PNOC 98

The Effects of 5" Slotted Liner Extensions on Production and Reinjection Wells

Eugene T. Aleman

PNOC-Energy Development Corporation, PNPC Complex, Merritt Road,
Fort Bonifacio, Makati, Metro Manila, Philippines

Abstract

This report investigates the effects of using small diameter (5") slotted liner extensions on the injection capacity and discharge capacity of standard size injection and production wells.

There have been quite a number of instances at Philippine National Oil Company Energy Development Corporation (PNOC-EDC) where changes to the programmed well configuration have been made during the course of drilling deep wells. This is due to a variety of hole problems encountered before reaching the programmed total depth. In the worst cases, this necessitates drilling of a smaller diameter hole extension to reach the programmed total depth where the major geological structure is projected to be intersected. The well then consists of two sizes of slotted liner, a 7-5/8" liner and a 5" slotted liner extension with the major permeable horizon intersected by the smaller size liner. The effect of using the 5" slotted liner extension has been investigated using the PNOC-EDC injection capacity estimation method for injection wells and the Wellsim Wellbore Simulator for production wells. A significant drop inflow capacity of the well is identified as a result of using the two liner (7-5/8" and 5" slotted liner extension) configuration against the standard 7-5/8" slotted liner. Capacity loss is more severe in high permeability wells, and depends on the length of the small diameter slotted liner.

A simple correlation is provided to determine the percentage of capacity loss in reinjection wells, based on injectivity data obtained after drilling. An attempt was also made to correlate productivity losses to initial injectivities but this was unsuccessful, probably because of the more complex nature of two-phase fluid in the wellbore.

1.0 Introduction

Drilling of geothermal wells deeper than 1500m is common in the geothermal fields operated by Philippine National Oil Company Energy Development Corporation (PNOC-EDC). Most of these wells are standard size consisting of 9-5/8" production casing and a 7-5/8" slotted liner (Fig. 1a).

It is often difficult to reach the programmed depth of the well without encountering hole problems. Successive tight spots which is a term used to describe the difficulty of the drill string to be rotated and formation collapse may cause hole deterioration which could result to stuck pipes. In severe cases, drilling the 8-1/2" open hole section is terminated to prevent further deterioration of the hole. However, in most cases. drilling ahead with a smaller bit is undertaken especially where no permeable horizon.has been encountered so far and a major geological structure is expected to be encountered at the original programmed total depth. This **is** carried out by first setting the 7-5/8" slotted liner then drilling ahead down to the programmed depth. **As** a result, the well configuration usually consists of a 7-5/8" slotted liner and a 5" slotted liner extension with the major permeable horizon intersected by the smaller diameter hole (Fig. 1b).

In recent years, there have been a number of studies made on the effect of casing sizes on the well's discharge capacity. Increasing the size of the well from the standard 9-5/8" casing and 7-5/8" liner to 13-3/8" casing and 9-5/8" liner would significantly increase the capacity (Barnett, 1989; Freeston and

Gunn, (1993). The increase was found to be more significant in wells feeding from highly permeable zones. Related studies comparing flowrates from slimholes against standard size wells are discussed by Pritchett (1993) and Hadgu et al. (1994).

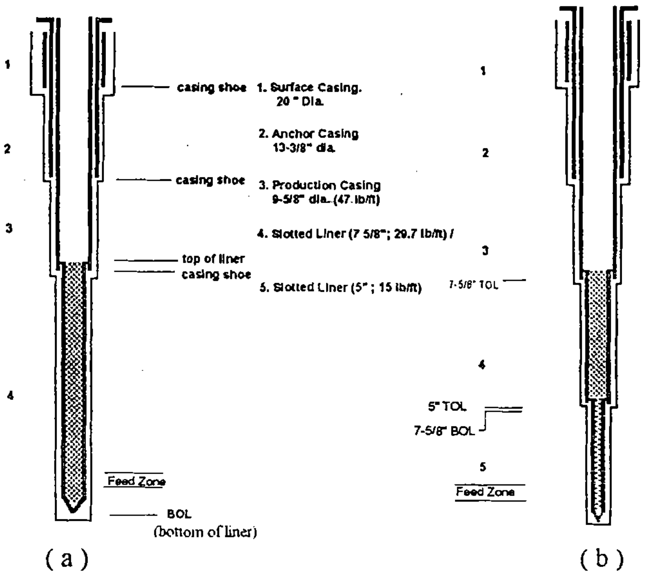


Figure 1. Two types of well configuration: a) normal standard size well consisting of 9-5/8” production casing and 7-5/8” slotted liner; b) standard size well completed with a 5” slotted liner extension.

