KING SAUD UNIVERSITY
COLLEGE OF ENGINEERING
PETROLEUM AND NATURAL GAS ENGINEERING DEPARTMENT

PGE 477: DRILLING FLUIDS LABORATORY
LABORATRORY MANUAL

Compiled by
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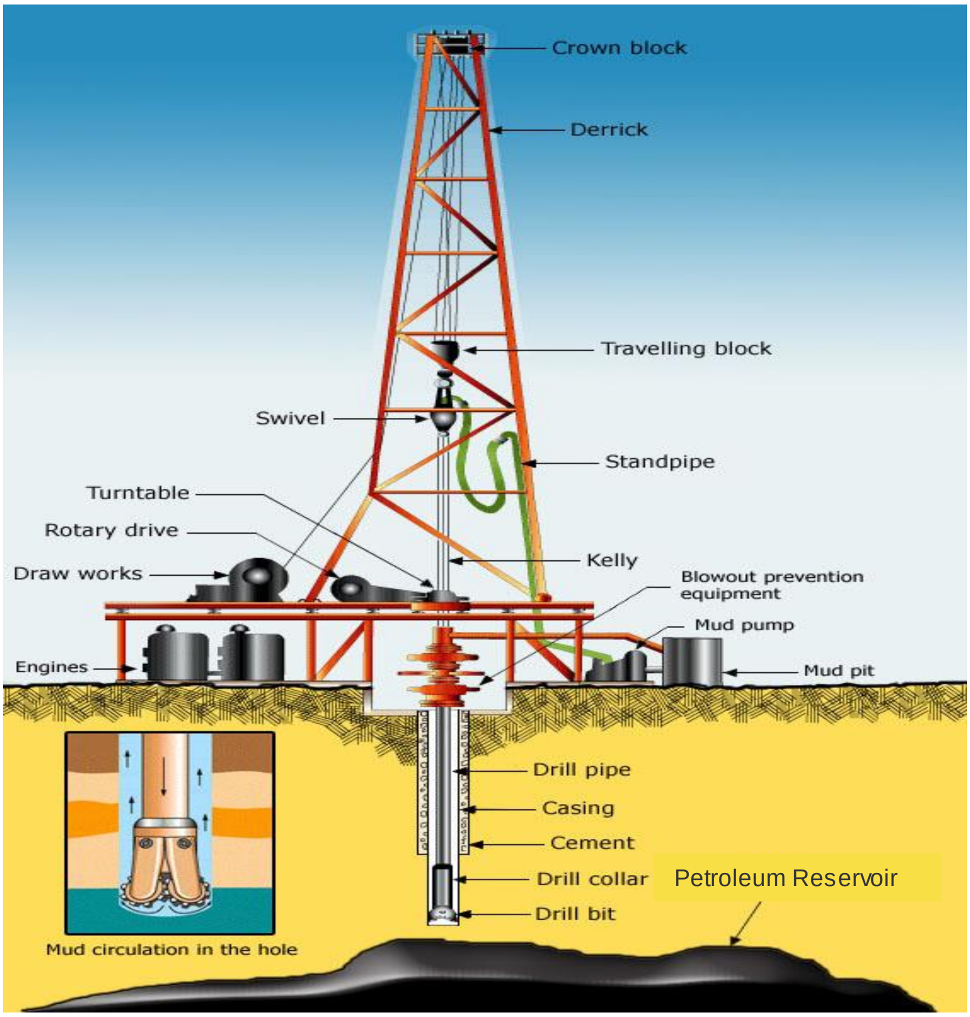

July 2016

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PREFACE

This laboratory manual is designed to serve in achieving the following objectives:

1) Providing the students of the petroleum and natural gas engineering department with the basic techniques of formulating, testing and analyzing the properties of drilling fluid and oil well cement.

2) Exposing the students of the petroleum and natural gas engineering department to practical drilling and well control operations by means of a drilling software simulator.

To achieve the required objective, the manual is divided into two parts:

1) The first part consists of and introduction explaining course contents, grading criteria, safety issues to be followed in the drilling fluids and cement laboratory, drilling fluids functions and types. Then the theory, objectives, equipment, testing procedures and analysis methods of results for thirteen experiments are presented. These experiments dealing with measuring the physical properties of drilling fluid such as mud weight (density), rheology (viscosity, gel strength, yield point) sand content, wall building and filtration characteristics. There are also experiment for studying the effects of, and common contaminants on drilling fluid characteristics. Additionally, there are experiments for studying physical properties of cement liquid slurry such as free water and thickening time; and for hard set cement such as compressive and tensile strength.

2) In the second part, the students of the petroleum and natural gas engineering department will practice on drilling operations and well control by means of a drilling software simulator "Pay-Zone Drilling Simulator". The students while study the effect of mud type and properties, mud circulation rate, bit type, weight-on-bit, rotation speed, formation lithology and formation fluid pressure on the rate of penetration.

PGE 476: Drilling Engineering Laboratory

COURSE LEARNING OUTCOMES MAPPING

Topic addresses Course learning outcome:
(0) Not at all (1) slightly (2) moderately (3) considerably

	Topics Related to Course Learning Outcomes	Outcome 1	Outcome 2	Outcome 3	Outcome 4	Outcome 5	Outcome 6	Outcome 7	Outcome 8	Outcome 9	Outcome10	Outcome11
	Safety Issues and basics of drilling fluids engineering.		2		0							
	Measurements of drilling fluid density and sand content		3		0							
	Measurements of drilling fluid pH and resistivity		3		0							
	Measurements of drilling fluid viscosity by Marsh funnel.		3		0							
	Measurements of drilling fluid rheological properties.		3		1							
	Measurements of drilling fluid API filtration.		3		1							
	Measurements of drilling fluid HT-HP filtration		3		1							
	Measurements of drilling fluid lubricity		3		1							
	Measurements of oil well cement thickening time and free water		3		1							
	Measurements of oil well cement compressive strength and direct and indirect tensile strength		3		1							
Group work	Bentonite quality evaluation.		3		3							
Group work	Effect of contamination on drilling fluid properties.		3		3							
Group work	Effect of contamination on oil well cement properties		3		3							
	Average weight		72%		28%							

Course Learning Outcome:

1. Apply the knowledge of mathematics, geology, physics, chemistry as well as other engineering sciences. (Corresponds to ABET Outcome "a").
2. Conduct experiments safely and accurately and to be able to correctly analyze the results. (Corresponds to ABET Outcome "b").
3. Design an engineering process or system to meet desired needs. (Corresponds to ABET Outcomes "c").
4. Work in a team environment. (Corresponds to ABET Outcome "d").
5. Identify, formulate and solve engineering problems. (Corresponds to ABET Outcome "e").
6. Understand professional and ethical responsibilities. (Corresponds to ABET Outcome "f").
7. Communicate successfully and effectively. (Corresponds to ABET Outcome "g").
8. Understand the impact of engineering solutions in a global, economic, environmental and societal contest. (Corresponds to ABET Outcome "h").
9. Recognize of the need for, and an ability to engage in life-long learning. (Corresponds to ABET Outcome "i").
10. Knowledge of contemporary issues. (Corresponds to ABET Outcome "j").
11. Understand the use of modern techniques, skills and modern engineering tools necessary for petroleum and natural gas engineering practice. (Corresponds to ABET Outcome "k").

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PART -1-

LABORATORY EXPERIMENTS ON PROPERTIES OF DRILLING FLUIDS AND CEMENT AND EFFECT OF CONTAMINANTS

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INTRODUCTION TO DRILLING FLUIDS ENGINEERING

1. Objectives and Outcomes of the Course:

The main objectives of this course are to teach the B. Sc. students in the Department of Petroleum and Natural Gas Engineering the main engineering aspects of testing, analysis and design of drilling fluids, cement slurry and hard set cement used in drilling and completing oil and gas wells for a specific lithology.

By the end of this course, the student should be able to conduct experiments and analyze results and design the proper drilling fluids required to drill oil and gas wells for a given lithology and examine the main properties of the designed drilling fluids. Furthermore, the student should know how to design and test cement slurry and hard set cement required for completing the drilled oil and gas wells.

The objectives of this course will be achieved in two parts:

i- First by providing the students with the basic techniques of formulating, testing and analyzing the properties of drilling fluid and oil well cement, and

ii- Second, to familiarize the students with practical drilling and well control operations by means of drilling simulation software.

2. Grading Criteria:

i. Course work: including how to perform the experiments accurately and safely in a team work environment (reports, attendance and participation): 60 Marks.

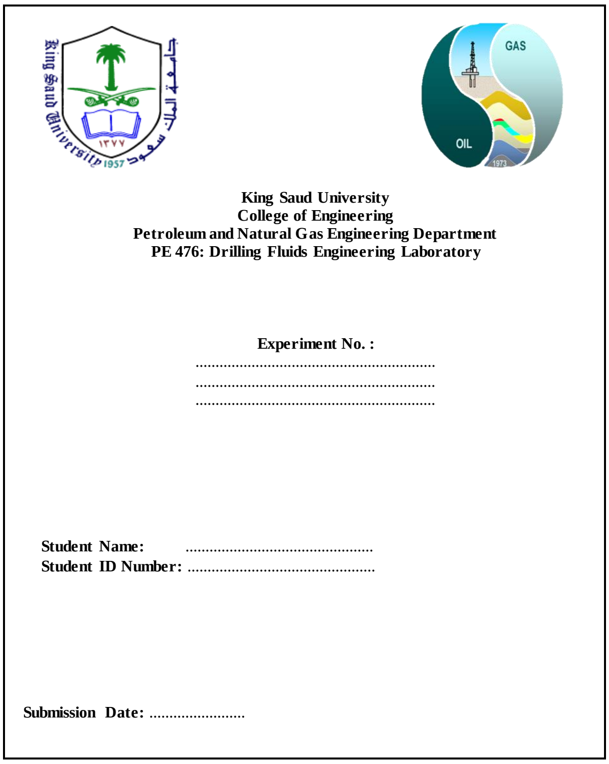
ii. Final examination (oral + written): 40 Marks

3 Report Format

Each student must submit a report within one week from the time of performing the experiment. The report will be evaluated and returned back to the student. The report must explicitly have the following parts:

- Cover page.
- Objectives.
- Theory (Introduction).
- Apparatus.
- Procedure.
- Observations and Experimental raw data.
- Results and Discussion.
- Conclusions and Recommendations.
- References.

All students must use the cover page format shown below in their weekly reports:



King Saud University
College of Engineering
Petroleum and Natural Gas Engineering Department
PE 476: Drilling Fluids Engineering Laboratory

Experiment No. :
....
....
....

