March 14, 2011

TELEDYNE ISCO
A Teledyne Technologies Company

Unconventional Natural Gas: Laboratory Modeling with High-Precision Syringe Pumps

• *white paper*

Abstract

Natural gas is a fossil fuel of growing importance due to its abundance in various forms, environmental friendliness (it burns cleaner than crude oil or coal), and availability of large reserves, particularly in North America. Natural gas has the potential to lower CO_2 emissions while promoting energy independence. However, despite these advantages, some natural gas reserves are difficult to recover through conventional means and must therefore be extracted using unconventional technology. Natural gas recovered using these unconventional techniques is considered Unconventional Natural Gas. While there is some existing technology borrowed from the oil industry, improvements and new technologies are needed to expand natural gas production to meet the expected demand.

This report will provide an overview of the rapidly expanding natural gas industry, as well as a discussion of unconventional retrieval methods and the research required to reduce their costs and risks.

An Abundant Source of Clean-Burning Energy

Natural gas is a fossil fuel made up of the gases ethane, propane, butane, and about 70% methane. Other components such as carbon dioxide, hydrogen sulfide, nitrogen, and water can also be present. These components are separated, purified, and used in many ways, including:

• Fuel for transportation and electricity generation	(Methane)
• Feedstock for petrochemicals, refrigerant	(Ethane)
• Fuel for transportation, stove gas, central heating	(Propane)
• Carbonation in soft drinks, Enhanced Oil Recovery	(Carbon Dioxide)

Natural gas can be used directly as a vehicle fuel, for power generation, and in the production of chemicals, plastics, and fertilizers. Natural gas currently accounts for over 25% of the total energy used in the United States. There are many advantages to using natural gas in comparison with oil and coal, including its lower cost on an energy/dollar basis, and its lower carbon footprint, which can reduce greenhouse gas emissions by 30 to 40%

Natural Gas is often associated with oil, coal fields, or shale fields, as it is produced during the same recovery process. These sources, however, are often located at great depths, making coal or oil recovery unfeasible but not necessarily preventing recovery of the associated natural gas. Deeper depths mean higher pressures; therefore, higher pressure equipment is required to perform the necessary research and development.

Growing Energy Demands vs. Environmental Concerns

The rapid growth of developing countries and evolving economies worldwide has accelerated over the last few decades, directly affecting a sharp increase in global demand for energy, which, according to Peter Voser, CEO of Royal Dutch Shell, is expected to double in the first half of this century. Accompanying the steeply rising demand for energy is the increasing imperative to control greenhouse gas emissions.[1]

Natural gas combustion produces significantly less greenhouse emissions than that of either coal or oil.[2]

Unconventional Natural Gas

Unconventional energy is that which is produced by any non-standard means. Unconventional Natural Gas is usually associated with low- permeability reservoirs located in sandstone, shale, or coal beds. These reservoirs can be difficult to access, as they may be formed in thin layers. Recovery, therefore, may require advanced techniques such as horizontal drilling, hydraulic fracturing, and in some cases, the injection of fluids (enhanced gas recovery) to stimulate production.

World Distribution of Conventional and Unconventional Natural Gas Reserves

Worldwide, 61% of conventional natural gas reserves are located in the Middle East and Eurasia, and about 4% or 283 trillion cubic feet located within the United States. However, when unconventional natural gas is also considered, most reserves are located in North America, as seen in the following table[3]:

Region	Coal Bed Methane (Tcf)	Shale Gas (Tcf)	Tight-Sand Gas (Tcf)	Total (TcF)
North America	3017	3842	1371	8230
Latin America	39	2117	1293	3449
Western Europe	157	510	353	1020
Central and Eastern Europe	118	39	78	235
Russia	3957	627	901	5485
Middle East and North Africa	0	2548	823	3371
Africa	39	274	784	1097
China	1215	3528	353	5096
Asia	470	314	705	1489
Other	39	2313	745	3097
World	9051	16112	7406	32560

When the recoverable reserve estimates are combined with the conventional reserves, the USA estimates add up to about 2,074 trillion cubic feet. According to energy independence advocate and investor T. Boone Pickens, “This is equivalent to the energy in 350 billion barrels of oil, or about the same as total oil reserves in Saudi Arabia.” The figure below[4] shows expected trends in conventional and unconventional natural gas.

