Gas Storage Field Deliverability Enhancement and Maintenance: An Intelligent Portfolio Management Approach.

Final Report

Reporting Start Date: September 1, 2004 **Reporting End Date:** December 31, 2006

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Reporting Issue Date: January 2007

Subcontract No. 3040-WVRC-DOE-1779

Report prepared for:

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ABSTRACT

Portfolio management, a common practice in the financial market, is essentially an optimization problem that attempts to increase return on investment. The objective of this project is to apply the state-of-the-art in optimum portfolio management to the gas storage field in order to optimize the return on investment associated with well remedial operations.

Each year gas storage operators spend hundreds of thousands of dollars on workovers, recompletions, and re-stimulations of storage wells in order to battle the decline in deliverability due to well damage with time. A typical storage field has tens if not hundreds of production wells. Each well will respond to remedial operations in its own unique way. The well's response to the remedial operation is a function of a set of uncontrollable reservoir characteristics such as porosity and permeability and a set of controllable parameters such as completion and stimulation practices.

The objective of this project is to identify the combination of best candidate wells for the remedial operations that will result in the most successful program each year, and consequently provides the highest return on investment. The project deliverable is a Windows-based software application that would perform the analysis and provide the list of wells and their corresponding remedial operation for each year based on the budget constraints identified by the user.

The state-of-the-art in intelligent systems application that is currently being used extensively in the Wall Street is the methodology to achieve the objectives of this proposed project. This methodology includes a hybrid form of artificial neural networks, genetic algorithms and fuzzy logic. Columbia Gas Transmission Corporation is the industry partner of this project and cooperated with the research and development team in order to ensure successful completion of the project.

The software application that is the deliverable of this project and is explained in much detail in this report is available to public free of charge. One important note about the software is that the current, publicly available version of the software includes a neural network model that has been developed for our industry partner based on the data that they made available. Once a storage operator decides to implement this software, they should contact the principal investigator of this project (*Shahab D. Mohaghegh, Professor, Petroleum & Natural Gas Engineering, West Virginia University, Email: shahab@wvu.edu - Tel; 304-293-7682 ext. 3405 – Web Site: http://shahab.pe.wvu.edu)* and arrange for development of a neural network model for their specific storage field. In order to make the best use of capabilities of the software package, it is recommended that the storage filed have a minimum of 75 wells (wells with data that can be used for analysis).

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INTRODUCTION

Each year Gas Storage operators spend hundreds of thousands of dollars to combat the inevitable decline in the deliverability of their production wells. The decline in deliverability with time has two major contributors. The first contributor is geology and reservoir characteristics that are uncontrollable parameters. The second sets of parameters that contribute to the decline are associated with well damage that is addressed by well remedial operations such as workovers, recompletions, and re-stimulation of the producing wells. The parameters associated with these remedial operations can be controlled by the operator.

It is a fact that every well will respond to a specific remedial operation in a unique way. For example, the deliverability of well "A" will increase two folds if a proper restimulation is performed on it while the same operation performed on well "B" will result in little or no deliverability enhancement. Same is true for workovers. Finding the best candidate for restimulation or workover, each year, among the tens or hundreds of wells is a challenging task. Consider another situation where well "C" will have a 70% increase if a restimulation is performed but it would have a 65% increase if a far less expensive workover is performed. Obviously performing a workover instead of a restimulation on well "C" would be more economical this year.

EXECUTIVE SUMMARY

Portfolio management, a common practice in the financial market, is essentially an optimization problem that attempts to increase return on investment. The objective of this project is to apply the state-of-the-art in optimum portfolio management to the gas storage field in order to optimize the return on investment associated with well remedial operations.

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EXPERIMENTAL

No experimental work was performed during this project.

RESULTS & DISCUSSIONS

This is the detail report of the progress made so far in the above mentioned project, which consists of following components:

- 1- Project Overview
- 2- Data made available and its format
- 3- Neural Network Model
- 4- Genetic Optimization Model
- 5- Database & Software

PROJECT OVERVIEW

The objective of this project is to apply state-of-the-art intelligent, optimum portfolio management to the gas storage field in order to optimize the return on investment associated with well remedial operations. Columbia Gas Transmission Corporation is the industry partner in this project and provided us with very valuable data and in-depth knowledge about their gas storage field operations.

The data in very crude form was provided to the research and development team in the last week of March, 2005. The team extracted valuable data and organized it in a form of database, with generic make up in order to be reusable. Windows-based software was developed which can help the user in viewing and later populating the data with easy to use interface. One of its modules provides the user with all the valid stimulations required as an input for Neural Network. A Neural Network was trained in order to predict skin for different stimulation parameters. A Genetic Optimization tool was developed and associated with the trained Neural Network in order to find the optimum stimulation parameters. The software ranks the well according to maximum change in skin value or/and stimulation cost for a well. Then a decision is made to restimulate a well or not accordingly.

DATA MADE AVAILABLE AND ITS FORMAT

The research and development (R & D) team was initially provided data in MS excel worksheets. On further request, some pdf files with well schematics, well test files and well summary files were provided but still the required data especially relating to stimulations and well-tests was so scarce that the team in July, 2005 went to the Columbia Transmission Corporation Office in Charleston, WV to get more information. Retrieval of data from different files and thousands of microfiche was taking so long at the office that it was decided that West Virginia University lab facilities will be used to read thousands of microfiche. So, for the next few weeks the team concentrated its efforts on data collection. That data could be segregated into five main tables, each relating to specific characteristic features of the gas storage wells. The five characteristic features are as below:

- 1- Well-bore data
- 2- Completion Data
- 3- Perforation Data
- 4- Stimulation Data
- 5- Well-Test Data
- 6- Reservoir Characteristic Data

WELL BORE DATA

It includes basic features of the well like location, depth, well name ... etc. Data about well-bore was retrieved mostly from well schematics and well summary reports. The data already provided by Columbia Transmission Corporation was also verified. The complete list of the data type retrieved is as below:

- 1. API Number
- 2. Field Name
- 3. Well
- 4. Lease Name
- 5. Classification
- 6. Latitude (Lat)
- 7. Longitude (Long)
- 8. Section
- 9. Township
- 10. County
- 11. State
- 12. Operator
- 13. Total Vertical Depth
- 14. Formation

Picture of one of the forms from which this data was retrieved is on next page

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Fig1. Well-bore data retrieved from a file

SubGroup

Completion Type

40.72111 -8 Well Classification ACTIVE

Key Well

No

Group

6

Est.DeepFW (ft)

The tables contained many minor mistakes like wrong Well API number, length, and many spelling mistakes. A picture of this correction is shown below:

	A	В	C	D	E		F	G	Н	I	J	K
1	Field Name	Well	Lease Name	API	Classific	cation	Latitude	Longitude	Section	Township	County	State
32	LUCAS	03897	"SYLVIA C. KROUT, ET AL"	34-005-93897	ACTIVE		40.6961	-82.3058	17	GREEN	ASHLAND	OH C
33	LUCAS	03912	P. SHAFFER #1	34-005-602660000	SPECIAL		40.7133	-82.24	1	GREEN	ASHLAND	OH C
34	LUCAS	03921	G. W. HINER #2	34-005-93921	ACTIVE		40.7383	-82.2719	34	VERMILLION	ASHLAND	OH C
35	LUCAS	03926	JOHN BUSLER #1	34-005-602650000	ACTIVE		40.7106	-82.2358		GREEN	ASHLAND	OH C
36	LUCAS	03929	D. KICK #1	34-005-93929	ACTIVE		40.7103	-82.2611		GREEN	ASHLAND	OH 0
37	LUCAS	03931	W. E. GUTHRIE #1	34-005-93931	ACTIVE		40,6889	-82 3047	17	GREEN	ASHLAND	OH C
38	LUCAS	03932	H. J. TRUMPOWER #1	34139601180000	ACTIVE	Wre	ong Al	т		MONROE	RICHLAND	OH C
39	LUCAS	03935	J. O. ANDREWS #2	34-005-93935	ACTIVE		-			GREEN	ASHLAND	OH C
40	LUCAS	03939	M. A. MAURER #1	34-005-93939	ACTIVE	Nun	aber l	ength		VERMILLION	ASHLAND	OH C
41		03945	"RUSSEL J. LIFER, ET UX"	34-005-93945	ACTIVE			-		GREEN	ASHLAND	OH C
42	LUCAS	03946	C. SMITH #1	34005602420000	ACTIVE		40.6703	-82.3339	19	GREEN	ASHLAND	OH C
43	LUCAS	03950	G. W. PURVINE #1	34139601230000	octive .		40.6736	-82.3453	24	MONROE	RICHLAND	OH C
44	LUCAS	03953	J. H. ROWE #1	34139201590000 🏒	ACTIVE		40.6761	-82.3417	24	MONROE	RICHLAND	OH C
45			WM. & MARY BRENNSTUHL #	34.005.93963	ACTIVE		40.6228	-82.2925	9	HANOVER	ASHLAND	OH C
46			J. F. MANG #1	34005602590000	ACTIVE		40.6983	-82.3061	8	GREEN	ASHLAND	OH C
47	LUCAS	03969	J. & E. PARR #1	34-005-93969	ACTIVE		40.6739	-82.3375	19	GREEN	ASHLAND	OH C
48	LUCAS	03972	J. H. ROWE #2	34-139-93972	ACTIVE		40.6797	-82.3408		MONROE	RICHLAND	OH C
49	LUCAS	03976	W. & M. APPLEGATE #1	34-139-93976	ACTIVE		40.6836	-82.3494		MONROE	RICHLAND	OH C
50	LUCAS	03978	A. & C. GUTHRIE #1	34-005-93978	ACTIVE		40.6806	-82.3356		GREEN	ASHLAND	OH 0
51	LUCAS	03983	E. & M. OSWALD #1	34139601590000	ACTIVE		40.6836	-82.345		MONROE	RICHLAND	OH C
52	LUCAS	03995	S. E. MCKENLEY #1	34-005-93995	ACTIVE		40.7378	-82.2231	36	VERMILLION	ASHLAND	OH 0
53	LUCAS	03997	W. & M. APPLEGATE #2	34-139-93997	ACTIVE		40.6856	-82.3536	13	MONROE	RICHLAND	OH C
54	LUCAS	04008	H. & M. MCGUIRE #1	34005216200000	ACTIVE		40.6983	-82.2614	10	GREEN	ASHLAND	OH C

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32	LUCAS	03897	34-005-93897	ACTIVE	40.6961	-82.3058	17	GREEN	ASHLAND	OH	Columbia Gas Transmissic
33	LUCAS	03912	34-005-60266	SPECIAL	40.7133	-82.24	1	GREEN	ASHLAND	OH	Columbia Gas Transmissic
34	LUCAS	03921	34-005-93921	ACTIVE	40.7383	-82.2719	34	VERMILLION	ASHLAND	OH	Columbia Gas Transmissic
35	LUCAS	03926	34-005-60265	ACTIVE	40.7106	-82.2358	12	GREEN	ASHLAND	OH	Columbia Gas Transmissic
36	LUCAS	03929	34-005-93929	ACTIVE	40.7103	-82.2611	10	GREEN	ASHLAND	OH	Columbia Gas Transmissic
37	LUCAS	03931	34-005-93931	ACTIVE	40.6889	-82.3047	17	GREEN	ASHLAND	OH	Columbia Gas Transmissic
38	LUCAS	03932	34-139-60118	ACTRAE	10 6764	-82.3478	24	MONROE	RICHLAND	OH	Columbia Gas Transmissic
39	LUCAS	03935	34-005-93935	Corrected		-82.247	2	GREEN	ASHLAND	OH	Columbia Gas Transmissic
40	LUCAS	03939	34-005-93939			-82.2375		VERMILLION	ASHLAND	OH	Columbia Gas Transmissic
41	LUCAS	03945	34-005-93945	API Numb	oer	-82.3017	17	GREEN	ASHLAND	OH	Columbia Gas Transmissic
42	LUCAS	03946	34-005-60242	AUTIVE	40.6703	-82.3339	19	GREEN	ASHLAND	OH	Columbia Gas Transmissic
43	LUCAS	03950	34-139-60123	Active	40.6736	-82.3453	24	MONROE	RICHLAND	OH	Columbia Gas Transmissic
44	LUCAS	03953	34-139-20159	ACTIVE	40.6761	-82.3417	24	MONROE	RICHLAND	OH	Columbia Gas Transmissic
45	LUCAS	03963	34-008-93963	ACTIVE	40.6228	-82.2925	9	HANOVER	ASHLAND	OH	Columbia Gas Transmissic
46	LUCAS	03967	34-005-60259	ACTIVE	40.6983	-82.3061	-	GREEN	ASHLAND	OH	Columbia Gas Transmissic
47	LUCAS	03969	34-005-93969	ACTIVE	40.6739	-82.3375	19	GREEN	ASHLAND	OH	Columbia Gas Transmissic
48	LUCAS	03972	34-139-93972	ACTIVE	40.6797	-82.3408	24	MONROE	RICHLAND	OH	Columbia Gas Transmissic
49	LUCAS	03976	34-139-93976	ACTIVE	40.6836	-82.3494	13	MONROE	RICHLAND	OH	Columbia Gas Transmissic
50	LUCAS	03978	34-005-93978	ACTIVE	40.6806	-82.3356	19	GREEN	ASHLAND	OH	Columbia Gas Transmissic
51	LUCAS	03983	34-139-60159	ACTIVE	40.6836	-82.345	13	MONROE	RICHLAND	OH	Columbia Gas Transmissic
52	LUCAS	03995	34-005-93995	ACTIVE	40.7378	-82.2231	36	VERMILLION	ASHLAND	OH	Columbia Gas Transmissic
53	LUCAS	03997	34-139-93997	ACTIVE	40.6856	-82.3536	13	MONROE	RICHLAND	OH	Columbia Gas Transmissic
54	LUCAS	0/008	34.005.21620	ACTIVE	AD 6983	.82 2614	10	GREEN	ASHLAND	OH	Columbia Gae Tranemiseir

Analysis of raw data vs. refined data:

	_	_	_	WE	LLB	ORE	DATA	1		_		_	_	
DATA FIELDS	API Number	Field Name	Well	Lease Name	Classification	Lat	Long	Section	Township	County	State	Operator	Total Vertical Depth	Formation
INITIIAL DATA AVAILABLE	430	427	430	430	427	429	430	430	430	430	430	430	425	430
FINAL Data Available	430	430	430	430	430	430	430	430	430	430	430	430	430	430

WELLBORE DATA

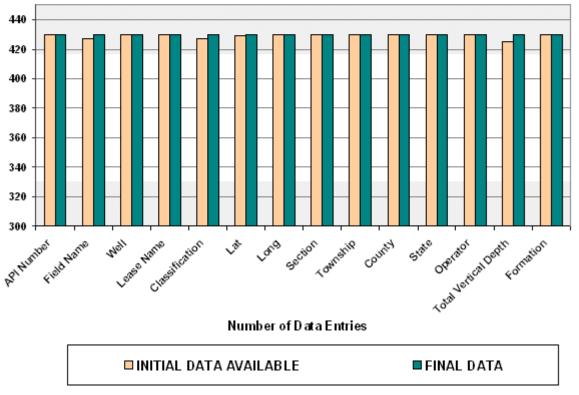


Fig3. Data addition and refinement for Well-bore Data

COMPLETION DATA

Completion data mostly relates to the type and depth of casing/liner/tubing run in the gas storage wells. The data type retained for the database includes the following:

- 1. API Number
- 2. Field Name
- 3. Well Name (Well)
- 4. Completion Description (Des)
- 5. Date Tubing Run (Dt Tm Rn)
- 6. Outer Diameter (OD)
- 7. Top of Casing
- 8. Bottom of Casing(Bot)
- 9. Casing Weight (Weight)
- 10. Casing Grade (Grade)

Unfortunately the data was mostly in an excel file and had to be verified with well schematic drawings. This led to the most unusual step in this project as it lead to reduction of valuable data available to us. This was due to the erroneous and multiple data entry originally in the completion table. Identification of the multiple entries and their removal from table was the most focused act of cleaning the data, as omission of desirable records was unacceptable. Following pictures show one of such flawed multiple data entries which were removed.

