Central Petroleum
EP-93-004-1 Well
Purni Formation
Perdika Basin
December 2009
Water Injection-Falloff Test Analysis Summary

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Summary

Weatherford Laboratories (WFT Labs) conducted one water injection-falloff test between December 28th and December 29th, 2009, of the Purni Formation penetrated by Central Petroleum's EP-93-004-1 well. Table 1 summarizes the pressure and temperature conditions of the tested interval. Table 2 summarizes the test analysis results.

This well is a core hole that was not produced before testing and the coal natural fracture (cleat) systems were water filled during each test. Therefore, estimates of permeability to water were equivalent to the absolute permeability.

Table 1. **EP-93-004-1 Pressure and Temperature Conditions**

Test Interval	Coal Top Depth	Coal Bottom Depth	Static Pressure	Pressure Depth	Pressure Gradient*	Temperature	Temperature Gradient**
	m	m	kPaa	m	kPa/m	°C	°C/m
Purni Formation	874.0	878.0	8,398	873.5	9.50	74.7	0.0569

* Pressure gradient computed with a surface pressure of 101.325 kPaa.
** Temperature gradient computed with a mean annual surface temperature of 25 °C.

Table 2. **EP-93-004-1 Reservoir Property Summary**

Test Interval	Coal Thickness	Effective Conductivity to Water	Effective Permeability to Water	Skin Factor	Radius of Investigation
	m	md-m	md	-	m
Purni Formation	4.0	1.56	0.39	-3.3	28.6

The test was evaluated with a pressure-dependent permeability model with infinite boundary conditions. The permeability estimate of 0.39 md was moderate. The estimated skin factor of -3.3 suggests that a fractured near-well area exists with higher permeability than the reservoir. The static pressure estimate indicated that the tested interval was under pressured relative to the hydrostatic head of water to surface.

The estimated radius of investigation during the test was 28.6 m due to the extended falloff test.

The remainder of this report discusses the test data and the analysis thereof.

Test Analysis Details

The water injection-falloff test was performed between December 28th and December 29th, 2009. The test interval was the Purni Formation at depths between 874.0 and 878.0 m. The upper and lower packers were placed at depths of 873 and 878 m, respectively. The gauge was set between the packers at a depth of 873.5 m. This section discusses the analysis of the data collected during this test.

Figure 1 illustrates pressure and temperature measured by a transducer at a depth of 873.5 m. The test consisted of an 8-hour injection period at an average rate of 2.56 liters per minute that started approximately 4.5 hours after the transducers were initialized followed by a 16-hour falloff period with no injection.

