PRODUCTION VERIFICATION TESTS

Final Report – Phase II

County	State	Date	Wells	Stages	Pkg #
Chautauqua	NY	12/93	3	3	12
Mercer	Pa	7/95	1	1	16
Putnam	WV	9/98	3	3	23

By
RAYMOND L. MAZZA

September 2003

Worked Performed Under Contract No.: DE-AC21-90MC26025

For:
U. S. Department of Energy
National Energy Technology Laboratory
Morgantown, West Virginia

By
Petroleum Consulting Services
Canton, Ohio

Table of Contents

Table of Contents

Table of Contents

DISCLAIMER

I. ABSTRACT

A summary of the demonstrations of a novel liquid-free stimulation process which was performed in three groups of "Candidate Well" situated in Chautauqua CO, Ny, Mercer Co, Pa, and Putnam Co, Wv. The stimulation process which employs carbon dioxide (CO_2) as the working fluid and the production responses were compared with those from wells treated with conventional stimulation technologies, primarily N_2 foam. A total of seven stimulations were performed in seven wells and the gas production was compared with that from nearby "Control Wells". The results indicated no significant benefit in any of the three groups, although the poor response from Devonian Shale wells is suspect as there were TV confirmed casing failures as a consequence of acid attack, and an unusual application of perforating bullets rather than shaped charges.

II. INTRODUCTION

The demonstration of a unique liquid-free stimulation treatment technique which utilizes carbon dioxide (CO_2) as the working fluid and which was previously unavailable in the U.S. was initiated and performed under the subject contract. The technology held promise for stimulating liquid-sensitive reservoirs in that the CO_2 is pumped as a liquid to hydraulically create fractures, and then will vaporize at reservoir conditions and flow from the reservoir as a gas resulting in a liquid-free induced fracture remaining. Additionally, the process which had been developed in Canada utilized specialized equipment to enable proppant to be mixed with and transported by the liquid CO_2 thereby resulting in a propped fracture to prevent it from closing.

These efforts required the cooperation of gas well operators to provide "Candidate Wells" wells for the demonstrations, and in return they received financial cost-shared support for this DOE sponsored program. The operators provided the Candidate Wells, the specifics on nearby "Control Wells", and the production data from the Candidates for five years following the stimulations. The production responses from the Candidate Wells, which were stimulated with the CO_2/Sand process were then compared to that from the conventionally stimulated Control Wells to determine if any advantage would be realized from this process.

These efforts were funded to consist of up to 27 stimulation events separated into three contractual codicils. The first (Phase I) consisted of 15 events, the second (Phase II) which could depending on the Phase I experience be funded, and was to consist of 9; and later, after successful experiences in Phases I and II resulted, another 3 were subsequently added by a modification (#7) bringing the total to 27.

Initially, the contract provided for a single-stage stimulation event in each well, but after the work commenced it was recognized that because of some area-specific local practices where in some instances more than one stimulation event or stage is conducted in each well, that the funding was to be directed toward 27 stimulation events irrespective of the number of wells required. In actuality 21 stimulation events were performed in 17 wells.

	Phase #1	Phase #2	Mod #7	Total
Contract	15	9	3	27
Executed	14	7	0	21
Locations	E Ky	NY, PA, WV		

Additional wells were identified which would have resulted in the entire 27 stimulation events (in 20 wells) commitment, the operator was completely supportive in the cost-shared participation, and preparations made to treat them. However, an inability to obtain the necessary resources (CO_2) due to market conditions prohibited these last 6 events from being executed and the unexpended funds were returned to the DOE.

The contract also specified that each demonstration group of Candidate Wells was to include a minimum of three wells. By design this requirement was to enable the statistical confidence in the results to be elevated. The 15 stimulations provided for in Phase I, because of these minimum well constraints actually ended up consisting of 14, and the remaining 7 were conducted under Phase II.

As it turned out, these first 14 stimulation events were all situated in eastern Kentucky; and those stimulated in Phase II were in three separate groups located in New York, Pennsylvania, and West Virginia. This convenient areal separation between Phases I and II resulted in all of the eastern Kentucky wells being conducted under Phase I and reported separately, and all of those wells the remaining three groups which included 7 stimulations in 7 wells being addressed herein.

These Phase II demonstrations consisted of three separate well groups situated in New York, Pennsylvania, and West Virginia. The test in Pennsylvania was discontinued after a failed attempt to place proppant was encountered on the first well. Because of the difficulties in treating the uncased, open-hole interval in the first well it was concluded that there would very likely be difficulty in treating additional wells, and the remaining scheduled demonstration was aborted. The stimulation events conducted under Phases I and II are summarized as follows:

County	State	Date	Wells	Stages	Pkg #
Phase I					
Perry	Ky	1/93	3	3	6
Pike	Ky	1/93	2	2	7
Pike	Ky	5/93	3	3	9
"	"	9/93	Same	2	9
Pike	Ky	10/93	2	4	10
`		Sub Total	10	14	
Phase II					
Chautauqua	NY	12/93	3	3	12
Mercer	Pa	7/95	1	1	16
Putnam	WV	9/98	3	3	23
		Sub Total	7	7	
		Total	17	21	

III. BACKGROUND

The first demonstrations of the CO_2/Sand stimulation process were initiated through this DOE sponsored project were conducted in eastern Kentucky's Big Sandy gas field in January, 1993. Significant successes resulted in that considerably larger gas volumes were produced from wells

which were stimulated with the liquid-free CO_2/Sand stimulation process than from nearby wells which had been hydraulically fractured with other treatment types namely N_2 gas and especially N_2 foam. The five year per well incremental benefit (two stages) of the production from the CO_2/Sand stimulations resulted in an improvement of 135.4 MMcf over that from N_2 foam stimulations and 110.4 MMcf improvement over N_2 gas stimulations.

Other liquid sensitive reservoirs were sought to further apply the CO_2/Sand technology and to determine if any benefit would result.

IV. IDENTIFICATION AND SELECTION OF CANDIDATE WELLS

There were 24 Appalachian Basin Candidate Well packages developed and submitted to the DOE seven of which were approved for treatment. These approvals have resulted in 21 Stages (17 wells) being stimulated with the CO2\Sand process with cost shared participation under the subject contract.

Pkg						DOE				
#	Opr	Form	Depth	County	St	?	#	Stg	Date	Status/Date
1	Peake			Jackson	WV		3	3	May-92	OP-With
2	Peake			Mingo	WV		1	1	May-92	OP-With
3	EREX			Perry	KY		2	2	May-92	DOE-Rej
3	EREX			Letcher	KY		2	2	May-92	OP-With
4	EREX			Perry	KY		1	1	May-92	OP-With
5	Jura			Johnson	KY		1	1	Jun-92	DOE-Rej
6	Kinzer	Dev Sh	3700	Perry	KY	Y	3	3	Sep-92	Jan-93
7	CD&G	Dev Sh	3300	Pike	KY	Y	2	2	Sep-92	Jan-93
8	Chesterfield			Boone	WV		4	4	Feb-93	DOE-Rej
9	CD&G	Dev Sh	3500	Pike	KY	Y	2	4	Feb-93	Oct-93
9	CD&G	Dev Sh	3500	Pike	KY		1	2	Feb-93	OP-With
10	Kinzer	Dev Sh	3900	Pike	KY	Y	3	3	Mar-93	May-93
10	Kinzer	Dev Sh	3200	Pike	KY	Y	2	2	Sep-93	Sep-93
11	Westar			Morrow	OH		4	4	Mar-93	DOE-Rej
12	Pefley	WP	4300	Chaut	NY	Y	3	3	May-93	Dec-93
12	Pefley	WP	3500	Chaut	NY		1	1	Jul-93	DOE-Rej
13	CNG-P			Westm	PA		1	1	Jun-93	DOE-Rej
14	CNG-P			Somerset	PA		1	1	Jun-93	DOE-Rej
15	ECU			Cattar	NY		3	3	Sep-93	DOE-Rej
16	Seneca	Lockport	5200	Mercer	PA	Y	1	1	Apr-94	Jul-95
16	Seneca	Lockport	5200	Mercer	PA	Y	1	1	Apr-94	Op-With
17	Cabot	Med Snd	5100	Crawford	PA		2	2	Apr-94	DOE-Rej
17	Cabot	Med Snd		Venango	PA		1	1	Apr-94	DOE-Rej
18	Cabot	Big Injun		Kanawha	WV		2	2	May-94	DOE-Rej
19	Penn Va	Weir Snd	3400	Wyoming	WV		4	4	May-94	Op-With
20	Cobham	Gor	2800	Wetzel	WV		6	6	Jul-94	DOE-Rej
21	E States	Dev Sh	3000	Floyd	KY		5	5	Jun-95	DOE-Rej
22	Alamco	Chatt	2300	Campbell	TN		2	2	Jan-96	DOE-Rej
23	Cabot	Dev Sh	4000	Putnam	WV	Y	3	3	Jun-98	Sep-98
24	Blue Fl	DS/Ber	4500	Pike	KY		3	6	Apr-99	CO_2 Unavail

V. METHODOLOGY

The evaluation of the CO_2/sand stimulations was effected through the comparison of the five-year cumulative produced gas volumes from the Candidate wells which were stimulated with CO_2/sand with that from nearby Control wells which had been stimulated with other processes. These other stimulation processes included nitrogen (N_2) gas, N_2 foam, and in some instances through explosive shooting.

The wells with the larger projected five-year cumulative produced gas volumes, after the flush production was removed, were considered to be superior.

A. Mathematical Analog of Production Data

The procedure to remove the flush production volumes utilizes a fit of a mathematic equation of the later time production, and then utilizing that relationship to extrapolate the early production if the flush production rates had not occurred.

There were some instances where the flush production volumes were minimal which reinforces the benefit of being able to more acutely focus in on the reservoir characteristics through the elimination of this bias. This process can also provide a significant benefit when there is missing production data.

B. Removal of Flush Production Rates

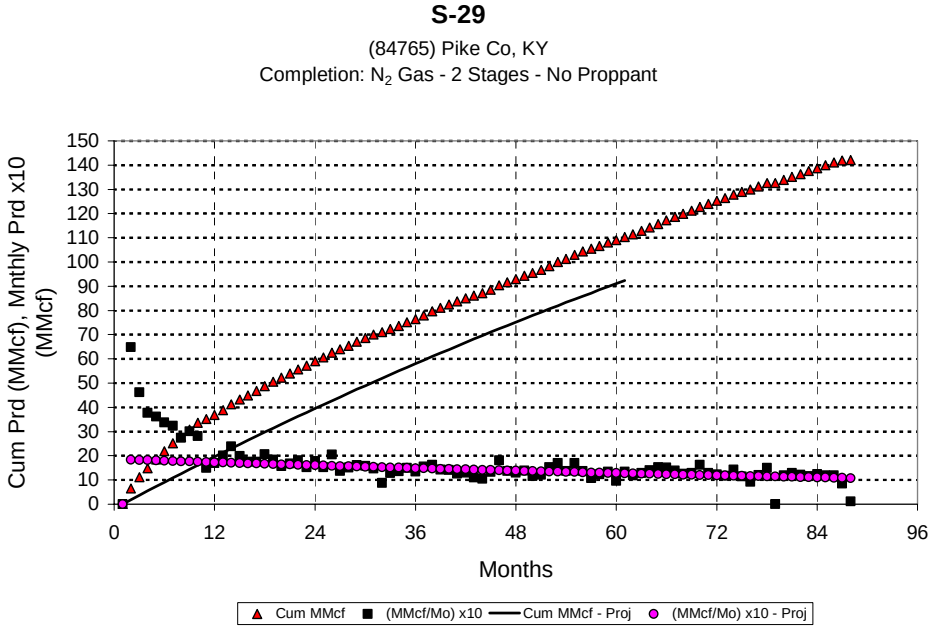
The procedure utilized to remove the flush production volumes involves a mathematic fit of the later time production and then utilizing that relationship to determine the what the early production would have been if the flush production rates had not occurred. There were some instances where the flush production volumes were minimal which reinforces the benefit of being able to more acutely focus in on the reservoir characteristics through the elimination of this bias.

C. Missing Data

This process can also provide a significant benefit when there is missing production data. There was only a very limited knowledge of the early production histories and co-metered gas production volumes were commonplace, particularly in Perry County, and the process provided method for utilizing this limited or late time production data.

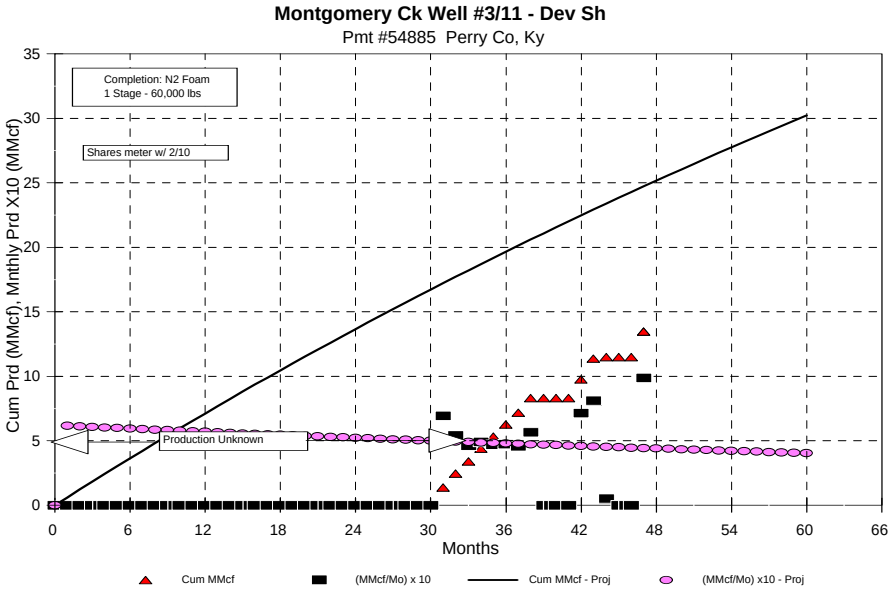
D. Examples

The following examples demonstrate the procedure utilized to remove the gas produced during the flush production period which in this case lasted approximately 13 months. The actual produced gas volume was 41 MMcf while the projected volume was 23 MMcf or a difference of 18 MMcf. The projected five year cumulative production is 92 MMcf whereas the actual production volume measured was 110 MMcf.



In the second example there was no production data available for the first 29 months, additionally the available data included two shut in periods which are followed by flush production periods. By utilizing a mathematic fit of the steady state production data a

realistic projection of the production resulted. The limited data set was then utilized, and the bias resulting from the flush production periods following the shut in periods was removed.