	A	В	C	D	E	F	G	н		J	K	L
1	Field Name	Well	API	Des	DtTmRun	OD	Top	Bot	Weight	Grade		
71	LUCAS	00873	34-005-90873	Casing	03-Oct-17	7.00	0	2043	20.00			
72	LUCAS	00873	34-005-90873	Casing	02-Mar-64	5.50	0	2908	17.00	Seamless		
73	LUCAS	01981	34-005-91981	Drive Pipe	01-Nov-24	10.75	0	33	40.00			
74	LUCAS	01981	34-005-91981	Surface Pipe	02-Nov-24	8.63	0	299	24.00			
75	LUCAS	01981	34-005-91981	Casing	03-Nov-24	7.00	1893	1931	20.00			
76	LUCAS	01981	34-005-91981	Casing	04-Nov-24	5.50	0	2681	17.00			
77	LUCAS	01981	34-005-91981	Casing	02-Nov-63	3.50	0	2694	9.20	Used		
78	LUCAS	01981	34-005-91981	Packer	03-Nov-63	5.50	2684	2694	_	Straight Anchor		
79	LUCAS	01981	34-005-91981	Packer	03-Nov	Multi	n la D	ata				
80	LUCAS	01981	34-005-91981		03-N0W		-	ata		Straight Anchor		
81	LUCAS	02008	34-005-92008	Drive Pipe	01-Jul	Entry			00			
82	LUCAS	02008	34-005-92008	Surface Pipe	02-Jy							
83	LUCAS	02008	34-005-92008	Packer	00 Jul-25	8.63	1829	1839		Larkin Lead B.H.		
84	LUCAS	02008	34-005-92008	Packer	03-Jul-25	8.63	1829	1839				
55	LUCAS	02008	34-005-92008	Casing	03-Jul-25	7.00	1793	1839	20.00			
36	LUCAS	02008	34-005-92008	Packer	04-Jul-25	7.00	2500	2510				
87	LUCAS	02008	34-005-92008	Packer	04-Jul-25	7.00	2500	2510		O'VS Midget		
36 I	LUCAS	02008	34-005-92008	Casing	04-Jul-25	5.50	0	2510	17.00			
i9	LUCAS	02008	34-005-92008	Casing	02-Oct-63	5.50	0	2654				
90	LUCAS	02008	34-005-92008	Packer	02-Oct-63	5.50	2551	2561				
31	LUCAS	02008	34-005-92008	Anchor	02-Oct-63	5.50	2561	2571				
32	LUCAS	02008	34-005-92008	Packer	02-Oct-63	5.50	2551	2561				
93	LUCAS	100008	34,005,92008	Anchor	02-Oct-63	5.50	2561	2571				
34	LUCAS	02060	34-005-92060	Casing	01-Oct-25	10.75	0	64	40.00			

Fig4. Multiple Data Entries in Completion Table

In the completion table, the following notations used as casing description were replaced in place of different notations being used to have a standard definition

NOTATION KEPT IN DATABASE	Surface casing
NOTATIONS DISCARDED	Drive pipe
	Driver Pipe
	Swedge
	Two stage

Completion data was mostly re- checked for accuracy from the documents, picture of which is shown below for a Well.

12	dones.	- ATUR 0	LUCAS -					1			Lu			10.0					
		r	Redined By	/		Field	lline Date		red by erson			fied by ander		Cor	ment				
			Field Name		h trans	Unstand	API Numbe		Lease N	la su s	BOG		Spud Dat	LA cross	e TVD (10 .	MD (ft)		atum referenc
			LUCAS		OL.o.		340056111					- 1	8/1/191			10	2857		atum reterenc
F		1	Township/T	lay District	No.a	Tax Nu			TC.	ounty				elProvince		:027	I Operatin		
		Sign, See Roy,	GREEN	IAN DISOTO		30050	110/CH			SHLAND			OH			Wposter			
		010	Latitude (DD)) Lonat	ude (DD)		Number	Sta	State Permit #										ory Map #
-		J	. 72111			5		-											
			Well Classif	fication	Key Well	Group	1	SubGro	oup	Comp	letion Type	2		Est.Deep	EW (ft)	Gri	Elev (ft)	}	(B Elevation (
			ACT	IVE	No	6													
		1	Directions T	io Well				-											
		The Casing DWB																	
	- 11		Wellhead								Lama		1.		Le.				
			Type API Wellhes		nstall Date	Make		-lowstsz	(in) Sup	portstsz	(in) WP ()	psi()	Con	ection 3° 10R	Commen				
1	- 0110		API weines	10										3" 10R	Wellhear	0.5628-3	X.5.		
		٦ L	Wellhead	d Compo	nents														
		1 5 1 21, Carlos 200	Des		all Date	7928	e / A	fake	Size (in	WPO	psi) Op	erable	Leaking	Restrict	10		Com	ment	
-			Annular Va	lve		Ball	Nibo	0	2.00		0.000		and a second second						
			Master Vall	ve		Gate	Barto	n	3.00	0 2.	000.0 Yes	3	NO	No					
			Side Valve			Gate	Barto	n	3.00	2,	000.0 Yes	5	No	No					
		t	Downhol	o Como	mante /	Dates -	1000 ar		wine who	. dli								Т.	
	010		Downhol	e compo	snents (Dates	1990 ar	e appro	oximate	ea)	WY	1		T T					
		1101 PMIA 124058	Run Date	Pull Date	10.64	00.60	0	.	Top (R)	8tm (ft)		Grade	Thread	r Cmta			Comm		
	6.2		8/1/1913	Play Dote	10 110		Drive Pipe		00000	42	Incong	Charles	7111000	Cango			CONTAIN	<u> </u>	
IT.		1100 Den		6/3/1968			Surface F		0	303								+	
		4		6/5/1968	-		Casing		Ő	1256		-						+	
			8/3/1913				Casing		1256	1949									
-			8/4/1913			5 1/2	Casing		0	2688									
			8/5/1913	6/1/1968			Casing		0	2825									
		1	6/7/1968				Casing		0	310	17,00	Used		Y					
		¹ 5 KBr, Casky, DHB	6/9/1968	6/3/1968	3.000		Anchor		2857	2857									
1			6/9/1968	11/8/1995			Casing		0	1291	9.20								
	11		6/9/1968				Casing		1291	2857	9.20	Used		Y					
			6/9/1968	6/3/1968	3.000		Anchor		2857	2857		<u> </u>						_	
-	- r h		11/9/1995				Patch		1288	1291		-						-	
		a come a series	11/9/1995				Patch		1288	1291	0.00							-	
		Rin, Casing, 120048				I 31/2	Casing		0	1291	9.20		1	1 1					

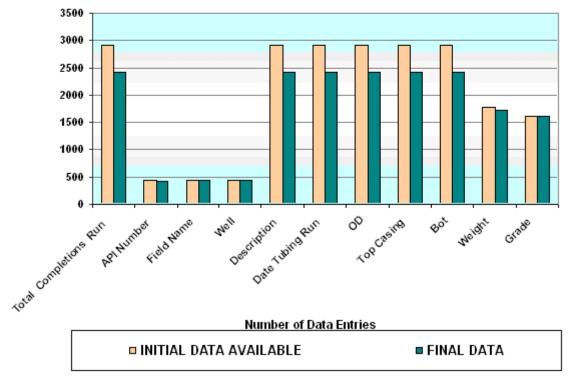
							Wt		Τ
Run Date	Pull Date	ID (in)	OD (in)	Des	Top (ft)	Btm (ft)	(Ibs/ft)	Grade	
8/1/1913			10 3/4	Drive Pipe	0	42			Ι
8/2/1913	6/3/1968		8 5/8	Surface Pipe	0	303			Ι
8/3/1913	6/5/1968		7	Casing	0	1256			
8/3/1913			7	Casing	1256	1949			
3/4/1913			5 1/2	Casing	0	2688			
3/5/1913	6/1/1968		3 1/2	Casing	0	2825			
5/7/1968			7	Casing	0	310	17.00	Used	
3/9/1968	6/3/1968	3.000	4 1/4	Anchor	2857	2857			
3/9/1968	11/8/1995		3 1/2	Casing	0	1291	9.20		
3/9/1968			3 1/2	Casing	1291	2857	9.20	Used	
5/9/1968	6/3/1968	3.000	4 1/4	Anchor	2857	2857			
1/9/1995			3 1/2	Patch	1288	1291			
11/9/1995			3 1/2	Patch	1288	1291			
11/9/1995			3 1/2	Casing	0	1291	9.20		Ĩ

Fig5. Well-bore data retrieved from a file

Analysis of raw data vs. refined data:

Please note that multiple data entry was the major reason for the reduction in the refined data from the initial data.

	-	C	OMP	LETI	ON DA	ATA					
DATA FIELDS	Total Completions Run	API Number	Field Name	Well	Des cription	Date Tubing Run	00	Top Casing	Bot	Weight	Grade
INITIIAL Data Available	2910	431	431	431	2909	2909	2909	2909	2909	1781	1607
FINAL DATA AVAILABLE	2413	430	431	431	2413	2413	2413	2413	2413	1723	1607



COMPLETION DATA

Fig6. Data addition and refinement for Completion Data

PERFORATION DATA

This data set contains all the information relating to the perforations done on the gas storage well like perforation top & bottom depth and shots per foot. Following are the data types included in this type of data set:

- 1. Well API Number
- 2. Field Name
- 3. Well Name
- 4. Completion Type
- 5. Perforation Date (Perf Date)
- 6. Perforation Top (Perf Top)
- 7. Perforation Bottom (Perf Btm)
- 8. Shot Type
- 9. Shot Per foot (Shot Per ft)

The picture of a document showing this information is shown below.

E E	1	Jack Th		LUCAS	- 00	1000000000	32222322222	322322322	12132222233	202232	22232222	232222	1322322322	223222	22222	223222223				2232222	822323223
m	<u> </u>		- Bellend	Redined B			Redlin	ie Date	Entere				Verified by	/		Com	ment				
									Anders				Bolander								
				Field Name	2		Number AF	² I Number	r 🛛 🗠	ease N	ame			Spud		Acreage				Datum r	reference
1				LUCAS Township/	Tay Dist	00.	Tax Numi	0056		In	ounty			81/	1913 Istate	148 Province	2827		2857 Operating Are	63	
			(0.3)6h, Celeb Papa,	GREEN	Tax Dis	194	30050				SHLAND				OH	rionice			Nooster	-01	
			09/3	Latitude (D	(D) L(ingitude (DD)		umber	State	Permi			inė Numbe	r		d Number	Léase Nur			ntory Ma	ao#
k I		114				31306	5					- F					~				
		IL.		Well Class		Key We	I Group		SubGrou	p	Comp	letion 1	Type			Est Deep	FŴ (ft)	Gr El	lev (武)	KB Ele	vation (ft)
					TIVE	No	6									L				L	
	L	HH.	The Case of The Owner	Directions	To Well																
				Wellhea	d: API	Wellhead	i. <make3< th=""><th>> on <</th><th>Install D</th><th>ate?</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></make3<>	> on <	Install D	ate?											
	1			Type		Install Dat			lowStSz (in			(in) V	VP (psi)	0	Conne	ction	Comment				
H.F.				API Wellhe	ad										3	" 10R	Wellhead Si	ze 3 x	3.		
		1	1	Mallhan	d Con	ponents															
	1		a schu Ceeleg (MIR	Des		Install Date	Type	1 14	ake S	20 ()n)	M/R/	(psi)	Onerable	1 100	ikina.	Restricte	d		Comment		
			- 2 Solit, Calley, Mr.B	Annular V		Monar Dave	Ball	Nibco		2.00		000.0		1 2.00	and a	116027510			Contractor		
				Master Va			Gate	Barto		3.00		000.0		No		No					
				Side Valve	2		Gate	Barto	n	3.00	0 2	000.0	Yes	No		No					
LL.				Daumha			(Dates of			in a to	-										
11		5		Downing	ne cor	nponents	(Dates <1	aso are	approx	imate	ia)	W	1	-		-					
			3 Sills, Pach, 1 Joint B	Even Date	BW	Date ID (in)	00.001	Des	. 77	n /m	Btm (ft)	abs		6 7h	read	Cmfd			Comment		
	6	- 4	1000	8/1/1913	1			Ortve Pipe		0	42					2000			201111000		
11			9 st3n, Palch 1,29809-0	\$/2/1913			8 5/8 8	Surface Pr	ipe	0	303										
				8/3/1913	6/5/19	68		Casing		0	1256										
				8/3/1913				Casing		1256	1949										
n i		F		8/4/1913 8/5/1913	6/1/19	80	5 1/2 0	Casing		0	2688 2825			-	_						
				6/7/1968	0/1/19	08		Casing		0	310	1	7.00 Used			v					
			S 101. Codes 1918	6/9/1968	6/3/19	68 3.00				2857	2857		/ 100 00000	-	-	<u>'</u>					
M				6/9/1968	11/8/1		3 1/2 (0	1291	1	9.20								
				6/9/1968			3 1/2 0			1291	2857	1	9.20 Used			Y					
			1	6/9/1968	6/3/19	68 3.00				2857	2857		_	_							
M	E F	1	1	11/9/1995			3 1/2 9			1288	1291	<u> </u>		-	_						
			To Casta 125846	11/9/1995			3 1/2 0			1200	1291		9.20	+	_						
	I H	4					1 0 1041				1801							_			
ME				Perforat	tions																
	-W/-	1		E							hot Dens					G					
	dana 🕴			Date 6/7/1968	Top (f) 282		Shot Type	Gan	Type Sz	000 p	shots/ft) 1.1	0	Strin	<u> </u>	Perf C	omp sq	2	- c	ani.og/Com	ment	
h f	4	1	a site daska	101/1000	1 202	al 1001		-		_		-1					-	-			
			2 YON CHING 1,201043			Formatio	ns				1										
				Formation																	
ME				Drillers Log		nations Jame		The state	1 5	_ /	7.04.00						A				
				Big Lime T		lame		700 (ft) 17	8	- 1	Ruid Si	0.000		******			Comme	w/			
				Big Lime	up			26		1			<u> </u>								
ш.				any carrie						1											
070	700323 -	LUC	AS:				F	teport ru	in date		y, Fet	nuary	/ 22, 200	5						Pa	ge 1 of 4
										L .											
-												- 1									
L																					
	Pe	rfe	oration	c																	
		110	nation	-		-				-	-	Le		-							0.1
											Gun		hot Dei	ns P	has						Cmt
		Dat	e To	o (ft) Bt	m (ft)	Sho	t Type	G	un Typ	e Is	Sz (in)	6	shots/f	ηl	C) [5	String	P	erf Com	p L	sqz
	6/7			and an other states of the sta	283					Ť	- 111/	1,		2		<u> </u>	y			~	
	0//	/19	00	2823	283	1								1.1							
	1.												A CONTRACTOR OF A CONTRACT							40.000	100000000000000000000000000000000000000

Fig7. Perforation data retrieved from a file

Analysis of raw data vs. refined data:

	Р	ERF	ORA	TIO	N DA	ATA				
DATA FIELDS	Total Perforations	API Number	Field Name	Well Name	Completion Type	Perf Date	Perf Top	Perf Bottom	Shot Type	Shot Per ft
INITIIAL DATA AVAILABLE	392	57	57	57	48	392	392	392	209	383
FINAL Data Available	392	57	57	57	48	392	392	392	209	383

PERFORATION DATA

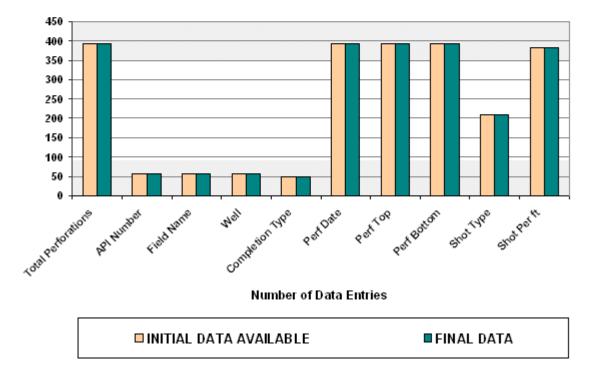


Fig8. Data addition and refinement for Perforation Data

Stimulation data is one of the most significant datasets about the storage wells. Because of this, it was very important that we have maximum records of valid stimulations. Following data type is used to represent stimulation:

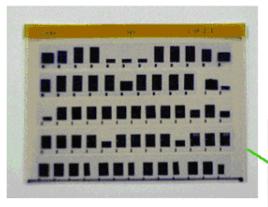
- 1. API Well Number
- 2. Well Name
- 3. Size of String
- 4. Stimulation From
- 5. Stimulation To
- 6. No Of Shots
- 7. Fractured by
- 8. Stimulation Type
- 9. Stimulation Date
- 10. Water
- 11. Acid
- 12. Gel
- 13. Foam
- 14. Nitrogen
- 15. Alcohol
- 16. Cushion
- 17. Flush
- 18. Sand Quantity
- 19. Sand Type
- 20. Injection Rate
- 21. Total Fluid
- 22. Breakdown Pressure
- 23. ISIP

Unfortunately, initially we didn't have much data about the stimulations being done in this Lucas field. With this in mind, every record with Columbia Transmission Corporation was carefully examined. The largest source of stimulation data came from the thousands of microfiche with some data being found in well summary reports. Following is a picture of data in well summary reports.