Student Name: ....
Student ID Number: ....

Submission Date: ....

4. Course Syllabus:

The following experiments will be performed during this course for drilling fluids and cement slurry and hard set cement:

Experiments	Week
Drilling fluids:	
Drilling fluid density, pH and resistivity	1
Drilling fluids sand content and Marsh viscosity	2
Drilling fluids rheology	3
Drilling fluids API filtration	4
Drilling fluids HT-HP filtration	5
Cement slurry:	
Cement slurry thickening time	6
Hard set cement:	
Hard set cement compressive and tensile strength	7
Team-work experiments:	
Bentonite quality evaluation	8
Contamination of water-based drilling fluid	9
Contamination of oil or gas well cement	10
Practicing on the drilling simulation software	11
Revision	12
Final Exam	13

5. Laboratory Safety Instructions:

Safety in the laboratory must be of vital concern to all those engaged in experimental work. It is therefore the responsibility of everyone to adhere strictly to the basic safety precautions provided and to avoid any acts of carelessness that can endanger his life and that of others around him. It is equally important to always abide by all the instructions for conducting the experimental work during the laboratory sessions. Below are some guidelines for general laboratory safety and procedures:

- All students must be familiar with the locations and operational procedures of the emergency shower, fire extinguishers, gas masks and fire blankets.
- Laboratory coats, safety glasses and safety shoes must be worn at all times during the laboratory session. no open sandals are allowed during the laboratory sessions.
- Eating and drinking are strictly prohibited in the laboratory at all times. Laboratory glassware should never be used for drinking purpose.
- Report any injury immediately for first aid treatment, no matter how small.
- Report any damage to equipment or instrument and broken glassware to the laboratory instructor as soon as such damage occurs. Emergency shower fire blankets, gas mask and fire extinguisher
- Carefully handle chemicals, acids, mercury, HP-HP equipments, etc.
- Clean any water or oil spill from laboratory floor.
- Distinguish between 110V and 220 V appliances to avoid equipment damage.
- Don't attempt to work in the laboratory alone at any time.

6. Drilling Fluid Engineering:

Generally speaking, drilling fluid may be defined as a suspension of solids in a liquid phase. Drilling fluid (mud) is a vital element of the drilling process. In fact, the success or failure of the mud program will largely determine whether a well can ultimately be drilled to the operator's specifications in a safe and economical manner. The drilling fluid engineer's task in designing a drilling fluid program is to derive from the variety of available mud-making materials the precise combination of physical and chemical properties needed to meet the demands of the well. This aspect of drilling cannot be underestimated; the slightest miscalculation can result in huge, unnecessary costs in time and money.

7. Functions of Drilling Fluids

Drilling fluid was introduced simply as a way to circulate rock cuttings out of the wellbore. But today, as deeper and more hazardous wells are being attempted to meet the demand of oil, drilling fluid is an increasingly important and complex part of the rotary drilling process. The basic functions of drilling fluid are to :-

- Cool and Lubricate the Drill Bit and the Drill String

The drilling action requires a considerable amount of mechanical energy in the form of weight-on-bit, rotation and hydraulic energy. a large proportion of this energy is dissipated as heat, which must be removed to allow the drill bit to function properly. Also, the drilling fluid helps in cooling and lubricating the drill string.

- (2) Remove Drilled Cuttings

As the bit penetrates the formation, the rock cuttings must be removed, otherwise the drilling efficiency will decrease. In removing the cuttings there are two separate operations: Lifting and dropping on surface the cuttings while circulating; and Suspension of cuttings while not circulating.

- (3) Control Formation Pressure

For safe drilling, high formation pressures must be contained within the well to prevent blow-outs. The drilling fluid achieves this by providing a hydrostatic pressure just greater than the formation pressure. In practice, an overbalance of 100-200 psi is normally used to provide and adequate safe guard against blow-out (well-kick). Drilling fluid density is the controlling factor in this function:

$$P = 0.052 \times \rho_m \times TVD$$

If drilling fluid weight is increased too much, lost circulation will occur. Barite ($BaSO_4$) is added as a weighting material due its high specific gravity (Sp. Gr. = 4.2).

- (4) Maintain Borehole Stability

The drilling fluid should deposit a mud cake on the wall of the borehole to consolidate the formation and to prevent formation damage. A good mud cake must be thin, hard and impermeable to provide enough stability and less formation damage.

- (5) Transmit Hydraulic Horsepower to the Bit

Drilling fluid is the medium for transmitting available hydraulic power from the pumps on surface to the bit at the bottom of the well. Optimum hydraulic power enables the hole to be cleaned.

- (6) Aiding Formation Evaluation

Drilling fluid properties such as resistivity and conductivity are crucial in evaluation formations. The drilling fluid must be formulated to aid in the production of good logs.

8. Classification of Drilling Fluids:

A) Water-based Drilling Fluids:

(i) Fresh water muds - little or no chemical treatment:
1. Spud Mud.
2. Natural Muds.

(ii) Chemically treated muds - No calcium compounds added:
1. Phosphate muds.
2. Organic treated muds.

(iii) Calcium treated muds:
1. Lime.
2. Calcium chloride.
3. Gypsum.

(iv) Salt water muds:
1. Sea water muds.
2. Saturated salt-water muds.

(v) Oil - Emulsion Muds (Oil-in-water):
1. Low solids oil-emulsion muds.
2. Low clay solids weighted muds.

3. Surfactant muds.

B) <u>Oil-based Drilling Fluids</u>:
(i) Oil base muds.
(ii) Inverted Emulsion Muds (water-in-oil).

C) <u>Gaseous Drilling Fluids</u>:
(i) Air or Natural gas
(ii) Aerated muds

9. <u>Composition of Water-based Drilling Fluids</u>:

Water-base mud consists basically of:

- **Continuous Liquid phase:**
  - (a) Water.
  - (b) Oil.
  - (c) Emulsion.
- **2. Solids phase** - Inert, non-reactive components:
  - (a) Sand, silica, limestone, chert, dolomite, etc.
  - (b) Barite, Galena.
- **3. Colloidal phase** - Small particle size:
  - (a) Non-swelling.
  - (b) Swelling clay – Bentonite.
- **4. Miscellaneous** (Chemical phase):
  Thinners, lost circulation material, dissolved solids, filtrate reducing agents, surfactants, corrosion inhibitors and other chemicals.

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EXPERIMENT # 1
DRILLING FLUIDS DENSITY AND SEPECIFIC GRAVITY

1. Objectives:
Determination of the density, specific gravity, and hydrostatic pressure gradient of drilling mud.

2. Introduction and Theory:
Subsurface formation contains fluid under specific values of pressure. This pressure is controlled by the hydrostatic pressure exerted by mud column. Drilling through high pressure zones requires relatively high pressure mud to avoid blowout; while low pressure formation need low density mud to avoid formation fracture or loss of circulation. Therefore, it is extremely important to know and specify the mud density, through out drilling operations to avoid the previous problems.

Normal pressure gradient by fresh water is equal to 0.433 psi/ft, and for salt water is 0.465 psi/ft. In abnormally pressured formations, pressure gradient may reach 1.0 psi/ft. In case of abnormal pressures, weighting materials such as barite must be used.

3. Test Equipment:
A mud balance is an instrument generally used to determine mud weight that will permit accurate measurement within 1/10 lb/gal or 1/2 lb/ft3. Mud weight can be expressed in lb/gal, lb/ft3, psi/1,000 ft of depth or specific gravity (S.G.). For the density determination of a drilling mud, Baroid Mud Balance is used. The mud balance consists of a graduated arm with a rider and built in spirit level. The arm has constant weight on the opposite end. This arm is mounted on a fulcrum with a knife adage and a base to allow good stabilization. The balance arm is also provided with level glass to assure stabilizing point. Fresh water density is equal to 8.33 ppg or 1.0 g/cc or 62.4 pcf. Figure 1 shows a typical mud balance.

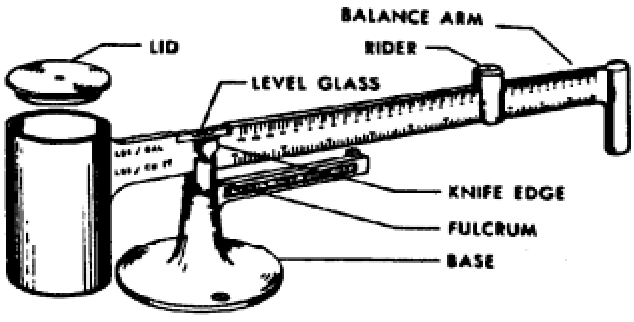

Figure 1: Typical Mud Balance

4. Apparatus Calibration:
Mud balance apparatus need frequent calibration to maintain measurement accuracy. The mud balance should be calibrated frequently with freshwater at 70°F which will give a reading of 8.33 lbs/gal or 62.3 lbs/ft^3. The calibration steps are as follows:

- Remove the lid from the cup, and completely fill the cup with water.
- Replace the lid and wipe dry.
- Replace the balance arm on the base with knife-edge resting on the fulcrum.
- Move the rider until balance is reached and record the measured water density. 8.33 ppg reading means that the mud balance is accurate, other wise a correction factor (CF) must be set for this apparatus as follows:

$$CF = \frac{8.33}{\text{Measured water density, ppg}}$$

This correction factor must be re-evaluated frequently and used to correct actual mud measurements. This correction factor can be used to calculate the true mud density as follows:

$$\text{True mud density} = \text{Measured mud density} * CF$$

5. Test Procedure:

- Fill the cup with mud to be weighed.
- Place the lid on the cup and seat it firmly but slowly with a twisting motion. Be sure some mud runs out of the hole in the cap.
- With the hole in the cap covered with one finger, wash or wipe all mud from the outside of the cup and arm.
- Set the knife on the fulcrum and move the sliding weight along the graduated arm until the cup and arm are balanced.
- Read the density of the mud at the left-hand edge of the sliding weight.
- Note down mud temperature corresponding to density.
- Report the result to the nearest scale division in lb/gal, lb/ft3, S.G., or psi/1000 ft of depth.
- Wash the mud from the cup immediately after wash use. It is absolutely essential that all parts of the mud balance be kept clean if accurate results are to be obtained.