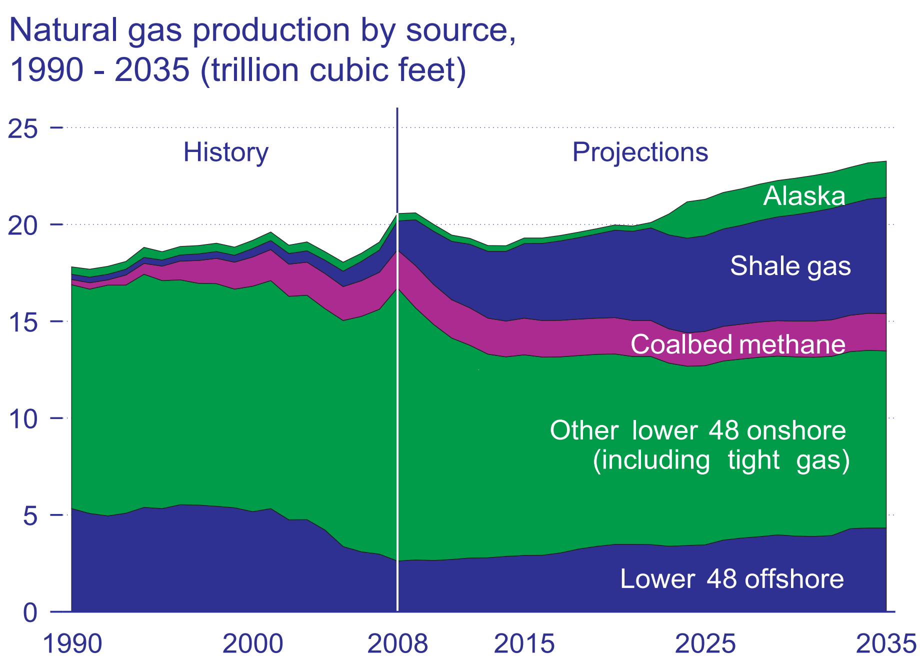

Figure 1: Natural gas production by source, 1990-2035 (trillion cubic feet)

As can be seen in Figure 1, unconventional natural gas currently represents most of the natural gas development, particularly in North America.

Types of Unconventional Natural Gas

Any natural gas reserves that require the use of unconventional technology are thereby known as Unconventional Natural Gas. Some types of unconventional natural gas include:

- Coal bed Methane – Found in coal seams, this may be largest source of natural gas.
- Shale Gas – Trapped in lateral deposits of highly immpermeable shale, these gases are formed under great heat and pressure.
- Tight Gas – This gas occupies small, unconnected cavities in impermeable rock.
- Deep Gas – These natural gas deposits are located at depths greater than 15,000 feet – mostly located undersea.
- Geo-Pressurized Zones – deposits under high pressure located between 15,000 and 25,000 feet. Total reserve estimates may exceed conventional and unconventional gas combined, with the exception of methane hydrates.
- Methane Hydrates – Possibly the largest reserves of all unconventional sources, methane hydrates consist of methane locked inside the crystalline lattices of water molecules in sediment below the ocean floor, formed under low temperature and high pressure.

Coal Bed Methane

Human activity accounts for about 60 percent of atmospheric methane emissions, as can be seen from the following:

- Decomposing forests and wetlands – 40%
- Rice cultivation – 19%
- Livestock – 11.5%
- Landfills – 8%
- Biomass burning – 11.5%
- Oil & Gas well venting – 4%
- Coal mining – 6%

Of the list above, the best chance of improving methane recovery is from coal mining, with the additional gain of increasing methane gas production. Coal stores 6 to 7 times more gas than the equivalent rock volume of a conventional gas reservoir[5].

