TITLE PAGE

Report Title: A Study to Evaluate the Effect of Completion and Production Procedures on the Ultimate Recoverable Reserves from Knox Formation Wells: Rose Run Sandstone and Beekmantown Dolomite

Type of Report: Final Technical Progress Report

Reporting Period Start Date: 06/01/2005

Reporting Period End Date: 12/31/2006

Principal Author: Tim Knobloch

Date Report was issued: March 2007

SWC Award Number: 2969-JEI-DOE-2098

Name and Address of Submitting Organization:
James Engineering, Inc.
231 Third Street
Marietta, Ohio 45750

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Abstract

Over the years various drilling, completion, and production methodologies have been applied to the Knox Formation, specifically the Rose Run Sandstone and the Beekmantown Dolomite, resulting in various levels of production. The varying levels of success are due not only to the technology used to identify the prospects and the quality of reservoirs encountered, but also to the petroleum engineering principles applied to the completion and the production methodologies employed.

Completion and production technical issues include cased-hole versus open-hole completions, matrix acidizing versus fracture stimulation, perforation concentration and interval selection, fluid removal methods, paraffin treatments, operating wellhead pressures, gas sales line pressures, as well as general operating procedures. As in all plays, the combined influence of these factors and the reservoir quality ultimately determine the recoverable oil and natural gas reserves.

The Knox-Beekmantown (or equivalent) has been drilled though or tested in approximately 9,500 wells in the Appalachian Basin including the states of Kentucky, New York, Ohio, Pennsylvania, and Tennessee. It is well known that many Knox/Beekmantown wells are initially very prolific. Experience indicated that the past and current completion and production practices employed may have negatively impacted the ultimate recoveries of some Knox wells.

The study evaluated critical factors associated with completion and production practices and the effect on the ultimate reserves predicted. The study results were inconclusive in some regards as there was not a clear relationship identified between completion method, stimulation method, and the resultant EUR. However, the results of the study did enable a better understanding of the methodologies employed by various operators which was translated into the preparation of a procedure guide to assist operators in delineating areas of opportunity to increase production and ultimate recoverable reserves.

The results of the study appear to indicate that one of the most significant factors behind successful Knox well development is the ability to initially identify appropriate reservoir targets through geologic and geophysical analysis. The complex geologic nature of the Knox and associated potential pays provides an impetus to operators to apply a standard methodology towards their approach to Knox wells. Experience and the study indicate that a consistent methodology towards the drilling, completion, and production of Knox wells should ultimately increase production and associated reserves.

Table of Contents

List of Graphical Materials……..3

Introduction……4

Executive Summary……5

Experimental Apparatus and Operating Data……6

Results and Discussion…….……..7

Conclusion…….…...……45

References…….…….46

Bibliography…….. ..46

List of Acronyms and Abbreviations…….…… ..46

Appendices…….……..47

Article I. List of Graphical Materials

None

Introduction

Over the years various drilling, completion, and production methodologies have been applied to the Knox Formation, specifically the Rose Run Sandstone and the Beekmantown Dolomite, resulting in various levels of production. The varying levels of success are due not only to the technology used to identify the prospects and the quality of reservoirs encountered, but also to the petroleum engineering principles applied to the completion and the production methodologies employed**.**

Completion and production technical issues include cased-hole versus open-hole completions, matrix acidizing versus fracture stimulation, perforation concentration and interval selection, fluid removal methods, paraffin treatments, operating wellhead pressures, gas sales line pressures, as well as general operating procedures. As in all plays, the combined influence of these factors and the reservoir quality ultimately determine the recoverable oil and natural gas reserves. Experience indicates that past and current completion and production practices employed have negatively impacted the ultimate recoveries of some Knox wells.

The study evaluated the critical factors associated with completion and production practices and the effect on the ultimate reserves predicted. The ultimate reserves of a study group of wells were estimated through volumetric analysis based on open-hole log analysis and production decline curve analysis. A lack of vital pressure data and actual daily and monthly production data precluded the use of P/Z and RPI analysis.

This final technical report reviews the results of the study. Deliverables of the study include a companion CD which contains a searchable Microsoft Access database, a detailed analysis of a study group of wells, geologic analysis of the study group of wells, an Ohio production data database, production decline curves for 1,500 Ohio Knox wells, and an application guide to assist operators in the drilling, completing, and operating of Knox wells.

Executive Summary

Over the years various drilling, completion, and production methodologies have been applied to the Knox Formation, specifically the Rose Run Sandstone and the Beekmantown Dolomite, resulting in various levels of production. The varying levels of success are due not only to the technology used to identify the prospects and the quality of reservoirs encountered, but also to the petroleum engineering principles applied to the completion and the production methodologies employed**.**

Completion and production technical issues include cased-hole versus open-hole completions, matrix acidizing versus fracture stimulation, perforation concentration and interval selection, fluid removal methods, paraffin treatments, operating wellhead pressures, gas sales line pressures, as well as general operating procedures. As in all plays, the combined influence of these factors and the reservoir quality ultimately determine the recoverable oil and natural gas reserves. Experience indicates that past and current completion and production practices employed have negatively impacted the ultimate recoveries of some Knox wells.

This final technical report reviews the results of the study, highlights specific results identified in previous quarterly reports, and provides a database and application guide for assisting in the drilling, completing, and producing Knox wells. Fifty-two papers and articles were identified as pertinent to the research related to the Knox formation or equivalent. The papers and articles identified to date were a result of searching the Society of Petroleum Engineers website, the American Association of Petroleum Geologists, the Ohio and Kentucky Geologic Surveys, the Internet, Penn Well Books, and the South West Petroleum Short Course CD paper database.

Datasets were created in a Microsoft Access Database for wells from each of the study states including Kentucky, New York, Ohio, Pennsylvania, and Tennessee. Datasets available from each state were inconsistent to their content and were modified for ease of data access. Individual well completion reports were reviewed and information added to each dataset regarding completion, stimulation, and production results.

While no clear relationship was identified between completion method, stimulation method and EUR, the results of the study did indicate the critical importance of geologic and geophysical analysis for proper site selection. The application guide provides steps for operators to follow to allow them a "check list" method for ensuring that critical steps are not overlooked. The guide is designed as a basis for operators to build upon and refine to make it more applicable to their specific area. Deliverables of the study include a searchable Microsoft Access database, a detailed analysis of a study group of wells, a production data database, production decline curves for ~1,500 Ohio Knox wells, and an application guide to assist operators in the drilling, completing, and operating of Knox wells.

It was noted that operators are hesitant to share "company secrets" regarding their successful methods for developing Knox wells. Future research should include continued analysis of Knox well completion methods and their relationship to EUR.

Experimental Apparatus and Operating Data

No experimental methods, materials, or equipment were used in this research.

Results and Discussion

This final technical report discusses the results of the study by summarizing the results of the specific steps of the study. The steps to the study included: Perform a Literature Search of All Information on the Knox Formation; Compile a Database of All Knox Formation Wells; Identify a Study Group of Wells; Complete a Completion and Production Practices Analysis; Perform Volumetric, Material Balance, and P/Z analysis; Complete Traditional Decline Trend Analysis Utilizing Aries (James Engineering); Complete Decline Trend Analysis Utilizing RPI Analysis (BJ Services); Summarize the Volumetric, Material Balance, P/Z, Decline Trend, and RPI Results; Analyze Reserves As a Function of Completion and Production Practices; Prepare an Application Guide; and Transfer the Technology.

Perform a Literature Search of All Information on the Knox Formation

As per the original proposal:
"Complete a literature search of all publications, studies, and information related to the Knox Formation in Kentucky, New York, Ohio, Pennsylvania, and Tennessee. Consult with geologists, geophysicists, operators, and engineers familiar with the Knox Formation or its equivalent."

Data Reduction and Methodology
Fifty-two papers and articles listed in Appendix 1 were identified as pertinent to the research related to the Knox formation. The papers and articles identified were a result of searching the Society of Petroleum Engineers website, the American Association of Petroleum Geologists, the Ohio Geologic Survey, the Kentucky Geologic Survey, the Internet, Penn Well Books, and the South West Petroleum Short Course CD paper database. The information researched addresses the geology, stimulation, or production analysis of the Knox formation.

Four references were of noted benefit: A book available from Penn Well entitled "Production Enhancement with Acid Stimulation", "Measuring and Predicting Heterogeneity in Complex Deposystems: The Late Cambrian Rose Run Sandstone of Eastern Ohio and Western Pennsylvania" available from the Pittsburgh Geological Society (PO Box 58172, Pittsburgh PA 15209) , " The Atlas of Major Appalachian Gas Plays (also available from the Pittsburgh Geological Society), and "Stimulation Treatment Handbook- An Engineers Guide to Quality Control" by John W. Ely.

The book entitled "Production Enhancement with Acid Stimulation" notes the following, **"**In terms of potential return on investment and generation of immediate productivity enhancement and cash flow, at a reasonable price, acidizing has no equal.", and "acidizing is not an exact, predictable science." The book discusses the history of acidizing, acid treatment categories, formation damage, sandstone acidizing, six steps to successful sandstone acidizing, carbonate acidizing, carbonate matrix acidizing, carbonate fracture acidizing, quality control, safety, and provides example procedures for various acid treatments.

Information was also provided by the Rose Run Consortium, however, there was no accompanying report text. The data provided is not included in the Appendix since it was agreed to be held confidential.

Mr. Artie Janssens, a consulting geologist from Granville, Ohio, prepared a paper for the 1992 Ohio Oil and Gas Association meeting entitled "Oil and Gas from Rose Run sandstone and Beekmantown dolomite in Ohio". In the paper, Mr. Janssens provides an historical prospective that is appropriate for this report.

Mr. Janssens writes; "The first of these (events) occurred in 1965 when Kin-Ark drilled its No. 1 Reuben Erb in Holmes County, Clark Township, as the discovery well. A limited number of unsuccessful wells were drilled subsequently in the vicinity of the No. 1 Erb and exploration efforts slowed down until the second event took place in the mid-1970's when Howard Atha (Worthington Oil), the pioneer of deep exploration in Coshocton county, drilled his No. 2 Adams in Coshocton County, White Eyes Township as the Beekmantown discovery well in east-central Ohio. Still in Holmes Coshocton area, the third key event occurred when H&S Operating in late 1986 drilled its No. 6 Smith in Holmes County, Clark Township. The success of this Rose Run (sandstone) well, said to have been a non-seismic prospect, pointed to the drilling boom in Holmes county that is reflected in the accompanying tables. Elsewhere in eastern Ohio, the successful drilling of the Park Ohio Industries No. 3 Rhoa in Ashtabula County, New Lyme Township in 1982 marked a key event for future drilling of Rose Run wells in northeastern Ohio. It was followed in 1985 by the successful drilling of the Lomak Petroleum No. 1 Hess Whiting in Geauga County, Burton Township. The drilling of two widely scattered rank wildcat Rose Run wells in more southern Ohio may yet be regarded as key events. Gas Corporation of America drilled its No. 1 Danford in Noble County, Noble Township in 1972 and Kentucky Drilling & Operating probably successfully drilled its Bigham-Strait in Perry County, Reading Township in 1973."

The importance of the literature searches is that it enables operators to benefit from work others have already completed and to build upon it. While the individual papers identified each have some value, readers are referred to the three texts previously mentioned. Finally, the importance of Mr. Janssens' historical perspective statements indicate that singular wells can often trigger significant development in previously undeveloped areas.

Compile database of all Knox Formation wells

As per the original proposal:
"Create a database of all Knox Formation wells based upon information available from the respective oil and gas and geology sections in the states of Kentucky, New York, Ohio, Pennsylvania, and Tennessee Information in the database would include well identification, operator, location, spud and completion dates, casing and cementing, completion (perforating, acidizing, and fracturing), pressure, and production (oil, gas, and water. A statistical analysis would be completed of the casing and cementing and completion practices. Further, annual production data through 2004 would be utilized for calculating cumulative production to date and decline trend analysis."

The development of a Microsoft Access database based upon information obtained from the oil or gas or geological divisions for the states of Kentucky, New York, Ohio, Pennsylvania, and Tennessee was one highlight of the project. The database is provided to the consortium as a part of the final work product.

The initial databases from the individual states contained the following information:

KENTUCKY: permit, operator, well number, farm name, well name, county code, county, state, topographic map name, elevation, section, total depth, target formation, result, deepest pay, td date, latitude and longitude.

NEW YORK: API number, identification number, lease, well number, operator, county, township, quadrangle, field, deepest formation, producing formation, elevation, actual total depth, proposed total depth, approval date, spud date, completion date, plug date, well type, status, latitude and longitude, and the availability of raster, logs, production, formation tops and paper files.

OHIO: API number, status, td date, completion date, plug and abandonment date, comments, P&A date II, Status II, scan image number, current operator, original operator, well name, driller number, lease unit, operator well number, state, county code, county, township, date status, date permit, date permit expires, date spud, date completion report, date last completion, date first production, measured depth, loggers total depth, true vertical depth, plug back measured depth, plug back true vertical depth, ip natural gas, ip natural oil, ip natural brine, ip after treatment oil, ip after treatment gas, ip after treatment brine, initial shut in pressure, acres, formation object code, formation object name, rule authority, category, and rig type.

