Technology to Counter Silica Scaling in Binary Power-Generating System Using Geothermal Hot Water

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ABSTRACT

A geothermal hot water binary power-generating system that uses reinjection hot water from a flash geothermal power-generating system as the heat source is able to draw heat from geothermal fluid efficiently, achieving high economic efficiency. However, there are concerns that cooling of thermal water causes silica scaling to adhere to power-plant equipment and wells. Field tests at the steam production well pad in the Kakkonda Geothermal Power Plant of Tohoku Hydropower & Geothermal Energy Co., Inc. have proven that in thermal water with low silica concentration the speed of silica scaling is not affected by water temperature, because the silica polymerization reaction is halted; thus, practical use of the system is just in sight. Field tests have also proved that intermittent alkaline injection can help to prevent and/or dissolve silica deposits.

1. Introduction

In geothermal power generation, a geothermal fluid containing steam and hot water is extracted from underground and used to generate electricity. This fluid is at a high temperature and high pressure under the ground, many components are, therefore, dissolved in the geothermal fluid, and these components can cause corrosion and scaling on the power generation facilities. In particular, there is a tendency for silica precipitation and scaling to occur when the heat is recovered from the geothermal fluid and the temperature of the fluid falls. The expense of measures to this scaling has a great effect on the economic efficiency of geothermal power generation.

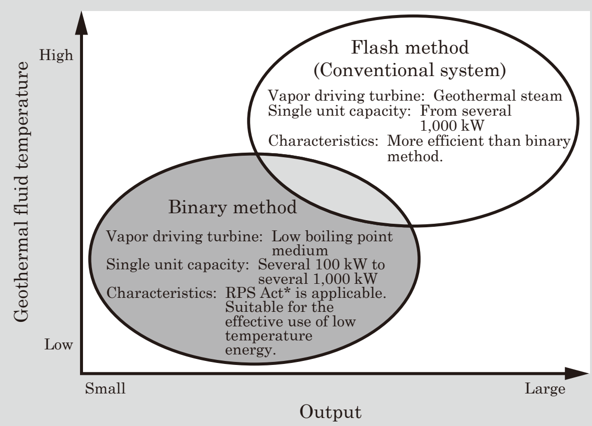
Fuji Electric has worked with the objective of the efficient extraction and utilization of heat from the geothermal fluid to develop measures technologies for the silica scaling that becomes an issue for it. This article particularly introduces the technologies to evaluate the rate of silica scaling and technologies to inhibit and dissolve the silica scale in geothermal hot water binary power-generating systems.

2. Geothermal Hot Water Binary Power-Generating Systems

The methods of geothermal power generation can be broadly categorized into the flash type and the binary type. The flash method uses a separator to separate off just the steam from the mixed fluid of geothermal steam and hot water, which is taken from underground from a well (production well). This steam is then sent to the steam turbine to generate electricity. The binary method uses the geothermal fluid as a heat source. Heat is exchanged with a medium that has a lower boiling point than water, and then the vaporized medium is sent to the turbines to generate the electricity.

High temperature and high pressure geothermal steam are required for the flash method of geothermal power generation, in which Fuji Electric has accumulated great experience so far, and one issue has been the securing of the geothermal resources sufficient for power generation.

Figure 1 shows the concept of the scope of the geothermal power generation systems for different geothermal fluid temperatures and outputs. The flash method is used when the geothermal fluid temperature is high and the output is large, and the binary method is used when the temperature is low and the output is small.



* RPS Act: "Act on Special Measures Concerning New Energy Use by operators of electric utilities"

Fig.1 Scope of geothermal power generation systems

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In order to expand its range of geothermal power generation systems, Fuji Electric has performed development work for the commercialization of binary power-generating systems.[1] Verification testing of a binary power-generating system using geothermal steam with a rated output of 150 kW and a maximum output of 220 kW was carried out between August 2006 and October 2009 with the cooperation of the Daiwabo Kanko Co., Ltd. Kirishima Kokusai Hotel in Kirishima City, Kagoshima Prefecture. The continuous operation was achieved according to the plan. The results of the verification testing were then incorporated and the commercialization was completed.

