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Lessons Learned from Kamojang Geothermal Steam Field Management: from the Beginning Until Now

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ABSTRACT

Kamojang is the first geothermal field in Indonesia, and it is known as one of the vapor-dominated systems of the world. It was first producing steam in 1978 to generate electricity for its own use through a 250 KW mono-block unit. The first commercial operations of 30 MW started in 1982. Subsequently, an additional 110 MW started commercial operations in 1987. A new 60 MW unit entered commercial operation in January 2008. In addition, the possibility of having another 60 MW unit is now being evaluated. The current rate of mass withdrawal shows the imbalance of discharge and recharge induces decreases of water level to deeper parts of the reservoir. Also, the 25 years of continuous commercial production have led to slight declines in the reservoir pressure and temperature within the active production sector. As a result, some of the 33 production wells show slight production decline and tend to approach superheated conditions. The reinjection programme, may have slowed down these phenomena, and especially that of the reservoir being superheated. The present state of the field is characterized by the increase from 140 MW to about 200 MW commercial operations in the early part of 2008. Thus, the increase of withdrawal rate might affect the Kamojang reservoir and energy production unless the right steam field management strategies are applied.

1. INTRODUCTION

The Kamojang geothermal field is one of the world's few developed dry steam reservoirs. It is located in an area of high elevation, 40 km south east of Bandung, Indonesia (figure 1).

The field, which is operated by Pertamina, a state owned oil company, has been producing steam to supply PLN'S Unit 1, 30 MW, since 1982 and an additional 110 MW (2 x 55 MW) as Units 2 and 3 since 1987.

The exploration began under New Zealand government aid in 1974. At that stage, five exploration wells were drilled down to 700 m throughout the Kamojang area.

Pertamina continued from 1975 and developed the first geothermal field, with the initial state of development producing 30 MWe, utilizing steam from 6 wells.

Commercial operations expanded in 1987 from 30 MW to 140 MW capacity, supplied from 26 wells. To date 81 wells have been drilled within an area of 14 km^2 (figure 2). An additional 60 MW power plant started commercial operation in early 2008. This paper presents the lessons learned from the 27 years of operation.

2. POTENTIAL RESERVE

A reservoir area of 14 km^2 has been estimated from DC Schlumberger sounding (Hochstein, 1975) and a further field delineation of up to 21 km^2 has been determined from CSAMT studies (Sudarman et al., 1990).

The first two exploration wells drilled produced dry steam from shallow feed zones with a temperature of 237°C at about 600 m depth. The Kamojang geothermal reservoir is dominated by vapor with temperature of 235 - 245 °C and pressure of 34 - 35 bar abs. The potential resources calculated using volumetric analysis suggest a power potential of 150-250 MWe (Pokja Pertamina Kamojang, 1999) within the reservoir area of 7.52 km^2 – 12.5 km^2. Independent calculations were also made. Fauzi (1999) calculated proven reserve from a reservoir area of 8.5 km^2-15 km^2 and suggested a power of 140 MW to 360 MW for 25 years utilization. Sanyal et al. (2000) estimated that proven reserves ranged from 210 to 280 MW for 30 years. Base on the reservoir simulation, the most likely power potential is 230 MWe for 25 years operation, which has been proven by drilling wells. To date, the field producing steam is equivalent to 200 MW electric.

3. TWENTY-SEVEN YEARS OF COMMERCIAL OPERATION (1982-2009)

3.1 Reservoir Response

The continuous commercial operation from 1982 to 2009 is characterized by a slight decline in the wellhead. The natural state of the Kamojang geothermal field is characteristic of typical vapor-dominated systems. The Kamojang reservoir has a water saturation in the order of 25-35%. It mostly produces 100% steam. Values of permeability-thickness of production area range from 500 to 140,000 Darcy-meter where the productive wells display values greater than 4900 Darcy-meter (GENZL, 1992).

The non-condensable gas content in the discharging fluid is less than 1% by weight, mostly CO_2 and H_2S, and very low to nil chloride content.

The general distribution of permeability (K) is subdivided in three zones, i.e. high K-zone, moderate K-zone, and low K-zone (figure 3).

After 15 years of production, all wells at Kamojang can be expected to decline at an annual harmonic rate of 4.2%, the reservoir pressure declined by about 5 bar (Sanyal et al., 2000).