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EXPERIMENT # 2
DETERMINATION OF HYDROGEN ION CONCENTRATION

1. Objectives:
Determination of hydrogen ion concentration of drilling mud by pH meter and paper indicator.

2. Introduction and Theory:
The degree of acidity or alkalinity of drilling mud is determined by hydrogen ion concentration. The hydrogen icon concentrations ~expressed in terms of pH and defined as the "log of reciprocal of moles of hydrogen ion concentration per liter of solution".

$$pH = -\log(H+).$$

Since pure water has $(H^+) = (OH^-) = 10^{-7}$, the pH of pure water equals to 7. Thus a neutral solution has a pH value of 7.0. The alkaline solution has pH value above 7.0 for slightly alkaline and 11.0 for the strongest alkaline. However, acid solutions have pH from just below 7.0 for slight acid to less than 1.0 for strangest acidity. The pH measurement is used as an acid in determining the need for chemical treatment of the mud as well as indicating the presence of contaminants in mud during drilling. The pH of a mud seldom is below 7 and in most cases fall between 8 and 12.5 depending upon the type of mud. The pH is important because the pH affects the solubility of the organic thinners and the dispersion of clays presents in the mud.

3. Test Equipment:
There are two common methods for pH measurement as follows:

- The pH Paper Indicator: The pH paper strips have dyes absorbed into the paper display certain colors in certain pH ranges. It is useful, inexpensive method to determine pH in fresh water muds. The main disadvantage is that high concentrations of salts (10,000 ppm chloride) will alter the color change and cause inaccuracy.

- The pH Meter: The pH meter is an electric device utilizing glass electrodes to measure a potential difference and indicate directly by dial reading the pH of the sample. The pH meter is the most accurate method of measuring pH.

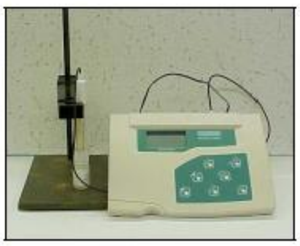
Figure 1: pH meter.


Figure 2: pH paper indicators.

4. Apparatus Calibration and Test Procedure:

- Check the battery by turning selector to battery check.
- Turn selector to stand by position.
- Remove plastic cap of the electrode and immerse it in distilled for few minutes and then wipe it with soft tissue.
- Add sufficient buffer solution to a test tube and insert electrode.
- Set temperature knob to the solution to record the temperature.
- Turn the selector to read position.
- Set meter to pH of buffer with standardized knob.
- Turn selector to stand by position.
- Remove electrode and rinse with distilled water.
- Insert electrode into the mud to be contained in a 100 ml baker.
- Turn selector to read position and stir the solution carefully.
- Remove hand from electrode and take reading.
- Turn selector to off position. Rinse electrode in distilled water and wipe it with soft tissue. Wet it with few drops of pH=7.0 buffer solution and replace plastic cap.
- If you have many samples, repeat steps from 9 to 13.

5. Precautions:

- Keep selector in stand by position while rinsing, removing or inserting electrode to avoid damage to electrode components.
- Pour solution or sample in test tube to be sufficient to cover the electrode when it inserted.
- Do net support electrode by hand while taking the reading.

6. Results:

Measure the pH of the given mud using pH meter and pH paper indicator.

	pH	
	1	Battery acid
Acidic ↑	2	
	3	Acid rain
	4	
	5	Normal rain (5.6)
	6	
Neutral	7	Pure water (7.0)
	8	Ocean water
	9	
	10	
↓	11	
Alkaline	12	
	13	
	14	Liquid drain cleaner

Figure 3: pH scale.

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EXPERIMENT # 3
DETERMINATION OF MUD RESISTIVITY

1. Objectives:
Determination of drilling mud resistivity (R_m) and the equivalent NaCl concentration.

2. Introduction and Theory:
Control of the resistivity of a mud and mud filtrate while drilling may be desirable to permit better evaluation of formation characteristics from electric logs. The determination of resistivity is essentially the measurement of resistance to electrical current flow through a known sample configuration. Measured resistance is converted to resistivity by use of a cell constant. The cell constant is fixed by the configuration of the sample in the cell and is determined by calibration with standard solutions of known resistivity. The resistivity is expressed in ohm-meters (Ω-m). The resistivity (R_m) of a drilling mud is influenced by the dissolved salts (ppm) or (gpg, grain per gallon) in the water portion and the insoluble solid material contained in the water portion. The greater the concentration of dissolved salts, the lower resistivity of the solution. Unlike metals, the resistivity of a solution decreases as temperature increases. It is necessary to measure resistivity because the mud, mud cake, mud filtrate resistivity exert a strong effect on the electric logs taken in that mud. The mud resistivity varies greatly from the actual resistivity values due to the various factors encountered in the actual operation.

3. Test Equipment:
Equipment used is the resistivity meter (Figure 1).

Figure 1: Resistivity meter.

4. Apparatus Calibration and Test Procedure:
The measurement of electrical resistivity of the mud and mud filtrate requires:

(a) A calibrated resistivity cell.
(b) An instrument or apparatus for measuring -the resistance of the sample in the cell.
(c) A thermometer for measuring the sample temperature.

Any type of cell and instrumentation which is sufficiently accurate to permit determination of resistivity within 5 percent of the correct value may be used. If the instrument indicates the sample resistance in ohms, the cell constant must be known. The resistivity in ohm-meters is obtained by multiplying the resistance in ohms by the cell constant in square meters per meter. If the instrument is a type of direct-reading resistivity meter, the cell constant has been adjusted to a particular value or accounted for in the electrical circuit of the meter. Such an instrument measures the sample resistance and converts it to resistivity so that the reading is taken directly as ohmmeters. For all instruments, the manufacturers' instructions for current source, calibration, measurement, and calculation should be followed. Typical procedure should be followed while measuring mud resistivity using resistivity meter is as follows:

- Fill the clean, dry resistivity cell with freshly stirred mud or with filtrate. Be sure that no air or gas is entrained in the sample.
- Connect the cell to the measuring instrument.
- Measure the resistance in ohms and, using the cell constant or calibration chart, convert to resistivity; or measure the resistivity directly with a direct-indicating resistivity meter.
- Measure the temperature of the sample to the nearest degrees F.
- Report the mud resistivity (R_m) or filtrate resistivity (R_{mf}) in ohm-meters to the nearest 0.01 ohm-meter.
- Using Figure 2, convert the measured resistivity to NaCl salt concentration.
- Report the sample temperature in degrees F.
- Clean the resistivity cell. Scrub with a brush and detergent solution if necessary. Rinse the cell thoroughly with distilled water and allow it to dry.

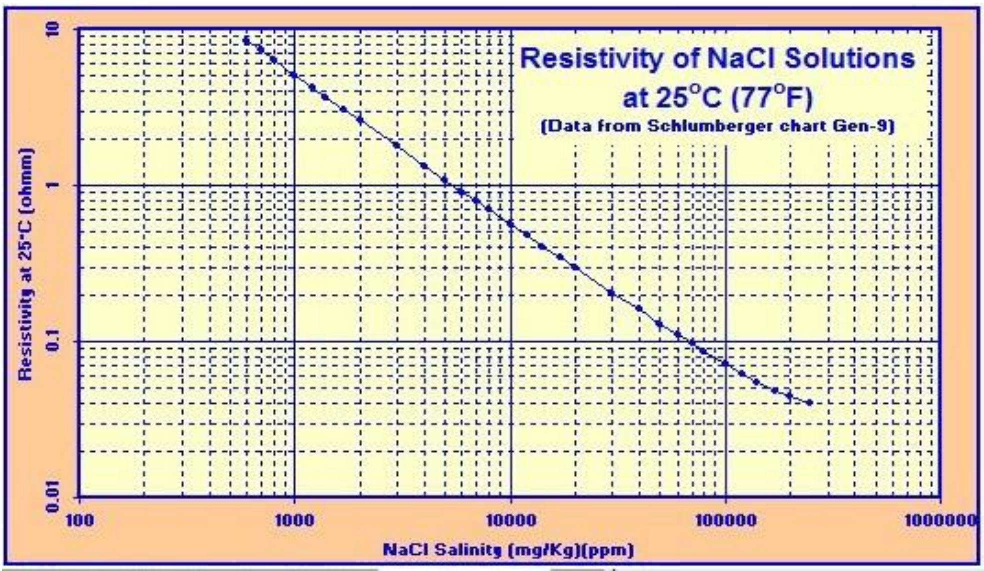

Figure 2: Resistivity of NaCl solutions.

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EXPERIMENT # 4
DETERMINATION OF MUD SAND CONTENT

1. Objectives:
Determination of sand content of drilling mud.

2. Introduction and Theory:
Sand content is undesirable in drilling mud because of its abrasive nature and its tendency build a thick mud cake on the wall of the borehole. Also, when drilling is interrupted, it settles at the bottom around the bit causing trouble in reaming operation. It is, therefore, necessary to check the mud at a regular interval and if it is higher than a trouble limit, the mud should be treated to remove the sand content.

3. Test Equipment:
Sand content is determined by elutriation, settling, or sieve analysis. Of the three methods, sieve analysis is preferred because of reliability of test and simplicity of equipment. The volume of sand, including void spaces between grains, is usually measured and expressed as percentage by volume of the mud.

Sand content in mud is determined by sand content set which consisted of a 200 mesh sieve, a funnel and a glass tube calibrated in percentage by volume (zero to 20%) as shown in Figure 1.

Figure 1: Sand content measurement set.

4. Test Procedure:
- Pour mud into the sand content tube until it fills up to the mark labeled "Mud to Here". Then add water to the mark labeled "Water to Here". Cover mouth of the tube with thumb and shake vigorously.

- Pour this mixture through the screen, being careful to wash everything out of the tube with clear water through the same screen. Wash sand retained on screen with a stream of water to remove all mud and shale particles.

- Fit funnel down over top of screen, invert slowly turning tip of funnel into mouth of tube, and wash sand back into tube with a fine spray of clear water on the back side of the screen. Allow the sand to settle.

- Observe the quantity of sand settled in the calibrated tube as the sand content of the mud.

5. <u>Results and Care of Instrument</u>

Report the sand content of the mud in percent by volume (% by volume). Take into account coarse solids obtained on the screen. After each use, wash the screen, funnel and tube free of any dirt, and dry thoroughly. Take special care to clean and dry the 200-mesh screen.

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EXPERIMENT # 5
DETERMINATION OF MUD VISCOSITY BY MARSH FUNNEL

1. Objectives:
Determination of mud viscosity by Marsh funnel viscometer.

2. Introduction and Theory:
Cutting suspension when mud circulation stops is one of the main functions of drilling mud. To fulfill this function, the mud should have sufficient gel strength which in turn depends on its viscosity. On the other hand, higher viscosity is undesirable during drilling because higher viscosity corresponds to high flow resistance and hence high pump input to maintain flow of mud. Mud density, mud additives, borehole conditions, cuttings size, and caving problems influence the mud viscosity. It is necessary to control and keep the viscosity in desirable limit.

