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# Kamojang Geothermal Field, Indonesia Evaluation and Expectation After 15 Years Operation

**Uum Komaruddin and I Ketut Sujata**

**Geothermal Division-PERTAMINA , Indonesia**

## ABSTRACT

Kamojang geothermal field was discovered in the early 1920's, and extensive exploration work was initiated in 1973 through cooperation between the Government of Indonesia and the Government of New Zealand.The geothermal system of Kamojang is associated with Quaternary volcanic centers about 400,000 years old and appears to occupy a graben like structure. The field is two-phase, steam dominated reservoir with low gas content, found at an average depth of 1300 m below the ground level. Based on results of 13 exploration wells and 1980 vintage D-C Schlumberger resistivity using 1,000-m spacing the field size was first indicated of about 14 square kilometers with proven reserve around 200 megawatts of generation potential.

The first large Indonesian geothermal power plant, rated at 30 Mwe, began operation at Kamojang in 1983, followed by another two power plant units each having capacity of 55 MWe in 1987. These power plant have a design life of 25 years .

A geophysical survey using the CSAMT method was carried out in 1988 using a radial configuration The survey objective was to delineate any possible field extensions to help achieve optimum use of the Kamojang geothermal resources. This survey indicated extension of the reservoir size to 21 square kilometers with estimared resource potential of about 300 MWe.

Since 1987, when total field production reached of 140 Mwe, production decline has been about 6-7 % per year. This decline is believed to be caused mainly by scaling in near-wellbore fractures, since only a small decline in reservoir pressure has been noted in monitor wells in certain part of the area.

A reservoir simulation study for the 21 square kilometers reservoir area was conducted in 1992 with the objective of evaluating the reservoir's ability to support increased electricity generation. This study indicated that the reservoir is capable of supporting an extension of generation up to a total of 200 MWe for 30 years. A design study for the addition of 60 Mwe has performed using modern power plant technology of greater efficiency than the current plants.

Finally, geoscienctific surveys work has been conducted in areas surrounding the field. This work support the idea that other prospects, separated from the main Kamojang field are attractive for possible development in the future.

## Introduction

The Kamojang geothermal field is believed to have potential for a maximum capacity of 200 Mwe power generation. From the resources viewpoint, the field, which is classified as a two-phase, vapor-dominated reservoir system, produced dry steam with low non condensable gas content (<1 %wt %). Generation of electricity from produced steam is simpler than generation from two-phase, liquid-dominated reservoir system. The top of the reservoir, at 1,200 m below the surface, is relatively shallow compared with other fields, resulting in lower drilling expense.

