It was not so long ago that experimental research was at a nadir here in the petroleum engineering department (Dr Mamora’s *Ramey Thermal Laboratory* being the exception). Experimental laboratories in our industry had mostly fallen out of favor and academic labs did not have the wherewithal to perform cutting edge research.

Now, thanks to the support from industry sponsors, the arrival of new experimentalists on our faculty, and new equipment, there are eight active programs incorporating laboratory testing. To introduce these, we have put together this special edition of the Crisman newsletter to highlight the experimental research being funded by the Institute.

In the following pages you will find cutting edge research in the field of high temperature high pressure (HTHP) fluids, behavior of fracturing fluids, production optimization, and low impact drilling systems technology. In addition, to support our laboratory capabilities, Laboratory 822 is being re-equipped with analytical testing capabilities. A short description of the equipment loaned to use is contained in the newsletter as well.

Give us a call and let us know if you know of someone in your organization who would like to be briefed on these projects and their related research programs.

This issue of the Crisman Newsletter contains the following articles:

- Viscosities of Natural Gases at High Pressures and High Temperatures
- Reservoir Rock Mechanics Research
- CT Scanner
- “Tower Lab” and “Non-Darcy Transient Flow Research Lab”
- Simulation of the Fracture Fluid Cleanup

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Viscosities of Natural Gases at High Pressures and High Temperatures

Project Objectives and/or Milestones:

1. Measure the viscosity of four naturally occurring hydrocarbon gases at various pressures and temperatures, with emphasis on high pressures and temperatures.
2. Use the measured viscosities to check and extend an existing correlation proposed by Lee et al.
3. Use gas compressibility factors to check and extend the gas compressibility correlation equation proposed by Piper et al.
4. Develop a new correlation to predict viscosity as a function of composition, pressure, and temperature.

Gas viscosity is one of the gas properties that are vital to petroleum engineering. Its role in the oil and gas production and transportation is indicated by its contribution in the resistance to the flow of a fluid. One of the most important things in petroleum engineers routine work is to calculate the pressure at any node in a production and/or transportation system. Although gas viscosity at low-intermediate pressure and temperature had been studied intensively and been understood thoroughly, gas viscosity at HPHT is still a gap in oil industry. Every type of viscometer has its advantages and disadvantages. In this research a modified falling body viscometer is used to measure gases viscosity at HPHT. The viscometer we used is Cambridge Viscosity SPL440 viscometer (Figure 1). It is designed by Cambridge Viscosity, Inc. exclusively for measuring viscosities of petroleum fluids, oils and gases. The measurable range of the gas viscosity is from 0.02 to 0.2 cP. The accuracy of the VISCOpvt is reported to be around 1% of full scale of range. Its operating pressure and temperature are up to 25000 psi and 400° F, respectively. Viscosity of nitrogen at HPHT is measured first since it is much safer than air or natural gas.

Methane and air viscosity will be measured in the coming experiments. All of these measured data will be compared with the available data from other investigators to check the consistency. Even if data at HPHT may not be available from other investigators, data at intermediate pressure and temperature can be used as calibration data.

Work Accomplished

Experiments in July 2007 illustrated that gas purity plays an important role in friction force. Three experiments (Test 23 to 25) were finished this month. The pressure range is from 3000 to 15000 psi. One temperature (174° F) was set for the experiment. Each experiment shows significant noise from gas impurity. In test 23, gas viscosity varies from 0.016 to 0.0185 cp at 11000 psi and 174° F and from 0.0155 to 0.0180 cp at 7000 psi and 174° F during the downward measurement. Even at the upward measurement viscosity also varies from 0.0155 to 0.0180 cp at 7000 psi and 174° F during the downward measurement. Even at the upward measurement viscosity also varies from 0.0155 to 0.0180 cp at 7000 psi and 174° F. Same phenomena can be observed in tests 24 and 25. The deviation of measurement could be over 10% between high value and low value. When we compared gas viscosity at the same pressure and temperature measured at different tests, the mismatch between different tests is obvious.
Viscosities of Natural Gases at High Pressures and High Temperatures

Figure 1.2

Pressure, Viscosity vs. Time (Temperature=174°F)
Rock mechanics permeates all facets of reservoir development, from drilling to completions to seafloor stability. The Rock Mechanics Group at the Harold Vance Petroleum Engineering Department conducts research in geomechanics modeling and experimental rock mechanics to assist the industry in finding solutions for the development of increasingly challenging reservoirs, particularly in HPHT environments. Analytical and numerical rock mechanics research activities include:

**Coupled Reservoir-Geomechanics Modeling**
- Reservoir Compaction & Casing Integrity in HPHT Reservoirs
- Poroelastic modeling of fractured reservoirs
- Poroplastic FEM of poorly consolidated reservoirs
- Geomechanics issues related to gas hydrate reservoir development

**Tight Gas Reservoir Development**
- Shale gas reservoir characterization (geomechanical) and optimum wellbore trajectory
- Fracture propagation and coalescence
- Investigation & analysis of injection-induced seismicity

**Wellbore Stability**
- Chemo-porothermoelastic stress analysis in chemically-active, anisotropic shales
- Mud weight window calculations
- Porothermoelastic analysis of breakouts & drilling induced cracks
- Poromechanical stress analysis in poorly consolidated rocks

**Geothermal Reservoir Development**
- Critically-stressed fracture networks
- Fracture slip and induced seismicity
- Fracture propagation in geothermal systems

The above activities are supported by a state-of-the-art Rock Mechanics Lab that is under development. Initially, the laboratory will house:

- **A triaxial testing system** designed for reservoir geomechanics applications. The system simulates actual in-situ conditions and characterizes a test sample’s behavior under those conditions. Axial load (up to 100,000 lbs), confining pressure, and pore pressure of up to 10,000 psi (70 MPa) can all be precisely controlled. The system’s ultrasonic measurement component permits measurement of ultrasonic P- and S-wave velocities and attenuation under confining and pore pressure as well as deviatoric loading. Both 25 and 50 mm diameter specimens can be tested.

- **A pressure pulse permeability measurement system** that can measure permeabilities as low as $10^{-9}$ md. The system also can make measurements on cores with fractures.

Additional rock mechanics testing equipment will be developed to enhance the range of tests that can be performed.

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The Harold Vance Department of Petroleum Engineering has a state-of-the-art CT scanner. The scanner has been used by TTI for scanning asphalt samples, the Agricultural Department for scanning vegetable and fruit samples and our own department for various studies of fluid flow through porous and fractured rock.

The specifications of our CT Scanner and various research performed on the scanner are shown below.

**Brand:** Universal Systems [http://www.universal-systems.com](http://www.universal-systems.com)

**Model:** HD-350E

**Features:**
- Versatile Gantry System
- 140kV Source
- High Throughput, 1 sec. Scan Speed
- 1,2,3,4,5,8 & 10mm Slices
- 1.5~10 mm beam thickness
- .35mm Spatial Resolution (.25mm on Enhanced)
- Core Analysis of Plugs to full size Core up to 81cm long

![CT Scanner Image](image1.png)

**Fig. 1-** CT scanner and CT images of an artificially fractured core under 2500 psi confining pressure.

![Fractal Dimension and Amplitude Graph](image2.png)

**Fig. 2-** Change of fractal dimension (D) and amplitude (A) with increasing sampling area. Two values become stable above the sampling area 1400 mm².

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Research Areas

- Liquid Loading in Gas Wells
- Multiphase Flow in Wellbores: Modeling and Metering
- Transient Multiphase Flow in Porous Media
- Characterization of the Near-Wellbore Region of the Reservoir

Liquid loading in gas wells is a phenomenon in which the liquid content of the well is sufficient to create a back pressure (usually dominated by gravitational pressure changes) which restricts, and in some cases even stops, the flow of gas from the reservoir. Liquid loading is an all too common problem in mature gas fields around the world. It is estimated that in the U.S.A. alone at least 90% of the producing gas wells are operating in liquid loading regime. The phenomenon is more detrimental in tight wells than in prolific wells and it poses a serious problem in subsea tie-backs, where back pressure effects through the risers and the flowlines may have an important role. Such is the importance of liquid loading, the industry has devoted a lot of attention to the alleviation of the problem using various measures. However, the fundamental understanding of the associated phenomena is still surprisingly weak. This applies not only to the flows in the wells, but also to the ways in which these flows interact with those in the reservoir.