The continuous operation steam supply from 1982 to 2009 has shown the decline of reservoir pressure from initial conditions by about 17% to 25% (an average of 0.35 Ksc/year or 1.06%/year). Over the 27-year operation the reservoir pressures have dropped 8.5 Ksc (8.34 bar) on average.

Temperatures have declined from initial conditions by about 2% to 7% (average 0.71ºC/year or 0.29%/year) and over 27 years the temperature reservoir drop is about 14 ºC on average.

The decline rates of pressure and temperatures are correlated with reservoir permeability zone (Suryadarma et al., 2005) and reservoir storage and flow capacity due to the response of production and reinjection strategy.

Furthermore, the initial well head pressure in the east sector has not changed during the production period for Units 1, 2 and 3 (figure 4), but has shown decline during production of Unit 4.

3.2 Casing Design

80 wells were drilled over at least five periods in which different types of casing design were used. In the period of 1926–1928, before Pertamina took over the field, there were 5 exploration wells that were drilled by the Dutch, with depths of 66 –128 m with unknown casing design.

From 1974–1975, Pertamina and GENZL drilled another five exploration wells with depth varying from 536 – 753 m. These wells were completed with slim-hole casing from 18 inch diameter stove pipe to 4½ inch diameter production casing.

The third period is 1976 – 1979. During these years, ten development wells were drilled by Pertamina and GENZL with depths of 935 to 1800 m. Those wells used semi standard casing diameters from 18 inch stove pipe to 7 inch production liner, except KMJ-15 that still used 4½ inches.

The fourth period is 1979 – 1993. These years are characterized by the change of 18 inch stove pipe to a 20 inch casing design. Total depth varied from 1150 m to 2200 m. These wells were drilled by Pertamina, with a total of 33 wells.

The last period is 1993 to the present. During these years, 28 directional and delineation wells were drilled to 1003 – 2200 m depth using standard casing design comprised of 30 inch diameter of stove pipe, 9-5/8 inch production casing and 7 inch production liner. One of the newest two big-hole wells was drilled in 2002 using 9-5/8 inch production liner.

3.3 Gathering System

To supply the 140 MW power plants, the steam transmission pipe lines are divided into four supported pipe lines (PL) called PL-401 (Ø 32 inch); PL-402 (Ø 24 inch); PL-403 (Ø 40 inch) and PL-404 (Ø 40 inch). Designed pressures are up to 10 bars, which are fed into a PLN's commence interface with PLN’s pipe line at the header. The turbine inlet pressure and temperature are 6.5 bars and 161.9 °C respectively. Steam flow in each PL is controlled manually, and is supplying 2.5% greater than power plant demand. The excess of steam is controlled automatically by a butterfly vent valve into a vent structure under normal operating condition. In order to reduce the excess steam from the vent structure, since 1998, Pertamina controls the steam supply from four main production wells by using automatic control valves. This advance control system enables the well to immediately stop and reduce the excess steam at the vent structure by up to 2%. The SCADA system was installed and developed in 2003 by adding transmitters to those control valves. This continuous venting is due to the gathering system design of the turbine with steam consumption rate of 8 tonnes/hour/MW average at power plant operating condition of 6.5 bar inlet pressure.

Operation of the 60 MW power plant that is owned by Pertamina is supported from nine production wells and two wells as backup. The pipe line of steam gathering system is called PL-405 with 36 inch diameter. The turbine inlet pressure and temperature are 11 bars and 184.2 °C respectively.

The wellheads used in Kamojang production wells are comprised of WP 3000 psi, 900 ANSI-class. This high-pressure ANSI-class of wellhead can be reduced into 600 ANSI-class (WP 2000) corresponding to 35 bar (abs.) of wellhead pressure as it is used in KMJ-73, KMJ-74 and KMJ-76, but KMJ-75 as a big hole used WP 3000 psi, 900 class.

4. STEAM FIELD MANAGEMENT STRATEGIES

4.1 Production Strategies

The field began generating 30 MWe in 1982 supplied by steam at optimum well head pressure of about 15 to 17 bars to feed 6.5 bars inlet pressure at the plant. At the start of generating 140 MWe in 1987, 26 wells produced 1315 tons/hour steam and gradually decreased to about 1086 tones/hour in 1993 giving an average decline of 2 – 3 %. The minimum feed of the three Mitsubishi condensing turbine units of 1 x 30 MWe and 2 x 55 MWe are 1100 tones/hour steam. Therefore, up to the year 2000, six make-up wells have been drilled to keep a constant flow rate of steam fed to the plant. Figure 5 shows the history of KMJ-11, one of the wells supplying steam for the 140 MW plants, gradually decreasing during the time of production.