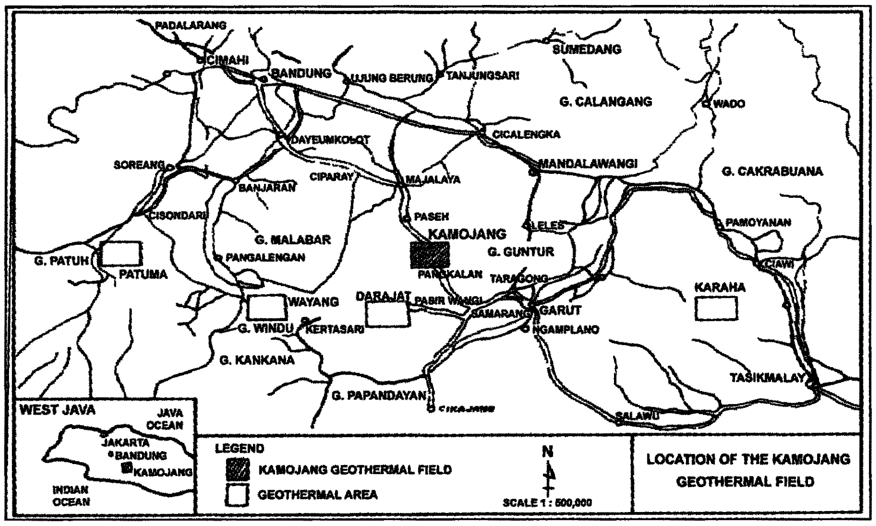


**Figure 1.** Map showing the location of the Kamojang Geothermal Field.

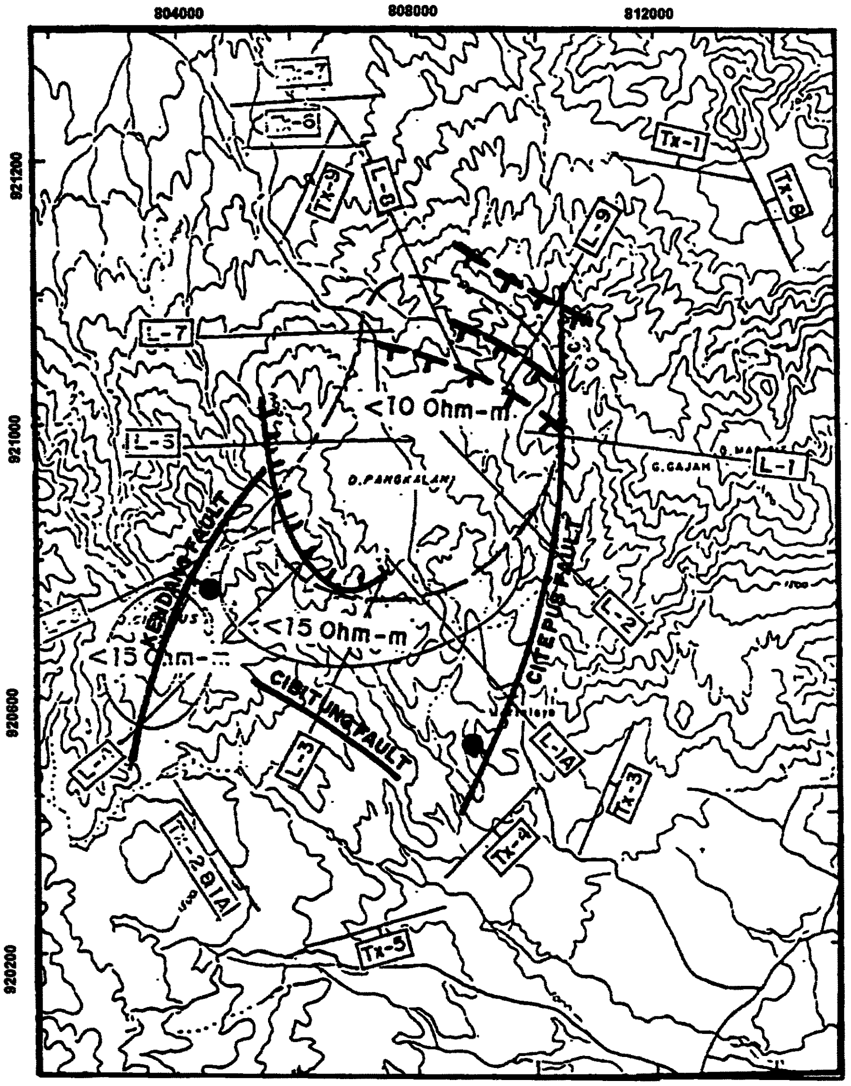


Figure 2. The main fault structures at Kamojang Field.

Geographically, the Kamojang field is located near Bandung, capital of West Java Province and Garut, capital of the local region (Figure 1). This location is advantageous in terms of infrastructure. Moreover, the connection of the Kamojang electric transmission system to Java-Bali system bring the possibility of further development at Kamojang as well as development of other fields surrounding Kamojang such as Darajat, Wayang Windu, Karaha.

## Field Characterization

### *Geological setting*

The Kamojang geothermal field is situated in the East-West trending Rakutak-Guntur volcanic chain lying at altitude of about 1,500 meters above sea level. The system is associated with 400,000 years-old Quatenary volcanic rock of the Pangkalan and Gandapura volcanic centers. It appears to occupy a volcanic depression created by Pangkalan caldera rim inside the northeast-southwest graben formed by the Kendang fault in the west and Citepus fault in the east. Most of the productive wells lie within the Pangkalan depression which consist of colluvial, alluvial deposits, and volcanic-sedimentary debris.

The southern rim of the Pangkalan depression is well-recognized . Borehole data reveal that the depression is bounded by a low-angle fault, but this structure is not a boundary of the field. Four mayor faults, including the Citepus, Cibitung , and Kendang Fault , encompass the field in a rectangular shape (Figure 2). The top of the Kamojang reservoir is found at an average depth about 1,300 m below the surface. The basaltic-andesite hosted reservoir is overlain by a thick, low-permeability cap rock of volcanic with pervasive argillic alteration.

Surface manifestations in the Kamojang field consist of fumarols, steaming ground, turbid hot lakes, and mud pools with temperatures mostly close to boiling point. A lower-temperature hot-spring of Citepus, located in the southeast of the field margin, represents distal outflow fluids from the main system.

### *Resource characterization*

The Kamojang reservoir classified as a two-phase, steam dominated reservoir having an initial water saturation of the order of 25-30 %, temperature ranging from 235 to 245 degrees Celcius, and reservoir pressures of about 32-40 bars ( GENZL 1992). Wells were drilled and completed in the vapor zone and produce mostly steam. The non-condensable gas content in the produced fluid is less than 1 % by weight, being composed mostly of $CO_2$ and having very low chloride content.