There are several means to extract gas from coal:

- Removing water present in coal, which reduces the pressure and allows the gas to de-absorb from the coal
- Coal seam fracturing
- Enhanced Coal bed methane recovery (ECBM)

Permeability is a key factor for coal bed methane, with almost all the permeability due to fractures. Increasing fractures via hydraulic fracturing is common in the oil industry and can be used effectively with coal seams.

ECBM involves injecting gases, including nitrogen and carbon dioxide. These gases will displace the methane that permeates coal fields and drive it toward the production well. In the case of un-mineable coal, the use of CO_2 has the dual benefit of extracting usable methane while sequestering the CO_2. Considerable R&D effort is underway to combine ECBM and carbon sequestration projects.

Major Coal Bed Methane Sites

- Powder River Basin - Wyoming and Montana
- Central Appalachian Basin - West Virginia, Kentucky
- Northern Appalachian Basin – Pennsylvania, Ohio
- Illinois Basin – Illinois
- Cherokee Basin - Kansas
- Arkoma Basin - Oklahoma
- Powder River Basin - Wyoming
- San Juan Basin – Colorado, New Mexico

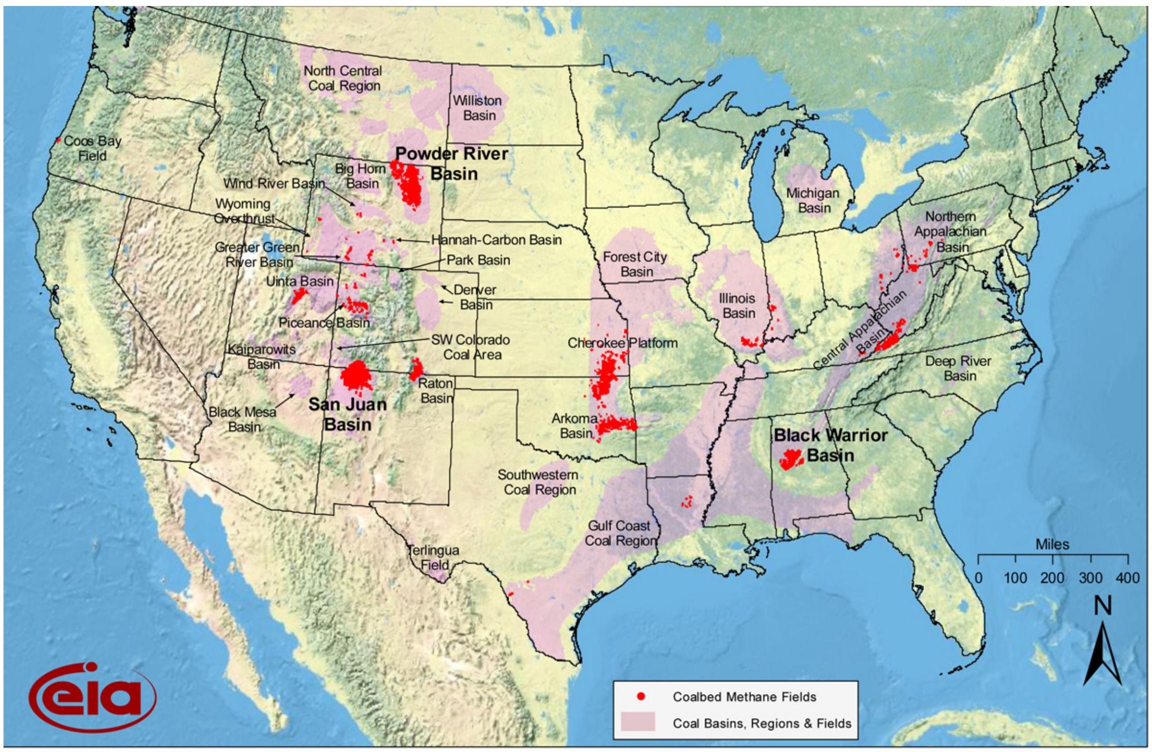

Figure 2: Coalbed methane fields, Lower 48 Source: Energy Information and Administration based on data from USGS and various published studies. Updated: 4-8-2009.[6]

Shale Gas

Shale gas is an unconventional natural gas extracted from shale and is expected to become a major source of natural supplies in the United States by 2020. Because most shale does not have sufficient permeability, significant fluid flows are not naturally possible. Therefore, shale gas is considered an unconventional natural gas, whereby special techniques are required to recover it. These techniques include horizontal drilling and hydraulic fracturing to create artificial flow paths for the gas to follow.