Figure 1. Pressure and Temperature Data

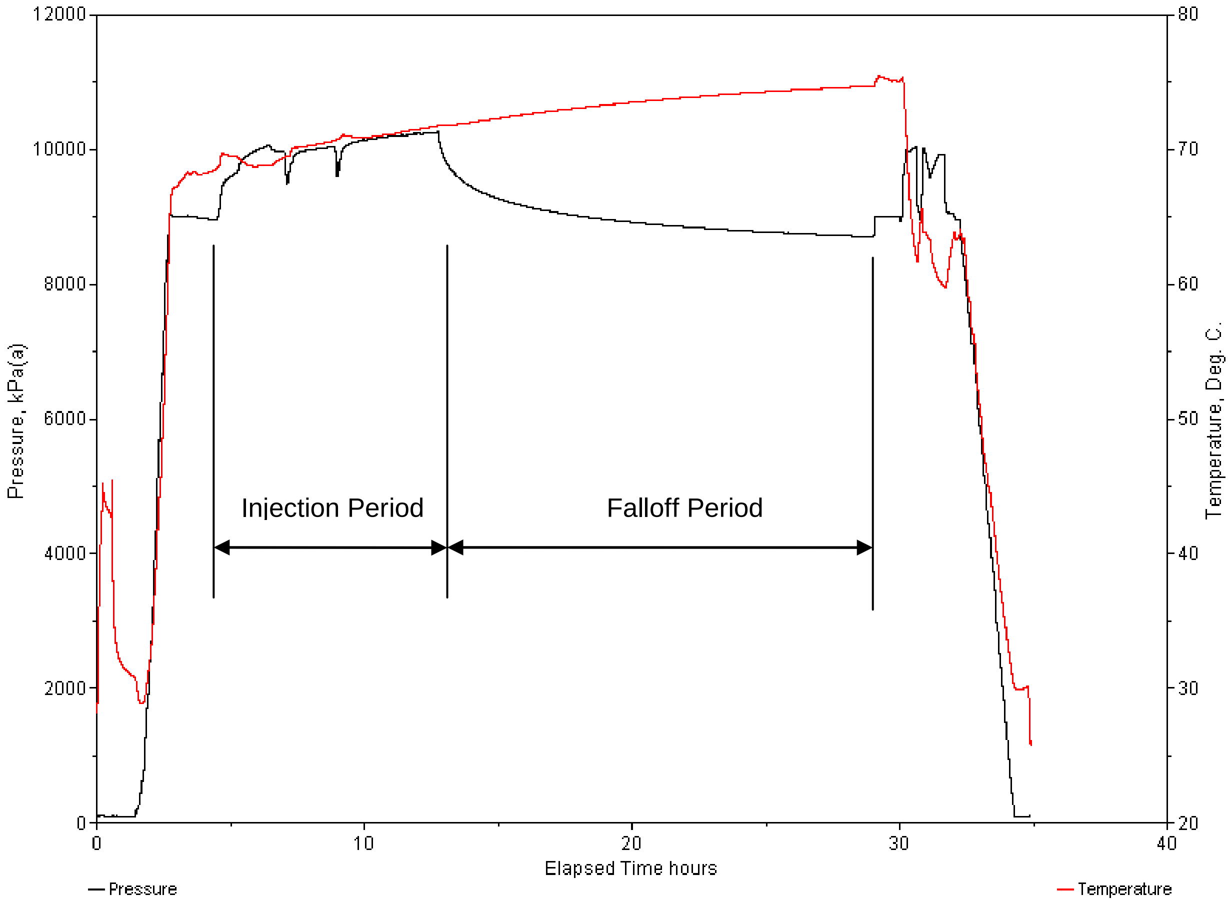


Figure 2 illustrates the surface water injection rate data. The injection rate data were simplified to the test history summarized in Table 3 for analysis.