In 2000, it was anticipated that major increase in mass withdrawal may cause further decline in pressure. There were three deep unproductive wells that have been used as reinjection wells to cope with the total field production.

Another scheme of maintaining the reservoir pressure is to operate different productive wells alternately.

The effect of this process in the operating of the field is manifested in the stabilization of output of producing wells and increase of wellhead pressure. The immediate response is the recovery of mass production corresponding to increase in the steam output.

4.2 Reservoir

The standard Kamojang wells were drilled either straight or directionally using standard completion casing size of 9-5/8 inch and 7 inch perforated liner, and have had an average production of 7 MWe. A well bore simulation study revealed that large hole configuration of 13-3/8 inch casing and 9-5/8 inch perforated liner in the east and north sectors are capable of two times greater steam production (on average) than that of a standard size well with 7 inch liner (Kris Pudyastuti, 1994). However, until year 2000, the wells in Kamojang were still drilled by conventional methods. The wells with standard completion had been drilled in the east sector of Kamojang to support the 60 MW turbine units. In 2002, one big-hole well was also drilled to campaign more steam production and to support the 60 MW plant. The results of this last big-hole well produced 65 ton/hour of steam.

To monitor the reservoir performance, wellhead static pressure is one of the parameters measured during well testing and reservoir monitoring programs. Downhole measurement is also done for this purpose by using conventional Kuster gauge mechanical tools. Pressure and temperature are also monitored continuously for accuracy using electric digital wire line logging.

Tracer tests have used deuterium as natural tracer, and tritium and methanol as artificial tracers. They have been performed to observe the pattern of fluid flow in the reservoir. The tritium tracer was injected at injection wells KMJ-15 in 1983 and 1992. The tritium was also injected in KMJ-46 in 2003, KMJ-13 in 2007, KMJ-21 in 2008 and KMJ-20 in 2009. The tritium gave good response in KMJ-46 and KMJ-13 but not in KMJ-21. The tritium in KMJ-20 is still being monitored until the present day.

Data management is conducted to collect pressure build up data, well productivity history, well deliverability data, and reservoir performances.

Those data that combine with the update of geoscience data are used to develop a numerical reservoir model. A three-dimensional reservoir model started development in 2006 and was undergoing update in 2009. The first three-dimensional model shows that the steam supply for 140 MW is safe until the end of the contract of Units 1, 2 and 3. Simulation also shows that exploitation at Unit 4 does not influence the steam supply of Units 1, 2 and 3.

The updated reservoir numeric model is still underway in May 2009. Hopefully, its results will be available at the congress.

4.3 Reinjection Strategies

Up until today, eight deep unproductive wells have been used for reinjection. Three of them are located in the center of the field and low permeability zone but the other two are in medium permeability. This reinjection does not yet give impact to maintain the productivity, but wells KMJ-33, KMJ-18, KMJ-40 gave a good response from reinjection to minimize the decline of productivity.

On the other hand, some reinjection wells gave negative response i.e. made decline production, as in KMJ-11. To anticipate it, reinjection strategy changed by repositioning the reinjection well. In Figure 5 we can see the times before injections, the decline 0.88%/year harmonic. Then during injection times (2001 – 2006) the decline rate increased to be 7.4%/year exponential. During the next period (2006 – 2008), increasing of injection rate by active injection well KMJ-13 caused increasing decline rate 14.58%/year harmonic. Than from the next year 2007 until to the present day, reduction of injection rate has shown a good response to reduce decline rate to be 0.18%/year exponential.

4.4 Scaling

The scale formed in the steam pipelines is known mainly as silica. Scale might have also been formed and blocked the wells at depth (e.g. KMJ-18, 41, 51, 67, 11, 14, 17, 26 and KMJ-27) and affect the reservoir within its surrounding.

The action taken to address this problem was to operate steam flows at higher WHP (at least 15 bar), acidizing and hydro blasting of the blockages tagging its maximum clear depth, and work over operation. In the gathering facilities, silica scale is cleaned by using chemical inhibitor (chemical light bolt 103) and neutralized by agent for coating white powder component. It also uses scale remover liquid (SR 982 liquid).

