INJECTION MANAGEMENT AT DARAJAT FIELD, INDONESIA: IMPACT OF MOVING INFIELD INJECTION TO EDGEFIELD

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ABSTRACT

Power plant condensate has been injected back into the reservoir since the Darajat Field started commercial generation in 1994. For almost 20 years, condensate was injected infield as the injectors were located in the central portion of the field. Although infield condensate injection provides pressure support to the reservoir it has also resulted to reservoir cooling, which led to steam condensation and high production decline, and wellbore scaling. To combat these negative impacts of injection, condensate injection was moved to the northern edge of the field in 2012.

As expected, fieldwide production decline went down as a result of edgefield injection. About four years after edgefield injection, reservoir boiling in the central portion of the field is more prevalent as evidenced by increasing superheat, production of more Injection Derived Steam (IDS), and the deuterium (^{2}H) and boron contents of most central production wells. Edgefield condensate injectate appears to move deep in the reservoir as indicated by microearthquake (MEQ) swarms. To date, edgefield injection has not had any detrimental impact to the Darajat reservoir. A time-lapse of gravity response shows a decline in the net-mass produced in northeast Darajat since the implementation of edgefield injection suggesting a mass balance condition due to support from the peripheral injection.

1. INTRODUCTION

The Darajat Geothermal Field is located ~145 km (aerially) southeast of Jakarta at elevations of 1,750-2,000 m (Figure 1). It is found within a range of inactive volcanoes and lies along the main trend of the Sunda Volcanic Arc which extends from Sumatra to Flores (Hamilton, 1979; Hutchinson, 1989) (Figure 1).

Darajat is the biggest vapor-dominated geothermal field in Indonesia with a current installed capacity at 271 MW from three generating power plant units. Unit I, with a capacity of 55 MWe, is owned and operated by PT. Indonesia Power (PTIP). Meanwhile, Units II and III, both operated by Star Energy Geothermal Darajat II, Ltd. (SEGD), have capacities of 95 and 121 MWe, respectively.

The Darajat geothermal system is a steam-dominated reservoir with temperatures of about 240ºC (Pasaribu et al., 2012). This geothermal reservoir is associated with the Kendang volcanic complex, an eroded Quaternary andesitic stratovolcano, and is composed of mostly andesite lava flows that were intruded by dioritic rocks. It is believed that the current steam-dominated reservoir is the remnant of the subvolcanic portion of an earlier hot water-dominated geothermal system (Moore, 2012; Pasaribu et al., 2012).

Figure 1: Location map showing the Darajat contract area (red rectangle) vis-à-vis other producing geothermal fields in West Java, Island. Both the Salak and Wayang Windu fields (yellow polygons) are operated by Star Energy Geothermal.

2. BACKGROUND

Injection of power plant condensate into the Darajat reservoir first began in 1994 when commercial production commenced. During the early years, surface water was occasionally injected into the reservoir at <20 lps to maintain vacuum condition in the injection wells during power plant shutdowns. Intermittent surface water injection was also utilized to support drilling campaigns or workover programs.

Injection in the central portion of the Darajat Field was implemented for almost 20 years (Figure 2). DRJ-C, the main injector for Unit I, was injected with 20-40 lps of condensate. Meanwhile, DRJ-AE, the primary injector for Units II and III, was injected with 40-110 lps of condensate. DRJ-AB was utilized for about eight months to dispose Units II and III condensate (~60 lps) during 2008-2009.

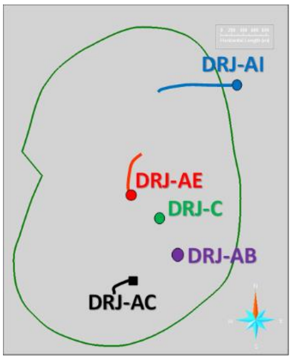

Figure 2: Map showing the location of the Darajat injection and production wells discussed in this paper. Injectors DRJ-C and DRJ-AB were drilled vertically. The green polygon indicates the commercial production boundary of the Darajat Field.

A surveillance program to monitor reservoir changes in response to field management activities was developed since the beginning of commercial operation. The integration of surveillance with other multi-disciplinary datasets has been used to determine the impact of injection management changes at Darajat.