Currently most shale gas is being produced in the United States and Canada. Potential fields in China and Europe are not yet being developed.

Major Shale Gas Sites

- Barnett Shale – Texas
- Barnettte Shale, Fayetteville Shale, Bakken Shale, Haynesville Shale, Marcellous Shale, Woodford Shale, Cotton Valley, Eagle Ford Shale, Niobrara Shale, Utica Shale, and Piceance-UintaFayetteville Shale – Arkansas
- Bakken Shale – Montana & North Dakota
- Haynesville Shale – Louisiana, Texas and Arkansas
- Marcellus Shale – Pennsylvania, West Virginia, New York and Ohio
- Woodford Shale – Oklahoma

Figure 3: Shale gas plays, Lower 48 Source: Energy Information Administration based on data from various published sources. Updated March 10, 2010.[7]

Tight Gas

Tight gas is natural gas that is located in low permeability deposits and therefore much more difficult to recover than other gas sources. With natural gas prices rising, however, these types of deposits are attractive for investment.

Natural gas production from tight, low permeability sandstones (generally rocks with less than 1/10 of a millidarcy permeability), is expected to contribute significantly to the U.S. gas supply.

Major Tight Gas Sites

- Wind River Basin - Wyoming
- Greater Green River Basin - Wyoming
- San Juan Basin – New Mexico
- Piceance Basin – Colorado
- Uinta Basin – Utah
- Denver Basin – Colorado, Nebraska

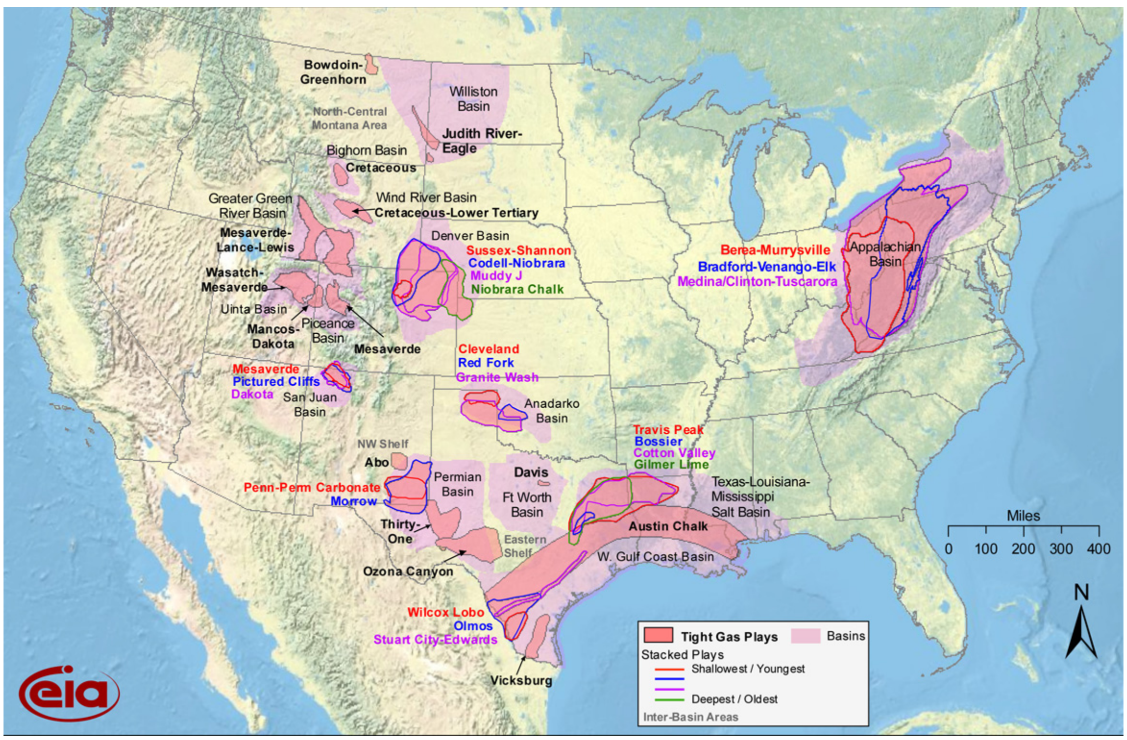

Figure 4: Major tight gas plays, Lower 48 Source: Energy Information Administration based on data from various published studies. Updated 6-6-2010.[8]