One of the issues for geothermal power generation is the securing of geothermal heat sources. To extract the geothermal fluid that becomes the heat source for geothermal power generation from underground, it is necessary to target a location that has high temperature and high-pressure water in what is called a reservoir, and to drill a production well. If the geothermal fluid that can be taken from the production well is insufficient, or if the amount of heat or flow of the geothermal fluid declines, then it becomes necessary to add another production well. The heat of the earth is generally thought to be an inexhaustible source of heat, but from the point of view of economic efficiency, it is necessary to regard the geothermal fluid as a limited resource.

Fuji Electric is promoting geothermal hot water binary power-generating systems for the efficient generation of electricity using geothermal fluid. This is the additional installation to existing flash type geothermal power generation systems of a binary power-generating system that uses reinjection hot water as a heat source. It is therefore called hybrid geothermal power generation. Up until now, the reinjection hot water that remained after the separation of the steam from the geothermal fluid was returned to the well (reinjection well) while still at a high temperature but unused. This system uses that water as a heat source. Figure 2 shows a conceptual diagram of geothermal hot water binary power-generating systems.

Geothermal hot water binary power-generating systems are highly economical because they utilize the infrastructure of the existing flash type geothermal power generation system, for example, the site, personnel and power transmission lines. Furthermore, as it is not necessary to drill a new production well, there is low business-related risk that the drilling will fail. However, recovering heat from the reinjection hot water and lowering the temperature of the reinjection hot water often results in silica scaling and measures to this silica scaling are an issue for consideration. Silica sometimes attaches to the pipes and valves above the ground, but it causes the greatest problems when it attaches inside the reinjection well and in the geological strata around it, and in some cases the reinjection well can become blocked. If this occurs, then it becomes necessary to dredge the well or to drill a new one, which harms the business.

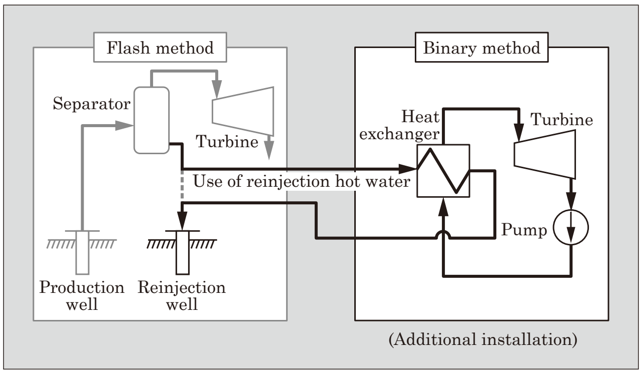


Fig.2 Conceptual diagram of geothermal hot water binary power-generating systems

Fuji Electric considers the problem of silica scaling to be a large risk when using geothermal hot water binary power-generating systems, and has worked to develop technologies for silica scaling measures, in particular technologies to evaluate the speed of scale build up and technologies to inhibit and dissolve the scale.

This development work was carried out with the cooperation of the Tohoku Hydropower & Geothermal Energy Co., Inc. as one part of the feasibility study (FS) carried out for a geothermal hot water binary power-generating system at the steam production well pad in the Kakkonda Geothermal Power Plant. It was joint research with the Tohoku Hydropower & Geothermal Energy Co., Inc., JMC Geothermal Engineering Co., Ltd. and Kyushu University.

3. Technologies to Evaluate the Rate of Silica Scaling

Since the geothermal fluid exists underground in a high temperature and high-pressure state, it dissolves many components. The concentration of the fluid and a drop in temperature occurs when it is taken out of the ground, when it is depressurized and flashed (evaporated) above the ground and when the heat is recovered from the hot water. At this time, silica components in particular reach a concentration above the solubility for amorphous silica, meaning that they reach a supersaturated state, and the more the concentration progresses, and the lower the temperature falls, the more the risk of silica precipitation increases. It is necessary to perform quantitative evaluations before the additional installation of a geothermal hot water binary power-generating system to evaluate whether the installation will aggravate the rate at which the reinjection well becomes blocked and whether that rate is at an acceptable level.

3.1 Mechanism of silica scaling

(1) Characteristics of amorphous silica

When silica precipitates from geothermal hot water, it precipitates in an amorphous state. Amorphous silica grows and precipitates in a polymerization reaction in the silica supersaturation. Therefore, the silica polymerization reaction rate V is the major factor determining the rate of silica precipitation.