PENNSYLVANIA: permit number, field name, operator, well id, well name and number, farm name, farm number, county code, county, state, elevation, total depth, total depth formation, quad, well type, completion date, municipality, pool, project number, map number, latitude, and longitude.

TENNESSEE: API Number, state, county, permit, permit date, total depth date, spud date, plug date, total depth, operator, well name, section, township, range, feet east/west and north/south, quad number, quad name, field type, elevation reference, elevation, proposed total depth, proposed formation, logger total depth, total depth formation, result,

gas test, ip gas, oil test, ip oil, pressure 1, pressure type 1, pressure 2, pressure type 2, choke, log low, log high, log type 1-15, sample record date, sample study, sample type, latitude, and longitude,

Challenges regarding the various state databases included: varying datasets, incomplete datasets, inaccurate datasets as compared to completion reports, and varying dataset formats. It was further noted that most operators vary rarely share sufficient completion data in the required completion reports to fully understand their methodology.

Knox well completion reports were reviewed for Kentucky, New York, Ohio, Pennsylvania, and to some extent Tennessee. The completion reports were reviewed based upon what was available on line, on state databases, or to a much lesser extent what was specifically requested. The data was either in summaries provided by queries provided by the state or in canned images. It is recognized that in some cases re-completions may not have been picked up during the review or may not have been included in the scanned dataset.

Examples of completion report with "under reported information" include:

- Listing of the gross perforation interval which may cover more than just one perforated interval.

- Providing the total acid volume but not listing type of acid, or the associated treatment pressures and rates.

- Providing total sand and total fluid but not reporting treatment pressures (breakdown, average treating, initial shut in, or 5 minute shut in).

- Providing the production string cement volume of total sacks or cubic feet, but not providing the type of cement. Further, the fill-up provided may or may not be the actual top of cement nor reflect the quality of cement job achieved.

- Possibly not reporting successive acid stimulations, but just reporting as a total acid treatment volume.

It is also generally understood that the IP's listed, whether before or after treatment, were of limited comparative value due to the inconsistent manner in which IP's are gathered and or reported. It was also noted that produced water volumes were also assumed to include treatment water economical and/or sufficient. One method used by some operators is to isolate specific lower zones by setting bridge plugs and attempting to produce treated zones above. Experience indicates that often the lower Knox zones are often the culprit should excessive water volumes be problematic.

Specific testing of isolated intervals by operators was generally not identified in the completion reports, although experience indicates that many operators "test" several intervals collectively and then see if the results are acceptable.

It should be noted that some operators provided very complete information on the completion reports although most would provide only a modicum of data sufficient to meet state reporting obligations.

The final database as presented on the companion CD included the following columns, although not all data is available for all states: API Number, Well Name, State, County, Township, Producing Formation, Original Operator, Current Operator, Comments, Status, RRCD, Stimulation Type, Stimulation Comment, Date Spud, Date TD, Date Completion, Date of First Production, Date P&A, Completion Type, Production Casing Cement Volume (sacks), Type Acid, Acid Volume (gallons), Water Volume (barrels), Sand Volume (sacks), Breakdown Pressure, Treatment Rate (bpm), Treatment Pressure (PSI), Initial Shut In Pressure (PSI), Producing Formation Top, Producing Formation Bottom, Perforation Top, Perforation Bottom, Number of Perforation Holes, Number of Perforation Intervals, Perforation Size, Logs Run, Logging Company, Measured Depth, Logging Total Depth, Initial Production Natural Oil (bbls), Initial Production Natural Gas (mcf), Initial Production Brine (bbls), Initial Shut In Pressure (PSI), Cumulative Oil (bbls), Cumulative Gas (mcf), Cumulative Brine (bbls), Cumulative Mcfeq, EUR Oil (bbls), EUR Gas (Mcf), EUR Brine (bbls), EUR Mcfeq, Longitude, and Latitude

Table I provides a brief summary of the wells in the database by well status. Additional detail is provided for each state below.

Table I - Summary of Total Knox Wells by State by Status

State	Total Wells	Dry Holes	Oil/Gas	Other
Kentucky	6,856	4,377	2,318	161
New York*	933	382	459	92
Ohio	4,794	2,316	1,582	987
Pennsylvania	95	51	12	32
Tennessee	2,765	1,501	693	571
Total	**15,443**	**8,627**	**5,064**	**1,843**

* includes all wells that penetrated the Knox

The following presents a detailed review by state of the data review, geographic location, geology, drilling, completion, production, and conclusions for each state in the study.

Kentucky

Data Review

The Kentucky Geological Survey identified 6,856 wells that had targeted the Knox or its equivalent. A database of some information as listed above was provided by the state. Over 3,000 completion reports from the state's scanned completion report database were printed and reviewed. The additional information was added to the original database information provided.

Based upon the information, 2,318 wells were reported as gas, oil, or oil and gas, while 1,665 of the reports were classified as "Knox producing". The remaining 4,377 wells were classified as "dry and abandoned" or had insufficient information. The success ratio indicates only a 30-40% success rate for the top four counties as presented in Table II, Knox Well Summary by County by Well Status.

The completion report review indicated that most operators tend to provide as little information as required. Due to the nominal data identified in the 3,000 completion reports reviewed, which included the Knox producing wells, the remainder of the completion reports (dry and abandoned) were not printed for review.

Geographic Location

Of the seventy-six counties identified that had wells that penetrated the Knox, 95% of the wells were in ten counties located in the south central part of Kentucky. Table II.

Table II - Summary of Knox Wells by County by Well Status

County	D&A	O&G	% Success*	Other	Total Wells	% of Total
Cumberland	1,332	627	32%	9	1,968	29%
Clinton	1,023	681	40%	11	1,715	25%
Adair	872	549	39%	21	1,442	21%
Russell	390	126	24%	0	516	8%
Monroe	148	35	19%	39	222	3%
Green	83	93	53%	3	179	3%
Casey	103	59	36%	0	162	2%
Metcalfe	91	19	17%	5	115	2%
Wayne	76	19	20%	0	95	1%
Clay	19	63	77%	0	82	1%

represents the "Oil and Gas" wells as a percentage of the "Total Wells" less the "Other" wells.

Geology

The Knox dolomite ranges from run from approximately 1,800-2,000', with a total thickness from twenty to thirty feet. Due to the relatively shallow depth, experience indicates that site identification using is not a tool generally employed for the identification of potential sites. Site selection would generally be high graded with geologic analysis or offset well analysis.

Drilling
Completion reports for these generally shallow wells, less than 2000', indicated that in many cases only one string of surface casing was set (to protect the surface waters) with completions made open hole. Similarly, a number of wells did not have open hole logs reported. Due to the shallow depth, it is suspected that site selection is limited to exploratory drilling, offset well, or trend drilling.

Completion
The completion reports review provided little insight into the volumes or types of acid used, or the associated treating pressures and rates. However, several observations were made during the completion report review. The majority of the Knox wells were reported to be completed Natural, that is, no stimulation. Although not confirmed, the natural productivity and method of drilling (on air) generally denote the quality of the well drilled. The remainder of the wells completed were generally acidized, with a very limited number of sand fractured wells. Acidizing information generally provided the volume but rarely specified the type of acid used. Similarly, for those that were fractured little information was provided, with data limited to the volume of sand and fluid. No treatment pressure data was available

Specifically, of the 2,104 wells with sufficient completion information, 2,023 wells were reported as being completed Open Hole, while only 81 wells were completed Through Casing (perforated). There were 1,817 wells noted as completed Natural (no acid or fracture treatment reported), while 306 completed with acid. Of the 306 wells completed with acid, 22 wells (7%) greater than 4000 gallons, 69 wells (23%) 2,000-3,900 gallons, 70 wells (23%) 1,001-1,999 gallons, 134 wells (43%) 500-1000 gallons, and 9 wells (3%) with less than 500 gallons. Two wells were reported as being shot with nitroglycerine.

A number of the wells had only surface and intermediate casing set, with completion made open hole either through a string of tubing or casing, often set on an open hole packer. The tubing can then be used to swab or pump through once the well is no longer able to flow naturally.

Only eleven wells were noted as being fracture stimulated with sand with average sand volumes ~ 300 sx.

Open hole logs run by companies were generally limited to Gamma Ray, Caliper, and Density, with some operators also running a Neutron and Temperature log. Many of wells were noted as having no open hole logs run.

Production
Very limited production data was available for the Kentucky wells since production reporting has only been required since 1997. Therefore, limited data was unavailable for analysis for wells drilled from 1997 forward. Some cumulative production volumes were included with the database, but no decline curve nor EUR analysis was completed.

No specific information was provided regarding the production practices for Kentucky Knox wells, however, experience indicates that swabbing or pumping would generally be required for effective fluid removal and EUR optimization.

Conclusion

The study results indicate that Kentucky Knox operators appear to be very efficient at minimizing overall well cost for drilling and completion. Most of the Knox wells were generally less than 2000', with a limited open hole logging suite, and were completed open hole using no stimulation. While seismic identification of the target reservoir is not a viable option, geologic and production analysis as well as a consistent methodology for drilling, completing, and producing should assist operators in optimizing production and associated ultimate reserves.

New York

Data Review
The New York Geological Survey identified 933 wells that had penetrated the Knox or its equivalent, the Theresa. However, of the 933 wells reviewed, 459 wells were identified as productive (including confidential wells) fifteen wells were identified as productive from the Knox equivalent, the Theresa Sandstone.

Codes for New York wells included Brine (BR), Dry hole (DH), Diposal (DS), Dry Wildcat (DW), Gas Development (GD), Gas Extension (GE), Gas Wildcat (GW), Gas Injection (IG), Enhance Oil Recovery (IW)

Geographic Location
Of the productive wells, counties included Cattaraugus (3), Chautauqua (), Erie(), Madison (), and Wyoming(), which are all located in the western corner of the state.

Geology
The Knox equivalent of the Rose Run in New York is referred to as the Theresa Sandstone. The general formation order for wells in New York is as follows:

Formation Order
Onondaga (Limestone)
Oriskany (Sandstone)
Helderberg (Sandstone)
Salina (Salt)
Lockport (Dolomite)
Clinton (Grimsby)
Medina (Sandstone)
Queenston (Sandstone)
Trenton (Limestone)
Black River (Limestone)
Tribes Hill (Dolomite)l
Little Falls (Dolomite)
Theresa (Sandstone)
Potsdam (Dolomite)

Due to the depth of the Theresa, often greater than 5000', it is presumed that potential targets are identified with geophysical as well as geologic mapping support.

Drilling
Completion reports for these generally deep wells (5000'-6000') indicate that most completions are made through casing, or cased hole. The completion reports indicated that many of the wells are generally drilled in on air.

According to permit applications, steps to drill to total depth would generally include the following steps:

- Drive 16” 65# H40 conductor to 65’
- Drill 14 ¾” hole to 250’ with mud
- Set 11 ¾” 42# H40 surface casing and cement to surface with 60% excess
- Wait on cement for seven hours
- Pressure test 11 ¾”casing to 1000 psi
- Drill 10 5/8” hole to 850’ with air
- Set 8 5/8” 24# J55 intermediate casing and cement to surface with 60% excess
- Wait on cement seven hours
- Install casing head, blow out preventer, and choke manifold
- Test casing head, blow out preventer, choke manifold, and 8 5/8” to 1500 psi.
- Drill 7 7/8” hole to Total Depth on air
- Logging suite: Caliper, Gamma ray, Neutron, Density, Resistivity, Dual Laterolog, Compensated Neutron, Litho Density

The completion reports indicate that natural shows appeared to be common in the Theresa, and that mud loggers were not always used to identify specific shows.

Additional state requirements include the following conditions for Theresa wells:

- All pits must be lined and all fluids disposed of properly.
- Wells must be equipped with BOP good to 1000 psi.
- Lithology and porosity logs must be run from surface to TD.
- NY casing and cementing requirements must be followed.
- Drillers must be registered with the NY DEC.
- Wildcat wells are subject to additional special conditions.

Completion

A review of the completion reports indicated the following:

- Production string: 4 ½” , E-75, 11.6 #/foot.
- Casing centralizers: Set from 2,000’ – 5,000’, every 200’
- Cement baskets: As needed 2,000’ – 5,000’
- Production string cement: 555 sx 12.5 ppg 1021 cu ft Unifill Light and 150 sx 75/25 Pozmix +10% salt + 6% gypsum (14.9 ppg and 204 cu ft) (minimum 10% excess)

The completion reports indicated that most operators verified cement quality (bond) and top of cement utilizing a cement bond log. Completion reports indicate wells are completed cased hole, with the exception of a few early wells.