3. Test Equipment:
For field measurements the marsh funnel has become the standard instrument. For laboratory, the Fann V-G meter, a direct indicating rotational multi-speed instrument has become the standard, allowing measurements of plastic viscosity, yield point, gel strength to be made.

The Marsh funnel is a device that is common to every drilling rig (see shown in Figures 1). The viscosity is reported in seconds allowed to flow out of the funnel. API specifications call for 1500 ml and one quart (946) ml out. For API water at 70 ^oF + 0.5 ^oF = 26 + 0.5 sec. The Marsh funnel measures the apparent viscosity.

Figure 1: Marsh Funnel and One-liter Cup

4. **<u>Calibration and Test Procedure:</u>**

Fill the funnel to the bottom of the screen (1500 ml) with water at 70 ^{o}F (plus or minus 0.5 ^{o}F) time of outflow of the quart (946 ml) should be 26 seconds plus or minus 1/2 second. If water viscosity

is found greater or less than 26 sec, then replace the apparatus orifice or calculate apparatus correction factor (CF):

$$CF = \frac{26 \sec}{\text{Mesured viscosity of water}, \sec}$$

After that, the mud viscosity is measured as follows:

- With the funnel in an upright position, cover the orifice with a finger and pour the freshly collected mud sample through the screen into a clean, dry funnel until the fluid level reaches the bottom of the screen (1500 ml).

- Immediately remove the finger from the outlet and measure the time required for the mud to fill the receiving vessel to the 1-quart (946 ml) level.

- Report the result to the nearest second as Marsh funnel viscosity at the temperature of the measurement in degrees Fahrenheit or Centigrade.

5. **<u>Results and Care of instrument</u>**

It should be remembered that the measurement of viscosity by the Marsh funnel are only qualitative (thick or thin) and do not reveal the cause of the variation in viscosity nor dictate the treatment of a mud. Correct the measured mud viscosity using the apparatus correction factor:

$$\text{True mud viscosity} = \text{Measured mud viscosity} * CF$$

Clean and dry thoroughly after each use. Take special care not to lend or flatten the special brass orifice in the bottom of the funnel.

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EXPERIMENT # 6
DETERMINATION OF MUD RHEOLOGY BY FANN VG VISCOMETER

1. Objectives:

Determination of mud rheological properties (apparent viscosity, effective viscosity, Bingham yield point and gel strength) by Fann VG viscometer (see Figure 1).

Figure 1: Fan V-G 6 speed viscometer.

2. Introduction and Theory:

Rheology refers to the deformation and flow behavior of all forms of matter. Certain rheological measurements made on fluids, such as viscosity, gel strength, etc. help determine how this fluid will flow under a variety of different conditions. This information is important in the design of circulating systems required to accomplish certain desired objectives in drilling operations.

(A) Viscosity:

Viscosity is defined as the resistance of a fluid to flow and is measured as the ratio of the shearing stress to the rate of shearing strain. Two types of fluid characterizations are:

- Newtonian (true fluids) where the ratio of shear stress to shear rate or viscosity is constant, e.g. water, light oils, etc. and
- Non-Newtonian (plastic fluids) where the viscosity is not constant, e.g. drilling muds, colloids, etc.

(B) Gel strength:

The Fann VG viscometer is also used to determine the Gel strength, in lb/100 sq. ft., of a mud. The Gel strength is a function of the inter-particle forces. An initial 10-second gel and a 10-minute gel strength measurement give an indication of the amount of gellation that will occur after circulation ceased and the mud remains static. The more the mud gels during shutdown periods, the more pump pressure will be required to initiate circulation again. Most drilling muds are either colloids or emulsions which behave as plastic or non-Newtonian fluids.

The flow characteristics of these differ from those of Newtonian fluids (i.e. water, light oils, etc.) in that their viscosity is not constant but varied with the rate of shear, as shown in Figure 2. Therefore, the viscosity of plastic fluid will depend on the rate of shear at which the measurements were taken.

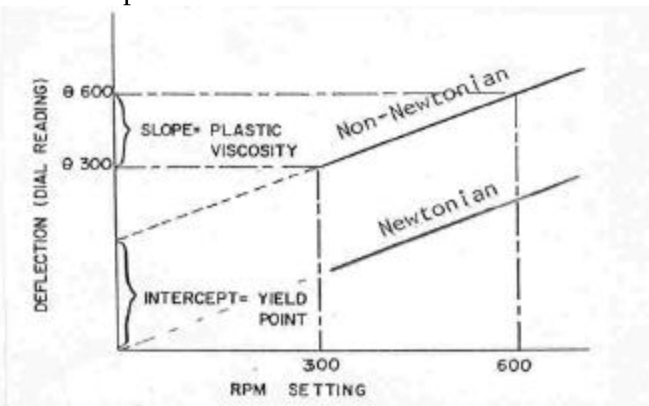

Figure 2: Flow curves of Newtonian and non-Newtonian fluids.

(C) <u>Yield point</u>:
This is the measure of the electro-chemical or attractive forces in the mud under flow (dynamic) conditions. These forces depend on (i) surface properties of the mud solids, (ii) volume concentrations of the solids and (iii) electrical environment of the solids. The yield point of the mud reflects its ability to carry drilled cuttings out of the hole.

3. <u>Test Equipment:</u>
Fann V.G- Viscometer is an electrically operated viscometer with multiple rotational speeds of 3, 6, 100, 200, 300, and 600 rpm. Any of these speeds is selected by switch and rpm knob as shown in the diagram-

4. <u>Calibration and Test Procedure:</u>
Fann VG viscometer should be calibrated frequently by a specialized technician. The following steps are followed for measurement of mud rheological properties:

- Pour freshly agitated mud sample in container up to scribed line and place of under the rotor sleeve.
- Raise the sample container until the rotor sleeve is immersed exactly up to scribed line marked on the rotor and hold it in this position by tightening the lock screw on the leg of the instrument.
- Rotate the rotor at speed of 600 rpm (knob all the way down position and switch to the right position) for about 15 sec and note the dial reading when it becomes steady.
- Keep the knob in down position and shift the switch to low position (300 rpm). Note the dial reading when it becomes steady.
- Raise the knob to up position and shift the switch to high position (200 rpm). Note the dial reading when it becomes steady.
- Keep the knob in up position and shift the switch to low position (100 rpm). Note the dial reading when it becomes steady.

- Lower the knob to intermediate position and shift the switch to high position (6 rpm). Note the dial reading when it becomes steady.

- Keep the knob to intermediate position and shift the switch to low position (3 rpm). Note the dial reading when it becomes steady.

Data measured in the above steps are tabulated in Table 1.

5. Results and Care of instrument

The following calculations are performed using raw data obtained from the previous section:

$$\text{Plastic viscosity}(\mu_p),\text{cp} = 600\,\text{rpm reading} - 300\,\text{rep reading}$$

$$\text{Apparent viscosity}(\mu_a),\text{cp} = \frac{600\,\text{rpm reading}}{2}$$

$$\text{Yield point }(Y_p),\text{lb/100 ft}^2 = 300\,\text{rpm reading} - \mu_p$$

$$\text{Effective viscosity}(\mu_e),\text{cp} = \frac{300 \times (\text{Reading at rpm})}{\text{rpm}}$$

$$\text{Shear rate}(\gamma),\text{sec}^{-1} = \text{rpm} \times 1.7034$$

$$\text{Shear stress}(\tau),\text{lb}/100\text{ft}^2 = \text{Rep reading} \times 1.067$$

The 10 sec and the 10 min gel strength of drilling mud are measured as follow:

- Stir a sample at 600 rpm for about 15 seconds.
- Turn the rpm knob to the stop position.
- Wait the desired rest time (normally 10 seconds or 10 minutes).
- Switch the rpm knob to the 3 rpm position.
- Record the maximum deflection of the dial before gel breaks, as the gel strength in lb/100 ft^2.

Table 1: Raw data obtained by Fann VG Viscometer.

Rpm	Reading	Shear stress	Shear rate	Effective viscosity, cp
600				
300				
200				
100				
6				
3				

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EXPERIMENT # 7
DETERMINATION OF API MUD FILTRATION

1. Objectives:

Determination of the API volume of mud filtration loss and mud cake thickness.

2. Introduction and Theory:

The filter loss of the mud is a measure of the ability of mud to plaster the wall of the bore hole with a thin impermeable filter cake. The lower the permeability of mud cake, the thinner is the cake and the lower the filtrate volume. This property is dependent on the amount and physical state of colloidal material in the mud. The loss of liquid from a mud due to filtration is controlled by the filter cake formed of the solid constituents in the drilling fluid. The test in the laboratory consists of measuring the volume of liquid forced through the mud cake into the formation drilled in a 30 minute period under given pressure and temperature using a standard size cell. It has been found in early work that the volume of fluid lost is roughly proportional to the square root of the time for filtration, i.e.

$$V \alpha \sqrt{t}$$

$$V = \text{constant} \times \sqrt{t} \qquad \text{or} \qquad \frac{V}{\sqrt{t}} = \text{constant}$$

The two commonly determined filtration rates are the low-pressure, low temperature (API) and the high-pressure high-temperature (HT-HP).

3. Test Equipment:

The low pressure filtration test is made using standard cell under the API condition of 100 psi for 30 minutes at room temperature. The test is conducted by a standard filter press and mud cell assembly at a specified pressure of 100 psi and time of 30 minutes. It consists of a mud cell having caps at its top and bottom. The base cup is fitted with rubber gasket, screen, filter paper and rubber gasket again. This base cup has a filtrate tube at the bottom. The top cup has a pressure inlet and is fitted with rubber gasket. This unit is mounted in a frame fixed with T-screw on the top of the frame" compressed nitrogen cylinder is used as a pressure source which is connected to pressure inlet of the top cup in cell assembly as shown in Figure 1.

4. Test Procedure:

- Assembly the parts in this order a. Base cup, b. Rubber gasket, c. Screen, d. Sheet of filter paper, e. Rubber gasket and f. Cell.
- Fill the cell with test sample to within 1/4" of the top and mount this unit in the frame.
- Place the rubber gasket in place in the top cup and set it on the cell with T-screw.
- Place a dry graduated cylinder under the filter tube.