The silica polymerization reaction rate V can be simplified and expressed as in Formula (1). The rate increases when the reaction rate constant K increases and when the amorphous silica solubility C_e decreases.

$$V=K\,(C\text{-}C_e)^n \quad \cdots\cdots (1)$$

V : Silica polymerization reaction rate
K : Reaction rate constant
C : Silica concentration
C_e: Amorphous silica solubility
n : Constant (n>0)

K and C_e increase with higher temperatures and with higher pH values. Therefore, the relationship is such that V will have a maximum value for some value of temperature and pH. In typical geothermal hot water, the V increases the lower the temperature falls and the higher the pH becomes.

For this reason, the measures generally taken to prevent silica scaling include to prevent the falling of the reinjection temperature and to add sulfuric acid to lower the pH.

(2) Mechanism of silica scaling at geothermal power plants

It is common for the formation of silica scale to be discussed only in terms of the rate of the polymerization reaction. However, when considering the formation of silica scale within a geothermal power plant, it is necessary to consider the form of the silica at each position in the power plant.

It is often the case that the reinjection well is drilled at a location away from the production well so that the reinjection hot water does not affect the reservoir. It is therefore not unusual for it to take several hours for the hot water to flow from the production well to the reinjection well. It is necessary to evaluate the rate of silica scaling in the reinjection well through comprehensive consideration of issues such as how far the polymerization reaction is progressing, how much precipitation as particles there is and whether or not the silica polymerization reaction is progressing in the hot water.

3.2 Method for evaluating the rate of silica scaling

Silica scaling becomes a problem in the reinjection well and particularly in the geological reservoir around the reinjection well. For this reason, reservoir simulation for silica scaling testing equipment was developed to evaluate the rate of blocking at these points beforehand.

Figure 3 shows the conceptual diagram of the testing equipment and Fig. 4 shows the external appearance of the testing equipment.

The reservoir simulation testing equipment is installed inside a geothermal plant and evaluates the changes in the rate of reinjection well blocking that result from a fall in the hot water temperature. Table 1 shows the correspondence between binary power generation facilities and reservoir simulation testing equipment.

The evaluation of the rate of blocking is performed by monitoring the pressure difference between the entrance to the porous material column and the various points inside the porous material. In addition, the concentration of silica at various positions inside the retention piping is measured to evaluate the rate of silica concentration decline and therefore the rate of the silica polymerization reaction.

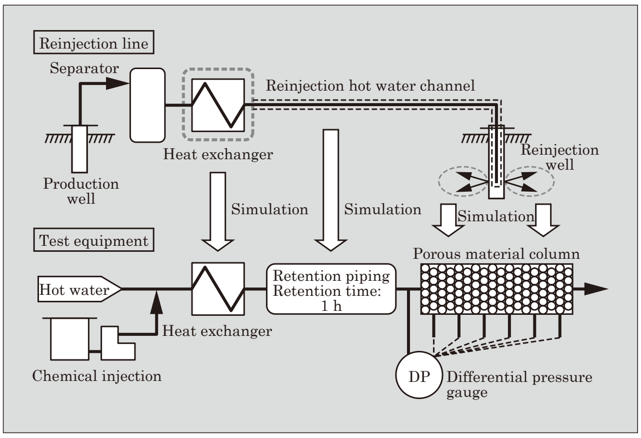


Fig.3 Conceptual diagram of reservoir simulation testing equipment

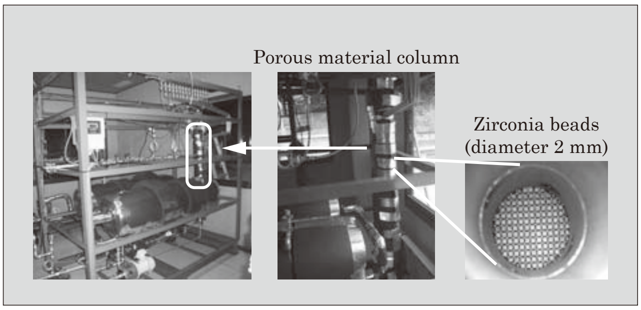


Fig.4 External appearance of the reservoir simulation testing equipment

Table 1 Correspondence between binary power generation facilities and reservoir simulation testing equipment