In removing the effects of the flush production volume a more realistic assessment of the response to the different stimulation types resulted. The production plots for each well including the actual and projected values are included in this report.

The wells which were stimulated by N_2 gas or by shooting contained no liquid nor proppant; whereas those stimulated with N_2 foam contained both liquid (water) and proppant. Generally, those wells stimulated with N_2 gas also included some minor quantity of liquid. Hydrochloric (HCl) acid is employed to attack and weaken the cement used to seal the steel casing to the formation. When used, it generally consisted of a volume of 500 gallons which was the only liquid which entered the reservoir during the N_2 gas treatments. The Candidate wells which were stimulated with the CO_2/sand process also required this small quantity of "breakdown acid" which was introduced during the perforation stage and then removed prior to the treatments.

VI. CO_2/SAND STIMULATION TREATMENTS

A. Design

A stimulation design was prepared and presented to the operators. Because of the immediate prior successes in placing full blender volumes, it was concluded that the first effort would be to attempt a maximum quantity of 47,500 lbs. This recommended stimulation design was;

PROPPANT FLUID SCHEDULE					
	Cum	Stage	Proppant	Proppant	Cum
	(bbl)	(bbl)	(ppg)	(lb)	(lb)
Stage					
Hole Fill (Liquid CO_2)	53	53		0	0
Pad (Liquid CO_2)	190	115		0	2310
Start Sand	55	55	1.0	2,310	2,310
Increase Sand	110	55	2.0	4,620	6,930
Increase Sand	165	55	3.0	6,930	13,860
Increase Sand	383	218	3.5	32,046	45,906
Flush (Liquid CO_2)	615	44		0	45,906
	Total	615			

TREATMENT FLUID REQUIREMENTS						
	Hole +	Prop	Flush	Tot Pumped	Bottom	Total
Liquid $_{CO2}$ (bbl)	168	403	44	615	10	625
CO_2 (T)						120
Nitrogen (Mscf)						74

VII. DOE APPROVALS

A submittal package was prepared for each of the 24 groups and submitted to the DOE for consideration. After their review and some additional information provided, some of the treatments were approved for the cost-shared demonstration.

The treatments were conducted in reservoirs in four states which were selected for their liquid sensitive properties, and involved five operators. The first treatments were conducted in eastern Kentucky where the results were good and ultimately ten wells were treated with a total of 14 stages.

The seven groups were located in Kentucky (10 wells, 14 stages), New York (3 wells, 3 stages), Pennsylvania (1 well, 1 stage), and West Virginia (3 wells, 3 stages):

Pkg #	Operator	Co, St	Stages	Wells
6	Kinzer	Perry, Ky	3	3
7	CD & G	Pike, Ky	2	2
9	CD & G	Pike, Ky	4	2
10	Kinzer	Pike, Ky	3	3
10	Kinzer	Pike, Ky	2	Same
12	Sinclairville	Chautauqua, Ny	3	3
16	Seneca	Mercer, Pa	1	1
23	Cabot	Putnam, Wv	3	3
		Total	21	17

VIII. FIELD ACTIVITIES

A. Preparations

Preparations for the field activities included perforating the Candidate Wells and the placement of two 60 or 70 ton CO_2 storage vessels on the location and then filling them with liquid CO_2 during the 24 hour period prior to the treatment.

Stimulations

B. A summary of the perforation, stimulation specifics (volumes, rates, pressures) for all of the Candidate Wells is presented in the Final Report for this group.

IX. IS THE PROPOSED RESERVOIR LIKELY TO BENEFIT FROM THE CO_2/SAND TECHNOLOGY?

Because the CO_2/sand stimulation utilizes CO_2 as the working fluid which is pumped as a liquid and subsequently vaporizes at formation temperature and flows from the reservoir as a gas, no liquid remains behind and the gas can flow from the reservoir unimpeded.

X. OPERATORS

The following questions were considered and each of the operators, and each of the test areas provided or afforded:

A. An interest in CO_2/Sand technology

B. An adequate test opportunity

C. A presently active drilling program

D. A future for successful results? Is the operator likely to continue implementing this technology without DOE cost support?

E. An interest in DOE cost-supported participation?

F. Share production data for five years?

G. Letter of Intent

The operator provided a letter of intent agreeing to:

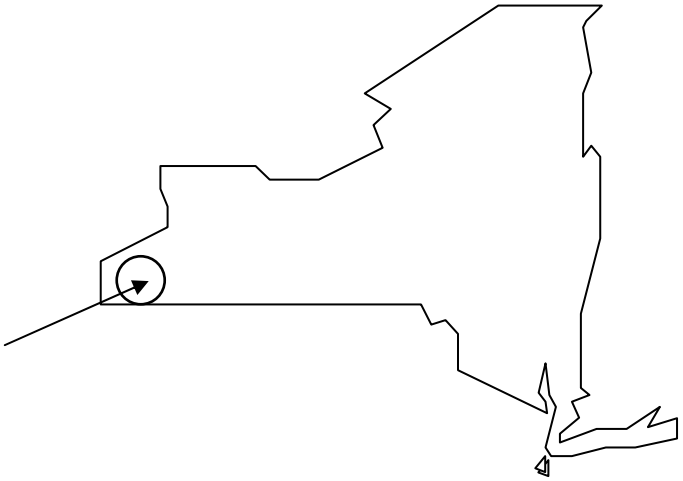
1. Provide legitimate well opportunities for three mutually agreed upon wells,
2. Provide acceptable background information on the nearby wells including the drilling, completion, and production specifics,
3. Bear the normal additional expenses of cement bond logging, perforating, bull dozers, and other normally occurring expenses associated with stimulation events,
4. Participate in the demonstration project and the anticipated treatments specifics, and
5. Provide the production and flowing pressure information from the Candidate Wells for five years.

XI. TEST AREAS

A. TEST AREA #1 - Chautauqua Co, NY – Package #12 - 3 Stages / 3 Wells

1. Location

The test area encompassed an area on the South and East edges of Johnstown and could be considered to be in the Busti Field or is sometimes referred to as the South Jamestown Field



2. Operator – The operator was, at the time Sinclairville Petroleum, but the wells are now operated by National Fuel.

3. Reservoir

The target formation was the Whirlpool Sandstone which is within the Medina Group (Lower Silurian Period) and which is well recognized for its gas production potential. Both the Grimbsby (or Red Medina) Sandstone and the subjacent Whirlpool Sandstone, contain gas without any associated oil or condensate in this area, and both were strongly suspected, by the operator of being susceptible to formation damage caused by the liquids utilized in conventional hydraulic stimulation processes.

4. Producing Horizon

The Medina Sands at the Busti Field have been commercially produced for a number of years and the following reservoir information was obtained.

a. Porosity

The porosity of the Medina generally ranges from six to ten percent.

b. Permeability

Twelve porosity and permeability measurements were made on February 5, 1992 from sidewall plugs obtained from the C Nelson #1 well (31-013-22152). As would be anticipated, the permeability is directly proportional to the porosity ranging from lows of approximately 0.05 millidarcies (md) where the porosity is less than about seven percent up to approximately two to five md, and sometimes greater where the porosities exceed seven percent.

c. Reservoir Pressure and Temperature

The wellhead shut-in pressures in the vicinity of the Candidate Wells are generally on the order of 1,100 psi and the temperature indicated on the electric log headers is on the ranges from 100 to 102 degrees Fahrenheit. The reservoir pressure of the Medina in Chautauqua county generally ranges from 310 to 1,200 psi indicating that it is under pressured.

A review of the phase behavior at these temperatures and pressures confirmed that the CO_2 would vaporize under these conditions. A phase diagram for each well group was prepared and is not included here, but accompanies the report for that group

d. Sensitivity to Stimulation Liquids

The operator indicated that the formations produced little, if any water naturally, and a strong suspicion that the liquids used in the conventional stimulations was impairing gas production. It was learned later, some time after the wells had been stimulated that both the Grimsby and the Whirlpool contain connate water. And, that water production is commonplace within the Busti Field.

5. Control Wells

There were 11 Control Wells. Three were completed exclusively in the Whirlpool, five completed both in the Whirlpool and the overlying Grimsby, and three which are completed in the Whirlpool, but it is unknown if they were also completed in the Grimsby. The stimulation process utilized on these Control wells was primarily gelled water with a nitrogen (N_2) assist, a few were however stimulated without N_2.

	Well	Pmt # 31-013-xxxxx	5 Yr Prod (MMcf)
	Whirlpool		
1	Hoover #1	21857	268.2
2	C Nelson #1	22152	191.1
3	Pascatore #1	20903	165.1
		Total	624.4
		Average	208.1
	Grimbsby &		
4	Schuyer #1	20893	262.6
5	Nelson #1	20815	155.9
6	Foe #1	21146	74.0
7	Aiken #1	16908	65.1
8	Ganey #1	15934	22.0
		Total	579.6
		Average	115.9
	Whirlpool + ?		
9	Hainer #1	22265	140.9
10	Kidder #1	15494	37.9
11	Kidder #2	17932	19.0
		Total	197.8
		Average	65.9

6. Candidate Wells

Three Candidate Wells were identified. They were completed in and produced solely from the Whirlpool, at a depth of approximately 4,300 feet. They are situated in close proximity to the Control Wells, and the electric logs, completion details and production plots for each well are included in the final report for this group (#12).

	Well	Pmt # 31-013- xxxxx	5 Yr Prod (MMcf)
	Whirlpool		
1	Porter #1	22324	42.7
2	Miele Scala #1	22284	30.5
3	Lamonica #1	22384	37.9

a. Candidate Well #1 – Porter #1 - Permit #22324

The Porter #1 was drilled in February 1993 to a total depth of 4500 feet. Casing (4-1/2 in) was installed and cemented, and the Whirlpool was perforated, and a CO_2/sand treatment was executed. A total of 412 bbls of liquid CO_2 were pumped The well screened out as a consequence of a direction given by service co representative to increase the sand concentration. After the sand was removed from the well bore it was estimated that 26,500 lbs of proppant had been placed in zone.

An attempt to restimulate the well was executed following the stimulation of the other two Candidate Wells. It was unsuccessful, and added another variable to the evaluation. This second attempt employed a total of 365 bbls of liquid CO_2, and resulted in as much as an additional 9,000 of proppant being placed bringing the in-zone total to something on the order of 35,500 lbs.

b. Candidate Well #2 – Miele Scala #1 - Permit #22284

The Miele Scala #1 well was drilled in November 1992 to a total depth of 4506 feet. Casing (4-1/2 in) was installed and cemented, the Whirlpool was perforated, and a CO_2/sand treatment was executed. A total of 516 bbls of liquid CO_2 were pumped

After the sand was removed from the well bore it was estimated that 26,500 lbs of proppant had been placed in zone.

c. Candidate Well #3 – Lamonica #1 - Permit #22384

The Lamonica #1 well was drilled in 1992. Casing (4-1/2 in) was installed and cemented, the Whirlpool was perforated, and a CO_2/sand treatment was executed. A total of 525 bbls of liquid CO_2 were pumped. After the sand was removed from the well bore it was estimated that 28,000 lbs of proppant had been placed in zone.

7. Costs

The total costs for stimulating the three Candidate wells with the CO_2/sand process, exclusive of the restimulation expenses for Porter #1, were $125,180 which results in an average of $41,727 per well for a single stage treatment.

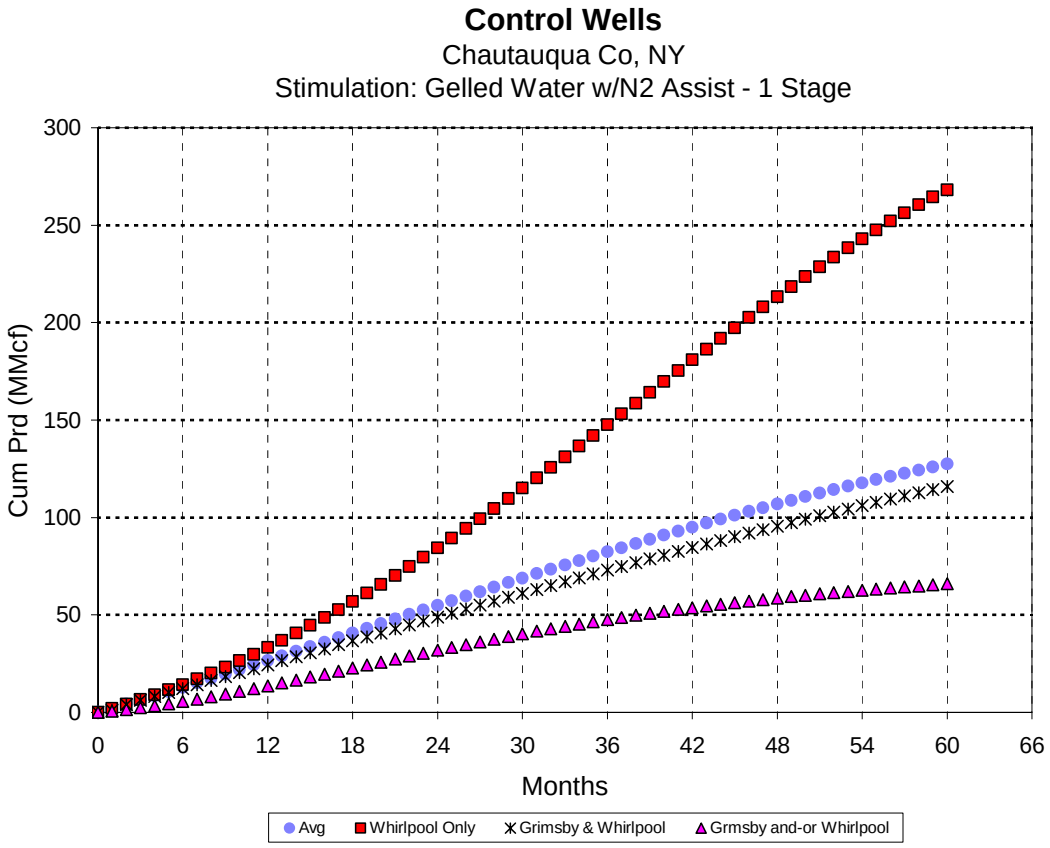
Well:	Porter #1	Miele Scala#1	LaMonica #1	Porter#1	Average
Permit #:	22324	22284	22384	22324	
				*Refrac	
Pumping($)	20,472	19,952	21,777	1,247	15,862
N_2	4,017	3,489	3,755	1,200	3,115
	24,489	23,441	25,532	2,447	18,977
CO_2	16,000	13,400		13,400	10,700
Blender	4,000	4,000	6,000	0	3,500
	44,489	40,841	31,532	15,847	33,177
Trucking – To	5,442				1,361
Trucking – From	?				
CO_2 Services	1,169	1,320		110	650
Misc		387		459	212
Total	51,100	42,548	31,532	16,416	35,399