Perforations were generally limited to one interval with the number of perforations ranging from 27 to 76. Wells were generally initially stimulated with 250 gallons of acid (15% HCL) with perforation balls to ensure that all perforations were open. The wells were then later fracture stimulated with sand. Most wells were fracture stimulated with approximately 300 sacks of 20/40 sand with an associated 200 to 300 scf per barrel of nitrogen. Power Gas Corporation completed a number of the early wells, with some wells fraced with 600 sacks of sand (60,000 #).

It was noted that operators were allowed to have a six-month initial confidentiality period, upon request, with the confidentiality period extended up to a maximum of two years total.

Production

Table III, New York Theresa Production Summary by Well by County, presents the twenty one wells, operator, completion date, and their associated available cumulative production. No oil production was reported for the Theresa wells with only one well having significant brine production. Public access to reported production data is on an annual basis from 1989 - 2005. Based on the cumulative production volumes, only six wells have production to date over 100,000 mcf. Insufficient production data was available for significant production decline curve analysis for EUR determination, although annual volumes are provided for each well on the companion CD. One well was noted as having been completed in 1963, although the production history or cumulative volume was unavailable.

No specific information was available regarding the production practices for the Theresa. However, experience indicates that operators for this depth of well would benefit through the use of tubing and tubing plunger to assist with fluid removal. The tubing would also enable operators to easily identify fluid build up, and pressures for production for optimization.

Table III: New York Theresa Well Production Summary by Well by County

API Number	County	Operator	Lease	Comp Date	Prod YRS	Cum. MCF*
3100921809	CATTARAUGUS	HEBDON CHARLES	HEBDON 1	01/20/1990	0	0
3100923534	CATTARAUGUS	STEDMAN ENERGY	BIXBY HILL 1	01/21/2004	2	32,281
3100923545	CATTARAUGUS	STEDMAN ENERGY	CAGWIN 1	10/29/2004	1	196
3101322616	CHAUTAUQUA	NY GAS & OIL CO.	CROWE 3	05/08/1996	3	6,744
3102923533	ERIE	ARDENT RESOURCES	BOCKHAHN Wm 1	01/05/2004	2	166,365
3102923551	ERIE	ARDENT RESOURCES	BOCKHAHN G 1	06/03/2004	2	100,505
3102923599	ERIE	ARDENT RESOURCES	DEGOLIER 1	03/16/2005	1	225,103
3105323098	MADISON	ARDENT RESOURCES	MEEKER 1	06/03/2004	0	0
3110121601	STEUBEN	SEMGAS STORAGE	MITCHELL 2	07/29/1996	0	0
3112104436	WYOMING	TRANSAMERICAN PET	WELLMAN L 1	09/30/1963	?	Unknown
3112121840	WYOMING	MILLER GAS CORP.	HOWES A 1	06/24/1990	1	8
3112121900	WYOMING	MILLER GAS CORP.	LEATON G 1	02/08/1991	0	0
3112121908	WYOMING	MILLER GAS CORP.	HOWES A 3	12/03/1990	2	29,652
3112121909	WYOMING	MILLER GAS CORP.	HOWES A 2	02/07/1991	3	10,405
3112121920	WYOMING	MILLER GAS CORP.	TITUS BROTHERS 1	12/07/1990	3	227,382
3112121945	WYOMING	MILLER GAS CORP.	HOWES A 4	02/06/1991	1	1,617
3112121946	WYOMING	MILLER GAS CORP.	CHAMBERLAIN B 1	12/07/1990	2	21,228
3112121964	WYOMING	GFS ENERGY INC.	JOHANNES E 1	12/12/1991	2	117
3112122042	WYOMING	MILLER GAS CORP.	TITUS BROTHERS 4	08/29/1991	3	125,458
3112122046	WYOMING	MILLER GAS CORP.	TITUS BROTHERS 3	07/22/1991	3	12,174
3112122520	WYOMING	GREAT LAKES EP	MATUSIK J 1	12/08/1994	11	104,323

Cumulative production for all New York Theresa wells is currently 1,063,558 mcf.

Conclusion

While a number of well have tested for the New York Knox Theresa, only a limited number of wells to date have been able to develop commercial production volumes. The sandstone play does appear to permit fracture stimulation with sand through casing similar to the Rose Run sandstone of Northern Ohio. Additional well development will assist operators in better defining the play and associated critical factors.

NY operators may benefit by reviewing the completion data associated with Rose Run wells for a comparison of reservoir properties and potential well enhancement. Operators will benefit through the implementation of a methodical approach to the drilling, completion, and production.

Theresa completions, in general, should lend themselves to traditional quantitative post completion analysis such as material balance and production decline curve for comparison to volumetric analysis.

Operators are advised that gathering and recording early time pressure, rate, and volume information is critical to problem analysis later in the life of the well.

Ohio

Data Review

Research identified 4,794 wells that had penetrated the Knox formation. Of the 4,794 wells, 1,582 wells were productive in the Knox, 2,316 were dry or dry and re-completed up hole, 781 wells were excluded from the study, and 106 had incomplete records.

Of the dry wells, 1269 were Dry and abandoned, 360 were dry and abandoned after stimulation, 53 were dry after stimulation and plugged back, and 634 were dry and plugged back 634.

Geographic Location

Knox wells are located across 65 counties with eighty percent of the wells being in twelve counties, Coshocton (600), Morrow (574), Wayne (504), Muskingum (455), Holmes (391), Tuscarawas (240), Portage (227), Licking (197), Fairfield (172), Ashtabula (165), Stark (154), Pickaway (141), and Hocking (140).

Geology

The Ohio Knox includes the Trempeleau, Knox, Beekmantown, and Rose Run. However, only the Knox, Beekmantown, and Rose Run were the focus of this study.

Experience indicates that site selection for most operators in Ohio generally require seismic data to identify specific targets. Experience indicates that many operators drilled wells without seismic data knowing that there was a back out, or up hole opportunity. For those operators, it was generally a Rose Run or Beekmantown test with a Clinton Sandstone back out if it was unproductive in the Rose Run or Beekmantown.

Drilling

Drilling is generally completed on air, with many operators switching to fluid for drilling to TD if a significant show is identified. Mudloggers are often used on the hole to better define gas and oil shows, drilling breaks, and formation identification. Operators generally prepare prognosis prior to drilling which contains pertinent data such as anticipated tops, casing and cementing programs, and emergency contact numbers.

Completion

Of the 4,794 wells drilled, 600 were completed open hole, and 1,928 were completed cased hole, 277 were unknown, and 1,989 were drilled dry and not stimulated. A summary excel table for the Ohio wells is included on the companion CD.

Open hole completions appear to have been utilized in thirty counties, although 80% of the 600 have occurred in Coshocton (15%), Muskingum (14%), Wayne (10%), Holmes (10%) Perry (10%), Morrow(10%), Pickaway(7%), and Tuscarawas (4%). Most operators now use cased hole completions unless hole conditions demand otherwise.

Of the 4,794 wells that were completed, 1,822 were acidized, 309 were fracture stimulated, 361 were completed natural, 3 were shot stimulated, 309 were unknown, and 1,990 were not completed.

Of the 309 wells that were fracture stimulated, eighteen wells were acid fraced, 31 foam fraced with CO2 or Nitrogen, 254 sand fraced, and 7 water fraced. Most of the wells that were fracture stimulated were completed in the Rose Run Sandstone. The wells were located in twenty-one counties, with eighty percent of the wells located in four counties; Portage (50%) Stark (11%), Coshocton (11%), and Wayne (9%). Sand volumes varied from 10 sx to 1000 sx, with treatment volumes varying from 100 to 2900 barrels. The foam fraced wells utilized either Nitrogen or Carbon Dioxide.

EUR's for wells that were fraced varied from plugged or plugged back after stimulation to wells with greater than 800,000 mcfeq.

Treating pressure and rate information was generally not available. Acidizing information was limited to the volume but rarely specified the type of acid used. Similarly, for those that were fractured little information was provided, with data limited to the volume of fluid. No pressure data or proppant was available for most reports reviewed.

Production

Extensive production data was available for decline curve analysis. Over 1,500 wells were reviewed and the cumulative production and the remaining reserves and associated estimated ultimate recoverables (EUR) determined. The cumulative production and EURS for each well evaluated were provided in the database. Production decline curves were also included on the cd for each well analyzed.

For the 1,531 wells that were completed and produced, EUR's ranged from 24 mcfeq to 3.95 BCF. The distribution indicated that 622 wells (41%) had EUR's less than 100 mmcfeq, 374 wells (25%) had EUR's in between 100 and 250 mmcfeq, 281 wells (18%) between 250 -500 mmcfeq, 180 wells (12%) between 500 and 1,000 mmcfe, and 74 wells (5%) greater than 1000 mmcfeq. Table IV below presents a summary by EUR distribution by county.

For the 1,000 wells that were acidized, the EUR's ranged from 192 mcf to 3.95 BCF. The distribution indicated that 410 wells (41%) had EUR's less than 100 mmcfeq, 235 wells (24%) had EUR's in between 100 and 250 mmcfeq, 168 wells (17%) between 250 -500 mmcfeq, 126 wells (13%) between 500 and 1,000 mmcfe, and 61 wells (6%) greater than 1000 mmcfeq.

For the 227 wells that were fraced (177 in Portage in Stark Counties), the EUR's ranged from 24 mcf to 1.05 BCF. The distribution indicated that 106 wells (47%) had EUR's less than 100 mmcfeq, 61 wells (27%) had EUR's in between 100 and 250 mmcfeq, 42 wells (19%) between 250 -500 mmcfeq, 15 wells (7%) between 500 and 1,000 mmcfe, and 3 wells (1%) greater than 1000 mmcfeq. The overwhelming majority of these wells were Rose Run wells.

The remainder of the wells were natural or shot stimulated. No summaries are provided.

Table IV – Summary of EUR Distribution, MMCFEQ, by County						
County	<100	100-250	250-500	500-1000	>1000	Total
ASHTABULA	23	27	12	9	0	**71**
CARROLL	1	0	0	0	0	**1**
COLUMBIANA	1	0	2	0	0	**3**
COSHOCTON	116	64	41	24	10	**255**
FAIRFIELD	30	17	13	10	6	**76**
FRANKLIN	1	0	0	0	0	**1**
GEAUGA	1	0	0	0	0	**1**
GUERNSEY	10	5	6	4	1	**26**
HOCKING	28	22	10	8	3	**71**
HOLMES	46	34	55	44	16	**195**
HURON	0	0	0	1	0	**1**
KNOX	7	0	0	0	0	**7**
LICKING	37	26	5	3	5	**76**
MORROW	2	0	0	0	0	**2**
MUSKINGUM	117	51	38	29	10	**245**
NOBLE	3	0	2	1	0	**6**
PERRY	29	16	11	10	2	**68**
PICKAWAY	25	9	3	3	1	**41**
PORTAGE	62	48	40	13	4	**167**
ROSS	4	1	0	0	0	**5**
STARK	30	22	13	13	10	**88**
TRUMBULL	2	0	0	0	0	**2**
TUSCARAWAS	31	20	22	7	3	**83**
VINTON	3	0	0	0	0	**3**
WASHINGTON	1	0	0	0	0	**1**
WAYNE	12	12	8	1	3	**36**
Grand Total	**622**	**374**	**281**	**180**	**74**	**1,531**

Decline curves with historic production are provided on the companion CD for greater than 1,500 Ohio Knox wells. Decline curve analysis noted the following:

- All water (assumed completion fluid) and oil produced within year 1
- Multi zone completions complicate the analysis
- Many wells exhibited significant production decline from year 1 to year 2
- Many wells obviously rate restricted
- Water production for some wells does not begin initially
- General "b" factor 0.3 to 0.5

Conclusion

The Ohio Knox review identifies that operators have been progressive in heir approach to stimulations. Operators have successfully stimulated the Rose Run Sandstone with encouraging results. Still in certain areas, operators tend to stimulate the Rose Run with only acid initially and resorting to more aggressive stimulation only when necessary. The Beekmantown dolomite is generally acidized, and then re-acidized with larger volumes and higher rates when lower stimulation volumes are unsuccessful results.

Pennsylvania

Data Review

Research identified 95 wells that had penetrated the Knox formation. Of the 95 wells, 11 were productive in the Knox (12%), 45 were dry (47%), and 33 were completed in the Medina, Trenton, or Oriskany.

Geographic Location

Most of the activity and associated productive Knox wells were located in Northwestern Pennsylvania with 72% occurring in 4 counties. Table V presents the total wells by type by county.

