Long-Term Response of the Tongonan I Geothermal Reservoir, Philippines

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ABSTRACT

The response of the Tongonan I sector of the Tongonan geothermal field during the first 16 years has been monitored to ensure that changes in the field management are introduced to sustain long-term production. Some of the major reservoir problems encountered include reinjection returns to the production wells, mineral depostion and natural reservoir drawdown. Increased enthalpies and well output are observed in most wells in response to the additional 600 MWe load in 1996-1997. The current steam availability of Tongonan I field is much greater than that required to supply the plant.

Introduction

The Tongonan geothermal field (Figure 1) is currently exploited from the following sectors: Upper Mahiao (4x31.8 MWe), Tongonan I (3x37.5 MWe), Malitbog-South Sambaloran (3x77 MWe). South of the field is the Mahanagdong sector (where a 3x60 MWe plant is operating) which is interpreted to be distinct and separate from the main Tongonan geothermal resource. The recent installations are brought about by the liberalization of the power and energy sector paving the way for build-operate-transfer (BOT) companies like the California Energy International (CalEn) to finance and construct these additional power plants. The Philippines is thus able to maintain its second position to the United States in terms of total installed capacity with 1858 MWe (Sarmiento, 1998), and remains on top of those countries utilizing the liquid dominated type of reservoirs.

Before 1996, development of the resource was restricted in the Lower Mahiao-Sambaloran sector which now comprises the Tongonan I geothermal field, where the 112.5 MWe power plant is located. With its variable loading and lack of load demand however, steam supply to the plant is currently averaging only about 50-80 MWe. Its maximum peak load attained was 110 MWe in 1995 and was only for a few hours.

Owing to the more stable performance of Tongonan I from 1983 to 1992, a study by Sarmiento, *et al.* (1993) was conducted on the use of high pressure turbine to optimize the resource and assess the risk on its sustainability in the long term. Thus, the additional 600 MWe turbine units installed in the field in 1996-97 were set to operate at 1.0 to 1.1 MPag at a steam consumption rate of about 2 kg/s-MWe as compared to 0.5 MPag inlet pressure and steam rate of 2.5 kg/s-MWe for Tongonan I.

This paper will deal only with the performance of Tongonan I during the last 16 years of operation, including the last 3 years when the additional 600 MWe plants were commissioned.

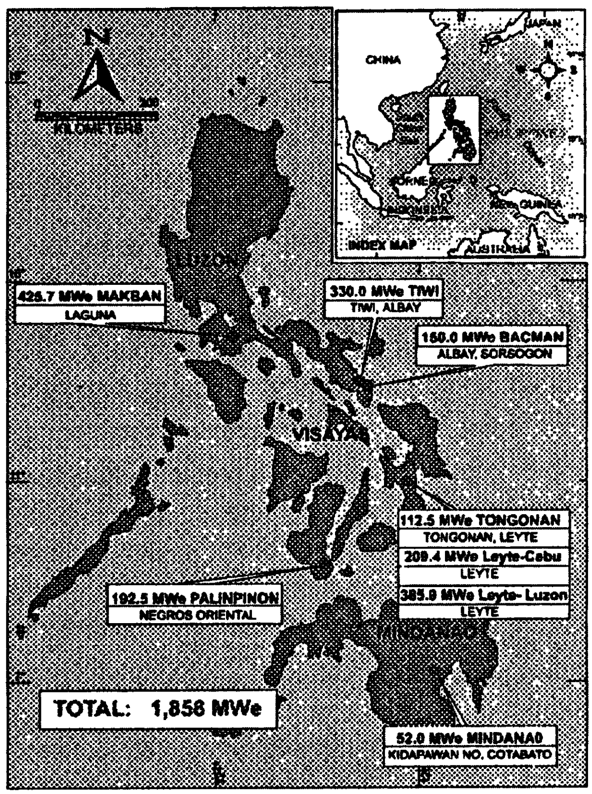

Figure 1. Philippine Geothermal Fields.