- With the regulator T-screw in its maximum outward position (closed position) open the valve of nitrogen. Apply 100 psi pressure to the filter cell by rapidly screwing the regulator T-screw inward. Time of test begins at that moment.
- At the end of 1, 4, 7 1/2, 9, 16, 25, 30, and 36 min. measure the volume of filtrate and record it.
- After that close the valve of nitrogen cylinder and open the safety bleeder valve. This will release the pressure of the entire system. Bring regulator T-screw in its maximum outward position.
- Disassemble the cell and remove the filter paper from the cup. The mud cake is deposited on filter paper. Wash excess of the mud from the cake gently with water and measure its thickness. Mud cake thickness should be reported in thirty-second of an inch in whole number. Vernier caliper could be used to measure the thickness, however, while measuring care should be taken not to press Vernier jaw on mud cake to penetrate through.

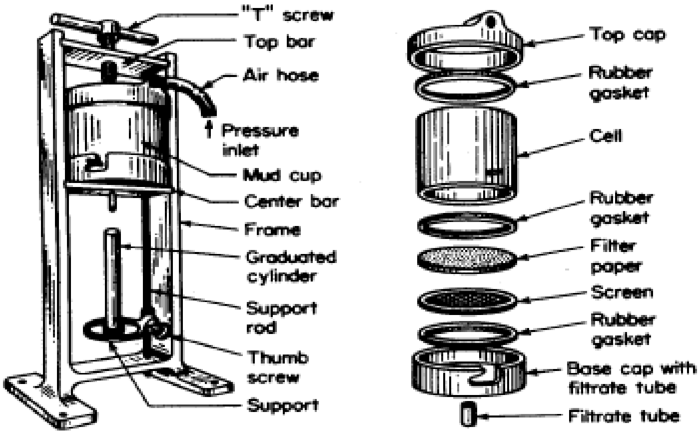

Figure 1: API low temperature low pressure filter press.

5. Results and Care of instrument

Fill Table 1 with the measured raw data. Plot filtrate volume versus square root of time and determine corrected 30 minute filter loss (API filter loss) and initial spurt (volume of filtrate collected just at applying the pressure) if any.

Table 1: API filtration test raw data.

Mud composition=
Room temperature ^{o}C = Spurt volume, cc =
Corrected 30 minutes API filtration, cc =
Mud cake thickness =

Time	$\sqrt{Time}$	Filtrate volume, cc
1		
4		
7.5		
9		
16		
25		
30		
36		

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EXPERIMENT # 8
DETERMINATION OF HT-HP MUD FILTRATION

1. Objectives:
Determination of the HT-HP volume of mud filtration loss and mud cake thickness.

2. Introduction and Theory:
The theoretical concept mentioned in the experiment no. 7 is valid for this test as well. When drilling deep geothermal wells, the drilling fluid will be affected by high temperature and high circulation pressure is exerted to overcome flow of formation fluids into the wellbore. Therefore, a modified filtration test must be performed accounting for high temperature and pressure.

3. Test Equipment:
A special apparatus that withstands high temperature-high pressure conditions. Baroid HT-HP pressure filter press is used in this experiment as shown in Figure 1.

Figure 1: HT-HP filter press apparatus.

4. Test Procedure:
Before the test is started, connect the well to 110 volt line and leave it for about one hour to set the temperature adjusted by thermostat.

- Assembly the parts in this order a) Base cup, b) Rubber gasket, c) Screen, d) Sheet of filter paper, e) Rubber gasket and f). Cell.
- Fill the cell with test sample to within 1/4" of the top and mount this unit in the frame.

A) Setting the mud cell unit:
- 1oose the screws in the cell and remove the cap.

- Tighten the outlet valve stem at the bottom of the cell and fill it with mud to within 3/4 in. of the top.
- Carefully place in circle of filter paper on "0" ring and set the cap in the cell and screw it. Tighten the inlet valve in the cap.
- Place the cell in the heating well and wait for about 30 min so that the cell may come up to the required temperature. Thermometer is placed in the thermometer hole.

B) Setting the pressure unit:

- Connect the pressure unit to the inlet valve on the top of the mud cell. Set the desired pressure by regulator and open the inlet valve by turning the inlet valve stem about one half turn.
- After the above setting, place a graduated cylinder under the outlet valve and open the outlet valve stem by turning it about one half turn. Time of test is begin now.
- Note the volume of the filtrate collected in the cylinder after 1, 4, 7 1/2, 9, 16, 25, 30 and 36 minutes. This volume should be corrected to 7. 1 in^2 filtration area by multiplying by a correction factor of two corresponding to the ratio of the API filtration paper to the HT-HP filtration paper.
- After the test is finished, close both inlet and outlet valves, bleed pressure and remove regulator. Remove the mud cell form the well and let it cool to the room temperature.
- Loosen the inlet valve to bleed pressure from the cell, then loosen the cap locking screws and take out the cap and remove up the filter paper with the deposited mud cake.

5. Results and Analysis:

Fill Table 1 with the measured raw data. Plot filtrate volume versus square root of time and determine corrected 30 minute filter loss (HT-HP filter loss) and initial spurt (volume of filtrate collected just at applying the pressure) if any.

Table 1: HT-HP filtration test raw data.

Mud composition=
Room temperature ^oC = Spurt volume, cc =
Corrected 30 minutes HT-HP filtration, cc = Mud cake thickness =

Time	$\sqrt{Time}$	Filtrate volume, cc	Corrected filtrate volume, cc
1			
4			
7.5			
9			
16			
25			
30			
36			

6. Precautions:

The temperature in this test should be not exceeding 200 ^oF, otherwise another procedure slightly differ from the above must be followed. Do not attempt to bleed cell pressure before it cools to room temperature.

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EXPERIMENT # 9
DETERMINATION OF BENTONITE QUALITY

1. Objectives:

Bentonite clay is a natural deposit available in several places worldwide. Treated Bentonite are packed in sacks and marketed worldwide by numerous companies. Therefore, it is necessary to check Bentonite quality before purchasing. Thus, the objective of this experiment is to investigate the quality of commercial Bentonite by comparing the measured properties with the API standard requirements.

2. Introduction and Theory:

Bentonite is ground clay consisting of hydratable mineral Montmorillonite (greater than 85% as shown in Table 1) with appearance of light yellow powder. It is used on oil well drilling fluids and underground water well drilling fluids. Bentonite is universally used as a cost effective viscosifier and fluids loss reducing agent. It is most effective in fresh water but can be used in sea water or salt brines if pre-hydrated. Bentonite swells 20 times of its initial volume when sufficient fresh water is available. This swelling is attributed to the invasion of water molecule between clays platelets.

Table 1: XRD analysis of typical pure Bentonite clay.

Constituents	%
Montmorillonite	85
Quartz	5
Feldspar	5
Illite	2
Calcite and Gypsum	2
Others	1

3. Test Equipment:

Standard API apparatus for testing drilling fluids used in previous experiments are required including Fann V-G viscometer and API filter press. Additionally, an oven and a set of sieves and a shaker are required.

4. Test Procedure:

Prepare water-Bentonite suspension by mixing 22.5 g of Bentonite clay powder in 350 cc (i.e. 6.43 % by weight of water) de-ionized water while stirring the mixer for maximum 20 minutes at room temperature. Perform all tests shown in Table 2.

Table 2: Measure Bentonite properties and API requirements.

Commercial name of tested Bentonite: Manufacturing company:			
Properties	Previously done in experiment No.	Measured values	API requirements
Fann V-G viscometer reading at 600 rpm	6		30 minimum
Yield point/Plastic viscosity ratio	6		3 maximum
API filtrate volume	7		15 cc maximum
Residue greater than 75 µm mesh	--		4% by weight maximum
Moisture	--		10% by weight maximum

5. Results

Comparison between columns 3 and 4 in Table 2 may give a good guide for decision on the tested Bentonite quality.

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EXPERIMENT # 10
CEMENT SLURRY THIECKENING TIME AND FREE WATER

1. Objectives:

Investigating the effect of mixing water amounts on the physical properties of Portland cement. These properties are free water separation and thickening time.

2. Introduction and Theory:

A) Free Water:

In order to develop cement strength, cement powder must be mixed with sufficient amount of water to perform chemical reaction (hydration). 40% water by weight of the cement powder is considered as the minimum amount required for producing good hydratable cement slurry. After full hydration, the remaining water will be considered as free water (see Figure 1). High free water content may produce permeable hard set cement with possible cracks. API has set 2% as maximum allowable free water.

B) Thickening Time:

Thickening time is defined by the API as the time required for the cement slurry to reach a consistency of 100 Uc or poises, at different well temperature, depth and pressure conditions. It also represents the length of time the slurry is pumpable. When cement slurry reaches 100 Uc, it is no longer being moved through a pipe by any reasonable amount of pressure. In the field, thickening time translates into pumping time which is the time available to move the slurry to its final place in the well.

3. Test Equipment:

The atmospheric consistometer consists of a stainless steel water bath that houses the slurry containers (Figure 2). An instrument panel houses components that allow control of the bath at any temperature from ambient to 93^{o}C, and rotation of the slurry containers at 150 RPM. Units of consistency of the cement are directly indicated on the top dials of the slurry containers. The containers are rotated by engaging the pins of the lid in the slots of the rotator.

The rotators have timing sprockets, belt driven by a gear-head motor. The belt also drives an impeller, which agitates the bath water. The motor should be turned off while engaging or disengaging the containers. Temperature is indicated and controlled by a thermocouple actuated potentiometric type temperature controller. The controller actuates a relay, controlling a 1,500 watt heater. Switches and pilot lights are provided as required by the operation.

A dial thermometer indicates bath temperature when the temperature controller indicator is off the scale.

4. **Test Procedure:**

(A) Free Water Separation Test:

- Weight out 400 grams of cement into each of three quart jars. The dry cement sample should be passed through the sieve in order to remove lumps and foreign materials. The cement temperature should be 80 + ^{o}F.
- Prepare 170 cc, 190 cc and 210 cc of fresh water into three 250 graduate cylinders. This amount of water will produce cement slurries with water to cement ratio of 0.425, 0.574, 0.525 by weight.
- Add the cement samples to the three water volumes in metal quarts while the mixer was on low speed. When all cement has been added, turn the blender to high speed, and mix the slurry for 35 seconds.
- Pour 225 c.c. of slurry into 250 c.c. graduated cylinder. Tightly cover them with aluminum foil. Allow to stand for two hours.
- Carefully decant the free water and measure in a 10 c.c. graduated cylinder. Do this for each slurry. Calculate the percent (%) free water upon settling.