Figure 2. **Surface Water Injection Rate Data**

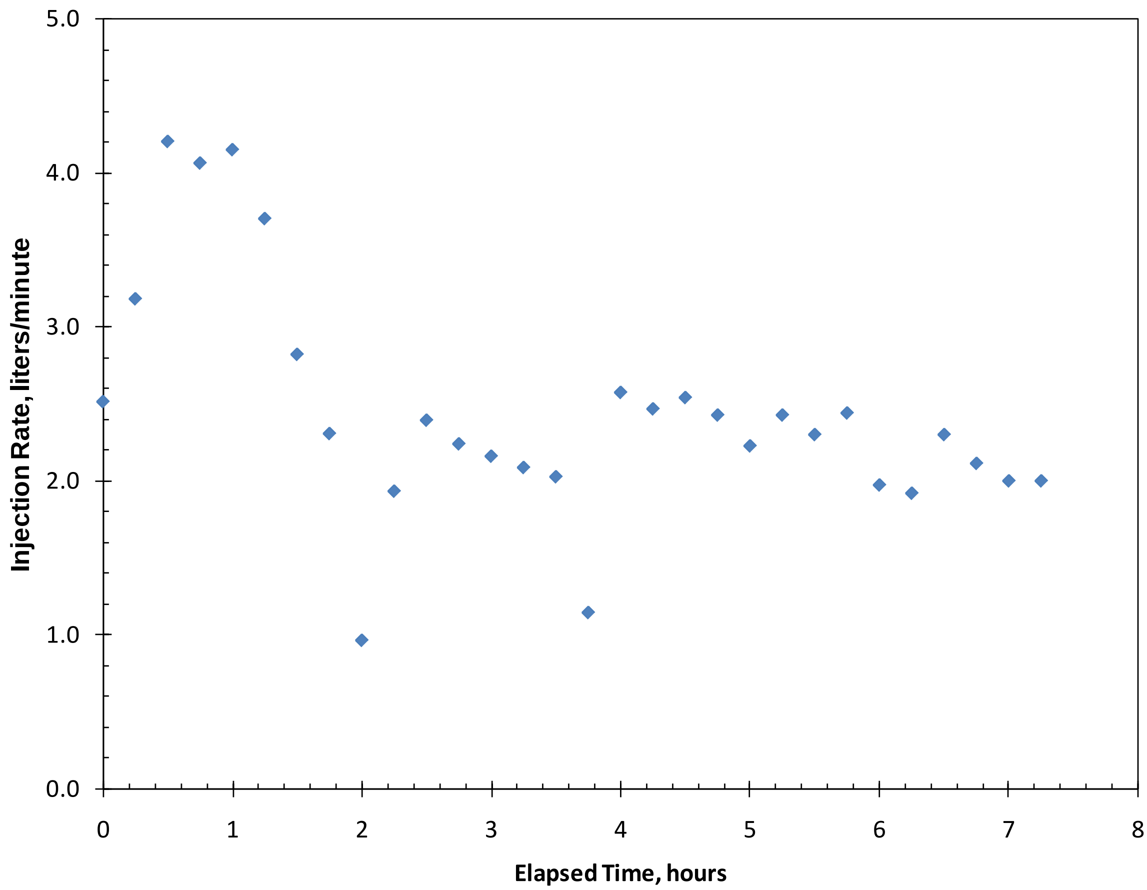


Table 3. **Injection-Falloff Test Times**

Test Period	Elapsed Time at Period Start	Elapsed Time at Period End	Surface Water Injection Rate	Pressure at Period Start	Pressure at Period End
	hours	hours	liters/min	kPaa	kPaa
Injection	0.000	8.242	2.56	8,977.2	10,272.2
Falloff	8.242	24.505	0	10,272.2	8,703.5

Table 4 summarizes the test analysis parameters. The coal thickness was determined by visual observation of the coal during coring activities. The values for Young's Modulus and Poisson's Ratio were typical values for coal and were used to compute the pore volume compressibility. The porosity estimate was obtained by application of the variable permeability model discussed at the end of this report. Water properties were estimated from correlations[1] for fresh water at the reservoir temperature.

Figure 3 illustrates a diagnostic graph of the falloff period data. A diagnostic graph presents the logarithm of the pressure change and the logarithm of the derivative of the pressure change versus the logarithm of the elapsed time during the period.

The data were evaluated with an infinite reservoir model. The model matched the falloff period well as illustrated in Figure 4, which is a semilog graph of the falloff period data. Figure 5 illustrates the match with entire test history. The computed behavior generally matched the measured data throughout the test.

Table 4. **Analysis Parameters**

Parameter	Units	Value
Geometry		
Top Depth	m	874.0
Bottom Depth	m	878.0
Coal Thickness	m	4.0
Wellbore Radius	m	0.089
Coal Matrix Properties		
Temperature	°C	74.7
Young's Modulus	kPaa	$3.65(10^{6})$
Poisson's Ratio	-	0.25
Natural Fracture Properties		
Porosity	vol. fraction	0.001
Total Compressibility	kPa^{-1}	$2.29(10^{-4})$
Water Properties		
Viscosity	cp	0.382
Formation Volume Factor	res. vol./surface vol.	1.023

Table 5 summarizes the analysis results that resulted from matching the infinite model to the observed test behavior.

Table 5. **Test Analysis Results**

Property	Unit	Value
Model	-	variable permeability model with wellbore storage and skin effects
Static Pressure	kPaa	8,398
Temperature	°C	74.7
Pressure and Temperature Depth	m	873.5
Pressure Gradient to Surface	kPa/m	9.50
Temperature Gradient to Surface	°C/m	0.0569
Effective Conductivity to Water	md-m	1.56
Effective Permeability to Water	md	0.39
Dimensionless Wellbore Storage Coefficient	-	100
Skin Factor	-	-3.3
Flow Efficiency	%	243.4
Radius of Investigation	m	28.6

