SIMULATING EFFECT OF INSULATED DRILLPIPE ON DOWNHOLE TEMPERATURE IN SUPERCRITICAL GEOTHERMAL WELL DRILLING

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ABSTRACT

A research and development project on supercritical geothermal power generation technology, in which the exploratory drilling project is known as the Japan Beyond-Brittle Project (JBBP), is in progress in Japan. To design the first exploration well, which is planned to be drilled in a few years, we are studying a down-hole cooling strategy by mud circulation during drilling, casing running, cementing and completion operations. Because the drilling site is not yet determined, numerical simulations were conducted for subsurface conditions based on the Kakkonda WD-1a well, the world first super-hot geothermal well over 500°C previously drilled in Japan.

In this study, we focused on the effect of insulated drill pipe on down-hole temperature during drilling with drilling fluid circulation. It was found that the combination or configuration of insulated and normal drill pipes had considerable influences on the down-hole temperature profiles as well as the thermal performance of insulated drill pipe itself. The optimum insulated drill pipe configuration and drilling operation condition are discussed based on the results of the numerical simulation studies.

1. INTRODUCTION

Supercritical geothermal systems are unconventional high-temperature geothermal systems in which the reservoir fluid exists in the supercritical condition; the critical point for pure water is at 374°C and 22.1 MPa. In 1995, the world hottest geothermal exploration well at the day, Kakkonda WD-1a, was drilled in Japan. The maximum bottom-hole temperature of the well was estimated to exceed 500°C. In the second well of the Iceland Deep Drilling Project (IDDP-2) at the Reykjanes geothermal field in Iceland completed in January 2017, the measured bottom-hole temperature was 427°C. In this way, utilization of the high-enthalpy supercritical geothermal resources has been pursued to improve the efficiency and capacity of geothermal power generation as a next generation renewable energy (Figure 1).

In the year 2010, Japanese researchers have proposed a new concept for engineered geothermal systems (EGSs) called the "Japan Beyond-Brittle Project (JBBP)" in which the reservoirs are created in ductile basement formations in which the reservoir fluid is in supercritical condition. Originated in the JBBP project, a national research and development project on supercritical geothermal development is now in progress in Japan (Reinsch et al., 2017).

Figure 1: Ongoing worldwide superhot/supercritical geothermal drilling projects.

The overall temperature limitation of the down-hole tools used for drilling Kakkonda WD-1a well was approximately 150°C. The solution employed at that time was down-hole cooling by continuous mud circulation with a top drive system (Saito et al., 1998). The down-hole temperature was successfully cooled and estimated to be maintained below 200°C combined with high-temperature stable drilling mud and closed-type surface mud cooling systems. Although this technology was not widely used in geothermal well drilling at the time, down-hole cooling by mud circulation is an essential drilling operation for safe and cost effective supercritical geothermal well drilling.

In this study, down-hole temperature profiles during drilling were simulated for a model well in which the formation temperature profile was based on Kakkonda WD-1a well. Based on the simulation studies on various combinations of drilling operation parameters, down-hole cooling strategies in supercritical geothermal drilling using insulated drill pipe technology which was previously developed by Sandia National Laboratory are discussed

2. WELL BORE THERMAL SIMULATOR

The computer code of the well bore temperature simulator GEOTEMP2, which was developed at the Sandia National Laboratory (Wooley, 1979, 1980; Mitchell, 1982; Mondy and Duda, 1984), was modified to deal with arbitrary subsurface formation temperature profiles in supercritical geothermal fields. However, drilling fluids in a supercritical state are not accurately described in the current simulator model.

In the simulator, thermal properties of materials including formation rock, carbon steel, cement, and drilling fluids are defined as shown in Table 1. The temperature dependence of drilling fluid viscosity were considered in GEOTEMP2. The specific heat capacity and thermal conductivity for drilling fluids were calculated as functions of fluid density.

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Table 1: Thermal properties of materials.