Workover and acidizing have been found to be effective in recovering the output of each well. The use of chemical inhibitor is being considered due to the cost-effectiveness compared to drilling more make-up wells.

5. CONCLUSIONS

Until 2009, the Kamojang geothermal field has been in operation for 27 years for Unit 1 (30 MW) since 1982 and 22 years for Unit 2 and 3 (110 MW) since 1987 and one year for Unit 4 (60 MW) since 2008.

There are changes in the reservoir temperature and pressure – at block Units 1, 2 and 3 there has been a drop of 14°C (0.71°C/years) from initial temperature 245°C and a pressure drop of 8.5 Ksc (0.35 Ksc/year) from the 34 bar initial pressure, but in block Unit 4 there is still only slight changes because exploitation has only just begun. Reinjection is part of the important strategy in reservoir management of the Kamojang sustainable program. This program continues to monitor to find the proper formula for reinjection.

By simulation, the steam supply for 140 MW will be secure until 2012 and there is no influence to Unit 140 MW due to operation of Unit 4 (60 MW). The next step of development at Kamojang is looking at the opportunity by reservoir reassessment based on the reservoir response from current development.

6. ACKNOWLEDGMENT

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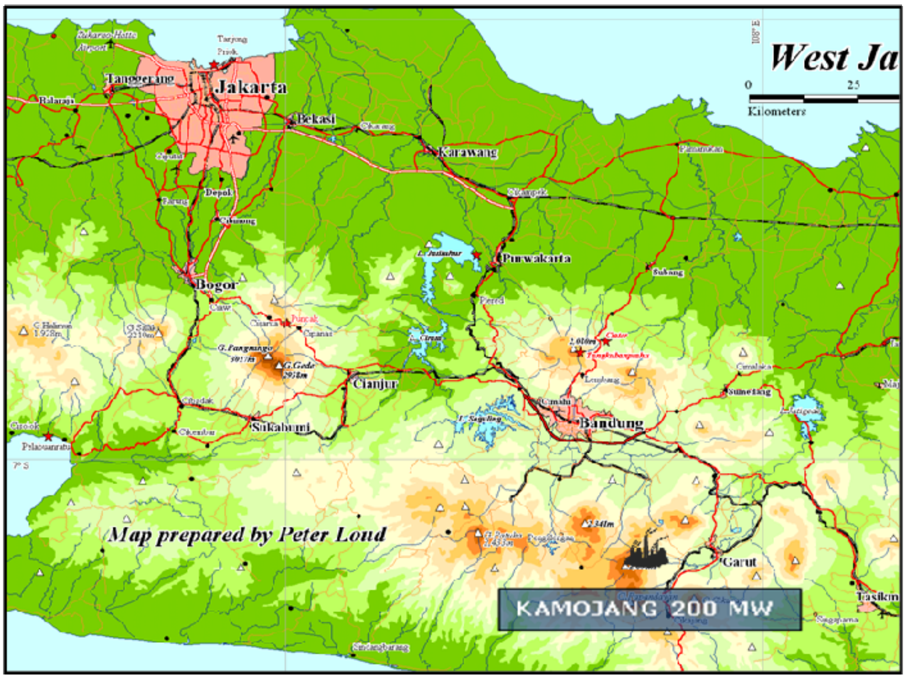


Figure 1: Location map of Kamojang, west Java, Indonesia.