Non-condensible gas (NCG) concentration is one of the parameters being used to monitor the impact of condensate injection into the reservoir. The condensate from the power plant is highly depleted in NCG. Mixing of the boiled injected condensate with reservoir steam results to lower NCG content in the produced steam. This mixing provides a semi-quantitative method of estimating the percentage of Injection Derived Steam (IDS) in the produced fluids (Rohrs et al., 2010). The IDS content offers an estimate of the relative proportion of injected condensate being returned as produced steam. Estimates indicate a significant increase in fieldwide IDS from 15% to 37% about five years after the start-up of Unit I (Figure 3). Current IDS estimates show that the produced steam contains as much as 40% of injected condensate.

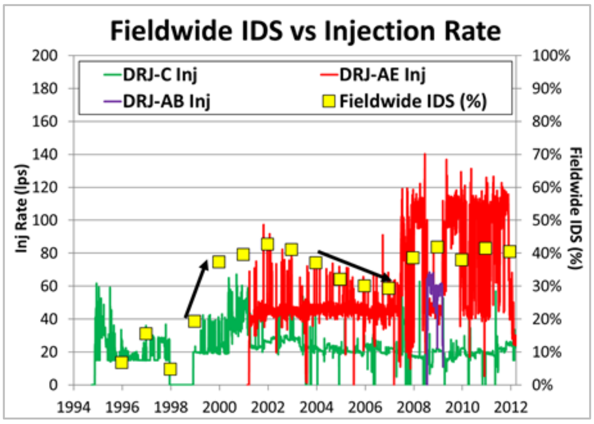

Figure 3: Historical fieldwide IDS and injection rates during 1994-2012. The injection rate for each well is the total for both condensate and surface water at any given time.

Besides NCG, stable isotopes are also a powerful parameter to monitor the impact of condensate injection into the reservoir. The power plant condensate disposed in injection wells contains heavier stable isotopes (i.e., deuterium (^{2}H) and oxygen (^{18}O)) as a result of evaporation in the cooling towers (Figure 4). An increase in heavier stable isotope content in production wells indicates higher contribution of steam from boiled condensate. DRJ-AG, a production well located on the same pad as infield injector DRJ-AE, exhibits more boiled injectate production as evidenced by increasing ^{2}H and boron concentrations in the produced steam (Figure 5).

Another impact caused by the injected condensate is reservoir cooling. Injecting the 30°C condensate causes significant cooling in the reservoir especially if injected at relatively shallow depths. Significant superheat decreases were observed at several Unit I producers in 2000. Rohrs et al. (2010) reported poorer cumulative artificial tracer returns at DRJ-C in 2001 than in 2008 suggesting that the reservoir was in near saturation condition during the early 2000s.

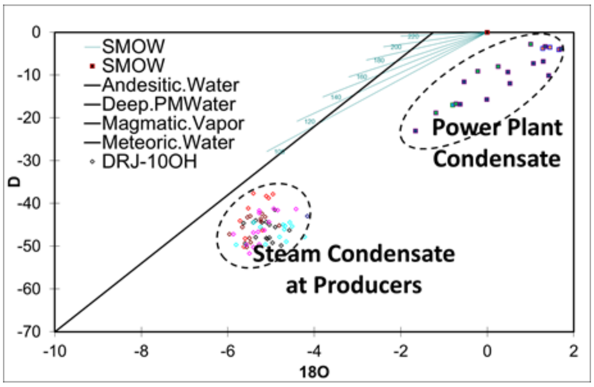

Figure 4: Chart showing the stable isotopes content of power plant condensate and steam condensate collected from production wells. Note that the power plant condensate has heavier isotopes than steam condensate.