Material	Density (kg/m^3)	Specific Heat Capacity (J/kg·K)	Thermal Conductivity (W/m·K)
Formation Rock	2242	1256.04	3.46
Carbon Steel	7849	460.55	45.3
Cement	1666	837.36	0.865
Water[1]	997.73	4184	0.7
Mud	1200		2.9

3. SIMULATION SETUP

Down-hole temperature profiles during drilling were simulated for a model well whose profile was based on the ultrahigh-temperature geothermal exploration well Kakkonda WD-1a shown in Figure 2. The temperature profile follows the boiling point for depth curve up to about 3100 m depth. Below 3100 m where the formation fluid is estimated in critical condition, the formation temperature profile is conduction heat transfer dominant with very high geothermal gradient higher than 20°C/100m.

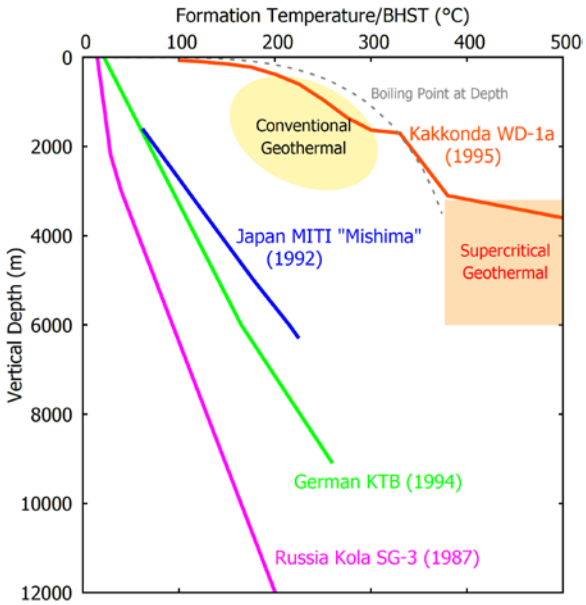


Figure 2: Comparison of subsurface temperature profiles between supercritical geothermal and past ultra-deep wells.

A supercritical geothermal exploration well is modeled as a vertical well with total depth of 4000 m. The casing program planned for the well bore temperature simulation is shown in Figure 3.

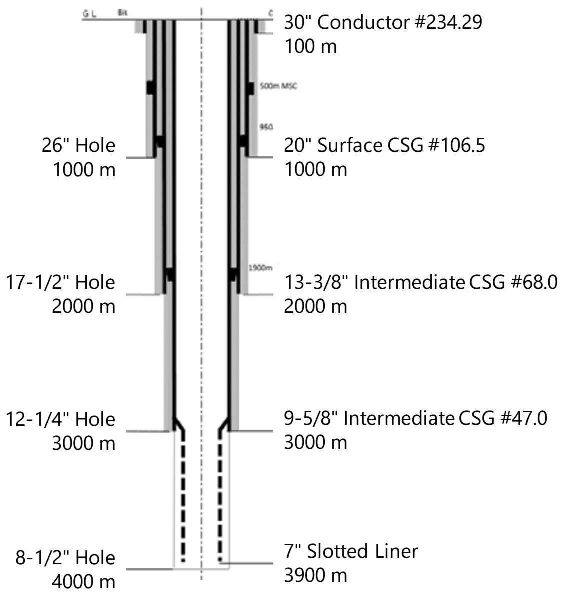


Figure 3: Assumed profile and casing program for simulated supercritical geothermal well.

Drilling parameters were set as follows: two types of drilling fluids, water (1.0 SG, PV=1, YP=0) and mud (1.2 SG, PV=15, YP=5); standard pump rate 2000 L/min (528 gal/min); inlet mud temperature at the surface 40°C; rate of penetration 5 m/hr.

4. RESULTS AND DISCUSSIONS

4.1 Down-hole Cooling during Drilling with Conventional Drill pipe

Figure 4 shows the simulated well bore temperature profiles during drilling 12 1/4-in. hole section from 2500 to 3000 m. In this section, the formation temperatures are below critical temperature of drilling fluid and its profile represents typical conventional high temperature geothermal field. The bottom-hole temperature does not exceed approximately 200°C in static drilling condition.

