

# AN INDUSTRY CONSORTIUM FOR ARTIFICIAL LIFT OF HORIZONTAL WELLS

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## ABSTRACT

The vast majority of new wells being drilled for both oil and gas production are horizontals. 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 lateral sections.

To address these challenges, the Artificial Lift R&D Council (ALRDC) invited a large number of companies to form a Consortium to develop new methods and understanding for advancing artificial lift of these wells. This Consortium is being led by the University of Tulsa.

This paper discusses the status of this effort and presents some of the challenges that the members of the Consortium are facing.

## INTRODUCTION

The face of the hydrocarbon production industry has changed dramatically in the last few years. The largest change is associated with the production of natural gas, condensates, and oil from shale formations. Figure 1 shows the major shale basins in the world. The potential is enormous.

Production of gas and oil from shale formations requires drilling, completing, and operating horizontal wells. The horizontal wells are needed to contact large portions of the reservoirs and the natural “micro” fractures they contain.

The wells must be treated with multi-stage hydraulic fractures to permit oil and gas to flow from the reservoirs to the wellbores. Figures 2 and 3 show numbers of horizontal wells drilled in the Marcellus Shale in Pennsylvania and the Barnett Shale in Texas. These are only examples of the development activity, but they show the significant rate of increase of this activity.

There are many challenges in producing horizontal wells.

- Much of the water used to fracture the wells must be produced back from the formations to reduce back-pressure and clear the flow paths for gas and oil production.
- Often some of the fracture sand will be produced back with the water; both the water and the sand must be artificially lifted from the wells.
- Most artificial lift systems are designed to work in the vertical sections of wells. Methods must be developed to help sweep and lift fluids from the deviated and/or horizontal portions of the wellbores.
- Most “horizontal” wells are not actually horizontal. Figures 4 and 5 show some typical basic and complex “horizontal” well profiles. These vary from “toe up,” to essentially horizontal, to “toe down.” Each profile presents special production challenges.

- Often the “horizontal” portions of the wells have up and down undulations as shown in Figure 6. Water can accumulate in the low spots and then be produced to the “vertical” part of the well in slugs. This can make artificial lift challenging, especially when pumping systems are used.
- Reasonable methods exist to determine the “critical” gas flow velocity needed to lift liquid out of vertical gas wells. There is a need for improved understanding and models to determine the “critical” gas flow velocity in horizontal wells.

For these and other reasons, the Petroleum Industry is forming a Horizontal Well Artificial Lift Consortium as described below.

#### HORIZONTAL WELL CONSORTIUM MISSION STATEMENT

One of the first steps taken by the group of interested companies was to develop a “mission statement” for the consortium. It is to work cooperatively in the Petroleum Industry to:

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

#### **Primary Focus of the Consortium**

Initially, the primary focus of this project was on horizontal gas wells. However, with the shifting economics of oil and gas production, and with the increase in hydrocarbon liquids production from horizontal shale formations, the emphasis has been expanded to focus on both liquids and gas production from horizontal wells.

#### **Survey of Operating and Service Companies**

The next step was to conduct a survey of interested companies to discern their challenges and priorities for dealing with horizontal wells. The primary results of the questionnaire are shown in the table below. The companies were asked to rank each potential initiative from 1 to 6. The averages of the rankings are shown on the right. The lowest average number represents the highest ranking; that is, number “1” represents the highest priority.

The highest priority items that the companies feel should be pursued are:

1. Focus on the investigation of flow pattern behavior and the development of new/improved models for understanding flow and critical rate in horizontal wells. Currently, the industry uses the Turner<sup>1</sup> and Coleman<sup>2</sup> methods for estimating the critical gas flow velocity in vertical gas wells, and a number of calibrations or mechanistic models for estimating the pressure profiles in vertical oil and gas wells. These methods are not sufficient for use in horizontal wells. A primary focus of the research to be undertaken by the Horizontal Well Artificial Lift Consortium will focus on development of new understanding and models for use in horizontal wells.
2. Focus on recommendations for well geometry and wellbore trajectory. As shown above, many “horizontal” wells are not truly horizontal. The companies feel that there may be significant benefits from choosing the “best” wellbore trajectory – toe up, horizontal, or toe down. They also feel there may be strong reasons to avoid undulations in the horizontal well if possible. There is also discussion of the pros and cons of drilling sumps before the heel of the wellbore to have a vertical or near vertical portion of the wellbore for landing artificial lift equipment. Research and a review of case studies will be undertaken to address these questions.
3. Focus on key well design issues such as placement of end of tubing, location for gas injection, and size of casing needed. There are always economic trade-offs between the cost of drilling and completing wells and the ease of producing the wells over time. The companies feel that they need strong evidence to support their recommendations for using casing sizes large enough to accommodate optimal types of artificial lift systems.