The proven area of the Kamojang geothermal field is approximately 14 square kilometers, giving a total proven resources of 200 megawatts. However, the latest geophysical survey using the CSAMT method indicates that the resources could be large as 300 megawatts of power generation potential, occupying an are of 21 square kilometers.

## Pre – Production Period Stage

### *Exploration stage*

The Kamojang field was found in 1920 through the drilling of three shallow wells. Extensive exploration work was conducted in early 1964 under cooperative agreements work between the government of Indonesia and New Zealand in order to assess resource potential for further geothermal development. Geological mapping showed that the Kamojang geothermal system is controlled by the Pangkalan depression and graben-like structure, and is bordered by Kendang fault in the west and Citepus faults in the east. Geophysical surveying using the DC-Schlumberger electrical resistivity method, and the drilling of 8 shallow temperature-gradient holes, with depth of approximately 50 meters, resulted in the definition of a 14 square kilometers area having geothermal potential (Figure 5, next page), with a reservoir as deep as 500-600 meters in field margins (Hochstein, 1976). Sudarman *et al.* (1983) in addition confirmed that the steam reservoir is about 1,300 meters deep in the center of the field. Geochemical analyzes of the surface thermal fluids and gas indicated that the system was two-phase and vapor-dominated with temperature the about 235 degrees Celcius.

### Development stage

After scientific exploration surveys were completed, the drilling of 5 exploratory well were conducted with depth around 700 meters in 1974-1975. In the period 1975-1979, nine standard development well were drilled within the center of the field, with the deepest well being 1,800 meters. Six wells produced 350 tonnes/hour of dry steam from shallow feed zone at approximately 700-900 meters depth and a deep feed zone at about 1,100-1,250 meters depth. In 1979 the construction of the first large geothermal power plant in Indonesia was started and in late 1982 the Unit I turbine, with a power capacity of 30 MWe, was put in operation.

In developing geothermal energy in Indonesia, the government of Indonesia instructed PERTAMINA ( The State oil and gas enterprise) to assess geothermal prospect in the country, particularly in the Kamojang field. The Unit II and Unit III turbines with power generation of 55 Mwe each were installed after the increased steam supply was confirmed. Another 16 wells were subsequently drilled in this area with a total deliveribility of almost 1,000 tonnes/hour of dry steam more than enough to power Unit II and Unit III. These two units were then put in operation in September 1987, with 24 production wells having a total output of 1,125 tonnes/hour, bringing the total electric generating capacity of the Kamojang field to 140 MWe.

## Production Period Stage

### Reservoir performance

Reservoir management technique have been applied to help optimize production performance. Production decline of about 6-7 % per year appeared soon after the reservoir began producing steam for 140 Mwe of power generation (see Table 1, page 554). This decline is likely caused by several factors, including (1) deposition of silica in the well bore and in the reservoir rock surrounding well bore,(2) normal reservoir pressure decline, reservoir temperature decline, and (3) well bore damage due to mechanical problems.

Production decline, in some cases, has been accompanied by an increase in production of superheated steam. This phenomenon is commonly due to reservoir dry out. On the other hand injection of water and condensate to reservoir tended to stabilize the production rate. Water injection into well KMJ 32 appears to cause a positive response in well KMJ 33 and KMJ 40.

A tracer transient test using tritium was performed in order to determine the patern of fluid flow in the reservoir. Tritium injected into well KMJ 32 was monitored in KMJ 33, KMJ 31,KMJ 38 and KMJ 45, while tritium injected into well KMJ 15 was monitored in wells KMJ 11, KMJ 14, KMJ 17 and KMJ 18. The pathway of injected water show a northeast-southwest orientation, and are indicated in Figure 3. These pattern clearly indicated how the re-injection system should be arranged to maintain the production level due to steam supply to 140 MWe power plant .

A reservoir simulation was conducted in 1992 indicated that the reservoir with 14 square kilometers of proven area, will be able to supply the 140 Mwe generation until the year 2021, corresponding to 38 year life for unit I (30 MW) and 34 year life

