

HORIZONTAL WELL ARTIFICIAL LIFT CONSORTIUM

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ABSTRACT

The Horizontal Well Artificial Lift Consortium, officially known as the “Tulsa University Horizontal Well Artificial Lift Projects (TUHWALP)” is now an official, funded project. The purpose is to develop an improved understanding of the issues for producing horizontal oil and gas wells, especially where application of artificial lift is required. The research is primarily conducted at the University of Tulsa. There are currently 15 member companies with the number expected to grow.

This paper gives an update of the status of the Consortium and the current research focus.

INTRODUCTION

The vast majority of new wells being drilled for both oil and gas production are horizontal wells. At some point most of these wells will require artificial lift to produce the liquid hydrocarbons and/or dewater the gas wells, but artificial lift of horizontal wells presents many challenges. Artificial lift can be particularly challenging in the shale assets in which the wells are often deep with long horizontal lateral sections.

The Artificial Lift R&D Council (ALRDC) invited a large number of companies to address these challenges. After several meetings, ALRDC with a group of companies has decided to address the problems in a consortium format and selected The University of Tulsa (TU) as the host institution for the consortium.

TU has formed the Tulsa University Horizontal Well Artificial Lift Projects (TUHWALP) to address the challenges of horizontal wells and develop new methods and understandings for advancing artificial lift of these wells. TUHWALP started its activities effective July 1, 2012 and currently has 15 members. Below, is detailed information on TUHWALP.

TUHWALP MISSION STATEMENT

The Horizontal Well Artificial Lift Consortium will work cooperatively in the petroleum industry to:

1. Advance the knowledge and effectiveness of people who design and operate horizontal oil and gas production wells.
2. Develop recommended practices for artificial lift of horizontal wells.
 - o Make recommendations to improve the design and operability of artificial lift for horizontal wells.
 - o Make recommendations to improve the selection, deployment, operation, monitoring, control, and maintenance of artificial lift equipment.
 - o Recommend artificial lift practices to optimize recovery of oil, natural gas, and associated liquids from horizontal wells.

SIGNIFICANCE OF THIS PROJECT

1. It is expected that half of the natural gas produced in the U.S. will be coming from unconventional sources by the year 2030¹ including very tight sands and shale plays. In 2005, the majority of U.S. gas shale production came from four basins²:
 - o San Juan Basin in New Mexico/Colorado (55 MMSCF/D)
 - o Antrim Shale in Michigan (384 MMSCF/D)
 - o Appalachian/Ohio Shales (438 MMSCF/d)
 - o Barnett Shale, Fort Worth Basin, Texas (1,233 MMSCF/D).

There are now several other shale plays in the U.S. that are being explored and proven to have significant reserves. These plays include:

- o Devonian Shale in the Appalachian Basin
- o Marcellus Shale in the Appalachian Basin

- o Mowry Shale in the Powder River Basin
 - o Mancos Shale in the Uinta Basin
 - o Woodford Shale in Ardmore Basin
 - o Floyd/Neal Shale play in the Black Warrior Basin
 - o Barnett Shale in the Permian Basin
 - o New Albany Shale in the Illinois Basin
 - o Eagleford Basin in South Central Texas
 - o Utica Shale in Ohio
 - o Others³.
2. The gas production from shale plays is primarily accomplished through a hydraulic fracturing operation of the horizontal wells. Shale reservoirs are typically naturally fractured and very tight with permeability measured in nano-darcies. Hydraulic fracturing is required to interconnect these natural fractures with the horizontal wellbore by injecting significant amounts of water. After the fractures are created, some of the water must be produced back to the surface, but not more than 20-25% of fracturing fluids are typically recovered; the rest is spread into the reservoir. Experience with the current shale plays indicates that for certain cases the wells still produce water long after the fracturing operation. Moreover, the formations below or above the shale formations may have water. During fracturing operations, the fractures may extend to water bearing formations and result in continuous water production through the life of the well. Even worse, fracturing in one well can interfere with the production operations of the neighboring wells by accelerating the loading problems along the lateral sections.
 3. In addition, water can naturally be present in oil and gas formations. In some shale formations, water is mixed with the gas in the formation. This water needs to be removed to be able to produce the gas effectively. Barnett shale gas wells can produce significant amounts of water. U.S. Geological Survey data indicates that some gas wells can produce up to 39 barrels of water per thousand cubic feet of gas (bblw/MSCF). In Denton County, Texas gas wells produce even more water, up to 53 bblw/MSCF gas. Devon Energy reports that in its Barnett Shale wells, some amount of water is produced for the life of the well with the amount produced varying from trace amounts to 400-500 Bbl/Day. One company producing gas from the New Albany shale in the Illinois basin has reported that the peak gas production from their wells is achieved after 6 to 12 months of dewatering. The Antrim shale in Michigan also contains water that must be removed in order to achieve maximum gas production.
 4. Oil production from oil-shale formations has been increasing significantly in recent years. Some of the gas producers are transforming their operations into oil producers primarily due to market forces. Most wells that are drilled to produce oil are drilled horizontally, and there is much that resembles the issues associated with shale gas horizontal wells.