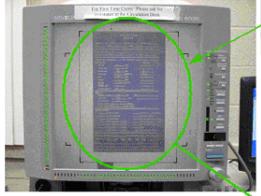
2.12		And and a state of the local division of the	N. Martin	LUCAS -													
ΠΠ				Chatana Cara	Name		Top (ft)		(11) 005		t Shows		_		Comment		
				Clinton San	9		28		2827								
				OTO			28		2857								
			20 Juni, Calve Figur,	ELog For	rmations(Reco	d Log &	Date in C	Comm	ents)								
1111			2993	Formation P	Ticks Group												
9	- 1	111		ELog Forma	ations(Record Log 8	Date in Co				1 21.1	. Ott						
11 1 1		ШH	- I	BigLime	Name		Top (ft)		itm (11)	PRINC	f Shows				20mment		
			1	Clinton San	d			+		+							
1111		l Ir	The Casing SNIB	DOTD				_									
				Logger's TD													
111		UU.		Big Lime To				_									
nH			- I		ions: Water Fra			1				lotics (Texas					Otion Ten do Mineros
11 1 1			2 12N, CHINA, 2918	Date	7/1/1968	Stim 1 Water	r Fracture					Stim/Trea	100	mpany			Stim Trade Name
8		114		Zone		1.1.010			Top (f	tt)			Both	om (ft)		Est.	Pore Press (psig) (psi)
					-						2823		_	2831			
				Breakdown	Pressure (psi)	Avg	Treat Pres	is (psi)			Avg BH rate	e (lapim)		Instant. Shut-in Pres	ssure (psi)		Flush Fluid Density (ppg)
11		5		Fluid Volum	e Pumped (bbl)	N	itrogen Am	ount (n	ncf) P	roppan	Type & Me	sh	_	Proppant Amoun	t(b) Max	BHIsa	nd conc.(Ib/gal)
	Ì	11	T Calenta														
		92		Comment Clinton													
1111		li it	9 12H Petro														
11 1 1		∎⊩	i I	breakdown	2500 #, ave press :	2434 #, ISIF	2 1000 #, 1	0,500 II	b. sand.								
				Build-Up	Tests												
nu		11	i	Duild op						True	DDRate	AOF	Π				
		11		Start Date		с	0	kħ	Skin	Skin	(mcf/day)	(mcf/day)	Ш		Con	went	
		11	5 10H, CHINA, 2948	8/1/1913	Open-Flow								₩				
11 1 1		11	1 1	4/13/1964 9/21/1966	Open-Flow Open-Flow			-	- 1				₩				
		88	1	4/5/1957	Open-Flow								#				
d	-	11		9/7/1967	Open-Flow			_					T				
			To Call 120MB	7/29/1968	Open-Flow Open-Flow			_					+				
				4/8/1969	Open-Flow								t				
a		11	-	10/2/1969	Open-Flow												
IIIt	- <u> </u>		1	4/1/1970	Open-Flow		0.720										
UT	····			4/2/1973	Open-Row Open-Row	0.454	0.750				4765.96	18054.4	4				
9			3 YOM Casing Converti	5/13/1981	Open-Flow			_					+				
			1.3466	6/14/1993	Multi-Point	0.047	0.750				497.89	1886.		pair casing / wellhe			
				1	1 1												ndicates significant loss of
111					1 1												de, very ambiguous Fill in . Reperf and frac well.
													1				
ШЦ																	
0707	00323	- LU	CAS				Report ru	in date	e - Tues	sday, F	ebruary 2	2, 2005					Page 2 of 4
												- 1					
												•					
												'					
Stimu	latio	ns:	Water Fra	acture or	7/1/1968												
ate					Туре					5	tim/Treat	Company					Stim Trade Name
		7/1/1	968		er Fracture					- F							
one						To	p (ft)				В	ottom (ft)			E	Est. Po	ore Press (psig) (psi)
							1.1.1	2	823			,,		2831	ľ		(Per)
reakd	lown F	ress	ure (psi)	Avi	g Treat Press (osi)			BH ra	ite (bo	m)	Instant	. St	hut-in Pressure	(psi)	F	lush Fluid Density (pp
											-						
luid Vo	olume	Pum	ped (bbl)	1	Nitrogen Amour	nt (mcf)	Proppa	ant Ty	pe & M	lesh		Pro	ppa	nt Amount (lb)	Max BH	sand	conc.(lb/gal)
omme	nt																
Clinton																	

Fig9. Stimulation data retrieved from a file

breakdown 2500 #, ave press 2434 #, ISIP 1000 #, 10,500 lb. sand.



Microfiche were read by digital Microfilm scanners



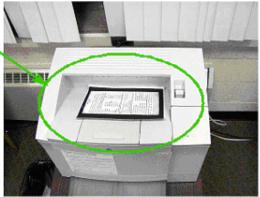
Prints were taken of the documents containing data

API_Number	Size0(String	StimFrom	StimTo	NoOfShots	Fracturedby	Type	SI
34-005-01272	4.5	2862	29061	8	Oowell Inc.	Water-Gel	11/
34-005-02420	4.5	2759	2764	11	Ocwell Inc.	Water-Gel	12/
34-005-02987	4.5	2904	2810	13	Dowell Inc.	Water-N2	
34-005-02989	4.5	2638	2845	12	Dowell Inc.	Water-N2	
34-005-02989	4.5	2830	2828	10	Oowell Inc.	Water-N2	6
34-005-02897	4.5	2863	2860	12	Haliburton Co.	Water-Gel	7.
34-005-02901	4.5	2723	2748	12	Halibuton Co.	Water-Gel	6
34-005-02907	3.5	2623	2845	13	Hallibuton Co.	Water-Gel	
34-005-02909	4.5	2796	2814	5	Haliburton Co.	Water-Gel	- 7
34-005-02909	4.5	2809	2814	6	Haliburton Co.	Water-Gel	7.
34-005-02911	4.5	2785	2005	13	Halibuton Co.	Water-Gel	- 9
34-005-02960	4.6	2911	2921	13	Oowell Inc.	Water-Gel	10
34-005-10516	6.6	2588	2608		Halibuton Co.	Visa-Frac	12
34-005-10517	5.5	2559	2990		Dowell Inc.	Water-N2	5
34-005-10518	5.5	2580	2622		Oowell Inc.	Petro-Gel	12
34-005-10519	5.5	2874	2882		Halibuton Co.	Water-N2	- 9
34-005-10520	5.0	2925	2964		Ocwell Inc.	Water-Gel	1.
34-005-10527	5.5	2066	2901		Dowell Inc.	Water-N2	
34-005-10533	5.5	2627	2653		Opwell Inc.	Petro-Gel	1
34-005-10538	5.5	2804	2844		Ocwell Inc.	Petro-Gel	12
34-005-10540	5.5	2860	2906		Dowell Inc.	Water-N2	6

Each Microfiche contained dozens of documents from invoices to valuable stimulation and well-test data



Each scanned image of the microfiche was searched and read for valuable data



Data was entered in the database

Fig10. Microfiche to Database process

Following are pictures of some types of data formats for fracture jobs found in the records

NITROGEN AM DIFFERENT	
See GED FRI CAR ONFART BELL FRACTOR Fare Stars And, 2 Totating Stars And, 2 Totating Stars Restore Constign Stars Production Stars Totating Stars Constign Stars Production Stars Totating Stars Production Stars Totating Stars Totating Stars Totating Colspan="2">Totating Colspan="2">Stars Totating Colspan="2">Totating Colspan="2">Totating Colspan="2" Totating Colspan="2" <td< th=""><th>ACID OR FRAC REPORT Formation Convicts top 2452 Bottom 244/ Statuturen Fervice Co. Mittil-ten/Date Frac Fift Pro- Acidiong Service Co. Date Acid Open Prov Before Fracturing 5,853 @ 959 Open Flow Before Acidiong Frod Used-Type: Mod Acid 71/1442 JST Gallons = Pressure Bork Modern 200 Gallons = Pressure Bork Modern 200 Gallons = Pressure Frost Plus = Pressure Gallons = Pressure Frost Plus = Pressure Gallons = Strut in Press Additives = Type = Amount Amount</th></td<>	ACID OR FRAC REPORT Formation Convicts top 2452 Bottom 244/ Statuturen Fervice Co. Mittil-ten/Date Frac Fift Pro- Acidiong Service Co. Date Acid Open Prov Before Fracturing 5,853 @ 959 Open Flow Before Acidiong Frod Used-Type: Mod Acid 71/1442 JST Gallons = Pressure Bork Modern 200 Gallons = Pressure Bork Modern 200 Gallons = Pressure Frost Plus = Pressure Gallons = Pressure Frost Plus = Pressure Gallons = Strut in Press Additives = Type = Amount Amount
Backbarn Francescon 1000 100 Bads Backers Francescon 10000 and	Inert Gassesi Amount Amoun

Fig11. Different formats of Nitrogen Amount

During the data entry different sign conventions and unit conversions were carried out as follows:

MEASURED QUANTITY	UNITS IN RECORDS	UNITS USED IN DATABASE
SAND	1 sack	100 lbs
	1 sks	
NITROGEN	52M	52,000 SCF
LIQUID	1 bbl	42 gal
PERFORATIONS	2000-2005 ft, 10 shots	2 shots/ft
	10/5	

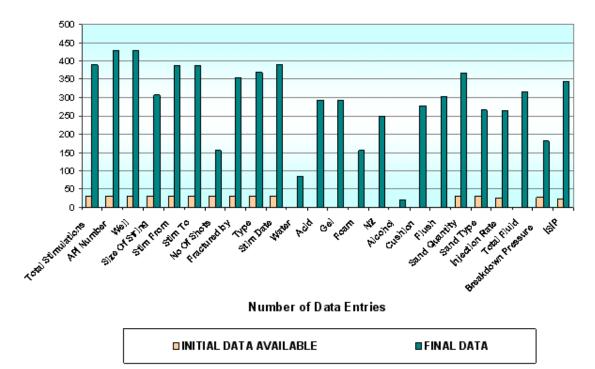
NOTATIONS	WATER	PETRO	FOAM	NITRO	WATER/N2	WATER	10/20
USED IN	GEL	GEL	FRAC	SHOT	FRAC	FRAC	SAND
DATABASE	FRAC	FRAC					
	Gelled	Petrl gel	Foam	Shot	Water / N2	water	10/20
	water						
NOTATIONS	frac						
THAT	Water	Petro Gel	foam		Water N2		Sand
WERE	Gel		Frac		Fracture		10/20
REPLACED		Petro gel	foam		Water nitrogen		
		fracture	fracture				
					Water/N2 assist		
					Water Fracture		
					w/N2 assist		

The following notations were used in place of different notations being used in the tables:

All records of Nitro-shots were discarded for this database as they have no stimulation parameters on record and are part of history now plus they also damage the well. Above all, they will tend to degrade the Neural Network.

Analysis of raw data vs. refined data:

								S	гіми	LAT	101	N DA	TA											
DATA FIELDS	Total Stimulations	API Number	Well	Size Of String	Stim From	Stim To	No Of Shots	Fractured by	Type	Stim Date	Water	Acid	Gel	Foam	N2	Alcohol	Cushion	Flush	Sand Quantity	Sand Type	Injection Rate	Total Fluid	Breakdown Pressure	ISI
INITIIAL DATA AVAILABLE	32	32	32	32	32	32	32	32	32	32	o	0	o	o	o	0	ο	o	32	32	25	ο	27	24
FINAL DATA AVAILABLE	390	430	430	308	388	388	156	354	370	391	85	293	294	157	249	21	277	302	368	266	263	317	181	345



STIMULATION DATA

Fig12. Data addition and refinement for Stimulation Data.

WELL TEST DATA

Well-test data is the most extensive dataset that our R & D team worked on. It has the maximum amount of records nearly 3365 and 29 data types that control every aspect of a well-test. The data type selected for a well-test representation consists of following:

- 1. Well API Number
- 2. Field Name
- 3. Test Date
- 4. Test Type
- 5. Time 1
- 6. Field Pressure 1
- 7. Flowing Pressure 1
- 8. Rate 1
- 9. Time 2
- 10. Field Pressure 2
- 11. Flowing Pressure 2
- 12. Rate 2
- 13. Time 3
- 14. Field Pressure 3
- 15. Flowing Pressure 3
- 16. Rate 3
- 17. Time Extended
- 18. Field Pressure Extended
- 19. Flowing Pressure Extended
- 20. Rate Extended
- 21. kh
- 22. Skin
- 23. True Skin
- 24. Non Darcy Co-efficient
- 25. n Value
- 26. C Value
- 27. Delta Pressure Squared
- 28. Peak Day Rate
- 29. Absolute Open Flow

Estimation of n, C, peak day rate & absolute open flow

Single/Open flow Tests:

The values used for point 1 and 2 are from different well-tests

1- Find
$$\Delta P^2$$

3- $\frac{1}{n} = \frac{\log(\overline{p}^2 - p_{wf}^2)_2 - \log(\overline{p}^2 - p_{wf}^2)_1}{\log q_2 - \log q_1}$ (Where q is in MMcfD)
4- $C = \frac{q_g}{(\overline{p}^2 - p_{wf}^2)^n}$ (Where q is in McfD)
5- $AOF = C(1150^2 - 0^2)^n$ McfD
6- $PDRate = (C \times 250,000)^n$ McfD

Multi-Point Tests:

Estimation of n, C, PD rate & AOF:

Same as above except that the points used are from the same test

NOTE: The n, C, PD rate & AOF values for more than 400 well-tests were manually calculated

Estimation of kh, skin, true skin, non--darcy coefficient

- 1- From extended draw-down test plot (P_i-P_{wf}) vs. time on log-log paper. Draw unit-line for un-stimulated wells and half-slope line for Stimulated wells. Find end of well-bore storage effects after $1-1/2 \log$ time cycle
- 2- Find values of viscosity, z-factor, compressibility of storage gas at different pressure assuming Gas gravity = 0.585 & temperature = 75 F = 535 R

Draw-Down Test:

- Plot P_{wf}^{2} vs. time 1-
- Draw straight line after pseudo-steady state starts 2-
- Find slope m and P^2 1hr 3-

т

$$4- \qquad kh = \frac{1637qTzu}{m}$$

5-
$$S = 1.151 \left[\frac{p^2 - p_{1hr}^2}{m} - \log \left(\frac{k}{\phi \mu c r_w^2} \right) + 3.23 \right]$$

- 6-Plot skin vs. flow-rate. It should be a straight line
- 7-Slope of this line is D
- Find True Skin (S') at q=0. 8-

Build-Up Test:

- 1- Plot P_{wf}^{2} vs. (tp+dt)/dt on semi-log paper
- 2- Draw straight line after well-bore storage effects diminishes
- 3- Find slope m and P^2 1hr

4-
$$kh = \frac{1637qTzu}{m}$$

5- $S = 1.151 \left[\frac{p_{1hr}^2 - p^2}{m} - \log\left(\frac{k}{\phi\mu cr_w^2}\right) + 3.23 \right]$

- 6- Plot skin vs. flow-rate. It should be a straight line
- 7- Slope of this line is D
- 8- Find True Skin (S') at q=0.

We require time, flow-rate & Bottom hole pressure from the data which are present in two txt files as bottom hole & surface recording files. The flow rates are at Wellhead so we match the BHP & THP with time.

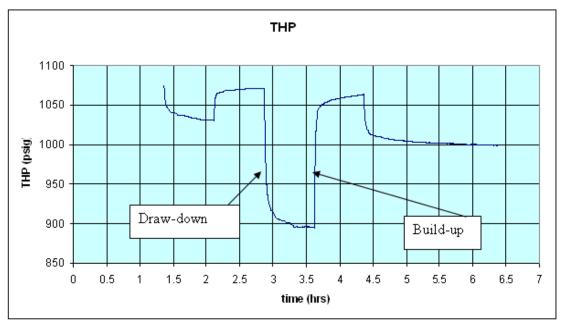


Fig13. Tubing Head Pressure profile for Multi-Point test

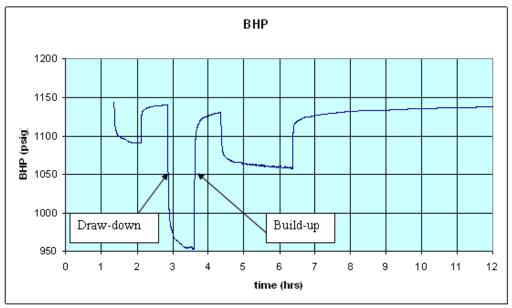
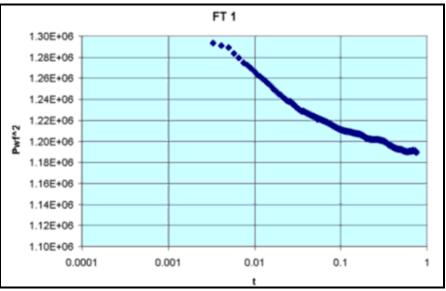


Fig14. Bottom Hole Pressure profile for Multi-Point test

The multipoint-test data is divided into Draw-down & build-up test and each one is analyzed separately.