Deep Gas

A “deep” gas well is any well that is more than 15,000 feet deep. According to the National Energy Technology Laboratory, deep gas wells are about three times as deep as the average onshore gas well and about twelve times the cost. The Department of Energy is sponsoring a Deep Trek Program to improve the economics of drilling and completing deep gas wells. Of the 29,000 oil, gas, and dry holes drilled in 2002, about 300 were deep wells. Of those, 25% were dry, 50% were high temperature/high pressure completions, and 25% were simply deep completions.

Figure 5: Primary deep gas basins in the Lower 48 Source: NETL, Exploration & production technologies[9]

Geo-pressurized Zones

Geo-pressurized zones are deposits of natural gas under unusually high pressure, and occupying layers of sand or silt located at depths between 15,000 and 25,000 feet. These zones may be found either under dry land or beneath sea beds. Such zones are particularly abundant along the Gulf Coast. Total global resources of geo-pressurized gas are believed to exceed all other conventional and unconventional gas resources put together with the exception of methane hydrates.

Given the size of the resource and the continued ascent of natural gas prices, the geo-pressurized zones will be tapped in time, but the time has not yet arrived. No commercially feasible extraction techniques have been developed to date, and only exploratory drillings have been made.

Methane Hydrates

Methane Hydrates consist of methane locked inside the crystalline lattices of water molecules, existing in sediment below the ocean floor, which can be released when exposed to the atmosphere. Also known as “burning ice” for their unique physical properties, methane hydrates are a potential, relatively clean energy source that could provide a solution to our growing energy needs.

According to the U.S. Geological Survey, the organic carbon content of methane hydrates worldwide is estimated at 104 gigatons—roughly twice the amount contained in all fossil fuels combined.

Each volume of hydrate can contain over 160 volumes of methane gas. If these hydrates are harvested, there could be as much as 20,000 trillion cubic meters available worldwide, compared to 250 trillion cubic meters of conventional natural gas in remaining worldwide reserves.[10]

Unconventional Recovery Methods

Natural gas reserve estimates in the USA have recently increased by over 30% with the inclusion of unconventional natural gas. In the case of natural gas, new techniques in horizontal drilling and fracturing are used to access gas deposits in shale and coal beds that were previously unattainable. Oil and energy analyst Daniel Yergin, co-founder of Cambridge Energy Research Associates, has called unconventional natural gas “the biggest innovation in the energy business in the past 25 to 30 years.”[11]

The development and implementation of these non-standard methods requires precise laboratory testing.

Horizontal Drilling

The drawing below shows a well that has been drilled to a particular depth and then turned 90 degrees to intersect a layer of shale. The shale is then fractured by hydraulic means to release the gas and allow a path for the gas to follow.