(B) Thickening Time Test:

- Cement slurry is prepared and poured immediately into the Atmospheric Consistometer and begin stirring.
- Record the consistency after every 5 minutes. Tabulate the results in the appropriate table.
- Plot the Consistency in Uc versus time on a log-log paper and extrapolate the straight line to 100 Uc, to determine the thickening time for the tested cement slurry as shown in Table 1.

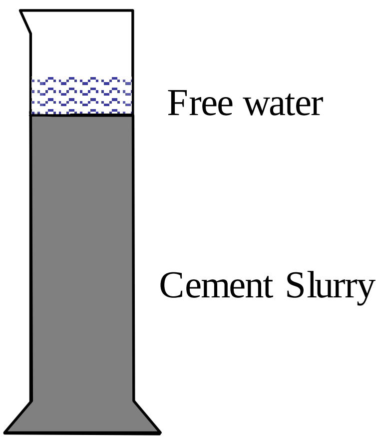
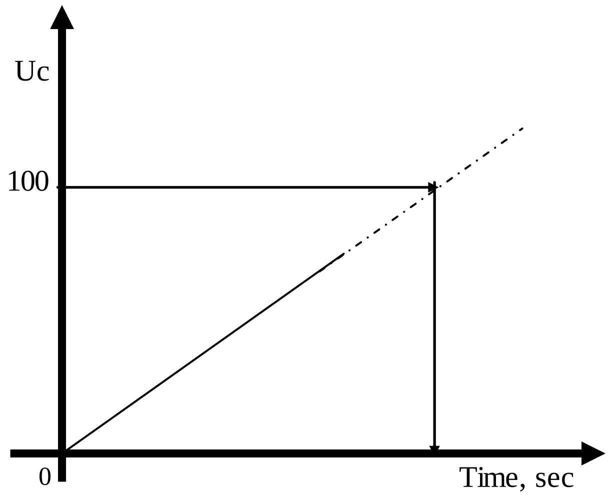


Figure 1: Free water test.

Figure 2: Atmospheric consistometer.

Table 1: Uc versus time for thickening time prediction

Time	Measured Uc
0	
5	
10	
15	
20	
25	
30	
35	
40	
45	
50	
55	
60	



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EXPERIMENT # 11
CEMENT COMPRESSIVE AND TENSILE STRENGTH

1. Objectives:
This experiment is intended to measure directly the uniaxial compressive strength of hard set cement and indirectly measure the uniaxial tensile strength of the same material.

2. Introduction and Theory:
Cement is used in oil and gas wells to support casing and to prevent fluid movement between drilled formations. Therefore, it must develop sufficient compressive and tensile strength to carry the dead weight of the casing string and to withstand drilling vibration and perforating shock. A minimum 1000 psi uniaxial compressive strength is required for oil and gas well cement at loading rate of 1000 psi/min.

3. Test Equipment and Samples Specifications:
In this experiment, cylindrical samples of length to diameter (L/D) ratio of 2 to 2.5 are used for uniaxial compressive strength (UCS) measurements as shown in Figure 1.A. Tensile strength is measured directly and indirectly (Brazilian test method).

In indirect tension (Brazilian method) test, a cylindrical disk of diameter to thickness (D/t) ratio equal to 2.0 is used as shown in Figure 1.B.

In direct tensile strength measurement, a dumbbell shaped cement specimens are used as shown in Figure 1C.

In all tests, a heavy duty compression tester is used to develop the required axial load as shown in Figure 2. This machine is stiff enough to stop loading once an initial micro crack is initiated in the test sample.

4. Test Procedure:
A) Uniaxial Compressive Strength:

- The test a cylindrical cement specimen prepared to standards (L/D = 2 to 2.5) is placed vertically between the upper and lower platens of the compression machine.
- Compression axial load on the test specimen is increased steadily at 1000 psi/min. When the specimen fails in compression, the applied axial load at failure is recorded.
- Load at failure is used to calculate the uniaxial compressive strength of the test sample using the following mathematical formula:

$$UCS = \frac{\text{Axial load at failure}}{\text{Test specimen cross sectional area}}$$

A) Indirect Uniaxial Tensile Strength (Brazilian Test):

This test is intended to indirectly measure the uniaxial tensile strength of a disk shaped cement specimen. The following steps are followed during this test:

- The test disk cement specimen prepared to standards (D/t= 2.0) is placed diametrically between the upper and lower platens of the stiff machine.
- Compression axial load on the test specimen is increased steadily at 1000 psi/min. When the specimen fails in compression, the applied axial load at failure is recorded. At failure, a crack is initiated in the contact point between the machine upper platen and the test specimen. The imitated crack starts propagating vertically parallel to the loading direction.
- Compression axial load at failure is used to calculate the indirect tensile strength of the test sample using the following mathematical formula:

$$UTS = \frac{2 \times \text{Axial load at failure}}{\pi D t}$$

C) Direct Uniaxial Tensile Strength:

This test is intended to directly measure the uniaxial tensile strength of a dumbbell shaped cement specimen. The following steps are followed during this test:

- The test dumbbell shaped cement specimen prepared to standards (failure area = 1.0 in^2) is clamped into the upper and lower platens of the stiff machine.
- Tension axial load on the test specimen is increased steadily at 1000 psi/min. When the specimen fails in tension, the applied axial load at failure is recorded. At failure, the test specimen is separated into two identical parts.
- Tensile load at failure is used to calculate the indirect tensile strength of the test sample using the following mathematical formula:

$$UTS = \frac{\text{Axial load at failure}}{\text{Failure area}}$$

For fast prediction of tensile strength, the following correlation may be applicable:

$$\text{Tensile Strength} \approx \text{Compressive strength} \times 0.10$$

4. Results:

Results of both compression and indirect tensile (Brazilian) tests should be tabulated in Table 1. Using raw data, uniaxial compressive strength and indirect tensile strength can be calculated.

Table 1: Raw and calculated data of the tested cement samples.

Cement slurry composition:			
Curing time:		UTS/UCS ratio =	
Uniaxial compression test		Indirect tension (Brazilian) test	
Sample shape		Sample shape	
Specimen length, inch		Specimen thickness, inch	
Specimen diameter, inch		Specimen diameter, inch	
(L/D) ratio		(D/t) ratio	
Applied load at failure, lb		Applied load at failure, lb	
Uniaxial compressive strength, psi		Uniaxial tensile strength, psi	

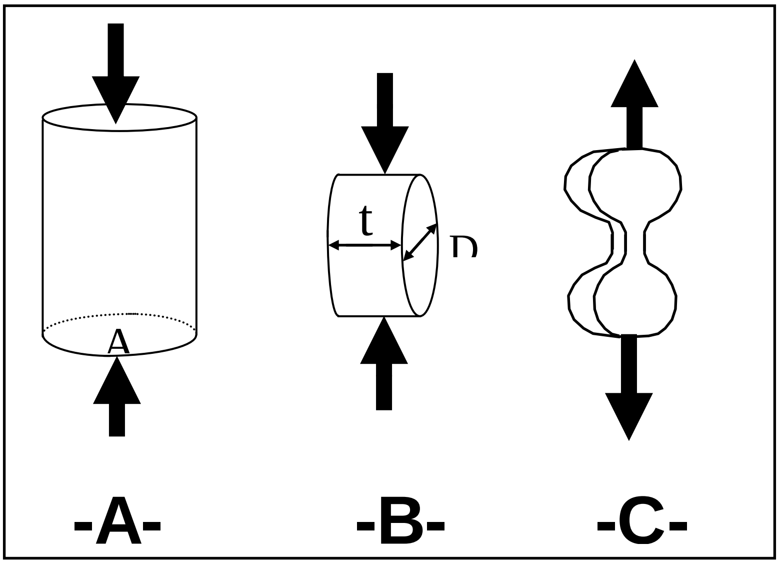

Figure 1: Specimens for:
(A) Compression test, (B) Indirect tension (Brazilian) test, (C) Direct tension test.

Figure 2: Stiff Compression-Tension machine.

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EXPERIMENT # 12
CONTAMINATION OF WATER-BASED DRILLING FLUIDS

1. Objectives

1- Training students on team-work skills and data sharing.

2- Investigating the effect of contaminations that may encountered during oil or gas well drilling on the designed properties of the drilling fluid being utilized.

2. Introduction

In general, a contaminant is any material that causes undesirable changes in drilling fluid properties. Several contaminants may encountered during the drilling process such as sand or solid particles, salts (sodium, calcium, magnesium, sulfide, Bicarbonates, carbonates, etc.), cement, hydrocarbons, etc.

Some contaminates can be predicted and a treatment started in advance. The predictable contaminates are: cement, make-up water, gypsum and acid gases (hydrogen sulfide or carbon dioxide). Other contaminants may be unexpected and unpredictable such as those whose concentration increases gradually. Thus, it is necessary to keep accurate records of drilling fluids properties to ensure that any gradual buildup of contaminant is monitored, detected and treated.

Chemical contaminants can be chemically treated to restore drilling fluid properties. While there are specific treatments for each contaminant, it is not always possible to remove the contaminant form the system. Some more contaminants and associated treating agents are shown in Table 1.

3. Description of Equipment

Standard API equipment for drilling fluid properties testing should be used according to procedures studied in the previous experiments performed in this course.

4. Testing Procedure

Follow experimental procedures studied in the previous experiments (1 to 8) in this course. A water based drilling fluids is prepared (Base Mud). Sodium Chloride (NaCl) is added to the prepared base mud at different concentrations by weight (3, 6, 9 and 12%). Students are divided into five groups, each group measure drilling fluids properties studied in the previous experiments and share data with other groups to complete Table 2.

5. Required Analysis

1. Plot each mud property versus NaCl salt concentration.
2. Indicate your comments on the effect of added NaCl salt on mud properties by completing the last column in Table 2.

Table. 1: Common contaminants and treating agents.		
Contaminant	Source	Treating method
Solids	Drilled cutting, Barite, etc.	Dilution, dispersion, displacement or mechanical removal.
Carbonates	CO_2 intrusion due to thermal or bacterial degradation of mud components.	Precipitate CO_3^{--} ion by adding gypsum or lime.
Anhydrite or Gypsum	Drilled formations or an overtreatment of previous contaminates.	Convert to Gypsum or Lime mud, or precipitate Ca^{++} ion by adding soda ash.
Salt, Saltwater	Drilled formation or formation water	Convert to saturated salt mud or add fresh water.
Cement or Lime	Cementing operations or overtreatment with lime	Convert to Lime mud, or participate Ca^{++} ion by adding soda ash.
Hydrogen Sulfide	Drilled formations, thermal or bacterial degradation of mud components.	Rise pH and/or precipitate sulfide with a Zink compound.