Draw-down test



Analysis of drawdown tests was done as described above and following graphs were obtained

Fig15. Flow Test 1 – Delta pressure squared vs. time

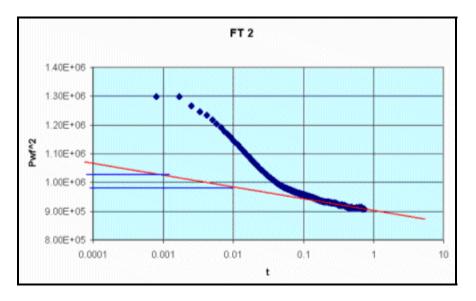


Fig16. Flow Test 2 – Delta pressure squared vs. time

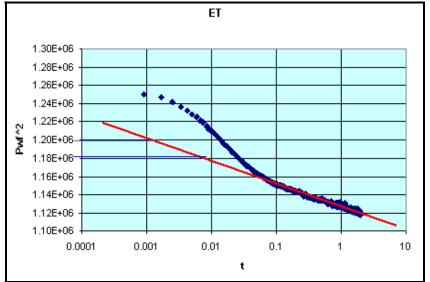


Fig17. Extended Flow Test – Delta pressure squared vs. time

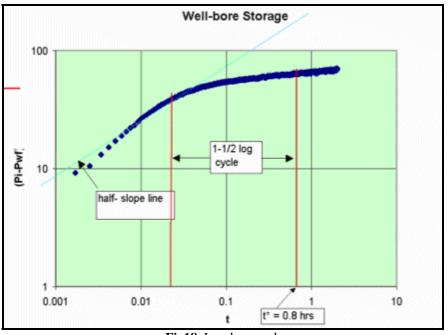


Fig18. Log-log graph

For well-tests after fracture half-slope line is drawn and for un-simulated wells unit slope line is drawn to find end of well-bore effects and start of pseudo-steady state.

Gas production Simulator was used to find the values of viscosity, z-factor and compressibility of storage gas at different pressure assuming Gas gravity = 0.585 & Temperature = 75 F = 535 R that are also used by Columbia Trans.

1 1	Creekation Smithter							ALR
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1000 1000 <td< td=""><td>other tutorements for recording</td><td></td><td>18-697.31</td><td>1,0827408-82</td><td>.1081395</td><td>1,0842578-00</td><td></td><td></td></td<>	other tutorements for recording		18-697.31	1,0827408-82	.1081395	1,0842578-00		
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DB11 8.52 Presonation Not Presona								
D011 152 Pressed								
ESS Pressedjed Not Presse								
	EXIII 8.521			Pennedavil			Man Paramet	

Fig19. Gas Properties Simulator

The slope from Pwf^2 vs. time on semi-log graph was used to find kh & then skin. The three values of skin were plotted on Q vs. S graph and extrapolated to Q = 0 to get True skin (S').

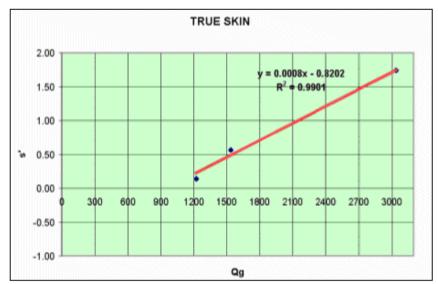


Fig20. Calculation of True skin

	FLOW	FLOW	EXTENDED
	TEST 1	TEST T2	TEST
porosity	0.14	0.14	0.14
rw	0.1458333	0.1458333	0.1458333
Ct	1.02E-03	1.08E-03	1.04E-03
Uav	1.28E-02	1.26E-02	1.27E-02
Zav	0.8558691	0.8635354	0.859119
Р	1143	1140	1127.3
Qav	1223.8668	3038.7039	1536.1134
Tav	533	533	533
h	10	10	10
m	2.00E+04	5.40E+04	2.20E+04
kh	5.86E+02	5.36E+02	6.67E+02
k	5.86E+01	5.36E+01	6.67E+01
plhr^2	1.185E+06	9.000E+05	1.128E+06
S	0.14	1.74	0.57
S'	-0.8202		
D	0.0008		

 Table 1. Draw down Test Results

Build-up test

In build-up tests, the slope drawn for Horner plot is after the time when well-bore storage effects were found to be minimizing from previous draw-down test. This slope is then used to find the values of kh & skin. The True skin is found the similar way as in draw-down test.

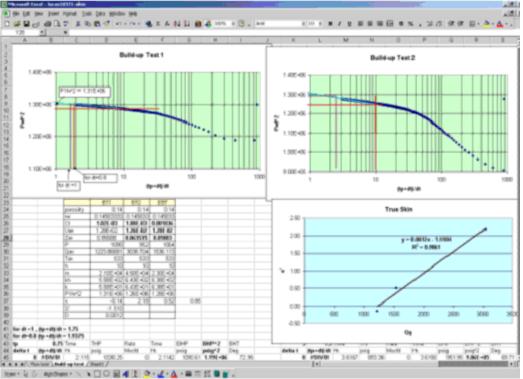


Fig21. Calculation of True skin Build-up test

	BUILD-UP	BUILD-UP	EXTENDED				
	TEST 1	TEST 2	BUILD-UP TEST				
porosity	0.14	0.14	0.14				
ıw	0.14583333	0.145833	0.145833				
Ct	1.02E-03	1.08E-03	0.001036				
Uav	1.28E-02	1.26E-02	1.28E-02				
Zav	0.85588	8 0.863535 0.85803					
Р	1090	952	1064				
Qav	1223.86681	3038.704	1536.113				
Tav	533	533	533				
h	10	10	10				
m	2.10E+04	4.50E+04	2.30E+04				
kh	5.58E+02	6.43E+02	6.38E+02				
k	5.58E+01	6.43E+01	6.38E+01				
P1hr^2	1.31E+06	1.26E+06	1.28E+06				
s	-0.14	2.18	0.52				
S'	-1.510						
D	0.0012						

Table 2. Build-up test results

	DRAW-DOWN	BUILD-UP	AVERAGE	ACTUAL
S'	-0.8202	-1.510	-1.165	-1.17
D	0.0008	0.0012	0.0010	.00126

 Table 3. Average Results

Due to large errors corresponding to estimating skin and kh values manually, it was decided that for time being these values will not be entered in the database.

Following are some pictures of the documents to show the different format in which the data was presented in files and microfiche.

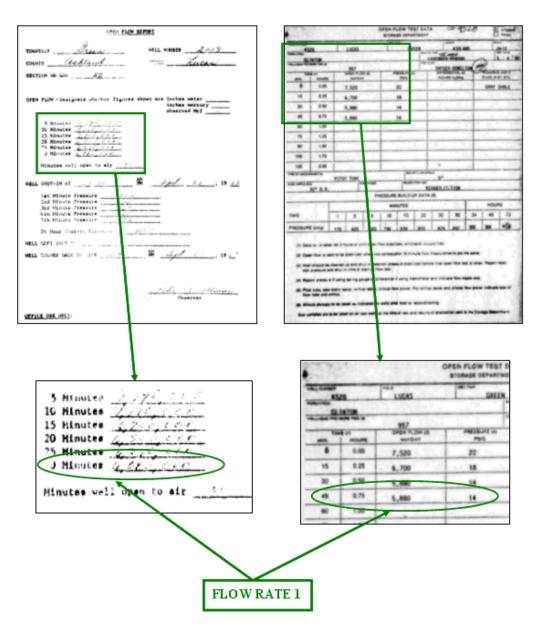


Fig22. Retrieving flow-rate of an open-flow test

Laminar Inertial Turbulent (LIT) Test

Analysis of data from isochronal type test using Laminar Inertial Turbulent (LIT) flow equation will yield considerable data. This method can also be used to find skin of a well from single-point test when the value of permeability of reservoir is known from prior multi-point test. The LIT equation is written as:

$$\Delta \psi = \overline{\psi}_R - \psi_{wf} = a_t q_{sc} + b q_{sc}^2$$
Pressure drop due to laminar
Pressure drop due to laminar
Pressure drop due to laminar

flow and well conditions Procedure for calculating Skin from LIT analysis for known permeability (k) value is as shown below:

1. Calculate a_t and b from equations below:

$$a_{t} = \frac{\sum \frac{\Delta \Psi}{q_{sc}} \sum q_{sc}^{2} - \sum q_{sc} \sum \Delta \Psi}{N \sum q_{sc}^{2} - \sum q_{sc} \sum q_{sc}}$$

$$b = \frac{N \sum \Delta \Psi - \sum q_{sc} \sum \frac{\Delta \Psi}{q_{sc}}}{N \sum q_{sc}^{2} - \sum q_{sc} \sum q_{sc}}$$
N= Number of data points

- 2. Plot $(\Delta \Psi bq_{sc}^2)$ vs. q_{sc} on a logarithmic scale. The transient data points should form a straight line. If they don't form a straight line, calculate a_t and b again with the data which forms the straight line.
- 3. Calculate Skin (S) with the formula.

$$S = \frac{1}{0.869} \left[a_t \times 10^6 \frac{kh}{1.632 \times 10^6 T} - \log\left(\frac{kt}{\phi \mu_i c_i r_w^2}\right) + 3.23 \right]$$

Where:

- $\Delta \Psi$: Delta Pseudo Pressure
- k : Effective permeability to gas, md
- h : Net pay thickness, ft
- t : Flow time, hrs
- φ : Porosity, %
- u_i : Initial Viscosity, cp
- c_i : Initial compressibility, psi-1
- T : Temperature of the reservoir, ^oR
- r_w : Well-bore radius, ft
- S : Skin, dimensionless

Flow Diagram of Well Test Analysis procedure

Following is the flow diagram of the well test analysis procedure and the type of values that we get from the data.

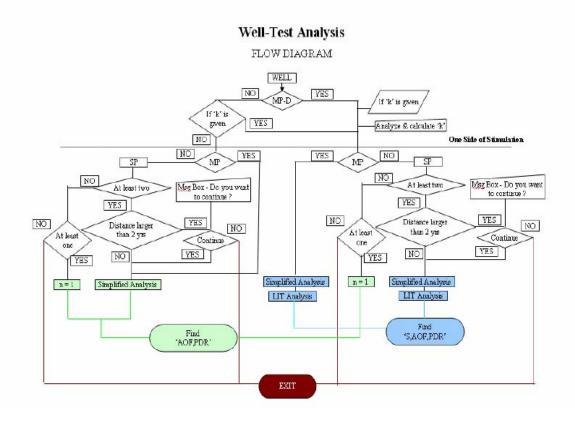


Fig23. Flow Diagram of Well Test Analysis procedure

RESERVIOR CHARACTERISTIC

It includes some reservoir properties. The complete list of the data type retrieved is shown below:

- 1. API Number
- 2. Well Radius
- 3. Reservoir Porosity
- 4. Reservoir Temperature
- Gas Specific Gravity
 Reservoir Thickness

NEURAL NETWORK MODULE

The Neural nets are very powerful in predicting non-linear relationships. As the relationship between skin and stimulation parameters is non-linear and very complicated, thus neural nets are used which are very good at it. With skin values before and after the stimulation calculated and stimulation parameters known, we can now use these valid stimulations to train the Neural Network to use it as a prediction tool. Intelligent Data Evaluation and Artificial Network IDEA® software by Intelligent Solutions Inc. was used to design the neural network. This software is very versatile in making different nets with different training algorithms. Generalized Regression Neural Net (GRNN) was used to train the neural net. The net had 11 inputs and 1 output as skin. The source of data for the neural net is given in Figure 24.

	Inputs	Source
1	L at	D atab ase
2	Long	D atab ase
3	Sum Fluids	Sum of item 5,6,7,8
4	Prior-kh	D atab ase
- 5	Water (bbls)	GA
6	Acid (bbls)	GA
7	Gel (bbls)	GA
8	Foam (bbls)	GA
9	N2 (Mcf)	GA
10	Sand Quantity (lbs)	GA
11	After-Test Type 3- Multi-Point 2- Single-Point 1- Open-Flow	GA

Fig24. Neural Network Inputs and their source

Out of the 78 valid stimulations available, the Neural net was trained on 60 data items while 14 were used as calibration data and 4 as verification data. The Neural network showed very good results for all three types of data. The screen shot taken from the IDEA software for training of the neural net is shown in Figure 25.

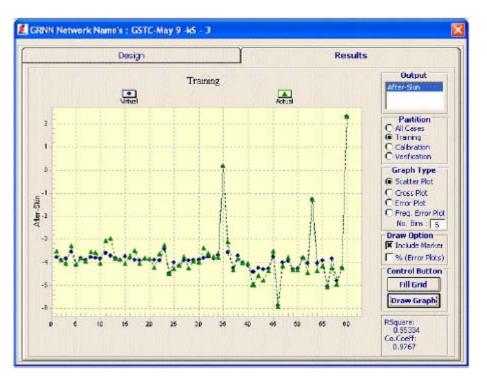


Fig25. Accuracy of training data for the Neural Net

The calibration and verification of the Neural net is shown in Figure 26 and Figure 27 respectively. After the accurate results of this GRNN, the software was updated to use the GRNN generated files to be used in the Genetic algorithm.

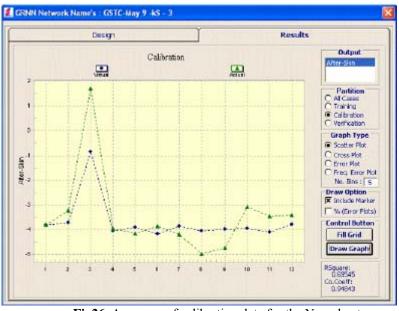


Fig26. Accuracy of calibration data for the Neural net

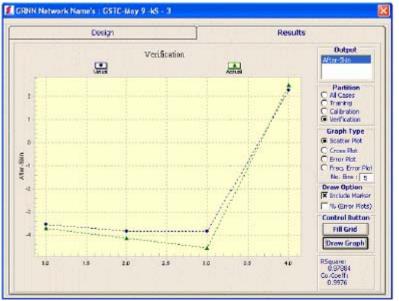


Fig27. Accuracy of verification data for the Neural net

GENETIC OPTIMIZATION MODEL

Genetic Algorithm was written to optimize the stimulation parameters used in the neural net. Out of the 11 input parameters, 7 can be varied to obtain optimum skin. The range of these variables was calculated and accuracy desired was determined to design the length of the chromosome of Genetic Algorithm (GA) that will be required. The calculation is shown in the table 4. for the chromosome length if all the parameters are selected.

	GA Input Parameter	Min	Max	Range	Accuracy Required	Accuracy Size	Range Size	Chromezome Size	Miin Byte size	Max Byte size
1	Water (bbls)	D	345	345	t	1	345	9	2/2 =256	249=512
2	Acid (63-36)	D	11.9	11.9	0.01	100	1190	11	2^10 -1024	2^11-2048
3	Gel (bbls)	D	535	535	L	1	535	10	2/9-512	2/10=1024
4	Foam (bb ls)	D	1.7	17	0.01	100	170	8	247 -128	218-256
3	N2(Blef)	D	368	368	1	1	3.68	9	2/3 =256	219-512
6	Sand Quantity (Ibs)	D	30000	30000	100	0.01	300	9	213 -256	219-512
7	After-Test Type 3- Multi-Point 2- Single-Point 1- Open Flow	1	з	З	ı	1	3	2	2^1-2	242 =4

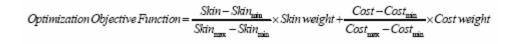
Table 4. Calculation to determine the length of chromosome

The length of chromosome came out to be 9 + 11 + 10 + 8 + 9 + 9 + 2 = 58. The GA characteristics that were used are shown in Table 5. These were the best but can be changed as desired to suit other neural nets in the future.

GA CHARACTERISTICS	VALUE
Crossover rate	60 %
Mutation rate	10 %
Population size	500
No of Generations	10
Next Generation criteria	Top 30 % ranked from previous generation
Crossover criteria	Top 25 % has 75 % chance of Crossover

Table 5. CA characteristic

There are two optimization methods made available in this software. One is optimization just based on skin and other, based on both skin and cost. The optimization objective function is calculated using the following formula and GA minimizes this optimization objective function.



Software compatibility and variability:

In the software user has been given many options to accommodate the particular situation that he has and data availability if different from the data that we have used to verify the results from this software.