8. Results

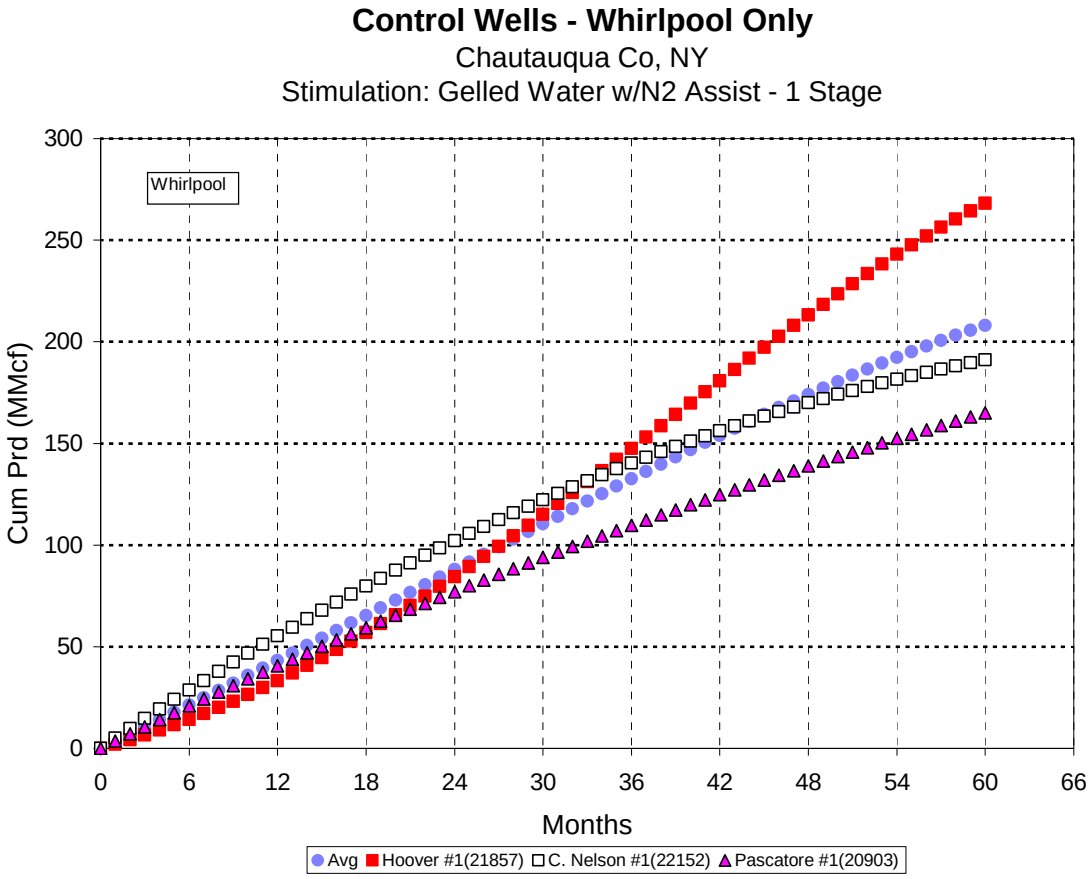
a. Production Comparisons

(1) The Control Wells which were stimulated only in the Whirlpool Sand were better producers than those which were stimulated, as a single–stage, in both the Grimbsby and the Whirlpool.

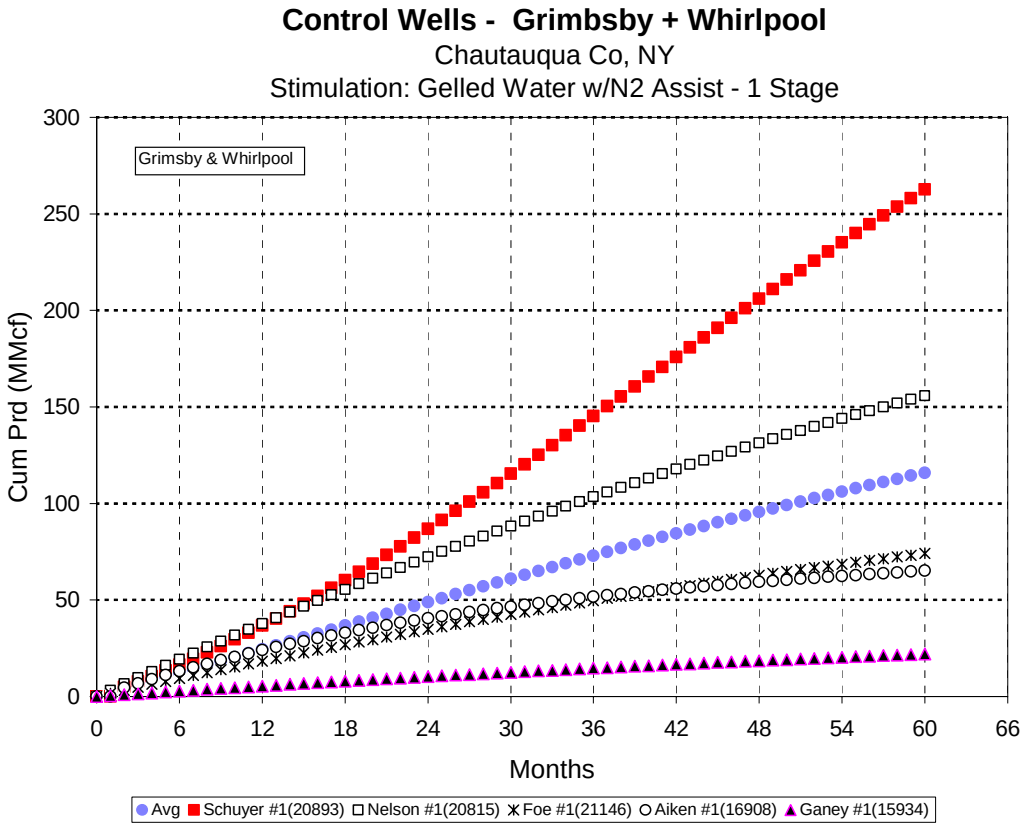
(2)



(3) The three wells which were completed only in the Whirlpool had five-year cumulative productions ranging from 165.1 to 268.2 MMcf, averaging 208.1

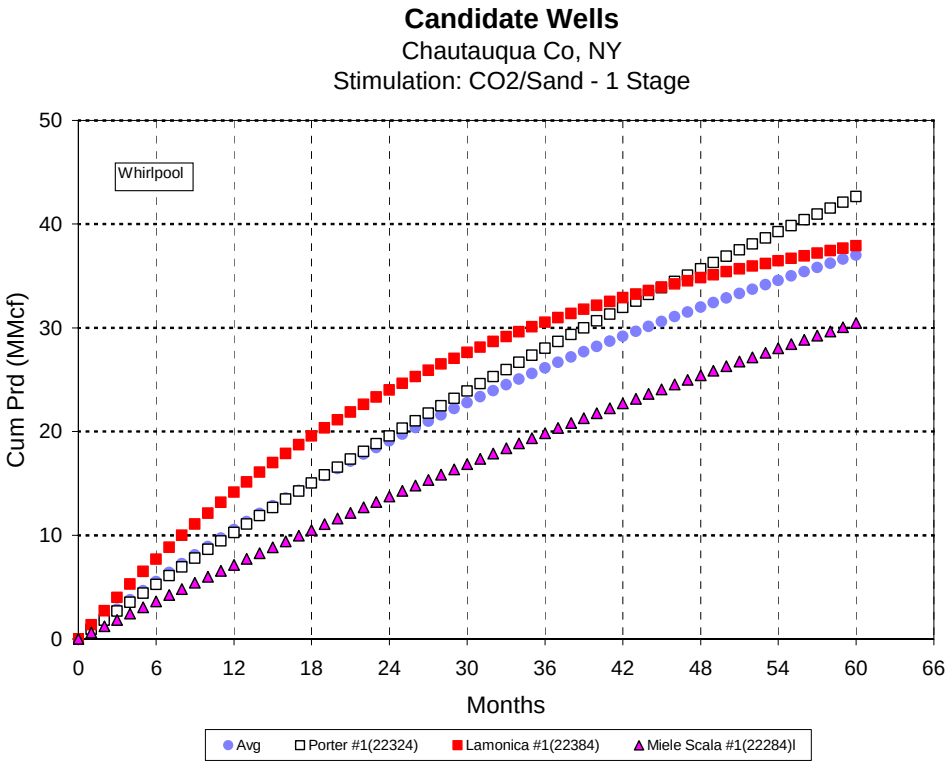


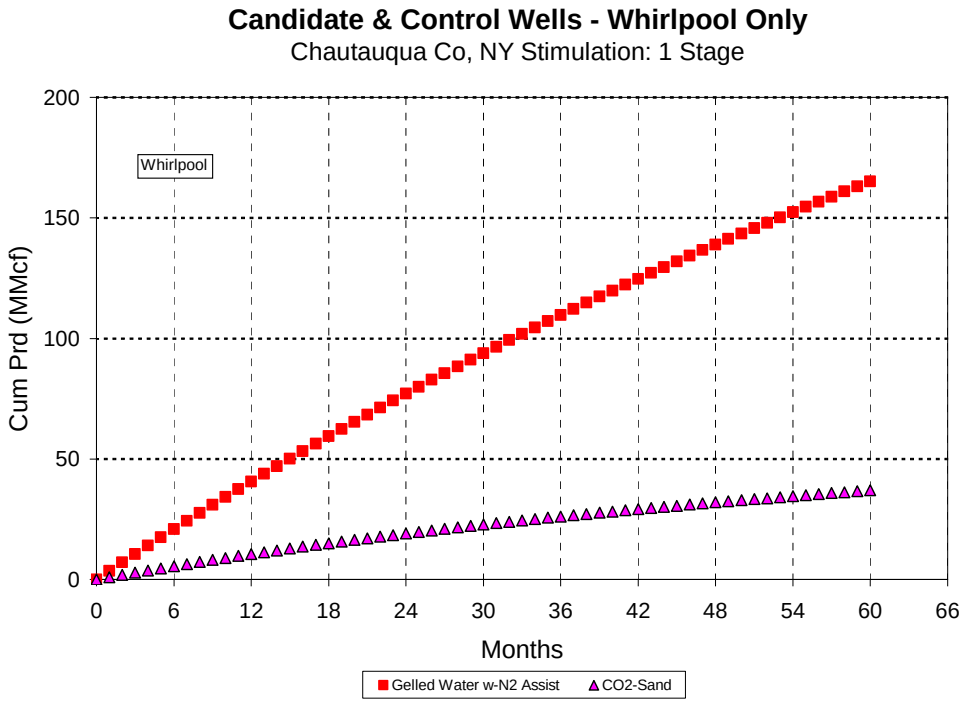
(4) The five which were completed in both zones (Grimsby and Whirlpool) had lesser productions which ranged from 22.0 to 262.6 MMcf, averaging 115.9 MMcf, or approximately 55% of that from the group completed exclusively in the Whirlpool.



(5) There are also three wells for which the completed formations are unknown. It is assumed that they are completed in the Whirlpool, but it is unknown if they are completed in any other zones in addition to the Whirlpool. They have five-year cumulative productions ranging from 19.0 to 140.9 MMcf, averaging 65.9 MMcf.

(6) The five-year cumulative productions from the CO_2/Sand Candidate Well group were completed in the Whirlpool only, as were the better producing wells in the Control Well group, but the production ranged only from 30.5 to 42.7 MMcf. Averaging 37.0 MMcf; or, only 18% of those wells stimulated with N_2 foam in the Whirlpool. (compared to 140.9 to 227.1 MMcf – see above).





(7) The liquid based stimulations generally contained approximately twice the volume of proppant than those stimulated with CO_2/Sand. 58,400 lbs vs. 32,500 lbs.

9. Conclusions

a. Production from this reservoir derives no benefit from the liquid-free CO_2/Sand stimulation process.

b. It is evident that the wells which were stimulated with liquid-based nitrogen foam stimulations produced gas at considerably greater rates than those which were stimulated with the liquid-free CO_2/Sand stimulations.

c. The production rates are dependent upon the quantity of sand placed with the greater production rates associated with larger proppant volumes.

d. The maximum sand volume which could be placed with the CO_2/Sand process was approximately one-half of that placed with the nitrogen foam treatments and ranged from 28,000 to 35,500 pounds; whereas those stimulated with the foam treatments generally contained at least 60,000 pounds.

e. The ability to place proppant was limited, because the wells would not accept any more. One screened out (26,500 lbs) because of an over aggressive sand schedule, a second fracturing attempt was tried later and a minimal volume of additional proppant was placed (9,000 lbs).

f. The total costs for stimulating the three Candidate wells with the CO_2/sand process, exclusive of the restimulation expenses for Porter #1, were $125,180 which results in an average of $41,727 per well for a single stage treatment.

g. The wells produce water which differs from the information provided by the operator. It had been indicated that the wells in this area produce little if any water. A tank containing approximately 15 barrels of water was provided as evidence of the total lifetime production of a group of approximately 50 wells. It was determined after the treatments that all of the wells produce small volumes of water and that the initial representation has no factual basis.