They also need guidelines on where to inject gas when gas-lift is used; whether in the vertical part of the well, in the deviated area, at the heel, along the horizontal portion of the well, or at the toe of the well. And they need guidelines on where to place the end of the tubing. Research and a review of case studies will be undertaken to address these questions.

4. Focus on choice of the “optimum” method of artificial lift for horizontal wells. Operating Companies have many choices for artificial lift systems. The ALRDC has historically sponsored industry efforts to develop information and methods to assist in selecting the “best” or “optimum” method of artificial lift for wells<sup>3</sup>. Here-to-fore much of this has focused on artificial lift of vertical gas wells. Choices for types of artificial lift include chemical systems, plunger lift, various types of pumping systems, various configurations of gas-lift, and other techniques including wellhead compression, use of velocity strings, “stop cocking,” downhole water separation and disposal, use for vortex creation devices, and various other operating techniques. Recommendations and guidelines are needed for which method(s) of artificial lift are most suitable for different horizontal well operating conditions. Research and a review of case studies will be undertaken to address these questions.
5. As part of these efforts, and in addition to them, a comprehensive review will be conducted of all available literature to determine current “best” practices for artificial lift of horizontal gas and oil wells.
6. Finally, this list is by no means exhaustive. New ideas will be generated as this project unfolds over time. The members of the Consortium will meet at least twice annually to review progress, set and/or adjust priorities, and establish new initiatives.

#### CONSORTIUM MEMBERSHIP

Membership in the Consortium is open to any Operating Company, Service/Supply Company, Consulting Company, or University. The annual membership fee will initially be \$50,000. The Consortium Advisory Board may change this amount in the future depending on the number of Consortium members and the amount of work to be done.

With the prior approval of the University of Tulsa and the Consortium Advisory Board, a member may make an equivalent amount of in-kind contributions in lieu of the membership fee and will be assigned the rights of a member. The in-kind amount must be verified annually to assure the equivalent amount meets the membership fee effective for that year.

The membership terms are detailed in a letter of agreement which has been supplied to interested organizations and can be made available to any other interested organization.

**ALRDC Role.** There will be a special role for ALRDC. It will assist in formation of the Consortium and coordination of its activities. If necessary, it can provide “seed money” or pay some upfront costs to get this program going.

**Limitations.** No member company may sell, give, or otherwise make results available to any non-member of the Consortium without the expressed permission of the Consortium Advisory Board. Results of the consortium will not be published or released publically until they have passed the University review process. This usually requires two years after the information is first provided to the members.

#### CONSORTIUM R&D PLAN

The horizontal well artificial lift research and development priorities listed above will be addressed with the following four projects. Other projects will likely follow as this project unfolds.

- Project 1: Understand flow regimes and critical flow rates and investigate multiphase flow behavior in horizontal gas wells.
- Project 2: Investigate artificial lift techniques in horizontal gas wells. This will help with:
  - Selection of optimum method(s) of artificial lift in horizontal wells.
  - Placement of end of tubing, location for artificial lift equipment (pump, gas lift), and casing size.
  - Design of well construction and applicability for various artificial lift techniques.

- Project 3: Develop guidelines and recommended practices for horizontal gas wells.
  - Summarize industry learning's and literature information.
  - Develop guidelines for when to start artificial lift operations in horizontal wells.
- Project 4: Investigate multiphase flow behavior in horizontal oil wells.

### SCOPE

The scopes of the four projects listed above are given below.

