BJ SERVICES COMPANY
RESEARCH AND TECHNOLOGY CENTER

Special Core Analysis Group

TECHNOLOGY CENTER PROJECT NO. 06-10-0906SCA

NORTHEAST REGION BJ SERVICES COMPANY

ACID FLOW TESTING

BIG LIME FORMATION (1386 TO 1407.9 FOOT INTERVAL)
HARDY # 14 WELL, CHARLESTON EAST FIELD
KANAHWA COUNTY, WEST VIRGINIA

REPORT PREPARED FOR:

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SUMMARY

General – Six boxes of core sections, representing gas productive Big Lime Formation lithologies, Hardy #14 Well, were submitted to the Tomball Technology Center to fully characterize the formation and to provide data to determine if 15% hydrochloric acid, both foamed and unfoamed, is effective as a fracture acidizing fluid.

Rock Characteristics were determined previously by the GS Group at TTC. Sample lithologies range from limestones to calcareous dolostones to dolostones. Samples from depths less than 1388 feet contain minimal quartz. Samples from depths greater than 1388 feet contain 8% - 19% quartz.

Reservoir Quality – As part of the mineralogic report, results of baseline porosity and permeability testing are presented. Porosities range from 0.7% to 14.8%, and dry nitrogen permeabilities range from 0.01 md to 0.70 md. Based on the permeability of samples submitted for analysis, the overall reservoir quality of the interval is low, relative to the potential for natural production from the interval. Acid fracturing should improve productivity.

Flow Testing – Three one inch in diameter plugs were selected for testing - 1387.9, 1392.4, and 1397.4 feet. The shallow plug contains minimal quartz, whereas the two deeper plugs contain greater than 10% quartz. Plugs were fractured along the long axis of the core. A confining pressure of 600 psi was for pre-acid and post-acid flow. After the establishment of an initial permeability, pulses of foamed and unfoamed 15% HCl were injected. Injection was terminated after three pulses of each. Results of testing are given below:

Sample Depth, ft	Geological Services Sample Letter	Pre-fracture k to gas, md	Post-fracture k to Gas, md	k to Gas after Acid, md	Change, %
1387.9	D	0.02	4.4	3.1	-30
1392.4	R	0.02	6.3	2.1	-67
1397.4	TT	0.70	14.6	61.5	+321

The 1397.4 foot sample, which exhibited the greatest prefracture gas permeability, was the only plug which was stimulated by the treatment. Other plugs tested may have experienced fracture face softening and post acid fracture closure.

INTRODUCTION

Scope and purpose

The analysis of carbonate cores, Hardy #14 Well, Charleston East Field, Kanahwa County, West Virginia, serves as the data base for this study. Samples were submitted for analysis by Mr. Roger Myers, BJ Services technical representative, Pittsburgh, Pennsylvania. Samples analyzed in this portion of the study are listed below:

CORE DEPTH, Feet	SAMPLE NO. 06-10-0906	ANALYSIS					
		XRD*	SEM*	TS*	∅*	KN_2*	FLOW
1387.9	SCA-1	X	X	X	X	X	X
1392.4	SCA-2	X	X	X	X	X	X
1397.4	SCA-3	X	X	X	X	X	X

*** = PREVIOUSLY REPORTED** **X = ANALYSIS PERFORMED**
SEM = SCANNING ELECTRON MICROSCOPY **XRD = X-RAY DIFFRACTION ANALYSIS**
TS = THIN SECTION EXAMINATION **KN_2 = NITROGEN PERMEABILITY**
FLOW = FLOW TESTING **∅ = POROSITY**

This study was initiated to provide data for use in treatment/stimulation design for the interval. Specific objectives of the study are as follows:

- Generate flow test results to determine the effectiveness of 15% HCl (foamed and unfoamed) as a fracture acidizing fluid.
- Determine if the proposed acid treatment is effective in stimulating the rock