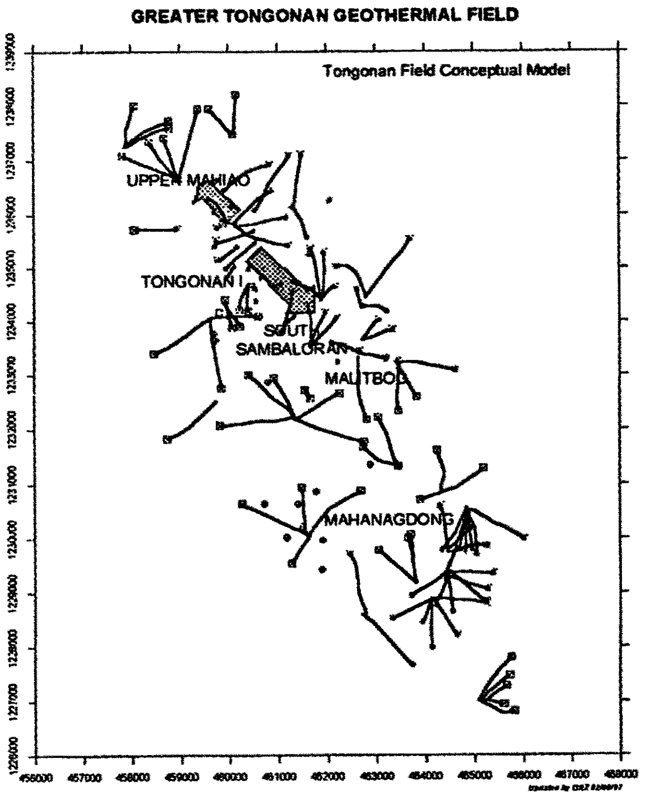

Figure 2a. Location Map and Hydrological Flow.

Reservoir Characteristics

The Tongonan field (Figure 2) is characterised as a high-temperature liquid-dominated reservoir. Temperatures encountered at depths range from 280–350 degrees Centigrade. The main heat source of the geothermal system appears concentrated in the area of numerous splinter faults identified within the eastern and central branches of the Philippine Fault, a major fault going through the archipelago from north to south. Subsurface geology consists basically of andesitic flows, breccias and tuffs, underlain by a variety of intrusives referred to as the Mahiao Plutonic Complex. The reservoir has a distinctive upwelling region that surges vertically at the Mahiao/Sambaloran region and outflows towards the Malitbog and Upper Mahiao regions. In the natural state, the onset of the two-phase zone at deeper levels coincides with the top of the upwelling zone and to some extent to the shallow depths in the outflow zones (Sarmiento *et al*, 1993). Geologic faults control the main permeability in the field with minor contribution from the formation transition zones as well as from the fractured rock matrix. The wells are thus completed with production coming from multiple feed-zones. The wells discharge neutral pH chloride brines with low non-condensible gas concetration (1-2% by weight in steam). Geothermometers also support physical evidences of the upflow in the Mahiao/Sambaloran area.

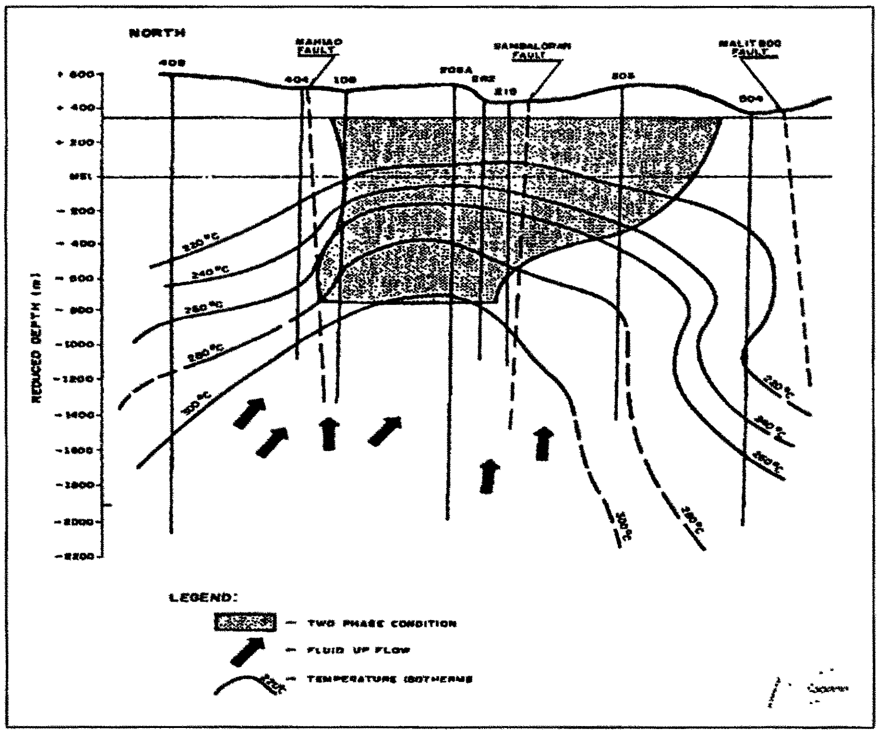

Figure 2b. Tongonan Conceptual Model.

