Central Petroleum
EP-93-004-4 Well
Purni Formation
Perdika Basin
December 2009
Water Injection-Falloff Test Analysis Summary

Prepared by:
Yi Wang
Weatherford Laboratories

December 20, 2009

Table of Contents

List of Tables

List of Figures

Weatherford
LABORATORIES

Summary

Weatherford Laboratories (WFT Labs) conducted one water injection-falloff test on December 19th, 2009, of Purni Formation penetrated by Central Petroleum's EP-93-004-1 well. Table 1 summarizes the pressure and temperature conditions of 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	612.9	621.0	5,722	615	9.14	54.4	0.0478

*   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	8.1	14.6	1.8	1.85	45.6

*   na - not applicable

The test was evaluated with a pressure-dependent permeability model with infinite boundary condition. The permeability estimate of 1.8 md was high. The estimated skin factor of 1.85 suggests that a damaged near-well area with lower 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 45.6 m due to the extended falloff test.

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

Weatherford®
LABORATORIES

Test Analysis Details

The water injection-falloff test was performed on December 19th, 2009. The test interval was Purni Formation at depths between 612.9 and 621.0 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 615 m. The test consisted of an 6-hour injection period at an average rate of 4.14 liters per minute that started approximately 1.8 hours after the transducers were initialized followed by a 12-hour falloff period with no injection.

