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ANALYSIS OF TRANSIENT PRESSURE TESTS FOR OLKARIA EXPLORATION WELLS

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ABSTRACT

Analysis of transient pressure tests for Olkaria West wells shows that both infinite acting and double porosity models can be used to analyse the well behaviour and infer reservoir properties from fall-off steps of long enough duration, in wells where no siginificant thermal recovery occurs. The double porosity model gives better estimates of reservoir properties than the infinite acting model, for long fall-off steps in wells intercepting fractures. Semilog methods give fairly good estimates of reservoir transmissivity for the long fall-off steps but are highly inaccurate when used independently, especially for the short fall-off steps conducted in most of the wells. Double porosity models can also be used for recovery test analyses where two phase transients are not siginificant.

INTRODUCTION

In order to delineate the Olkaria geothermal field and define a new area for development nine wells have been drilled to the north and west of the present field (Fig. 1), referred to as Olkaria West. The pressure/temperature distribution from drilled wells indicates a large extension of the present field northwards with uplow around 702, large central cold zone associated with Ololbutot fault and separate field to west with an uplow to the west of 301, 303 area (Fig. 1). Transient pressure tests consisting of injection and fall-off steps during well completion tests have been carried out for all the wells. Recovery tests following discharge have also been done for some wells. Normally these tests have as a routine been analysed by Horner methods. Because of the short duration of the tests, selection of the proper slope for semilog lines is not easy. Tests for OW 101 to 501 were re-analysed using the curve match for infinite acting reservoir, semilog methods and using a computer fit to analytical models, for infinite acting reservoir, double porosity system and uniform flux vertical fracture. Since then further recovery data for OW 301 and completion tests on OW 701, 702 and 303 have become available.

These analytical models have been used in the analysis of recovery data from Krafla Wells by Sigurdsson et al (1985) which showed good fits to measured data, but gave generally lower transmissivities than initially estimated from the injection tests at well completion. The analytical models have also been used in interpretation of interference tests at Ngahwa geothermal field in New Zealand in which it was found that the reservoir response to production/ injection was better modelled with double porosity systems that with infinite acting system McGuiness (1984).

In the infinite acting reservoir and double porosity models computer fit of field data, initial guess values of reservoir parameters from the type curve match were used. The programme then adjusted these figures for a best fit to measured data in a series of interation steps.

Injection/Fall-off Tests

Table 1 summarises the results of the transient analysis of the fall-off and injection steps using type curve match, semilog methods, analytical infinite acting and double porosity models. The injection and fall-off steps for wells 101 to 201 were of short duration typically 40-50 minutes, making reliable estimates of wellbore and reservoir properties difficult especially using the semilog methods. The transmissivity is $4.8\text{-}8.0 \times 10^{-8}$ m^3/Pas for OW 101. Transmissivity for OW 201 is $1.8\text{-}2.0 \times 10^{-8}$ m^3/ Pas, (with the double porosity model giving the better fit (Fig. 2b), indicating large fracture permeability with no restriction to fluid flow in fractures.

Injection and fall-off tests for OW 301 were influenced by large thermal recovery with no conclusive results. Two injection and fall-off steps were conducted for OW 401. The fall-off steps lasted over 2 hours and give transmissivity in the range $1.8\text{-}4.3 \times 10^{-3}$/Pas. In the first step no semilog line develops (Fig. 3) making determination of transmissivity by semilog method inaccurate. In the 2nd step (Fig 4) all methods give fairly close estimates of transmissivity.

Two long injection/fall-off steps were conducted in well 501, the fall-off steps lasting 5 and 8 hours, conducted at 1400 and 1300 m depth. All the methods gave similar transmissivities of 0.4-0.7 x 10^{-8} m^3/Pas for the first step and 0.8-1.2 x 10^{-8} m^3/Pas for the repeat step. The double porosity model (Fig. 5) gave near perfect fit to measured data and all methods indicated negative skin showing the effect of the fracture intercepted at 1390 metres. They also indicate high wellbore storage with very low formation storage.