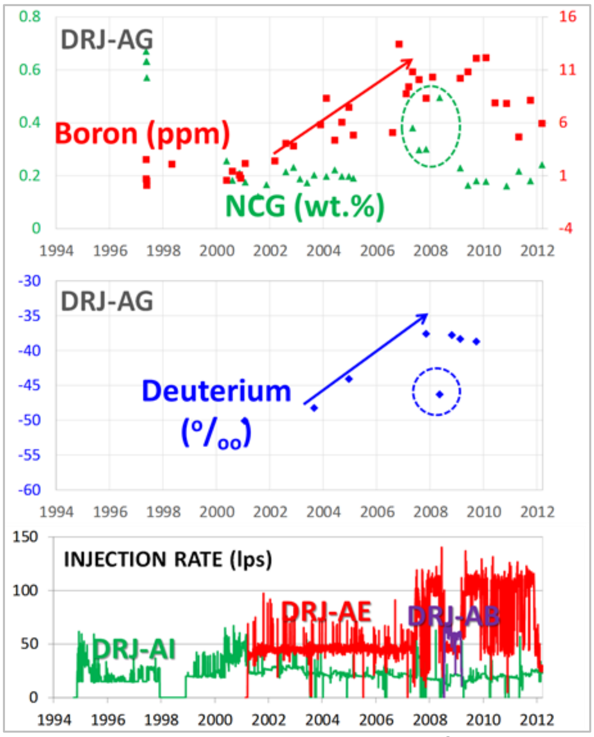

Figure 5: Chart showing boron, NCG, and ^{2}H content at DRJ-AG during infield injection. Measurements inside the green dashed polygon represents temporary NCG increase (coinciding with the lighter ^{2}H in the blue dashed circle below) as a consequence of make-up well drilling where nearby wells were flushed with surface water and caused condensation in the steam reservoir.

Continuing infield injection, which provides pressure and mass support, maintains the near-saturation condition in the fracture system and consequently increases the risk of water breakthrough. However, Paramitasari and Molling (2016) reported that several southern production wells (including DRJ-AC) experienced steam condensation, as shown by an increase in their NCG, due to the presence of a foreign fluid (i.e., marginal recharge or MR) about four years after Unit II was commissioned. The decrease in fieldwide IDS that started in 2004 possibly reflects more condensation in the Darajat reservoir due to condensate injection and/or MR influx (Figure 3).

3. DISCUSSION

To combat the unfavorable impact of infield injection, condensate injection into DRJ-AE was terminated in late 2011 and moved to the edge of the field to DRJ-AI. Routine surveillance determined several changes in the reservoir due to this change in injection strategy and details of these reservoir changes are described in the following sections.

3.1. Geochemical Monitoring Results

Surface superheat measurement is a suitable proxy to monitor superheat conditions in the reservoir because surface measurements are quick and easy to conduct and can be done frequently (Mahagyo et al., 2010). While injecting at DRJ-AE and DRJ-C until mid-2011, surface superheat ranged from 2-4 ºC at the central and southern portions of the field (Figure 6).

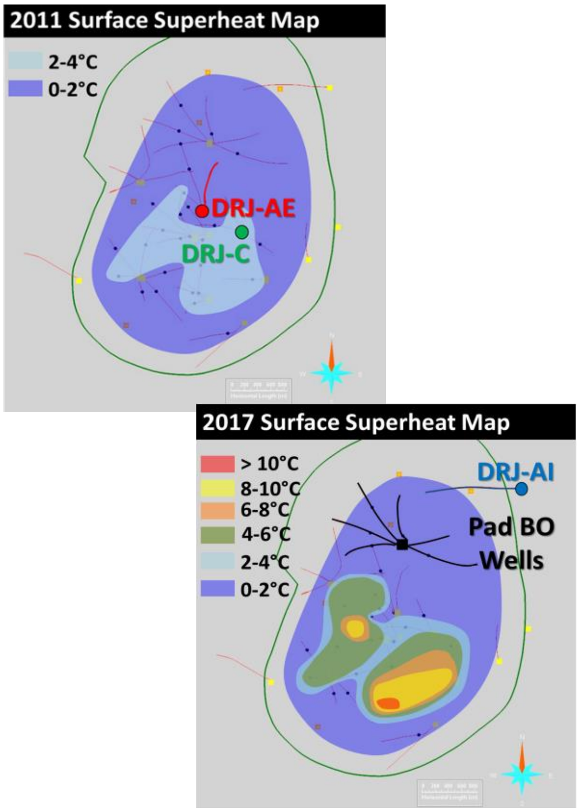

Figure 6: Surface superheat distribution between 2011 and 2017.

As condensate injection was moved out to peripheral injector DRJ-AI in late 2011, superheat developed at the central and southern portion of Darajat. By 2017, the central and southern portions of Darajat exhibit a more defined area of superheat development (Figure 6). Note that these areas are where initial production came from and the highest surface superheat (>10ºC) is observed at the southeastern area where reservoir quality is relatively lower.