The studies described above were either based on stepped production size wells with only one size of slotted liner in the open hole section or uniform size slimhole. The scope of this study covers reinjection and production wells drilled with a standard size hole consisting of a 9-5/8” casing, 7-5/8” liner and a 5” slotted liner extension and does not include large diameter or other well configurations. The RICAP program used by PNOC-EDC has been utilised for the calculation of the injection capacity of reinjection wells while the wellbore simulator WELLSIM is used for the calculation of production well output. These methods are briefly discussed and several production and reinjection wells representing different permeabilities and characteristics are examined.

2.0 Reinjection Wells

2.1 Reinjection Well Capacity

2.1.1 Measurement

The injection capacity of a well is the ability of the well to accept fluid. This fluid may be separated water from a separator station or condensate from the cooling tower. Normally, the well’s injection capacity at different wellhead pressure is measured to produce an “injection capacity curve;’ which is similar to an “output curve” of a production well. The flowrate can be measured by several methods such as using an orifice plate or chemical tracers. The pairs of wellhead pressure and injection flow-rates are then plotted to generate the “injection capacity curve”.

The importance of this curve is that it determines the suitability of a reinjection well to be used for brine disposal and is likewise a useful reference in daily plant operations to estimate the flow of reinjection fluid into the well given the wellhead pressure or vice versa.

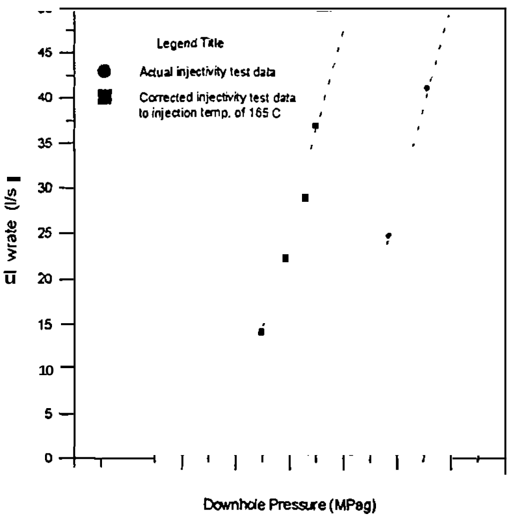


Figure 2. Typical flow versus stable downhole pressure plot of a well showing the actual test data and the data corrected to desired hot injection temperature of 165 °C.

2.1.2 Prediction

The "injection capacity curve" of a well can be predicted when operational constraints make it impossible to test the well before it is used for actual operations. The method of estimating the well's injection capacity **used** by **PNOC-EDC** involves **4** steps.

Step 1: Calculation of Injection Zone Pressure

Injectivity test data gathered during completion tests is used to determine the reservoir injectivity relationship and the injection zone static pressure to calculate the zone pressure at a particular flowrate. The injectivity test is carried out after drilling by injecting cold fluid at different flowrates while the feed/loss zone pressure is measured. The best fit line is usually determined by linear regression method and the slope is obtained. The slope is called the injectivity indes and is an approximate measurement of a well's permeability (Grant et al, 1982). The extrapolated feed / loss zone pressure at zero flow is used as the injection zone static pressure (Fig.2). Since the temperature of the injected fluid during the injectivity test is low, the pressure and the condition of the zone will be different from that for the desired hot fluid injection. To correct this, the feed pressure measured during the injectivity test is adjusted by using equation 1. This correction factor was found to improve the injection capacity estimate.

$$\text{Corr. Press.} = \text{Measured Press.} \times \frac{\text{Density of hot fluid}}{\text{Density of Cold Fluid}} \qquad \text{eqn.1}$$

Using the corrected values, a new injectivity index and extrapolated zero flow pressure will be obtained and will be used to calculate the injection zone pressure at the flow rate specified.

Step 2: Calculation of the Static Pressure Due to Elevation

This calculation assumes that the well will be completely filled with fluid during injection and that the depth of the major permeable zone is the same depth where the tool was set during the injectivity test.

Step 3: Frictional Pressure Drop Caculation

For this calculation, the actual liner configuration of the well is required. Where the reinjection pipeline size and length is available: this can be incorporated in the calculation. **A** specified value of the injection flowrate is used.