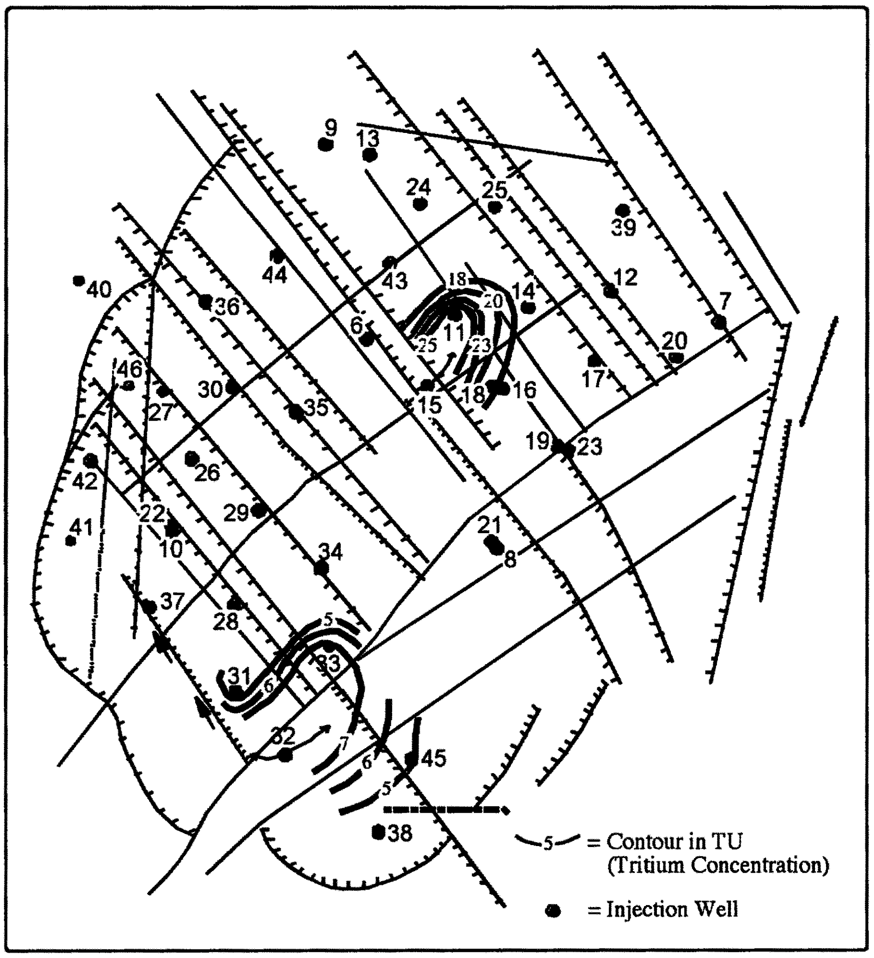


**Figure 3.** The pathway of tritium injection in reservoir of Kamojang Field

for unit II and III (55 MWe each). The incorporation of extra production units of 55 MW would drain reservoir before year 2021 (GENZL, 1992). However, with the extended field, as discussed further below, production increase to 200 Mwe are possible.

## Production facilities

The steam supply to 140 MWe power plant use four groups of transmission pipes named PL 401, PL 402 PL 403 and PL 404 (Figure 4).The steam flow is directed to a header before distributing to each unit of the power plant, and completed with a venting system to take care of excess flow and pressure during fluctuation of the power plants.

Each pipe group in the transmissions system was constructed without connection to the other, so decreasing flow occurring in one group cannot be compensated by other transmission groups. This system has limited the ability to keep the flow rate constant in the face of production declines. To eliminate energy loss due to a venting, automatic control systems will be installed on four big producer wells, KMJ 36, KMJ 41, KMJ 27 and KMJ 18. An accumulation of fluid in the header due to shut down of the power plant will automatically send a signal and close these wells. The mass loss due to venting system is about 6 % of total mass production. The largest mass loss results from evaporation in the cooling tower, and amount to 75 % of total mass production.

## Geo-science evaluation

As mention above, the reservoir structure in Kamojang field is controlled by a fault system created by a depression feature. Thus, these faults are the targets of drilling. An evaluation of subsurface condition in production wells gives a figure of transmissivity distribution in the field, and can be used as a guide to drilling.

In order to increase the resource capacity of the field, PERTAMINA has re-examining the interpretation of the reservoir boundary. Additional Schlumberger mapping ( up to AB/2 = 100 m) and MT sounding done in between 1984 and 1987, identified a lobe of low resistivity value ( < 15 ohm m) that were believed to indicate an extension of the field south-southwest of the central reservoir (Figure 5). This lobe of low resistivity values coincided with a soil mercury anomaly. Wells drilled into the lobe produced steam with higher pressure and temperatures than observed in the central reservoir, and suggesting that the lobe is an extension of the reservoir.