#### **Project-1: Investigation of Multiphase Flow Behavior in Horizontal Gas Wells**

The objectives of this project are:

- Investigation of the multiphase flow characteristics for horizontal gas wells. experimentally/theoretically and how they are affected by well geometry or trajectory.
- Development of mechanistic liquid loading criteria for horizontal gas wells.
- Based on the developed criteria, development of a predictive software tool for liquid loading.

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 2 in. ID experimental facility.
- The facility will be modified to include:
  - At least two undulations (one undulation consists of one downward and one upward inclined pipe with a dip).
  - Gas and liquid feeds along the test section to mimic the horizontal well fractures.
  - Toe-up and toe-down configurations.
  - Proper instrumentation.

Testing

- Testing will be performed for various gas and liquid flow rate combinations that are typical of horizontal well production to investigate the liquid loading/unloading.
- 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 predict the liquid loading will be developed.
- The experimental results will be utilized in model development.

#### **Project-2: Investigation of Artificial Techniques in Horizontal Gas Wells**

The objectives of this project are:

- Acquire field data and summarize field practices.
- Experimentally and theoretically investigate the performance of various unloading techniques.
- Develop performance evaluation tools based on flow dynamics and well construction profile.
- Generate an unloading 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 to characterize the flow in horizontal wells.

#### 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:
  - At least two undulations (one undulation consists of one downward and one upward inclined pipe with a dip).
  - Large pipe diameter between 4 in. or 6 in.
  - Gas and liquid feeds along the test section to mimic the horizontal well fractures.
  - Toe-up and toe-down configurations.
  - 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 the liquid loading.
- The testing is expected to produce efficacy 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) 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**

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

#### Project plan

- Gather data on field practices in horizontal well unloading.
- Develop a database on the performance of various field artificial lift practices.
- Test the performance of various practices with the model simulations.
- Develop the guidelines and the recommended practices based on the above items.

### **Project-4: Investigation of Multiphase Flow Behavior in Horizontal Oil Wells**

The objective of this project is the investigation of the multiphase flow characteristics for horizontal oil wells experimentally/theoretically and how it is affected by well geometry or trajectory.

#### Project plan

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

#### Testing

- Testing will be performed for various gas and liquid flow rate combinations that are typical of horizontal oil well production.
- The testing is expected to reveal flow behavior that will help decide optimum production of the horizontal well.
- 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 will be developed.
- The experimental results will be utilized in model development.

## DELIVERABLES OF THE FOUR PROJECTS

The following deliverables will be provided:

### Project-1

- Understanding of the liquid loading for horizontal wells.
- New liquid loading criteria.
- Experimental data.
- Efficiency of self-unloading.
- Guidance to determine optimum horizontal well geometry from unloading perspective.

### Project-2

- Unloading performance of various artificial lift methods and their comparative analysis.
- Tubing insert.
- Gas-lift.
- Surfactants.
- Pumping systems.
- Impact of slugging.
- Experimental data.
- Analysis of setting location of artificial lift equipment.

### Project-3

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

### Project-4

- Understanding of the oil dominant flow behavior of horizontal wells.
- Experimental data.
- Model describing the flow behavior.

## CONSORTIUM STATUS

The first official meeting of the Horizontal Well Artificial Lift Consortium was held at British Petroleum's offices in Houston, Texas on Jan. 12, 2012. Thirty one people representing twenty one companies attended. Of these, six companies indicated that they will or are very likely to join the Consortium in the near future. Another seven said that they are interested but will need to review it with their management. Three companies will join on the basis of providing services in lieu of paying a membership fee.

Efforts will continue over the next few months to line up more members for the Consortium. Presentations will be made at the 2012 Gas Well Deliquification Workshop and the Southwestern Petroleum Short Course.

Currently it appears that the Consortium can officially begin its work in the summer of 2012. The next meeting of the Consortium members is tentatively planned for summer, 2012, at the University of Tulsa.

CONSORTIUM R&D TIMELINE

The current tentative timeline for the work of the Consortium is shown below.