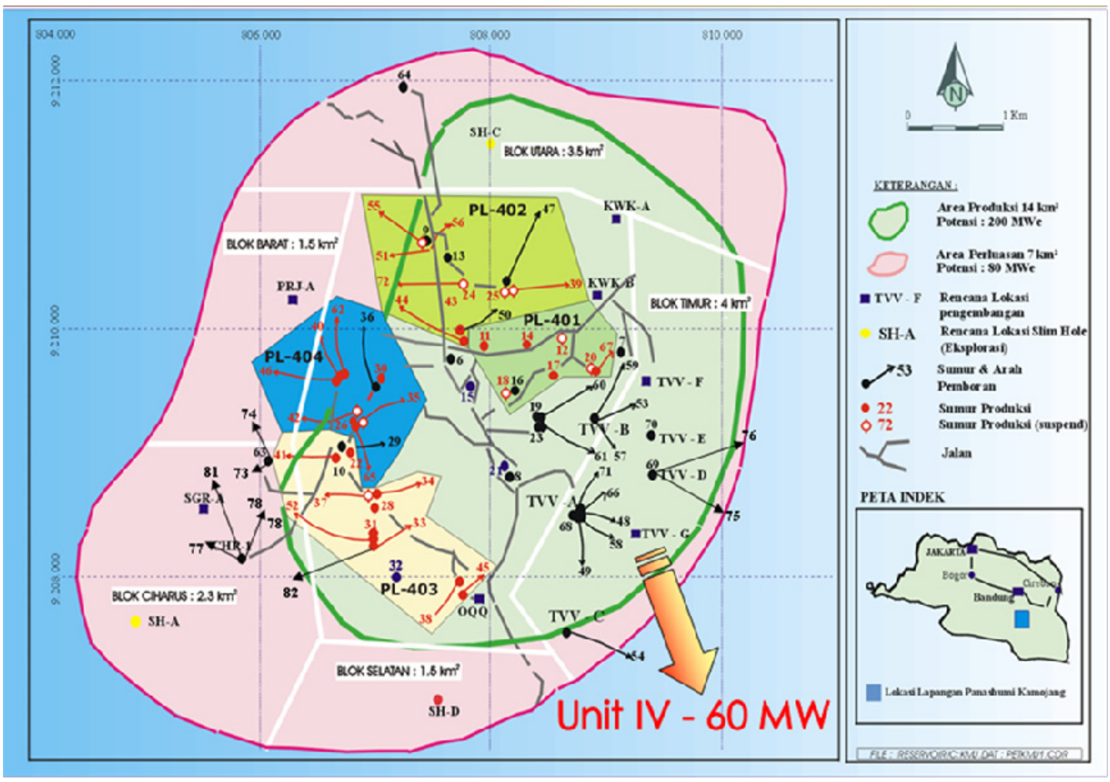


Figure 2: Map of the Kamojang field showing boundary of the prospect, well bores, and development of the east sector.

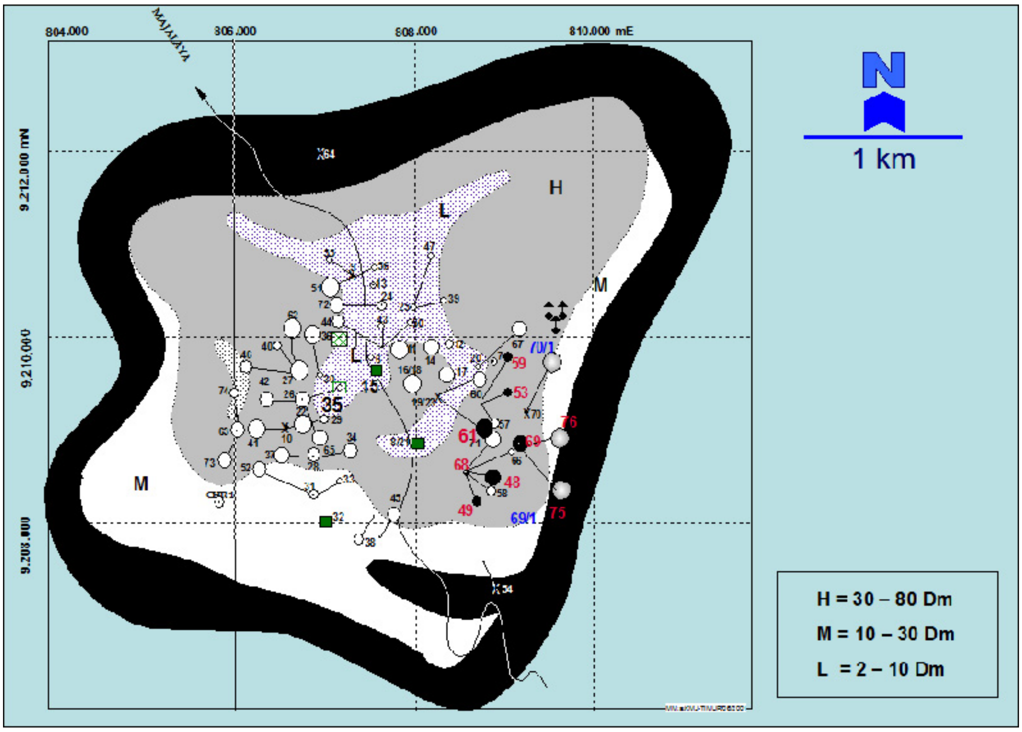


Figure 3: Permeability structure over KF; constructed from surface geoelectrical data, borehole data and production data.