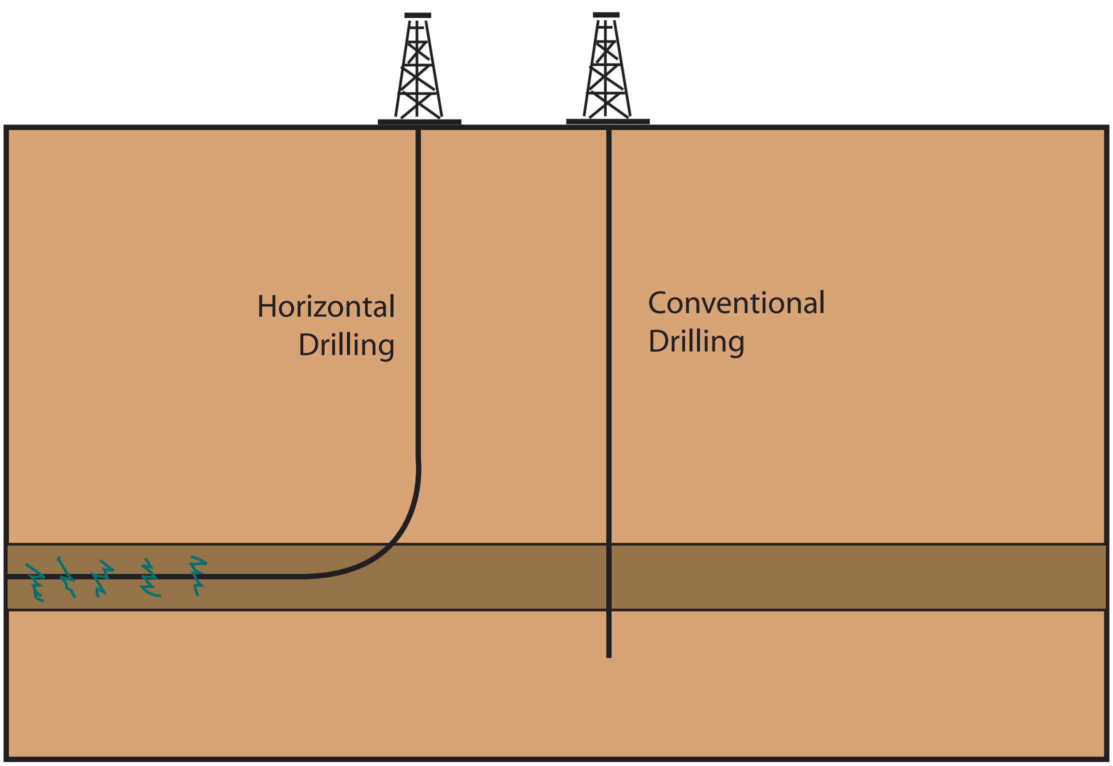

Figure 6: Horizontal drilling (Hydraulic fracturing shown after 90° turn)

Hydraulic Fracturing

Hydraulic Fracturing, also called "fracking," is a process that increases the amount of fractures in rocks or coal, and has been commonly used in the exploration and production of coal bed methane, shale gas, and tight gas. Hydraulic fractures are created by injecting fluids at high pressures, which opens the rock or coal matrix. A proppant material is then pumped in to "prop" the cracks open. The fluids pumped for either fracturing or propping can consist of:

- Oil
- Water
- Nitrogen
- CO_2
- Sand
- Plastics

One of the top concerns of fracturing is the contamination of drinking water resources by the injected fluids.

Enhanced Gas Recovery

As with depleted oil reservoirs using conventional techniques where some oil still remains, natural gas wells can continue production using similar reservoir depressurizing techniques. These techniques, commonly called Enhanced Gas Recovery, typically use CO_2 injected to depressurize the reservoirs.

In using CO_2 in depleted gas reservoirs, there is the double benefit of carbon sequestering. These reservoirs are of particular interest, since they are naturally impervious to gas leaks. By pumping in CO_2 to improve recovery, the CO_2 is left behind, is therefore sequestered, and offsets the CO_2 emissions from use of the natural gas.

Laboratory-Scale Method Testing

Laboratory duplication of the fluid and pressure conditions present in geologic formations is crucial for determining the most effective and economical methods and fluids to use in unconventional recovery, as well as prediction of production rates at a specific site. Accurate results are dependent upon steady, scalable proportioning and accurate flow data. At ±0.5% accuracy or better, Teledyne Isco's non-reciprocating syringe pumps deliver steady, pulse-less feeds at precise flow rates while maintaining critical scaled proportions.

Permeability Studies

To determine specific permeability characteristics of a geological formation, tests are conducted to see how easily various fluids can flow through the rock. Core flooding is a common test to determine rock permeability, and how well various fluids will flow through it.