As more injected condensate is boiled and produced by wells, the produced steam is expected to be concentrated in ^{2}H and boron. Expectedly, central producers discharge steam with lower ^{2}H and boron concentrations during infield injection in 2009 (Figures 7 and 8). In response to the termination of infield injection, central producers (e.g., DRJ-CC) discharged steam with significant ^{2}H (>-38‰) and boron (>20 ppm) concentrations in 2016. The high ^{2}H and boron suggests that the termination of infield injection has hastened boiling in the central portion of the reservoir which resulted in higher contribution of boiled condensate in the steam produced from these wells.

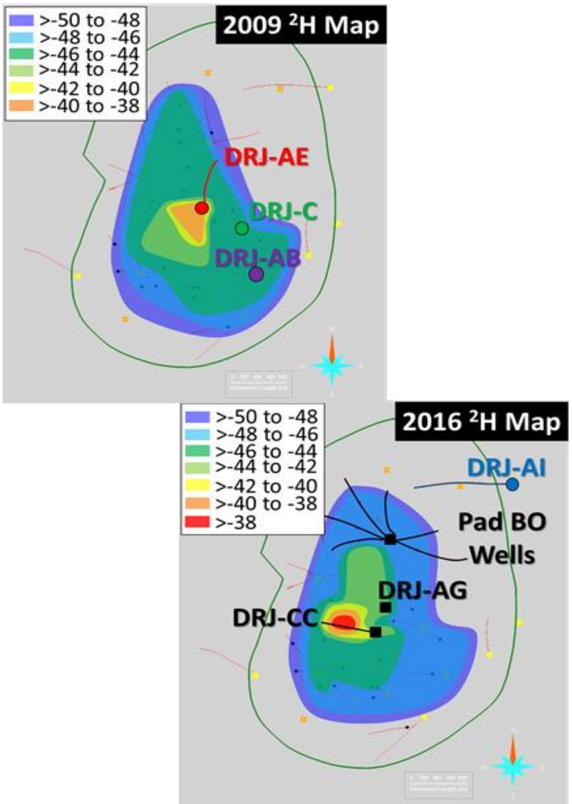

Figure 7: Deuterium (^{2}H) content distribution in per mille (‰) between 2009 and 2016.

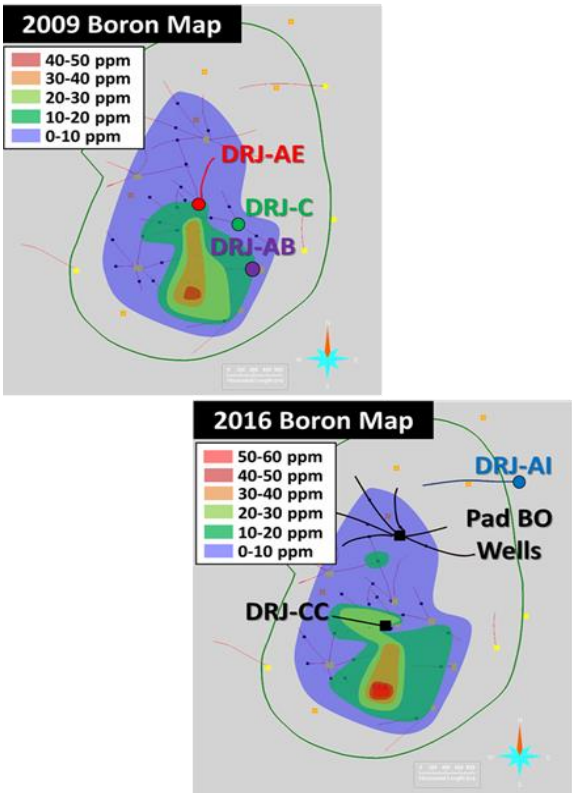

Figure 8: Boron distribution between 2009 and 2016. DRJ-AC consistent.

As previously mentioned, the contribution of boiled condensate injectate can also be estimated by estimating %IDS. Figure 9 shows that the central portion of Darajat was only producing about 60-80% boiled condensate in 2009 when infield injection was being implemented. When condensate injection was moved to the periphery of the field, the contribution of the boiled condensate injectate increased as shown by DRJ-AG and DRJ-CC which have >80% IDS in their produced steam in 2017 (Figure 9). The increasing contribution of remnant boiled injectate in the central part of Darajat is evidenced by the increase fieldwide IDS during 2012-2015 (Figure 10). The high IDS production at Darajat supports the hypothesis that there is more reservoir boiling in the central region as a result of terminating infield injection.