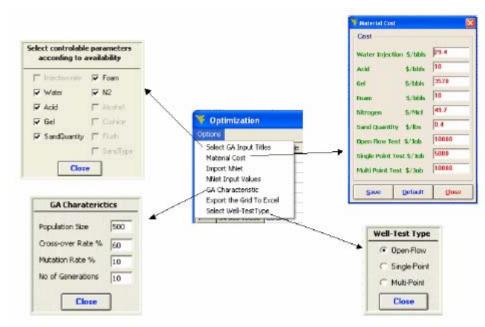


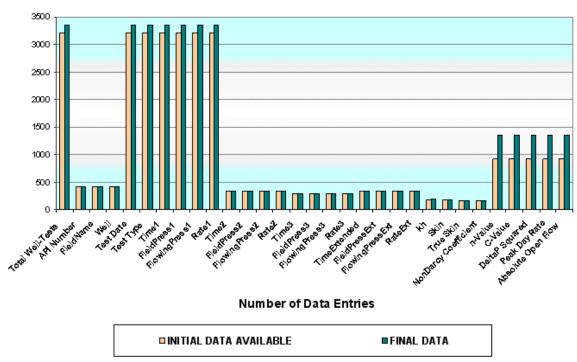
Fig28. Different options in the software that makes it versatile.

One of such variability introduced is that the software can use any other neural net if it is required. The option menu of the optimization screen has the option to import any other neural network. Plus, there is an option to select the available controllable parameters for the GA. For example, if the user does not want to use or does not have foam and nitrogen, then he can unselect them as shown in Figure 3.18. The length of GA will change according to the selection.

As the Neural Net has 'Well-Test Type' as its input, so the 'Select Well-Test Type' menu option gives the user an option to choose the test the user wants the neural net to interpret the well-test. With changing price of hydro-carbons, the petroleum industry is going through fluctuating material cost. The stimulation material prices change frequently and are a factor of demand and supply in that region. The software has the option to change the price of the stimulation material before applying the GA to the available data.

Analysis of raw data vs. refined data:

	WELL TEST DATA																														
DAT A FIEL D \$	Total Well-Tente	APINumber	Reid Name	Well	Text Date	Test Type	TIM e 1	Reid Pre 🗤 1	Howing Prem 1	Rate 1	Tm e2	Reid Pre 112	HowingPre #12	Rate 2	TIM e3	Reid Pre m 3	Howing Pre #13	Rate 3	TIM e Extended	Reid Pressure Et	Rowing Pressure Est	Rate Est	ки	Skin	True Skin	Non Darcy Coefficient	ы-V3I ие	C-Value	Delta P Squared	Peak Day Rate	Absolute Open How
INITIIAL DATA AVAILABLE	3223	431	431	431	3223	3223	3223	3223	3223	3223	347	347	347	347	292	292	292	292	345	345	345	345	191	182	163	163	916	916	916	916	916
FIN AL DATA AVAIL ABL E	3365	431	431	431	3365	3365	3365	3365	3365	3365	347	347	347	347	292	292	292	292	345	345	345	345	194	185	166	166	1362	1362	1362	1362	1362



WELL TEST DATA

Fig29. Data addition and refinement for well test data

DATABASE & SOFTWARE

SOFTWARE BASICS

This software allows you to add/edit well data in the database and choose the data that you want to look at, for a selected well. It also has a Well Test Analysis tool which calculates the well deliverability parameters like n, C, Peak Day rate & Absolute Open Flow

The database for this software consists of five main tables

- 1. Well bore Data
- 2. Completion Data
- 3. Perforation Data
- 4. Stimulation Data
- 5. Well Test Data
- 6. Reservoir Characteristic Data

The **API number** of a well is the primary key in this database so it must be known before adding a record and cannot be duplicated

🧾 GasStorage :	Database (Access 2000 file format)											
🚰 Open 🕍 Desig	着 Open 🔟 Design 🛅 New 🗙 🕒 🗽 📰 🏢											
Objects	Create table in Design view											
🔲 Tables	2 Create table by using wizard											
Queries	2 Create table by entering data											
📴 Forms	Completion_Data MaterialCost Data											
Reports	Perf Data											
🗎 Pages	🔲 Reservoir_Data											
🔁 Macros	Stimulation_Data											
💸 Modules	Wellbore_Data WellTest_Data											
Groups												
😹 Favorites												

Fig30. Screen shot of database showing different tables



The software starts with the main menu screen with six options

Fig31. Main Screen of software

Complete list of items and sub-items in the above command buttons is shown below: File

o Create Template o Import Data from filled-out Template o Remove all data from database o Exit Help o User Manual o Formulas o About Edit Well Data o Well bore o Completion o Stimulation o Perforation o Stimulation o Well Test • Well Test Analysis Tool o Reservoir o Find a Well View Well Data

o Select State & county o Select Wells o Selection Options o Select Well Data Candidate Selection

File

The file menu can be accessed from the top left corner of menu bar. It contains four options.

- o Create Template
- Import Data from filled-out Template
- o Remove all data from database
- o Exit

¥ Gas Storage Technology	y Consortium								
File Help									
Create Template									
Import Data from filled-out Te									
Remove all data from databas Exit	e								
	ALL PROPERTY AND	(BACHLY							
<u>E</u> dit Well Data	<u>V</u> iew Well Da	ita							
<u>C</u> anditate Selection									
West Virginia University									
8/15/2006		2:56 PM							

Fig32. File Menu options

Create Template

By executing this option first the user need to select a location in hard drive in order to save Template file.

Once the Template is successfully created in the hard drive, a message will appear indicating the user that the template file has been created.

Following is the screen shot of the Template file showing the Well bore data.

1	700 A	8	C	D	E	F	6	н	 Township	J	К	L	M TotalVerticalDepth	N	■ ᅖ 涵 \$ % , % 約 準 準 田 - <u>♪</u> - <u>▲</u> 〇 P Q R S T
															Please donot edit or change number of Titles in all the worksheets or worksheet names
ļ															
ļ															Please enter
ł														_	- only unique 'API_Number' in worksheet Wellbore'
t															
1															
1															
4															
-															
đ															
ł															
1															
-															
H															
4															
-															

Fig33. Screen shot of Template file

It has six worksheets, each representing the table in the database of the software.

- o Well bore Data
- Completion Data
- o Stimulation Data
- Perforation Data
- Stimulation Data
- o Well Test Data
- o Reservoir Characteristic
- 1. These are the fields of the table. Each field represents one characteristic of the table and each row is one record. If the user is not clear about any field, then he/she can drag the screen cursor to that field name and the comment will appear like in the picture below where it will give a little explanation, its format and an example so that the user understands what sort of data to enter in each field

	A		В	С	D				
1	API_Number	Fie	Kazim:						
2		Unique API number of the well							
3			Format: ##-###-####						
4		Example: 12-345-67890							

Fig34. Comments that shows format of some cells in Template Excel file

2. This section has two sets of warnings for the user entering data. One is to not edit or change number of Titles in all the worksheets or worksheet names and the other is to add only unique 'API Number' in worksheet 'Well bore Data' and all dates in worksheets where required. This has been done as the data is retrieved from the template according to some

This has been done as the data is retrieved from the template according to some specific format and non presence of any data in elementary field might stop program from using that record. All the elementary fields' background is orange/red while others are in green.

3. This section shows all the worksheets in the Template file.

Import Data from filled-out Template

¥ 0	🍟 Gas Storage Technology Consortium											
File	File Help											
0	Create Template											
In	nport Data from filled-out Template											
R	Remove all data from database											
E	Exit											

Fig35. Import data from filled-out Template

If this option is selected from the file menu, then the program will ask the user to select the filled Template file from the location. The new data will be appended to the existing data.

Remove all data from database

If the user doesn't want to append the data to the previous database but instead wants to up-load a whole new data, then there is an option in file menu as highlighted in the snapshot below. This option will remove all data in the previous database. After removing the data from previous database, the user can up-load the updated data from the template or enter it in the software.

🌱 Gas Storage Technology Consortium							
File Help							
	Create Template Import Data from filled-out Template						
R	Remove all data from database						
E	Exit						

Fig36. Remove all data from database

Exit

The program can be exited by two options. One is to exit by using the file menu and selecting 'Exit' while the other is to select the cross on the top right corner as in normal windows based applications.

	😽 Gas Stor	age Technolog	y Consortium	
	File Help			•
Exit Options		MAIN	MENU	
Gas Storage Technology Consortium File Help Create Template Import Data from filled-out Template				
Remove all data from database	Edit V	Vell Data	⊻iew Well D	ata
Exit			Selection	
	8/15/2006	West Virg	ginia Universi	ty 4:53 PM

Fig37. Exit form file menu

Help

Another option that can be accessed from the menu bar on top of the main menu screen is the Help menu option.

🌾 Gas Storage Technology Consortium 🛛 🛛 🔀							
File	Help						
	User Manual Formulas About	EN	MENU				
		11					
	<u>E</u> dit Well Data		<u>Y</u> iew Well Data				
	<u>C</u> anditate Selection						
🧡 West Virginia University							
8/2	1/2006		10:06 AM				

Fig38. Help menu options

It contains three types of information one is the User Manual for this software and second is the Formulas used in this software and third 'About' form which shows the system information and software contributors.



Fig39. "about" screen form help menu

Edit/View Well Data

This screen has all the well data in the form of five tabs (for five database tables) that can be edited / viewed or a Well Test Analysis can be performed in the Well Test tab.

First Well	Previous Well	Next Well	Last Well	J	l	<<	Main Menu
			A	ld New	<u>5</u> ave	Undo	
	Number 005-93939	Well Count Well # 39 of 4			<u>E</u> dit <u>D</u>	elete	Eind
Wellbore	Completion	Perf	oration	Sti	mulation	Υ	Well Test
Field Name	I-005-93939 JCAS 139 . A. MAURE	Latitude Longtitude Section Township County State	40.74306 -82.2375 25 VERMILLION ASHLAND OH		Operato TVD [ft] Formatio	28	lumbia Gas 79 nton

Fig40. Browsing through the well-bore data

To browse between different wells

First Well Previous Well Next Well Last Well

To move to the first well, previous well, next well & the last well in the record, click on the button assigned to it. The records are sorted in ascending order according to well number

API Number & Well Count

API Number	Well Count
34-005-93939	Well # 39 of 431

The progress bar shows the relative position of the record and well count shows the current well position in the well bore database out of the total records. The API number of the current well is also displayed

Back to main menu

<<--- Main Menu

Takes you back to the very first screen of the program

Editing Tools

<u>A</u> dd New	Save	Undo
Edit	Delete	Find

These buttons will help you to add a new record, edit or delete it or find a well for which you want the data to be retrieved if you know its API number.

Different Tabs

WELL BORE:

Wellbore	Completion	Perf	oration	Stimu	ulation	Well Test
Field Name Well No. Lease Name	34-005-93939 LUCAS 3939 M. A. MAURE ACTIVE	Latitude Longtitude Section Township County State	40.74306 -82.2375 25 VERMILLIC ASHLAND OH		Operator TVD [ft] Formation	Columbia Gas 2879 Clinton

Fig41. Well-bore tab

This tab contains all the data pertaining to the name, location & some main features of the current well.

COMPLETION:

Wellbore C	Completion	Perforation	Stimulation	Well Test
		Completion # 4 of 6		
Field Name	LUCAS		DD [in]	7
<u>W</u> ell No.	326		Fop [ft]	
Description	Casing	E	Bottom [ft]	75
		N N	Weight [lbs/ft]	17.00
Date Tubing Run	11/2/1969 MM/DD/YYYY	(Grade	SMLS USED
First Completio	n Previous Co	mpletion Next C	ompletion Las	t Completion

Fig42. Completion tab

This tab contains all the data relating to different completion run in the well.

To browse between different Completions

First Completion	Previous Completion	Next Completion	Last Completion

To move to the first completion, previous completion, next completion & the last completion in the record, click on the button assigned to it. The completions are assorted in ascending order according to date tubing run for current well.

PERFORATION:

Wellbore	Completion	Perforation	Stimulation	Well Te	st		
	Pe	erforation # 2 of 3					
Field Name	LUCAS	Perfo	ration Top [ft]	2,371			
Well No.	12058	Perfo	ration Bottom [ft]	2,407			
Perforation Type	Set-Thru	Shot	Туре	size, 50 / Glass			
Perforation Date	5-Sep-1981 MM/DD/YYYY	Shots	s Per foot	1.0			
First perforati	on Previous Perf	oration Next Per	forartion	st Perforation			

Fig43. Perforation tab

To browse between different Perforations

L				
	First perforation	Previous Perforation	Next Perforartion	Last Perforation

To move to the first perforation, previous perforation, next perforation & the last perforation in the record, click on the button assigned to it. The perforations are sorted in ascending order according to perforation date for current well.

STIMULATION:

Wellbore	Complet	tion	Perforation	ſ	Stimulation	Well Test	
Stimulation # 1 of 1							
Well No.	3932	Туре	Water-N2]	Flush (bbls)	30	
Size of String (i	n) 3.5	Water [bbls]	50	1	Sand Quantity [lbs]	8000	
Stim From [ft]	2906	Acid [bbls]	2.4		Sand Type	20/40	
Stim To [ft]	2928	Gel [bbls]	125		Injection Rate [bbls/min	13	
No of Shots	44	Foam (bbls)	0.07		Total Fluid [bbls]	229.87	
Fractured by	Dowell Inc.	N2 [Mcf]	50		Summary Total [bbls]	175	
Date	8/2/1966	Alcohol [bbls]	2.4		Break-down Pr. [psi]	2000	
	MM/DD/YYYY	Cushion [bbls]	20		ISIP [psi]	1000	
First	Stimulation Pr	evious Stimual	tion Next St	im	ulation Last Stime	Jaltion	

Fig44. Stimulation tab

To browse between different Stimulations

First Stimulation	Previous Stimualtion	Next Stimulation	Last Stimualtion

To move to the first stimulation, previous stimulation, next stimulation & the last stimulation in the record, click on the button assigned to it. The stimulations are sorted in ascending order according to stimulation date for current well.

WELL TEST:

Wellbore	Completion	Perforation	Stimu	lation	₩ell Test
Well Test	Time [hrs]		est # 3 of 9 Flow Pr. [psi]	Rate [McfD]	
First Reading	0.75	1030	860	2029	Field Name LUCAS
Second Reading	0.75	1020	955	1129	Well No. 10913
Third Reading	0.75	1015	926	1420	Test Date 12/28/1999
Extended Time	2	1015	924	1416	Test Type Multi-Point
kh [md-ft] 440 Skin 3.6 True Skin -2.1	5 n Value	0.630	DeltaP ² (psi ²) PD Rate (McfD AOF (McfD) Well Te	250000] 1743 5063 est Analysis	 PD Rate A0F Skin All Well Tests
First	WellTest P	revious WellTe	st Next	WellTest	Last Welltest

Fig45. Well-test tab

To browse between different Well Tests

First WellTest Previous WellTest	Next WellTest	Last Welltest
----------------------------------	---------------	---------------

To move to the first well test, previous well test, next well test & the last well test in the record, click on the button assigned to it. The well tests are sorted in ascending order according to well test date for current well.

Adding a new data

One can add a complete new well or just only a new well-bore/completion/perforation/ stimulation/well-test data by following method

Adding a complete new well data

1- Click on the Add New button Add New while keeping your well bore tab as active.

First Well	Previous Well	Next Well Last Well]	<<	Main Menu
	I Number 005-60183 Add	<u>A</u> dd New Edit	<u>5</u> ave Delete	Undo Find	
Wellbore	Completion	Perforation	Stimulation		Well Test
API Well No. Field Name Well No. Lease Name Classification		LatitudeLongtitudeSectionTownshipCountyState	Ope TVD Form		

Fig46. Adding a complete new Well – well-bore tab

The following messages will pop-up. If you want to add the complete new well-bore data then click No button $\boxed{N_0}$.

If you don't have the dates of Stimulation, Completion, Perforation & Well-Test data, then click Yes Yes and then add them one-by one.

Gas Cons	ortium
?	Do you want to Add only Wellbore Data ? Otherwise you must know the dates of Stimulation, Completion, Perforation & Well-Test
	Yes No

Following screen appears if No is clicked:

ias Storage Conso First Well	Previous Well Next Well	Last Well	<<-	Main Menu
	INumber Well Co 005-60183 Adding New We	unt	dd New Save	
Wellbore	Completion F	Perforation S	timulation	Well Test
Field Name <u>W</u> ell No.	Adding N	ew Completion OD (in) Top [ft]		
Description Date Tubing	,	Bottom [ft] Weight [lbs Grade	;/ft]	_
First Com	MM/DD/YYYY pletion Previous Complet		n Last Compl	etion

Fig47. Adding a complete new Well - completion tab

The background color of text boxes of all tabs including well-bore tab will be yellow indicating that they are ready for entering data.

2- Enter the data in all the tabs. The dates for completion, perforation, stimulation & well test job should be known.