JUSTIFICATION OF THIS PROJECT

1. Existence of water in a gas well may hinder the production of gas unless it is removed. Therefore, unloading of the wells is one of the most important production challenges. Unloading is especially challenging and not well understood for the horizontal portion of the well. There are several factors affecting the flow. Relatively low gas production rates make the water flow difficult and water may accumulate in the wells resulting in back pressure on the formation and in some instances the water may go back into the formation. Some horizontal wells can have an undulating trajectory resulting in low spots for water to accumulate and not be removed. Moreover, the heel of the horizontal well can sometimes be at a shallower depth than the toe of the well. This requires water to flow uphill in the horizontal portion of the well. For the low gas rates typically produced from these horizontal wells, the water is inevitably expected to accumulate at the toe of the well. There is no reliable model or software tool to predict the unloading of horizontal wells. Development of such a tool requires accurate understanding of the hydrodynamic interplay between the gas and the water.
2. For oil dominated systems, there are unique operating issues that affect the decisions concerning the production operation and artificial lift method to be used. Similar to gas dominated systems, the oil dominated systems require better characterization of the flow of various phases in the horizontal well. Some of the specific issues are:
 - o The determination of horizontal well trajectory, i.e., whether to drill the horizontal wells toe up or toe down

- o The existence of terrain induced slugging and its ramifications
 - o Placement of the artificial lift equipment in the well
 - o Scale formation
 - o Corrosion
 - o Foaming
 - o Asphaltene and paraffin deposition
 - o Frac-sand production.
3. Artificial lift techniques for horizontals are mostly based on practices established in vertical wells in offset fields, without acknowledging the fundamental differences. Pros and cons of the various techniques in horizontals are not well established. Modeling tools are lacking to compare the performance of different techniques.
 4. Moreover, there is no consensus within the petroleum industry as to drilling the wells toe-up or toe-down. Various artificial lift scenarios have been envisioned by the industry such as:
 - o Drilling sumps for placement of artificial lift equipment before the heel of the well
 - o Placing artificial lift equipment in the horizontal sections of well
 - o Placing artificial lift equipment in the toes of horizontal wells.
 5. The type of artificial lift system employed in a well affects the suitability for placement. In addition, the well design (casing size, hole angle build rate, and dog-leg severity), as well as reservoir performance, will affect artificial lift choice and placement. Current industry trends look to rod pumping, hydraulic pumping, progressing cavity pumping, electric submersible pumping, plunger lift, gas-lift, and foam as means for pumping or removing liquids from horizontal wells. Each form of artificial lift has constraints or limitations associated with it. These have been identified in the form of screening criteria for vertical or near-vertical wells. Similar criteria must be developed for horizontal wells. Placement of the end-of-tubing, location for artificial lift equipment (pump, gas lift), and casing size influence the scope and success of artificial lift.
 6. The horizontal well trajectory (e.g. toe up, toe down) will impact the flow regimes occurring along the wellbore, the effectiveness and location of artificial lift equipment, and ultimately the well capacity and ultimate recovery. The horizontal well trajectory is in many cases dictated by drilling location and reservoir architecture. Any compromise between the two needs to be struck early on in field development and requires clear qualification and quantification of the impact of trajectory on artificial lift success. There exists scope for optimizing any trajectory e.g. by drilling a sump to locate artificial lift equipment.
 7. Recommended practices for horizontal wells can be either experience-based or model-based. Model-based optimization starts with understanding the multiphase and transient flow phenomena that occur in horizontal wells. The critical rate in horizontal wells differs from the critical rate in vertical wells and will impact, among other things, the onset of liquid loading. Artificial lift techniques are intended to unload the liquids by changing the multiphase flow behavior. Therefore, the flow behavior is a key to understanding and helping design the artificial lift techniques.

