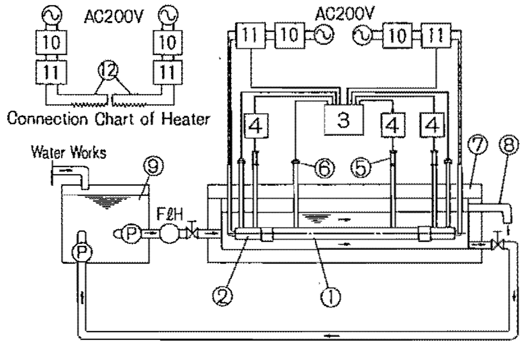

1: Test pipe (heater inserted)
2: Insulating cap
3: Recorder
4: Vacuum gauge
5: Vacuum gauge head
6: 8T current terminal
7: Insulated water tank
8: Over flow pipe
9: Constant temperature water bath
10: Stable power supply
11: Wattmeter
12: Heater

Fig. 4 Experimental apparatus

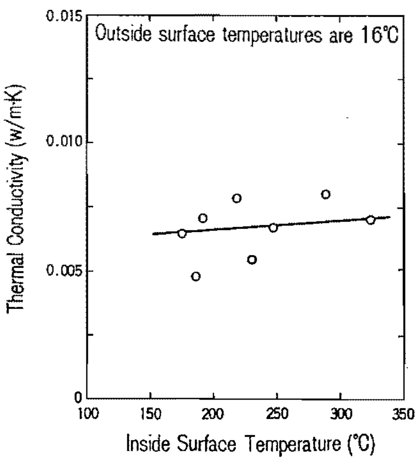

Fig. 5 Thermal conductivity of insulating layer

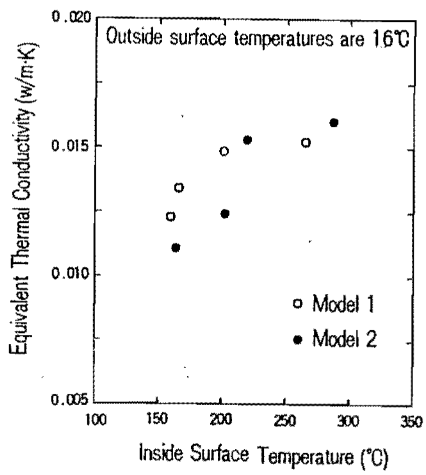

Fig.g. 6 Equivalent thermal conductivity of entire pipe (Model 1, Model 2)

Figure 6 shows values of equivalent thermal conductivity of entire pipe for Model 1 and Model 2. The values of the equivalent thermal conductivity increase as the temperature rises resulting in lower thermal insulation. The values of equivalent thermal conductivity of Model 1 and Model 2 are found to be about 0.017 W/(m·K) even in case the temperature of inside surface is 300°C. It is confirmed that the prototype models have sufficient high-heat insulating performance for the insulated inner pipe of the downhole coaxial heat exchanger.

6. CONCLUSION

Values of the equivalent thermal conductivity of the prototype models of insulated inner pipe are estimated to be 0.017 W/(m·K) at the inside surface temperature of 300°C, assuring sufficiently high thermal insulating performance. However, the corrosion resistance and strength of these models are evaluated prior to applying them to field experiments. Authors will investigate more about the above-mentioned points and plan to produce final models in 1989.

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DESIGNS OF WELLS AND SURFACE FACILITIES - PRELIMINARY CONSIDERATIONS FOR POWER GENERATION USING A DOWNHOLE COAXIAL HEAT EXCHANGER SYSTEM (III)

YAMADA, Y., Sumitomo Metal Industries, Ltd., Tokyo 100, Japan
TAGUCHI, Y., Kawasaki Steel, Corp., Tokyo 100, Japan
YAMAOKA, K., Mitsui Engineering & Ship Building Co., Ltd., Tokyo 104, Japan
FUJITA, T., Kawasaki Steel Corp., Naganuma-Cho, Chiba 281, Japan
MORITA, K., National Research Institute for Pollution and Resources, Onogawa, Tsukuba 305, Japan

