Achievement Ratio of Drilling Wells in the Kirishima Geothermal Field, Japan

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1 . Abstract

For the development of geothernal energy utilization. equipment cost reduction is one of the most important factors. In Japan, the cost ratio of drilling wells for geothermal energy amounts to about one/third, 35 % of development cost.

Achievement ratio(success ratio)of geothermal wells is a key factor for cost reduction. Several examples of 60—84% achievement ratio have been published in Japan. Kirishima Geothermal Project was divided into four development stages. For this project, we established achievement targets for each stage.

The attained achievement results were 88-92% against the planned ratio of 80 %. This is a very good result compared to the above published figure. The papers explain the targets, evaluates the drilling results and refer to items to be solved in the future.

2. Introduction

Kirishima Geothermal Field is located in the southern part of Kyushu island, in Kagoshima prefecture of Japan. Geothermal resources is abundant in this area and many beautiful landscape occur within the Kirishima-Yaku National Park. Location is shown in Figure 1.

In this field, we began surface survey in 1972 and test drilling in 1979. Based on the results of these survey.21 exploratory wells were drilled by our company and at the same time, 15 exploratory wells were drilled by the government. The exploratory wells drilled in the Ginyu area confirmed the existence of a geothermal reservoir. One important feature of the geothermal resources in the Ogiri area is that they are of typical fracture type, the Ginyu Fault.

Based on these facts, we drilled 14 development wells from 1989 to 1992. From the above, we confirmed the reservoirs sufficient for geothermal power plant with the capacity of 30 MW.

To be named Ogiri Power Plant, the facility is now under construction and is scheduled to be completed in 1996. Nittetsu Kagoshima Geothermal Co., Ltd. will produce the geothermal steam and Kyushu Electric Power Co., Ltd. will generate the electrical power from the steam.

In this paper, planning of achievement targets, analysis and evaluation of the results of drilling the geothermal wells are reported for each stage of development.

These wells produce steam and reinject accompanying hydrothermal fluid. Also future studies regarding additional wells and productivity of wells during in the stable operation will be discussed.

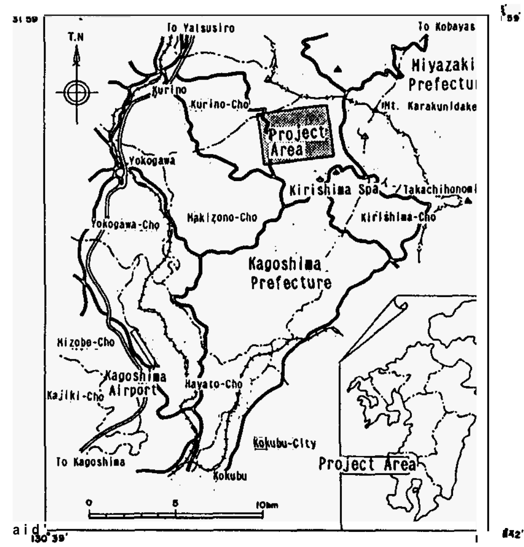

Fig. 1 Location of the Project Area

3. Achievement Ratio of Geothermal Well Drilling

3.1 Definition

In Japan, achievement ratio(success ratio or hitting ratio)of drilling wells, here in [A.W.] is defined

$$[A.W.] = \frac{\text{Number of Successful Wells}}{\text{Number of Drilled Wells}} \times 100\ \% \quad \text{--Equa. 1}$$

Number of drilled wells : Side tracked holes are not included, they are treated as repairs.

Number of successful wells : Production capacity. reinjection capacity and life of well are not defined clearly.

Wells damaged before use, those used for other purposes are included in failures, but in some cases wells used for other purposes are excluded from both denominators and numerators.

3.2 Examples of Achievement Ratio in Japan

1. Ishii, K., (1990) reports the following results of drill'ing.

Table 1 Achievement Ratio of Drilling Wells

Name of Power Plant	Period of Drilling	Average Achievement Ratio %
Hatchobaru I	Before 1974 — 1990	84
Hatchobaru II	1979 — 1990	74
Otake	Before 1974 — 1990	83

We developed various methods for geothermal exploration and drilling. We are able to achieve success ratio of 100% after 1985. The year 1985 was a turnning point. The average achievement of wells drilled to date is 82 %. Before 1913, we drilled a number of dry wells.

Dry wells were the result of drilling with uncertain knowledge of the characteristics of geothermal structure and reservoir.