INDUSTRY INTEREST IN THIS PROJECT

A survey of interest companies was conducted by using a questionnaire. It revealed the following potential project subjects; these are listed in order as ranked by the respondents. The average response of operators and service providers was reasonably consistent.

1. Select optimum method(s) of artificial lift for horizontal wells
2. Understand flow regimes and critical rates in horizontal wells
3. Recommend optimum horizontal well geometry and wellbore trajectory
4. Recommend placement of end-of-tubing, location for artificial lift (pump, gas lift), and casing size
5. Summarize industry learning's and literature information
6. Recommend when to start artificial lift operations in horizontal wells
7. Develop training materials and courses for Engineers and Operators associated with horizontal wells.

RESEARCH PLAN

The research subjects listed above are being addressed by the Consortium with three projects.

1. Investigation of multiphase flow behavior in horizontal wells
 - o Needed for the other two projects below.
2. Investigation of artificial lift techniques in horizontal wells
 - o Will help with selection of optimum method(s) of artificial lift in horizontal wells
 - o Placement of end of tubing, location for artificial lift (pump, gas lift), and casing size
 - o Needs to have a component on the well construction and applicability of various artificial lift techniques.
3. Development of guidelines and recommended practices for horizontal wells
 - o Summarize industry learning's and literature information
 - o When to start artificial lift operations in horizontal wells.

The scopes of the three projects are given below.

PROJECT-1: INVESTIGATION OF MULTIPHASE FLOW BEHAVIOR IN HORIZONTAL GAS WELLS

INTRODUCTION

Multiphase flow is encountered in both gas and oil wells: Gas wells will have water and condensate below dew point as the liquid phase while oil wells will have vapor phase as the pressure goes below the bubble point pressure. The available knowledge of multiphase flow in horizontal wells is limited.

GAS WELLS

Multiphase knowledge in gas wells becomes important and relevant when the wells start to load-up with liquids that hinder the production. Unloading of vertical and deviated wells has been studied and is understood to a certain level. The classical work of Turner *et al.*⁴ and studies after Turner such as Coleman *et al.*⁵ describe the mechanisms of the liquid loading and provide guidelines for the prediction of loading. There have primarily been two mechanisms to keep the wells unloaded: 1) keeping the liquid film moving in an upward direction; 2) keeping the entrained liquid droplets from falling.

Mechanisms of horizontal well liquid loading have not been sufficiently studied. The Turner and Coleman models are not applicable for horizontal wells. On the other hand, an appreciable amount of knowledge on low liquid loading flows in pipelines has been accumulated over the last two decades (Sarica *et al.*⁶, Meng *et al.*⁷, Fan *et al.*⁸, Dong *et al.*⁹, and Zhang and Sarica¹⁰). These studies can be classified into high and low gas flow rates. At high gas flow rates, the liquids are continuously produced and no accumulation or loading of the liquids is observed. While the low gas flow rate studies indicated accumulation of the liquids and irregular slugging.