Table V: Pennsylvania Summary by County				
County	**Dry**	**Productive**	**Other**	**Total Wells**
Armstrong	0	0	1(Huntersville)	1
Bedford	9	0	0	9(9.5%)
Bradford	1	0	1(TBR)	2
Butler	1	0	0	1
Clinton	1	1(Bald Eagle)	0	2
Crawford	12	9(Knox)	16(Medina)	37(38.9%)
Erie	8	0	7(Medina)	15(15.7%)
Franklin	1	0	0	1
Juniata	1	0	0	1
Lycoming	1	0	0	1
McKean	2	1(Gatesburg)	0	3
Mercer	2	0	5(Medina)	7(7.4%)
Mifflin	1	0	0	1
Northumberland	1	0	0	1
Pike	1	0	0	1
Potter	0	0	1(Oriskany)	1
Somerset	1	0	0	1
Sullivan	1	0	0	1
Tioga	1	0	1(TBR)	2
Union	1	0	0	1
Warren	2	1(BK)	0	3
Washington	1	0	0	1
York	2	0	0	2
Total	**51**	**12**	**32**	**95**

Geology

The Pennsylvania Knox is present as the Loyola, Beekmantown, and Gatesburg. Depending on the specific geographic area, the total depth can vary from 6000' to 6100'. Site selection for most operators generally require seismic data to identify specific targets.

Similar to Ohio, operators in certain areas had up hole opportunity in the shallower Medina Sandstone when the Knox was unproductive.

From the Measuring and Predicting Reservoir Heterogeneity
"Western Crawford County has been the primary site of Rose Run Exploration in Pennsylvania", two wells had significant natural gas and gas condensate production before water invasion of the reservoir caused them to be plugged and abandoned."

Drilling
Of the 95 wells, all wells were completed through casing.

Completion
The limited completion reports provided relatively little specific information.

Production
Limited production data was available for the few productive wells. Pennsylvania has a five-year "silent period" whereby production is not released until five years after the production year. Kastle Resources has been the most successful operator in this play.

Conclusion
Due to the limited number of wells and the limited data available, no significant conclusions can be drawn from the results of the data review. All wells were completed cased hole. Initial indications appear that additional Knox well development will continue in the Northwestern corner of Pennsylvania.

Tennessee

Data Review

A database of well information was purchased from the state of Tennessee. Very limited production data was available electronically, with the state indicating that less than one year had been entered. Production data would have had to been researched through paper records and therefore not completed. Completion data was also not a part of the database and only available if copies were purchased. The data was important, but due to time and financial restraints, the additional data was not purchased for review and inclusion in the database.

Research identified 2,765 wells that had penetrated the Knox formation. Of the 2,587 wells, 693 were productive (21%), 1,501 were dry (56%), 571 were other.

Geographic Location

Wells that encountered the Knox, as provided by the Tennessee Geologic Survey were spread over sixty counties, however, eight counties, as identified in Table VI below, accounted for 80% (2,203) of the total wells.

Table VI - Tennessee Summary of Knox Activity by County (80%)

County	***D&A***	***O&G***	***Other***	***Total***
Overton	537	261	20	**818**
Pickett	308	187	7	**502**
Clay	230	53	14	**297**
Fentress	97	57	19	**173**
Maury	1	0	98	**99**
Williamson	1	0	68	**69**
Rutherford	14	0	51	**65**
Jackson	41	7	16	**64**
Davidson	2	0	57	**59**
Coffee	5	50	2	**57**
Total	**1,236**	**615**	**352**	**2,203**

Tennessee Well Code Status Key

Description	**Result**	**Description**	**Result**
Disposal	D	Dry And Abandoned	D&A
Gas	G	Monitor	M
NCG - Domestic Use Gas	NCG	Oil	O
Oil And Gas Well	O&G	Shut-in Gas Well	SIGW
Shut-in Oil Well	SIOW	Test	T
Unknown	UK	Water	W

Geology
A general review of the limited data provided indicates that most Knox wells have a td between 1000-2000'.

Geography
The wells were generally spread over sixty-six counties, with 80% of the wells located in ten counties. The counties include Overton (818 or 30%), Pickett (502 0r 18%), Clay (297 or 11%), Fentress (173 or 6%), Maury (99 or 4%), Williamson (69 or2%), Rutherford (65 or 2%), Jackson (64 or 2%), Davidson (59 or 2%), and Coffee (57 or 2%).

Drilling
The limited completion reports provided relatively little specific information.

Completion
The limited completion reports provided relatively little specific information.

Production
No production data was available for the state. Tennessee is in the process of putting together the historic data but indicated it would be sometime until that task was completed.

Conclusion
The limited completion reports provided little specific information regarding completion, stimulation, and the relationship to Tennessee Knox EUR's.

Identify a Study Group of Wells

As per the original proposal:
"The large group of wells identified in the database would be refined to a smaller group of approximately 100 wells to include only those for which significant data was available. Artex, Belden and Blake, and Great Lakes Energy Partners have agreed to provide actual monthly sales volumes and pressure data for specific volumetric, material balance, p/z, and RPI analysis. Two fields of particular interest to the study that are largely operated by Belden and Blake and Great Lakes would be the Brewster Field and the Portage Randolph Field due to the variety of stimulation methods employed."

When requested, operators provided no production or pressure data and often only limited production data. Therefore, the anticipated study area was modified to an area of significant Rose Run and Beekmantown development which would be representative of typical Ohio Knox development.

A group of 183 wells located in Coshocton (100), Holmes (67) and Tuscarawas (16) counties were identified. The determining factors in establishing the study group of wells included more complete production histories, variety of completion methodologies, completion intervals, and open hole log data availability.

Of the 183 wells, 129 wells were productive in the Knox (Rose Run/Beekmantown) and 53 wells were either dry and abandoned or plugged back to shallower productive reservoir. In most cases wells that were plugged back were completed in the Clinton Sandstone. Development of the 183 wells was from 1975 to 2004. The wells were classified as follows in Table VII below.

Table VII - Summary of Study Wells by County

	Producing	P&A
COSHOCTON	57	43
HOLMES	64	3
TUSCARAWAS	9	7
Total	130	53

Geologic Analysis of the Study Group of Wells

Open hole logs were reviewed and analyzed for 183 wells located in Coshocton(100), Holmes(67) and Tuscarawas(16) counties. The analysis included an estimate of net pay, porosity, and water saturation. Maps were then created utilizing Landmark Geographic software for Rose Run net pay, porosity, average porosity, EUR, water saturation, and Beekmantown thickness. All geologic maps referred to below are provided on the companion cd.

Note: Only wells with full, un-eroded sections of the main Rose Run Sand body (B, C & D sands) were used in calculations. A grain density of 2.71 g/cc was used to calculate density porosities. The 2.71 grain density is used because the Rose Run has mostly a dolomite cement or matrix. Sample observations, core results and empirical log data indicate that good grain density is around 2.70 to 2.71. The bulk density cut-off for 5% density porosity with a 2.71 grain density is 2.63 g/cc.

General Geology: The source area for the Rose Run Sandstone is to the northwest in the Michigan Basin. Sand was transported along northwest to southeast tidal channels toward the Appalachian Basin. The Rose Run is productive in remnants and along the subcrop, where it was been preserved against up-dip erosional cuts. Up-dip is to the northwest, with deeper erosion to the west and northwest.

Rose Run Net Sand (>5% density porosity): The highest net sand values run from northwest to southeast across the study area. This is coincident with a structural low or syncline which also trends from northwest to southeast. The areas with less net sand to the southwest and northeast are coincident with regional structural highs, which are related to basement structural highs. Tight areas within the main thick trend are normally local structural highs within the syncline.

Rose Run Porosity-Ft x 100: The porosity-ft x 100 map shows the same trends as the Rose Run Net Sand map, running northwest to southeast.

Rose Run Average Porosity (%): This map shows the same general trend as the two previous maps, Rose Run Net Sand and Rose Run Porosity, with one exception. The high porosity trend is skewed to the west side of the Net Sand and Porosity x 100 trends. This is an important observation because it shows the effect that erosion had on porosity. The higher average porosity is skewed toward the direction of the erosion, which indicates that porosity along the west side of the syncline was enhanced at the time of the Post-Knox Unconformity (PKUNC).

PKUNC EUR (MMCFE): Most of the production data is Rose Run except for the Bakersville Field in southeast corner of the map. Like the Porosity data, the Production (EUR) data is skewed to the west and northwest toward the erosional edge. The better production is up-dip and against western basement generated structural high. Notice that the production is not as good to the east where the sand is trapped against the basement generated structural high to the east.

Rose Run Water Saturation (%): The Water Saturation map is similar to the Average Porosity and EUR Maps in that it is skewed slightly to the west of the structural syncline. The best production is coincident with the lower water saturation area that runs through northeast Mechanic Twp, southwest Berlin Twp and southeast Hardy Twp. The higher water saturation in southwest Mechanic Twp is probably due more to Rose Run Sand becoming tighter along the northwest to southeast structural high rather than to actual higher water saturation due to higher producible water. In the very southeast corner in Adams Twp, the water saturations are high due to a lack of a trap at the Rose Run.
This is the Bakersville Field, which is productive from the Beekmantown "A".

Beekmantown Thickness: This map shows the erosional patterns in the study area. To have a full section of Rose Run means that you have to have at least 1 ft of Beekmantown Dolomite present. Areas with contours indicate areas with full sections of Rose Run and a Beekmantown cap on them. The areas with no contours are areas where erosion has cut down below the top of the Rose Run. Wells with good production that do not coincide with a Beekmantown cap are producing from just 1 or 2 sands. Some of these wells are excellent producers.

Study Group Geologic Study Conclusions

The geologic study indicates the importance of looking at broad geographic areas for reviewing the highly heterogeneous Knox Rose Run and Beekmantown formations. This type of analysis provides insight into the trends that occur regarding net pays, porosity, EURs, and water saturations. Looking at trends will provide better insight as to not only what range of EUR's but also whether certain areas are more prone to being wet, or un-productive.

Completion and Production Practices Analysis

As per the original proposal:
"For the smaller study group of wells, identify production method history, current production cycles, operating conditions, and flowing bottom hole pressure. The analysis of these parameters would contribute to the overall study."

Completion Practices Analysis for 183 wells located in Coshocton(100), Holmes(67) and Tuscarawas(16) counties are summarized in Table VIII below.

Table VIII - Summary of Study Group Completion Methods

COUNTY	ACIDIZED	FRACED	NATURAL	NONE	UNK	Grand Total
COSHOCTON	59	6	1	30	4	**100**
HOLMES	60	0	1	0	6	**67**
TUSCARAWAS	9	0	0	7	0	**16**
Grand Total	**128**	**6**	**2**	**37**	**10**	**183**

Of the 183 wells, 128 wells were acidized. All completions were made through casing, in the Rose Run. Acid volumes varied from 200 gallons (perforating acid) to 7000 gallons. The largest EUR well (2.0 BCF) was only stimulated with 200 gallons of acid. There appears to be no correlation between acid volume or completion method and EUR. Perforations varied from 3 holes in the top of the pay to 248 holes. Reported breakdown pressures (13 wells)varied from 1000 to 2500 psi. Treatment rates varied from 0.2 to 10 bpm. Treating pressures varied from gravity feed to 2150 psi.

For the six wells that were fraced (all cased hole), EUR's varied from 0 to 312 mmcfeq. Four wells were sand fraced (30 sx to 400 sx). Two wells were completed open hole with no stimulation (natural) and had EUR's of 500 and 700 mmcfeq. 500 to 3500 gallons of acid were also employed in the fracture stimulations. Breakdowns were from 1000 to 3200 psi. Perforations were from 7 to 20 holes.

Forty wells have brine EUR's of 1000 bbls or less, 29 1000-3000, 22 3000-10000, 14 10000-50000, and 3 greater than 50000 bbl projected.

For the wells that were acidized, 66 wells used 15 FE or 15 HCL, 3 wells used gelled acid, 2 used 7.5 HCL, 1 used 20 HCL, 1 used mud acid, 48 were unknown, and 7 were other or unidentified.

Statewide, 309 Knox wells have been fracture stimulated in over 16 counties, however, 80% are located in four counties; Portage (50%), Stark(12%) Coshocton (11%), and Wayne (9%). Sand Volumes varied from 10sx to 1000 sx with the average ~330 sx with a corresponding fluid volume of 1000 bbls. The overwhelming majority wells that have been fracture stimulated are Rose Run wells.

Pressure and Production Data

Throughout the course of the study, efforts were made to obtain monthly production histories, pressure data, and data associated with the production of various wells. The various operators associated with the study group of wells either did not want to provide the data, or could not provide the data.

Completion reports were often very silent to the intimate details of the actual completion. Beyond gross intervals, total perforations, total acid, total sand, many operators provided very little pressure and rate information.

Operators either produced their wells at restricted flow rates initially for larger wells, or more open if the rates were not a concern. Experience indicates that operators generally have tubing in the wells and operate the wells initially by flowing the wells, then going to tubing plungers, and ultimately if necessary to remove fluids, pumping units.

Operating pressures are generally noted by well tenders by often do not make it to operator well files. Operators who have completed their wells open hole will struggle to isolate problems when they arise. Operators with cased hole completions have an advantage in being able to set bridge plugs or packers to identify problem zones and then isolate them.

The complex nature of the Rose Run and Beekmantown can yield up to as many as 4 or 5 potential horizons for completion.