Step 4: Wellhead Pressure Calculation

Using the parameters calculated in the first three steps, the wellhead pressure at the particular injection flowrate specified in step **3** *can* be calculated using equation 2

$$\text{Wellhead Press.} = \text{Zone Pressure} - \text{Static Press.} + \text{Frictional Press. Drop} \qquad \text{eqn. 2}$$

Once the value of wellhead pressure is obtained, the calculation can be repeated using other values of injection flowrates. The liner configuration can likewise be varied to consider different scenarios. **An** alternative method for determining the reinjection capacity is to plot the available pressures **and** the corrected injectivity line on the same graph, and the intersection would give the capacity. The available pressure is the sum of the separator pressure and the static pressure subtracted by the friction losses.

2.2 Investigation Methodology

TO evaluate the effects of using the slimhole extensions on the injection capacity of reinjection wells, five *(5)* representative reinjection wells were chosen for the evaluation. Each well represents different characteristics and permeabilties to determine the effect of the smaller diameter liner extension for each type of well. For this study, the basis of the wells' permeability is the injectivity index which were obtained during the completion tests.

The condition of the fluid to be injected was assumed to be **165 °C** which relates to a separator pressure of 0.7 MPaa which is common to most **PNOC-EDC** geothermal fields. The pressure drop along the pipeline was not considered as it was assumed that the separator is close to the wellhead.

Liner configurations were varied utilizing the same resenoir characteristics. Two scenarios were considered. The first scenario is the original capacity of the well having a normal size of **7-5/8"** throughout. The second scenario explores the changes in capacity of the well if it were completed with a **7-5/8"** liner and a varying length of 5" slotted liner. The location of the major injection zone was the same in all scenarios. The RICAP program which is based on the prediction method earlier discussed in item **2.1.2** was used for the calculations.

2.3 Representative Wells

All wells considered for this study are standard size with 9-5/8" production casing and **7-5/23"** liner. Two wells in the group, **4R4D** and **4R7D,** have **5"** liner extensions. Table 1 lists the representative wells and a brief description of each well is provided below.

Well Name	Injectivity Index (l/s-MPag)	Prod'n Casing Shoe mMD(mVD)	Main PZone Depth mMD (mVD)	Est. RI Capacity (kg/s) at **0.6** MPag Delivery Pressure
4R4D	45	**970 (865)**	**2300 (1826)**	*109
4R7D	13	**1148 (1144)**	**2100 (1910)**	**82**
4R3D	52	**957 (918)**	**1700 (1535)**	**188**
408	28	**984**	**1900**	**86**
405	39	731	**2150**	**114**

top of liner to the **major** permeable zone is **692 m**

Well **4R4D** is a deviated reinjection well drilled in the Upper Mahiao Sector of the Leyte Geothermal Power Project in Leyte, Philippines. It was initially drilled down to a depth of **1710 mMD (1385.8** mVD) but was later redrilled and deepened with a **6-1/4"** hole to intersect a permeable horizon at **2300 mMD (1826 mVD)**, resulting **in** blind drilling with water. Before redrilling, this well had very low permeability with an injectivity index of 13 l/s-MPa. Injectivity index after redrilling was **45** l/s-MPa. The new liner configuration of the well consists of a **7-5/8"** slotted liner and a 5" slotted liner extension.

Well **4R7D** is a deviated reinjection well drilled in the same sector as **4R4D**. The well was initially drilled down to a depth of **2374** mMD but was deepened to its programmed depth of **2492** mMD **(2227.5** mVD) with a smaller diameter hole after the initial completion tests yielded an injectivity index of 11 l/s-MPa. After deepening, the injectivity index was 13 l/s-MPa. The well was later stimulated by acid injection and a new injectivity index of 18 l/s-MPa was obtained. **As** a result of redrilling, the well consists of a 7-5/8" slotted liner and a 5" slotted liner extension. The well taps a major permeable horizon at 2100 mMD (1910 mVD) which has been intersected by the 7-5/8" slotted liner and is therefore not affected by the smaller diameter liner. This well has the lowest injectivity index among the 5 wells.

Well 4R3D is a deviated reinjection well in the same location as the two wells previously described and is a standard size well with a 7-5/8" slotted liner. This well has an injectivity index of **52** l/s-MPa and is the highest among the five wells considered for this study.

Well 408 is a vertical well drilled in the same sector as earlier wells. It is a standard size well with an injectivity index of **28 l/s-MPa**. This well is ranked fourth in terms of injectivity index among the five wells.