OIL WELLS

The interaction between main flow and side entry from the formation has been studied for single-phase oil flow in a perfectly horizontal pipe by Yuan *et al.*^{11, 12} and Aziz¹³. Very limited studies for two-phase flow of liquid and gas were conducted for perfectly horizontal wells. There are no studies of oil dominated multiphase flow in undulating horizontal wells with multiple entries. Multiphase flow is inevitable especially when the pressures are depleted below the bubble point which will be encountered when artificial lift is considered. A wide range of gas-oil-ratios (GORs) are expected to be experienced for oil wells. The performance and selection of the artificial lift methods will be dependent on the flow behavior.

WELL GEOMETRY

Most horizontal wells are not perfectly horizontal and can have undulations. Moreover, horizontal wells can be drilled toe-up or toe-down. The flow characteristics of an undulating horizontal well are more complicated than that in a pipeline considering the multiple fluid entry locations along the well. During multiphase flow, the phases may separate, and liquid and gas may accumulate at the lower and higher spots of the horizontal well, respectively, causing irregular slugging or back-flow into the reservoir that may significantly reduce the production capacity of a formation. Hydrodynamic behavior of two or multi phases (flow pattern determination and the predictions of pressure drop and holdup) for undulating horizontal well flow are crucial.

PROJECT OBJECTIVES

The objectives of this project are:

- o Investigate multiphase flow characteristics for horizontal oil and gas wells experimentally/theoretically and how they are affected by well geometry or trajectory.
- o Develop mechanistic liquid loading criteria for horizontal gas wells.
- o Develop a multiphase flow model that simulates multiphase flow in horizontal wells
- o Develop a predictive software tool incorporating model development results.

PROJECT PLAN

This project will have experimental and model development components to characterize the flow in horizontal wells.

EXPERIMENTAL STUDY

Operating conditions of horizontal wells will experimentally be simulated using an existing 3 in. ID, 1,400 ft. long experimental facility. The facility will be modified to include:

- o At least two undulations (one undulation consists of one downward and one upward inclined pipe with a dip)
- o Gas and liquid feeds along the test section to mimic the horizontal well fractures
- o Toe-up and toe-down configurations
- o Proper instrumentation

TESTING

Testing will be performed for various gas and liquid flow rate combinations that are typical of horizontal well production to investigate flow behavior and the liquid loading/unloading conditions. The testing is expected to produce an experimental map of liquid loading. The toe-up, toe-down and flat configuration will be studied. The detailed test matrix will be developed later based on the final configuration of the test section.

MODELING STUDY

A mechanistic model (physics based) to characterize the flow and to predict the liquid loading will be developed. The experimental results will be utilized in model development.

PROJECT-2: INVESTIGATION OF ARTIFICIAL TECHNIQUES IN HORIZONTAL WELLS

INTRODUCTION

Once the liquid loading is identified as a problem for vertical or deviated gas wells, many different loading mitigation and elimination techniques and methods can be utilized. The classical methods include velocity strings (production tubing size reduction), surfactant utilization to promote foaming (soap sticks or soap injection), beam pumping, plunger lift, electrical submersible and hydraulic pumping, and gas lift. Each method has its advantages, disadvantages, and applicability conditions. Several of these unloading methods can be and have been applied to horizontal wells with some prior design thought in horizontal wells. The performance and applicability of each unloading technique will be strongly influenced by the multiphase flow behavior and distribution of the fluids in the horizontal well.

Horizontal wells drilled into oil bearing formations will also need artificial lift typically when the reservoir pressures are depleted significantly. They will also be producing under multiphase flow conditions as discussed previously. Similar issues encountered in gas wells will also be encountered in oil wells.

PROJECT OBJECTIVES

The objectives of this project are:

- o Acquire field data and summarize field practices.
- o Experimentally and theoretically investigate the performance of various artificial lift techniques.
- o Develop performance evaluation tools based on flow dynamics and well construction profile.
- o Generate an artificial lift method selection criteria road map based on field data, and experimental and theoretical results.

PROJECT PLAN

This project will have experimental and model development components.