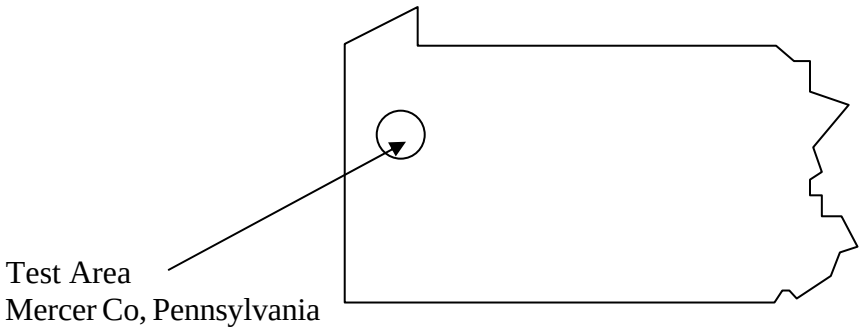
10. Well specific data

Well	Pmt #	Elev	Oper	O F	Press	T	TD	5 Yr Prd	Stim	Formation(s)
	31-013-									
	xxxx			Mcfd	Psig	F	Ft	MMcf	Type, Sxs, Bbls	
Hoover #1	21857	1,500	Sinclairville	1,250		100	4,433	268.2	Gld Wtr w/N_2, 600	WP
Schuyer #1	20893	1,470	Sinclairville	300	1,270		4,412	262.6	Gld Wtr w/N_2, 600	Gy, WP
C Nelson #1	22152	1,482	Sinclairville	27	720	95	4,495	191.1	Gld Wtr w/N_2, 345	WP
Pascatore #1	20903	1,410	Sinclairville	333	1,100	100	4,363	165.1	Gld Wtr w/N_2, 760	WP
Nelson #1	20815	1,360	Sinclairville	300	1,100	101	4,312	155.9	Gld Wtr w/N_2, 550	Gy, WP
Hainer #1	22265		Sinclairville					140.9		
Foe #1	21146	1,425	Sinclairville	300			4,395	74.0	Gld Wtr w/N_2, 600	Gy, WP
Aiken #1	16908	1,420	Bounty O&G	400			4,298	43.3	Gld Wtr w/N_2, 600	Gy, WP
Porter #1	22324	1,545	Sinclairville			102	4,493	42.7	CO_2/Sand, 265+90	WP
Lamonica #1	22384	1,365	Sinclairville			103	4,277	37.9	CO_2/Sand, 280	WP
Kidder #1	15494		Sinclairville					37.9		WP
Miele Scala #1	22284	1,560	Sinclairville			102	4,478	30.5	CO_2/Sand, 310	WP
Ganey #1	15934	1,360	Bounty O&G	600			4,203	22.0	Gld Wtr, 700	Gy, WP
Kidder #2	17932		Sinclairville					19.0		

B. TEST AREA #2 - Mercer Co, PA - Package # 16 – 1 Stage / 1 Well

1. Location

The Henderson Dome is located in south western Pennsylvania in Mercer County.



The Candidate Well(s) produce from the Lockport Dolomite at the structurally high Henderson Dome. There are 13 nearby Control Wells. Some had been stimulated with various techniques and others had not because the completion procedure had been designed

to eliminate the introduction of liquids into the Lockport as it was considered to be damaging. The more recent completion practices not only do not include stimulations, but also employ a set-on-top type of completion where the production casing is set above the Lockport which is subsequently air-drilled to avoid liquid damage. Operator - Seneca Resources

2. Operator – Seneca Resources

   Seneca offered two Candidate Wells which were situated in a test area which also contains 13 nearby Control Wells and provided the Control Well information.

3. Reservoir

   The target formation is the Upper Silurian Lockport Dolomite at the structurally anomalous Henderson Dome which is a structurally-positive, geologic feature in Mercer and Venango counties, western Pennsylvania.

4. Producing Horizon

   The Lower Silurian rock units, including the Medina and Whirlpool sandstones, comprise the primary development reservoirs in the area although deeper production has been established in the Lockport.

   a. Porosity

      The porosity of the Lockport generally ranges from six to eight percent.

   b. Thickness

      At porosities above six percent, the thickness of Lockport Dolomite at the Henderson Dome generally formation ranges from six to 32 feet.

   c. Permeability

      As would be anticipated, the permeability is directly proportional to the porosity which based on well test analysis ranged from lows of approximately 0.03 millidarcies (md)

where the porosity is less than about seven percent up to approximately 0.25 md where the porosities exceed seven percent. The maximum porosity is not much greater and generally less than eight percent.

d. Reservoir Pressure and Temperature

The wellhead shut-in pressures in the vicinity of the Candidate Wells range from 1,500 to 2,456 psi within the Control Well group, and the temperature indicated on the electric log headers is on the order of 110 degrees Fahrenheit.

A review of the phase behavior at these temperatures and pressures confirmed that the CO_2 would vaporize under these conditions. A phase diagram for each well group was prepared and is not included here, but accompanies the report for that group

5. Control Wells

There are 13 Control Wells the formation specifics, completion type and size, and the five-year cumulative production volumes are:

	Well	Cased or OH ?	Open Flow	Orig Press	BH Press	TD	5 Yr Prod	Stimulation
			Mcfd	Psig	psig	Ft	MMcf	Type, Sxs, Bbls
1	5998	Cased	353	2083	1149		975	Kiel, 370, 220
2	5988	Cased	245	TBD	TBD	5422	738	Acid
3	439 (349?)	Cased	195	TBD	TBD		334	Foamed Acid, TBD
4	5645	Cased	177	2456	1605	5785	306	Acid (20M gal)
5	5996	OH	220	TBD	TBD		178	None
6	6224	OH	203	2278	1284	5559	152	None
7	5987	Cased	144	2275	1400	5445	116	Shot
8	6201	Cased	217	2016	962	5478	101	Kiel, 500, 3177
9	6207	Cased	200	1942	1333	5950	94	Kiel, 240, 1332
10	6424	OH	804	1700	1144	5451	51	None
11	6208	Cased	217	2270	1438	6150	47	Gld Wtr, 110, 464 w/3.9Mgal HCl
12	6356	OH	185	2068	1400	5609	34	None
13	6355	OH	9	1500	345	5610	9	None

a. The five-year cumulative productions range from 9 to 975 MMcf with the majority being greater than 100 MMcf.

b. The completion techniques have employed both open and cased hole procedures. One well, #5998 which was stimulated with an Othar Kiel designed hydraulic treatment significantly outperformed all of the other wells by a significant volume. The five-year cumulative production was 975 compared to 738 MMcf for the well with the second largest production rank. This production response is considered to be anomalous because of the significantly greater formation thickness, and the non-unique production responses from the other two wells which were stimulated with the Kiel process. However, it should be recognized that this well also had considerably less liquid pumped in it than did the other two Kiel treatments, 220 vs. 3,177 & 1,332 Barrels.

c. Other than the very large production response from #5998 the results are generally as would be anticipated, that is, the acid-based treatments have resulted in the greatest cumulative production volumes. The accompanying table addresses the well specifics and is ranked by production volumes.

d. All of the wells which were unstimulated were completed with an open hole procedure, as were the two Candidate Wells.

6. Candidate Wells

Two Candidate Wells #7305 & 7307 were provided by Seneca. They were both completed open hole, were unstimulated and situated within the group of Control Wells.

Cand Wells	Pmt # 37-085-	Elev	Cased or OH?	Oper	OF	Orig Press	BH Press	T	TD	5 Yr Prod	Stim	PROM AT Skin	PROM AT Perm	Por	h
	xxxx				Mcfd	Psig	Psig	F	ft	MMcf	Type,Sxs,Bbls		md	%	ft
7305	21829	1379	OH	Seneca	25	1200	1200e	110	5421	31	CO_2/Sand	0	0.20	5.9	12
7307	21842	1392	OH	Seneca	45	1803	1803	110	5405		None	-1.7	0.09	6.8	13

a. Candidate Well #1 – 7305 - Permit #21829

Well # 7305 was drilled to the top of the Lockport and casing (5-1/2 in) installed. The Lockport was then drilled with air a total depth of 5421 feet. The open hole interval across the Lockport was perforated, and a CO_2/sand treatment was executed, and 20,500 lbs of proppant were pumped at an average rate and pressure of 43.3 barrels per minute and 3,367 psi respectively. A total of 316 bbls of liquid CO_2 were pumped prior to the well screening out. After the sand was removed from the well bore it was estimated that 6600 lbs of proppant had been placed in zone.

Hole caving was experienced during the clean-out of the open hole interval which was performed with a cable tool type service rig. An unexpected occurrence of a significant quantity of Lockport Dolomite formation was also encountered. A geologic inspection of the formation material revealed that, because of its dark, argillaceous nature, to be the Lower Lockport. There was also the unexpected presence of formation water in both candidate wells, #7305 and #7307, standing 310 ft above the Lockport formation. The formation was previously considered to be free of formation liquids, which complemented its attractiveness for CO_2\sand stimulation technology.

b. Candidate Well #2 - #73077305 - Permit #21842

Well # 7307 was drilled to the top of the Lockport and casing (5-1/2 in) installed. The Lockport was then drilled with air a total depth of 5405 feet, and the open hole interval across the Lockport was perforated.

Because both of the Candidate Wells were open hole completions, the difficulties in placing proppant in well #7305, and additionally because of the findings of formation liquids and the subsequent caving, it was decided not to stimulate the second Candidate Well, #7307.

7. TV surveys

a. Candidate Well #1 - #7305 A.C. Grace

A TV survey indicated that there were diametrically opposed vertical fractures extending well below and above the pay interval. They extended down to the plug back depth, and up to the casing and because of the fracture width at this highest observable depth, they are believed to extend farther. They were massive in vertical extent, and based on the placed sand volume would extend laterally approximately 65 feet from the well - if they were uniform in thickness and cross section. There were two sets of diametrically opposed vertical fractures with approximately 30 degrees of separation. The fracture widths at the well bore were visually estimated to be on the order of ½ inch in width.

b. Candidate Well #2 - #7307 J.E. Dick

The TV survey indicated the presence of the perforations - which were premium charges (Schlumberger) and are notable because of the very minor depth of indentation into the Lockport formation. They were radially positioned in an conically ascending or "stair-stepped" manner and were almost imperceptible. The maximum depth of

penetration was less than 3/8^{ths} of an inch and each and every one was accompanied be a teaspoon size depression where the formation had rejected material irrespective of their orientation within the well bore.

8. Costs

The stimulation costs for this single treatment were

Pumping	$		25,894
Materials			4,539
CO_2 w/ Portables			15,385
Blender			6,000
		Total w/o Mob	51,818
Mobilization			9,280
		Total w/ Mob	61,098

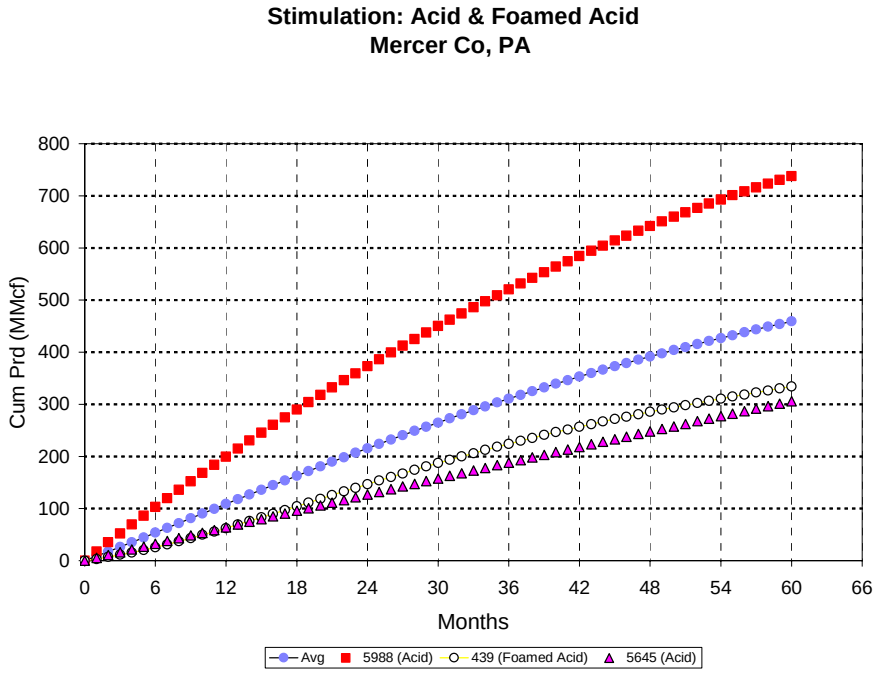
9. Results

a. Production Comparisons

(1) Acid and foamed acid

The five year cumulative production volumes from the three wells which were acidized ranged between 306.2 and 737.6 MMcf per well and averaged 459.3 MMcf per well. The wells which were acidized had the largest production volumes which would be anticipated from the carbonate mineralization of the Lockport Dolomite.

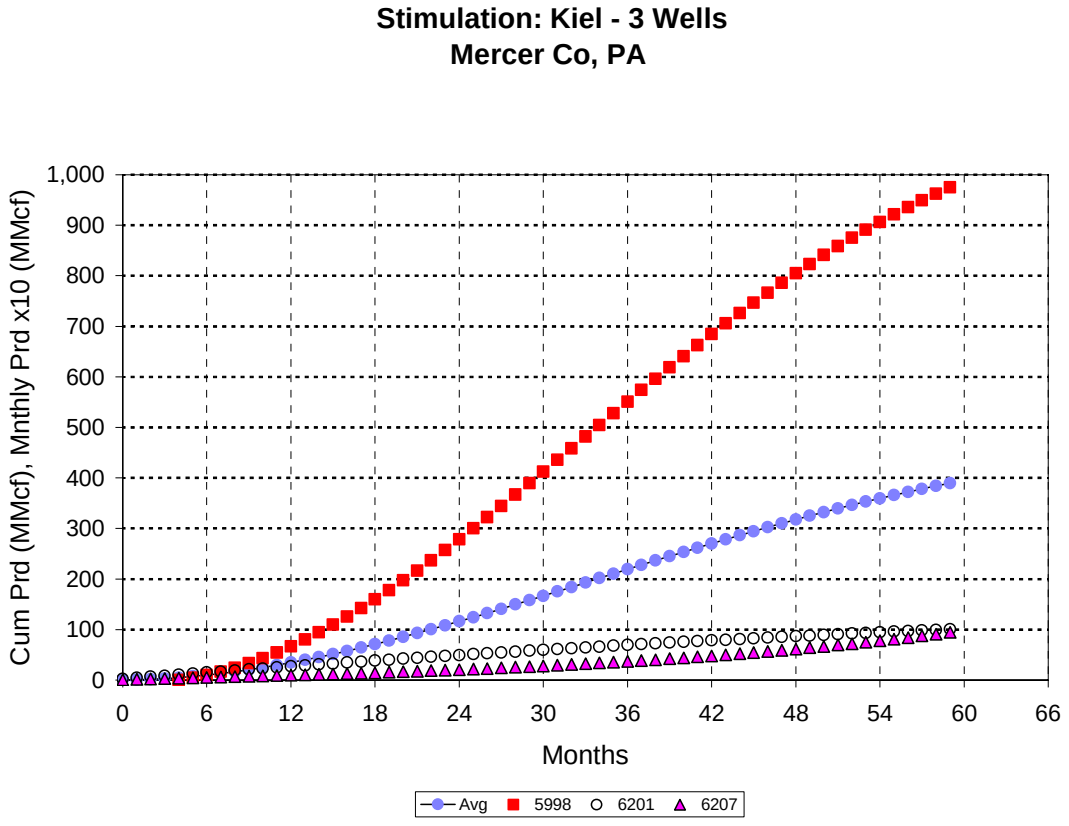
Stimulation Type	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
Acid	2	2	306.2	737.6	521.9	521.9
Foamed acid	1	1	334.1	334.1	334.1	334.1