2. Achievements cited at the
「N.E.F. Geothermal Development Seminar for Manegers」

1) Kodama, M. (1991)
N.E.F. Seminar Materials pp 2-13, 47

Drilling cost occupies a comparatively large share of the total geothermal energy development cost in Japan. Therefore, reduction of drilling cost is one of the very important problems for the developers.

In order to reduce the drilling cost, the following should be taken into consideration.

a. Plan drilling operation in detail.
- Utilize drilling equipment effectively and decrease idling time.

b. Improve the efficiency of drilling and well completion.

c. Improve achievement ratio of drilling

In case of Kirishima Project, we planned the achievement ratio to be 80% and attained 87.5% in 1990.

2) Matsuda. N. (1991) reports the following in
N.E.F. Seminar Materials pp 9-1.9-16

For considering the economic feasibility of geothermal energy development, we used a model of 50 MW geothermal power plant and calculated the power generation cost as a basis for the study.

The items assumed for this study is laid out in Tab.2.

Table 2 Number of Wells in Each Stages

Stage	Kind and Number of Wells	Achievement and Others
Exploration and Exploitation	Small diameter test holes 8 Large diameter test holes 1,800 m class 10 1,000 m class 5	5 within 10 are diverted to production well 2 within 5 are diverted to reinjection w.
Development	Prodution wells 10 Reinjection w. 11	Achievement ratio 80 % Achievement ratio 80 %

4. Planning of Kirishima Geothermal Project

Geothermal development in Kirishima field (Ogiri Power Plant) were divided into several stages which are shown in Table 4, together with the objectives of each geothermal development stage. Location of the project area is shown in Figure 1.

Table4 Geothermal Development Chronological Table—Kirishima Project

Year / Stage \ Item	Area Name	Size	Geothermal Development Object	Number of Wells
1912 '73 '14 '75 '76 '77	Kiri-shima	km km 4 × 3 km km 4 × 3	Surface Survey, Geothermal Survey	0 Soil temp. 30m× 50 holes
①st Stage '78 '79 '80 '81	Kiri-shima	km km 4 × 3	Geothermal Resources Exploration	Slim hole 3
②nd Stage '82 '83 '84	Ginyu	km km 2.8 × 1.3	Geothermal Resources Exploration	Slim hole 4 Large D.W. 7 Total 11
③rd Stage '85 '86 '87	Ginyu	km km 2.8 × 1.3	Corroboration Test	Large D.W. 6
④th Stage '88 '89 '90 '91	Ogiri	km km 1.9 × 0.5	Development Investigation	Large D.W. 14
'93 '94 '95 '96	Ogiri	km km 1.9 × 0.5	Construction Operating	Production Well 10 Reinjection Well 9

Explanation of Each stage

Surface Survey
- An Outline of geothermal potential area.
- Acquisition of data for planning drillng wells.
- Natural and social environment survey.

1st stage Exploration (Slim hole)
Study by means of small diameter geothermal wells.
- Existence, quantity and quality of geothermal fluid.
- Geothermal structure.
- Draft plan for next stage.

2nd Stage Exploration
- Confirmation of the overall possibility for development.

3 rd Stage Corroboration test
- Check and estimate the capability of the area.
- Actual production and reinjection tests using 4 production wells and 2 reinjection wells (140 t/hr steam).

4 th Stage Development investigation
- Full scale production and reinjection tests (360 t/hr steam) continuously for 2 months.

5. Achievements of Drilling Wells in the Kirishima Geothermal Field

Ouantity and quality of geothermal resources depend on the characteristics of individial geothermal field. For Kirishima Geothermal Field, we established standards for calculating achievement ratio for the follow-ing three cases: slim holes, production wells, and reinjection wells.

5.1 Slim holes

A. Concept

1. The purpose of drilling slim holes is to acquire data concerning geological sturucture, underground temperature and other relevant to geothermal exploration. The quality and quantity of geothermal fluid is measured by test and the capability of production-size holes is calculated.
2. In the Kirishima Project, achievement ratio must be 100 % with a stable steam production capacity of more than 40 tons/hr. The above must be achieved under the following conditions. Within the planned schedule, within the planned budget, fluid with suitable quality for power generation and stable production.
   Calculation is based on numerical values of steam quantity, underground temperature, transmissibility and characteristics of geothermal fluid.
3. Holes for temperature measurement and structural drill holes are excluded from achievement ratio calculation.