No transient tests were taken in OW 601 due to lack of permeability. Both transient injection and fall-off steps were taken for OW 701 and were analysed using only type curve and semilog methods. Type curve and semilog analysis of fall-off show a high transmissivity of 5.7-6.3 x 10^{-3} m^3/Pas with high well bore storage and zero skin. The injection steps show higher variation between semilog and type curve match with transmissivity of 4.7-10.5 x 10^{-8} m^3/Pas and correspondingly higher Kh when cold water viscosity is used. Similar analysis for OW 702 shows a transmissivity in the range of 0.8-1.2 x 10^{-8} m^3/Pas, but this well is completely plugged by the stuck drill string from the original depth of 1744 m to 840 metres and similar tests on OW 303 yielded no reliable data as little pressure change occurred down-hole with injection of up to 35 l/s water.

Recovery/Drawdown

Recovery tests have been carried out in wells 101, 201 and 301. Pressure during flow for OW 101 indicates a drawdown of 30.0 bar at 1000m, but on shut in pressure recovers rapidly showing a small radius of influence. The transmissivity from drawdown is 0.5 x 10^{-8} m^3/Pas using a radius of 50 metres. The gas content of the discharge is 0.44% (mainly CO_2). Therefore, the large drawdown may be due to formation scale deposits which makes estimation of transmissivity erroneous (Petty, 1983). Taking into account the gas partial pressure, (Sutton, 1976) the minimum pressure for single phase conditions in the reservoir is 50.4 bar, showing that recovery is influenced by two phase conditions for the first two hours, hence no good fit is obtained using analytical models. Semilog methods (Fig 6) indicate a transmissivity of 17.9 x 10^{-8} m^3/Pas.

Similar analysis for OW 201 taking into account the gas content indicate two phase conditions are present for only 20 minutes, with the draw-down during discharge equivalent to 5.0-10^{-8} m^3/Pas. No good fit was obtained using the type curve or analytical infinite acting model. A good fit was obtained using the double porosity model (Fig. 7) and together with semilog methods give a transmissivity of 11.2-16.4 x 10^{-8} m^3/Pas, with high formation storage and a large positive skin.

Recovery tests on OW 301 indicate a very high transmissivity of 28.2 x 10^{-8} m^3/Pas from the type curve match (Fig. 8) with zero skin and very high formation storage. The semilog methods give higher transmissivity of 33.8-37.5 x 10^{-8} m^3/Pas. Results of the type curve match are influenced by lack of early time shut in data as a flowing profile could not be taken.

A recent flowing pressure survey of OW 401 indicates a drawdown of 35.5 at 1100 metres equivalent to a transmissivity of 0.7 x 10^{-8} m^3/Pas, but could also be influenced by scale deposits. A shut in test is yet to be conducted.

CONCLUSION

From the analyses presented, type curve match, analytical infinite acting, double porosity and semilog methods can be used to infer reservoir properties from long fall-off/injection steps, with no siginificant thermal recovery. Double porosity model gives a better estimate for wells intercepting fracture and only semilog methods can be used for recovery tests where large two phase transients occur. The average transmissivity of wells located within the Olkaria fault zone is high but compares with that obtained from the history match for the best wells in Olkaria East (KPC 1984), with recovery tests indicating higher transmissivities. The average output of Olkaria West wells is high with low discharge enthalpy, but the output does not directly correllate with transmissivity because of varying discharge enthalpy.