EXPERIMENTAL STUDY

Operating conditions of horizontal wells will experimentally be simulated using a large scale experimental facility. A new experimental facility, dedicated to this project, will be designed and constructed. The features of the facility will include:

- o At least two undulations (one undulation consists of one downward and one upward inclined pipe with a dip)
- o Large pipe diameter between 4 in. or 6 in.
- o Gas and liquid feeds along the test section to mimic the horizontal well fractures.
- o Toe-up and toe-down configurations
- o Ability to incorporate and test various artificial lift methods

TESTING

Testing will be performed for various gas and liquid flow rate combinations that are typical of horizontal gas and oil wells. The testing is expected to produce efficacy measures of various artificial lift methods. The detailed test matrix will be developed later based on the final configuration of the test section and the artificial lift methods to be investigated.

MODELING STUDY

Mechanistic models (physics based) will be developed to predict the efficacy of various artificial lift methods. The experimental results will be utilized in model development.

PROJECT-3: DEVELOPMENT OF GUIDELINES AND RECOMMENDED PRACTICES FOR UNLOADING HORIZONTAL GAS WELLS

INTRODUCTION

The industry needs basic guidelines and recommended practices for the unloading of horizontal gas wells. Currently, the guidelines and recommended practices developed for vertical and deviated wells are used. In the field new practices are being tried and applied for horizontal wells. Currently, there is no concerted effort to develop the basic guidelines and recommended practices.

PROJECT OBJECTIVES

The objective of this project is to develop guidelines and recommended practices for the selection of the proper artificial lift techniques.

PROJECT PLAN

- o Gather data on field practices in horizontal well artificial lift.
- o Develop a database on the performance of various field artificial lift practices.
- o Test the performance of various practices with the model simulations.

PROJECT DELIVERABLES

The following deliverables will be provided:

Project-1

1. Understanding two-phase gas-liquid flow in horizontal wells
2. Model and software to predict flow behavior
3. Understanding liquid loading for horizontal wells and liquid loading criterion
4. Experimental data
5. Guidance to determine optimum horizontal well geometry.

Project-2

1. Unloading performance of various artificial lift methods and their comparative analysis
 - o Tubing insert
 - o Surfactants
 - o Pumping systems
 - o Gas-lift

- o Impact of slugging
- 2. Experimental data
- 3. Analysis of setting location of artificial lift equipment

Project-3

- 1. Database consisting of both field and experimental data
- 2. Analysis of the data
- 3. Guidelines and recommended practices based on field and experimental data.

CURRENT STATUS OF THE PROJECT

There has been significant progress on every project since the inception of the consortium. Status updates are given below on project by project basis.

Project-1:

- 1. The construction of a new facility for this project has recently been completed. The experimental studies have been started. The facility specifications are given in Table-1. The facility is versatile to investigate not only the multiphase flow behavior of horizontal wells but also for investigating and testing various artificial lift systems. Currently, testing is underway for toe-down conditions.
- 2. A CFD (computational fluid dynamics) model has already been developed and tested successfully for toe-up configuration for a single entry using severe slugging data of pipeline-riser flow systems. The model will be tested with the data to be acquired from the facility. The next steps in model development will be to incorporate multiple fluid entry locations along the horizontal well.

Project-2:

- 1. The design of a large scale facility has been completed. The construction efforts are currently underway. Graduate students are identified and commitments are made for them to start working on the project effective August, 2013.

Project-3:

- 1. The graduate student for this project has started his studies beginning of January, 2013. A data collection survey is being prepared. This survey will be sent to the member companies. Moreover, the public domain information on horizontal well artificial lift will be collected.

COMMITTEES, SUB-COMMITTEES, AND THEIR ROLES

The main body of the Consortium is the Advisory Board. The Advisory Board consists of assigned people from each of the member companies. Each member company has one person assigned to the Advisory Board. They direct the overall operation of the project. There are two sub-committees, The Technical Support Sub-Committee and The Technology Transfer Sub-Committee. These monitor and advise the activities of the Consortium. Each member company has the option to assign a representative to these sub-committees. Rob Sutton of Marathon is chair of the Technology Support Sub-Committee. Greg Stephenson of ConocoPhillips is chair of the Technology Transfer Sub-Committee. In addition, each project has three to four project champions who are intimately involved in the conduct of the projects.