This result explains that conventional high temperature geothermal wells can be drilled by use of conventional drilling technologies, equipment and materials with adequate surface mud cooling systems. As for drilling fluid, weighted mud that has some solid content and viscosity, is more effective for down-hole cooling than water because of the differences in their thermal properties.

1 Ambient temperature 22°C.

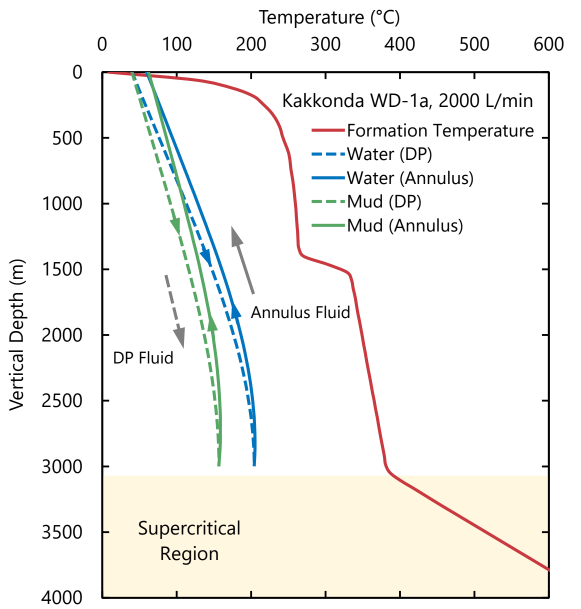
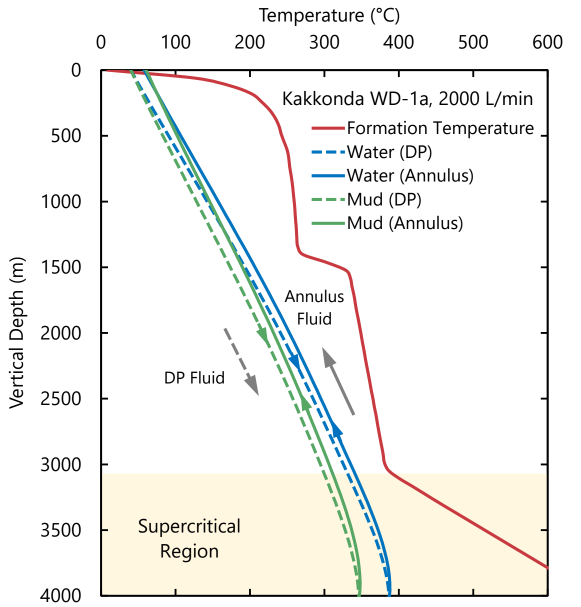
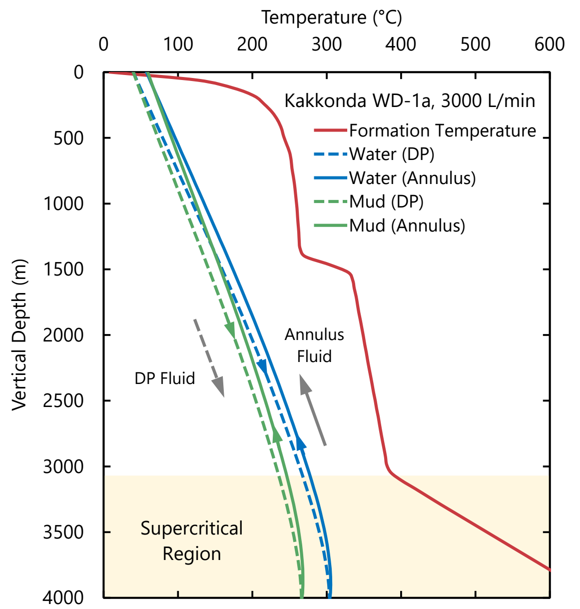


Figure 4: Simulated well bore temperature profiles during drilling 12-1/4 in. hole section from 2500 to 3000 m.