Well 405 is also a vertical well drilled in the Same sector and is a standard size hole with a 7-5/8" slotted liner. The well has an injectivity index of 39 l/s-MPa.

2.4 Results and Discussion

The effect of the different liner configuration on the individual wells is depicted in Figures 3a-e. **A** comparison based on a 0.6 MPag reference wellhead pressure and slotted liner lengths of 100 m. 300 m and 600 m is shown in Figure 4. Well 4R7D, which has the lowest permeability, was least affected **with** a reduction of 3 kg/s at 100 m length to 13 kg/s at 600 m length. In contrast, Well 4R3D, the most permeable well, showed the highest reduction of 21 kg/s at 100 m of 5" liner extension. increasing to 69 kg/s at 600 m. The higher the permeability of the well, the higher is the impact of the 5" slotted liner in the configuration.

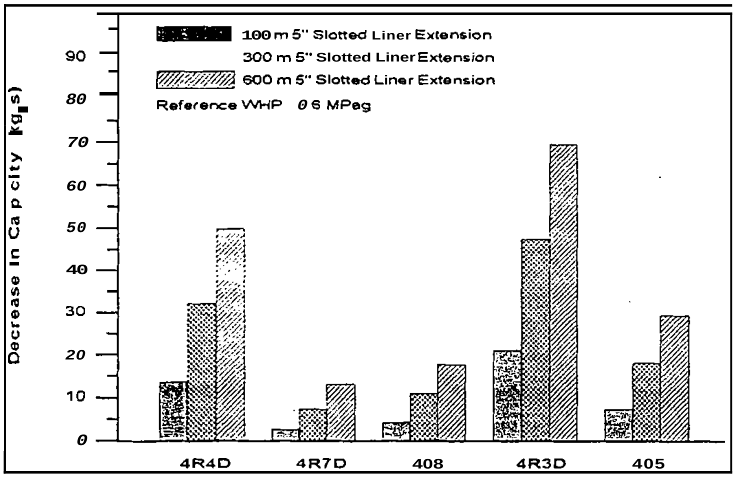
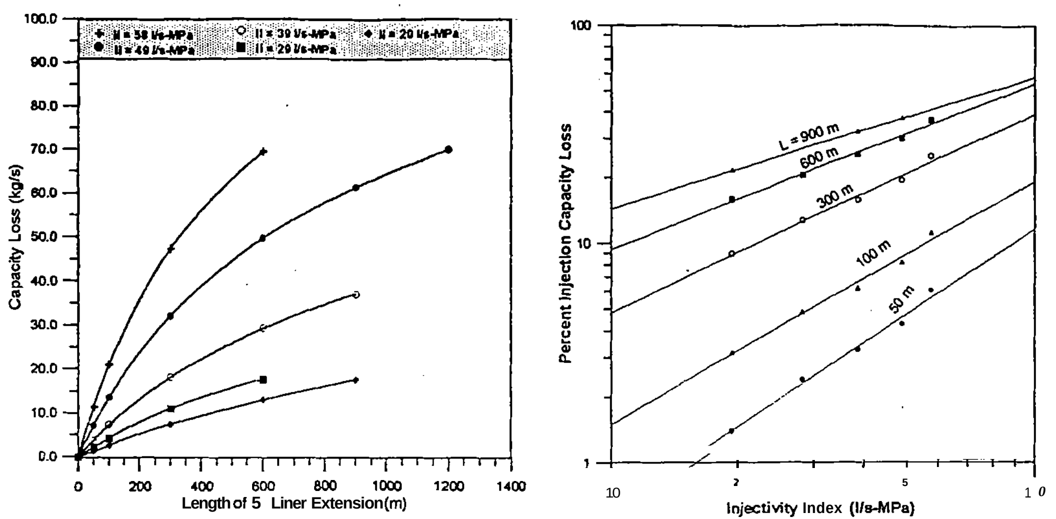


Figure **4.** Different well response to the presence of 5" slotted liner extension at lengths of 100 m, 300 m and 600m for reinjection wells.

The relationship of capacity loss with liner length at different injectivities is presented in Figure 5a. This figure shows the increasing capacity loss with increasing length of 5" slotted liner extension over a wide range of injectivity. The increase in injection capacity loss is due to the increase in pressure drop experienced by the fluid as it flows within a longer length of the small diameter liner. Pressure drop is directly proportional to the length and inversely proportional to the diameter to the 5th power (Darcy-Weisbach Equation).