B. Definition of Estimation

1. After all calculations, the final achievement ratio of drilling wells [A.W.] ranges from 0 to 100 %.
2. [A. W.] of 100 % is defined as steam production exceeding 40 t/hr converted in production-size hole with final well diameter of 216 mm and well head pressure of 5.0 kg/cm^2 atomospheric pressure.
   A.W. will be reduced proportionately when the steam production is lower than the above.
   Conversion from slim holes to production-size holes is made by simulator NSC GREATS or final well sectional area ratio.
   Note: NSC GREATS is the pet name of numerical reservoir simulator, which was made by members of our team.
3. Geological correction factors.
   a. Underground temperature
   We estime the subsurface temperature by Activity Index [A. I.] from 0 to 100. The standard value of A. I. for Kirishima slim hole is 60. Over A. 1.60 we add, under 60 subtract the achievement.
   Note : [A. I.]
   Activity Index was proposed by Hayashi et.al(1981).
   A.I. is obtained by the following equation.

$$[A.I.] = \left(1 - \frac{Tb - Tm}{Tb - Tg}\right) \times 100 \quad \text{------ Equation 2}$$

where Tm :Maximum temperature measured or estimated for a particular drill hole.
Tb :Boiling temperature at the same depth.
Tg :Assumed temperature at the same depth, calculated from the normal geothermal gradient.

   b. Transmissivity (Permeability thickness)
   We set the standard transmissivity[k.h.] as 1Dm Over 1Dm (darcy meter) we add, and under 1Dm we subtract the figure from the achievement.
   The figure ranges from +10 to −10 with + 1Dm= +1.0 and −0.1 Dm= −1.0 .
   c. Quality of geothermal fluid (steam and hot water)
   It is assumed that the quality of geothermal fluid is suitable for development. So, when the fluid is accompanied by acid hot water of pH under 4.0 , the achievement is reduced by 1/2 .

5.2 Production-Size Hole--Production Well

We call the well which has the final diameter of 216 mm (8-1/2 inch) and over, as production-size hole or large size diameter well.

1. Achievement ratio 100% of production well has a steam production capacity of 40 t/hr or higher with well head pressure of 5.0 kg/cm^2 atm. in stable flowing state.
   If the flow is under 40 t/hr, the achievement will be reduced proportionately by the steam volume.
2. Correction of steam production volume for the difference of well diameter is made by the simulator or final sectional area ratio.
3. Geological correction factors.
   a. Underground temperature
   We evaluate the temperature by A. I..Standard value of A. I. for production well is 70.
   b. Transmissivity (Permeability thickness) kh
   Standard transmissivity is 5Dm.
   The figure ranges from +10 to −10.
   c. Quality of geothermal fluid
   In case of the fluid accompanied by acid hot water with pH under 4.0, we reduce the achievement to 1/2.
4. Side track well
   In a case of side track drilling, concept and defini-tion of estimation are the same as for the main well drilling. But they are counted as 0.5 wells such as, main well 1.0+side track well 0.5 = number of wells 1.5

5.3 Production-size hole--Reinjection Well

1. The achievement ratio of reinjection well, which can accept the natural flow of 200 m^3/hr or higher in a stable state, is 100 %.
2. Correction of reinjection volume for the difference of well diameter is made by final sectional area ratio.

6. Achievement of Drilling Wells ;Results

The detailed output results of A.W. in the Kirishima Geothermal Field are as follows.

6.1 Achievement ratio corrected data output

These corrections were made for each well under the concept and definition of estimation mentioned in Section 5. Output is shown in next tables.

