heat that enters the pre-heater and evaporator rate can be assumed to be the same as the steam heat that is being transferred from the binary well, therefore the equation can be re-arranged as follows:

$$Q_{PH/E} = Q_s \quad (6)$$

$$Q_{PH/E} = \dot{m}_s(H_{s-in} - H_{s-out}) \quad (7)$$

Because heat rate occurs in isobaric condition therefore the equation (7) can be re-write as:

$$Q_{PH/E} = \dot{m}_s C_{ps}(T_{s-in} - T_{s-out}) \quad (8)$$

Where ṁs (kg/s) stands for steam flowrate, Cps (kJ/kg.K) is specific heat steam, and T (K) shows the steam temperature when in/out the heat exchanger.

3.3.1 Back Pressure Low Pressure Turbine

Using the above assumptions for the backpressure method, equations 3–5, and a value of 0.86 bara as atmospheric pressure. The summary of backpressure low-pressure turbine calculation for KMJ-A and KMJ-B can be obtained as follows:

Table 6: Back Pressure Low Pressure Turbine Calculation Summary

Well	Hs@tip (kJ/kg)	Ss@tip (kJ/kg.K)	Sl@atm (kJ/kg.K)	Ss@atm (kJ/kg.K)	x@at (%)	Hl@atm (kJ/kg)	Hs@atm (kJ/kg)	H@atm (kJ/kg)	W (MW)
KMJ-A	2815.82	7.06	1.26	7.41	0.94	400.22	2668.45	2539.64	0.62
KMJ-B	2834.28	7.06	1.26	7.41	0.94	400.22	2668.45	2539.64	1.18

Where the lower s and l shows steam and liquid, respectively., @tip stands for turbine inlet pressure, @atm in atmospheric condition, and @at is after turbin.

3.3.2 Condensing Low Pressure Turbine

Using the above assumptions for the condensing method, equations 3–5, and a value of 0.079 bara as condenser pressure. The summary of condensing low-pressure turbine calculation for KMJ-A and KMJ-B can be obtained as follows:

Table 7: Condensing Low Pressure Turbine Calculation Summary

Well	Hs@tip (kJ/kg)	Ss@tip (kJ/kg.K)	Sl@cds (kJ/kg.K)	Ss@cds (kJ/kg.K)	x@at (%)	Hl@cds (kJ/kg)	Hs@cds (kJ/kg)	H@cds (kJ/kg)	W (MW)
KMJ-A	2815.82	7.06	0.59	8.23	0.85	172.86	2575.81	2207.09	1.37
KMJ-B	2834.28	7.06	0.59	8.23	0.85	172.86	2575.81	2207.09	2.51

Where @cds stands for the calculation in condenser.

3.3.3 Binary Low Pressure Turbine

Using the above assumptions for the binary method, equations 6–8, and a value of 1.996 kJ/kg.K as specific heat steam. As a calculation with binary method, the author makes five temperature variations from 90 ºC to 130 ºC with the following considerations: 90 ºC (Hinde and Mulazzani, 2016), 100 ºC (The rule of thumb brine reinjection temperature to prevent scaling, Thorhallsson, 2012), 110 ºC (reinjection temperature on Los Azufres, Mexico, Grassiani, 2000), 120 ºC (Binary Cycle OEC Brine Sarulla), dan 130 ºC (Monroy Parada, 2013). The summary of the binary generation calculation for KMJ-A and KMJ-B can be obtained as follows:

Table 8: Binary Low Pressure Turbine Calculation Summary

Well	KMJ-A		KMJ-B	
Temp ºC	Power (MW)	Net Power (MW)	Power (MW)	Net Power (MW)
130	0.25	0.04	0.55	0.08
120	0.31	0.04	0.65	0.09
110	0.36	0.05	0.75	0.10
100	0.42	0.06	0.85	0.12
90	0.47	0.07	0.95	0.13

According to the table, the lower the temperature-out that we apply, the more electricity we can produce. As a result, 90 ºC is chosen as the optimal temperature-out.

Therefore, the results from the three methods can be summarized as follows:

Table 9: Total Generation Capacity From Three Methods

Type	Generation Capacity KMJ-A (MW)	Generation Capacity KMJ-B (MW)	Total Generation Capacity (MW)
Backpressure	0.62	1.18	1.8
Condensing	1.37	2.51	3.88
Binary	0.07	0.13	0.2

It can be seen that the condensing method produces the highest value of low-pressure turbine generating capacity in this study. This value is also influenced by the effect of superheated steam from within the well. If the fluid is not in a superheated state, using the same condensing method, the generation capacity values of KMJ-A and KMJ-B should be 3.18 MW. The superheated effect gives a 22 percent increase in the value of generation capacity.

4. CONCLUSION

In this study, the generation method for steam-dominated fields with the condensing low pressure turbine type from low pressure wells has the highest value of 3.88 MW. As can be concluded from the backpressure and condensing methods, the smaller pressure value after the turbine (atm or condenser) will provide a greater generation output. And the binary method for steam-dominated wells is an ineffective method to be chosen. This is because the low thermal efficiency value of the binary generator and the specific steam value is much lower when compared to water-dominated fields. The superheated steam effect in this study provides an increase in the generation capacity value of 22%. The result of this calculation is still an initial estimate for measuring the potential for generating low-pressure wells. There are other aspects that can still be improved, such as the actual value of the final design against the assumed values, economic aspects, generation needs in the field, and the other things. These matters must be studied further and in a comprehensive manner in order to provide a mature decision-making process in choosing the type of generator to be used.

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