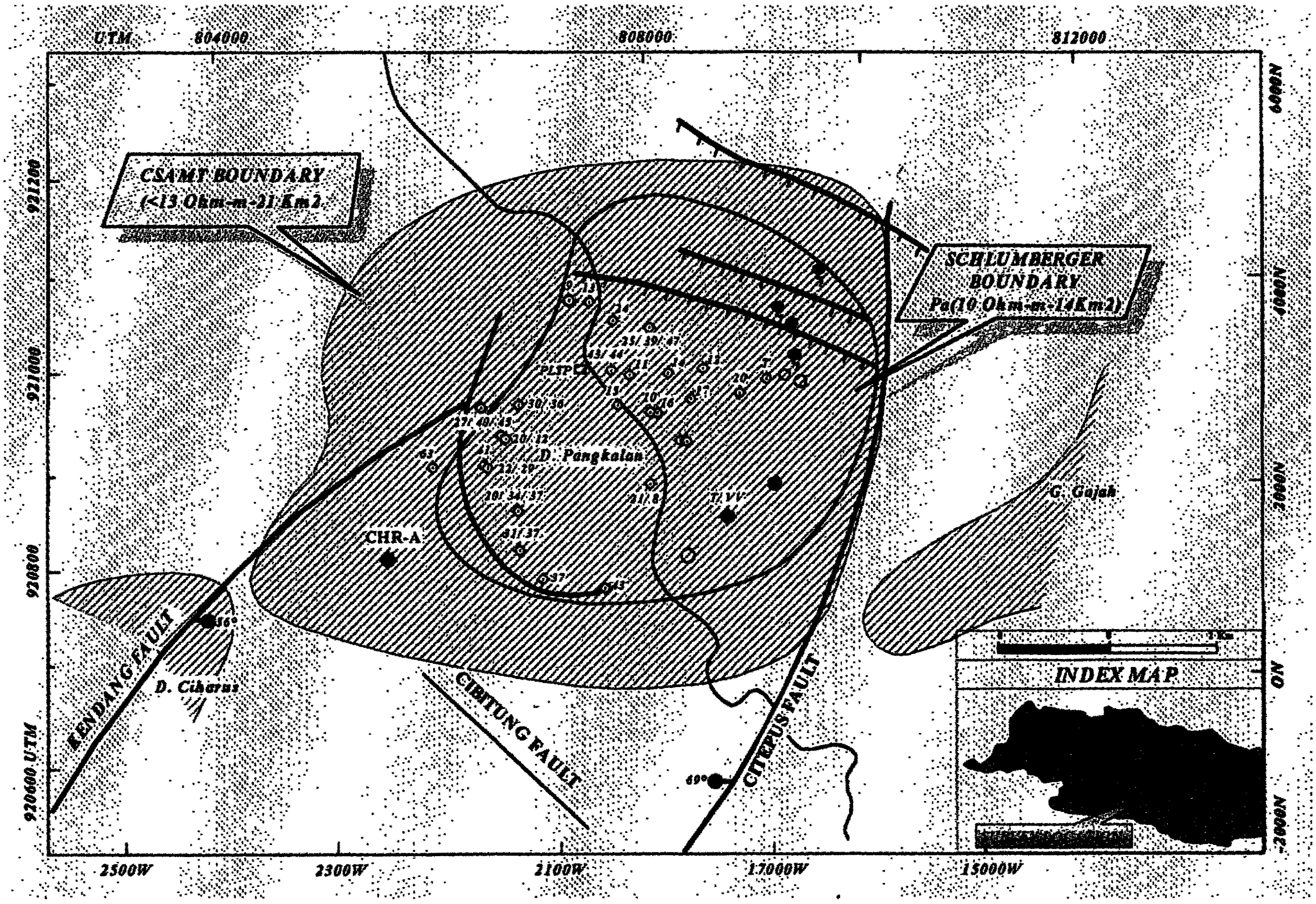
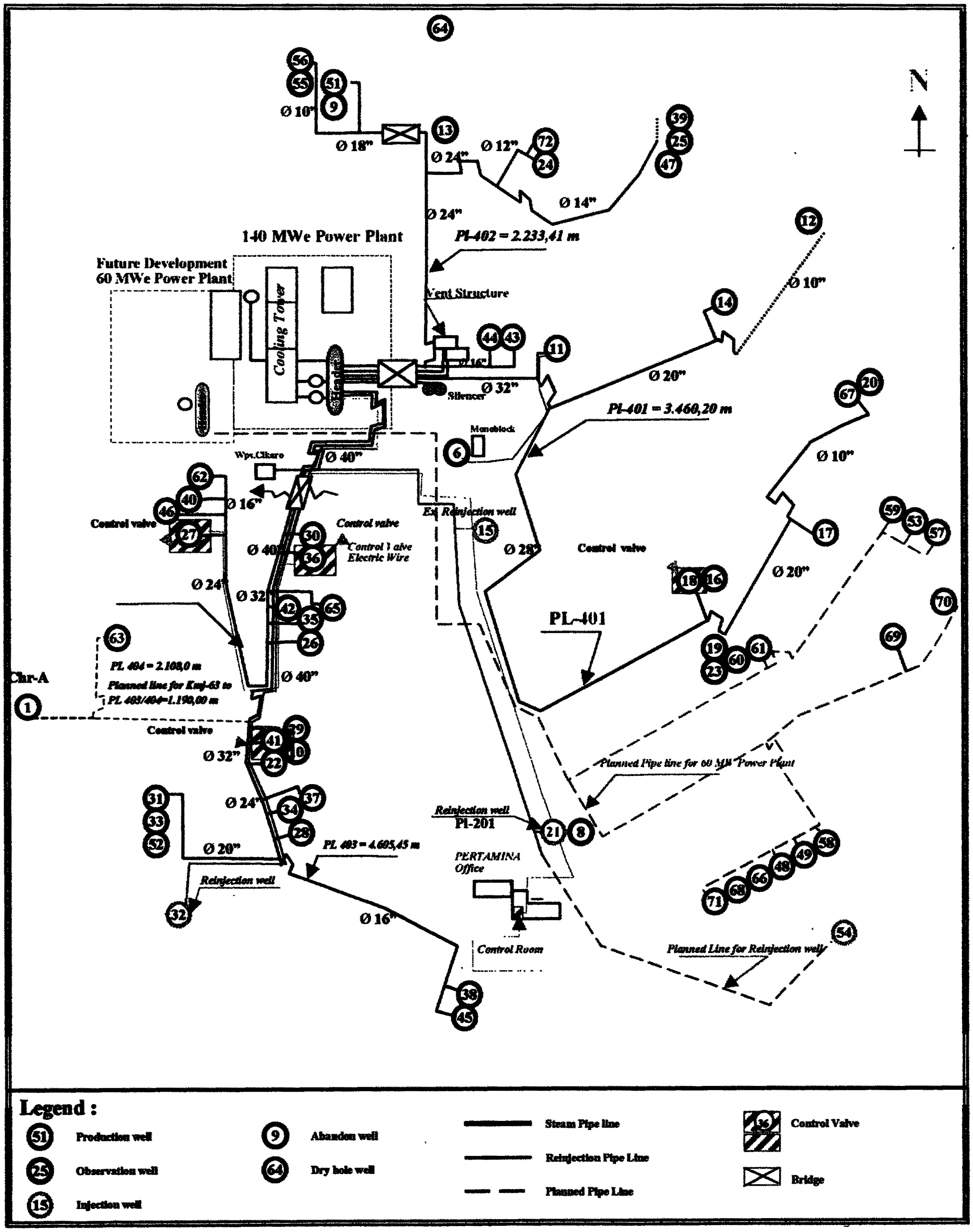