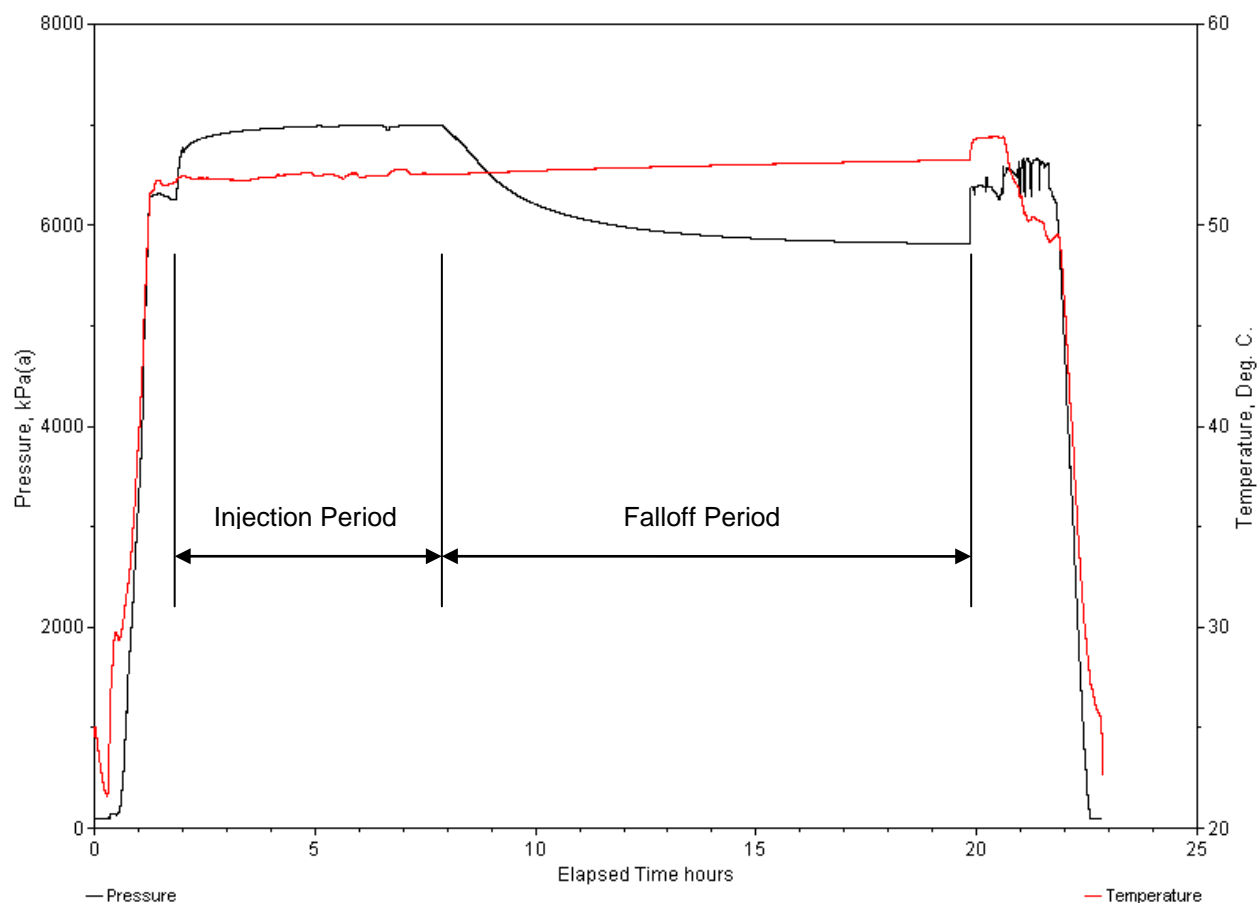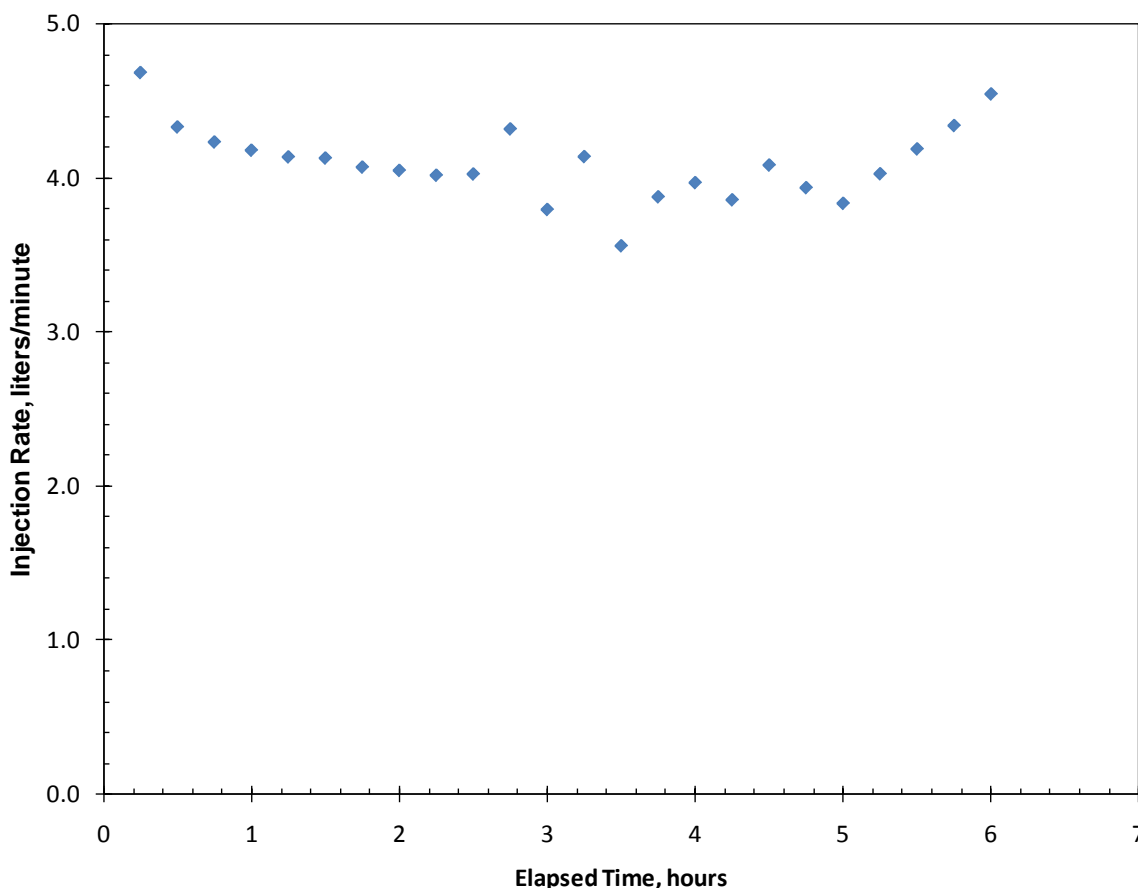**Figure 1.** **Pressure and Temperature Data**

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

Weatherford
LABORATORIES

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	6.118	4.14	6,253.4	7,001.3
Falloff	6.118	18.053	0	7,001.3	5,817.4

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**Error! Bookmark not defined.** for fresh water at the reservoir temperature.

Figure 3 illustrates a diagnostic graph of the falloff period data. A diagnostic graph presents the log of the pressure change and the log of the derivative of the pressure change versus the log of the elapsed time during the period. The derivative was computed with respect to a multirate superposition function.**Error! Bookmark not defined.**

The data were evaluated with an infinite reservoir model**Error! Bookmark not defined.**. 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.

Weatherford
LABORATORIES

Table 4.   **Analysis Parameters**

Parameter	Units	Value
Geometry		
Top Depth	m	612.9
Bottom Depth	m	621.0
Coal Thickness	m	8.1
Wellbore Radius	m	0.089
Coal Matrix Properties		
Temperature	°C	54.4
Young's Modulus	kPaa	$3.65(10^6)$
Poisson's Ratio	-	0.25
Natural Fracture Properties		
Porosity	vol. fraction	0.0005
Total Compressibility	kPa^{-1}	$4.57(10^{-4})$
Water Properties		
Viscosity	cp	0.510
Formation Volume Factor	res. vol./surface vol.	1.012

Table 5 summarizes the analysis results that resulted from matching the infinite model to the observed test behavior. The model matched the falloff period well as illustrated in Figure 3 and Figure 4, which is a semilog graph of the falloff period data. Figure 5 illustrates the match with the entire test history. The computed behavior generally matched the measured data throughout the test.