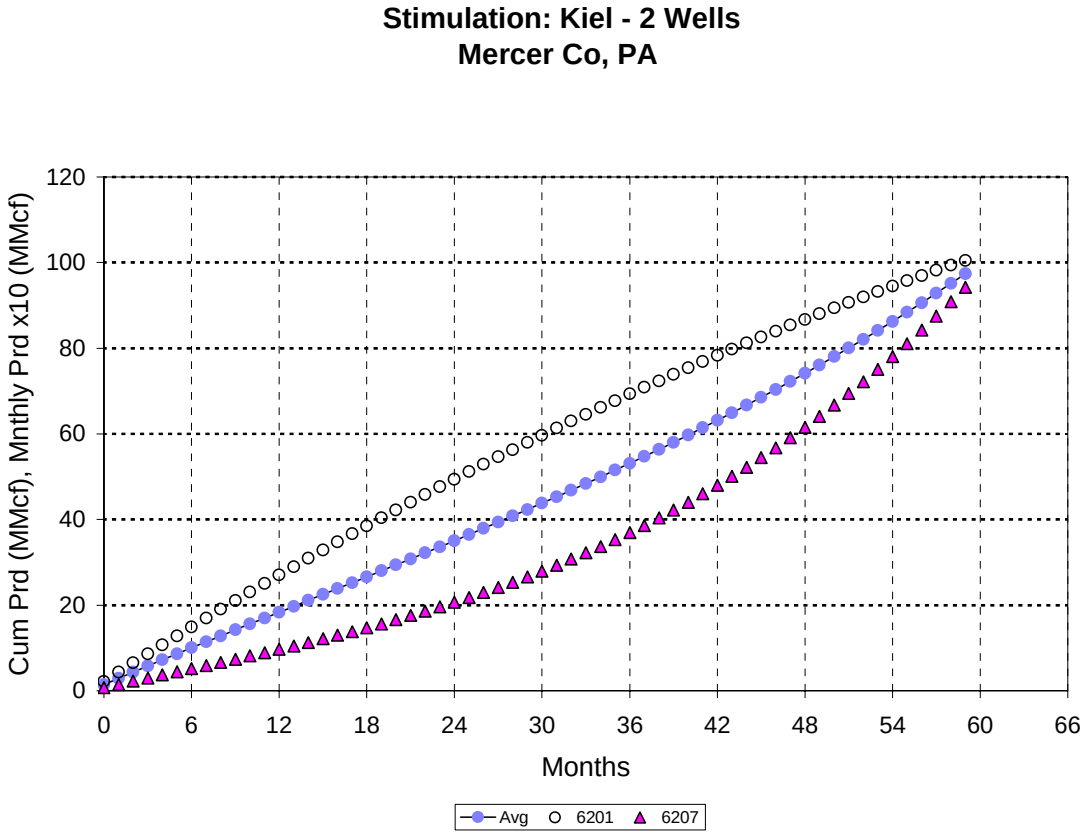
(2) Kiel

The five year cumulative production volumes from the three wells which were stimulated with the Kiel treatments ranged between 94.3 and 975.0 MMcf per well and averaged 389.9 MMcf per well.

Stimulation Type	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
Kiel	3	3	94.3	975.0	389.9	389.9



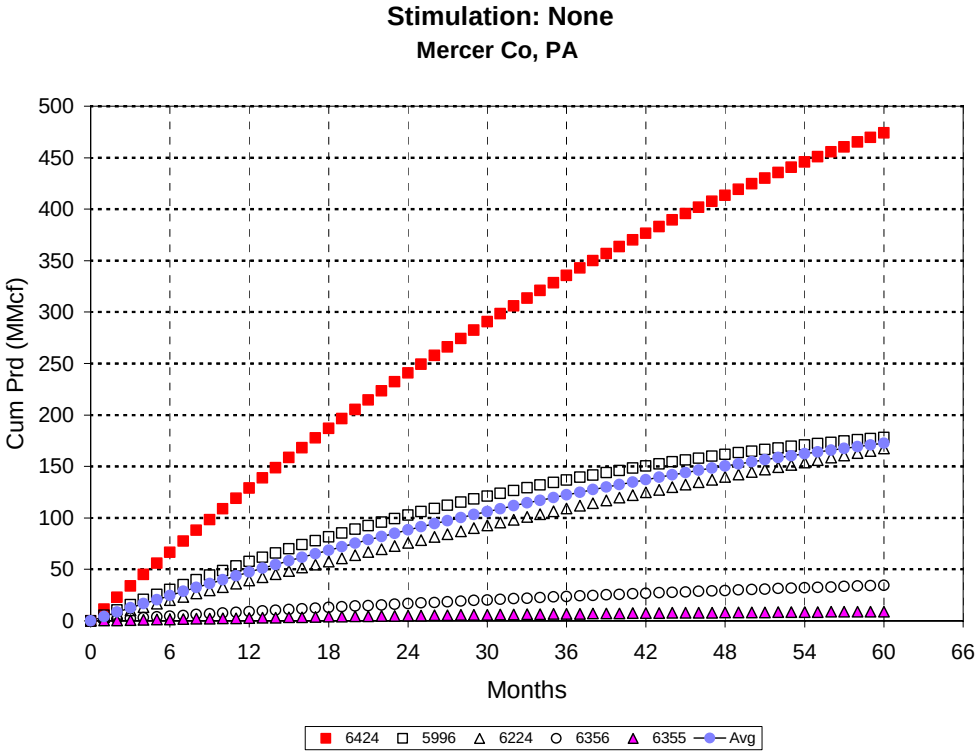
One of the wells, 5998 had a significantly larger volume if it were to be removed, the production from the remaining four wells would range between 94.3 and 10.5 MMcf and the average would become 97.4 MMcf per well.



(3) Unstimulated

The five year cumulative production volumes from the five unstimulated wells ranged between 8.9 and 474.1 MMcf per well and averaged 172.6 MMcf per well. One of the wells, 6424 had a significantly larger volume if it were to be removed, the production from the remaining four wells would range between 8.9 and 167.4 MMcf and the average would become 97.2 MMcf per well.

Stimulation Type	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
Unstimulated	5	5	8.9	474.1	172.6	172.6



(4) Shot

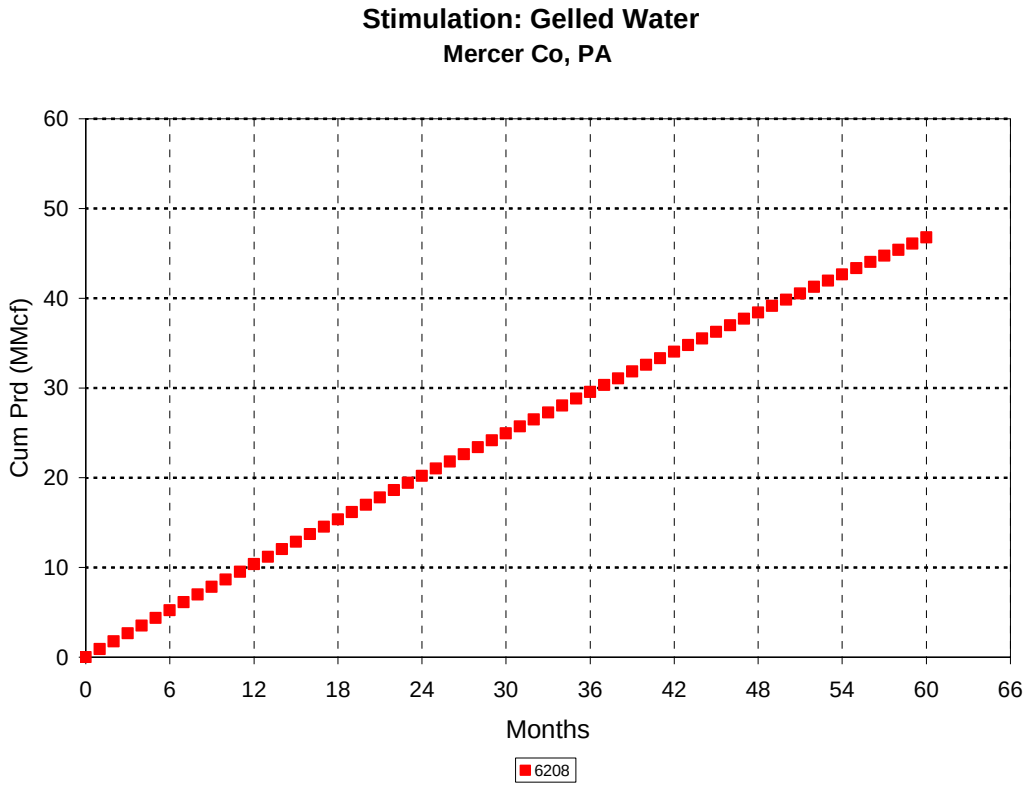
The five year cumulative production volumes from the one well which was explosively shot was 116.5 MMcf.

Stimulation Type	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
Shot	1	1	116.5	116.5	116.5	116.5

(5) Gelled water

The five year cumulative production volumes from the one well which was stimulated with gelled water which included 464 barrels of water, 3900 gallons of HCl acid and 110 sacks of 20/40 proppant was 46.8 MMcf.

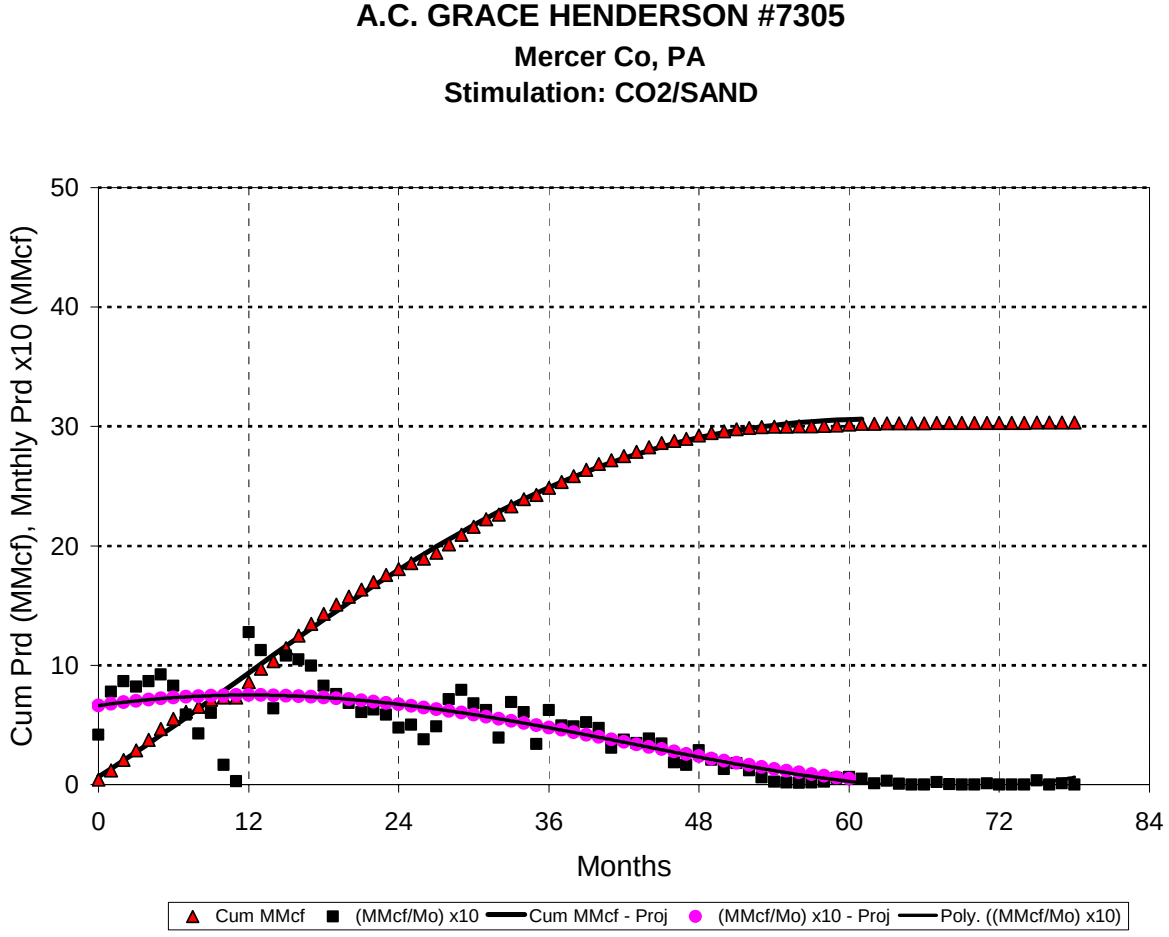
Stimulation Type	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
Gelled water	1	1	46.8	46.8	46.8	46.8



(6) CO_2/sand

The five year cumulative production volumes from the one well which was stimulated with CO_2/sand including 316 barrels of CO_2 and 6600 lbs of 20/40 proppant was 30.5 MMcf which is the smallest of any of the groups.