Figure 5. Boundary of the Kamojang Field, CSAMT data and Schlumberger data.



C : Data/Prod/Pipe line.ppt

Figure 4. Steam and reinjection transmission pipe line at Kamojang Geothermal Field.

| WELL | Initial static pressure (Psi, ksc) | PRODUCTION | | | | DECLINE CALCULATION | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | INITIAL | | CURRENT | | CONVENTIONAL METHOD | | | | | | TYPE CURVE MATCHING METHOD | | | | REMARKS |
| | | Flow rate (ton/hour) | $P_{wf}$ (ksc) | Flow rate (ton/hour) | $P_{wf}$ (ksc) | Ci | $P_{ec}$ (ksc) | Time (years) | Normalized Flowrate (ton/hour) | ANNUAL DECLINE (ton/hour) | ANNUAL DECLINE (%) | MATCH POINT t (month) | MATCH POINT tDd | ANNUAL DECLINE (%) | ANNUAL DECLINE (ton/hour) | |
| [illegible] | | | | | | | | | | | | | | | | |
| KMJ-11 | 32.8 | 83.00 | 13.5 | 68.89 | 13.5 | 0.0929 | 30.4 | 14.68 | 68.89 | 0.96 | 1.16 | 100 | 0.35 | 4.20 | 3.49 | Harmonic |
| KMJ-14 | 33.0 | 64.20 | 11.5 | 37.11 | 11.5 | 0.0671 | 26.2 | 14.74 | 37.11 | 1.84 | 2.86 | 100 | 0.40 | 4.80 | 3.08 | Harmonic |
| KMJ-17 | 32.0 | 67.50 | 12.4 | 57.41 | 12.4 | 0.0776 | 29.9 | 14.16 | 57.41 | 0.71 | 1.06 | 100 | 0.27 | 3.24 | 2.19 | Harmonic |
| KMJ-18 | 32.2 | 105.70 | 15.9 | 93.57 | 15.9 | 0.1348 | 30.8 | 14.66 | 93.57 | 0.83 | 0.78 | 100 | 0.22 | 2.64 | 2.79 | Harmonic |
| KMJ-67 | 28.8 | 64.20 | 18.1 | 55.47 | 18.1 | 0.1279 | 27.6 | 1.66 | 55.47 | 5.26 | 8.19 | | | | | |
| | | | | | | | | Average Decline: | | | 2.50 | | | 3.60 | | |
| [illegible] | | | | | | | | | | | | | | | | |
| KMJ-24 | 33.5 | 43.50 | 12.5 | 38.36 | 12.5 | 0.0450 | 31.8 | 9.05 | 38.36 | 0.57 | 1.31 | 100 | 0.20 | 2.40 | 1.04 | Harmonic |
| KMJ-25 | 33.0 | 21.70 | 7.4 | 10.51 | 7.4 | 0.0210 | 23.6 | 9.14 | 10.51 | 1.22 | 5.64 | 100 | 0.83 | 9.96 | 2.16 | Eksponensial |
| KMJ-39 | 31.6 | 17.80 | 14.4 | 4.63 | 14.4 | 0.0225 | 20.3 | 8.97 | 4.63 | 1.47 | 8.25 | 100 | 1.13 | 13.50 | 2.40 | Eksponensial |
| KMJ-43 | 32.8 | 37.00 | 8.9 | 18.75 | 8.9 | 0.0371 | 24.2 | 10.75 | 18.75 | 1.70 | 4.59 | 100 | 1.30 | 15.60 | 5.77 | Eksponensial |
| | | | | | | | | | | | | 100 | 0.55 | 6.60 | 2.44 | Harmonic |
| KMJ-44 | 33.3 | 53.50 | 7.0 | 18.76 | 7.0 | 0.0505 | 20.5 | 9.32 | 18.76 | 3.73 | 6.97 | 100 | 1.00 | 12.00 | 6.42 | Eksponensial |
| KMJ-51 | 31.5 | 93.10 | 14.9 | 83.09 | 14.9 | 0.1209 | 30.2 | 6.14 | 83.09 | 1.63 | 1.75 | 100 | 1.50 | 18.00 | 16.76 | Eksponensial |
| | | | | | | | | | | | | 100 | 0.74 | 8.88 | 8.27 | Harmonic |
| KMJ-56 | 27.8 | 18.00 | 8.0 | | | | | | | 1.44 | 8.00 | | | | | Assume |
| KMJ-72 | 28.3 | 67.70 | 14.4 | | | | | | | 5.42 | 8.00 | | | | | Assume |
| | | | | | | | | Average Decline: | | | 3.87 | | | 8.53 | | |
| 403 | | | | | | | | | | | | | | | | |