First Well	Previous Wel	Next Well	Last Well			<<-	Main Menu
	Number 005-60183	Well Count Adding New Well-bo			New dit	<u>5</u> ave	
Wellbore					ulation	Ţ	Well Test
Field Name LL Well No. 67 Lease Name K	-345-67891 JCAS '891 AM CTIVE	Latitude Longtitude Section Township County State	40.7366 -82.2527 33 GREEN ASHLAND		Opera TVD [Forma	ft]	CTNS 1000 Clinton

Fig48. Adding a complete new Well – entering data for wellbore

First Well Previous Well Next Well Last Well << Main Menu						
API Number Well Count 34-005-60183 Adding New Well-bore data						
Wellbore Completion Perforation Stimulation Well Test						
Field Name	Adding	New Perforation Perforation Top [ft] 1675				
Well No.		Perforation Bottom [ft] 1679				
Perforation Type Tubing-Packer		Shot Type 51/2"				
Perforation Date	09/26/2005 MM/DD//////	Shots Per foot				

Fig49. Adding a complete new Well – entering data for perforation

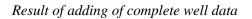
Gas Storage (Consortium					
First W	/ell Previous W	ell Next Well Last We	ll			
API Number Well Count 34-005-60183 Adding New Well-bore data						
Wellbore	Completi	on Perforation	Stimulation Well Test			
		Adding New Stimulation				
Well No. Size of String (Stim From [ft] Stim To [ft] No of Shots Fractured by Date	in)]3]1670]1680 [20 [20 [KAM [09/26/2004 [MM/DD/YYYY]	TypeWater [bbls]Acid [bbls]Gel [bbls]Gel [bbls]Foam [bbls]N2 [Mcf)Alcohol [bbls]Cushion [bbls]	Flush [bbls] Sand Quantity [lbs] Sand Type Sand Type Injection Rate [bbls/min] Total Fluid [bbls] Summary Total [bbls] Break-down Pr. [psi]			
First	First Stimulation Previous Stimualtion Next Stimulation Last Stimualtion					

Fig50. Adding a complete new Well – entering data for stimulation

Gas Storage Conso First Well	Previous \	Vell Next V	Vell Last W	ell	<<	Main Menu
	1 Number 005-60183		ll Count Well-bore data	<u>A</u> dd Ne	w <u>S</u> ave	Undo Find
Wellbore	Comple	etion	Perforation	Stimulati	on	Well Test
Well Test First Reading Second Reading Third Reading Extended Time	Time (hrs)	Field Pr. [psi]	ng New Well Test	Rate [McfD]	Field Name Well No. Test Date Test Type	09/26/2005
kh [md-ft] NonDarcyCo-eff DeltaP ² [psi ²] Image: Well Test Skin n Value PD Rate [McfD] Image: Well Test True Skin C Value AOF [McfD] Image: Well Test						
First We	llTest	Previous Wel	Test Next	WellTest	Last Welltes	it

Fig51. Adding a complete new Well – entering data for well test

3- Click the Save button **Save**



First Well Pre	evious Well Next	Well L	ast Well	<	< Main Menu
API Nur 12-345-		/ell Count # 433 of 433	_	ld New Sa Edit Del	
Wellbore	Completion	Perforatio	in Sti	imulation	Well Test
API Well No. 12-345 Field Name LUCAS Well No. 67892 Lease Name KAM Classification ACTIV	67892 Lo Se To Co E	ngtitude [.82 :ction [33 :wnship [GF	7366 2527 EEN HLAND	Operator TVD [ft] Formation	CTNS 1000 Clinton

Fig52. Result of adding a complete new well

Warnings – If API Numb		
	Gas Conso	ortium 🔀
	٩	This API Well Number is not valid - Enter again
		OK

Warnings – If API Number entered is already in the database



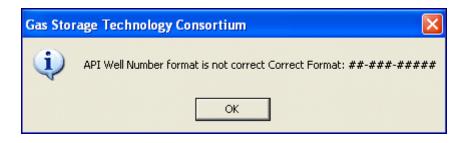
Note: The dates for completion, perforation, stimulation & well test should always be entered as the output of the software is directly dependent on the chronology of events. The format of date is also specified for the user where required. A close picture of that format is below:

Perforation Date	11/06/1971
	MM/DD/1111

You need to enter API well number only once in the well-bore tab and it will be automatically copied in the rest of tabs and procedure is the same for editing. The format for entering well API Number is:

API Well No. 12-345-67890

If wrong format or well API number is entered for a new well, then you will be greeted with the following message



Adding only well-bore/completion/perforation/stimulation/well-test data

1- Click on the Add New button you want to add the data.

Only for well-bore tab following message pops up:

Gas Cons	sortium
?	Do you want to Add only Wellbore Data ? Otherwise you must know the dates of Stimulation, Completion, Perforation & Well-Test
	Yes No
Click	Yes ves button to add only Well-bore data.

The background color of all text boxes of that tab will be yellow indicating that they are ready for entering data.

- 2- Enter the data. The dates for completion, perforation, stimulation & well test job should be known.
- 3- Click the Save button **Save**

Editing data

One can edit complete well or just only a new well-bore/completion/perforation/ stimulation/well-test data by following methods:

Editing a complete well data

1- Click on the Edit button while keeping your well bore tab as active.

Following screen pops up:

Gas Cons	ortium	×
?	Do you want to Edit only Wellbore Data ? Otherwise you must know the dates of Stimulation, Completion, Perforation & Well-Tes	;t
	Yes No	

Select accordingly.

First Well Previous W	ell Next Well Last Well	i l	<< Main Men
API Number 12-345-67892	Well Count Editing Wellbore Data		Save Undo Delete Find
Wellbore Comple	tion Perforation	Stimulation	Well Test
API Well No.12:345:67892Field NameLUCASWell No.67892Lease NameKAMClassificationACTIVE	Latitude 40.7366 Longtitude -82.2527 Section 33 Township GREEN County ASHLAND State DH	Operato	1000

Fig53. Editing well data

	Add New Save Undo
API Number Well Cour 12-345-67892 Editing Wellbord	
Wellbore Completion Pe	erforation Vell Test
Editing Com	mpletion Data
Field Name LUCAS	OD [in]
<u>₩</u> ell No. 67892	Top (ft)
, Description	Bottom [ft]
	Weight [lbs/ft]
Date Tubing Run <mark>9/26/2005</mark> MM/DD/YYYY	Grade

Fig54. Editing completion data

The background color of text boxes of all tabs including well-bore tab will be yellow indicating that they are ready for entering data.

- 2- Enter the data in all the active tabs. The dates for completion, perforation, stimulation & well test job should be known.
- 3- Click the Save button **Save**

Editing only completion/perforation/stimulation/well-test data

1- Click on the Edit button v edit the data except well bore tab.

while keeping that tab active for which you want to

Gas Storage Consortium	
First Well Previous Well Next Well	Last Well
API Number Well Cou	Add New Save Undo
12-345-67892 Well # 433 o	f 433 Edit Delete Find
Wellbore Completion Pe	erforation Y Stimulation Well Test
Editing Con	npletion Data
Field Name LUCAS	0D (in) <mark>5</mark>
<u>W</u> ell No. 67892	Top [ft] 1650
Description SurfaceCasing	Bottom [ft] 1680
	Weight [lbs/ft]
Date Tubing Run 9/26/2005 MM/DD/YYYY	Grade <mark>K-55</mark>
First Completion Previous Completio	on Next Completion Last Completion

Fig55. Saving completion data

The background color of all text boxes of that tab will be yellow indicating that they are ready for entering data.

Enter the data. The dates for completion, perforation, stimulation & well test job should be known.

Click the Save button **Save**

Result of editing only completion data

First Well Previous Well Next V	/ell Last Well]	<<	Main Men
		<u>A</u> dd New	Save	Undo
	1 Count 133 of 433	Edit	<u>D</u> elete	Find
Vellbore Completion	Perforation	Stimulation		Well Test
Co	npletion # 1 of 1			
Field Name LUCAS	OD (ïn]	5	
<u>₩</u> ell No. 67892	Тор	[ft]	1650	
Description SurfaceCasing	Botto	om [ft]	1680	
Description SurfaceCasing	Weig	ght [lbs/ft]		
Date Tubing Run 9/26/2005 MM/DD/YYYY	Grac	le	K-55	
	[]

Fig56. Saved completion data

Deleting data

One can delete complete well or just only delete completion/perforation/ stimulation/well-test data by following methods:

Deleting a complete well data

1- Click on Delete button while keeping your well bore tab as active

Editing only completion/perforation/ stimulation/well-test data

1- Click on Delete button while keeping that tab active of which you want to delete the data except well bore tab.

😽 Gas Storage Consortium	
First Well Previous Well Next W	Well Last Well
· · · · · · · · · · · · · · · · · · ·	ell Count
12-345-67892 Well # 4	\$ 433 of 433 Edit Delete Find
Wellbore Completion	Perforation Stimulation Well Test
Per	erforation # 1 of 1
Field Name LUCAS	Perforation Top [ft]
Well No. 67892	Perforation Bottom [ft]
Perforation Type	Shot Type
Perforation Date 09/26/2005 MM/DD/YYYY	Gas Consortium
First perforation Previous Perl	Yes No

Fig57. Deleting perforation record

You will be greeted with the above message to make sure that delete button is not accidentally pressed.

2- Click on yes if you want the selected record to be deleted.

To undo the edit or add operation before they can be saved click undo button

Finding a well

Follow the following procedure to find a well for which you have some idea of its API well number:

Click on Find button

The following screen is displayed:

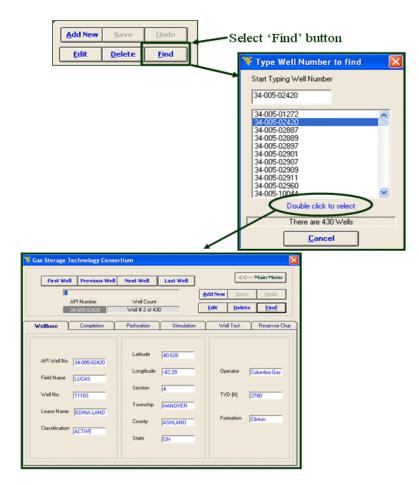


Fig58. Finding a well

WELL TEST ANALYSIS

To perform well test analysis on a well and draw graph of Peak day rate and Absolute open flow, use the option / command buttons below:

PD Rate
O AOF
🔿 Skin
○ All Well Tests
Show

Fig59. Well-test Analysis Option in well-test tab

Peak day, AOF, Skin, and all well test graph

Select *PD rate*, *AOF*, *Skin or All well Tests* option button and then click on the **Show** button **Show**. The following screens will appear according to the option selected:

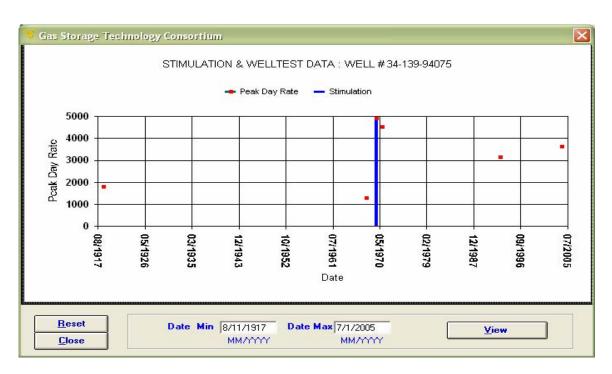


Fig60. Show Chart – Peak Day Rate



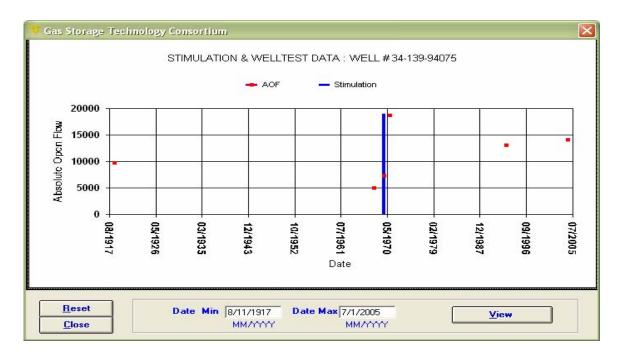


Fig61. Show Chart – Absolute Open Flow

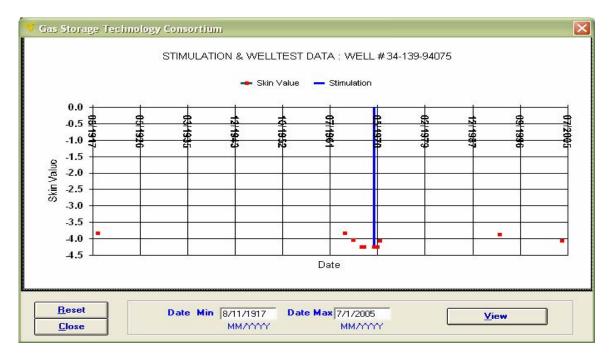


Fig62. Show Chart - Skin

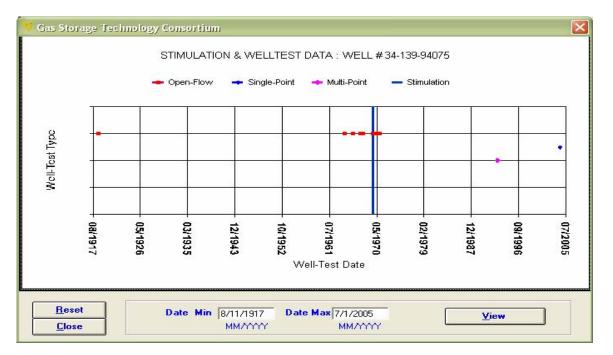


Fig63. Show Chart – All Well Tests

WELL TEST ANALYSIS TOOL

The user can do three types of Well Test Analysis in this software:

- 1- Simplified Analysis (for calculating n, C, PD rate & AOF)
- 2- LIT Analysis (for calculating Skin if 'k' is known)
- 3- Build-up Test Analysis (If Detailed Multi-Point Test data is available)

Gas Storage Technology		Add New Save	Main Menu Undo	
API Number 12335-67850 Welbore Completio		Edit Delete	Eind Reservoir Char	
Well Test Time In First Reading 0.75 Second Reading 0.75 Third Reading 0.75 Extended Time 2	WellTest # 7 of 8 s Field Pr. [pai] 890 846 883 617	Rate [MctD] 328 386 Well No.	ABCD 1234 7/12/2004	Well Test Analysis
kh [md-R] 123 NonDa Skin 1.63 n Valu True Skin 1 C Valu First WellTest		Analysis Sh	d Tests	

Fig64. Well Test Analysis button

The analysis tools are very similar for Simplified and LIT Analysis except where mentioned. The interface below will appear when you select 'Well Test Analysis' button. It will give you a glimpse of what has happened on the well since it was drilled.

Well Tests			Simp	plified Anal	ysis		LIT Analysis	
API_Number		TestType	kh	Skin	PeakDayRate		Detailed MP Data	
1 12-345-67890	5/11/1965	Open-Flow		-2.98	195	1033		
STIMULATION								
2 12-345-67890				-3.3956				
3 12-345-67890				-3.3956				220
4 12-345-67890				-3.2152	2807			
5 12-345-67890				-3.2152				
6 12-345-67890				-3.3222	2068			1212
7 12-345-67890	7/12/2004	Multi-Point	123	1.63	606	1853	YES	1000
						ed Analysis' or 'L e well-test wher	IT Analysis' e 'YES' is written	
	n the 'Detailed				ermeability for th			1
2 Single click in	n the 'Detailed	MP Data' co		estimate pe	ermeability for th	e well-test wher	e YES' is written	1
2 Single click in	n the 'Detailed	MP Data' co		estimate pe	ermeability for th	e well-test wher	e YES' is written	1
2 Single click in	n the 'Detailed	MP Data' co		estimate pe Multi-Point	ermeability for th	e well-test wher	e YES' is written	1
2 Single click in	n the 'Detailed	MP Data' co		estimate pe	ermeability for th	e well-test wher	e YES' is written	1
2 Single click in	n the 'Detailed	MP Data' co		estimate pe Multi-Point	ermeability for th	e well-test wher	e YES' is written	1
2 Single click in	Sin	MP Data' co		Multi-Point	× ×	Selected Test	YES' is written Stimulation1	1
2 Single click in	Sin	MP Data' co		Multi-Point	× ×	Selected Test	YES' is written Stimulation1	1
2 Single click in	Sin	MP Data' co		Multi-Point	× ×	Selected Test	YES' is written Stimulation1	1
2 Single click in	n the 'Detailed	MP Data' co		Multi-Point	ermeability for the	e well-test wher	e YES' is written	1
2 Single click in	Sin	MP Data' co		Multi-Point	ermeability for the	Selected Test	YES' is written Stimulation1	1

Fig65. Well Test Analysis Module

1. This section contains all the data in a grid form API Number, Date of well test, Test Type, kh value, Skin value, Peak Day rate, Absolute Open Flow and information in 'YES' or 'NO' form if the Detailed Multi-point data (Pressure profile & flow-rate vs.

time) is available for a given test or not. The back color of selected well-test is yellow while of stimulation is purple. The first well-test is selected by default.