(a) (b)

Figure 5. Plot showing (a) Relationship of injection capacity loss and length of 5" slotted liner extension at different injectivities. (b) correlation of percent injection capacity loss and corrected injectivity index at various lengths of 5" slotted liner extension.

A correlation between the injection capacity loss and the corrected injectivity index at various lengths of 5" slotted liner can be established based on the results of the calculations. Figure 5b allows the percent loss of injection capacity to be estimated given the corrected injectivity index and the length of the small diameter slotted liner. The total capacity loss can be determined where a well's injection capacity is known. The correlation was applied to other reinjection wells and a reasonable agreement between the calculated and the estimated loss was obtained, as shown in Table 2. At low flows (<1 10 kg/s) the variance is within ± 3 kg/s and is within ± 10 kg/s at higher flows (>120 kg/s). The accuracy of this method needs to be further verified as more data from other wells become available for comparison.

Table 2. Comparison between calculated and estimated loss at L=100m and 600m.

Well	Corr. Injectivity index (l/s-MPa)	Injection Capacity at 0.6 Mpag (kg/s)	Calculated loss at L=100 m (kg/s)	Estimated loss using the correl. (kg/s)	Calculated loss at L=600 m (kg/s)	Estimated loss using the correl. (kg/s)
MG16	72.8	187	30	26	77	79
MG18	77.7	219	27	33	87	97
MG5RD	58.4	172	15	19	55	61
109	41.9	102	8	8	25	28
5R7D	26.1	103	5	5	23	20

3.0 Production Wells

3.1 Wellbore Output Curve

3.1.1 Measurement

The output curve of a well is sometimes referred to as "deliverability curve" or "productivity curve". It is the relationship of discharge mass flowrate and wellhead pressure which can be directly obtained by discharge testing a well. Flow from the well is varied by adjusting the wellbore opening which can be either achieved by using choke valves or by installing back pressure plates of various sizes. The different techniques of wellbore flow measurements are described by Grant et. al (1982). Each mass flowrate and wellhead pressure data pair is plotted to produce the well's characteristic output curve.

The deliverability curve is useful for determining the suitability of a well for energy production. It is also important in the day to day production field operations to estimate well output with changes in operating wellhead pressures.

3.1.2 Prediction

The use of wellbore simulators allow the full output curve of the well *to* be predicted using only one or two sets of available mass flowrate and wellhead pressure data. Calculations of wellbore simulators are based on one dimensional steady flow momentum equations and two phase flow correlations from literature. These correlations were derived by experimental tests and observations. Some of the two phase flow pressure drop models **used** in geothermal applications are the Duns and Ros Model (Duns and Ros, 1963), Hadgu and Freeston Model (Hadgu and Freeston, 1990) and Hagedorn and Brown Model (Hagedorn and Brown, 1965).

The accuracy of this method of prediction depends largely on the accuracy of the wellbore simulator, validity of the conceptual well model, and on the parameters used as the input data for the wellhead - down simulation. Prediction of a well's output curve and the accuracy of wellbore simulators **has** been discussed by Gunn and Freeston, 1991a:

3.2 Investigation Methodology

To study the effects of small diameter liner estensions on the output characteristic of production wells, five representative production wells were selected. The Wellsim Wellbore Simulator which was jointly developed by Geothermal Energy New Zealand (GENZL) and the Geothermal Institute, University of Auckland was used. The features of the simulator have been described by Gunn and Freeston, 1991b.

For each well, two sets of available discharge test wellhead data mere used as the starting conditions. These initial conditions include wellhead pressure, mass flow, enthalpy and equivalent percent weight of CO_2. The installed well casing configuration was used for the initial simulation runs before varying the liner configuration by including a 5" liner extension and further varying the length of the liner extension. Each representative well was simplified by assuming there was only one productive zone at depth. Using these wellhead parameters, a wellhead - down simulation was performed to determine the corresponding feed zone conditions. The drawdown relationship used for all wells was the quadratic relationship, escept for Well 4, which utilised the linear drawdown relationship as only one set of discharge test data was available.

In all cases, the roughness values used for the casing and liner were 1.811×10^{-3} in. and 5.394×10^{-3} in. respectively which are the roughness values recommended by Gould (1974). The effect of heat loss to the surrounding rocks was not considered since no data is available. **As** suggested by Probst et. al (1992) in their study on the comparison of pressure drop models used in simulating geothermal production wells, the Duns and Ros two phase pressure drop correlation was chosen for the calculations.