Analyses Performed

To supply data required from the study, the following analyses were performed:

- Mineralogy - X-ray Analysis, SEM Examination, Thin Section Examination
- Baseline Porosity and Permeability
- Flow Testing of Plugs with Proposed Fluids

PERMEABILITY AND FLOW TESTING

General

Prior to testing, residual hydrocarbon and other contaminants were removed from plugs drilled from submitted core sections, using the toluene vapor extraction technique. In this technique, extraction is continued until the fluid in contact with cores is colorless. Plugs were further cleaned with methanol to strip any residual fluids from the pore system. After cleaning, plugs were dried at 150 °F for 16 hours. After cleaning, porosities and permeabilities were determined. Results of analyses for plugs are given below:

Sample Depth, m	Sample ID	Bulk Density g/cm^3	Pore Volume cm^3	Grain Density g/cm^3	Porosity, %	Permeability, md
1387.9	D	2.768	0.3	2.804	1.3	0.02
1392.4	R	2.675	1.1	2.792	4.2	0.02
1397.4	TT	2.421	3.7	2.840	14.8	0.70

Special Testing

- Most operators in Kentucky and West Virginia do nitrified acid or foamed acid jobs on the shallow, low pressure Big Lime Formation. This study was initiated to determine the effectiveness of foamed and unfoamed 15% HCl as a fracture acidizing fluid. In testing by the Acid Group, the recommendation was forwarded to use a pulsed foamed/unfoamed acid treatment.

Test Procedure: All testing was performed according to standard BJ Services test procedures, as given below:

1. Plugs were fractured along the long axis of the plug.
2. Plugs were saturated with 2% KCl water + 0.5% $CaCl_2 \cdot 2H_2O$, based in tap water.
3. Plugs were seated in rubber sleeves and heated to 95 ºF. The confining pressure was increased to 600 psi for flow testing.
4. Flow is established in an arbitrary formation to wellbore in a forward direction with nitrogen gas to steady state permeability.
5. The acid was injected in alternating slugs of foamed and unfoamed 15% HCl. Three slugs of each were injected.

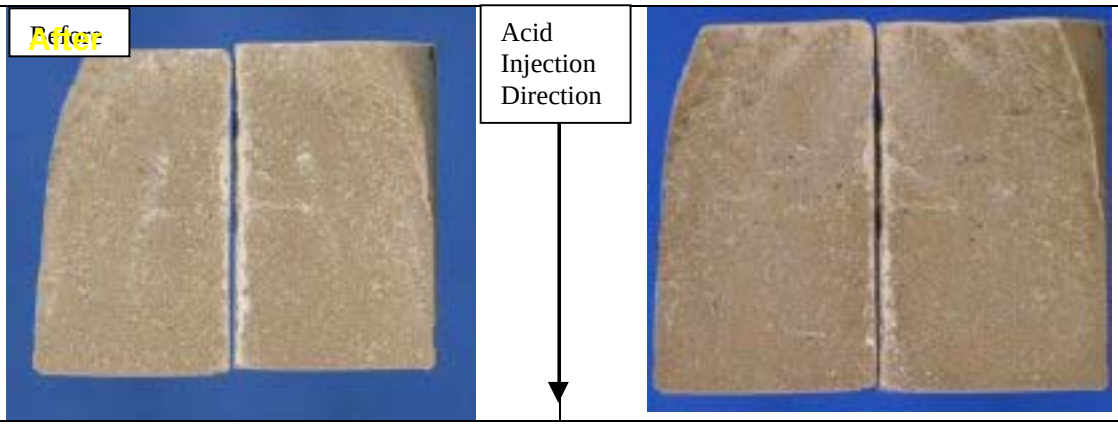
6. Flow was reestablished in the production direction with nitrogen gas to steady state. Results are presented on Figures 1 – 3.