Figure 5 shows the simulated well bore temperature profiles during drilling 8 1/2-in. hole section from 3500 to TD 4000 m. The situation is similar to the actual drilling condition of past Kakkonda WD-1a well. The bottom-hole temperature in drilling with water exceeds critical temperatures while the bottomhole temperature with mud is approximately 350°C.



(a) Pump Rate: 2000 L/min



(b) Pump Rate: 3000 L/min

Figure 5: Simulated wellbore temperature profiles during drilling 8-1/2 in. hole section from 3500 to TD 4000 m.

Because there are no water base muds or drilling additives which resist temperatures above 300°C, water is the first and may be the only choice for drilling fluid during drilling this section. However, from the aspect of effects on bottom-hole cooling, weighted mud may be considered as a drilling fluid instead of water. Moreover, the bottom-hole temperature still exceeds 250°C even at the higher pump rates of 3000 L/min. Emerging technologies should be developed for deep supercritical geothermal drilling.

4.2 Effect of Insulated Drill pipe for Supercritical Geothermal Well Drilling

As shown in the previous section, it seems to be difficult to drill in supercritical conduction heat transfer dominant formation with very high geothermal gradient using conventional bottom-hole cooling technique by mud circulation. Additional efforts to sufficiently cool the downhole may be needed.

Sandia National Laboratory in collaboration with Drill Cool Systems Inc. has developed insulated drillpipe (IDP). The insulated drillpipe allow much cooler drilling fluid to reach the bottom-hole, making possible the use of conventional downhole tools and equipment (Finger et al. 2000, 2002). The schematic of the insulated drill pipe is shown in Figure 6. The insulated drill pipe is constructed by welding a 3.5-in. OD by 3.068-in. ID steel liner tube inside conventional 5-in. drillpipe, and filling the annulus between the tubulars with an insulated material.

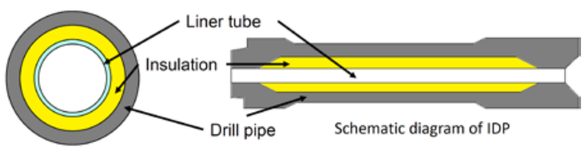


Figure 6: Schematic of a unit length of insulated drillpipe.

In an actual insulated drill pipe drill string, the tool joints (threaded connections) on the both ends of each pipe are not insulated. Finger et al. (2000, 2002) obtained overall effective thermal conductivity for a complete drillstring as summarized in Table 2.

Table 2: Properties of conventional and insulated 5-in. drill pipes.

5-in. Drill pipe	Inner Diameter (in.)	Overall Effective Thermal Conductivity (W/m·K)
Conventional (19.5 lb/ft)	4.276	45.3
Insulated (33 lb/ft)	3.068	3.12

Using the above disscussed thermal properties of insulated drillpipe, wellbore temperature simulation was conducted for drilling 8 1/2-in. hole section of the supercritical geothermal model well from 3500 to TD 4000 m. As the simulation result is shown in Figure 7, down-hole temperature was largely lowered to less than 100°C despite the high geothermal gradient in supercritical geothermal region.