Crisman projects 2.4.13-15-16-17 are already underway. They focus on the understanding of the onset of liquid loading and on available remedial options. Each project can be complemented by experimental work to validate assumptions and conclusions associated with the theoretical effort. To provide a dedicated facility for the experimental study and modeling of liquid loading in gas wells, a new flow loop will be accommodated in the “Tower Lab” facility at the Petroleum Engineering Department. Substantial changes to the current configuration of the facility will be made, according to the findings of project 2.4.16. The new loop will be able to handle higher pressures and higher gas volume fractions. However, the true novelty of the new loop will be represented by the ability to mimic the dynamic interactions between the wellbore and the near-wellbore region of the reservoir.
Another project that will investigate the physics of liquid loading in gas wells, though with a more fundamental approach, is the JIP on “Liquid Loading in the Operation of Gas Fields: Mechanisms, Prediction and Reservoir Response”. The research will be carried out by a consortium of four universities, centrally managed by Texas A&M University. The other participating universities will be Imperial College London, UK (Dept. of Chem. Eng), University of Rome “La Sapienza”, Italy (Dept. of Raw Materials) and Federal University of Santa Catarina, Brazil (Dept. of Mech. Eng). The JIP will provide reliable predictive models to link the well dynamics with the intermittent response of a reservoir that is typical of liquid loading in gas wells. Thus, the focus of the JIP is on the transient multiphase flows that take place both in the near-wellbore region of the reservoir and in the wellbore, including re-injection of the heavier phase into the reservoir, which still has not been proved to date. In order to validate and fine-tune the theoretical multiphase flow models, experimental data will be required for the JIP. The data will be obtained from tests carried out in the new flow loop in the “Tower Lab” facility (see above) and from the “LOTUS” flow loop at Imperial College.

Another type of experiments that will be required for the JIP involves the investigation of the effects of fast-changing pressure waves propagating from the wellbore into the reservoir when phase redistribution occurs in the well. To this aim, single-phase (air) and two-phase (air and water) flow laboratory experiments will be carried out in the newly established “Non-Darcy Transient Flow Research Lab”. Small-scale porous media (simulating the near-wellbore reservoir) to assess what frequency of pressure variations at one end of a porous medium can lead to a significant divergence from Darcy and Forchheimer’s laws for the prediction of the pressure-rate response.

The outcomes of the JIP will be applicable to liquid loading in gas wells, but also to any other situation where the transient flow behaviour of the near-wellbore region of the reservoir cannot be ignored.

Three industry sponsors have already committed to participating in the JIP: RWE Dea (Germany), Petrobras (Brazil) and ENI-Agip (Italy). The ticket price is $60,000 per company per annum for three years. In addition to support from the industry, appropriate additional funding will be sought from local Government sources and research councils. All necessary contracts are being drafted and the JIP work is about to commence. To join, contact Dr. G. Falcone.
Simulation of the Fracture Fluid Cleanup

Project Objectives and/or Milestones

- Do a detailed literature review of the fracture fluid damage mechanism and the cleanup process
- Work with other students to design laboratory experiments to gain further insight on how polymers behave in the hydraulic fracture
- Derive the mathematical models to describe the fracture fluid behavior
- Couple the mathematical models to the 3D, 3-phase simulator, which will be the "ultimate fracture fluid cleanup model" by incorporating all the necessary features
- Use the model to analyze real data from the literature and from the companies sponsoring this research
- Use the model to evaluate various options and scenarios for well stimulation, and come up with new methods for creating long, high-conductive fractures in tight gas reservoirs
- Finally, give recommendations to the industry for the fracture treatments in tight gas Reservoirs

Work Accomplished

Experimental work: The area of contact between a rough surface and smooth surface was calculated using a different method than before which seems more appropriate. We also determined other surface parameters like number of peaks, skew, mean asperity height and standard deviation of height distribution. The data available were again analyzed and bad data points removed and different correlating formulas used to determine most appropriate correlation. We are using two sets of correlating equations, one from a parametric method and one from a non-parametric method. In order to develop the second correlation to relate treatment parameters to the parameters that control conductivity in the above developed first correlation, we tried to gather information about acid systems, like viscosity, reaction rate and effective diffusion rate.

Three experiments were conducted in order to fill the gaps for development of this secondary correlation.

1. Built the polymer residue model into the simulator
2. Ran simulations to investigate the effect of the polymer residue on the cleanup process
3. Programmed the filter cake model into the simulator and did some preliminary simulation runs.

Figure 6 shows the existence of polymer filter cake along the reservoir rock face after a fracture treatment. The filter cake is a very thin layer of fracture fluid with very high polymer concentration, likely 300-400 or even 1000 lb/1000 gallons [Ayoub 2006].

Project Number: Crisman 3.1.1
Project Title: Simulation of the Fracture Fluid Cleanup and Its Effect on Long-term Recovery in Tight Gas Reservoirs
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Simulation of the Fracture Fluid Cleanup

Figure 6—Residual gel damage from 35 ppt CMHPG Zr XL fluid, with breaker (StimLab Consortia 1997-2006)