- 2. This section contains instructions as how to select well-tests for analysis. Single click on any well-test will make it the current well-test with background changed to yellow and by double click; it will be selected for Simplified and LIT Analysis. If the Detailed MP Data for a well-test is given, then it can be selected for permeability analysis (build-up test) by single click on the cell where 'YES' is written. This way the build-up test analysis module will show up.
- 3. This section shows the time of different well tests which are indicated by three types of markers and stimulations on a well which are represented by straight blue vertical lines. The selected well have the similar marker according to its test-type but its color is dark green.

Once any well-test is double clicked, it is selected and added in the list box of simplified and LIT Analysis.

Simplified Analysis:

The screen shot of Simplified Analysis tab is below with Well-test # 2 to # 7 selected for analysis.

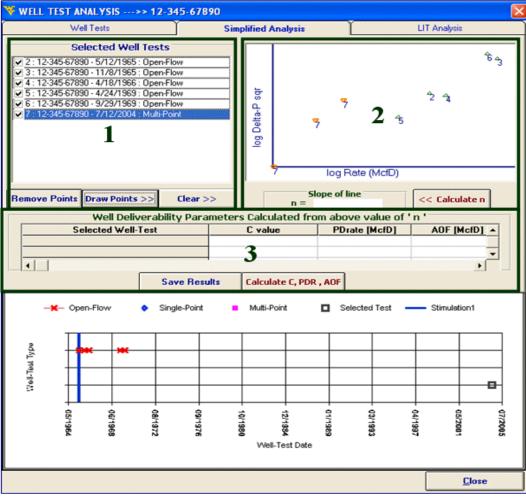


Fig66. Well Test analysis tool

- This section contains the list box which has the entire well-tests selected for an analysis. Any test now again can be selected or de-selected by using the check-box in front of it. Once the well-tests are selected, then they can be drawn on log-log graph of Flow-rate (McfD) vs. Delta Pressure Square (Delta P sqr) by selecting the 'Draw Points' button. This graph can be cleared by selecting the 'Clear>>' button also if the well-tests drawn need to be changed.
- 2. Once the data points have been drawn, the user can draw a line in the picture box keeping left mouse button held down like shown below:

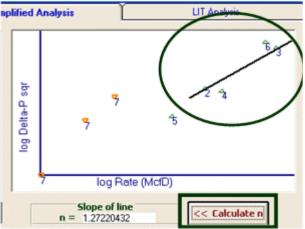


Fig67. Draw a line and calculate the slope

Select 'Calculate n' button to find the slope of the drawn line. The slope will be calculated in front of 'n' text box.

 Now the user can select the well-tests that he/she intended to the simplified analysis on them. Then a line should draw based on the selected well tests in the picture box (Figure 68). The slop (n) will be calculated by mouse clicking on the "Calculate n" Button. The values of C, Peak Day Rate and Absolute Open Flow will be calculated and shown in the grid as shown in the picture shot on next page. These results can be saved in the database by selecting the 'Save' button.

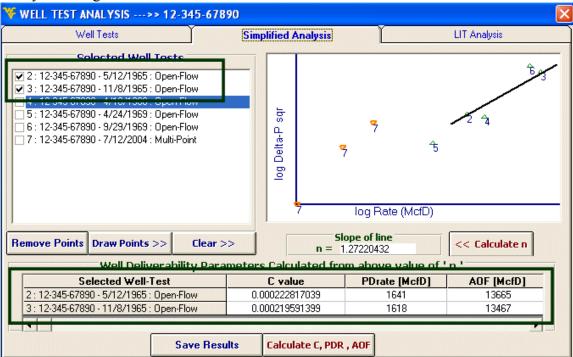


Fig68. Simplified well test analysis tool

Note: If there is only one well-test before or after the stimulation, then the value of n can be assumed and written in the textbox in front of label 'n' as shown in the picture below. The value of 'n' cannot be assumed for more than one well at a time so if there is more than one well-test for which the value of 'n' has to be assumed, then they should be selected one by one.

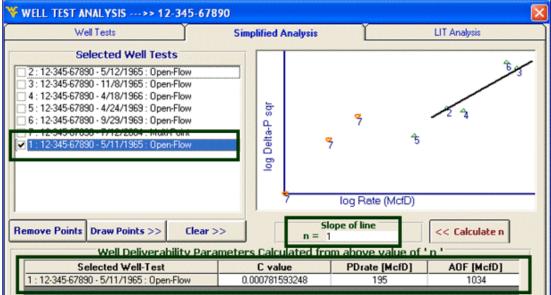
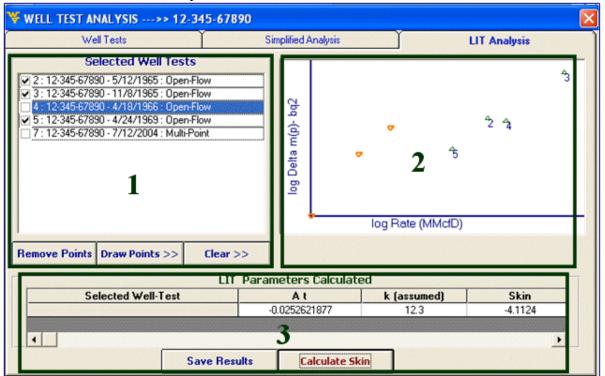


Fig69. Simplified well test with one well test before or after stimulation

Laminar Inertial Turbulent (LIT) test Analysis:



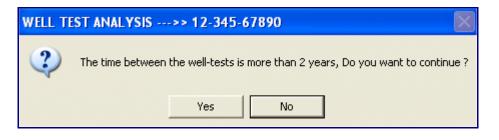
The screen shot of the LIT analysis is below:

Fig70. LIT well test analysis

- 1. This section is the same as for Simplified Analysis.
- 2. In this section, the well-test points are drawn on $\log \log \operatorname{plot} \operatorname{of} \operatorname{Flow} \operatorname{rate} (MMcfD)$ vs. Delta pseudo pressure $- \operatorname{bq}^2$. There is no need to draw a slope line in this plot. Instead, the points can be selected by visual inspection that they form a straight line and that they were conducted preferably within 2 years. In the snapshot above, well test points 2,3 and 5 have been selected to calculate Skin.
- 3. When the 'Calculate' button is pressed, the program uses the permeability value 'k' from the nearest well-test and calculates skin. The new value of skin can be saved in the database by selecting 'Save Results' button.

Note: Multi-point test points give erroneous calculations if selected with other well-tests as they are recorded one flow after another simultaneously, not like Open Flow and single point tests, which are recorded once a year.

If the selected well-tests are not within 2 years, then the following message will appear giving the user choice either to select other well-tests or continue with the well-tests selected.



Build-up test Analysis:

If any Multi-point well test has a detailed data (pressure and flow-rate profile vs. time), then the 'Detailed MP Data' column in front of that test will show 'YES'. It means that the data for this well-test can be analyzed to estimate a value of permeability.

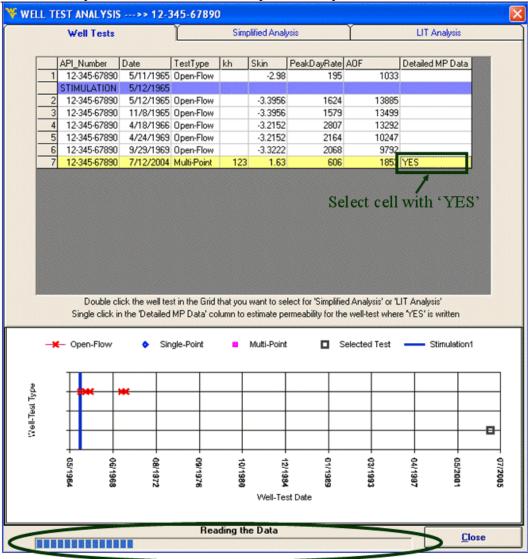


Fig71. Multi point well test analysis

If the cell with value 'YES' is selected the software will read the data from the excel file and progress bar will become visible like in the picture shot above showing that the data is being read.

After the complete data has been read by the software, the following screen will appear showing the pressure profile of the well-test.

Well 1	TEST ANALYSIS>> 12-345	-67890			×
	Input Data		ľ	Permeability Analysis	
	tp (flow/production time) hrs Wellbore Radius (ft) Porosity (%)	2 1.5 0.14	Temperature (F) Specific Gravity Thickness (ft)	75 0.585 10	
Pressure	•	me (hrs)			
	Selec	t the Extended Buid-up) Test with left mouse butt	on down	

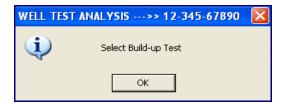
Fig72. Well extended pressure profile

All the Input data is retrieved from the database and if it is not found, then default values are inserted. The value 'tp (flow/production time' is 2 hrs by default but can be changed by the user. The Extended build-up test for 2 or more hours should be selected by keeping the left mouse button down. The green lines will indicate portion of build-up test selected.

¥ WELL TEST	ANALYSIS>> 12-345	-67890			×
	Input Data	ľ		Permeability Analysis	
	tp (flow/production time) hrs	2	Temperature (F)	75	
	Wellbore Radius (ft)	1.5	Specific Gravity	0.585	
	Porosity (%)	0.14	Thickness (ft)	10	
		$\bigvee \land$			
Pressure	Tin	me (hrs)			
		t the Extended Buid-up T	est with left mouse bu	utton down	

Fig73. Selecting the build-up section from pressure profile

If by mistake draw-down data is selected, then the following message will appear informing the user to select build-up data again.



After the portion of build-up data has been correctly selected, the permeability analysis tab will show following graphs. The first one is the log-log diagnostic plot between 'Del Pressure' and 'Del Time'. The user should select the first point which does not fall on the unit slope line drawn by holding the left mouse button down. The initial pressure 'Pi' and flow rate text box values will be selected from the build-up portion of the extended well-test selected. The graphs will be drawn again with a green line drawn on the Horner plot indicating The End of Well-Bore Storage (tewbs).

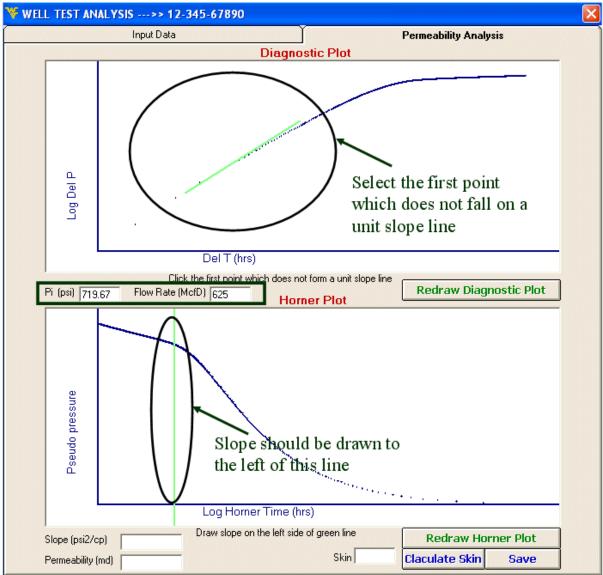


Fig74. Diagnostic plot analysis

The slope should be drawn on the Horner plot on the left side of the end of well bore storage line shown in green on Horner plot.

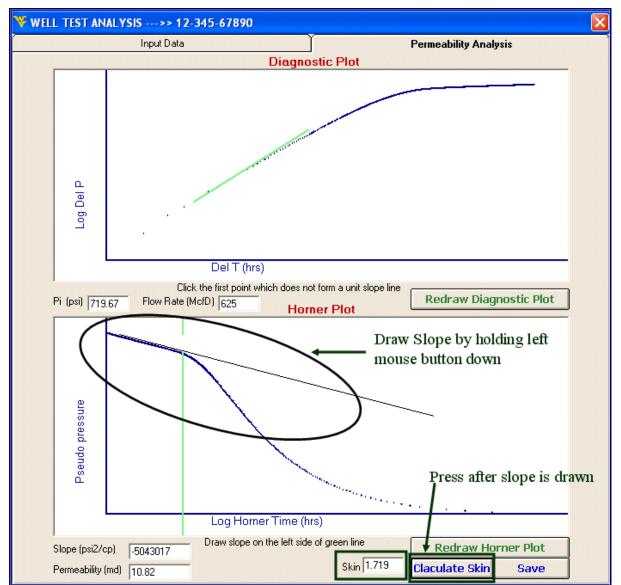


Fig75. Calculating skin from Hornet plot

After the slope is drawn, the user can select 'Calculate Skin' button to find the skin of the well. The respective graphs can be redrawn any time by selecting the 'Redraw Diagnostic Plot' or 'Redraw Horner Plot'.

The value of permeability and Skin can be saved in the database by selecting 'Save' button.

SELECT WELL DATA

In this form the user can choose to select the data of the wells that he wants to look at. Following are a few ways he can choose the data:

Selecting a well by State/County:

The user selects the state first and then the county. All the wells will be selected for that county in the selected wells list box:

SELECT		SELECTED WELLS
OHIO	COUNTY	API Well Number
OH	ASHLAND	34-005-01272
	RICHLAND	34-005-02420
		34-005-02887
		34-005-02889
		34-005-02897
		34-005-02901
		34-005-02907
		34-005-02909
		34-005-02911
		34-005-02960
		34-005-10044
		34-005-10516
		34-005-10517
Res	et	Select All

Fig76. Selecting Ohio County

Selecting wells by stimulation year:

The user can select the option button for stimulated year and input the year values. If Select Wells button **select Wells** is clicked, then all the wells that have been stimulated between these years will be shown in the selected wells list box

😽 Gas Storage Consortium		×
	SELECT WELL DATA	A
SELECT STATE COUNTY	SELECTED WELLS API Well Number & Year of Stimulation 34-005-93872, 1995 34-005-60265, 1995 34-005-60265, 1995 34-005-60200, 1994 34-005-60248, 1996 34-005-60243, 1996 34-005-60250, 1993 34-005-60243, 1996 34-005-60250, 1993 34-005-20250, 1993 34-005-20250, 1993 34-005-20250, 1993 34-103-20515, 1993 34-005-22979, 1994	SELECTION OPTION
Reset	Select All	Stimulated between year 1992 and 1996 Km Off-set Wells
<< Main Menu	Select Well Data	Select Wells

Fig77. Selecting wells according to stimulation year

Selecting offsets wells form a well:

The user selects the offset option and the well near which he wants to find the off-set wells, and then enters the distance of off-set in kilometers. If Select Wells button is clicked, then all the wells that are off-set of the selected well will be shown in the selected wells list box

¥ Gas Storage Consortium		X
	SELECT WELL DAT	Ā
SELECT STATE COUNTY	SELECTED WELLS API Well Number 34:005:01272 34:005:0287 34:005:02887 34:005:02901 34:005:02901 34:005:02901 34:005:02901 34:005:02901 34:005:02901 34:005:02901 34:005:02901 34:005:02901 34:005:93963 34:005:958839 34:005:96225 34:005:97782	SELECTION OPTION
Reset	Select All	Stimulated between year and and Z Km Off-set Wells
< Main Menu	Select Well Data	Select Wells

Fig78. Offset wells

Display the selected wells data:

When the wells for which the user want the data to be retrieved have been selected, click the Select Well Data button **Select Well Data** and select the parameters.

Table Names						
Y Gas Storage Technology Consortium						
WELL BORE DATA COMPLETION DAT FieldName Des Well LeaseName OD Classification TopCasing Lat Weight Section Grade Township County State Operator TotalVerticalDepth	TA PERFORATION DATA	STIMULATION DATA	WELL-TEST DATA ✓ TestDate ✓ TestType ✓ Time1 ✓ FieldPress1 ✓ FieldPress2 FieldPress3 FieldPress3 FieldPress3 FieldPress3 FieldPress4 FieldPress5 FieldPress5 FieldPress4 FieldPress5 FieldPress5	RESERVOIR DATA		
Select all well-bore Select all Comple	tion Select all Perforation	Select all Stimulation	Select all WellTest	Select all Reservoir		
	<< <u>S</u> elect Well	Reset Show Wel	Data			

Fig79. Selecting Well Parameters

Click Show Well Data Show Well Data to retrieve the data.

				SELEC	TED W	/ELL C	ATA		
API_Number	FieldName	Lat	Long	TestDate	TestType	Time1	FieldPress1	FlowingPres	Rate1
12-345-67890	ABCD	20.62222	-62.27472	9/29/1969	Open-Flow		1138	0	9602
2-345-67890	ABCD	20.62222	-62.27472	4/18/1966	Open-Flow		679	0	4970
2-345-67890	ABCD	20.62222	-62.27472	11/8/1965	Open-Flow		1070	0	
2-345-67890	ABCD	20.62222	-62.27472	5/12/1965	Open-Flow		699	0	
2-345-67890	ABCD	20.62222	-62.27472	5/11/1965	Open-Flow		465	0	
2-345-67890	ABCD	20.62222	-62.27472	4/24/1969	Open-Flow		522	0	
2-345-67890	ABCD	20.62222	-62.27472	7/12/2004	Multi-Point	0.75	890	846	328

Fig80. Result of the wells & parameters selected

CANDIDATE SELECTION

This module will appear on selecting the 'Candidate Selection' button from Main Menu.