Acidizing Basics: Matrix vs. Fracturing

Acid treatment types can generally be defined by the injection rate and the pumping pressure. Acid treatments carried out below formation fracture pressure are termed matrix acidizing, while those carried out at pressures greater than the formation fracture pressure are termed fracture acidizing

Matrix acidizing is generally performed on either carbonate or sandstone formations. The purpose of matrix acidizing is mainly to remove or bypass near wellbore damage. The damage is often due to: drilling, perforating, workover or completion fluids, and precipitated mineral deposits from injection or production of formation water. Acid is pumped at low rates into the formation and allowed to react with solids and/or fines in the formation pore system.

Fracture acidizing is generally performed only on carbonate formations and performed at pressures greater than the formation fracture pressure. Fracture acidizing goal as compared to matrix acidizing, is to create long open conductive channels that reach deeper into the formation from the wellbore. The acid etches the walls of the fracture and creates channels for formation fluids and/or gases to be produced back through to the wellbore. .

Acidizing is generally a very cost effective method significantly improving the drainage efficiency of the reservoir rock around the wellbore.

Service Company Stimulation and Completion Comments

The following were comments provided by three basin service companies who wanted to remain anonymous, as well as an interview with a respected Knox drilling, completion, and production consultant.

Stimulation Company A

Initial stimulation:	200-500 gallons 15% HCL during perforating
Iron control with perf acid	Yes (sometimes extra is added)
Oil Emulsion Control	Yes (Surfactant/Penetrating Agent)
Clay Control	Yes
Stimulation Acid	500-2500 gallons (20% HCL + Iron Control)
Stimulation Rate	less than 1 barrel per minute(bpm) to 4 bpm
Volume Determination	50-75 gallons of acid per foot of perforated interval
Stimulation Rate determination	Operator determines (Recommend to inc. rate throughout job to 2 bpm.)
Perforation balls	Run in stimulation acid (Salt added to float balls)
Perf ball number determination	50% more than number of perforations

Recommendations

Solubility of formation advised
Test for secondary precipitates
Test formation water and oil for emulsions and fluid incompatibility

Stimulation Company B

- Net pay, permeability, and porosity were defining characteristics
- 15% HCl acid of choice
- Iron control additive often used
- Perforation ball sealers often used
- 20-25 gallons of acid per foot of pay
- Flow back immediately after job
- Generally 5-7% carbonate, however, verify formation solubility
- Assume fluid invasion by drilling mud or kill fluid
- Foam frac with no sand – some
- Cross link gel 450 barrels (a maximum) with 300 sx sand
- Morrow county (more oil) is less forgiving, but true matrix jobs
- Full section of Glenwood was kiss of death for well.

Stimulation Company C

- 600 barrels, 100 sx sand, gelled fluid
- 300 gallons 15% HCL
- Spotted with Tubing
- Corrosion Inhibitor 1gallon per 1000 gallons
- Clay Stabilizer at 1 gallon per 1000 gallons
- Surfactant at 2 gallons per 1000 gallons
- Rose Run: gelled acid system (retarded) results in better acid placement
- Pressure limitations a concern

Drilling and Completion Consultant Company D

Drilling General

- Rig selection important
- February 1988 drilled through and set first casing in Ohio
- Directional surveys
    - Base of surface
    - Queenston
    - Every 250' to TD
- At Utica shale took weight off and increased rpm's (80 rpm)
- Looking for 400 units or more with sustainable flare
- At Gull River
    - Mud Engineer on hole
    - Drilling Supervisor on hole
    - Change out air head rubber
    - Mud logger on hole

Prior to Drilling In

- Circulate any drilling breaks bottoms up
- Have (2) 200 barrels tanks of Fresh water
- Ensure everything is hooked up and tested (BOP)
- Ensure choke lines cleared
- Stop, clean hole, level rig, blow flow lines clear

- Load with 8.9 ppg blend, circulate to pit until soap stops, then go to steel pits
- Mud System
    - Polymer mud
    - Premix at 8.9 ppg
    - Mix KCL on the fly at 2 – 3% for shale protection
    - Salt gel, caustic soda, defoamer, starch
    - Viscosity mid 30's
    - Water loss below 15
    - Cannot accurately gauge earthen pits
    - (2)50 lb bags lost circulation material – for example, magnafiber
    - Pump rate 6-8 bpm (Redundant pumps advised but does not generally happen)
    - Monitor quality of mud
    - Monitor steel pits
    - Holes have been lost due to poor completion techniques or improper mud system
    - Some areas sensitive to just hydrostatic level of fluid, other more forgiving
- Drill though pay

At TD

- Sweep hole with 50-70 barrel viscous pill (gel, starch, and caustic)
- Condition hoe 1 ½ to 2 hours (bottoms up twice)

- 6-8 bpm pump rate
- Always keep bit rotating
- When coming out of hole, keep hole loaded, or circulate hole every 23 jts.

Logging Suites

- Fluid: GR, Density, Neutron, PE, Directional
- Air: GR, Density, Neutron, PE, Directional, Temperature
- Rose Run wells up to 50% Sw good chance of success, >50% Sw lose opportunity
- Isolation of Rose Run, start from bottom and work up

Casing and Cementing

- 4 ½" 10.5#/ft to 6500', 11.6 #/ft for greater than 6500'
- Cement: Rose Run blend Class A, 10% salt, 2 % Calseal, 1% Halad 322
- Sufficient cement for 450' over top of pay
- 25 barrels of gel ahead of cement
- Full joint at bottom for landing joint
- Float shoe with autofill, Shoe joint (10'), Latch down baffle
- Five joints, marker joint, 6-10 centralizers
- Two stage cement for strong Clinton (to protect from invasion)
- Brine to displace plug

Completions

- Cased Hole Logs: Gamma Ray, Bond Log, Casing Collar locator
- Beekmantown
    - C generally not productive
    - B is the big pay
    - A is just above AB notch
- Treat Rose Run from bottom up
- Swab hole, spot acid, load hole, perforate in acid, 4 shots per foot
- Spot 250 gallons HCl for perforating (15-20%)
- 15% Iron Controlled gelled (retarded) acid for stimulation (gel to recover insolubles)
- Run tubing, breakdown, minimum pressure
- Once achieve breakdown, open backside
- Spot completion acid (gelled acid in Rose Run)
- Pick up pumping rate as pressure decreases
- Leave shut in 1 ½ to 2 hours
- Get crew off location
- Prepare to flow to tank(to be able to record volumes recovered)
- Flow back through 3/8" choke
- Choke nipple
- Monitor tubing and casing pressure
- Ensure backside is cleaned up

Production

- Separator
- 2 Pen recorder
- Little or no production testing done when problems arise
- Start well with 10% of open flow
- 3/8” tubing
- Stub joint, perforated nipple, seating nipple
- If fluid anticipated, locate bottom of tubing in or below perforations
- Full opening gate valve
- Pad plungers (removes paraffin)
- PDC controllers
- Gas analysis
- Trempeleau as great as 1365 btu
- Rose Run/Beekmantown 1050-1200 btu
- Possible condensate

Perform volumetric, material balance, and P/Z analysis

As per the original proposal:
"Perform volumetric, material balance, and P/Z analysis as possible based upon production, pressure, and open-hole log data. These analyses will be compared to production trend analysis and the critical factors identified in the completion and production practices analysis."

Based on the log analysis for the 184 wells in the study group, volumetric analysis was completed based upon log data for varying drainage patterns, 40 acres, 80 acres, and 160 acres.

The results show generally that without an estimate of the areal extent of the reservoir, a gas in place analysis, while a useful tool, only provides a range of estimates. Operators with access to the areal extent of their seismic targets and in-house information on particular completion results should be able to better identify the area affected by the completion.

No P/Z analysis was performed due to lack of data. Estimated gas in place determination without having initial and periodic shut in pressures would have estimated results that would have been un-meaningful.

Discussion and Description of the Methodology Applied to Volumetric Calculations
Methodology Overview

The volumetric methodology was applied to selected deep well drilled and producing from the Beekmantown and/or Rose Run formation. Recorded electric well log data was utilized as a means to estimate the initial natural gas in place for various reservoir sizes (40, 80 and 160 acre).

A two step process was utilized as a part of this process. Initially the needed log parameters were developed. The second stage of the methodology applied the well log data to well reservoir. As with most reservoir studies, limited available data for each reservoir resulted in several assumptions being utilized in order to develop the original gas in place estimates.

Well Log Analysis

Compensated Density Tool
The primary porosity commonly used by operators is the compensated density tool. In order to calculate the porosity a rock matrix value for the formation of interest is needed. The rock matrix value applied in this study was 2.71 grams/cubic centimeter. This value was utilized due to the Rose Run formation being mostly a dolomite cement or matrix. Core results support utilizing this rock matrix value.

Determining Net Sand Thickness
Net sand thickness was based on a minimum porosity development cut-off of five percent (5%). Intervals having porosity greater than the minimum threshold were categorized as

the productive part of the reservoir and included in the net sand calculation. Reservoirs exhibiting less than 5% typically lack sufficient gas in place and permeability.

Water Saturation
Water saturation was determined by utilizing Archie's Equation:

$$Sw = \sqrt{\frac{(F)(Rw)}{Rt}} \text{ where}$$

F (formation resisitivity factor) is based on the rock property relationship to porosity (ϕ). For limestone/dolomite formations F is defined as: $1/\phi$ where ϕ is a decimal interest.

Rw (formation water resistivity) is typically observed to be in the range of .035 $\Omega - m$. The formation depth varies from 5,100' to over 7,000'. As such the formation temperature increases approximately 20 Fahrenheit degrees across these two intervals. Lacking specific formation water resistivity measurements the water resistivity was assumed to be constant and equal to .035 $\Omega - m$ for all wells in this study.

Rt (formation resistivity) was secured directly from the electric log data for each well. The values were read directly from the well log files. Mo corrections or adjustments to the log resistivity values were made.

Assumed Homogeneous Reservoir
As is the common case for volumetric calculations; the reservoir properties are assumed to be reflected by those observed on the well log data. In this volumetric analysis the reservoirs are assumed to be homogeneous in nature. This assumption clearly is one of the limiting factors when endeavoring to apply volumetrics to a highly heterogenous formation.

Initial Gas In Place Calculations

Initial Gas In Place
In order to estimate the initial gas in place (IGIP) it is necessary to apply the volumetric equation to each reservoir size (40, 80, 160 acres). A part of the volumetric equation includes the formation volume factor. The volumetric equation which includes the formation volume factor is presented and discussed below.

$$\text{Initial Gas In Place (scf)} = \frac{43560 * (A) * (H) * (\phi) * (Sg)}{Bgi} \text{ where}$$

A = Drainage, acres
H = Net reservoir thick (> 5% porosity), feet
ϕ = Porosity, decimal
Sg = Gas Saturation, decimal
Bgi = Gas Formation Volume Factor (initial), cf/scf

Discussion of the Volumetric Equation Variables
The *net reservoir thickness* is the total thickness as determined from the log analysis for all intervals of reservoir thickness having greater than 5% porosity. Portions of the reservoir having porosity lower than 5% are considered to be non-productive.

The *reservoir porosity* was determined using the compensated density porosity log values. A matrix density was assumed to be 2.71 grams/cc for the reservoirs. The bulk density values were captured from direct log measurements.

The *natural gas saturations (Sg)* was determined by deducting the oil and water saturations (1-(So + Sw). Typical the logging programs for deep wells in Ohio are not comprehensive enough to obtain oil saturation data. Accordingly a rationale methodology was developed as a means to generate estimates of oil saturation for each study well.

The *Gas – Oil Ratio (GOR)* was determined for the well based on operator reported cumulative production histories. Each operator reports individual well production to the State of Ohio on an annual basis. Based on these GOR ratios oil saturations (So) were assigned to each well. Values assigned were based on the below table:

GOR Range (mcf/bbl)	**So Value Assigned**
0-5	**.50**
5-10	**.40**
10-25	**.30**
25-50	**.20**
>50	**.15**

Note: The residual oil saturation is assumed to be .15 (15%).

The *water saturation (Sw)* was determined by utilizing Archie's equation:

$$\text{Sw} = (\sqrt{(F)(Rw)/Rt} \quad \text{where}$$

Sw = reservoir water saturation as a decimal interest
F = reservoir formation factor assumed to be $1/\phi^2$
R_t = resistivity measurements secured from the log measurements (ohm-meters)

The *Gas Formation Volume Factor*
Bgi was determined by applying industry accepted assumptions to the reservoir in order to develop appropriate estimates for the Bgi values.

The Gas Formation Volume Factor is defined as:

$$\text{Bgi} = \frac{.02827 * Z * T}{P} \quad \text{where}$$

Bgi = Gas formation volume factor (initial)
Z = Gas compressibility factor at initial reservoir conditions
T = Reservoir Temperature (Rankin degrees)
P = Reservoir Pressure (psia)

Reservoir properties assumed included a reservoir pressure based on a pressure gradient of 0.4 psi/vertical foot of depth, a reservoir temperature gradient based on 1.0 Fahrenheit degree/100', and a Z factor based on average reservoir properties for each township. For wells not having water saturation data; average saturation data for other wells in the township was utilized. In a few instances adjacent township water saturation was utilized.