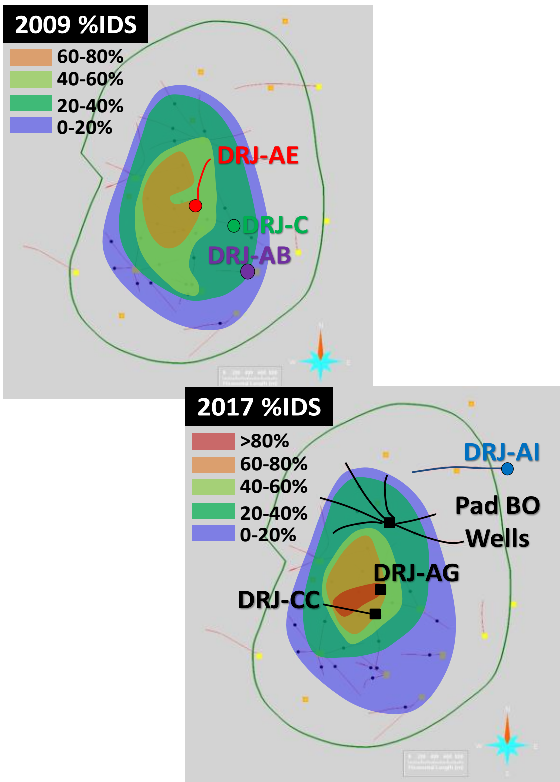

Figure 9: IDS distribution during infield injection in 2009 and edgefield injection in 2017.

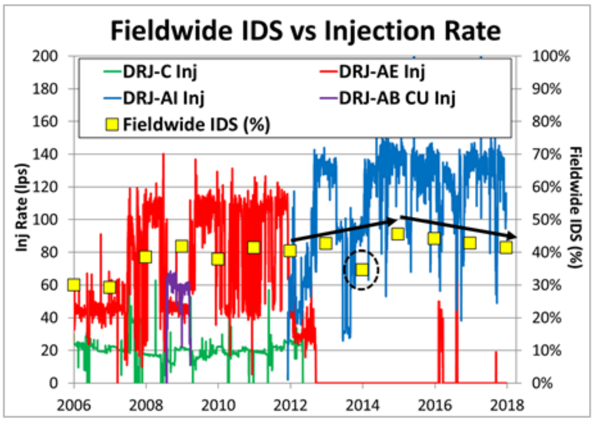

Figure 10: Historical fieldwide IDS and injection rate in 2004-2018. Fieldwide IDS decrease in 2014 (black dashed circle) is affected by steam condensation at several producers in response to Unit II prolonged shutdown in 2013-2014.

From 2015 onwards, fieldwide IDS production started to slightly decrease (Figure 10). Although not yet concluded, it is believed that the injected condensate at peripheral injector DRJ-AI may be moving back towards the reservoir resulting to condensation. Steam condensation in the northern portion of the field is demonstrated by lighter deuterium content in Pad BO wells in 2016 compared to 2009 (Figure 7).

3.2 Geophysical Monitoring Results

Majority of the micro-earthquakes (MEQ) at Darajat Field is related to injection activities (Tanuwidjaja and Nelson, 2016). The association of MEQs with injection was based on the temporal correlation between the MEQ events and injection rate variation and, also, the spatial clustering of most MEQs in the vicinity of the injection wells. MEQ density maps shows a significant amount of MEQ epicenters are spatially observed near infield injector DRJ-AE in 2006-2011 and edgefield injector DRJ-AI 2011-2016 (Figure 11). The central MEQs are located west of DRJ-AE suggesting movement of the injected fluid and fracture network in this part of the field. The northern MEQs are mostly located southwest of DRJ-AI and extend toward the production area to Pad BO.