Binary power generation facilities	Reservoir simulation testing equipment
Heat exchanger	Heat exchanger
Reinjection hot water channel from location of binary power generation facilities to reservoir near to the reinjection well	Retention piping
Reservoir near to reinjection well	Porous material column filled with ceramic beads

3.3 Feasibility study at the steam production well pad in the Kakkonda Geothermal Power Plant

Between July and September, 2011, a FS was implemented for the assessment in advance of the rate of silica scaling that would result if geothermal hot water binary power-generating system facilities were installed at the steam production well pad in the Kakkonda Geothermal Power Plant of Tohoku Hydropower & Geothermal Energy Co., Inc.[(2)]

The water planned to be used in the geothermal hot water binary power-generating system was used to evaluate the rate of silica scaling using reservoir simulation testing equipment. The hot water temperatures used were 120 °C and 95 °C, and the total silica concentration was 435 ppm. It was confirmed that the silica polymerization did not progress when the water was maintained at 120 °C and 95 °C for 1 hour. In other words, it can be said that during this 1 hour, there is no formation of silica particles and no growth of the silica particles that have already formed. This 1 hour simulates the time required for the hot water to flow from the location of the reservoir simulation testing, which is the planned location of the binary power generation facilities, to the geological reservoir around the reinjection well.

The following knowledge about the rate of silica scaling was obtained over the three weeks of reservoir simulation testing.

(a) It is scale in the form of particle aggregation that contributes to the blocking of the reservoir, and the rate of scaling is not dependent on temperature.

(b) It is thought that the reason why the rate of silica scaling is not dependent on temperature is that the main mechanism of the scaling is particle deposition.

(c) The injection of sulfuric acid is generally done to slow the rate of silica polymerization, but it is also thought that it is effective in preventing the attachment of particles.

The test results and the basis for these findings were as shown below.

(1) Temperature dependence of the rate of scaling

Figure 5 shows the amount of silica attachment to the porous material column after the completion of the three-week long testing. It can be seen that there was

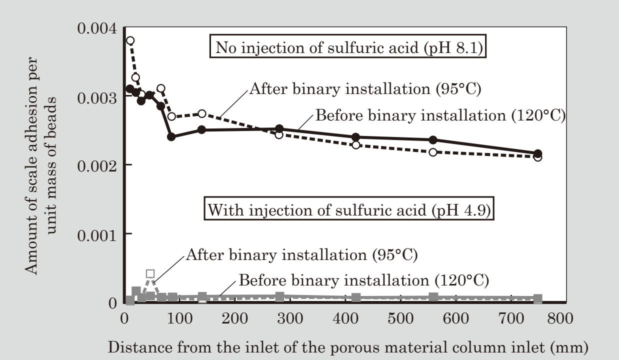
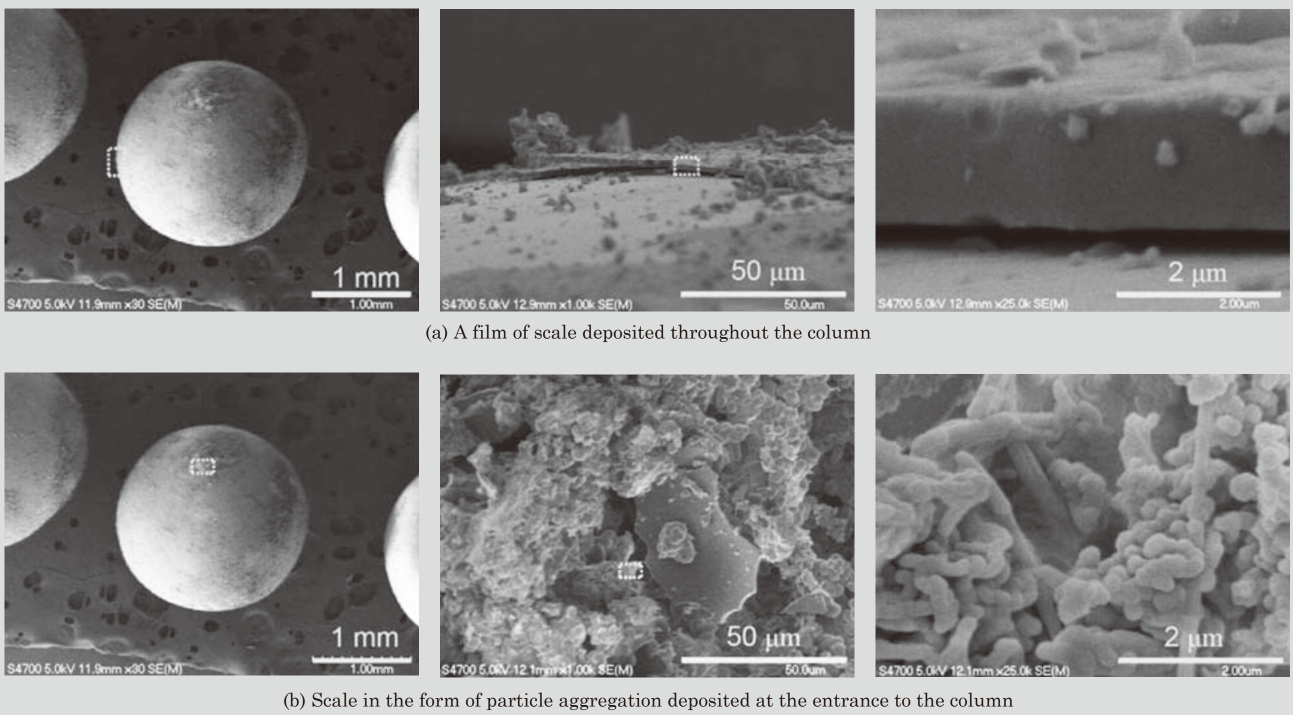