After the feed zone conditions have been determined and the drawdown indices calculated, these are used as starting conditions for a series of feed zone - up simulation runs to generate an ouput curve over the specified range of mass flowrates. Different "what if' scenarios were then considered; changing the liner configuration by including a 5" slotted liner and varying the length of the liner. In all cases the main producing zone is at the same depth and only the liner configuration has been altered.

It is however stressed that in these calculations, the actual magnitude of the predictions are not to be considered as highly accurate but rather, it is the difference between the "what if' scenarios that would be of interest. This is achieved by using the same set of initial conditions and same set of underlying conditions.

3.3 Representative Production Wells

All production wells considered for this study are liquid fed wells with fluid enthalpies of 1000-14000 kJ/kg. the representative wells are listed in Table 3 and are briefly described below.

Well 1 represents a highly productive well in the Malitbog Sector of the Leyte Geothermal Power Project, discharging a mass flowrate of about 105 kg/s at fullbore conditions with an enthalpy of 1301 kJ/kg. It is a standard size vertical well with a 9-5/8" production casing and a 7-5/8" slotted liner. Well 2 represents a moderately productive well in the Malitbog Sector of the Leyte Geothermal Power Project, discharging a maximum mass flowrate of 56 kg/s with enthalpy of 1348 kJ/kg. It is a standard size vertical well with a 9-5/8" production casing and a 7-5/8" slotted liner. Well 3 is another representative well in the Malitbog Sector of the Leyte Geothermal Power Project with a fullbore discharge mass flowrate of 87 kg/s and an enthalpy of 1283 kJ/kg. It is a standard size vertical well with a 9-5/8" casing and 7-5/8" liner.

Table 3. Representative Production Wells.

Well Name	Injectivity Index	Prod'n. Casing Shoe mMD (mVD)	Major Prod'n Zone	Output 1 Enthalpy / Massflow	Output 1 Wellhead Press.	Output 2 Enthalpy / Massflow	Output 2 Wellhead Press.
	(l/s-MPa)	mMD (mVD)	mMD (mVD)	(kJ/kg)/(kg/s)	(MPag)	(kJ/kg)/(kg/s)	(MPag)
Well 1	56	1142 (1153)	2457 (2400)	1301 / 105	1.02	1259 / 41	3.85
Well 2	30	914	2050	1348 / 56	0.70	1228 / 24	2.18
Well 3	196	671	860	1283 / 87	0.80	1189 / 33	2.89
Well 4	13	1717 (1658)	2750 (2589)	1086 / 23	0.25	--	--
Well 5	35	1188	1700	1390 / 85	1.14	1208125	2.90

*CO_2 content was assumed to be 1% by weight for all wells.

Well 4 represents a well with low permeability and a poor producer drilled at Mt. Labo Geothermal Field Prospect, discharging a mass flowrate of 23 kg/s and is considered as non commercial. This deviated well was completed with a 5" liner extension after drilling problems were encountered while drilling the 8-1/2" hole for the 7-5/8" liner. The well is mainly producing from a feed at 2750 mMD / 2588.5 mVD. The well required stimulation by nitrogen injection before fluid was able to flow to the surface. Only one set of discharge test data is available for this well and is shown in Table 4. The length of 5" liner extension from the 5" top of liner to the main production zone is 70 m.

Well 5 is a representative vertical well drilled at the Mahanagdong Geothermal Power Project in Leyte and is a good producer, discharging 85 kg/s mass flow and 1390 kJ/kg at fullbore condition. It was drilled with a standard size 9-5/8" casing and a 7-5/8" slotted liner.

3.4 Results and Discussion

The five representative production wells evaluated produced the same declining mass flow trend with increasing length of 5" slotted liner estension as shown in Figures 6ae. This is espected since the longer the length of the smaller diameter slotted liner, the higher will be the additional pressure drop. A comparison of the output decline of the five wells based on a wellhead pressure of 1.2 MPag at different lengths of 5" liner extension is shown in Figure 7. Well 2, which is less productive than Wells 1. 3 and 5, suffered a smaller mass flow decrease at the same length of 5" slotted liner extension.