Conclusions of the Volumetric and Material Balance (P/Z) Analysis

Volumetric analysis, while generally overstating potential reserves, is a useful analysis tool. However, without seismic data which was not available, an estimate of the drainage pattern would not have been meaningful. With the information provided, operators can benefit from this type of analysis to compare their results to actual performance.

Operators also have the ability to gather initial and periodic shut in pressure data to perform material balance (P/Z) analysis for comparative purposes.

<u>Complete Traditional Decline Trend Analysis Utilizing Aries (James Engineering).</u>

As per the original proposal:
"James Engineering will complete traditional decline curve analysis based upon the historic monthly production data provided utilizing Landmark Graphics Aries. This analysis will then be compared to the other reserve analyses completed."

Production decline curve analysis was completed for the study group of wells in addition to over 1,300 other Ohio Knox wells. All of the analysis was completed based upon state reported averaged annual data.

The EUR's for the study wells are included in the volumetric study spreadsheet included on the companion CD. EUR's for the 116 well productive well study group ranged from 0.4477 mmcfeq to 2036 mmcfeq (2.0 BCF). The average EUR is 446 mmcfeq. Eleven wells had EUR's greater tan 1000 mmcfeq, thirty wells with EUR's from 500 to 1000 mmcfeq, twenty two wells with EUR's from 250 to 500 mmcfeq, twenty four from 100 to 250 mmcfeq, and twenty nine wells with less than 100 mmcfeq.

Data import problems included minimal production data prior to 1984, operators misreporting data, and multiple operators reporting for the same api number.

The basis for production decline curve analysis is predicated on that a well is producing at it maximum unrestricted flow rate. That is, that the well is not being controlled at the surface by a choke or valve to maintain a steady rate. In many cases the gas flow rate appeared restricted for the first one to two years for the more prolific wells.

Wells with limited production data (1 year), the estimates have less confidence than those with several years. Wells were often noted as NP No production data, IP or incomplete production data, or CP for complete production data. Basis for decline curve analysis predicted on maximum unrestricted flow rate. Track oil, gas, water, casing pressure, tubing pressure, and line pressure. Wells could have been re-completed without it noted in state data or it was overlooked (missed). No water initially not necessarily an indicator of no water forever. Some wells have an oil leg essentially unrelated to gas production. It should be noted that future water production not predictable. Water production can also be independent of oil and gas production. In some wells, no oil was noted until after well was deepened .

Some factors that could affect decline forecast and associated EUR include; Volume of Data, Operating conditions, Size of reservoir, Production method (to minimize flowing bottom hole pressure), Fluid buildup, Change in relative permeability if shut in, and Effect of offset wells.

Finally, experience indicates that operators not often inclined to gather and store needed early pressure and production data to accurately evaluate reservoirs when production problems arise later in the life of the well.

Complete Decline Trend Analysis Utilizing RPI analysis (BJ Services)

As per the original proposal:
"BJ Services has agreed to complete decline trend analysis utilizing Performance Sciences, Inc.'s Reciprocal Productivity Analysis as previously described. This analysis will then be compared to the other reserve analyses completed."

For those unfamiliar with RPI, the following is the abstract for SPE 37409 by J.W. Crafton of Performance Sciences. "The ability to estimate descriptive engineering parameters, such as permeability, and to generate production forecasts and estimated ultimate recovery based on those parameters, without the cost of full numerical simulation or extended build up tests, is provided by the Reciprocal Productivity Index (RPI) graphical production analysis method. The method's theoretical basis arises not from the fact that the traditional constant rate or constant boundary pressure conditions are sufficient, but that the necessary boundary condition only requires that the outflow face transmissibility remain constant over time. With that difference, it is possible to accurately evaluate production histories in which both the rate and producing pressures are varying over time, using traditional well testing methods. Examples for both oil and gas wells demonstrate the interpretive capability and limitations. The parameters derived from RPI method are testable for sensitivity and reasonableness. The forecast can also be used to test the benefits of changes in operating pressure, pump inlet level or stimulation. When relatively noise free data sets are available, it is possible to derive geologic and other production engineering information from them."

Several unsuccessful attempts were made to analyze production data based upon average annual data. No meaningful RPI analysis was completed. The work completed suggested that RPI analysis is effective for single interval reservoir analysis with daily and monthly production data combined with detailed pressure data sufficient to estimate the flowing bottom hole pressure. Generally the Knox is completed in several intervals.

Operators would be advised to detail daily production volumes for a minimum of the first 30 days (available from chart data and tank gauges) and the associated tubing and casing pressures. Monthly volumes and average pressures should also be recorded and filed for potential future analysis.

Experience indicates that while pumper and chart information are often readily available initially, this type of data seldom makes it to the well file for future reference and analysis.

Included on the companion cd are an RPI input data requirements sheet, and two pdf files on work prepared by Dr. James Crafton regarding RPI analysis

1.) Reservoir Pressure and Skin form Production Data Using the Reciprocal Productivity Index Method(The Intercept Method)
2.) A presentation by Dr. Crafton entitled "Why Shut the Well in, You already have the data; Production Data is Enough
3.) Although not provided on the cd, the reader is also referred to Dr. Crafton SPE Paper37409 entitled "Oil and Gas Well Evaluation Using the Reciprocal Productivity Index Method

Summarize Volumetric, Material Balance, P/Z , Decline Trend, and RPI results

As per the original proposal:
"The estimated reserves by the various methods employed will be compared to each other and statistically analyzed. The results of each method will be categorized as follows: performing as expected, affected by depletion, exhibiting formation damage, or exhibiting fluid accumulation."

The volumetric calculations have to assume an areal extent, which was unknown to the study. A comparison to actual EUR estimates would have little meaning without knowing the areal extent of the reservoir. The problem is further compounded by the highly heterogeneous nature of the Rose Run and Beekmantown.

No pressure data was available for material balance analysis. No meaningful RPI analysis was completed due to the lack of pressure and rate information .

A significant effort was extended to completed production decline trend analysis. EUR's were determined by the available average annual data. The results were interesting and would require more research to be able to analyze the trends that were identified during the course of the study. It was noted however, that for larger wells, rate was restricted, while for smaller wells, the wells would have a "typical decline curve." Many wells were noted to have significant production decline after year 1. Other wells were noted as not having water production initially would have significant water production later in life.

No statistical analysis was made of the production decline trends, but all production decline curves based upon average annual data are included on the companion cd.

Analyze Reserves as a Function of Completion and Production Practices

As per the original proposal:
"The estimated methods by the various methods will be compared to the completion and production practices employed and statistically analyzed for critical parameters."

Several summaries were provided in the Ohio section regarding well completion practices. The driving factor behind successful Knox well development appears to be the ability to locate suitable reservoir. This ability is based upon sound geologic and geophysical analysis combined with a methodical approach to drilling, completion, and production.

For the 1,531 wells that were completed and produced, EUR's ranged from 24 mcfeq to 3.95 BCF. The distribution indicated that 622 wells (41%) had EUR's less than 100 mmcfeq, 374 wells (25%) had EUR's in between 100 and 250 mmcfeq, 281 wells (18%) between 250 -500 mmcfeq, 180 wells (12%) between 500 and 1,000 mmcfe, and 74 wells (5%) greater than 1000 mmcfeq.

For the 1,000 wells that were acidized, the EUR's ranged from 192 mcf to 3.95 BCF. The distribution indicated that 410 wells (41%) had EUR's less than 100 mmcfeq, 235 wells (24%) had EUR's in between 100 and 250 mmcfeq, 168 wells (17%) between 250 -500 mmcfeq, 126 wells (13%) between 500 and 1,000 mmcfe, and 61 wells (6%) greater than 1000 mmcfeq.

For the 227 wells that were fraced (177 in Portage in Stark Counties), the EUR's ranged from 24 mcf to 1.05 BCF. The distribution indicated that 106 wells (47%) had EUR's less than 100 mmcfeq, 61 wells (27%) had EUR's in between 100 and 250 mmcfeq, 42 wells (19%) between 250 -500 mmcfeq, 15 wells (7%) between 500 and 1,000 mmcfe, and 3 wells (1%) greater than 1000 mmcfeq. The overwhelming majority of these wells were Rose Run wells.

The large majority of wells did not note the production tubing, however, for those that were included, it was observed that the tubing was generally set near the top of the top perforation.

Prepare Application Guide

As per the original proposal:
"An application guide will be prepared to provide a methodology for analyzing all Knox formation (or equivalent) wells and similar reservoirs for potential production enhancement depending on the current producing characteristics of the well."

An application guide has been prepared to assist operators for the drilling, completion, and production of Knox Rose Run/Beekmantown Wells. The guide presents review sheets for each of the following areas:

- Pre-Drilling
- Drilling
- Completion
- Production

The Accompanying CD provides detailed information for operators to query regarding completion methods according to state. Other files are presented as well for operator use. The application guide is intended as a basis for operators to build upon based on their intimate well knowledge and experience.

Prepare Technical Paper and Transfer the Technology

As per the original proposal:
"The summary report will be presented at either a PTTC conference or as a technical paper at the Society of Petroleum Engineer's Eastern Regional Meeting. Additional presentations may be arranged as requested."

An SPE paper may be prepared and submitted for consideration for inclusion into an SPE Eastern Regional Meeting. Presentation of the results may be presented if requested.

Conclusion

The literature search indicates that there has been a substantial amount of work in acid stimulation. Much of which many operators may or may not be taking advantage of. Experience indicates that operators often use a common methodology from well to well in a "cookie cutter" approach rather than evaluate each well separately. Stripper well operators in particular rely upon the most economical methods of stimulation and whatever has historically worked, or appeared to, even though the application may not be appropriate for particular wells. The results of the completion methodology will provide significant insight into the various methods utilized by operators.

A review of completion data confirms that there has been significant inconsistency amongst Ohio producers in their approach to Knox well completions. Well designs vary from open hole to cased hole. Stimulations vary from matrix acid to acid fracs to sand fracs. Stimulation volumes vary from no acid to several thousand gallons. No specific trends were apparent to indicate whether acid volume, acid concentration, frac volumes, treating pressures, or rates were related to overall EUR's. The study indicates that one of the main factors contributing to successful Knox development is the ability to identify good targets through geological and geophysical analysis.

Completion reports, while helpful, were often very silent to the detail necessary for post completion analysis. Cased hole completions will generally provide operators with more options regarding completions and better stimulation placement. Post completion analysis in the event of production problems are also enhance with cased hole completions. Analysis of production data based upon average annual volumes is not appropriate for evaluating post completion problems.

Rose Run completions, in general, should lend themselves to quantitative post completion analysis such as material balance and production decline curve for comparison to volumetric analysis. Beekmantown reservoirs are often multi layered and heterogeneous and therefore much more difficult to interpret post completion results.

Operators would benefit greatly through the gathering of early time pressure and volume data should analysis be need for the identification of production problems. Limited open hole log data works against operators who desired detailed analysis when results are not as expected.

In short, due to the complex reservoir parameters associated with Knox wells, the more quality data that is reviewed and recorded early on will be beneficial for analysis later in the life of the well.

Recommended Future Work

Continued review of completion methodologies and their relationship to EUR's. Monthly production and associated pressures as well as access to operator files would be a necessity for this type of analysis.

An extended research of all Knox production decline curves for analysis of production decline trends vs. log analysis combined with broad geologic mapping would also be interesting.

References:

Not Applicable.

Bibliography:

Not applicable

List of Acronyms and Abbreviations:

Not applicable.

Appendix

Appendix 1 Literature Search Results Summary
Appendix 2 Knox Well Drilling Application Guide

Article II. Appendix 1

Article III. Literature Search Results

Article IV.