Long-Term Reservoir Responses

Mass Extraction Rates

Figure 3 shows the mass extraction rates for the plant's load and generation. One hundred percent of the wastewater is re-injected back to the formation to dispose of the unspent brine and serve as a pressure support to the reservoir. The percentage of brine in the total mass discharge ranged from 40 to 60% during the initial production period and 10–30% in the high enthalpy sectors.

The projected cumulative generation for Tongonan I is calculated to be 14,125 GWH during the last 15 years assuming full load operation. However, as the plant operates at variable loads and has not really realized the initial projected consumers demand, the total generation only reached 7,824 GWH. Because the plant is not operated efficiently both from the point of view of the steamfield and the power plant, the total estimated generation corresponding to the total mass, water and steam produced approaches 11,000 GWH. The figure is close to the estimated full load generation of the plant. Hence, for 15 years, the Tongonan I plant appears to have been operating at near-full capacity in terms of the total mass witdrawal.

Enthalpy Trend and Field Steam Supply

The experience to date is that there has been some decline in the wells' output in Tongonan with respect to the total mass directly associated with reservoir boiling and chemical and

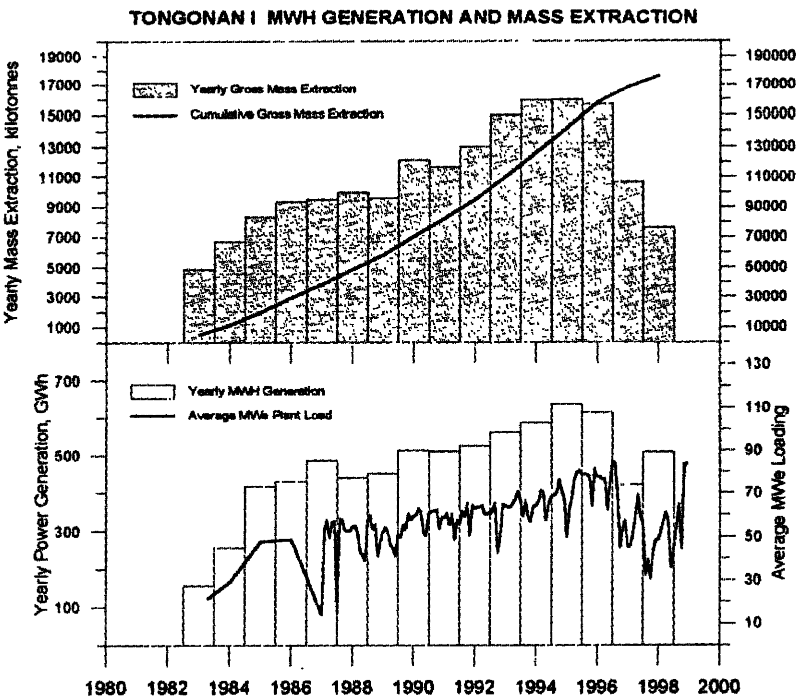

Figure 3. Mass extraction against plant loading for Tongonan 1 field.