Fig.5 Results of reservoir simulation testing



(a) A film of scale deposited throughout the column

(b) Scale in the form of particle aggregation deposited at the entrance to the column

Fig.6 Electron microscope images of the scaling on the beads no difference in the amount of scale adhesion before and after the hot water temperature reduction (120 °C and 95 °C) in either of the conditions, namely without the injection of sulfuric acid or with it.

Meanwhile, in the conditions of no injection of sulfuric acid, there was increased scaling near the entrance to the column. Figure 6 shows electron microscope images of the scaling in the porous material column. A film of scale was observed on the surface of the beads throughout the entire porous material column. At the inlet to the column, particle aggregation was observed on the surface of the beads. It is thought that the amount of scale deposition is greater at the entrance to the column because the particles in the hot water aggregate together at the entrance to the column and attach to the beads. Furthermore, in the results of the measurement of the water permeability of the porous material column, it was found that the water permeability is mostly reduced around the inlet of the column. It can be said that it is scale in the form of particle aggregation that contributes to the blocking of the reservoir and that the rate of scaling is not dependent on temperature.

(2) Mechanism of scaling

As there is no progression of silica polymerization in the hot water, it is thought that the particles that attached at the entrance to the column were particles that had been formed due to causes other than silica polymerization, for example, particles that were formed in localized concentration of the hot water during the flashing, or particles that came from the production well. It is believed that the rate of scaling was not dependent on the temperature of the hot water because the main factor in the scaling was that these particles attached near the entrance to the column.

(3) Effect of sulfuric acid injection

As shown in Fig. 5, the injection of sulfuric acid greatly reduced the rate of scaling. The injection of sulfuric acid is generally done to slow the rate of silica polymerization, but it is also thought that it is effective in preventing the attachment of particles.

3.4 Possibility of reinjection hot water

The results of the FS at the steam production well pad in the Kakkonda Geothermal Power Plant showed that the rate of the blocking of the geological reservoir is not dependent on temperature. In other words, they show that silica scaling would not become a major problem if a geothermal hot water binary power-generating system is installed. The reinjection hot water for which a geothermal hot water binary power-generating system is used is often hot water that has a low concentration of silica originally, and thus it is often the same conditions as at the steam production well pad in the Kakkonda Geothermal Power Plant. In other words, it is often the case that the silica polymerization stops. Therefore, these results are thought to be relevant generally when geothermal hot water binary power-generating systems are to be used.

Up until now, it has been thought that reducing the temperature of the reinjection hot water would increase the speed of the blocking of the reinjection well. However, it was clarified that within the range of temperatures where the silica polymerization is stopped, if the main mechanism of scaling is the attachment of particles, then there is no change in the rate of the blocking.