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 for Gas Dominated Systems																
	Data Analysis																
	Modeling Study																
	Final Report																
	Quarterly Updates																
Project-2 Investigation of Artificial Techniques in Horizontal Wells	Advisory Board Meetings																
	Large Scale Artificial Lift Facility Design Construction																
	Facility Commissioning and Preliminary Tests																
	Experimental Program																
	Data Analysis																
	Modeling Study																
	Final Report																
Project-3 Development of Guidelines and Recommended Practices	Quarterly Updates																
	Advisory Board Meetings																
	Literature Search and Field Data Solicitation																
	Data Analysis																
	Development of Guidelines & Recommended Practices																
	Final Report																
	Quarterly Updates																
Project-4 Investigation of Multiphase Flow Behavior in Horizontal Oil Wells	Advisory Board Meetings																
	Experimental Program for Oil Dominated Systems																
	Data Analysis																
	Modeling Study																
	Final Report																
	Quarterly Updates																
	Advisory Board Meetings																

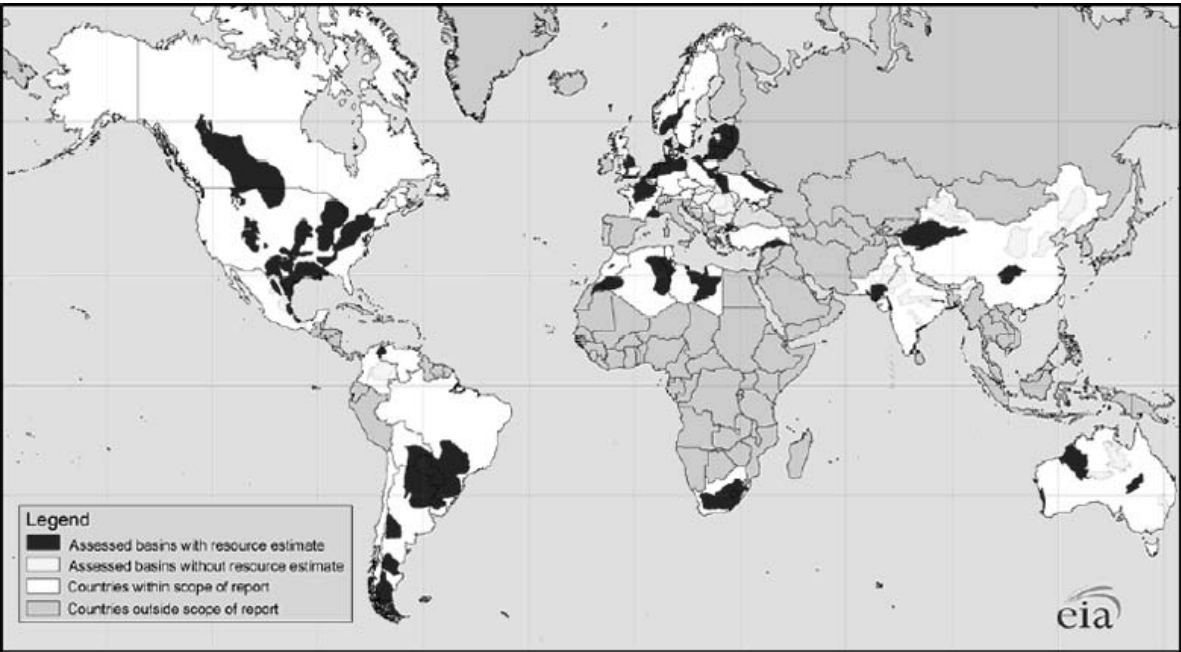