Table. 2: Effect of NaCl salt contamination on drilling mud properties.						
Properties	Measured data					
Teamwork group #	A	B	C	D	E	Overall effect
NaCl salt concentration by weight	0%	3%	6%	9%	12%	
Density, ppg						
pH						
Resistivity, Ω-m						
Marsh viscosity, sec						
Apparent viscosity, cp						
Effective viscosity @ 300 rpm, cp						
Yield point, lb/100 ft^2						
10 sec Gel strength, lb/100 ft^2						
10 min Gel strength, lb/100 ft^2						
30 min API filtration, cc						
HT-HP 30 min filtration, cc						
Base mud composition:						

Overall effect: ▬ No change ♦ Slight change ▲ Increase ▼ Decrease

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EXPERIMENT # 13
CONTAMINATION OF OIL WELL CEMENT SLURRY

1. Objectives

3- Training students on team-work skills and data sharing.

4- Investigating the effect of contaminations that may encountered during oil or gas well cementing jobs on the designed properties of the cement slurry being pumped.

2. Introduction

In general, a contaminant is any material that causes undesirable changes in cement slurry properties. Several contaminants may encountered during oil well casing cementing. The worst cement contaminant is the un-displaced drilling mud.

3. Description of Equipment

Standard API equipment for oil and gas well cement properties testing should be used according to procedures studied in experiments 10 and 11 in this course.

4. Testing Procedure

Follow experimental procedures studied in experiments 10 and 11 in this course. Cement slurry of pre-designed composition is prepared (Base Cement). Pre-hydrated Bentonite slurry (5% by weight of water) is added to the prepared cement slurry (Base Cement) at different concentrations by weight (2, 4, 6 and 8%). Students are divided into five groups; each group measure density, free water and thickening time for liquid cement slurry and compressive and tensile strength for hard set cement as studied in the previous experiments and share data with other groups to complete Table 1.

5. Required Analysis

3. Plot each cement property versus contamination concentration %.
4. Indicate your comments on the effect of contaminants on cement properties.

Table. 1: Effect of contamination on oil and gas well cement properties.

Properties	Measured data					
Teamwork group #	A	B	C	D	E	Overall effect
Contamination concentration by weight	0%	2%	4%	6%	8%	
Thickening time, min						
Free water, cc						
UCS, psi						
UTS, psi						
Density, ppg						

Overall effect: ▬ No change ♦ Slight change ▲ Increase ▼ Decrease

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PGE 476: DRILLING FLUIDS LABORATORY

PART -2-

PRACTISING THE EFFECT OF VARIOUS MUD PROPERTIES ON RATE OF PENETRATION AND COST USING

"PAY-ZONE DRILLING SIMULATOR"

KING SAUD UNIVERSITY
COLLEGE OF ENGINEERING
PETROLEUM AND NATURAL GAS ENGINEERING DEPARTMENT

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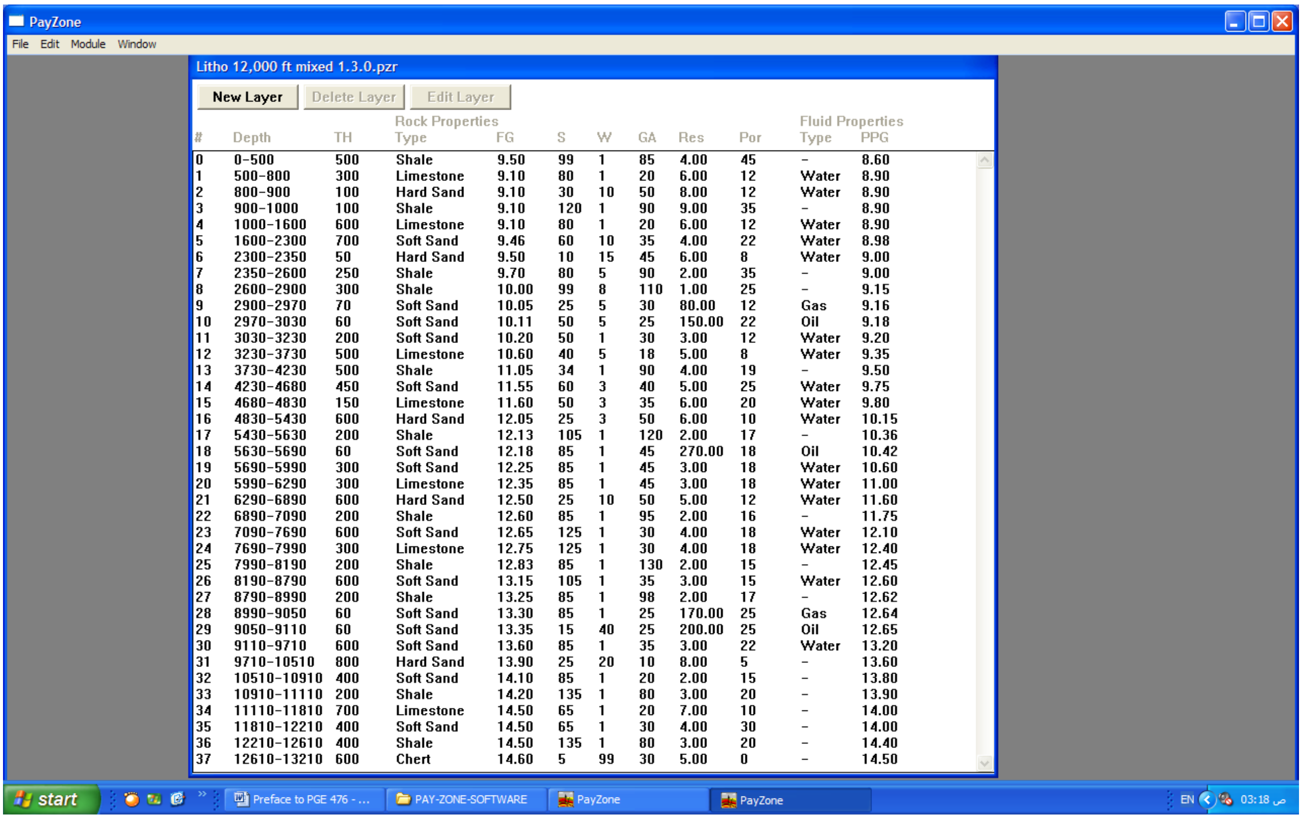
PAY-ZONE DRILLING SIMULATOR

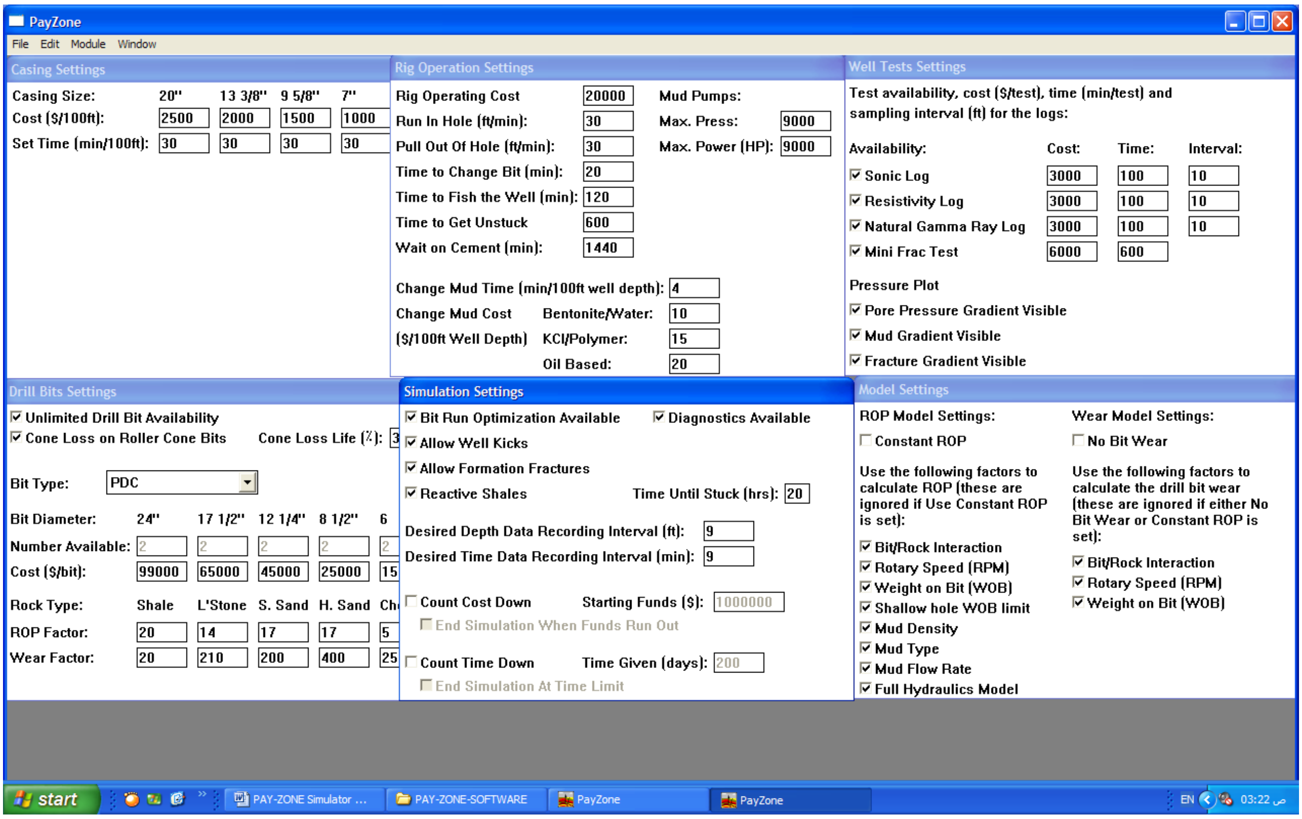
Using Pay-Zone Drilling Simulator" students can study the effect of mud type and properties, mud circulation rate, bit type, weight-on-bit, rotation speed, formation lithology and formation fluid pressure on the rate of penetration. The following steps should be followed:

1- Open Lithology Module and edit formation lithology and input all properties such as fracture gradient, thickness, type, pore fluid type and pressure, etc.