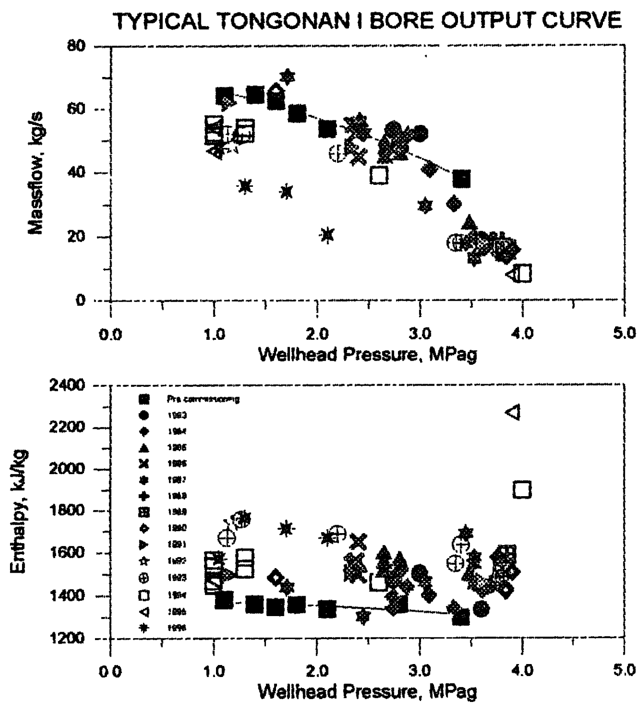

Figure 4. Bore output comparison for pre-commissioning and current data showing minimal change in maximum discharge pressure.

mechanical problems. However, the corresponding increase in enthalpies in the wells' discharges have not diminished the total steam available to the system compared to baseline and has even resulted to an excess capacity.

The expansion of the two-phase fluids in the field results in the discharge of high enthalpy fluids from the top zone in most wells. An increase in enthalpy from 1600 kJ/kg to 2600 kJ/kg before the full commissioning of the plants was measured without any associated decline in wellhead pressure (Figure 4).

Reservoir Pressure

The total reservoir pressure drawdown, since the Tongonan I plant commissioning in 1983 until 1996, prior to the commissioning of the additional plants in Leyte, ranges from 0.5 to 1.5 MPa. However, the pressure trend with time (Figure 5) also indicates periods of pressure increase brought about by reinjection returns. Greater reservoir pressure decline ensued with the commissioning of the Leyte-Cebu plants (in Upper Mahiao and the first unit of the Malitbog plant). This would indicate the dispersion of the Tongonan I brine injection away from the production wells, as previous pressure interference by injection returns disappeared. This condition impacts the Tongonan I producers turning highly two-phase as indicated by the increased discharge enthalpies.

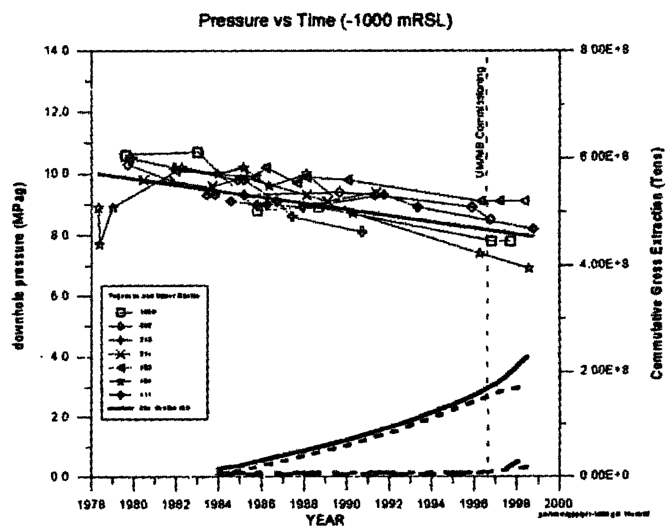

Figure 5. Tongonan & Upper Mahiao pressure trends.

Reservoir Temperature

No significant temperature changes in the majority of the wells were noted during the exploitation of Tongonan I from 1983 to present (Figure 6, overleaf). Cooling of the wellbore temperatures is usually brought about by injection returns and appears to be transient. In fact, there appears to be some temperature recovery in some wells with the commissioning of the Upper Mahiao plant and the first unit of the Malitbog plant due to the dispersal of reinjection returns away from the Tongonan I production field.

Within a year after the commissioning of the additional plants in Tongonan, fluids have attained saturated condition in large portions of the reservoir. Recent downhole logs in the Lower and Upper Mahiao sectors show that the expansion of the two phase fluids has become more pronounced as shown in the lowering of the vapor and brine interface (Figure 7). This has led to the reduction in mass extraction in the field and consequently a significantly lower amount of brine for re-injection.