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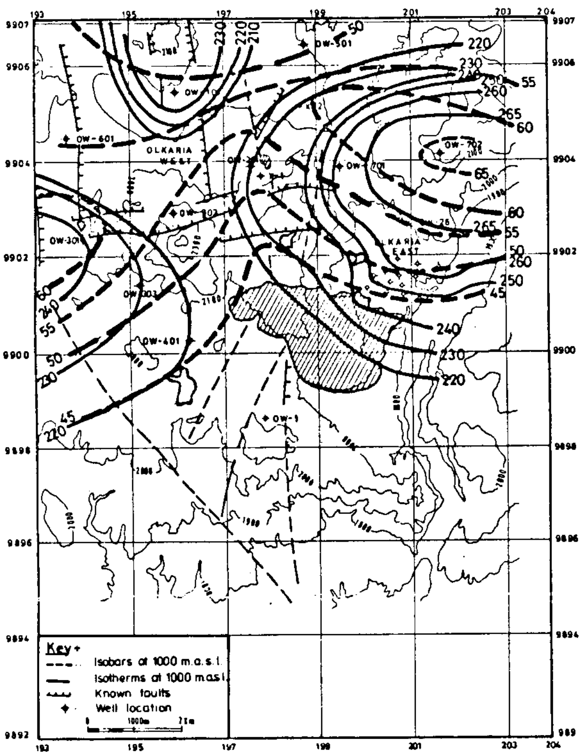

Fig:- 1. OLKARIA GEOTHERMAL FIELD

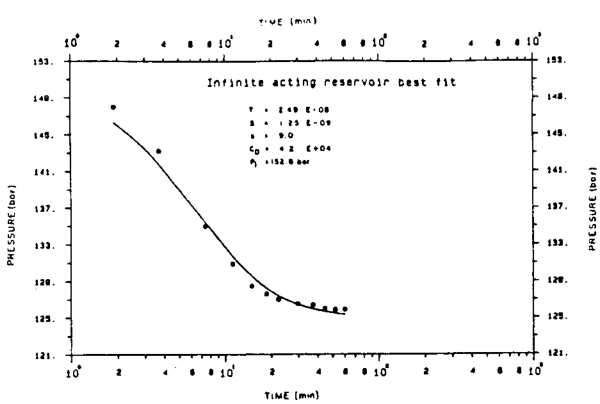

Fig. 2(a) Analytical infinite acting reservoir fit of pressure fall-off at 1900 m in well 201.

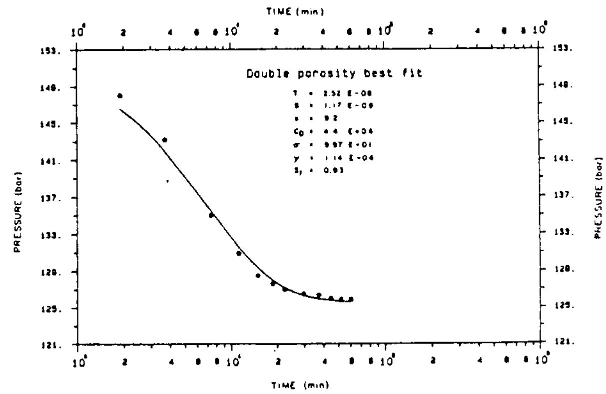

Fig. 2(b) Analytical double porosity fit of pressure fall-off at 1900 m in well 201.

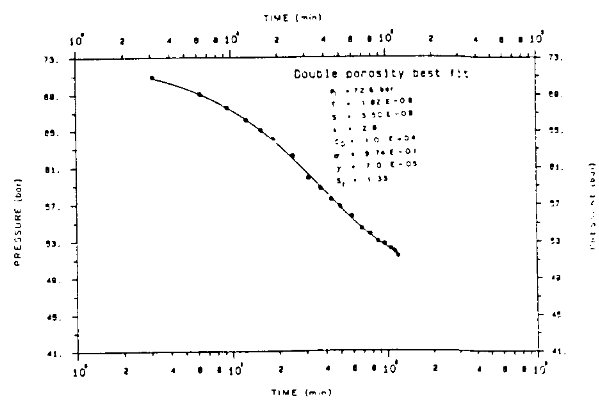

Fig. 3 Analytical double porosity fit of pressure fall-off at 1100 m in well 401.