Stimulation Type	Stages	Wells	Low	High	Mean	Mean
Candidate						
(CO_2/sand)	1	1	30.5	30.5	30.5	30.5



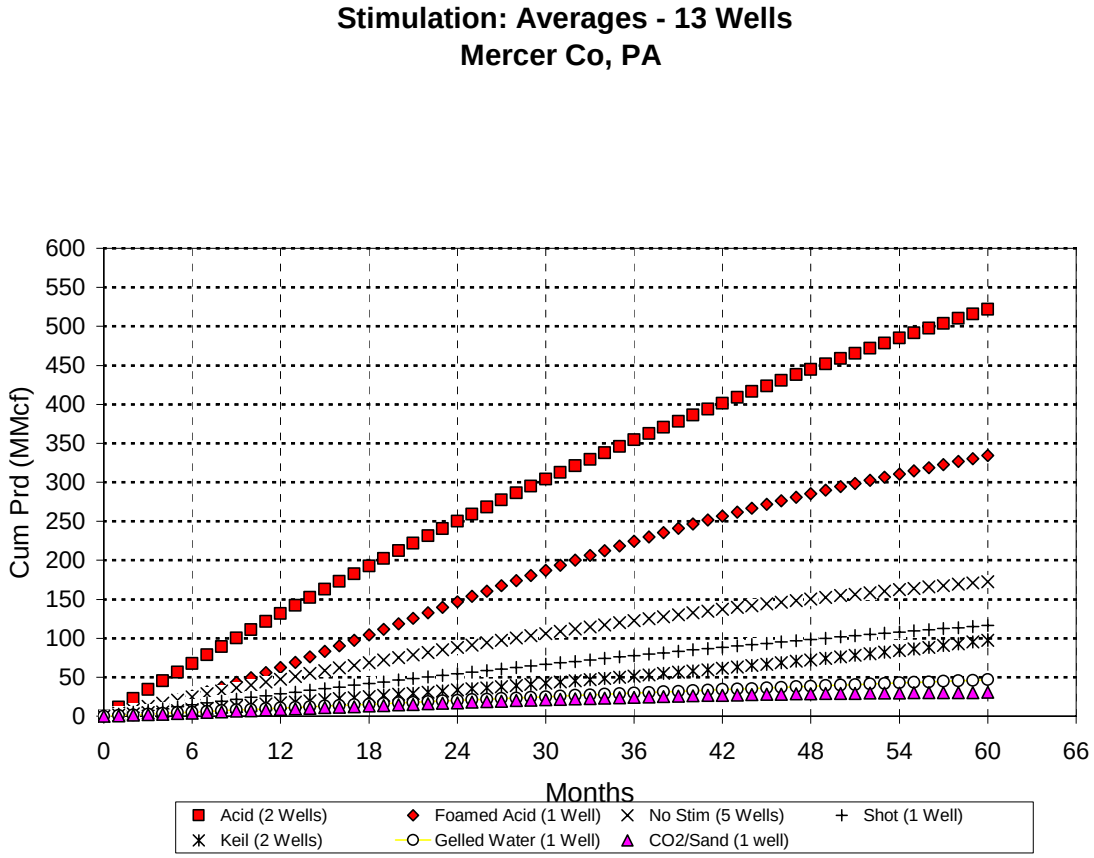
(7) Averages

The averages indicate that the:

(i) The largest produced volumes are from the wells which were stimulated with acid,

(ii) The smallest production volume was from the single well which was stimulated with the CO_2/sand process which screened out and only a limited volume of proppant 6,600 lbs was placed in zone. The well was completed as an open hole and the process would have been more realistically applied to a perforated interval.

Stimulation Type	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
Acid	2	2	306.2	737.6	521.9	521.9
Kiel	3	3	94.3	975.0	389.9	389.9
Foamed acid	1	1	334.1	334.1	334.1	334.1
Unstimulated	5	5	8.9	474.1	172.6	172.6
Shot	1	1	116.5	116.5	116.5	116.5
Gelled water	1	1	46.8	46.8	46.8	46.8
Total	13	13				
Candidate						
(CO_2/sand)	1	1	30.5	30.5	30.5	30.5
Total	14	14				



10. Conclusions

a. The five-year cumulative production projections from the Candidate well is 31 MMcf resulting in response much lower than the others.

b. The most productive wells have been cased and stimulated with acid

c. The stimulation of the open hole interval was unsuccessful in placing proppant. There were two attempts; the first attempt was aborted because of a mechanical inability to

blend sand, and the second attempt screened-out resulting in only a minimum volume of 20/40 mesh sand, 6,600 lbs being placed in the reservoir.

d. Sand rejection was evident immediately following the arrival of the sand at the formation.

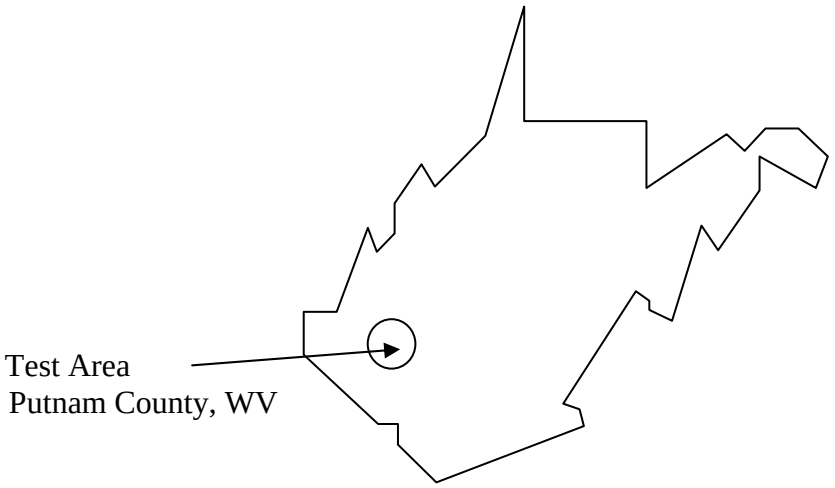
11. Well specific data

Control Well	Cased or OH?	Oper	O F	Orig Press	BH Press	TD	5 Yr Prod	Stim	PRO MAT Skin	PRO MAT Perm	Por	h
			Mcfd	Psig	Psig	Ft	MMcf	Type, Sxs, Bbls		md	%	ft
5998	Cased	Seneca	353	2083	1149		975.0	Kiel, 370, 220	-4.5	0.25	7.6	32
5988	Cased	Seneca	245	TBD	TBD	5422	737.6	Acid	TBD	TBD		8
6424	OH	Seneca	804	1700	1144	5451	474.1	None	16.0	1.4		
439 (349?)	Cased	Seneca	195	TBD	TBD		334.1	Foamed Acid, TBD				30
5645	Cased	Seneca	177	2456	1605	5785	306.2	Acid (20M gal)	3.6	0.2	7.2	24
5996	OH	Seneca	220	TBD	TBD		178.1	None				3
6224	OH	Seneca	203	2278	1284	5559	167.4	None	-1.0	0.19	7.0	13
5987	Cased	Seneca	144	2275	1400	5445	116.5	Shot	-3.0	0.08	7.7	
6201	Cased	Seneca	217	2016	962	5478	100.5	Kiel, 500, 3177	4.4	0.2	6.9	13
6207	Cased	Seneca	200	1942	1333	5950	94.3	Kiel, 240, 1332	-3.4	0.1	7.8	38
6208	Cased	Seneca	217	2270	1438	6150	46.8	Gld Wtr, 110, 464 w/3.9 Mgal HCl	5.0	0.15	7.6	13
6356	OH	Seneca	185	2068	1400	5609	34.4	None	15.0	0.1	5.6	17
6355	OH	Seneca	9	1500	345	5610	8.9	None	-2.9	0.03	5.8	6
Cand Well												
7305	OH	Seneca	25	1200	1200e		30.5	None	0	0.20	5.9	12
7307	OH	Seneca	45	1803	1803			None	-1.7	0.09	6.8	13

C. TEST AREA #3 - Putnam Co, WV - Package # 23 – 3 Stages / 3 Wells

1. Location

The test area is located in Putnam County, West Virginia in the Midway-Extra field north of Charleston. It is situated near Red House on the east bank of the Kanawha River. The gas production is from the Devonian shale's at depths of approximately 4,200 feet, there are other older wells where the Lower Huron member is farther up the southward plunging Evans Anticline where they lie at depths of 3,700 feet.



2. Operator - Cabot Oil and Gas

Cabot Oil and Gas Corp (Cabot) was aware of, and interested in participating in a cost-shared CO_2/Sand stimulation process for their Devonian Shale wells in the Midway-Extra field. They requested DOE cost-shared support in demonstrating the liquid-free CO_2/Sand stimulation technology.

3. Reservoir

The three Candidate Wells were located in central West Virginia and completed in the Devonian shale. They were situated in Putnam County in a test area that also included twelve conventionally stimulated Control Wells.

The Control Wells were initially completed in deeper formations, Oriskany and Newburg following some years of production, they were subsequently plugged back and cement was circulated across the shale. The shale was then stimulated with nitrogen foam treatments which was pumped down tubing as a single stage treatment.

4. Producing Horizon

The Upper Devonian shale sequence in the test area includes the both the Upper and Lower Huron members which are completed, the Middle Huron infrequently produces gas naturally and is generally non-productive. The lower Huron Member is roughly 400 feet in thickness in this area, with approximately 250 feet of potential pay zones.

a. Porosity

The porosity of the Devonian Shale in the target area is indicated on the electric logs at values considerably greater than that of the matrix formation. The electric log indicated porosity often exceed eight percent in the test area. However, the matrix porosity of the shale is much less, perhaps 2%.

b. Permeability

The permeability for 373 wells in central West Virginia, in Putnam and Jackson counties as reported in SPE Paper #17059 (Gatens, et. al.) ranged from 0.0052 to 3.03 millidarcies (md) and had a geometric mean of 0.151 md.

c. Reservoir Pressure and Temperature

The reservoir pressure and temperature were projected to be is approximately 600 psi and 95 ^{o}F respectively, and the pipeline pressure is approximately 55 psig. In actuality the reservoir pressure was much less, 360 psi and in one of the Candidate Wells was measured at 116 psi, the lowest of all the wells.

A review of the phase behavior at these temperatures and pressures confirmed that the CO_2 would vaporize under these conditions. A phase diagram for each well group was prepared and is not included here, but accompanies the report for that group

d. Sensitivity to Stimulation Liquids

The Devonian Shale in the test area has been producing natural gas for many years and the reservoir pressure is declining. At the time of the demonstrations, it was approximately 350, down from 700 psi. The liquid-sensitive nature of the shale, combined with the diminished reservoir pressure renders this reservoir a prime target for the liquid free CO_2/Sand stimulation technology. This is primarily because the liquids used with conventional stimulations often remain trapped within the reduced pressure formation and impede the flow of natural gas.

5. Control Wells

Nine of the 12 Control Wells were initially drilled into and completed in the Oriskany or Newberg sandstone. These deeper formations were stimulated and produced for a number of years. After the reservoir pressure in the deeper formation depleted, it was plugged, and four and one-half inch production casing was run and cemented across the Huron sections of the Devonian Shale.

The wells were being stimulated with 75 to 90 quality nitrogen foam. The typical treatment included 30 to 90,000 pounds of 20/40 proppant and a similar quantity to that which could be utilized with the CO_2/Sand stimulation process.

The twelve Control Wells have been rank-ordered by their projected five year steady-state cumulative production (46.2 to 135.0 MMcf) and the stimulation details have been summarized:

			API #	5 Yr Cum Prod	Press	Stim Liquid
	Well	No	47-079	(MMcf)	(psi)	(BBLs)
1	Black Betsy	17	1178	135.0	720	575
2	Black Betsy	14	1125	104.3	680	264
3	Black Betsy	4	532	104.1	700	319
4	Black Betsy	19	1201	103.5	600	443
5	Black Betsy	10	614	84.7	590	0
6	Black Betsy	6	541	82.8	530	371
7	Black Betsy	7	544	77.0	600	212
8	Amherst Coal	2	221	76.8	740	165
9	Black Betsy	1	207	74.0	725	110
10	Amherst	3	1131	58.5	715	301
11	Amherst Ind	2	1068	55.5	510	450
12	Putnam	49	1200	46.2	185	454

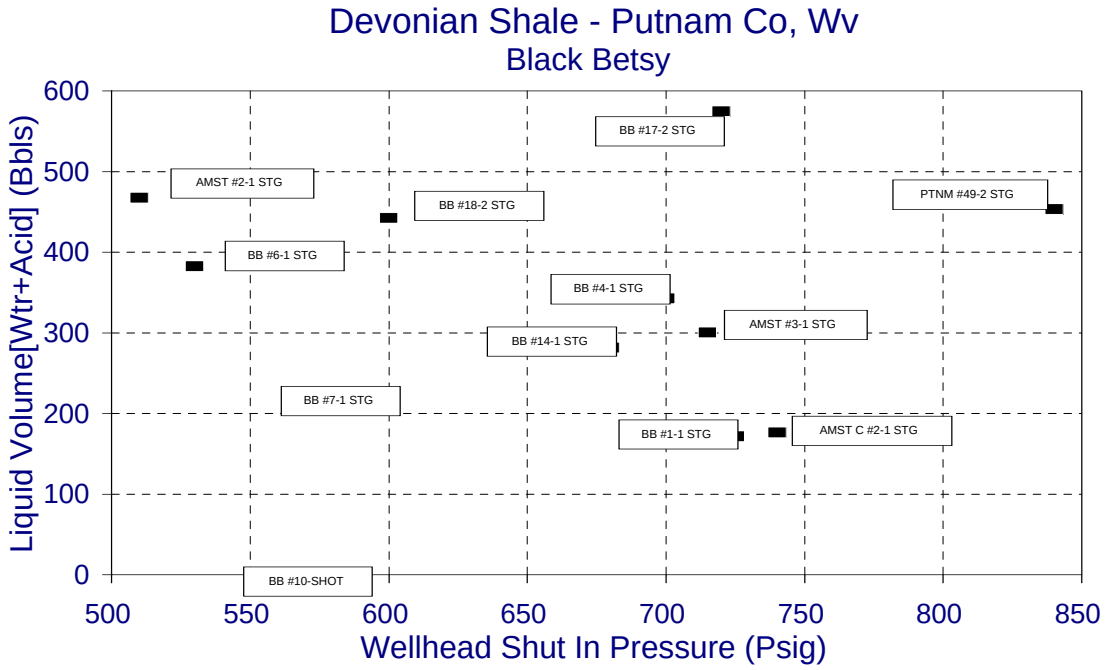
In an effort to understand the range of projected five-year cumulative production, some of the stimulation specifics, and the initial shut in wellhead pressures were reviewed versus the five-year cumulative production to identify any trends which may be related to the reservoir pressure or the liquid volumes used in the stimulation.

The observations are:

a. It is generally true, and as would be anticipated that greater reservoir pressures result in larger cumulative gas quantities.

b. It is generally true, and as would be anticipated that greater reservoir pressures result in larger cumulative gas quantities.

c. There is no obvious relationship between the liquid volume and the reservoir pressure



d. There is however, an inverse apparent relationship between the EUR and the liquid volume.

e. This is an example of how using the EUR can be misleading in evaluating the benefit of different fracturing techniques. The EUR calculation does not consider the time dependent aspects of the cost of capital and, as in this example, can be misleading in a short term evaluation where the return of the capital investment is more sensitive to the discount rate.

f. As would be anticipated, there is no apparent relationship between the liquid volume and the cumulative production.

g. There is no obvious relationship between the proppant volume and the cumulative gas production.

h. In an effort to determine if there was any cumulative production relationship between the ratio of the proppant volume to the liquid volume, they were also plotted.