Table 5 Achievement table of Production Wells

No. Stage Year	Area Name	Name	diameter (mm)	A.I. Activity Index: Index	A.I. Activity Index: Correction	Geothermal Fluid: Steam Volume (ton/hr)	Correction	Hot Water (ton/hr)	kh (Dm)	Correction	pH	Correction	Each Well A.W.	Each Stage and Arsa A.W. (%/No.W.): Ogiri	Ginyu	Kirishima
① 1979 –1981	Ginyu	KE1-2	79 (216)	84	24	7.3 (54.0)	100	1.4 (10.5)	5.1	5	9.4		100	100 ⁄2	100 ⁄2	100 ⁄3
		KE1-3	79 (216)	73	13	2 4 (33 8)	85	15.9 (166.2)	5.6	6	8.5		100			
	Shira-mizugoe	KE1-1	79	63	3			0	0.02	▲10	8.3		0			
② 1982 –1984	Ginvu	KE1-4	75 (216)	69	9	4.0 (37.2)	93	26.5 (185.0)	1 4 / 0.7	1 / ▲3	8.8		100	40 ⁄2.5	61 ⁄4.5	43 ⁄8.5
		KE1-5	98 (216)	75	15	5.2 (25.3)	63	(121 4)	61	10			75			
		KE1-7	216	78	8	42.1	100	178.0		▲10	8.5		100			
		KE1-13	216	74	4	0		0		▲10			0			
		KE1-13S	216	74	4	0		0		▲10			0			
	Shira-mizugoe	KE1-6	98	＊69	9	0		0	0.05	▲10	8.3		0			
		KE1-9	216	75	5	15.0	38	51.0	3.3	▲2	2.9	▲50	0			
		KE1-11	216	86	16	57.4 >	100	255.4 >	>10	5	2.4	▲50	71			
	Yamanjo	KE1-15	98	＊90	30	0		-		▲10			20			
③ 1985 –1987	Ginyu	KE1-17	216	73	3	40.0	100	211.0	90	10	8.7		100	86 ⁄3.5	59 ⁄5.5	59 ⁄5.5
		KE1-19	216	＊72	2	0		0	1.6	▲3			0			
		KE1-19S	158 (216)	70	0	12.8 (40.1)	100	66.8 (210.0)	98	10	8.7		100			
		KE1-21	216	＊72	2	8 6	22	4.8	3.2	▲2	7.9		22			
		KE1-22	216	76	6	40.4	100	213.0	68	10	8.7		100			
		KE1-23	216	69	▲1	0		0	0.9	▲10	8.3		0			
④ 1990 –1991	Ogiri	NT-A2	216	＊70	0	38.6	97	194.0	112	10	8.8		100	88 ⁄8.0	88 ⁄8.0	88 ⁄8.0
		NT-A3	216	＊72	2	38.1	95	185.8	134	10	8.8		100			
		NT-A4	216	＊69	▲1	35.1	88	183.7	49	10	8.7		97			
		NT-B1F	216	＊72	2	0		0		▲10			0			
		NT-B1	216	＊71	1	37.3	93	196.1	352	10	8.8		100			
		NT-B2F	216	＊72	2	0		0		▲10			0			
		NT-B2	216	＊73	3	38.1	95	198.1	87	10	8.8		100			
		NT-B3	216	72	2	35.2	88	177.8	49	10	8.7		100			
		NT-B4	216	73	3	37.3	93	176.8	20	10	8.6		100			

Note 1. Ogiri is inside of Ginyu Area. where well nam KE1-2, 7, 17, 19, 19S, 22 and NT-A2～B4 is located

2. Well Name KE1-13S, 19S and NT-B1, B2 are side track wells.

3. Activity Index ＊N is caluculated bv fluid inclusion temperature.

Table 6 Achievement table of Reinjection Wells

No. Stage Year	Area Name	Well Name	Well Diameter (mm)	Depth (m)	Maximum Temperatuture (℃): Actual Mesurement	Fluid Inclusion	Reinjection Capacity: Volume (m³/hr)	kh (Dm)	Each Well A.W	Each Stage A.W.
② 1982 –1984	Ginyu	KE1-8	216	601	154.2		30	3.3	15	60
		KE1-14	270	809	162.2		400	16	100	
	Shira-mizugoe	KE1-10	98	602	88.6		306		100	
		KE1-12	216	483	32.5		52	17	26	
③1985～1987	Ginyu	KE1-18	216	905	116.0		160	3.6	80	80
④ 1990 –1991	Ogiri	NT-D3	216	1,003	137.1	135.9	240		100	92
		NT-D4	216	1,053	155.0	145.8	330		100	
		NT-D5	216	1,250	214.9		550		100	
		NT-E1	216	1,074	92.8	110.5	139		70	
		NT-E2	216	1,181	106.0	115.2	153		77	
		NT-E3	216	1,278	61.6		330		100	
		NT-E4	216	1,257	115.5		560		100	

6.2 Progress of Achievement

Classification was made by each type of wells and survey stages. Progress is shown in next Figures.

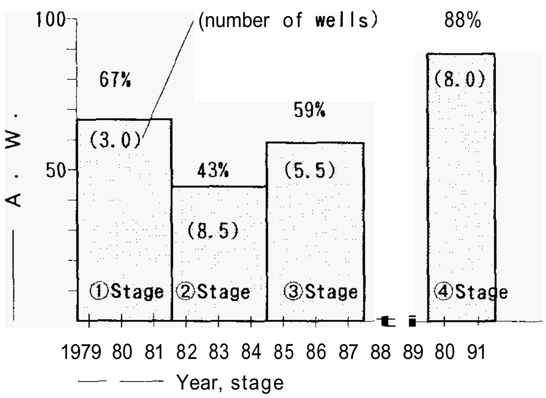

Figure 2. Progress of A. W. in all Production Wells [Kirishima Field]