PROJECT MEETINGS

There are two meetings of the full project membership each year, one in the Spring and one in the Fall. They are held at the University of Tulsa or at a facility in Tulsa designated by the University. The general agenda for these meetings is:

- o Review work completed since the last meeting.
- o Present work planned for the next six months.
- o Discuss and vote on any issues that need to be decided by the project membership.
- o Visit and tour the R&D facility.

Each sub-committee has four meetings in a year. Two are held in person during the Advisory Board meetings and two are conducted through teleconferencing in between the Advisory Board meetings. The project champions can meet with The University of Tulsa Research staff any time they feel necessary or as requested by the research staff.

MEMBER COMPANIES

The current member companies of the Consortium are:

- o ALRDC
- o BP
- o Chesapeake
- o Chevron
- o ConocoPhillips
- o Devon
- o Encana
- o ExxonMobil
- o GE Oil and Gas
- o Marathon Oil Corporation
- o Norris Production Solutions
- o Range Resources
- o Shell International EP
- o Southwest Energy
- o Weatherford

POSSIBILITY OF A HORIZONTAL TEST WELL

The Artificial Lift R&D Council (ALRDC) is interested in exploring the idea of having an actual horizontal well to test and evaluate the findings from the research project conducted at the University of Tulsa. There are a number of possibilities for implementing a horizontal test well. One that has been discussed is to drill a horizontal extension to the existing vertical Red Raider No. 1 test well at Texas Tech University. The University is willing. Now the task is to design the horizontal extension and to find companies that will be willing to contribute the drilling, completion, and equipping of the well.

PROJECT SCHEDULE

The currently planned project schedule is shown here.

Project Timeline (2012-2015)

Projects	Tasks	Year-1 (2012)				Year-2 (2013)				Year-3 (2014)				Year-4 (2015)			
		Q-1	Q-2	Q-3	Q-4	Q-1	Q-2	Q-3	Q-4	Q-1	Q-2	Q-3	Q-4	Q-1	Q-2	Q-3	Q-4
Project-1 Investigation of Multiphase Flow Behavior in Horizontal Wells	Small Scale Facility Modification																
	Facility Commissioning and Preliminary Tests																
	Experimental Program																
	Data Analysis																
	Modeling Study																
	Final Report																
	Quarterly Updates																
	Advisory Board Meetings																
Project-2 Investigation of Artificial Techniques in Horizontal Wells	Large Scale Facility Design & Construction																
	Facility Commissioning and Preliminary Tests																
	Experimental Program																
	Data Analysis																
	Modeling Study																
	Final Report																
	Quarterly Updates																
	Advisory Board Meetings																
Project-3 Development of Guidelines and Recommended Practices	Quarterly Updates																
	Advisory Board Meetings																
	Literature Search and Field Data Solicitation																
	Data Analysis																
	Development																

PROJECT BUDGET

The current project budget is shown here. This can be modified by vote of the Project Membership if required

Expense Item	Year One	Year Two	Year Three	Year Four	Total
Salaries and Wages	\$189,024	\$251,139	\$283,657	\$292,167	\$1,015,986
Fringe Benefits	\$51,416	\$67,208	\$71,223	\$73,360	\$263,207
Other Direct Costs (Equipment, Supplies, etc.)	\$662,000	\$554,500	\$499,500	\$449,500	\$2,165,500
Total Direct Costs	\$902,440	\$872,846	\$854,380	\$815,026	\$3,444,693
Indirect Costs	\$99,048	\$131,597	\$148,636	\$153,095	\$532,377
Total Costs	\$1,001,489	\$1,004,443	\$1,003,016	\$986,121	\$3,977,069

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