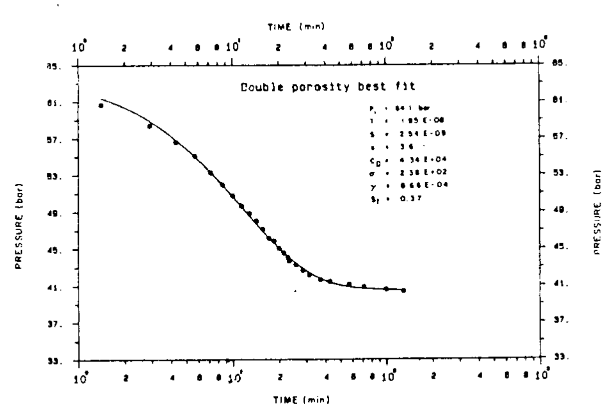

Fig. 4 Analytical double poorosity fit of pressure fall-off at 1000 m in well 401.

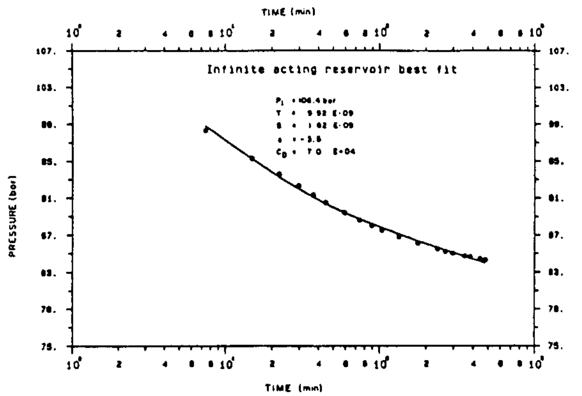

Fig.5(a) Analytical infinite acting reservoir fit of pressure fall-off at 1300 m in well 501.

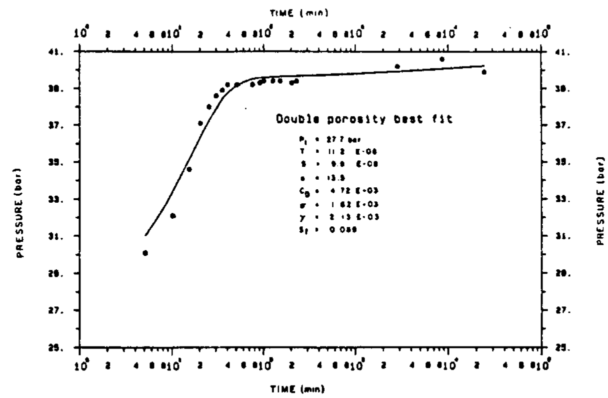

Fig. 7(a) Analytical double porosity fit of pressure recovery at 1000 m in well 201.

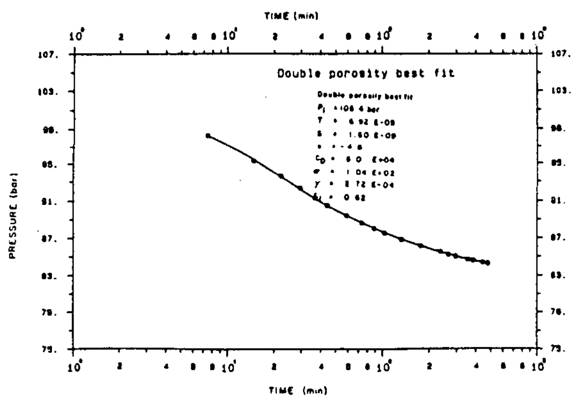

Fig. 5(b) Analytical double porosity fit of pressure fall-off at 1300 m in well 501.