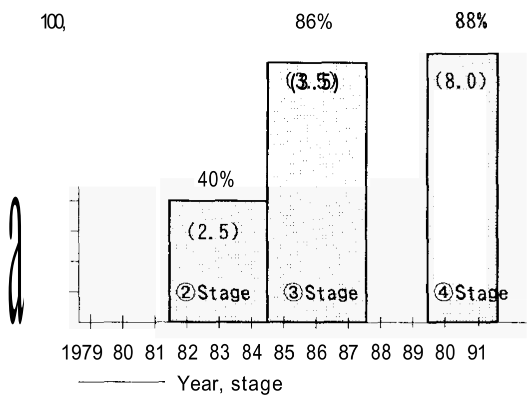

Figure 3. Progress of A.W. in Production-size, Production Wells [Ogiri Areal

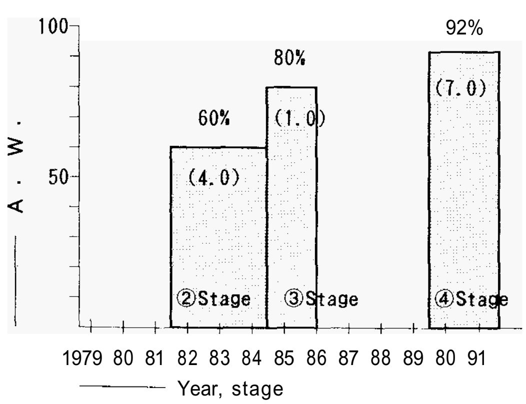

Figure 4. Progress of A.W. in all Reinjection Wells [Kirishima Field]

7. Discussions and Conclusions

Geothermal resources, similar to all underground resources, are characterized by the geological conditions of each area.

At Kirrshima Geothermal Field, we have carried out the development of resources of the area, using achievement as an index for evaluating the result of all stages from planning, exploration, exploitation to development.

We attained good A.W. results in our project, they were 88—92 %. After drilling, we have a capacity in reserve for production and reinjection compared with the provision scale of 30 MW. Now we are in construction stages and will be in operation in the middle of 1996.

The drilling target at Kirishima Geothermal Field is clear. Target area consists mainly of fracture type geo-thermal reservoir. We have a clear understanding of relevant faults and fractures and we have delineated the target of our development to Ginyu Fault. We were able to complete drilling successfully under favourable conditions within the original schedule.

In order to improve the Achievement ratio of drilling wells [A. W.] for geothermal development, our experiences indicate the importance of the following problems.

1) .Improvement of surface survey accuracy.
2) Improvement of test drilling.
3) Acquisition and careful analysis before drilling of the technical information, not only for the target area but also for the vicinity.
4) Maintaining a high technical level of drilling.

In this paper, we reported the satisfactory results obtained by the control system using A. W. index in drilling wells.

In the operational stages, productivity control system will be necessary for drilling supply wells and maintaining the production capacity. We plan to study productivity control system by such as [P. I.] productivity index at our Kirishima Geothermal Field in the near future.

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9. References

* in Japanese with English abstracts
** in Japanese

- Hayashi, M., Taguchi, S. and Yamasaki, T. (1981), Activity Index and Thermal History of Gethermal Systems. Geoth. Resources Council, Transactions. 5, 177-180.
- Ishii, K., (1990), Present State of Otake, Hatchobaru Power Plant and a View of Geothermal Development in Kyushu Island, Japan. Chinetsu. J. G. E. A. Vol 27, No.3 Ser. No. 113 pp 37, 38. **
- Kodama, M., Nakajima, T., (1983), Exploration and Exploitation of the Kirishima Geothermal Field. Chinetsu, J. G. E. A. Vol. 25 No. 3, Ser. 103 pp 201 — 230 *
- Kodama, M., (1991), Improvement of Success Ratio of Drilling Wells. Geothermal Development Seminar for Managers. Text Book of N. E. F. PP 2-13 — 2-47 **
- Kodama. M., Gokou. K., (1992), Achievement of Drilling Wells in the Kirishima Geothermal Field. 1992 Annual Meeting, Geothermal Research Society of Japan(G. R. S. J.) 8-35. **
- Matsuda, N., (1991), Cost Estimation for Model Case of Geothermal Energy (Electrical)Development. Geothermal Development Seminar for Managers. Text Book of N E. F. pp 9-1.9-16.31 1,326. **
- Tachimori, M., (1982), Description of Reservoir Simulator 「NSC GREATS」.