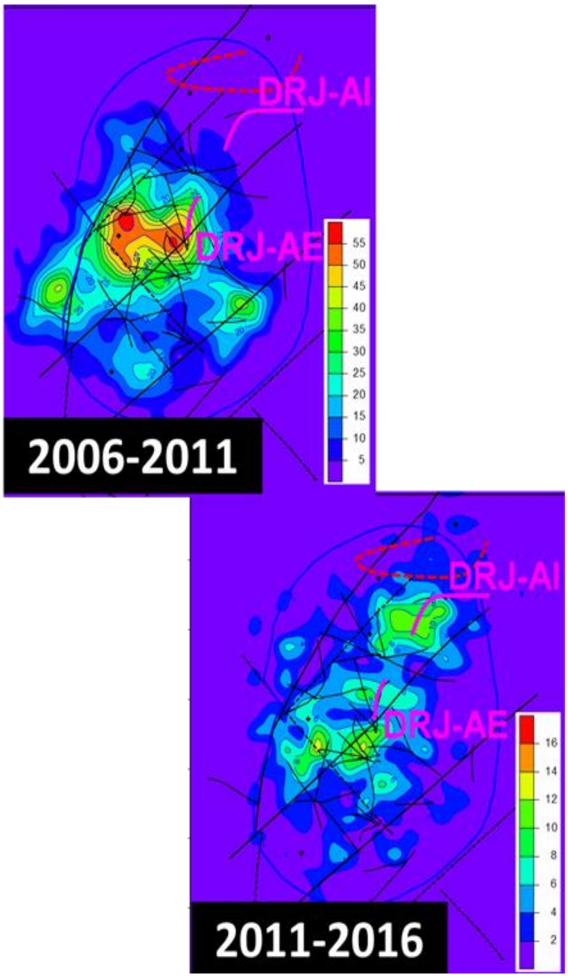

Figure 11: MEQ density maps during infield (2006-2011) and edgefield (2011-2016) injection.

The injected condensate at the periphery of the field appears to move into the deeper part of the reservoir as indicated by MEQ clusters below DRJ-AI (Figure 12). The deeper movement of liquid injectate below DRJ-AI is believed to have resulted to condensation of the steam reservoir as evidenced by lighter ^2H content in Pad BO wells in 2016 (Figure 7).

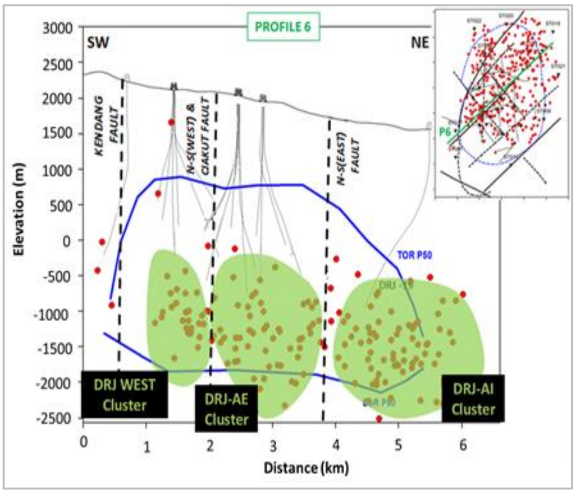

Figure 12: SW-NE cross-section of Darajat Field showing the swarms of injection-induced MEQs. Note that these MEQs occur deep below the injection wells suggesting the extent of the fracture network.

Another dataset used to determine the impact of changing the injection strategy at Darajat is precision gravity changes. Historical monitoring indicates the continuous decline in microgravity at Central Darajat even after the termination of infield injection at DRJ-AE (Figure 13). Meanwhile, the gravity decline rate in Northeastern Darajat appears to have significantly slowed almost right after beginning of condensate injection in DRJ-AI in late 2011. The slowing trend of gravity change is now approaching zero in Northeastern Darajat suggests a mass balance condition between the injected mass from DRJ-AI and the migrating mass towards the production area. Figure 14 shows the flattening microgravity decline rate since 2012 in Station H in northeastern Darajat after injection into DRJ-AI commenced (Figure 14).