Article V. Title	**Author**	**Source**
1.Measuring and Predicting Reservoir Heterogeneity in Complex Deposystems: Late Cambrian Rose Run Sandstone of Eastern OH and Western PA	Riley, Harper, Baranoski et al	Pennsylvania Geologic Survey
2. New Methodology to Effectively Stimulate Water Disposal Wells drilled in Acid Sensitive Sandstone Formations in Saudi Arabia	Nasr-El-Din, H.A.	SPE 93502
3. Stimulation of Tight Carbonate Reservoirs Using Acid Diesel Emulsions – Field Application	Al-Anazi, H. A	SPE 39418
4. Using a Unique Acid Fracturing Fluid to Control Fluid Loss Improves Stimulation Results in Carbonate Formations	White, D.J.	SPE 24009
5. Lessons Learned from Using Viscoelastic Surfactants in Well Stimulation	Nasr-El-Din, H.A.	SPE 90383
6. Field Cases of a Zero Damaging Stimulation and Diversion Fluid from the Carbonate Formations in North Kuwait	Al-Mutawa, Majdi	SPE 80225
7. Novel Application of Emulsified Acids to Matrix Stimulation of Heterogeneous Formations	Buijse, M.A.	SPE 39583
9. State of the Art in the Matrix Stimulation of Horizontal Wells	Frick, T.P.	SPE 26997
10. A New Effective Stimulation Treatment for Long Horizontal Wells Drilled in Carbonate Reservoirs	Nasir-El-Din, H. A.	SPE 86516
11. Zero Damaging Stimulation and Diversion Fluid	Al-Mutawa, Majdi	SPE 80225

12. Recent Oil and Gas Activities in Tennessee	Statler, Anthony	SPE 5449
13. Trapping Configurations for Cambrian Rose Run in Ohio	Coogan, A.H.	SPE 15922
14. Rose Run Stimulation: A Case History of Problem Identification Research, Planning, Implementation , and Evaluation	Cramer and Thomas	SPE 29189
15. GRI Advanced Stimulation Technologies Improve Production in Rose Run Formation	Fairchild, Mills, and Wood	SPE 37360
16. Evaluation of Infill Drilling Potential, Bakersville of the Beekmantown Formation Field, Coshocton County, Ohio	Yeager, Frantz, Moody, Neese	SPE 37335
17. Design of Acid Fracturing Treatments	Williams and Nierode	SPE 3720
18. Deep Potential of Ohio	Hennington, WH	SPE 4151
19. Prospects for Dually Completed Wells in the Northern Appalachian Basin	Tarr, Earl G.	SPE 9528
21. Practical Production Data Analysis for the Appalachian Basin	Frantz, Spivey, Voneiff, and Jacot	SPE 37347
22. Benchmarking of Re-stimulation Candidate Selection Techniques in Layered, Tight Gas Sand Formations Using Reservoir Simulation	Reeves, Spivey, Koperna, et al	SPE 63096
23. Evaluating Well Performance and Completion Effectiveness in Hydraulically Fractured Low Permeability Reservoirs	Cramer, D	SPE 84214
24. Prediction of Oilwell Performance in Bounded Reservoirs	Wiggins, Jochen, Jennings	Texas A&M

25. Reservoir Pressure and Skin from Production Data Using the Reciprocal Productivity Index Method	Crafton, James W	Performance Sciences
26. New Methods for Production Data Analysis to Identify New Opportunities in Mature Fields	Mohaghegh, Jalali – WVU	SPE 98010
27. Field Experiments with Automatic Casing Swabs	Haynes, Corp, Miller	SPE21695
28. Rome Trough Consortium Papers	Various Authors	University of Kentucky
29. Easywell – Open Hole Packer	Easywell	Easywell
30. Reservoir Oil Fingerprinting Workstation	Humble	Company
31. Crude Oil and Natural Gas Producing Industry	Ohio Oil and Gas Association	Association
32. Oil and Gas Well Evaluation Using the Reciprocal Productivity Index Method	Crafton, JW	SPE 37409
33. The Reciprocal Productivity Index Method, A Graphical Well Performance Simulator	Crafton, JW	Southwest Petro. Short Course
34. Porosity Zones in the Knox Dolomite of Northeastern Kentucky	McGuire, Wm	KOGA 1964
35. The Potential of the Knox in the Illinois Basin- A Regional View of the Knox	Stevenson, Schwalb	KOGA 1977
36. Geology and Economics of Knox Dolomite in Gradysville East Field, Adair County, Kentucky	Perkins, J H	Ky Geo. Survey
37. Mineralization and Hydrocarbon Emplacement in the Cambrian-Ordivician Mascot Dolomiteof the Knox Group in South Central Kentucky	Anderson, Warren	KY Geo. Survey
38. Unconformity at the Top of the Knox Group in the Subsurface of South Central Kentucky	Gooding, Patrick	KY Geo. Survey

39. Cambro-Ordivician Structural and Stratigraphic Relationships of a Portion of the Rome Trough.	Silberman, JD	Ky Geo. Survey
40. Preliminary Map of the Structure of the Precambrian Surface in Eastern Kentucky	Drahovzal, Noger	Ky Geo. Survey
41. Cambrian Pre Knox Group Play in the Appalachian Basin	Harris, Baranoski	Ky Geo. Survey
42. Cambrian Hydrocarbon Potential Indicated in Kentucky's Rome Trough	Harris, Drahovzal	Ky Geo. Survey
43. Gas Exploration in the Devonian Shales on Kentucky	Haney, D	Ky Geo. Survey
44. Exploration along the Northwestern Margin of the Rome Trough	Silberman, JD	Ky Geo. Survey
45. Article on Fluid Damage	Baroid Fluid Services	Company
46. Article on Carbonate Acidizing Treatments	Halliburton	Company
47. Article on Diversion in Matrix Acidizing Treatments	Halliburton	Company
48. Article on Well Stimulation	Gidatec	Company
49. Article on Production Enhancement	Panterra	Company
50. Article on Matrix Acidizing of Carbonates	Cleansorb	Company
51. Permeability and Porosity from Drill Cuttings	Darcylog	Company
52. Production Enhancement with Acid Stimulation	Various	Penn Well Books

Knox Well Completion Procedure Guide

Based on Stripper Well Consortium Project

"A Study Evaluate the Effect of Completion and Production Procedures on the Ultimate Recoverable Reserves from Knox Formation Wells: Rose Run Sandstone and Beekmantown Dolomite"

SWC Award Number: 2969-JEI-DOE-2098

Completed by:
James Engineering, Inc.
231 Third Street
Marietta, Ohio 45750

Index

Section	Page Number
Introduction	1
Pre Drilling	3
Drilling	5
Completion	9
Production	12

Introduction

The procedure guide was prepared as result of the Stripper Well Consortium project entitled "A study to Evaluate the Effect of Completion and Production Procedures on the Ultimate Recoverable Reserves from Knox Formation Wells: Rose Run Sandstone and Beekmantown Dolomite". The purpose of the study is better understood through the following abstract:

Over the years various drilling, completion, and production methodologies have been applied to the Knox Formation, specifically the Rose Run Sandstone and the Beekmantown Dolomite, resulting in various levels of production. The varying levels of success are due not only to the technology used to identify the prospects and the quality of reservoirs encountered, but also to the petroleum engineering principles applied to the completion and the production methodologies employed.

Completion and production technical issues include cased-hole versus open-hole completions, matrix acidizing versus fracture stimulation, perforation concentration and interval selection, fluid removal methods, paraffin treatments, operating wellhead pressures, gas sales line pressures, as well as general operating procedures. As in all plays, the combined influence of these factors and the reservoir quality ultimately determine the recoverable oil and natural gas reserves.

The Knox-Beekmantown (or equivalent) has been drilled though or tested in approximately 9,500 wells in the Appalachian Basin including the states of Kentucky, New York, Ohio, Pennsylvania, and Tennessee. Furthermore, it is well known that many Knox/Beekmantown wells are initially very prolific. However, all these wells eventually become stripper wells and could potentially benefit from the production practices portion of this study. The most significant value of the study may be the potential of stimulation of the poorer quality reservoirs encountered in a large percentage of the wells drilled, especially to the Beekmantown. Experience indicates that past and current completion and production practices employed have negatively impacted the ultimate recoveries of some Knox wells.

The study evaluated critical factors associated with completion and production practices and the effect on the ultimate reserves predicted. A study group was analyzed for ultimate reserves estimated through volumetric analysis based on open-hole log analysis, volumetric, and traditional decline curve analysis. The comparison of these reserve estimates to the critical completion and production factors resulted in a methodology and application guide to assist in delineating areas of opportunity to increase production and ultimate recoverable reserves.

The application guide incorporates the results of the study as identified by the specific steps of the study. Steps to the study included: Perform a literature search of all information on the Knox formation, Compile a database of all Knox formation wells, Identify a study group of wells, Complete completion and production practices analysis, Perform volumetric, material balance, and P/Z analysis, Complete traditional decline trend analysis utilizing Aries (James Engineering), Complete decline trend analysis utilizing RPI analysis (BJ Services), Summarize Volumetric, Material Balance, P/Z, Decline Trend, and RPI results, Analyze reserves as a function of completion and production practices, and Prepare Application Guide.

Knox Well Completion Guide

Due to complex nature of Ordovician Knox formations depending on the geographic area, the overall process is best considered according to the particular stage of well development. The four major stages of development include:

- Pre-Drilling
- Drilling
- Completion
- Production

Each section provides a series of decision-making sheets for determining an appropriate completion methodology based upon the specific operating area. Operators are encouraged to modify the sheets provided to enhance them and make them more appropriate for their specific application due to the highly heterogeneous nature of the Knox Beekmantown and Rose Run.

The application guide prepared was intended to provide a methodology for analyzing Knox wells and similar reservoirs for potential production enhancement depending on the current producing characteristics of the well. It was not intended as an exhaustive reference but only to provide basic guidelines and a basis for operators to review during Knox well development.

The companion CD provides a searchable database of Appalachian Basin wells by state and by county. Tables can then be copied and pasted into excel for further analysis or queried in MS Access for those who are knowledgeable.

The companion CD also provides details of a 183 study group results and associated geologic mapping, as well as production decline curves for over 1,500 Ohio Knox wells sorted by County by API number.

While Beekmantown wells may be more difficult to quantify production problems due to extensive heterogeneity, Rose Run Sandstone wells should be able to be analyzed through traditional methods provided operators gather and record basic pressure, rate, and volume information.

Stage I: Pre-Drilling

One of the most critical steps in the entire process may be what occurs during the pre drilling stage. While this stage of development was not necessarily a specific part of the study, the following is provided because this stage is so important to the ultimate success of Knox well development.

During the pre-drilling phase, the main focus is on site selection with efforts to focus on the geology and geophysical analysis of the particular area of concern. Two of best references include:

Measuring and Predicting Heterogeneity in Complex Deposystems: The Late Cambrian Rose Run Sandstone of Eastern Ohio and Western Pennsylvania prepared in 1993 for the U.S. Department of Energy by Riley, Harper, Baranoski, Laughery, and Carlton. The resource can be purchased from most of the state Geological divisions or from the Department of Energy using the OSTI ID: 6793603; DE93014539 or going to http://www.osti.gov/energycitations and ordering online.

The Atlas of Major Appalachian Plays section on the Cambrian-Ordovician Knox Group Unconformity Play by Baranoski, Riley, and Wolfe. This resource is generally available through the various State Geological Divisions.

Oil and Gas From rose Run Sandstone and Beekmantown Dolomite in Ohio" cites that Rose Run drilling in Holmes County is exceptionally sweet, but that one can find a ready explanation for the vastly improved success ratio: greater use of significantly improved seismic exploration methods. Drilling in Coshocton county since the mid 70's is no higher than 10%; that in Holes county since 1986 is better than 50%.

Operators generally base site selection on a combination of geological review, geophysical review, offset well review, identification of additional up hole potential, and identification of product market and access. This is in addition to ensuring that lease, title, and partners are in agreement.

The following list is provided to assist operators with the pre-drilling review of potential Knox wells.

Pre-Drilling Consideration Checklist

I. Geological Review

____Trend analysis of target reservoir(s) across the prospect area
____Detailed log analysis of logs from state geological division or other operators
____Preparation of structure maps
____Preparation of porosity maps
____Preparation of water saturation maps
____Preparation of EUR maps
____Preparation of isopach maps
____Review of completion reports and state database information
____Review of technical literature regarding the target reservoirs

II. Geophysical Review

____Identification of available seismic data
____Purchase, review, and possible reprocessing of seismic data
____Identification of sonic log data for correlation purposes
____Acquisition of additional seismic data(Single, 2-D or 3D)
____Processing of seismic data
____Interpretation of seismic data
____Note: Some operators drill Knox wells without seismic

III. Offset Well Review

____Identification of offset wells in target reservoir within a specified area of review
____Determine cumulative production (oil, gas, and water) and estimated ultimate reserves
____Identification of initial reservoir pressure
____Determination of initial flow rates

IV. Up Hole Formation Determination

____Determine up hole productive formations above target reservoir(s)
____Identification of cumulative production and associated estimated ultimate reserves
____Determination of the effects of pressure depletion

V. Identification of Product Market and Access

____Verification of lease
____Determination of site access
____Determination of market access for natural gas

VI. Key Questions

____Does Geological and Geophysical Review and analysis support the drilling prospect?
____Has all available information been considered?
____In the event of a dry hole, are there any up hole formations?
____Do we have a valid lease and access?
____Can we get our product to market?

Stage II: Drilling

Successful Knox well development benefits from sufficient planning and consideration of all steps. The drilling process, while dynamic with many unforeseen circumstances, is strengthened by pre-planning which develops into a plan generally called the drilling prognosis. A drilling prognosis should identify the location, geologic data, hole diameters, casing program, cementing program, drilling fluid requirements, contractor equipment requirements, contractors, and safety considerations.

The following list is provided to assist operators in the drilling of Knox wells.