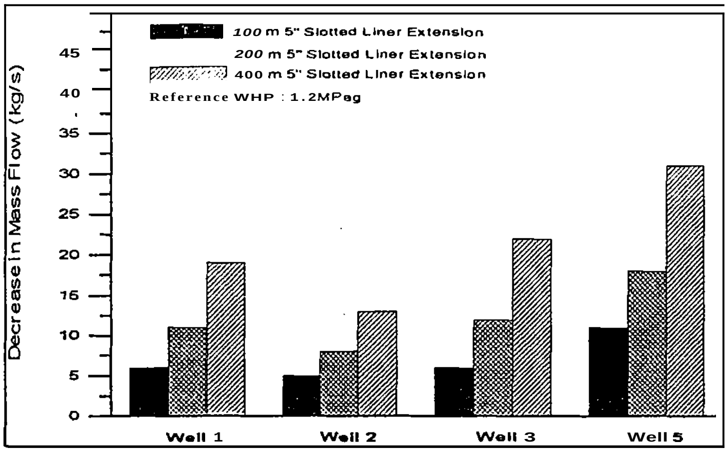
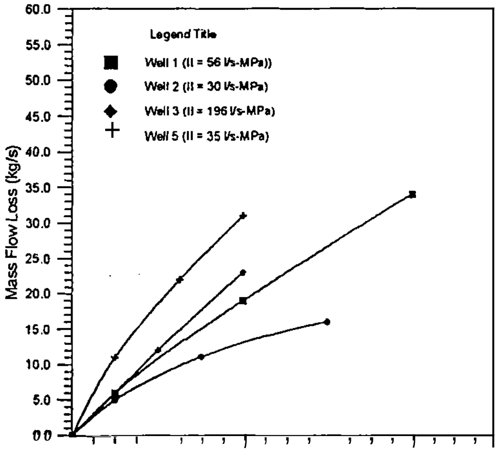
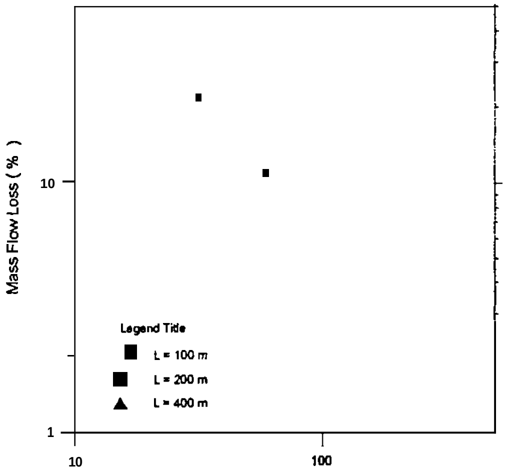


Figure 7. Different well response to the presence of 5” slotted liner extension at lengths of 100 m, 200 m and 400m for production wells.

Well 4 is not included in the plot since it is non commercial with a maximum discharging wellhead pressure of less than 1.2 MPag. As earlier shown in Fig. 6d, Well 4 showed the lowest effect from changes in liner configuration.

The results of the simulation runs also illustrate a strong dependence of the output loss on the well’s permeability. Pressure drawdown occurs in both the reservoir and in the wellbore. In high permeability reservoirs, the pressure drop from the reservoir to the well is insignificant and fluid can be delivered to a well at a greater rate than what the well can actually handle. In such behaviour, termed “wellbore controlled” flow, the pressure drop in the wellbore is the dominant factor and the discharge or output characteristic is dictated by the size of the liner. However, for reservoirs with low permeability, the pressure drop from the reservoir to the well is substantially greater than the pressure drop in the wellbore. In reservoir controlled flow, liner size changes have much lower impact on the discharge flowrate of the well. This applies for both reinjection and production wells although the flow is in the opposite direction.





The relationship of output loss with length of 5" slotted liner extension is shown in Figure Sa indicating that the higher permeability wells (ie. high injectivity) will have a higher capacity loss than the lower capacity wells such as Well 2. Correlation between output loss and injectivity index at various lengths of 5" liner extension is difficult to establish for production wells. The lack of good correspondence between the two parameters is shown in Figure Sb and may be due to several factors such as changes in well performance with time and complexity of two phase flow in the wellbore. Drilling materials such as cuttings and mud are ejected during discharge which may clear the flow path and improve the well's permeability. It is possible, therefore, that if injectivity tests were to be repeated after a period of production, they may show quite different results to those obtained immediately after drilling.

4.0 Similarities and Differences of Production and Reinjection Well Response to the 5" Slotted Liner Extension

The presence of a 5" slotted liner extension causes a decrease in output or capacity for both production and reinjection wells. It has been noted that both wells show; a.) increasing capacity or output loss with increasing length of 5" liner extension and b.) higher capacity or output loss with higher permeability. The pressure drop caused by the 5" liner extension is proportional to the length and becomes more significant on wells exhibiting wellbore controlled flow.