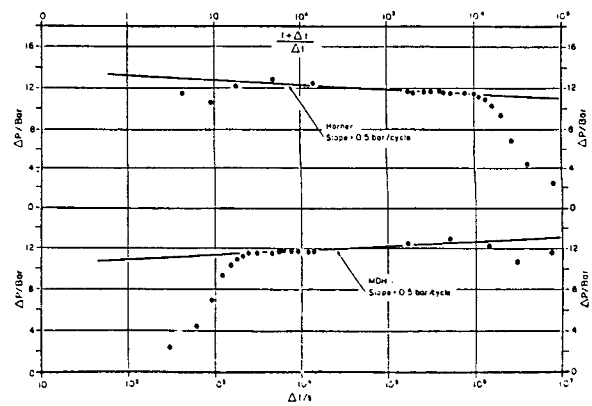

Fig.7(b) Semilog plot of pressure recovery at 1000 m in well 201.

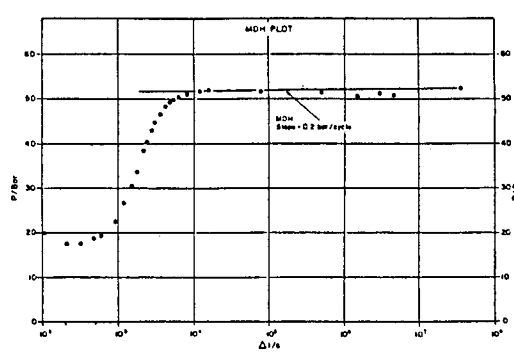

Fig. 6 MDH plot of pressure recovery at 1000 m in well 101.

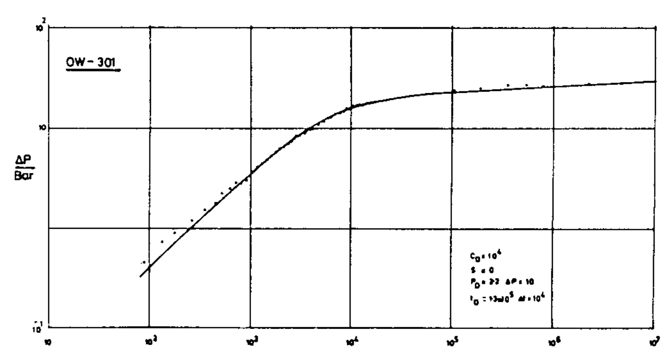

FIG.8 PRESSURE RECOVERY AT 1100 METRES

TABLE 1 (a): Summary of Exploration Wells Data

Well No.	Transmissivity $m^3/Pas/10^{-8}$ from					Discharge		
	Injectivity	Injection step	Fall-off step	Recovery	Productivity	WHP Bar	Enthalpy KJ/kg	Mass Kg/s
101	5.5	-	5.0	17.9	0.5	6.0	1085	16.0
201	1.8	-	2.2	14.0	5.0	4.5	1085	34.2
301	>4.8	-	-	33.2	-	6.6	1600	27.9
401	>0.97	-	2.2	-	0.7	4.7	1050	21.0
501	>0.84	-	0.85	-	-	-	-	-
701	-	7.3	6.0	-	-	9.4	1490	27.7
702	-	0.7	0.9			1.8	?	>3.0
303	>8.0	-	-					

TABLE 1(b): Results of transient pressure analyses, well 101

Type of test	Type of analyses	T/E-08 m3/Pas	S/E-08 m/Pa	CD	s
Injectivity	Injectivity Index	5.5	-	-	-
Fall-off at 1200 m	Analytical infinite acting	4.8	0.60	1.2E+4	-3.0
	Analytical double porosity	4.8	0.69	1.1E+4	-3.0
	Type curve	5.0	1.00	1.0E+4	0
	MDH	4.2			
	Horner	3.7			
	KPC (Horner)	3.6			
Drawdown at 1000 m	Productivity Index	0.5			
	MDH	17.9			
Recovery at 1000 m	Horner	17.9			
	KPC (Horner)	0.02			