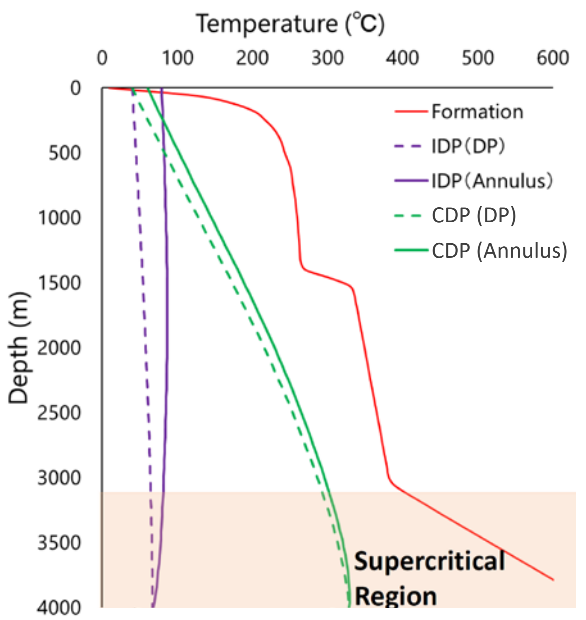


Figure 7: Comparison of simulated well bore temperature profiles with insulated (IDP) and conventional (CDP) drill pipes.

Although Finger et al. (2000, 2002) have evaluated the insulated drill pipe performance for down-hole cooling as an example calculation are shown in Figure 8, simulation study for drilling geothermal formation with higher temperatures than critical temperature of water has not yet been conducted. Our simulation results indicate that use of insulated drill pipe is a valid option for down-hole cooling in drilling deep supercritical geothermal wells.

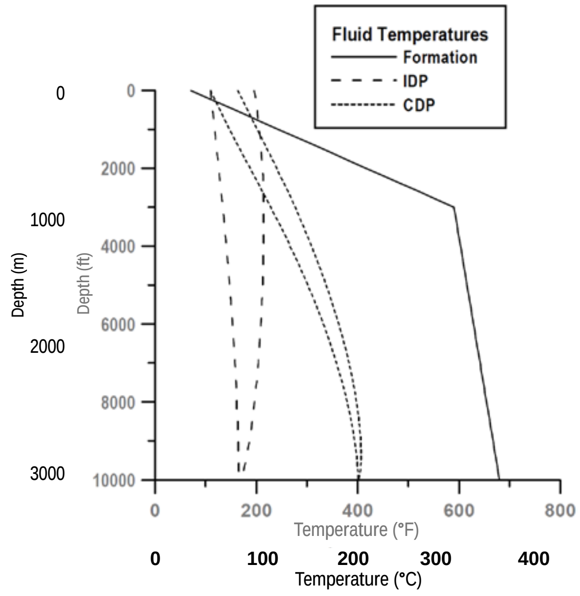


Figure 8: Comparison of calculated temperatures in IDP and CDP (from Finger et al., 2002).

To confirm the effect of insulation in drill pipe, we also conducted wellbore temperature simulation to compare with conventional drill pipe with small inner diameter same as insulated drill pipe (3.068 in.). The result is shown in Figure 9. With smaller diameter than normal conventional drill pipe, the velocity of drilling fluid flowing inside the drill pipe becomes higher than normal one. As seen in the figure, reduction of inner diameter of drill pipe itself has an effect of down-hole cooling. However, approximately 60% of down-hole cooling effect is considered to be acheived by the insulation material filled in the tubular annulus of the insulated drill pipe.

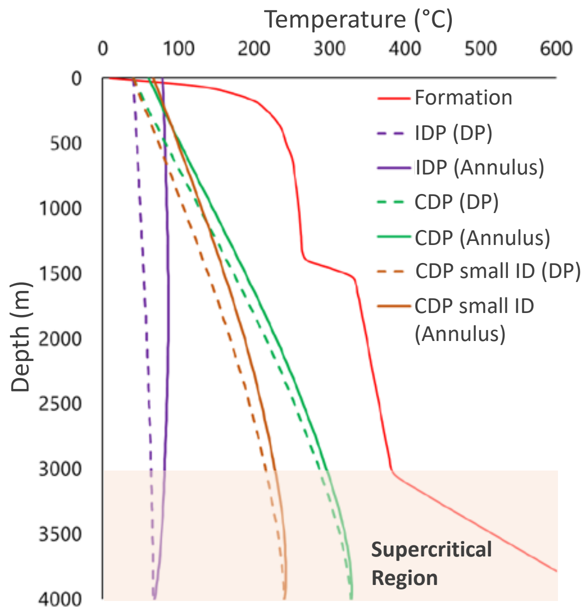


Figure 9: Comparison of simulated wellbore temperature profiles with insulated (IDP), conventional (CDP) and small ID conventional drillpipes.