Fig81. Start Candidate Selection form main screen

For intelligent candidate selection of wells, it is very important that only valid data is given to the Neural Network (NN) for training. Valid data is one which will not degrade the performance of the NN and is useful in NN training.

¥ ()ptimization								×
Optic	ns								
No.	API_Number	FieldName	Well	LeaseName	Classification	Lat	Long	Section	Ŧ
1	12-345-67890	ABCD	1234	XYZ	SPECIAL	52222	27472	10	1
2	34-005-10517		10517	L. & E. JENN	ACTIVE	70333	.285	9	1
3	34-005-10527		10527	E. M. DAHL	ACTIVE	7075	.25833	11	I
4	34-005-10549		10549	ZADA GUTI	ACTIVE	58472	.31611	17	I
Б	34-005-10552		10552	W. C. SCHA	ACTIVE	71222	.22444	1	1
6	34-005-10575		10575	ZELLA BITT	ACTIVE	70972	.2525	11	1
7	34-005-10657		10657	JOHN THO	ACTIVE	54472	.30611	32	I
В	34-005-10676		10676	BERNARD I	ACTIVE	59833	.29806	9	
B	34-005-10795		10795	ROGER F. S	ACTIVE	74889	.27472	27 1	I
10	34-005-10898		10898	FOREST E.	ACTIVE	72778	.30945	32 1	1
11	34-005-11029		11029	OHIO FUEL	ACTIVE	72778	.32777	31 '	1
12	34-005-20202		7359	E. HUNGEF	ACTIVE	57694	.33667	19	1
13	34-005-20370		8549	H. D. KEYSI	ACTIVE	56917	.3375	19	1
14	34-005-20373		8538	ESTHER HI	ACTIVE	57861	.33639	19	1
15	34-005-20388		8817	C. C. LEIBO	ACTIVE	71806	.31194	5	l
16,	34-005-20517	1	8947	M HINES #	ACTIVE	72583	32389	8	1
			0					<u> </u>	
-	pe of Analysis		 Destroyed resources in the second seco	ion Method					
				àA based on S	^{kin} 3		App	ly GA	
0	Single Well 🚄		00	A based on C	ost And Skin			-	
			Cost	c	kin 🗖		<< Ma	ain Menu	
	Select W	ell	Weightad	1e % 50 %	/eightage %	0			
	Select W	en	Weightad	te % <mark>1</mark> 00 //	kin /eightage %	U			

Fig82. Candidate Selection main screen

1. When this module is loaded, each row in this section of the grid represents a valid stimulation as shown in figure above. Following, is the criteria for valid stimulation selection:

Valid Stimulation – It should have skin value before & after stimulation. Valid Perforation – Perforation just before the stimulation. Valid Completion – The smallest size completion run before stimulation. Valid Well-test – Well-test having skin value just before or after the well-test.

2. Two types of analysis can be done on the wells: One option is to apply Genetic optimization on wells one at a time and the other is to apply it on all wells. If the 'All Wells' option is selected, then the 'Select Well' button will be enabled and the user can select the well the same way as shown in the previous section of the user Manual for – Find a well.

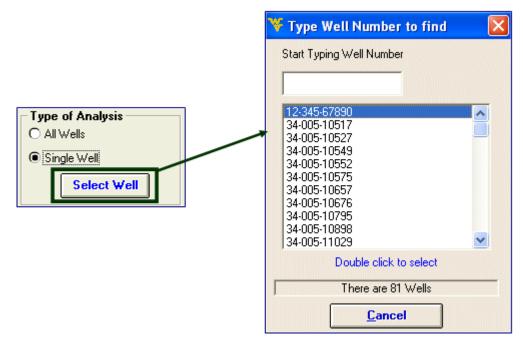


Fig83. Selecting a well for candidate selection process

3. This section of module relates to the Optimization methods available. User can optimize the stimulations according to only change in skin criteria or may choose to select the 'GA based on cost and skin' option where he/she can give different weight ages to cost and skin.

Optimization Method
igcologie GA based on Skin
GA based on Cost And Skin
Cost Weightage % 50 Skin Weightage % 50

Options Menu:

This software can cater for many varied situations. These options can be selected from the 'options' menu bar on the top of the form. It contains following items:

- Select controllable parameters
- Material cost
- Import NNet
- NNet Input values
- GA characteristic
- Export the Grid to Excel
- Select Well-Test Type

Following is a screen shot of the items in the Options menu tool bar.

¥ Opt	imization	
Options		
Select	controlable parameters	/ell
Materi	al Cost	234
Impor	t NNet	0517
NNet 1	Input Values	0527
GA Ch	aracteristic	0549
Expor	t the Grid To Excel	0552
	Well-TestType	0575
1 10		0657

Fig84. Options to control Candidate Selection process

Material cost can be changed by the user as the prices fluctuate. These prices can be saved in the database by selecting 'Save' button and Default values can be retrieved by selecting ' Default' button. The screen shot of material cost is shown below and price is just an estimate and can be changed by user.

¥ Material Cos	t	×
Cost		
Water Inject	tion \$/bbls	29.4
Acid	\$/bbls	10
Gel	\$/bbls	3570
Foam	\$/bbls	10
Nitrogen	\$/Mcf	49.7
Sand Quantit	ty \$/lbs	0.4
Open Flow Te	est \$/Job	10000
Single Point	Test \$/Job	5000
Multi Point T	njection \$/bbls 29.4 \$/bbls 10 \$/bbls 3570 \$/bbls 10 \$/bbls 10000 \$/bbls 100000 \$/bbls 100000 \$/bbls 10000 \$/bl	10000
<u>S</u> ave	<u>D</u> efault	Close

Fig85. Cost analysis module

lo.	API_Number	Lat		Long	Water	Acid	Gel	Foam	N2	SumFluids	SandQuantil	Prior-kh	After-TestTy
1	12-345-	2	222	\$72	255	1.2	131	0	50		12100	123	Open-Flow
2	34-005-		333	5	255	1.2	131	0	50		12100	123	Open-Flow
3	34-005-] 7	'5	333	255	2.4	136	1.6	80		13600	395	Open-Flow
4	34-005-] 4	72	511	0	1.2	75	0	0		6000	378	Open-Flow
5	34-005-] 2	222	144	265	2.4	140	0.2	85		13650	100	Open-Flow
6	34-005-	1 3	972	25	255	1.2	130	0	45		9500	523.3	Open-Flow
7	34-005-] 4	72	511	0	4.8	375	0.1	125		13100	362	Open-Flow
8	34-005-		333	306	234	2.4	129	0.2	60		11000	210	Open-Flow
9	34-005-		389	\$72	0	4.8	155	0.3	83.7		13900	557	Open-Flow
10	34-005-] 7	78	345	0	2.4	435	0.1	75		24400	1374	Open-Flow
11	34-005-] 7	78	777	0	6	435	0.1	75		20000	288	Open-Flow
12	34-005-		394	367	0	0	0	0	0		2000	793	Open-Flow
13	34-005-:		917	75	0	1.2	24	0	0		2000	134	Open-Flow
14	34-005-:		361	539	0	0	0	0	0		2000	120	Open-Flow
15	34-005-:	1 3	306	194	0	0	0	0	0		1700	141	Open-Flow
16	34-005-:	1 8	583	389	0	0	150	0	0		2000	1210	Open-Flow

Fig86.Inpurs that used to train the Neural Network

If the user wants to look at the Neural Network inputs being used, then 'NNet Input' option will take the user to a new form as shown above where all the inputs are shown. Keep in mind that this grid can only be seen once and that only after the Genetic optimization has been applied.

If some material is not available for stimulation, then still the user can optimize the stimulation by de-selecting that material from the 'Select controllable parameters' option. The materials not enabled are the ones that are not being used by the Neural Network in use.

Select controlable according to a	•
🔲 Injection rate	🔽 Foam
🔽 Water	✓ N2
🔽 Acid	🔲 Alcohol
🔽 Gel	🔲 Cushion
🔽 SandQuantity	🔲 Flush
	🔲 SandType
Close	•

Fig87. Select the controllable parameters in optimization process

A new Neural Network can be used if the data is changed or appended by importing its 'ida' file. When a new Neural Network is imported, it might change the optimum GA parameters. The user can change them from 'GA characteristic' option. The default values are always loaded at startup as shown in figure below but can be changed by user.

GA Charaterict	ics
Population Size	500
Cross-over Rate %	60
Mutation Rate %	10
No of Generations	10
Close]

Fig88. Setup GA pentameters

If one of the Neural Net inputs is well test before stimulation, the type of the wells test in optimization process should specify here.

W	ell-Test Type
	Open-Flow
	Single-Point
	Multi-Point
	Close

Fig89. Type of the wells test in optimization process.

When all the parameters for GA have been selected and user selects the 'Apply GA'

Apply GA button, then the screen below will appear showing the values of optimized stimulation slurry and change in skin due to this stimulation. The picture below shows the GA optimization done on well # 12-345-67890.

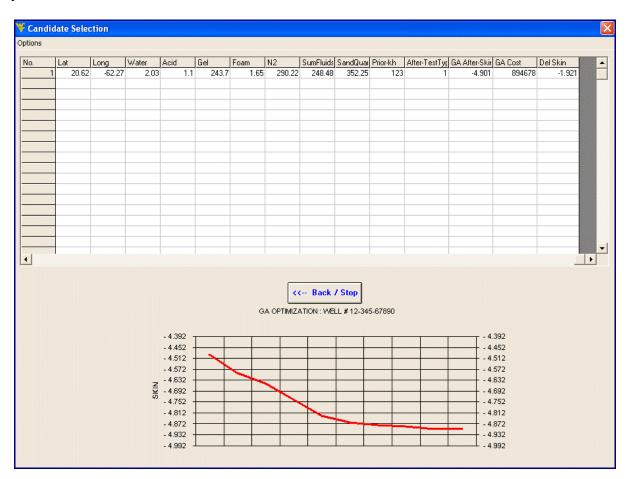


Fig90. Optimization process for one well

If the optimization is applied to all the wells, then we can rank the wells according to the change in skin by selecting 'Rank the wells' from Options menu bar on the top left corner of the form as shown in snapshot below.

ions															
Rank the W			Water	Acid	Gel	Foam	N2	SumFluids	SandQuai	Prior-kh	After-TestTyp	GA After-Skir	GA Cost	Del Skin	Г
xport resu	It to Excel	228	6.75	11.34	121.85	1.63	252.77	141.57	469.67	123	1	-5.024	458092	-2.044	ľ
Z	***.71	-**.26	0.68	10.52	161.08	1.7	162.04	173.97	5107.63	395	1	-4.959	595277	-1.1013	
3	.68	.32	3.38	6.17	153.75	1.66	272.94	164.96	6340.51	378	1	-5.048	575179	-1.3871	
4	.71	.22	4.05	11.21	103.03	0.03	46.09	118.32	23835.62	100	1	-4.457	389857	-1.7965	
5	.71	.25	10.8	5.71	78.45	1.7	205.96	96.66	3287.67	523.3	1	-4.882	301995	-1.2657	
6	.64	.31	0	9.67	124.47	1.7	315.43	135.84	880.63	362	1	-5.048	470491	-0.9724	
7	0.7	2.3	12.15	6.46	234.81	1.63	137.55	255.06	117.42	210	1	-5.04	855608	-1.4872	
8	.75	.27	2.7	8.14	102.5	1.67	163.48	115.02	7866.93	557	1	-4.797	387383	-0.5144	
9	.73	.31	272.08	11.89	434.59	0.03	356.48	718.6	28649.71	1374	1	-5.782	1598780	-0.859	
10	.73	.33	2.7	11.35	132.83	1.69	227.57	148.58	1115.46	288	1	-5.042	496186	-1.0263	
11	.68	.34	10.8	2.45	189.32	1.7	247.01	204.27	2407.05	793	1	-5.05	699456	-0.7801	
12	.67	.34	5.4	2.57	211.28	1.7	195.16	220.95	1819.96	134	1	-5.049	774901	-1.5019	
13	.68	.34	11.48	3.78	218.08	1.7	41.05	235.04	5107.63	120	1	-5.049	793018	-1.654	
14	.72	.31	8.1	7.01	211.28	1.69	109.46	228.07	2172.21	141	1	-5.039	770906	-1.0117	
15	.73	.32	103.97	11.88	446.62	0.4	364.4	562.87	29647.75	1210	1	-5.699	1637575	-2.6374	
16	.72	.33	8.78	9.56	144.34	1.64	177.88	164.32	5988.26	233	1	-5.043	536900	-1.4835	
17	.73	.31	2.7	7.75	182.52	1.67	223.25	194.63	1467.71	401	1	-5.026	673442	-1.1274	
18	74	31	180.26	11 33	448 71	0.53	362.96	640.83	29060.67	1770	1	-5 872	1646975	-1.8082	I.

Fig91. Optimization result for selected wells

The wells are ranked according to change in skin as shown in the figure below. These ranked wells and the optimized stimulation data now can be exported to excel by selecting 'Export to Excel' in the Option menu of Candidate Selection module.

Can	lidate	e Seleo	ction													
otions															>	
No.	La	t	Long	Water	Acid	Gel	Foam	N2	SumFluids	SandQuai	Prior-kh	After-TestTyp	GA After-Skir	GA Cost	Del Skin	
	64).71	.36	6 0	3.03	243.7	1.67	26.65	248.41	3698.63	957	1	-5.049	882877	-6.459	1
	35).67	2.3	3 1.35	5.84	164.21	1.7	234.77	173.1	6810.18	105	1	-5.046	610748	-2.8672	
	15).73		2 103.97	11.88	446.62	0.4	364.4	562.87	29647.75	1210	1	-5.699	1637575		
	43).66			1.65	192.45	1.69	333.43	197.82	176.13	308.7	1	-5.048	713794	-2.2202	
	65).71	.3		11.87	471.2	0.19	342.79	687.82	29941.29	1712	1	-5.879	1727323		
S.S.U.P.	1	10.7	.20	6.75	i 11.34	121.85	1.63	252.77	141.57	469.67	123	1	-5.024	458092	-2.044	
	61).71	.36	5 142.46	11.75	507.81	0.07	347.12	662.09	28356.16	1880	1	-5.894	1855766	-2.0423	
	69).71	.3	5 7.43	9.26	222.79	1.69	72.02	241.16	410.96	576	1	-5.048	809417	-2.0098	
	79).71	.34	4 C	6.52	234.81	1.7	150.51	243.04	1467.71	100	1	-5.047	856437	-1.9297	
	24	10.7	.2	9 7.43	2.69	212.33	1.65	84.98	224.09	3992.17	100	1	-5.027	774088	-1.8304	
	18).74	.3	1 180.26	11.33	448.71	0.53	362.96	640.83	29060.67	1770	1	-5.872	1646975	-1.8082	
	4).71	.2	2 4.05	11.21	103.03	0.03	46.09	118.32	23835.62	100	1	-4.457	389857	-1.7965	
	66).72	.36	6 261.28	11.85	456.03	1.1	353.6	730.27	26125.24	1317	1	-5.747	1673867	-1.7729	
	59).74	.3	1 3.38	8.82	172.06	1.65	295.98	185.9	2289.63	117	1	-5	640076	-1.7104	
	19).72	2.3	3 1.35	3.71	205.53	1.67	272.22	212.26	0	122	1	-5.024	757357	-1.6857	
	13).68	.34	4 11.48	3.78	218.08	1.7	41.05	235.04	5107.63	120	1	-5.049	793018	-1.654	
in the first	37).69	2.3	3 3.38	2.44	265.15	1.67	141.87	272.63	117.42	209	1	-5.045	963812	-1.6262	
•	70	168	36	8 0.68	0.08	343 59	17	65 53	346.04	234 83	206	1	-5 049	1240013	-1.6002	

Wells Ranked according to Change in Skin

Fig92.Rank the optimization result based on delta skin in order to find the best candidates

CONCLUSION

The main aim of this study was to find the re-stimulation candidate wells with the given data without trying to spend thousands of dollars on well-test and gas reservoir simulators. Detailed analysis of well-tests performed on the storage field was done and intelligent tools like Neural networks to predict the Skin and Genetic Algorithms were used to optimize the stimulation and to select the best stimulations for a well. The following conclusions can be drawn from this research:

- 1. The Artificial Intelligence Tool can predict Skin with high degree of confidence.
- 2. The Portfolio Management for re-stimulation candidate selection provides a cost effective method for taking full advantage of annual budget for remedial operations.
- 3. This software is the first successful attempt to combine Data editing, Well-Test analysis and Artificial Intelligence in one software package.

REFERENCES

NONE