There does appear to be a general relationship between the proppant to liquid ratio and the cumulative gas production suggesting that the cumulative production is directly proportional to the proppant volume and inversely related to the liquid volume.

i. There is however, an inverse apparent relationship between the EUR and the liquid volume.

6. Candidate Wells

The three Candidate Wells were new wells drilled for the sole purpose of producing from the shale:

a. Candidate Well #1 - Black Betsy #25

The Black Betsy #25 was drilled as a new well drilled through the Devonian shale in September, 1998. It reached a total depth of 4218 feet and had an open flow of 15 Mcf per day, casing (4-1/2 in) was installed, and it was the first well stimulated which included 602 Bbl of CO_2 and 45,000 lbs of proppant were pumped with 44,100 lbs placed in zone. An open flow of 97 Mcfd was gauged after 96 hours after it was cleaned up and a shut in pressure of 418 psi was recorded after 48 hours.

b. Candidate Well #2 - Black Betsy #26

The Black Betsy #26 was drilled as a new well drilled through the Devonian shale in October, 1998. It reached a total depth of 4461 feet and had an open flow of 25 Mcf per day, casing (4-1/2 in) was installed, and it was the second well stimulated which included 148 Bbl of CO_2 and 9,500 lbs of proppant were pumped with 3,000 lbs placed in zone.

The stimulation was performed four weeks after the breakdown acid had been placed in the casing. The delay was because of the inability of the CO_2 supplier to provide product.

It screened out shortly after the sand arrived at the perforations. Two attempts were made and resulted in pumping a total of 378 bbls of CO_2 (148 + 230) and a total of only 8,200 lbs of proppant being placed in the formation.

This was a completely unexpected response and to prevent a similar occurrence on the third and last well in the project, Black Betsy #24, actions were taken to reduce the risk of another screen out. These measures included placement of fresh acid, 400 gal of 15% HCl and modifying the sand schedule to reduce the proppant concentration.

An open flow of 112 Mcfd was gauged after 4 hours after it was cleaned up and a shut in pressure of 370 psi was recorded after 24 hours.

c. Candidate Well #3 - Black Betsy #24

The Black Betsy #24 was drilled as a new well drilled through the Devonian shale in October, 1998. It reached a total depth of 4556 feet and had an open flow of 15 Mcf per day, casing (4-1/2 in) was installed, and it was the third well stimulated which included 419 Bbl of CO_2 and 6,700 lbs of proppant were pumped with 4,800 lbs placed in zone.

Although the additional measures to reduce the risk of a screen out were taken, there was considerable difficulty in stimulating Black Betsy #24 with CO_2/Sand. Again, as was experienced in Black Betsy #26 a screen out occurred early in the sand schedule - beginning just after the sand arrived at the perforations. A total of only 4,800 lbs of proppant were placed in the formation. Following the screen out, the well was flowed back and after twelve minutes the flow abruptly stopped as if there were a mechanical blockage inside the casing. The wellhead was repressured and responded as if it were a closed vessel with an obstruction at a depth of something less than 1,000 ft. The well was eventually flowed back through a larger diameter tubular (3 in nom) and no blockages occurred, and nothing other than sand was observed to be blown from the

well, i.e., no objects which could have plugged the well bore. It is believed that the obstruction was the result of a dry ice plug as a consequence of a CO_2 phase change from vapor to solid.

Upon closer observation, broken pieces of cement, later learned to have a latex component, some with cellophane flakes were also found to have been flowed from the well. These pieces were readily found on top of the frac sand covering portions of the location and were observed to exhibit sharp edges indicating that they had not been in the presence of the breakdown acid. Subsequent observations of the response of these pieces to 10% HCl indicated a vigorous response which confirmed that the cement had not been in the presence of the breakdown acid.

The treatment was finished by pumping 100% CO_2 without any proppant, a total of 587 Bbls (419 + 168) of liquid CO_2 were pumped.

An open flow of 100 Mcfd was gauged after 4 hours after it was cleaned up and a shut in pressure of only 116 psi was recorded after 24 hours.

Upon review of a TV survey run in Black Betsy #24 major problems with the tubular and the lack of cement support were revealed. The casing was observed to have a split running the entire length of one joint. In all instances the splits are straight and because of this character are almost certainly a failure along the seam of the electric resistance welded (ERW) casing. It was not verified that the casing (M-65) was new and may have been used previously.

7. Costs

The CO_2 costs were unexpectedly greater than projected because the supplier failed to provide on schedule which resulted in a four week delay between treatments on Black Betsy #25 and those on Black Betsy #'s 24 & 26.

The total for all three treatments, excluding dozer costs is $7,187.64 greater than the total projected ($189,118.39 vs. $181,930.75). The per well total is $63,040.

8. Results

a. Production Comparisons

The 15 well test group (15 stages) was comprised of 12 Control Wells (12 Stages) in which 11 were stimulated with N_2 foam and one was explosively shot, and 3 Candidate Wells (3 stages) which were stimulated with CO_2/Sand.

Stimulation Type	Stages	Wells
Control		
N_2 foam	11	11
Shot	1	1
Total	12	12
Candidate		
(CO_2/Sand)	3	3
Total	15	15

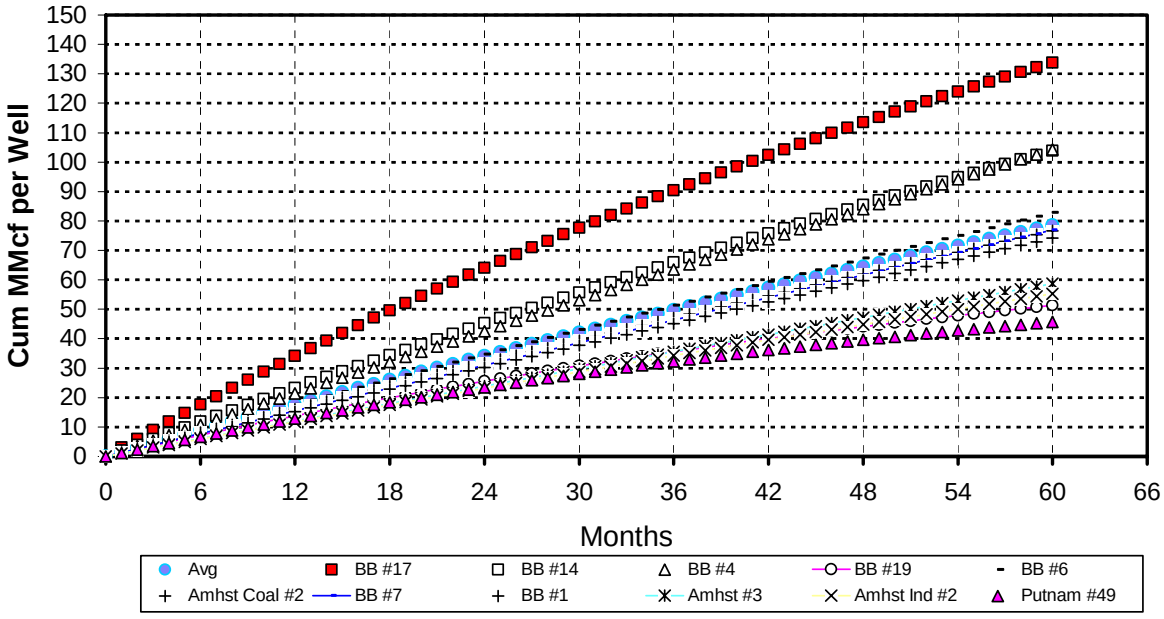
(1) The results of the five year cumulative gas production from this 15 well group are:

(i) The 12 Control Wells ranged from 46.2 to 135.0 MMcf per Well.

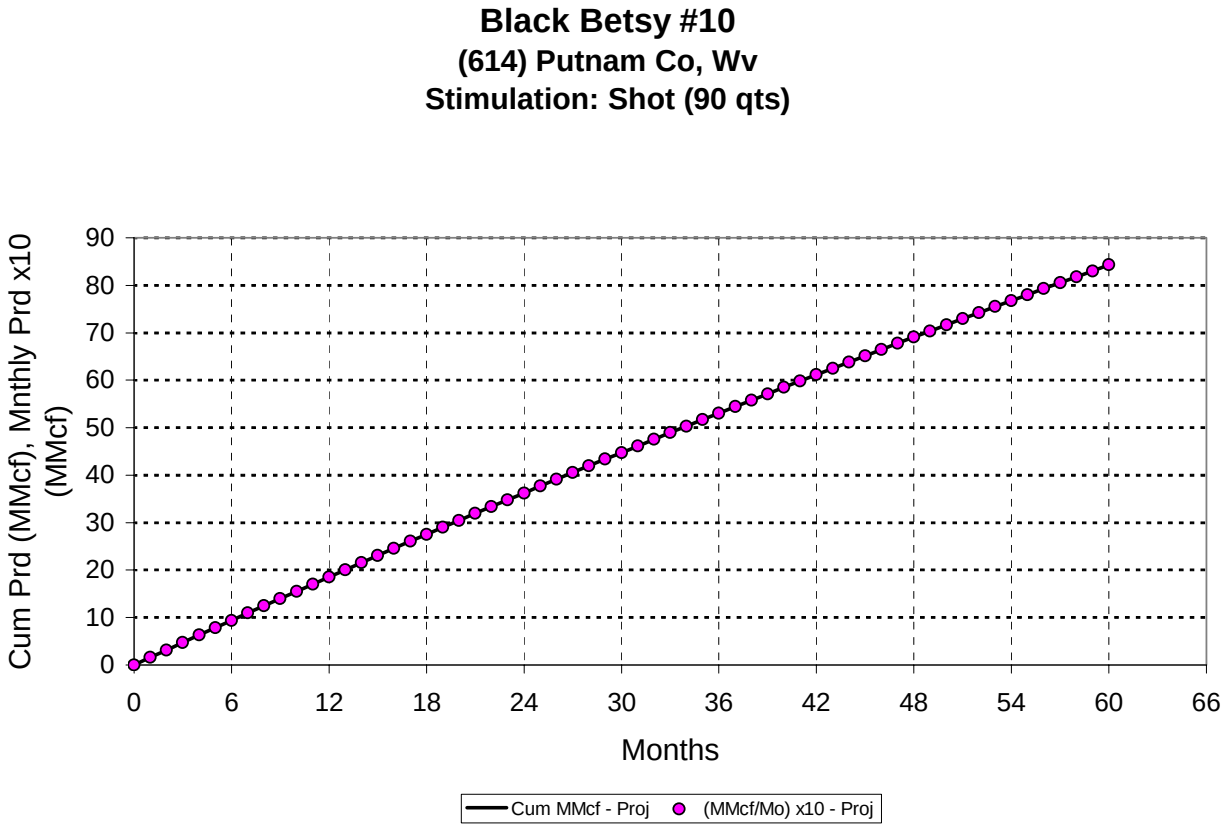
		Prod Yr 5	
		Excl Flsh Prod	Stim Type
	Well	(MMcf)	(Sxs, Bbls)
1	BB #17(PB)	135.0	N2 Fm(1,228+584, 575)
2	BB #14	104.3	N2 Fm(1250, 282)
3	BB # 4(	104.1	N2 Fm(499, 343)
4	BB #19(PB)	103.5	N2 Foam(750+450, 443)
5	BB #10	84.7	Shot
6	BB # 6(PB)	82.8	N2 Fm(600, 383)
7	BB # 7	77.0	N2 Fm(400, 212)
8	Amhrst Coal #2	76.8	N2 Fm(300, 177)
9	BB # 1	74.0	N2 Fm(300, 172)
10	Amherst #3	58.5	N2 Fm(1460, 30)
11	Amhrst Ind #2	55.5	N2 Fm(900, 468)
12	Putnam#49(PB)	46.2	N2 Foam(836+440, 454)

(ii) The production from the 11 wells stimulated with N_2 foam ranged from 46.2 to 135.0 and averaged 78.5 MMcf per well.

Putnam Co, Wv - Stim Type: N_2 Foam (11 Wells, 11 Stages)

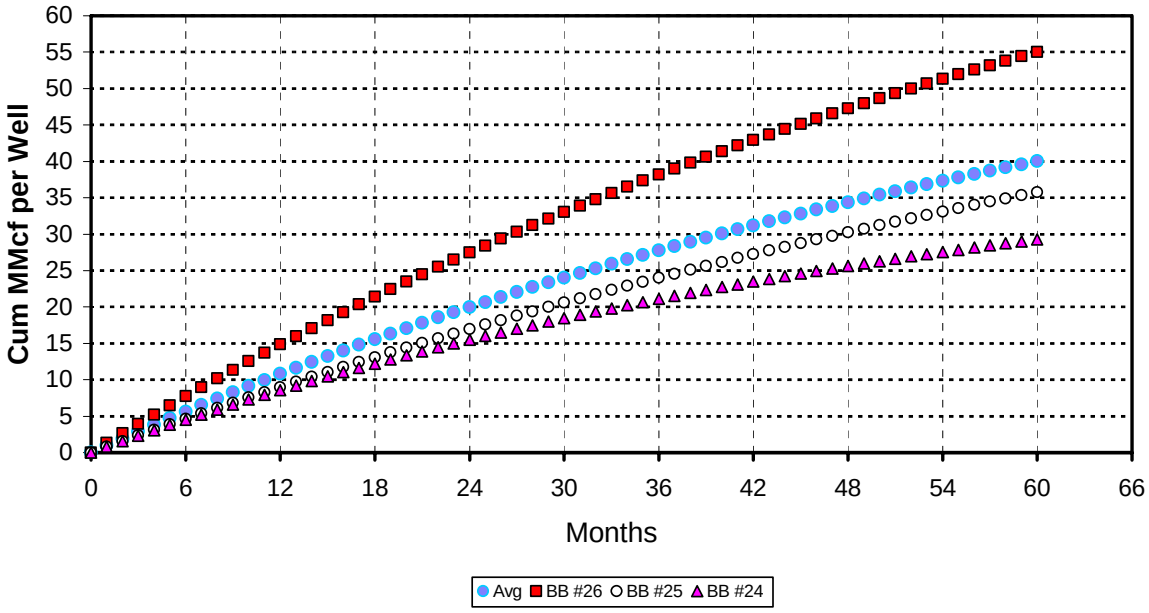


b. The production from the well which was explosively shot was 84.7 MMcf.