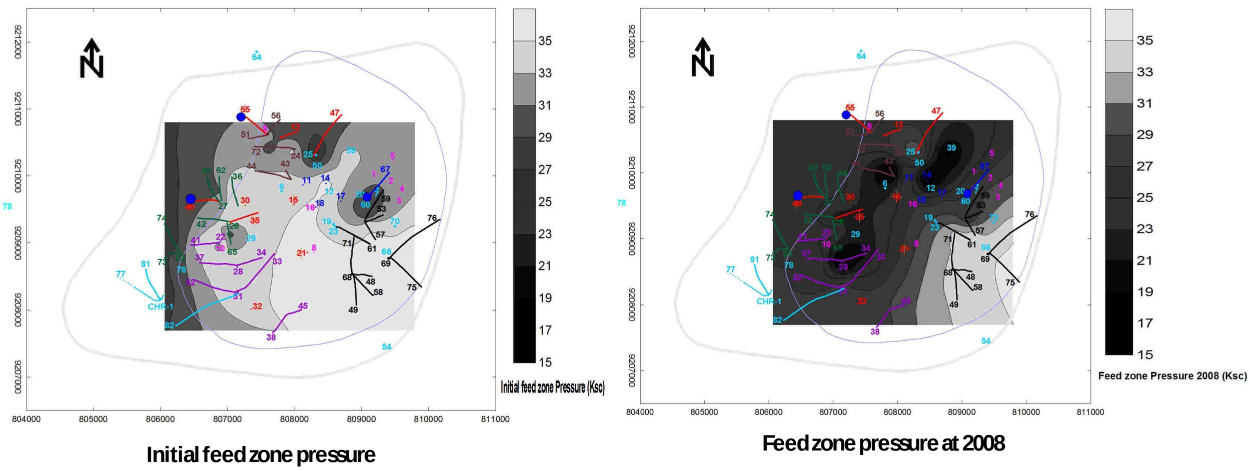
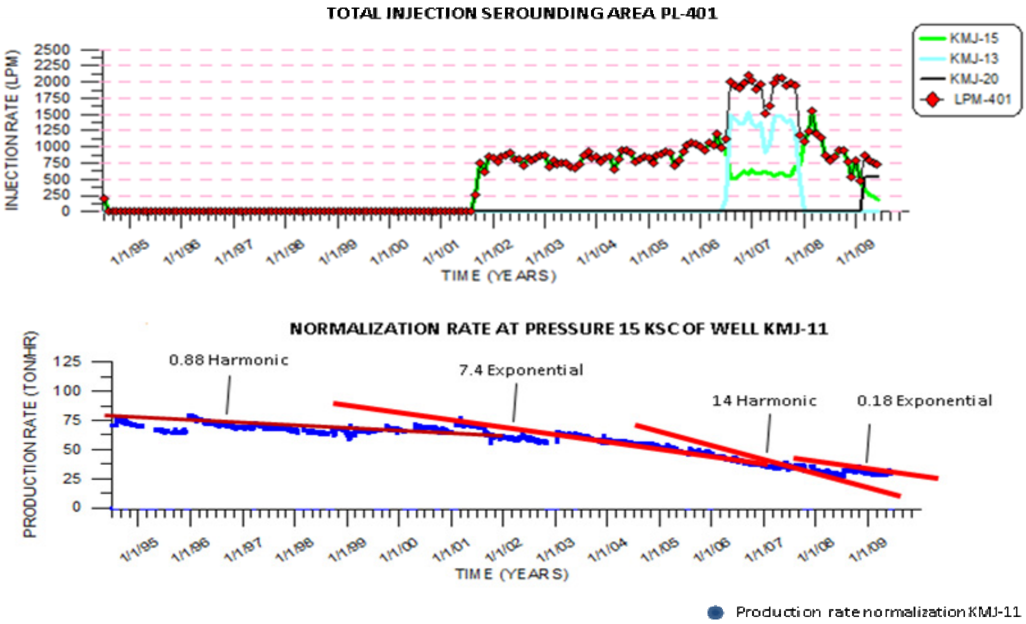


Figure 4: The comparison initial feed zone pressure of the wells to the beginning of start of Unit-4 commercial operation in 2008 at southeast block



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