1. INTRODUCTION

A unique system, as illustrated in Fig.1 and named as Downhole Coaxial Heat Exchanger (DCHE) System, to extract geothermal energy is proposed. Heat extraction medium (water) is heated during its downward flowing through annulus and flows up via insulated inner pipe without cooling down by downward flowing water as well as lower temperature formation at upper zone. The system is featured with (1) no pollutant emission, (2) minimum drilling risk to hit empty (non-productive) well, (3) simple configuration, etc. Details of the DCHE system and its anticipated performance are introduced by Morita and Sugimoto (1988), where the Effective Thermal Conductivity of the formation was assumed to be 2.7, 10, 20 and 30 kcal/mhK (hereinafter referred to as Cases 1, 2, 3 and 4, respectively). One of the possible utilizations of the extracted heat by the DCHE would be power generation, of which the authors studied techno-economical feasibility. Combination of the DCHE with Biphase turbine and steam turbine system is selected to convert the extracted thermal energy to electrical energy efficiently, since the turbine is fed with liquid phase hot water at saturation pressure, but not super heated steam. The principle and the most effective combination of the consisting unit systems are discussed by Sugimoto and Morita (1988).

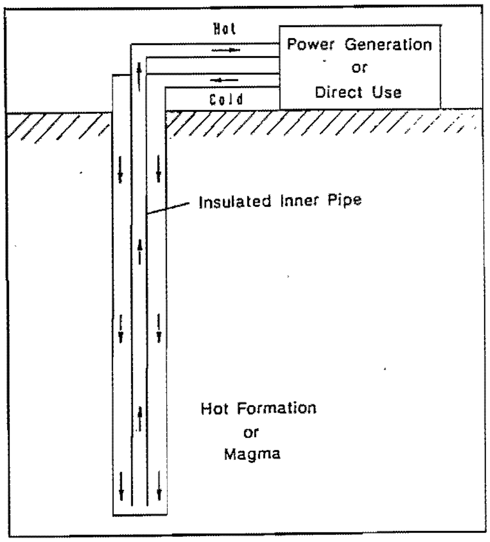

Fig.1 Concept of the Downhole Coaxial Heat Exchanger System

Design parameters of the plants to be considered in this report are summarized in Table 1, which consist of 15 DCHEs and one power generation plant. The design of the DCHEs and the surface facilities of the above mentioned system, which are basic information for the economic analysis (Fujita, T. et al., 1988), are described in this paper.

2. INSULATED INNER PIPE

Several insulation technologies are available in the world, but the DCHE requires the properties below:

1) The overall thermal conductivity of the inner pipe should sufficiently be low, since the heat extraction efficiency of the DCHE is greatly influenced by the insulation property.
2) The coupling should follow the API standard, since the inner pipes will be installed using

Table 1 Specified Design Parameters of the Plant

Cases		1	2	3	4
Water flow rate	(t/h)	180	540	1,080	1,260
Injection water temperature	(°C)	90	90	90	80
Injection water pressure	(kgf/cm^2-abs)	1.24	13.36	44.02	61.21
Produced hot water temperature	(°C)	192.5	201.4	198.6	212.2
Produced hot water pressure	(kgf/cm^2-abs)	13.53	17.22	16.13	20.38
Gross power generation	(MW)	3.46	12.84	25.71	37.28
House use power	(MW)	0.43	1.61	4.38	6.57
House use ratio	(%)	12.6	12.6	16.9	17.6
Net power generation	(MW)	3.02	11.24	21.36	30.71

drilling rig, where all of the devices follow API standards.

3) A sufficient mechanical strength is needed at the great temperature difference between fluids in the annulus and inner pipe.
4) Small wall thickness is expected to provide maximum cross section area for fluid flow, since the fluid friction determines power requirement of the total system.
5) Sufficient hanging strength and flatness of the pipe are required for the smooth handling of the pipes.