Figure 3. **Falloff Period Diagnostic Graph**

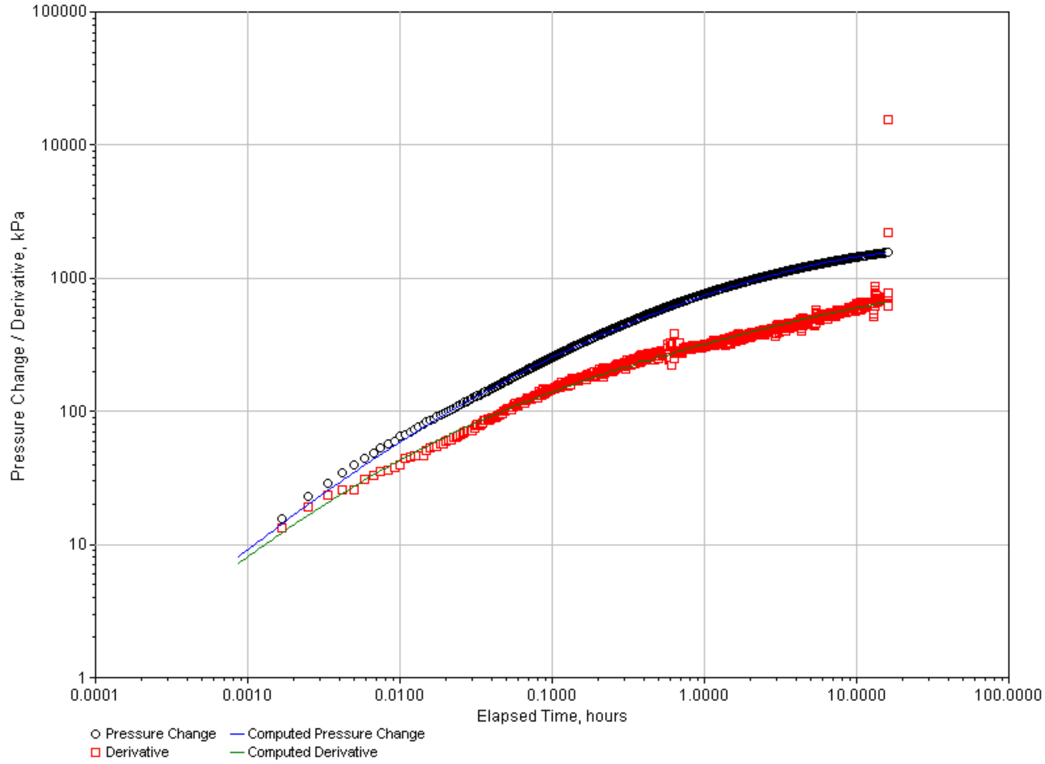


Figure 4. **Falloff Period Semilog Graph**

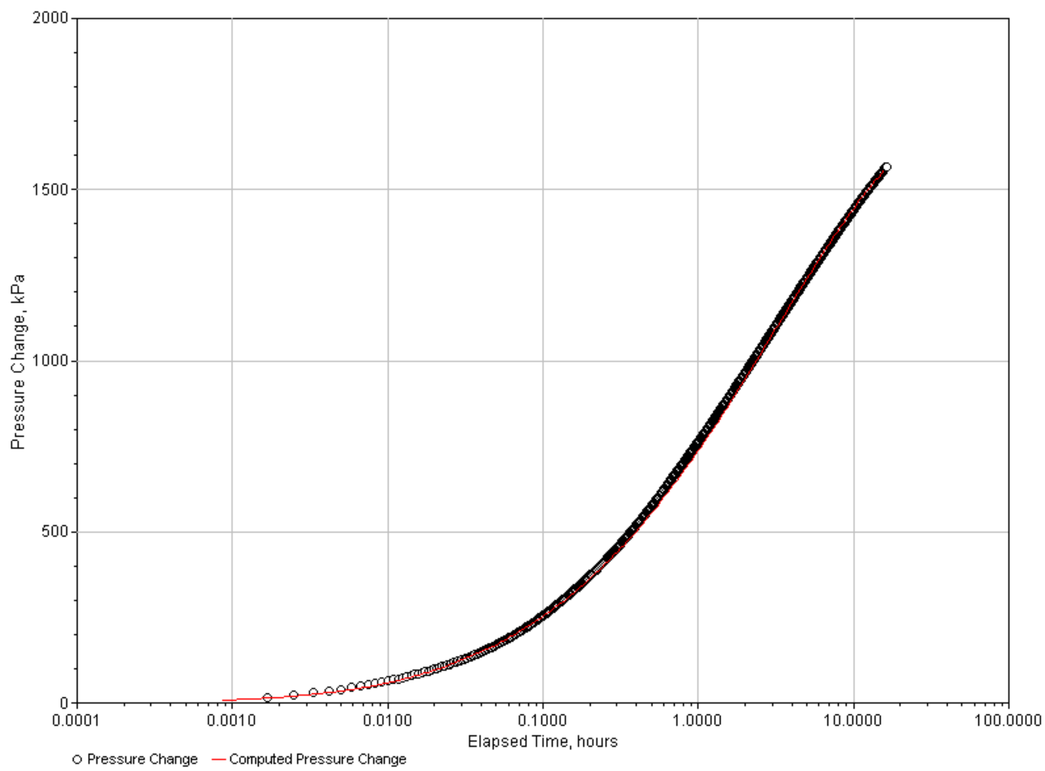
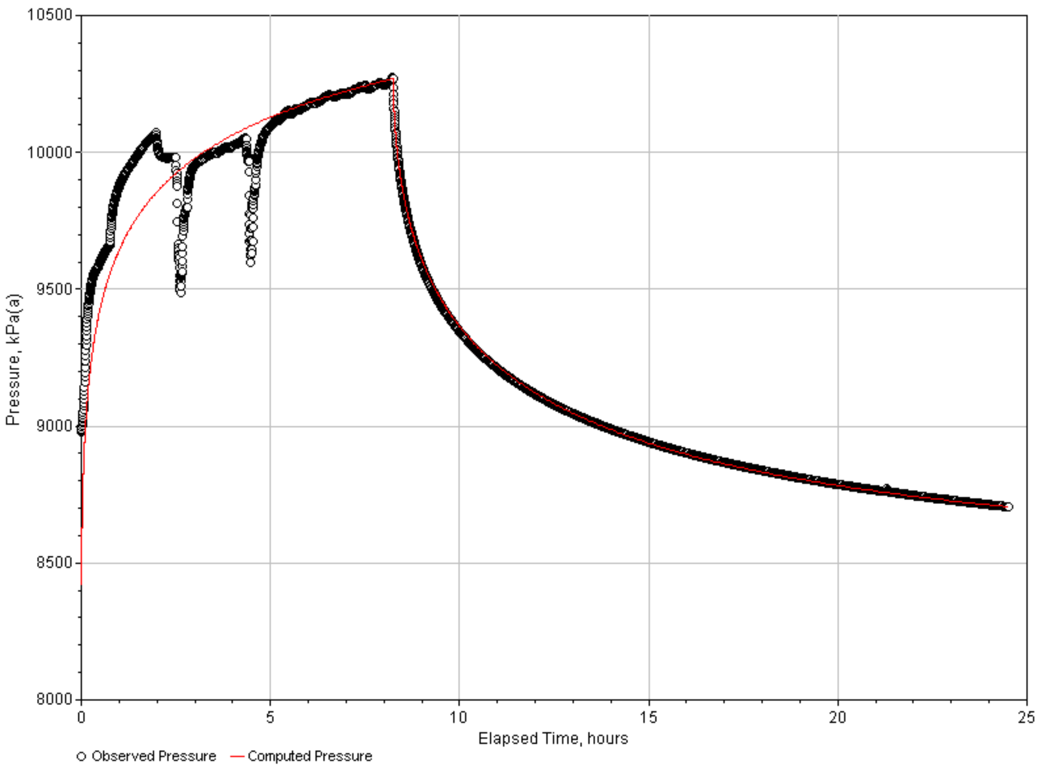


Figure 5. **History Match**



Pressure-Dependent Permeability Model

Analysis of water injection-falloff test data measured in coal seams is similar in many respects to well test analysis of conventional reservoirs. There is little interaction with the coal matrix in which the gas is stored during water injection. As a result, coal seam water injection tests can act very similar to those that may be performed in a sandstone aquifer for instance. The primary difference is coal permeability is not constant. Injection and production both change the natural fracture porosity and permeability. Palmer and Mansoori documented the changes that occur during production due to depletion of gas.[2] Mavor and Gunter documented the changes that occur during water and gas injection[3] based upon research in Canada performed by the Alberta Research Council (ARC).