Drilling Consideration Checklist

I. Location Information
____Well name
____API number, county, and township
____Directions to location from main road

II. Geologic Data
____Elevation Estimate, ground level and kelly bushing (GL and KB)
____Major formations and estimated depths from surface to total depth
____Potential fluid bearing zones

III. Hole Diameters
____Hole diameters, inches
____Hole total depths, feet
____Hole capacity, barrels per foot
____A schematic of the hole diameters and casing

IV. Drilling Fluids
____Specific fluids each hole size, air, foam, fluid
____Specific foam recommendations and chemical requirements, for example 3% KCl (potash)
____Mud pit requirements(steel or earthen)
____Flare requirements
____Procedures for killing well in event of a strong kick
____Fluid Requirements: brine weight, water loss, starch or polymer mud
____Circulation/hole conditioning requirements at TD prior to tripping out of hole
____Gel sweep requirements

V. Drilling Sample Collection
____Sample catching requirements, i.e., every 10' or 30' depending on specific intervals
____Specific formations to watch for shows
____All shows should be noted on the geolograph
____Samples bags gathered by mud logger or company representative at the end of the hole

VI. Hole Deviation Surveys
_____Equipment on location for deviation surveys
____Identification of specific locations to run deviation surveys: TD of surface, top of Big Lime

VII. General Equipment
____Geolograph
____Manometer to measure natural shows
____Annular and Double ram blowout preventer with a minimum of two 2" choke lines

VIII. Mud Logging Program

____Selection of appropriate depth to put mud loggers on hole
____Mudloggers are then on hole to TD
____Gather drilling samples, identify formations, monitor drilling rates, record gas shows, and perform unit show determination with gas chromatograph
____Alternative to contracted mudlogger is for operator to have microscope and black light for sample review and identifying fluorescence

IX. Logging Program

____Gamma ray in cased hole to surface
____Gamma ray, caliper, compensated density, sidewall neutron, dual laterolog in open hole
____Consider detailed logging across target intervals
____Consider need for sidewall cores and drill string tests

X. Casing Specifications (Conductor, surface, intermediate, and longstring)

____Identify Diameter, # per foot, capacity (barrels per foot), and optimum torque (ft-lbs)
____Determine Annular Volumes (cubic ft per foot and barrels per foot)

XI. Pre-Completion Production String Cement Design Considerations

____Determine cement types for all strings
____Determine water required, cmt yield, cmt density, pump time, and compressive strength
____Determine cementing equipment needs for surface and intermediate:
Float insert
Guide shoes
Wiper plugs or Latch down Plugs
Casing Centralizers
Thread lock.
____Determine whether to set through (cased hole) or set on top(open hole)
____If set on top, formation packer shoe
____Determine centralizer spacing and number of centralizers required
____Determine cement basket placement
____Determine use of auto-fill or float shoe
____Cement designed for primary target
____Two stage cement job for primary and secondary target

XII. General Drilling Considerations for Knox wells

____Set sufficient intermediate/surface casing in case of blowout
____Pressure test BOP prior to drilling out surface/intermediate casing shoe
____At specified depth above pay change airhead rubber, test BOP, and clear choke lines

XIII. Notification List

_____Prepare list of phone numbers for contractors involved and emergency phone numbers
____Company/Operator Personnel
____Casing Tong Companies
____Cementing Company
____Mud Company

XIV. Pre-Spud Meeting

____Conduct pre-spud meeting with all primary contractors: drilling, operators, cementers

XV. General Well Control Considerations

____Ensure all drilling personnel trained in blow out prevention
____Determine drill string, annular, and mud pump capacities
____Ensure sufficient kill fluid on location (for example, 1000 bbls brine and 500 bbls fw)
____Review well control procedure with personnel and assign duties to all involved
____Maintain BOP pressure
____Watch BOP for potential leaks
____Maintain choke lines, flare ignition torch, and mud pit levels
____Operate mud pump
____Operate water tank valves and mixing hoses
____Operate choke manifold
____Verify that all chokes, choke lines, and bypass lines are open and free of debris
____Ensure all unnecessary people are off location

XVI. General Gas Influx While Drilling On Air Considerations (Not intended as a complete procedure)

____Pick up Kelly and pull 1 joint of drill pipe
____Set drill pipe in the slips
____Extinguish all fires except flare ignition torch
____Shut down any un-necessary engines
____Open choke lines and verify they are clear
____Close BOP with choke lines open
____Calculate fluid volumes and prepare kill sheet
____Use de-foamer in liquids on holes where air or soap was used

XVII. Logging Suite Options

____None This should be an option only when top setting or when hole conditions warrant
____Basic Gamma Ray, Caliper, Neutron, Formation Density
____Medium Gamma Ray, Caliper, Neutron, Formation Density, Dual Laterolog, Resistivity
____Extended Gamma Ray, Caliper, Neutron, Density, Dual Laterolog, Sonic, Density
____Drill stem testing
____Side wall cores
____Quantitative log analysis often difficult due to chip blow out

XVIII. Top Set Considerations (Open Hole Completions)

____Concern over potential of water
____Limited ability to control where stimulation fluid goes
____Unstable hole or bit condition may warrant top setting

XIX. Other

____Permeability and Porosity Determination from Drill Cuttings available from Darcylog
____Potential for drill deeper or up-hole completion

Stage III: Completion

The major concerns appeared to be the idea of "getting into water and minimizing expenses. Much of the water concerns seem to have been overcome by setting casing through and selective perforating. However, most operators are still cautious regarding completions. With acidizing still being the most cost effective method for stimulation, it appeared that in areas where fracturing the Rose Run (Ashtabula, Portage, and New York) is not accepted as an initial treatment, operators often default to:

No.	Step
1	Identify all potential Knox Intervals Targets on Open Hole Log
2	Determine which formations to perforate (note which may be wet)*
3	Spot acid with perforating: 200 – 500 gallons 15% HCL (verify with solubility test)
4	Check results, if satisfactory produce, if unsatisfactory Step 5
5	Matrix acidize and ball out: 20-25 gallons per foot of pay (Matrix Acidizing)
6	Check Results, if satisfactory produce, if unsatisfactory, Step 7
7	Re-acidize with more acid and more rate/pressure
8	Check Results, if satisfactory produce, if unsatisfactory, Step 9
9	Frac well with acid and or sand (review results of other operators/stim companies)

Experience indicates that if multiple horizons are completed simultaneously, then post completion analysis will be difficult should results not turn out to the operators satisfaction. Open hole completions also complicate post completion analysis.

How much acid to use?

While acid stimulation is a very cost effective method of formation stimulation, operators in the Appalachian Basin tend to approach carbonate Knox wells with a stepwise approach. If the well is top set, drilled in and produces naturally, then the well is produced without further stimulation.

Matrix acidizing is generally defined as injecting acid into the formation (matrix) at or below the formation fracturing (parting) pressure. Fracture acidizing injects acid above the formation fracturing (parting) pressure.

In sandstone formations, matrix acidizing is employed as a removal treatment for formation damage. Therefore, if there are no acid soluble damage, then there will most likely be no substantial increase in production. In carbonate formations (limestones and dolomites), matrix acidizing is employed to create passages called "wormholes" in the acid soluble formation.

General guidelines for the volume of acid required is approximately 20-25 gallons per foot of net pay.

It was noted during the study that completion service companies were uncomfortable with providing specific information regarding company completion practices due to confidentiality.

The following list is provided to assist operators during Knox well completions.

Completion Considerations

I. General Completion Considerations

____Blow out preventer
____Tubing or no tubing
____Tubing size, 1/1/2" 2.75 #/ft or 2 3/8" 4.6 #/ft
____Tubing Setting Depth
____Wireline Re-Entry guide
____Identify initial completion interval(s)
____Put highlighted memo in file for uphole completion potential
____Test from bottom most zone upwards

II. Casing Considerations

____4 ½" VS 5 ½"
____Landing joint (full or pup jt)
____Pup Joint (marker)
____Frac Baffles
____Float Shoe or Guide Shoe
____Formation packer Shoe (for top setting)
____Cement plug latch down baffle
____Centralizers
____Cement baskets
____Two Stage Cementing Tool
____Rabbit

III. Cementing Considerations

_____Desired fill up above pay zone
____Fluid Loss

IV. Tubing Considerations

____Mud anchor
____Perforated Nipple
____Seating Nipple
____Tubing setting Depth
____Weight and Grade (1 ½ vs. 2 3/8")
____Future fluid removal method (Swab, Tubing plunger, Casing Plunger, Pumping unit)
____Wireline re-entry guide

IV. Acidizing Stimulation Selection Guide

____Matrix Acidizing
____Fracture Acidizing
____HCL(10%, 12%, 15%,20%, or 28%)
____Acetic Acid or Formic Acid (less corrosive)
____Mud acid(12% HCL 3% HF)
____Retarded Acids (gelled acids)
____Foamed Acids (Carbon Dioxide or Nitrogen Assisted)
____Perf Balls (50% more than number of perforations)

____Pickling pipe to remove iron deposits before acidizing (5% HCL + FE control + surfactant)
____15% HCL (20-25 gallons per foot of pay, clay stabilizer, iron control, and surfactant)

Examples of acid volumes identified with chemical additives
(1500 gallons 15% HCL, 3 ½ gallons ClaSta, 3 ½ gallons HAI 65, and 1 ½ gallons PEN 5)
(500 gallons 15% HCL, ½ gallon ClaSta, 1 ½ gallons HAI65, and ½ gallon PEN 5)

VI. Fracture Stimulation Selection Guide

____Volume of fluid required
____Volume of sand
____Type of sand
____Pad volumes
____Expected breakdown, treating pressures and rates (review offset wells)
____Flow back procedure
____Tubing setting depth due to possible sand flowback
____Use of nitrogen or carbon dioxide
____Minifrac pre-stimulation analysis?

Average Ohio Rose Run was treated with ~330 sx and ~1000 bbls of fluid. Average rate was 20-30 bpm at 2000-3000 psi average treating pressure.

V. General Knox Well Completion Steps

____Move In Rig up Service rig
____Check and record pressures on casing and all annulus
____Nipple up Blow out Preventer and pressure test
____Run Gamma Ray, CCL and CBL from PBTD to ~200' above top of cement.
____Perforate the using 3 1/8" select fire guns, hollow steel carriers, or selected gun.
____Provide open hole log with perforations identified and detail listing of perforations
____TIH with 2 3/8" 4.7#/ft. EUE 8 rnd tbg with seating nipple to below lowest perforation

a. Identify tubing capacity in barrels per foot
b. Identify tubing-casing annular capacity in barrels per foot

____Install stripping rubber in well head.
____Remove Blow Out Preventer and Install well head
____Move in rig up service company

c. Circulate hole volume with appropriate weight brine
d. Spot acid across perforations, for example, 500 gallons 15% HCL
e. Displace with brine

____Pull tubing to ~ 30 feet above top perforation, land tubing, secure wellhead.
____Breakdown perforations (identify maximum pressure)
____Ball out perforations in acid
____Surge perf balls off perforations
____Acid or Frac stimulate reservoir
____Record Initial Shut In Pressure, 5 minute, and 10 minute pressure readings
____Rig down move out service company
____Swab well back through 2 3/8" tubing
____Evaluate well
____Record pressure build up rate and estimate reservoir deliverability

Stage IV: Production

The tools available to analyze Knox production include Volumetric, material balance (p/z), and production decline curve analysis. Operators should take advantage of not only the geological and geophysical resources available to analyze production response, but also gather and record as much pressure, volume, and rate date during the early life of the well. Daily as well as monthly production volumes and pressures are invaluable resources for problem identification later in the life of the well.

Due to the high natural deliverability associated with many Knox wells, the life is generally limited to less than 20 years, with some less than 10. Some reservoirs may be very prolific, but have small features.

The following list is provided to assist operators in the production of Knox Wells.

<u>Production Considerations</u>

I. Fluid Removal Methods

____Flowing well (through tubing)
____Soaping
____Swab well
____Casing Plunger
____Tubing Plunger
____Pumping Unit

II. Production Monitoring Method

____Tabular
____Graphical
____Production Decline Curve Analysis

III. Information to gather

____Completion Record
____Workover history
____Wellbore Schematic
____Completion Intervals
____Tubing setting depth
____Record initial casing and tubing shut in pressures
____Record extended shut in pressures to well file for P/Z analysis
____Record initial daily rates and pressures
____Record tests for all fluids for baseline analysis (oil, gas, and water analysis)
____Record and chart monthly fluid volumes and average casing pressure

IV. In the event of suspected problem: reduced or increased fluid volumes

____Echometer to identify fluid levels in annulus
____Review artificial lift production cycles
____Compare Fluid Analysis to original
____Consider Shut in pressure build up test to analyze for skin damage
____Paraffin analysis
____Production logging: Temperature log, sonic log, camera log
____Zonal isolation
  Temporary bridge plug
  Tubing and packer
____Nodal analysis
____RPI Analysis
____Review well file for memo of uncompleted zones to be reviewed prior to moving up hole
____Experience indicate water problems are generally associated with lower stringers in Knox
____Ensure sufficient pump capacity to remove fluid effectively – confirm with Echometer
____Evaluate need to re-stimulate, plug back, or abandon