| KMJ-22 | 33.5 | 82.00 | 13.5 | 76.61 | 13.5 | 0.0872 | 32.6 | 11.08 | 76.61 | 0.49 | 0.59 | 100 | 0.19 | 2.30 | 1.89 | Harmonic |
| KMJ-28 | 33.2 | 52.00 | 10.3 | 26.19 | 10.3 | 0.0522 | 24.7 | 11.00 | 26.19 | 2.35 | 4.51 | 100 | 0.45 | 5.40 | 2.81 | Harmonic |
| KMJ-31 | 32.4 | 43.60 | 12.7 | 30.28 | 12.7 | 0.0491 | 27.9 | 9.58 | 30.28 | 1.39 | 3.19 | 100 | 0.46 | 5.56 | 2.42 | Harmonic |
| KMJ-33 | 31.0 | 21.50 | 10.3 | 16.94 | 10.3 | 0.0251 | 27.9 | 2.83 | 16.94 | 1.61 | 7.49 | | | | | |
| KMJ-34 | 32.9 | 50.50 | 7.9 | 19.70 | 7.9 | 0.0495 | 21.5 | 10.49 | 19.70 | 2.94 | 5.81 | 100 | 0.70 | 8.40 | 4.24 | Eksponensial |
| KMJ-37 | 32.4 | 58.50 | 20.3 | 45.50 | 20.3 | 0.0917 | 30.1 | 10.19 | 45.50 | 1.28 | 2.18 | 100 | 0.27 | 3.24 | 1.90 | Harmonic |
| KMJ-38 | 35.0 | 38.30 | 10.3 | 21.84 | 10.3 | 0.0342 | 27.3 | 11.16 | 21.84 | 1.47 | 3.85 | 100 | 0.50 | 6.00 | 2.30 | Harmonic |
| KMJ-41 | 32.8 | 83.50 | 11.9 | 74.01 | 11.9 | 0.0894 | 31.1 | 10.74 | 74.01 | 0.88 | 1.06 | 100 | 0.23 | 2.76 | 2.30 | Harmonic |
| KMJ-45 | 34.0 | 45.30 | 10.5 | 21.51 | 10.5 | 0.0433 | 24.6 | 11.41 | 21.51 | 2.09 | 4.60 | 100 | 0.45 | 5.40 | 2.45 | Harmonic |
| KMJ-52 | 31.3 | 45.30 | 14.8 | 38.73 | 14.8 | 0.0596 | 29.5 | 6.16 | 38.73 | 1.07 | 2.35 | 100 | 0.26 | 3.12 | 1.41 | Harmonic |
| | | | | | | | | Average Decline: | | | 2.99 | | | 4.35 | | |
| [illegible] | | | | | | | | | | | | | | | | |
| KMJ-26 | 34.0 | 89.60 | 11.0 | 46.49 | 11.0 | 0.0866 | 25.7 | 11.48 | 46.49 | 3.76 | 4.19 | 100 | 0.50 | 6.00 | 5.38 | Harmonic |
| KMJ-27 | 33.3 | 87.00 | 13.1 | 56.79 | 13.1 | 0.0928 | 28.0 | 11.58 | 56.79 | 2.61 | 3.00 | 100 | 0.55 | 6.60 | 5.74 | Harmonic |
| KMJ-30 | 33.0 | 32.20 | 8.7 | 11.98 | 8.7 | 0.0318 | 21.3 | 10.13 | 11.98 | 2.00 | 6.20 | 100 | 2.30 | 27.60 | 8.89 | Eksponensial |
| KMJ-35 | 33.5 | 29.70 | 7.5 | 8.08 | 7.5 | 0.0279 | 18.6 | 6.77 | 8.08 | 3.19 | 10.75 | 100 | 1.60 | 19.20 | 5.70 | Eksponensial |
| KMJ-36 | 33.5 | 111.20 | 12.8 | 87.36 | 12.8 | 0.1160 | 30.3 | 11.57 | 87.36 | 2.06 | 1.85 | 100 | 0.30 | 3.60 | 4.00 | Harmonic |
| KMJ-40 | 31.6 | 22.00 | 8.0 | 10.60 | 8.0 | 0.0235 | 22.7 | 2.68 | 10.60 | 4.25 | 19.34 | | | | | |
| KMJ-42 | 32.8 | 63.50 | 8.5 | 20.10 | 8.5 | 0.0633 | 19.7 | 8.72 | 20.10 | 4.98 | 7.84 | 100 | 1.17 | 14.04 | 8.92 | Eksponensial |
| KMJ-46 | 32.4 | 47.10 | 9.8 | 21.14 | 9.8 | 0.0494 | 22.9 | 10.41 | 21.14 | 2.49 | 5.29 | 100 | 0.57 | 6.84 | 3.22 | Harmonic |
| KMJ-62 | 28.9 | 81.40 | 15.3 | 72.31 | 15.3 | 0.1354 | 27.7 | 2.33 | 72.31 | 3.90 | 4.79 | | | | | |
| KMJ-65 | 29.6 | 73.00 | 15.1 | 65.22 | 15.1 | 0.1126 | 28.4 | 2.22 | 65.22 | 3.50 | 4.80 | | | | | |
| | | | | | | | | Average Decline: | | | 5.14 | | | 9.09 | | |
| | | | | | | | | Average Field Decline: | | | 3.77 | | | 6.33 | | |