WFT Labs has developed well test analysis software that is applicable to single and multiphase tests in conventional and unconventional reservoir including coal seams. Much of the coal seam well testing technology included in this software was published in Reference[4]. The variable permeability model used for coal analysis was developed during the ARC research. This model is based upon application of Equations 1 through 4 which were originally published by Palmer and Mansoori.[2]

Equation 1 is the relationship between porosity and pressure based upon the initial porosity and the rock mechanical properties. Equation 2 is the relationship between permeability and porosity changes. The rock mechanical properties are computed from Young's Modulus and Poisson's Ratio with Equations 3 and 4.

$$\frac{\phi}{\phi_i} = 1 + \frac{(p - p_i)}{\phi_i M} \qquad (1)$$

$$\frac{k_a}{k_{a-i}} = \left(\frac{\phi}{\phi_i}\right)^3 \qquad (2)$$

$$M = E\frac{1-\nu}{(1+\nu)(1-2\nu)} \qquad (3)$$

where:

ϕ	*natural fracture porosity, fraction of bulk volume*
ϕ_i	*initial natural fracture porosity at pressure p_i, fraction of bulk volume*
p	*pressure, psia*
p_i	*initial pressure, psia*
k_a	*absolute permeability, md*
k_{a-i}	*initial absolute permeability at p_i, md*
M	*constrained axial modulus, psi*
E	*Young's modulus, psi*
v	*Poisson's ratio, dimensionless*

The application to injection test analysis was based upon the integral transform listed in Equation 5 originally published by Samaniego et al.[5]

$$m(p) = \int_{p_m}^{p} \frac{k(p)\rho(p)}{\left[1-\phi(p)\right]\mu(p)}dp \qquad (5)$$

where:

$m(p)$	*pressure-dependent permeability potential, md-kg/m^3-cp*
$k(p)$	*pressure-dependent permeability, md*
$\rho(p)$	*pressure-dependent density, kg/m^3*
$\phi(p)$	*pressure-dependent porosity, volume fraction*
$\mu(p)$	*pressure-dependent viscosity, cp*

P *pressure, kPaa*

The software is used to match the observed pressure behavior by adjusting the initial natural fracture porosity, ϕ_i, and the initial absolute permeability, k_{a-i}, at the average reservoir pressure.

References

1. Whitson, C.H., and Brule, M.R.: *Phase Behavior*, Monograph Volume 20, Henry L. Doherty Series, Society of Petroleum Engineers, Richardson, Texas (2000).

2. Palmer, I. and Mansoori, J.: "How Permeability Depends on Stress and Pore Pressure in Coalbeds: A New Model," *SPE Reservoir Evaluation & Engineering* (Dec. 1998) pp. 539-544.)

3. Mavor, M.J. and Gunter, W.D., "Secondary Porosity and Permeability of Coal versus Gas Composition and Pressure," *SPE Reservoir Evaluation & Engineering* (April 2006) pp. 114-125.

4. Mavor, M.J. and Saulsberry, J.L.: "Coalbed Methane Well Testing," in *A Guide to Coalbed Methane Reservoir Engineering*, Saulsberry, J.L., Schafer, P.S., and Schraufnagel, R.A. (Editors), Gas Research Institute Report GRI-94/0397, Chicago, Illinois (March 1996).

5. Samaniego V, F., Brigham, W.E., and Miller, F.G.: "An Investigation of Transient Flow of Reservoir Fluids Considering Pressure-Dependent Rock and Fluid Properties," *Society of Petroleum Engineers Journal* (April 1977) pp. 140-150.