Table 5.   **Test Analysis Results**

Property	Unit	Value
Model	-	variable permeability composite model with wellbore storage and skin effects
Static Pressure	kPaa	5,722
Temperature	°C	54.4
Pressure and Temperature Depth	m	615
Pressure Gradient to Surface	kPa/m	9.14
Temperature Gradient to Surface	°C/m	0.0478
Effective Conductivity to Water	md-m	14.6
Effective Permeability to Water	md	1.8
Dimensionless Wellbore Storage Coefficient	-	950
Skin Factor	-	1.85
Flow Efficiency	%	76.6
Radius of Investigation	m	45.6

Weatherford
LABORATORIES

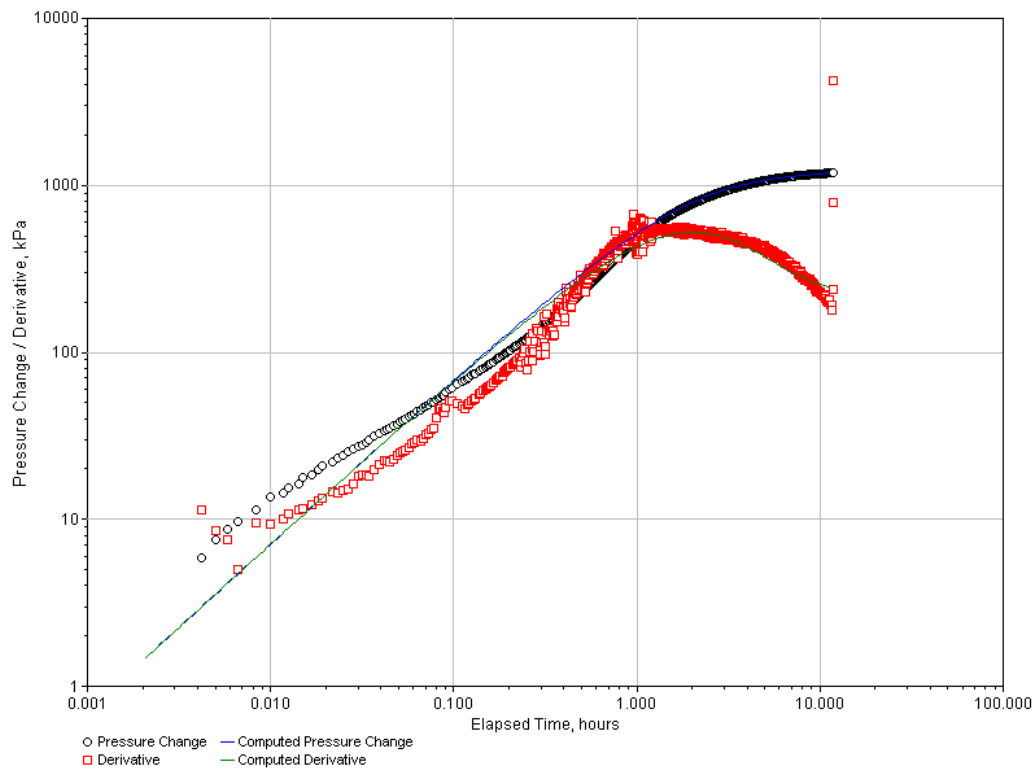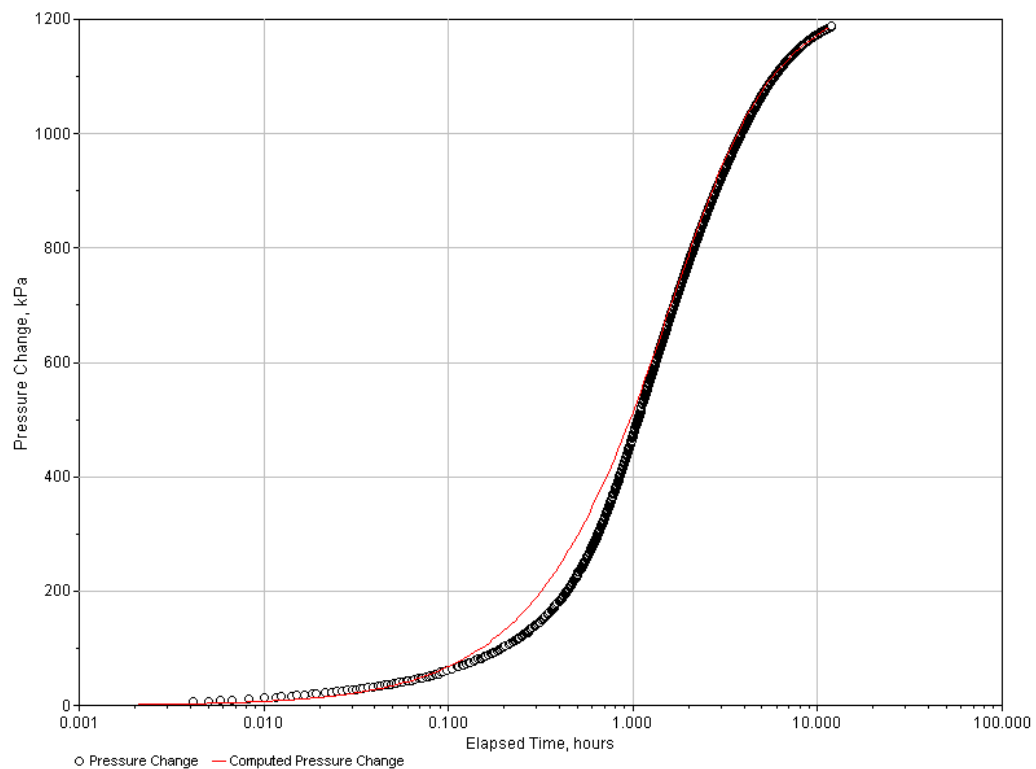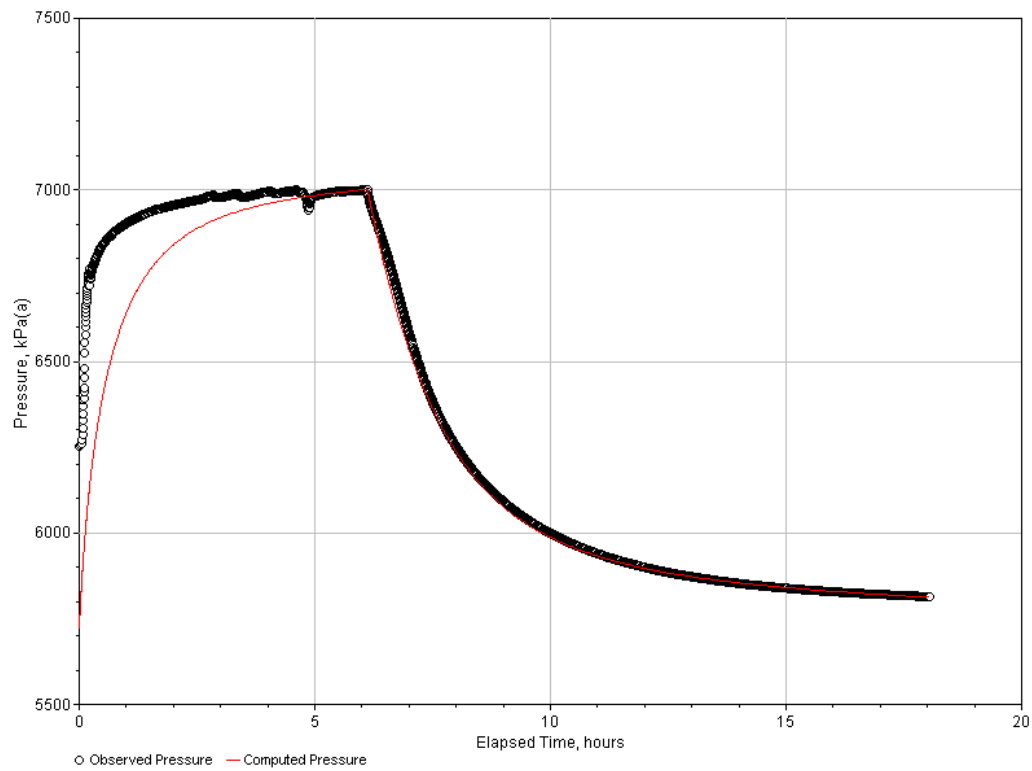**Figure 3.**　　　　　　　　　　　　**Falloff Period Diagnostic Graph**

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.[1] Mavor and Gunter documented the changes that occur during water and gas injection[2] 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 [3]. 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.[1]

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.

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

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

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

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*
ν *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.[4]

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

where:

$m(p)$ *pressure-dependent permeability potential, md-kg/m³-cp*
$k(p)$ *pressure-dependent permeability, md*
$\rho(p)$ *pressure-dependent density, kg/m³*
$\phi(p)$ *pressure-dependent porosity, volume fraction*
$\mu(p)$ *pressure-dependent viscosity, cp*

Weatherford
LABORATORIES

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, $k_{a\text{-}i}$, at the average reservoir pressure.

References

1.   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.)

2.   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.

3.   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).

4.   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.