Mass and Energy Balance

As part of the over-all field monitoring and accounting of the resource, daily mass and heat extractions are computed. The *over-all field steam utilization efficiency* (i.e ratio of theoretical steam rate per MWe and actual steam rate per MWe) is determined from these data, and used in guarding against excessive use of steam in operating the power plant i.e., exceedingly high *blow-off* to the atmosphere. It also indicates the percentage of the mass and heat extracted from the resource at any given period which can account for the total energy balance in the remaining plant life based on the original stored heat calculation. It is a first approximation that can guide in determining future actions that would be required to sustain production.

The total recoverable heat and mass used in standard reserve estimation is assumed to be about 10- 20 percent of the total mass assuming some porosity distribution in the reservoir (Nathenson, 1975). After 15 years of exploitation, approximately 160% of the total *mass-in-place* from Tongonan has been extracted. This shows and confirms that reinjection returns and fluids outside the delineated boundaries of the original resource are replenishing the reservoir in order for production to be sustained.

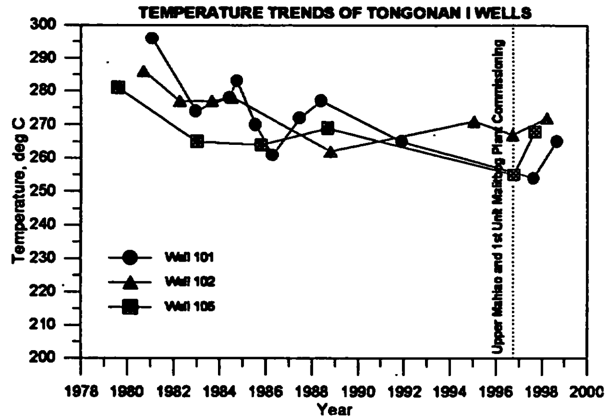

Figure 6. Tongonan 1 Wells temperature trends.

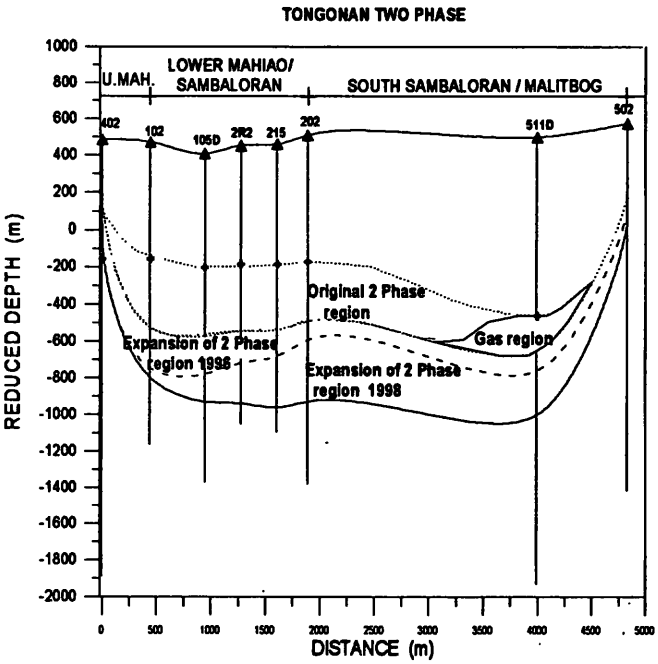

Figure 7. Expansion of two-phase region in Tongonan field.

Maintenance of Steam Supply

Scaling And Acidizing

No significant decline in steam capacity in Tongonan I due to calcite deposition has been observed which required the wells to be worked over. Similarly, silica deposition has not posed any risks yet in the operations of Tongonan I. Major silica scaling was only experienced in the re-injection wells where *spent brines* are re-injected at slightly supersaturated condition, i.e. at a silica saturation index range of 1.0-1.2. Acidizing jobs were thus programmed on reinjection wells that suffered significant decline in their injection capacities (e.g. 2R4D, 1R10). Acidizing was also done to treat wells found to be damaged by mud during well drilling (e.g. 109D, 110D). These were programmed after the wells had been tested and found to be producing below the expected production level.