Double tubular vacuum insulation pipe has a potential to fulfill those requirements, which is commercially utilized for the steam injection to enhance oil recovery. An example of the structure of insulated tubing for steam injection is illustrated in Fig.2. The standard sizes of the insulated tubulars are listed in Table 2. The overall thermal conductivity using vacuum insulated technology is 0.010 to 0.025 kcal/mhK. They have been practically utilized at the temperature up to 370°C. Mechanical and thermal properties of those insulated pipes are also attractive to the DCHE and their commercial experiences in oil well can also be employed.

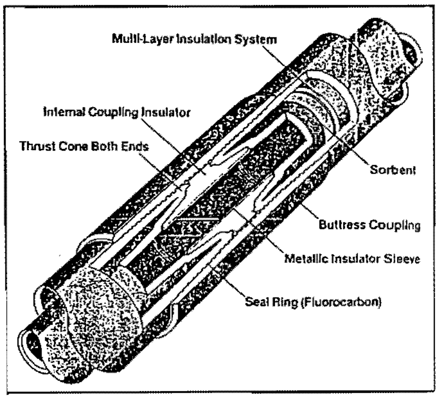

Fig.2 Configuration of Typical Insulated Tubulars for Oil Well Steam Injection

Table 2 Typical Insulated Tubulars for Oil Well Steam Injection

Nominal size	(inch)						
Outer tube		3.5	4.5	4.5	4.5	5.0	5.0
Inner tube		2.375	2.375	2.875	3.5	2.875	3.5
Total weight	(kg/m)	20.56	24.14	26.82	28.91	28.91	30.99
Length	(m)	11.6 - 12.8					
Outer tubular							
Grade		API spec.5CT Grade K55					
Wall thickness	(mm)	6.45	6.35	6.35	6.35	6.43	6.43
Outer diameter	(mm)	88.9	114.3	114.3	114.3	127.0	127.0
Coupling		API 5A, Buttless Casing Thread, K55					
Inner tubular							
Grade		N80	N80	N80	J55/N80	N80	J55/N80
Wall thickness	(mm)	4.83	4.83	5.51	5.49	5.51	5.49
Inner diameter	(mm)	50.7	50.7	62.0	77.9	62.0	77.9
Typical applications		Depth : 1,500 m					
		Operating temperature : 355 °C					
		Operating pressure : Well head : 180 kgf/cm^2; Down hole : 210 kgf/cm^2					
		Thermal conductivity : 0.01 - 0.025 kcal/mhK					

3. DESIGN OF DOWNHOLE COAXIAL HEAT EXCHANGER

Designed dimensions and materials of the casing and inner pipe are illustrated in Fig.3. Hydro sulfide as well as carbonate ion may exist in geothermal fluid which attacks casing material. Casing of conventional geothermal wells is normally constructed by carbon steel but anti-corrosive duplex stainless steel is proposed for the DCHE as the material of casing at deeper zone to minimize the corrosion ensuring its feature of indirect heat extraction. Titanium alloy might be required at more severe conditions. The thinnest casing pipe is selected from the standard sizes, since the casing is always filled with pressurized water which does not cause collapse stress.

Heat extraction medium of the DCHE is clean water which is pre-treated and is partially blown out to avoid increase of dissolved material, so that the solute does not deposit on the wall of heat exchanger or other equipment. Furthermore the water is continuously degassed to avoid oxidation attack to the materials. Therefore, the inner pipe is not exposed to corrosive fluid, and a normal steel can be employed. The temperature distribution in the DCHE, as shown in Fig. 4 (for the Case 3), leads to strict thermal stress at the well head level, where hanging stress is also the most severe. The dimensions of inner pipe for this consideration is selected from commercially available sizes, taking above factors into account, as to minimize pressure loss through the DCHE. The stress concentrates at both ends of unit pipe where outer and inner tubulars are welded together. Further detail stress analysis is required to finalize the pipe design.