Fluid Systems

Systems utilized in flow testing are given below:

Fluid Formulations		
Saturating Brine (for carbonate rocks) in Tap Water	**Acid Formulations**	
	15% Hydrochloric Acid	**15% Hydrochloric Acid**
2% KCl	1 gpt CI-14	1 gpt CI-14
0.5% $CaCl_2 \cdot 2H_2O$	10 gpt Ferrotrol-300L	10 gpt Ferrotrol-300L
	5 gpt FAW-21	
	Foam with Nitrogen gas	
FLUIDS ARE BASED IN FILTERED FRESH (TOMBALL TAP) WATER.		

FIGURE 1
FLUID RESPONSE TESTING
HARDY #14 WELL
PLUG D, 1387.9 FEET

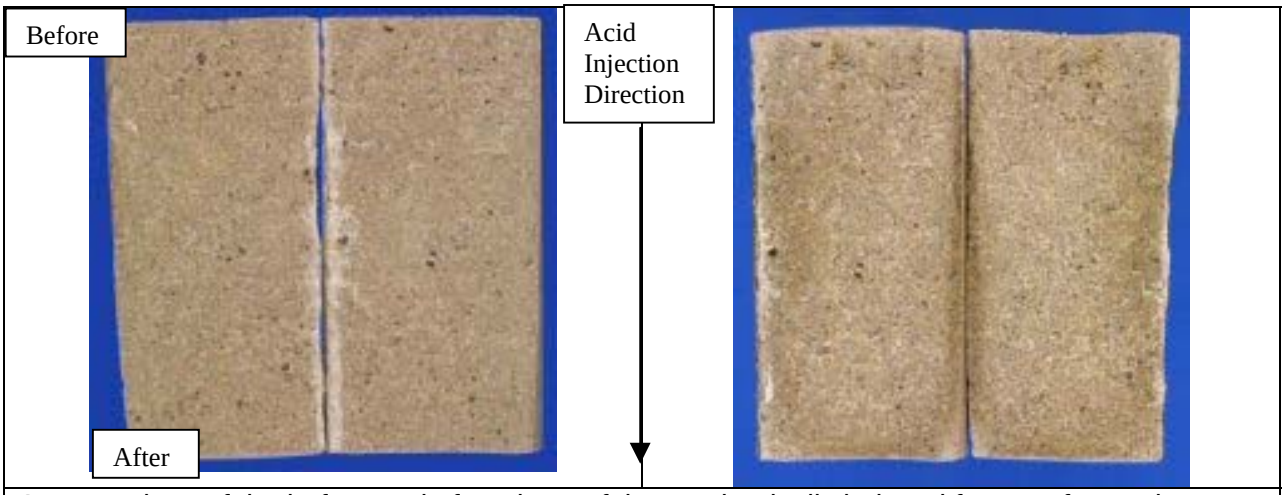


A comparison of the before and after views of the mechanically induced fracture faces shows that minimal etching occurred during acid contact. The fracture may have softened due to acid contact.

This view shows that no wormholes were initiated along the mechanically generated fracture. The acid appears to have spent only on the injection face of the plug. This sample, due to the low quartz content, is more homogeneous that are the two deeper samples tested.

Pre-fracture Permeability to Gas:	**0.02 md**
Post-Fracture Permeability to Gas:	**4.4 md**
Permeability after Pulsed Acidization:	**3.1 md**