TABLE 1(c): Results of transient pressure analyses, well 201

Type of test	Type of analyses	T/E-8 m3/Pas	S/E-8 m/Pa	CD	s
Injectivity	Injectivity Index	1.83	-	-	-
Fall-off at 1900 m	Analytical infinite acting	2.2	2.7	1.3E+3	10
	Analytical double porosity	2.6	2.3	2.3E+3	13
	Type curve	4.0	0.06	1.0E+5	20
	MDH	2.1			
	Horner	2.2			
	KPC (Horner)	0.17			
Drawdown at 1000 m	Poductivity Index	5.0	-	-	-
Recovery at 1000 m	Analytical double porosity	11.2	9.9	4.7E+3	13.5
	MDH	16.4			
	Horner	16.4			
	KPC (Horner)	12.9			

TABLE 1(d): Results of transient pressure analyses, well 301

Injectivity	Injectivity index >4.8				
Fall-off at 1000 m	MDH/Horner	No straight line			
Recovery at 1000 m	Type curve	28.2	187×10^{-8}	10^4	0
	Horner	33.8			
	MDH	37.5			

TABLE 1(e): Results of transient pressure analyses, well 401

Type of test	Type of analyses	T/E-8 m3/Pas	S/E-8 m/Pa	CD	s
Injectivity	Injectivity Index	>.97			
Fall-off at 1000 m	Analytical infinite acting	2.6	0.71	1.5E+4	6.6
	Analytical double porosity	1.9	0.25	4.3E+4	3.6
	Type curve	2.3	1.0	1.0E+4	5.0
	MDH	2.0			
	Horner	1.5			
	KPC (Horner)	0.33			
Fall-off at 1100 m	Analytical infinite acting	2.4	1.7	1.5E+4	5.5
	Analytical double porosity	1.8	3.5	4.3E+4	2.8
	Type curve	4.3	0.59	1.0E+5	5.0
	MDH	0.41			
	Horner	0.35			
	KPC (Horner)	0.31			
Drawdown at 1100 m	Productivity Index	0.7			

TABLE 1(f): Results of transient pressure analyses, well 501

Type of test	Type of analyses	T/E-8 m3/Pas	S/E-8 m/Pa	CD	s
Injectivity	Injectivity Index	0.84-4.0			
Fall-off at 1300 m	Analytical infinite acting	0.99	0.18	7.0E+4	-3.5
	Analytical double porosity	0.69	0.16	6.0E+4	-4.6
	Type curve	0.75	0.08	1.0E+5	-5.0
	MDH	1.18			
	Horner	0.79			
	KPC (Horner)	0.78			
Fall-off at 1400 m	Analytical infinite acting	0.45	0.17	4.7E+4	-4.2
	Analytical double porosity	0.44	0.14	6.0E+4	-4.3
	Type curve	0.39	0.07	1.0E+5	-5.0
	MDH	0.70			
	Horner	0.54			
	KPC (Horner)	0.45			

Table 1g Results of transient pressure analyses Well 701

TEST	TYPE OF ANALYSIS	$T/10^{-8}$ M^3/Pas	$S/10^{-8}$ M/Pa	CD	S	Kh d-m
2nd Injection step	Type curve match	8.0	2.46	10^4	0	14.4
"	MDH	4.7	-	-	-	8.5
3rd injection step	Type curve match	10.5	10.0	10^3	0	18.9
"	MDH	6.0	-	-		10.8
Fall-off step	Type curve match	6.3	1.0	10^4	5	6.3
	MDH	5.9	-	-	-	5.9
	Horner	5.7	-	-	-	5.7

TABLE 1(h) : Results of transient pressure analyses, Well 702

TEST	TYPE OF ANALYSES	$T/10^{-8}$ m^3/Pas	$S/10^{-8}$ m/Pa	CD	S	Kh d-m
First Fall-off Step	MDH	0.79	-	-	-	0.96
	Type curve match	0.79	0.068	10^5	0	0.96
First Injection step	MDH	0.58	-	-	-	1.28
	Type curve match	0.82	0.064	10^5	0	1.82
2nd Injection step	MDH	No semilog straight line				
	Type curve match	- No match				
2nd fall-off step	MDH	0.74	-	-	-	0.91
	Type curve match	1.21	0.086	10^5	0	1.48