The purpose of the system shown in Figure 7 is to recreate the conditions from which the core was removed, and then to pump fluids through the rock core to determine permeability. A syringe pump running in "constant pressure mode" is used to duplicate the loads and stresses. A dual pump system running in "constant flow mode" is used to introduce fluid into the rock core holder and monitor the flow rates. If the fluid is considered corrosive or potentially damaging to the pump, an accumulator or transfer cylinder is sometimes used. An accumulator has a bladder; a transfer cylinder uses a sliding piston. Both devices function by pumping a clean fluid into one end, thereby forcing the corrosive fluid out the other end without the fluids coming into contact with each other. Several hours at high pressures and low flow rates are required for the newly introduced fluid to displace the oil from the rock sample. From the data obtained from rock core flooding, studies on permeability or enhanced oil/natural gas recovery can determine the most economical ways to improve production.

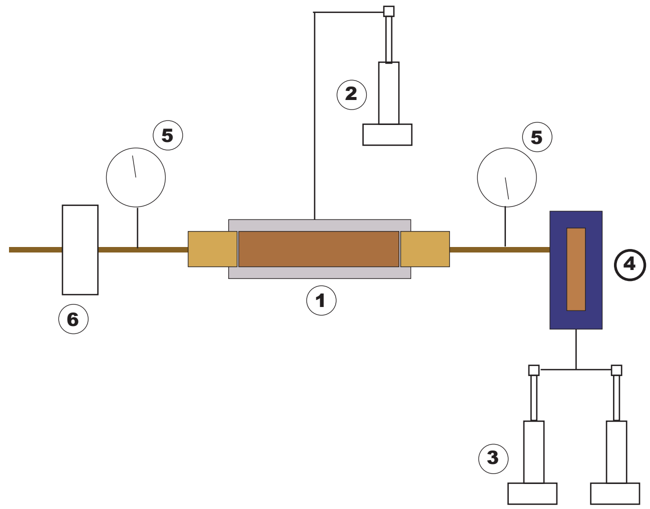

Figure 7: Schematic basic system components

1. Core Holder
2. Overburden pump (Syringe Pump)
3. Flow pump (dual Syringe Pump system)
4. Accumulator
5. Pressure gauges or differential pressure gauge
6. Back pressure regulator

Rock Core Testing

A fracturing test can include a syringe pump and tri-axial core holder to evaluate the mechanical, axial, and radial properties of a core. In a tri-axial setup, the axial and radial stresses are independent, with one pump system creating the axial load and another pump creating the radial load.

Teledyne Isco pumps can be used in this application by operating in constant pressure mode, and are also used to create methane hydrates in R&D applications.

Pressure/Volume/Temperature (PVT)

In enhanced gas recovery studies, key research issues include:

- Ability to inject the CO_2
- Required injection pressures
- Problems due to Joule-Thomson effects of CO_2 phase changes
- Permeability and flow characteristics within the reservoir
- Mixing of CO_2 and methane
- Methane production expectations

Varying the pressure, volume, and temperature of various fluids in a contained system or closed cell with a view window can determine the properties of fluids such as:

- Saturation pressure (bubble point)
- Gas-Oil Ratios (GOR)
- Compressibility
- Density

Data collected from these tests can be used to determine fluid or phase behavior in oil or gas extractions. Teledyne Isco syringe pumps, with their accurate volume and pressure control, can be used in such experiments, are very well suited for CO_2 research, and have been used extensively in enhanced oil recovery (EOR) research.

Currently, tight gas production relies on finding naturally open fractures, or “sweet spots.” Research includes sensing technologies such as multi-component, multi-azimuth seismic surveys, which can detect fractures and quantify their density and orientation prior to drilling[12].

About Teledyne Isco Syringe Pumps

Since 1971, Teledyne Isco’s rugged, high-pressure syringe pumps have served the energy industry, unmatched in reliability over a vast range of pumping applications. They provide precise flow and pressure control over a remarkable operating range, minus the pulsation or flow anomalies associated with other pump types.

A wide selection of pump sizes provides flow rates from the sub-microliter to over 400 ml perminute, and pressures from 2,000 to 20,000 psi.

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