4. Technologies to Inhibit and Dissolve Silica Scale

Depending on the nature of the reinjection hot water, it is also conceivable that there may be cases when the rate of blocking of the reinjection well will be aggravated by the use of a geothermal hot water binary power-generating system. Technologies to inhibit and dissolve the silica scale were therefore developed using new methods [3] and verified using reservoir simulation testing equipment.

As described in Chapter 3, it is often the case that sulfuric acid is added to the hot water to inhibit the silica scaling. However, there is concern about the corrosion of piping due to this sulfuric acid injection, the amount that can be injected is, therefore, restricted and the effectiveness in inhibiting scaling is limited.

There have also been other attempts to inhibit the silica scaling through methods such as the retention tank method, where the hot water is retained for a certain amount of time to encourage silica particle growth and lower the adhesiveness of the silica particles. Other methods tried include the injection of a scale inhibitor and the removal of the silica from the hot water. However, these methods cannot be described as generally established technologies due to reasons such as that they are uneconomical or have limited effects depending on the hot water properties.

Fuji Electric therefore focused on the method of alkali injection to inhibit and dissolve the silica scale, which uses the fact that the solubility of silica rises with higher pH levels. This alkali injection has already been considered at some institutions, but has not been put into practical use for mostly the following reasons.

(a) Metal components such as calcium combine with the silica and form scale other than amorphous silica.
(b) The cost of the alkali agent is higher than that of sulfuric acid.

Solutions to these issues were attempted with the following measures and development work was performed to make practical use possible.

(a) Use together with an agent to mask the metal components such as calcium.
(b) Intermittent injection of the agent to reduce the amount used.

Figure 7 shows the scale inhibition results when

Left: Injection of alkali agent only
Center: Joint use of alkali agent and agent to mask calcium
Right: No agent injection

Fig.7 Results in silica scaling inhibition with the alkali injection method

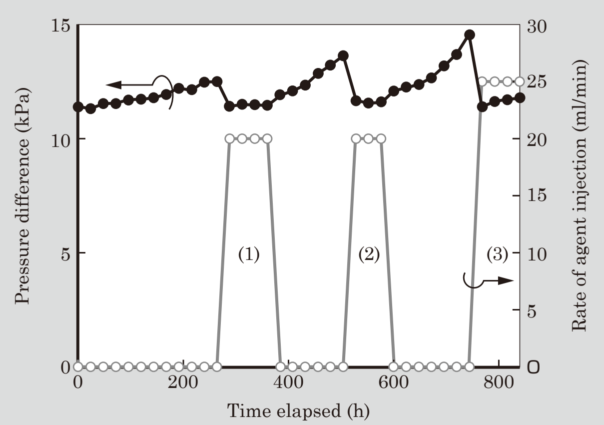


Fig.8 Changes in pressure differences inside the porous material column due to intermittent injection

the alkali injection method is used. If just an alkali agent is injected, then the amount of scaling is greater than when nothing is injected. However, the scaling is suppressed by using an agent to mask the metal components.

Figure 8 shows the changes over time in the pressure differences inside the porous material column when an agent (alkali agent and metal component masking agent) is injected intermittently on reservoir simulation testing equipment. By performing the intermittent injection of the alkali agent (the periods (1), (2) and (3) on the diagram), the pressure differences return to those before the scaling, meaning that the scaling that has attached is dissolved and the water permeability recovers.

5. Postscript

This article discussed measures to silica scaling, which was a major issue for the use of geothermal hot water binary power-generating systems.

Technologies were established to evaluate the rate of silica scaling and to inhibit and dissolve the silica scale and it is believed that the practical use of geothermal hot water binary power-generating systems is now in sight. Fuji Electric will continue development centered on these technologies for the establishment of measures to silica scaling in geothermal hot water binary power-generating systems and further geothermal power generation in general and will contribute to the effective use of geothermal resources.

This development was made possible by the cooperation of the Tohoku Hydropower & Geothermal Energy Co., Inc., for example, in the provision of the field. In addition, this research was performed jointly with Tohoku Hydropower & Geothermal Energy Co., Inc., GMC Geothermal Engineering Co., Ltd., Professor Itoi of the Graduate School of Engineering, Kyushu University and Professor Yokoyama of the Graduate School of Sciences, Kyushu University. We received much valuable advice from them. We would like to express our gratitude here.

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