The relationship between capacity loss and injectivity index at various lengths of 5" liner extension is more clearly defined for reinjection wells than for production wells. This was shown by the good correspondence of these parameters in Figure 5b. A similar relationship is however difficult to establish for production wells as previously shown in Figure 8b. The reason for the poor correspondence could be due to complexity of two phase flow phenomenon compared to single phase flow and clearing of the well during discharge which causes improved permeability.

5.0 Conclusions

- The decline in capacity of the injection and production wells due to the inclusion of 5" slotted liner to the standard 7-5/8" liner depends on the length of the 5" liner and the permeability encountered in the wells. The longer the length of the 5" slotted liner extension and the higher the permeability, the higher will be the loss. An injection well with an injectivity index of 35 l/s- MPa would lose about 25% injection capacity with a *600* m 5" slotted liner. The loss would be as high as 50 % for a 90 l/s-MPa well with the same length. Quantifying output loss for production wells with injectivity and length of 5" liner extension is not as clearly established, but a well with 30 l/s-MPa injectivity index would lose about 37 % output at 600 m length of 5" slotted liner. Wells with an index higher than 35 l/s-MPa would give a higher output loss.

- The percent injection capacity loss can be estimated using the simple correlation established given the corrected injectivity index and the length of the 5" slotted liner extension. The total capacity loss *can* be determined by multiplying the percent loss with the calculated or measured capacity. This correlation gives good agreement with calculated values. The variance is very small (±3 kg/s) for flows less than 120kg/s and is within ±10 kg/s for high flows (>120 kg/s). The accuracy of this method needs to be further verified as more data from other wells will be available and may be used to further refine this correlation. A similar correlation for production wells could not be established due to the complexity of two phase flow phenomenon and changes in well performance upon first discharge of the well.

References

Barnett. B. (1989) “ A Theoretical Study of the Effects of Bore Diameter on Well Outputs”. Proc. 11th N.Z. Geothermal Workshop. Auckland University, pp.181-187.
Duns, H. and Ros. N. (1963) “ Vertical flow of gas and liquid mixture in wells”. Proc. 6th World Petroleum Congress.

Freeston, D. and Gunn, C. (1993) “Wellbore Simulation - Case Studies”. Proc. 18th Workshop on Geothermal Resrvoir Engineering, Stanford University, Stanford, Calif., pp.261-266.

Gould, T.L. (1974) “Vertical Two Phase Steam Water Flow In Geothermal Wells, Journal of Petroleum Technology, pp. 833-842.

Gunn, C. and Freeston, D. (1991a) “Applicability of Geothermal Inflow Performance and Quadratic Drawdown Relationships To Wellbore Output Curve Prediction”. Geothermal Resources Council Transactions, Vol. 15, pp. 471-475.

Gunn, C. and Freeston, D. (1991b) “ An Integrated Steady-State Wellbore Simulation and Analysis Package”. Proc. 13th N.Z. Geothermal Workshop, Auckland University, pp. 161-166.

Grant, M.A., Donaldson, I., and Bixley, P. (1982), Geothermal Reservoir Engineering, Academic Press, New York.

Hadgu, T., Zimmerman, R.W., and Bodvarsson, G.S. (1994) “Theoretical Studies of Flowrates From Slimholes and Production-Size Geothermal Wells”. Proc. 19th Workshop on Geothermal Reservoir Engineering, Stanford University. Stanford, Calif., pp.253-260.

Hadgu, T. and Freeston, D. (1990) “ A multi-purpose wellbore simulator. Geothermal Resources Council Trans. Vol. 14, pp. 1279-1286.

Hagedorn, A. and Brown, K. (1965) “Experimental Study of Pressure Gradients Occurring During Continuous Two Phase Flow in Small Diameter Vertical Conduits”. J. Pet. Tech., pp. 475-484.

PNOC-EDC Internal Reports.

Pritchett, J. W. (1993) “ Preliminary Study of Discharge Characteristics of Slimholes Compared To Production Wells in Liquid-Dominated Geothermal Reservoirs”. Proc. 18th Workshop on Geothermal Reservoir Engineering, Stanford University. Stanford. Calif., pp.181-187.

Probst, **A.**, Gunn, C., and Andersen. G. (1992) “A Preliminary Comparison of Pressure Drop Models Used in Simulating Geothermal Production Wells“. Proc. 14th N.Z. Geothermal Workshop, Auckland University, pp.139-144.