**Table 1.** Estimated production decline, Kamojang Geothermal Field (March, 1999)

This interpretation encouraged further exploration using the CSAMT method. The CSAMT interpretation of the reservoir boundary to encompass to about 21 square kilometers. Well CHR-A and well KMJ 63 drilled outside the original 14 square kilometers boundary found commercial production rates, and supported the idea of extending the available productive area.. To prove this, another well is is recommended in the extended reservoir area.

In addition to the extension of Kamojang reservoir boundary, two other anomalies were identified witrh the CSAMT survey, one beneath Gunung Gajah to the east and another one at the Ciharus depression to the southwest (Figure 5).

## Future Development

Geothermal potential reserve calculations using the extended reservoir area have estimated that the extension has a potential of about 100 Mwe for 30 years. This lead to the idea of extending field generation to 200 megawatts. A plan of development for an additional 60 MW was designed and included in the production-well drilling program in southeast part of reservoir area.

The other program in the area is to continue exploration surveys of more detail study in the two new prospect, i.e. Gunung Gajah and Citepus, as predicted by CSAMT survey. This approach may lead to additional production in the future.

## Conclusions

Kamojang geothermal field today produces geothermal energy for 140 MWe and has a high possibility of increased production due to an extension of the original reservoir boundary, and due also to the discovery of new geothermal prospect surrounding the existing area. Expansion of geothermal power generation in this area is favored due to its geographic position and the existing electric transmission infrastructure, which facilitates distribution of electricity for use throughout Java.

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