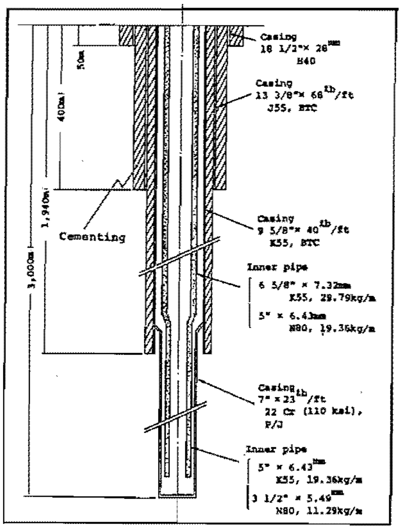

Fig.3 Casing and Inner Pipe Program

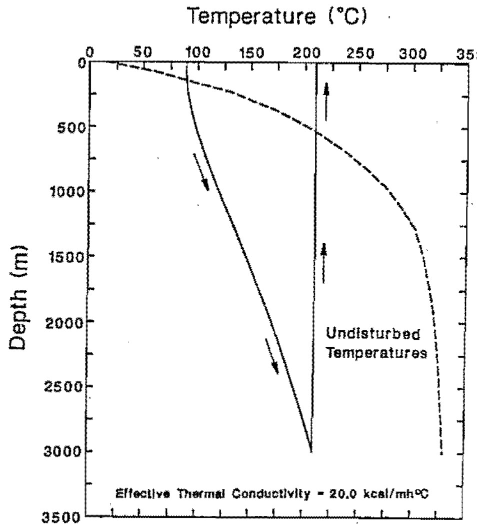

Fig.4 Temperature Distribution in the Heat Exchanger

4. DISTANCE BETWEEN DCHEs

After certain period of heat extraction, temperature profile in the formation must differ from the original undisturbed one. An example of estimated temperature profile at the level of the bottom of DCHE after 15 years heat extraction, for the case 3, is illustrated in Fig. 5. An "Affected Area", where the temperature is lower than original undisturbed temperature by more than 1°C, is defined. Distance between DCHEs was specified to be the same as the diameter of the "Affected Area". Those are 138m, 254m, 358m and 420m for the cases of 1, 2, 3 and 4, respectively.

Above temperature profile was estimated based on a simple conduction mechanism. The temperature profile, however, must depend on heat transfer mechanism. If phase change of the geothermal fluid is dominant mechanism, the "Affected Area" will much smaller than that estimated hereinabove.

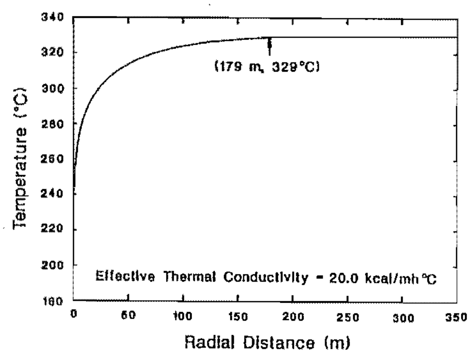

Fig.5 Estimated Temperature Distribution after 15 Years Heat Extraction

5. PLANT LAYOUT

Fifteen DCHEs are arranged as illustrated in Fig. 6, where each DCHE is connected with power plant by an independent pair of pipings for reinjection and hot water transportation. To minimize total length of piping, power generation plant is located at the center of the field. Required land areas for 4 cases based on those arrangement are listed in Table 3. The pipings are lined on the ground surface and lagged with calcium silicate. Pipings are designed as listed in Table 4.

The power plant consists of one unit of Biphase turbine, steam turbine, power generator, transformer, condenser as well as cooling tower, and 15 units of reinjection pumps for each

Table 3 Required Land Area (x $1,000m^2$)

Cases	Case 1	Case 2	Case 3	Case 4
Power plant	2.5	6.8	15.6	18.2
Total	260.0	630.0	1,160.0	1,630.0