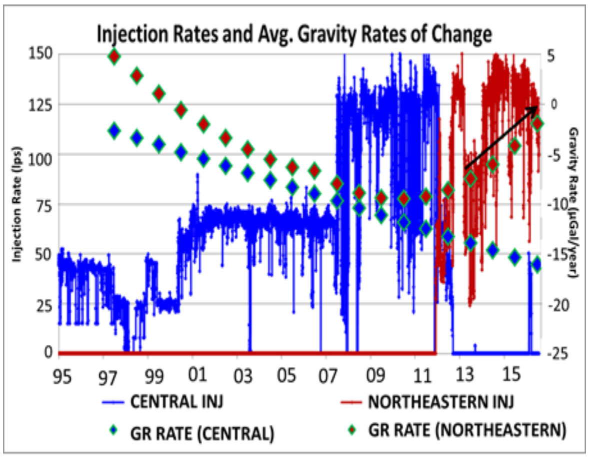

Figure 13: Historical injection rate and average gravity rate of change in Central and Northeastern Darajat.

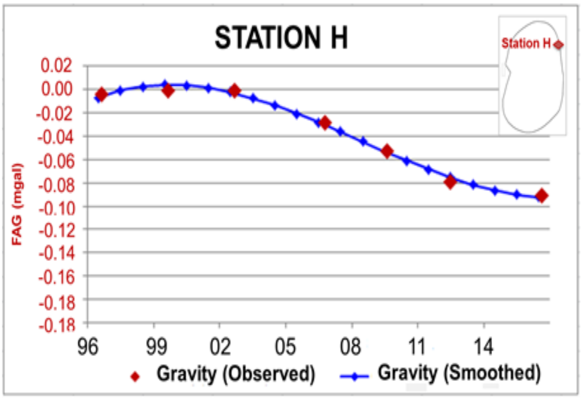

Figure 14: Chart showing the gravity trend at Station H which started flattening after injection into DRJ-AI commenced in late 2011.

3.3 Production Monitoring Results

Fieldwide production decline rate at Darajat is governed by the performance of Unit II and III wells because these wells produce steam the most (Figure 15). The high fieldwide decline rate (18.5%) during 2008-2009 may have been due to the uprating of Unit III from 110 MWe to 121 MWe and production loss in Unit I producers as a response to temporary injection at DRJ-AB (Rohrs et al., 2010). Prior to the implementation of edgefield injection, fieldwide decline rate was at 9.5% (Figure 15).

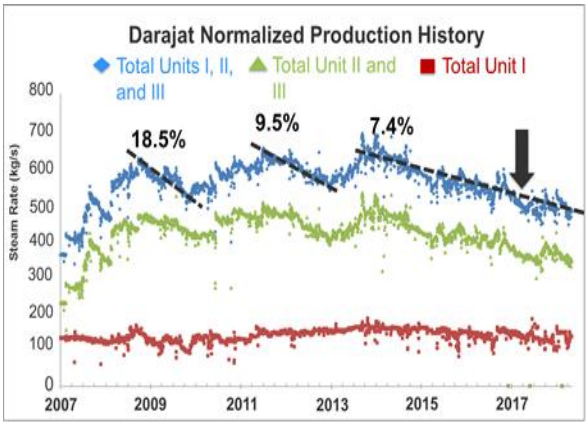

Figure 15: Chart showing the historical normalized steam production rates at Darajat Field. The black arrow shows a temporary steep fieldwide decline rate in early 2017 due to wellbore scaling.

After the implementation of edgefield injection at DRJ-AI, the fieldwide decline rate decreased to ~7.4%. This improvement in decline rate is believed to be due to renewed boiling (and termination of steam condensation) in the central portion of Darajat as evidenced the by high ^2H, boron, and IDS in produced steam of central producers. Meanwhile, the temporary steep fieldwide decline rate in early 2017 seems to be related to MR influx in the southeast and, consequently, wellbore scaling; some southern production wells exhibited >24% production decline (GSRO Team, 2018).

4. CONCLUSIONS

Moving infield injection to the periphery of the field resulted to an improved performance fieldwide at Darajat. Reservoir boiling in the central portion of the field was hastened when injection at DRJ-AE was stopped and evidenced by significant increases in surface superheat and ^2H, boron and %IDS in produced steam. Current fieldwide decline rate is now at about 7.4%, down from 9.5% during infield injection.

Monitoring indicates that the injected condensate at the periphery of Darajat moves deep into the reservoir based on swarms of MEQs. In addition, precision gravity data suggests that a mass balance condition between the injected mass and the migrating fluids toward the production area may have been attained in the north-eastern portion of the field. Conversely, edgefield injection may be condensing the reservoir in northern portion of Darajat based on lighter deuterium content in the produced steam; nevertheless, steam production has not been impacted to date.

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