Figure 1 - Major Shale Basins of the World

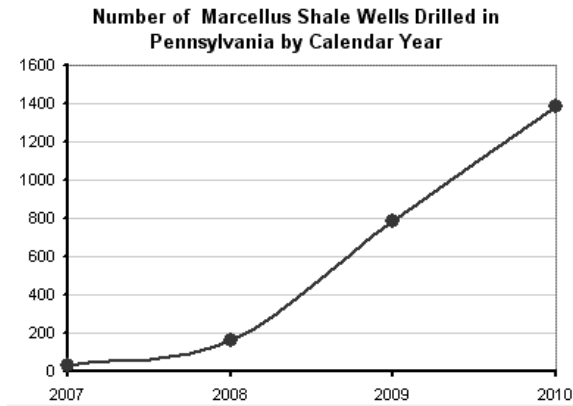


Figure 2 - Number of Marcellus Shale Wells Drilled

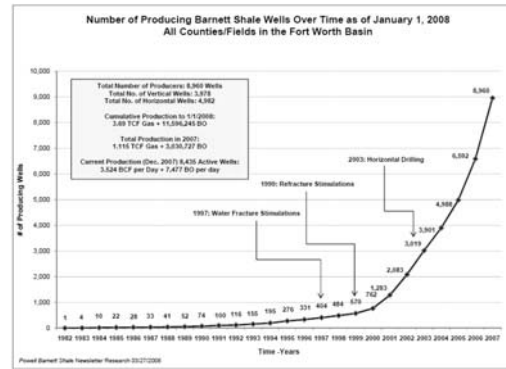


Figure 3 - Number of Producing Barnett Shale Wells

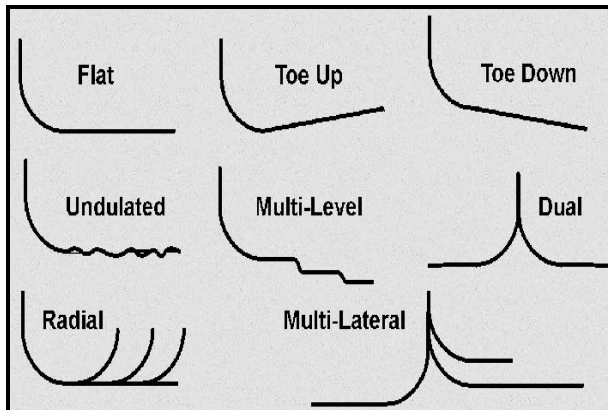


Figure 4 - Basic Horizontal Well Profiles

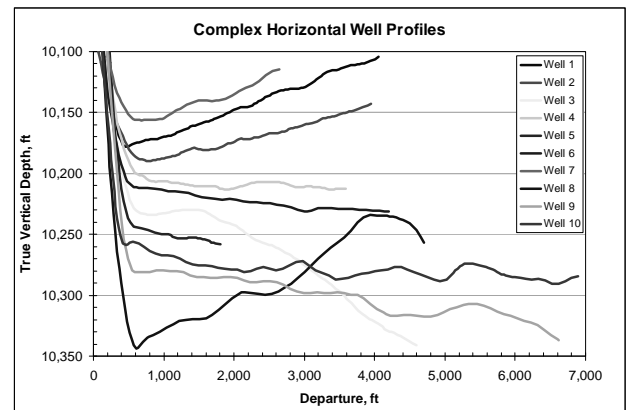


Figure 5 - Complex Horizontal Well Profiles

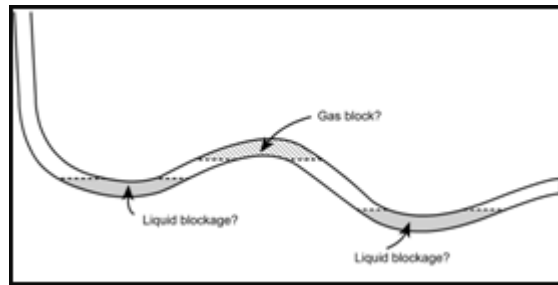


Figure 6 - Typical Undulations in Horizontal Wells



No. Should the project?		Priorities given by fourteen different companies																Avg.	Rank
1	Focus on choice of the "optimum" method of artificial lift for horizontal wells.	2	1	5	1	5	3	3	0	4	6	6	3	6	5			2.77	4
2	Focus on development of new/improved flow regimes or models for understanding flow and critical rate in horizontal wells.	1	3	2	4	1	4	1	0	2	4	1	2	5	1			1.77	1
3	Focus on recommendations for well geometry and wellbore trajectory.	3	4	3	5	5	1	4	0	1	1	2	6	2	3			2.23	2
4	Focus on key well design issues such as placement of end of tubing, location for gas injection, size of casing needed.	4	2	4	2	2	6	2	0	3	3	5	4	1	2			2.54	3
5	Focus on learning from work that has already been done in the Industry.	5	5	1	3	3	5	5	0	5	5	4	1	4	4			3.15	5
6	Other: Please define your objective	6	6	6	6	6	2	6	0	6	2	3	5	3	7			3.77	6