Maintenance and Replacement (M & R) Wells and Workovers

Additional well drilling in Tongonan has been done as a last resort in conjunction with changes in the production and reinjection strategy to: *a*) minimize reinjection returns to the production sector; and *b*) tap wells producing highly two-phase fluids and minimize the volume of brines for re-injection. Figure 8 shows the historical M&R well drilling in Tongonan. Wells 109D, 110D and 111D were drilled in 1992-1996 to provide additional steam when the steam supply in the field was being affected by widespread reinjection returns. With the commissioning of the additional plants in the other sectors however, steam availability in Tongonan I improved resulting to excess capacity. Reinjection wells 1R6D and 1R7D were drilled as additional disposal wells in an attempt to disperse the waste brine farther away from the production sector. Both wells are tight. Figure 8 also shows the workover history schedule of the wells in the fields. These work-over jobs were usually done using a

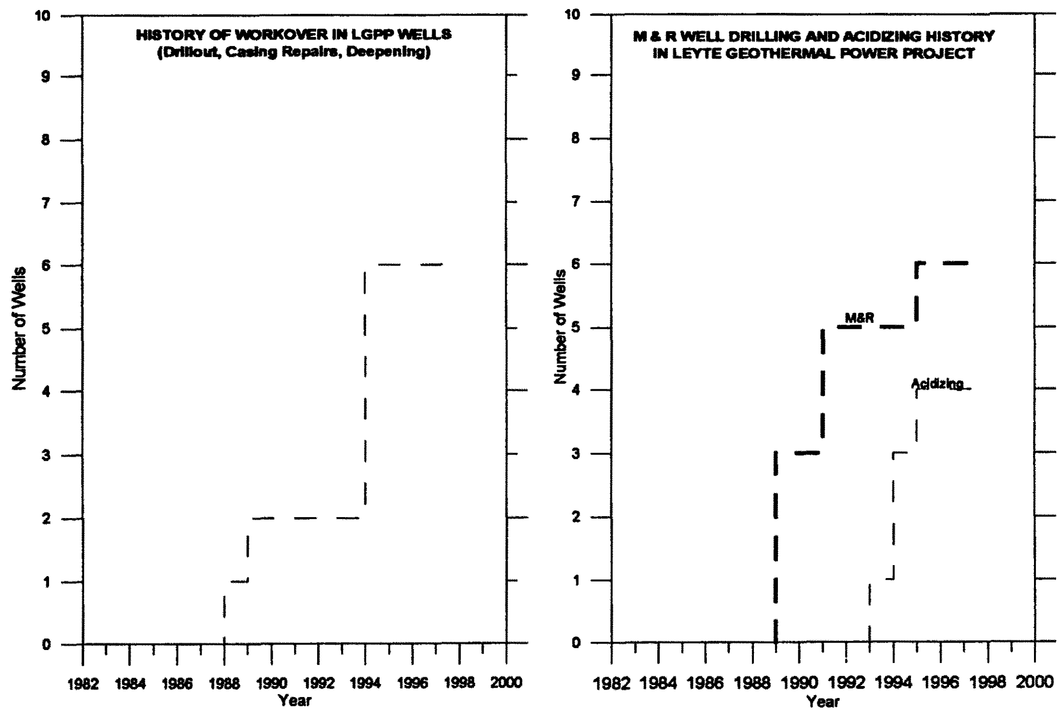

Figure 8. Workover, acidizing and M&R Drilling history in Tongonan Field.

rig by mechanical clearing of blockages and obstructions, relining the wells with smaller diameter casing and or strengthening the cement behind the casing through perforation and squeezed cementing. Most workovers done in Tongonan were in the other sectors. Only 109D was worked over due to casing damage resulting from poor cement bond behind the casing.

Pipeline Interconnection

For the long term sustainability and flexibility in supplying the power plants in Tongonan, it is likely that a pipe network that interconnects all the sectors in the Tongonan geothermal field will be constructed. This will allow utilization of the *buffer* production sectors in the field to supply steam in any sector that might experience a shortfall. Tongonan I sector is expected to contribute at least 30 MWe to the steamline interconnection system in the next five years.

Conclusions

Most of the changes observed in the field are found to be consistent with a depleting reservoir characterized by reservoir cooling due to boiling and expansion of the two-phase fluids and falling water levels. The addition of 600 MWe capacity in the Tongonan field has caused the upper two-phase section throughout the field to dominate the discharge resulting in significant increase in enthalpies (range 2300-2600 kJ/kg). In Tongonan I, the additional extraction from the other sectors has resulted to lower brine flow, less reinjection load and higher steam flow available.

Acknowledgement

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