Because the insulated drill pipe (approx. 33 lb/ft) is hevier than conventional drillpipe (19.5 lb/ft), drill string weight could be a problem in deeper wells for this supercritical geothermal project (Finger et al., 2000, 2002). Thus, the cooling effect of drill string partly using insulated drill pipes combined with conventional drill pipes is studied to reduce the drillstring weight.

Figure 10 shows the comparison of downhole cooling effect with three different insulated drill pipe configurations; case with full insulated drill pipe, case with insulated drill pipe at lower half of total drill string, case with insulated drill pipe at upper half of total drill string.

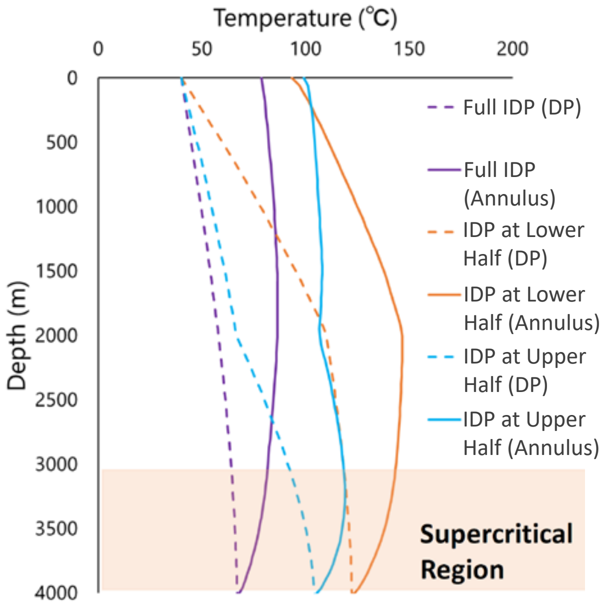


Figure 10: Simulated wellbore temperature profiles with different insulated drillpipe configurations.

The result shows that the drill strings with combination of insulated drill pipe and conventional drill pipe have sufficient down-hole cooling effect. Down-hole temperature for both cases of combination drill string were lowered to less than 150°C during drilling in supercritical geothermal reservoir. The case using insulated drillpipe at upper half of total drill string have better effect on down-hole cooling than the case using insulated drill pipe at lower half.

Although we have obtained an information from an insulated pipe supplyer that insulated drill collar can be available by custom-building, it will not be realistic to use insulated drill collar because of other operating requirements like hydraulics, hook load etc. The simulation results indicated that it is not problem to use conventional drill collar for deep supercritical geothermal well drilling.

In addition, the combination drillstring have advantage of drilling cost reduction when using insulated drill pipe for powerfull down-hole cooling effect.

5. CONCLUSION

In this study, downhole temperature profiles during drilling and cementing operations were simulated for a model well in which the formation temperature was based on the ultrahigh-temperature geothermal exploration well Kakkonda WD-1a.

- It was confirmed that conventional high temperature geothermal well can be drilled by use of conventional drilling technologies, equipment and materials with adequate surface mud cooling systems.
- Deep supercritical geothermal drilling is especially harsh even without including the effects of high geothermal gradients in the supercritical formation. Emerging technologies like insulated drill pipe may be needed for deep supercritical geothermal drilling.
- By using full insulated drill string, downhole temperature was largely lowered to less than 100°C despite the high geothermal gradient in supercritical geothermal region. Use of insulated drill pipe is a valid option for downhole cooling in drilling deep supercritical geothermal wells.
- Combination drill string with conventional and insulated drill pipes provides sufficient downhole cooling effect compared to full insulated drill string.
- It is not problem to use conventional drill collar for the combination drill string in deep supercritical geothermal well drilling.
- Combination drill string have advantage of drilling cost reduction when using insulated drill pipe for powerfull down-hole cooling effect.

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