FIGURE 2
FLUID RESPONSE TESTING
HARDY #14 WELL
PLUG R, 1392.4 FEET

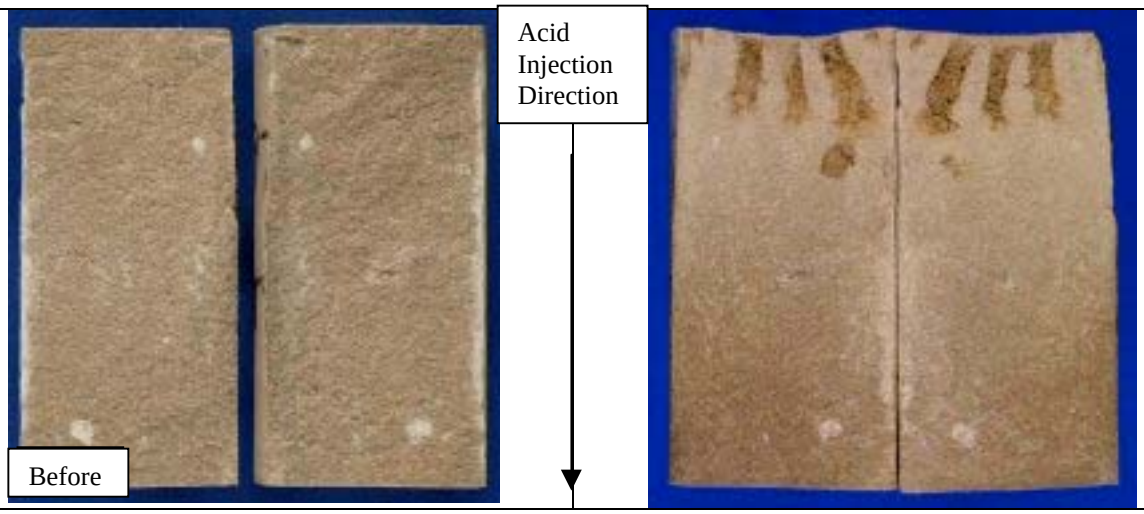


A comparison of the before and after views of the mechanically induced fracture faces shows that some etching did occur during acid contact. The fracture may have softened due to acid contact.

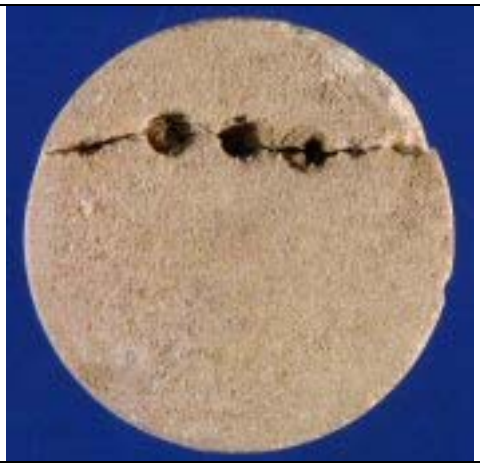
This view shows that two wormholes were initiated along the mechanically generated fracture. These wormholes did not penetrate the length of the core, perhaps due to acid spending at the face of the core and due to debris generation along the fracture face.

Pre-fracture Permeability to Gas:	**0.02 md**
Post-Fracture Permeability to Gas:	**6.3 md**
Permeability after Pulsed Acidization:	**2.1 md**

FIGURE 3
FLUID RESPONSE TESTING
HARDY #14 WELL
PLUG TT, 1397.4 FEET



A comparison of the before and after views of the mechanically induced fracture faces shows that etching did occur during acid contact. Four distinct acid pathways are obvious in the post-acid pair of photos. The partially generated wormholes did not fully penetrate the rock, but, perhaps, due to the higher permeability and porosity of this sample, live acid penetration did occur.



This view shows that at least four wormholes were initiated along the mechanically generated fracture. Although these wormholes did not penetrate the length of the core, due to debris generation along the fracture face good stimulation resulted.

Pre-fracture Permeability to Gas:	**0.7 md**
Post-Fracture Permeability to Gas:	**14.6 md**
Permeability after Pulsed Acidization:	**61.5 md**

COMMENTS

General – Analyses were initiated to fully characterize the Big Lime Formation and to provide data to determine if 15% hydrochloric acid, both foamed and unfoamed, is effective as a fracture acidizing fluid.

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Laboratory Report No.: 06-10-0906 Reported by: _____
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