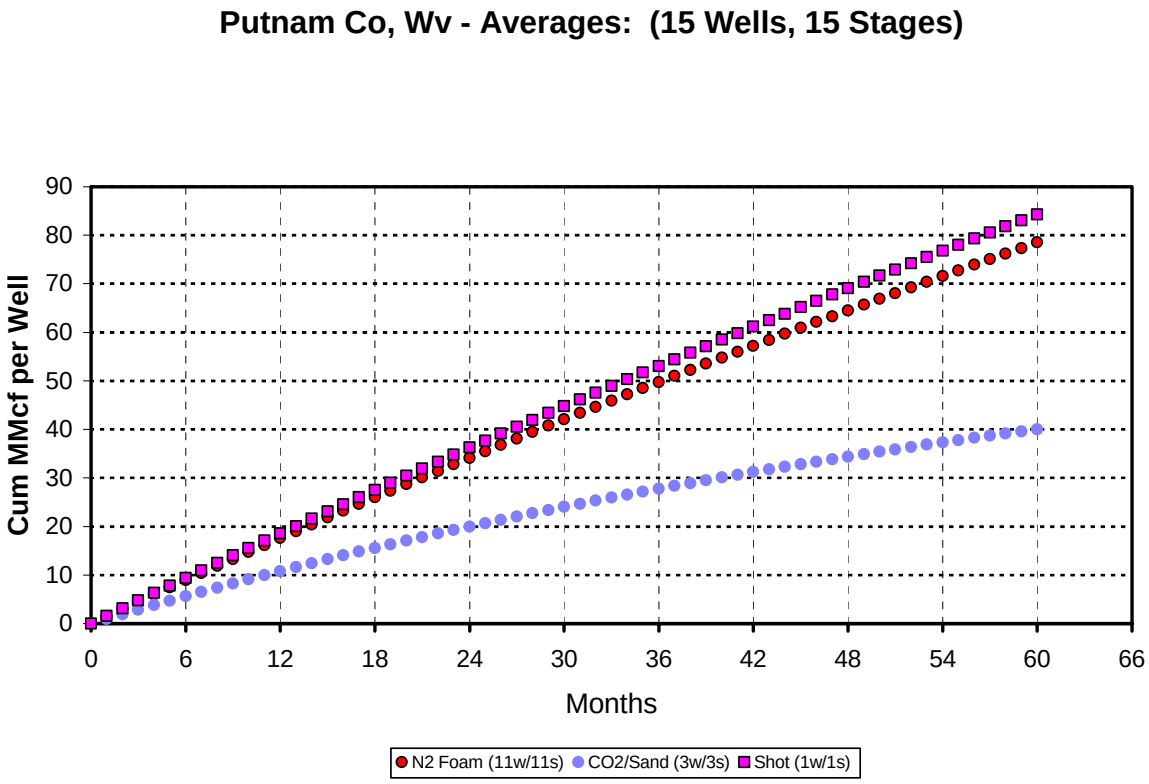


(1) The steady state, five year cumulative production from the three Candidate Wells are disappointing in that they rank 11th, 14th, and 15th of the fifteen wells in the test area. The production from the three wells stimulated with CO_2/Sand ranged from 29.6 to 55.6 and averaged 40.0 MMcf per well. The best Candidate well, Black Betsy #26 ranks 11th and the production is 41% of all fifteen wells in the test area.

Putnam Co, Wv - Stim Type: CO_2/Sand (3 Wells, 3 Stages)



c. There were unexpected problems in stimulating two of the three wells, which resulted in only minimal proppant volumes being placed. Additionally, one of the wells, Black Betsey #25, was stimulated with the design volume of proppant, 45,000 pounds and the production from it was also much less than expected.



d. In an effort to explain these responses, wire line television and temperature surveys were run on all three wells and the findings indicated a severely compromised casing in Black Betsy #24 and many of the perforations exhibited no erosion indicating minimal fluid passage. It is strongly suspected that the use of bullets rather than shaped charges for perforating impeded the fluid entry into the perforations and thereby compromised the stimulation.

(1) The inability to effectively place proppant in two of the wells, Black Betsy #s 24 and 26 combined with the significantly depleted reservoir pressure are the primary explanations for the poor production performance.

(2) It is clearly evident that the wells that were stimulated four weeks after the breakdown acid, 7-1/2% HCl, had been placed in them did sustain significant pitting of the casing even though the acid had been displaced into the formation and from the casing.

(3) The casing in the well in which the acid was displaced with nitrogen, Black Betsy #24 experienced a much greater degree of pitting than the well in which the acid was displaced with CO_2.

(4) The casing is split in Black Betsy #24 which is the explanation of the screen out early in the CO_2/Sand stimulation, because of the loss of transport velocity through the increased cross-sectional area.

(5) The casing in all three wells was perforated with bullets. Bullets and for some years considered to be an out dated method of perforating and very uncommon. A review of the ability to initiate hydraulic fractures in bullet holes with a low viscosity fluid should perhaps be initiated?

(6) The reservoir pressure in two of the Candidate Wells was significantly less than that of the Control Wells. The Candidate Wells, Black Betsy #s 24 & 26 had much reduced reservoir pressures, 116 & 370 psi respectively. Because of it these wells would not be expected to perform well.

(7) The cause of the poor performance in Black Betsy #25 is unknown but the use of bullets rather than shaped charges for perforating the casing is suspected as being a significant contributing factor to the disappointingly low production rate. It is also evident that no single perforation is responsible for a majority of the production.

(8) The stimulation costs for the three Candidate Wells including large blender and mobilization costs, and extraordinary additional costs for CO_2 wastage was $180,333 or approximately $60,000 per well. If the research costs were removed and with landed costs for CO_2 of $100 per ton, including the portable storage vessels then the costs are projected to have been on the order of $47,000 per well.

(9) The well which was stimulated first and received the designed proppant volume, Black Betsy #25 has a reduced, but reasonable reservoir pressure, 418 psi and should have performed much better. It is strongly suspected that the use of bullets for perforating is a factor.

e. Reservoir Pressure

The reservoir pressure in the Control Wells was significantly less than that of the Control Wells and it can therefore be concluded that the cumulative production would be significantly diminished.

9. Conclusions

a. The production volumes from the three Candidate Wells has been disappointingly low, ranging from 29.6 to 55.6 MMcf which results in a ranking of 11th, 14th, and 15th out of 15.

b. The inability to place proppant in two of the wells, Black Betsy #'s 24 & 26 is a circumstance or combination of placing acid in and then subsequently displacing it from them prior to the stimulation treatments. And, may also be a circumstance resulting from the use of bullets rather than shaped charges to perforate the casing and be a result of acid reactions with the metal bullets.

c. The reservoir pressure in two of the Candidate Wells was significantly less than that of the Control Wells. The Candidate Wells, Black Betsy #s 24 & 26 had much reduced reservoir pressures, 116 & 370 psi respectively. These wells would not be expected to perform well.

d. The inability to effectively place proppant in two of the wells, Black Betsy #s 24 and 26 combined with the significantly depleted reservoir pressure are the primary explanations for the poor production performance.

e. It is clearly evident that the wells that were stimulated four weeks after the breakdown acid, 7-1/2% HCl, had been placed in them did sustain significant pitting of the casing even though the acid had been displaced into the formation and from the casing.

f. The casing is split in Black Betsy #24 which is the explanation of the screen out early in the CO_2/Sand stimulation, because of the loss of transport velocity through the increased cross- sectional area.

g. The well in which the acid was displaced with nitrogen, Black Betsy #24 experienced a much greater degree of pitting than the well in which the acid was displaced with CO_2.

h. It is generally true, and as would be anticipated that greater reservoir pressures result in larger cumulative gas quantities The cause of the poor performance in Black Betsy #25 is unknown but the use of bullets rather than shaped charges for perforating the casing is suspected as being a significant contributing factor to the disappointingly low production rate. It is also evident that no single perforation is responsible for a majority of the production.

i. The stimulation costs for the three Candidate Wells including large blender and mobilization costs, and extraordinary additional costs for CO_2 wastage was $180,333 or approximately $60,000 per well. If the research costs were removed and with landed costs for CO_2 of $100 per ton, including the portable storage vessels then the costs are projected to have been on the order of $47,000 per well

10. Well specific data

									Prod Yr 5		Flush	
		Pmt #		Nat=l	OF	Press	Tmp	TD	Excl Flsh Prod		Prod/mo	
	Well	(47-079-)	Oper	(Mcfd)	(Mcf/d)	(psig)	(F)	(ft)	(MMcf)		(???)	Stim Type(sxs, Bbls)
1	BB #17(PB)	1178	Cabot		382	720		5787	135.0	100%		N2 Fm(1,228+584, 575)
2	BB #14	1125	Cabot	38	444	680		4556	104.3	77%		N2 Fm(1250, 282)
3	BB # 4(	532	Cabot	TSTM	575	700		5020	104.1	77%		N2 Fm(499, 343)
4	BB #19(PB)	1201	Cabot		353	600		4251	103.5	77%		N2 Foam(750+450, 443)
5	BB #10	614	Cabot	231		590		4487	84.7	63%		Shot
6	BB # 6(PB)	541	Cabot		178	530		4600	82.8	61%		N2 Fm(600, 383)
7	BB # 7	544	Cabot		231	600		3960	77.0	57%		N2 Fm(400, 212)
8	Amhrst Coal #2	221	TBD		411	740		4100	76.8	57%		N2 Fm(300, 177)
9	BB # 1	207	Cabot		180	725		4550	74.0	55%		N2 Fm(300, 172)
10	Amherst #3	1131	Cabot		664	715		4312	58.5	43%		N2 Fm(1460, 30)
11	BB #26	1237	Cabot	25	112	370		4461	55.6	41%		Liq CO2(82, 488)
12	Amhrst Ind #2	1068	Cabot		207	510		4795	55.5	41%		N2 Fm(900, 468)
13	Putnam#49(PB)	1200	Cabot		TSTM	185		4329	46.2	34%		N2 Foam(836+440, 454)
14	BB #25	1234	Cabot	15	97	418		4236	35.9	27%		LiqCO2(441, 638)
15	BB #24	1233	Cabot	15	100	116		4555	28.6	21%		LiqCO2(48, 592)

XII. CONCLUSIONS

A. **Test area #1** - Chautauqua Co, Ny – Package #12 - 3 Stages / 3 Wells – Whirlpool Sand

1. Production from this reservoir derives no benefit from the liquid-free CO_2/Sand stimulation process.

2. It is evident that the wells which were stimulated with liquid-based nitrogen foam stimulations produced gas at considerably greater rates than those which were stimulated with the liquid-free CO2/sand stimulations.

3. The production rates are dependent upon the quantity of sand placed with the greater production rates associated with larger proppant volumes.

4. The maximum sand volume which could be placed with the CO_2/Sand process was approximately one-half of that placed with the nitrogen foam treatments and ranged from 28,000 to 35,500 pounds; whereas those stimulated with the foam treatments generally contained at least 60,000 pounds.

5. The wells produce water which differs from the information provided by the operator. It had been indicated that the wells in this area produce little if any water.

B. **Test area #2** -Mercer Co, Pa - Package # 16 – 1 Stage / 1 Well – Lockport Dolomite

1. The five-year cumulative production projections from the Candidate well is 31 MMcf resulting in response much lower than the others.

2. The most productive wells have been cased and stimulated with acid

3. The stimulation of the open hole interval was unsuccessful in placing proppant. There were two attempts; the first attempt was aborted because of a mechanical inability to blend sand, and the second attempt screened-out resulting in only a minimum volume of 20/40 mesh sand, 6,600 lbs being placed in the reservoir.

C. **Test area #3** - Putnam Co, Wv - Package # 23 – 3 Stages / 3 Wells – Devonian Shale

1. The production volumes from the three Candidate Wells has been disappointingly low, ranging from 29.6 to 55.6 MMcf which results in a ranking of 11^{th}, 14^{th}, and 15^{th} out of 15

2. The inability to place proppant in two of the wells, Black Betsy #'s 24 & 26 is a circumstance or combination of placing acid in and then subsequently displacing it from them prior to the stimulation treatments. And, may also be a circumstance resulting from the use of bullets rather than shaped charges to perforate the casing and be a result of acid reactions with the metal bullets.

3. The reservoir pressure in two of the Candidate Wells was significantly less than that of the Control Wells. The Candidate Wells, Black Betsy #s 24 & 26 had much reduced reservoir pressures, 116 & 370 psi respectively. These wells would not be expected to perform well.

4. The inability to effectively place proppant in two of the wells, Black Betsy #s 24 and 26 combined with the significantly depleted reservoir pressure are the primary explanations for the poor production performance.

5. It is clearly evident that the wells that were stimulated four weeks after the breakdown acid, 7-1/2% HCl, had been placed in them did sustain significant pitting of the casing even though the acid had been displaced into the formation and from the casing.

6. The casing is split in Black Betsy #24 which is the explanation of the screen out early in the CO_2/Sand stimulation, because of the loss of transport velocity through the increased cross- sectional area.

7. The well in which the acid was displaced with nitrogen, Black Betsy #24 experienced a much greater degree of pitting than the well in which the acid was displaced with CO_2.

8. It is generally true, and as would be anticipated that greater reservoir pressures result in larger cumulative gas quantities The cause of the poor performance in Black Betsy #25 is unknown but the use of bullets rather than shaped charges for perforating the casing is suspected as being a significant contributing factor to the disappointingly low production

rate. It is also evident that no single perforation is responsible for a majority of the production.

XIII. DELIVERABLES

A. Target Area Work Plans

The descriptions of the Control and Candidate Wells were included with the submittal packages for each individual group with the request for DOE cost-shared support

B. Geophysical Well Logs

The well logs for both the Control Wells and in most cases for the Candidate Wells were included with the submittal packages, in some instances they were also included in the Final Reports for each of the 24 groups.

C. Well Stimulation Plans

The stimulation plans have been included in the seven Final Reports which have been submitted for each approved well group.

D. Stimulation Records

The stimulation plans have been included in the seven Final Reports which have been submitted for each approved well group.

E. Production and Pressure Records

The production and pressure records have been plotted and included in the seven Final Reports which have been submitted for each approved well group, and summarized in this Report..

F. Well Data

The well data for both the Control and Candidate Wells were included with the submittal packages, and in the seven Final Reports which have been submitted for each approved well group, and summarized in this Report..

G. Final Reports

1. Phase II - This document
2. Pkg # 12 – Submitted
3. Pkg # 16 – Submitted
4. Pkg # 23 – Submitted

These Reports include all of the well specific information on all of the wells situated in eastern Kentucky and stimulated under the provisions of this contract.

This completes the efforts to summarize the specifics and findings of these demonstrations of the liquid-free stimulation process. More detailed well-specific information i.e.: production plots, figures, logs, etc. relative to these efforts accompany the individual reports for each group.

Respectfully Submitted,

_____

Raymond L. Mazza, P.E.
Project Manager