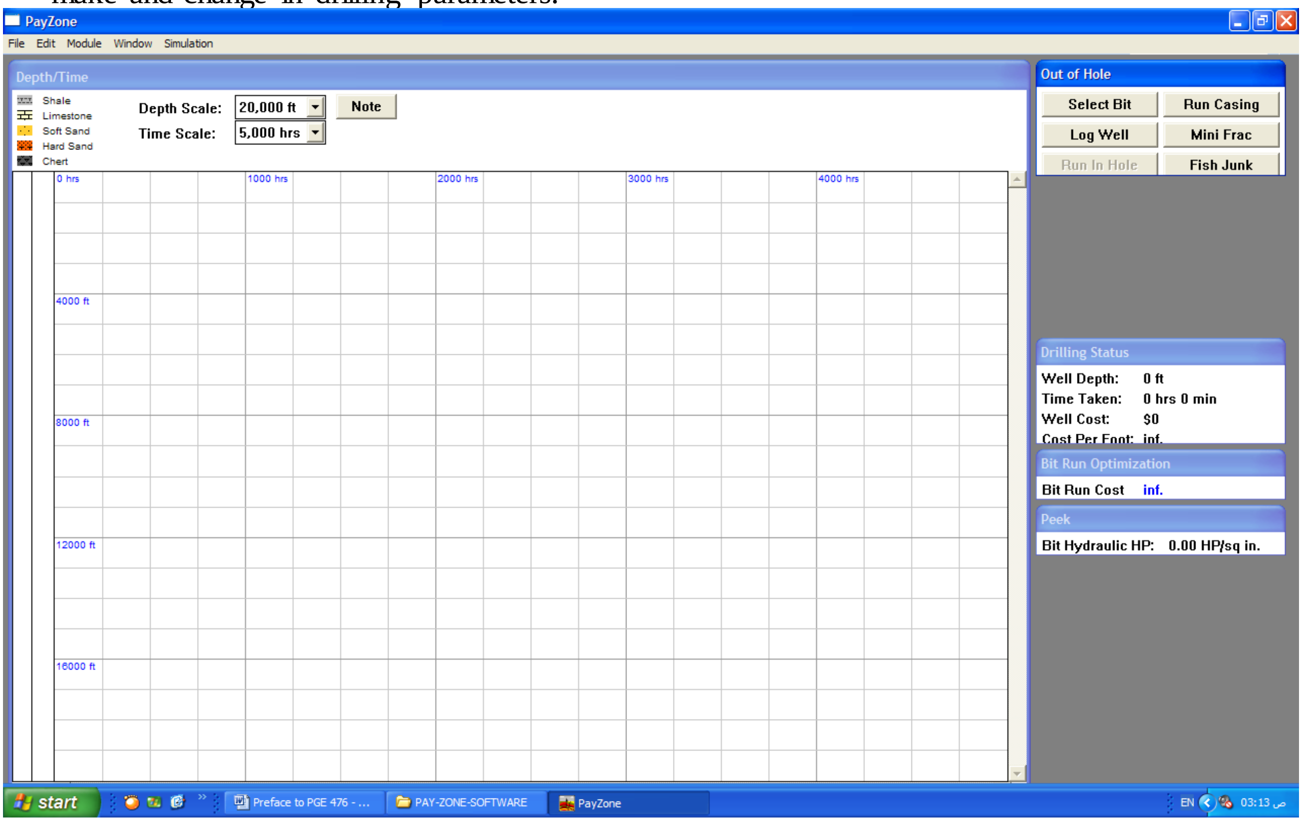


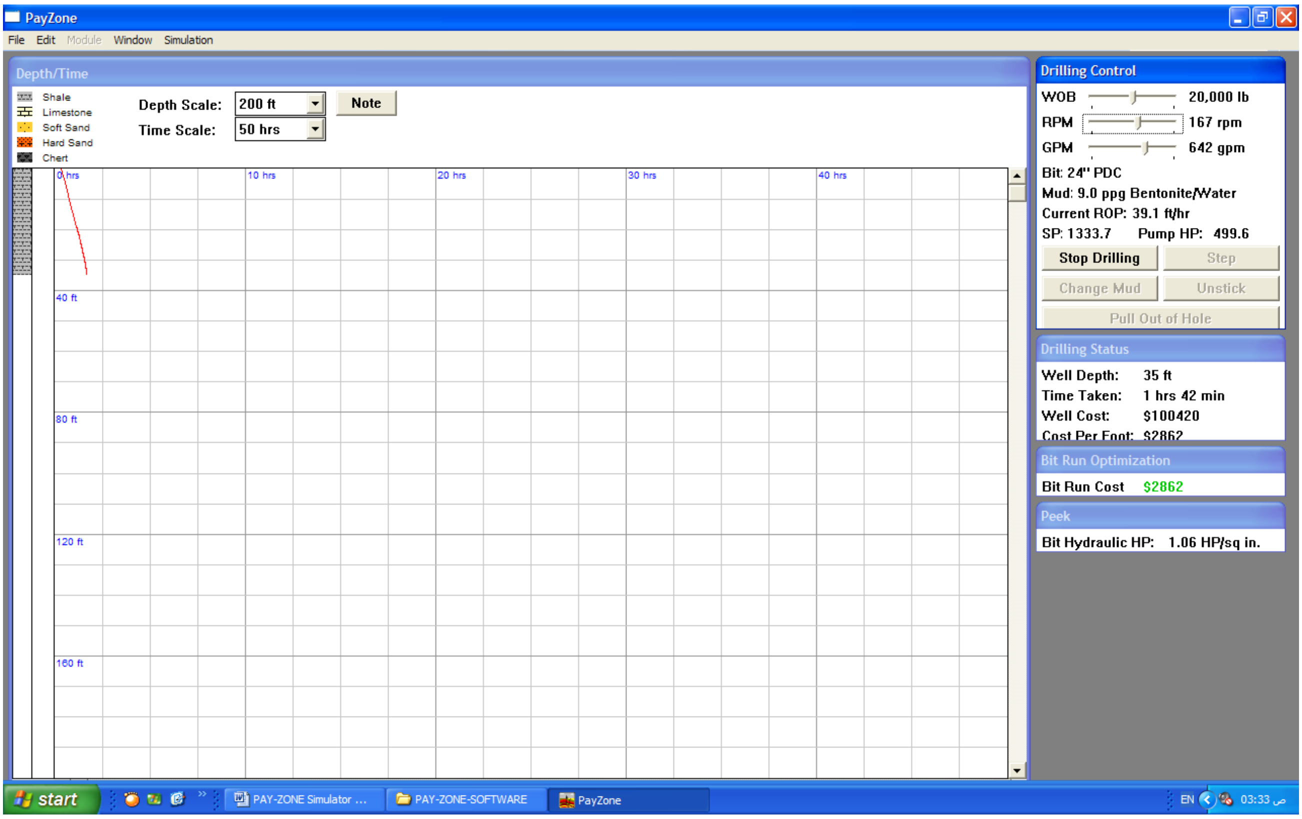
#	Depth	TH	Rock Properties Type	FG	S	W	GA	Res	Por	Fluid Properties Type	PPG
0	0-500	500	Shale	9.50	99	1	85	4.00	45	-	8.60
1	500-800	300	Limestone	9.10	80	1	20	6.00	12	Water	8.90
2	800-900	100	Hard Sand	9.10	30	10	50	8.00	12	Water	8.90
3	900-1000	100	Shale	9.10	120	1	90	9.00	35	-	8.90
4	1000-1600	600	Limestone	9.10	80	1	20	6.00	12	Water	8.90
5	1600-2300	700	Soft Sand	9.46	60	10	35	4.00	22	Water	8.98
6	2300-2350	50	Hard Sand	9.50	10	15	45	6.00	8	Water	9.00
7	2350-2600	250	Shale	9.70	80	5	90	2.00	35	-	9.00
8	2600-2900	300	Shale	10.00	99	8	110	1.00	25	-	9.15
9	2900-2970	70	Soft Sand	10.05	25	5	30	80.00	12	Gas	9.16
10	2970-3030	60	Soft Sand	10.11	50	5	25	150.00	22	Oil	9.18
11	3030-3230	200	Soft Sand	10.20	50	1	30	3.00	12	Water	9.20
12	3230-3730	500	Limestone	10.60	40	5	18	5.00	8	Water	9.35
13	3730-4230	500	Shale	11.05	34	1	90	4.00	19	-	9.50
14	4230-4680	450	Soft Sand	11.55	60	3	40	5.00	25	Water	9.75
15	4680-4830	150	Limestone	11.60	50	3	35	6.00	20	Water	9.80
16	4830-5430	600	Hard Sand	12.05	25	3	50	6.00	10	Water	10.15
17	5430-5630	200	Shale	12.13	105	1	120	2.00	17	-	10.36
18	5630-5690	60	Soft Sand	12.18	85	1	45	270.00	18	Oil	10.42
19	5690-5990	300	Soft Sand	12.25	85	1	45	3.00	18	Water	10.60
20	5990-6290	300	Limestone	12.35	85	1	45	3.00	18	Water	11.00
21	6290-6890	600	Hard Sand	12.50	25	10	50	5.00	12	Water	11.60
22	6890-7090	200	Shale	12.60	85	1	95	2.00	16	-	11.75
23	7090-7690	600	Soft Sand	12.65	125	1	30	4.00	18	Water	12.10
24	7690-7990	300	Limestone	12.75	125	1	30	4.00	18	Water	12.40
25	7990-8190	200	Shale	12.83	85	1	130	2.00	15	-	12.45
26	8190-8790	600	Soft Sand	13.15	105	1	35	3.00	15	Water	12.60
27	8790-8990	200	Shale	13.25	85	1	98	2.00	17	-	12.62
28	8990-9050	60	Soft Sand	13.30	85	1	25	170.00	25	Gas	12.64
29	9050-9110	60	Soft Sand	13.35	15	40	25	200.00	25	Oil	12.65
30	9110-9710	600	Soft Sand	13.60	85	1	35	3.00	22	Water	13.20
31	9710-10510	800	Hard Sand	13.90	25	20	10	8.00	5	-	13.60
32	10510-10910	400	Soft Sand	14.10	85	1	20	2.00	15	-	13.80
33	10910-11110	200	Shale	14.20	135	1	80	3.00	20	-	13.90
34	11110-11810	700	Limestone	14.50	65	1	20	7.00	10	-	14.00
35	11810-12210	400	Soft Sand	14.50	65	1	30	4.00	30	-	14.00
36	12210-12610	400	Shale	14.50	135	1	80	3.00	20	-	14.40
37	12610-13210	600	Chert	14.60	5	99	30	5.00	0	-	14.50

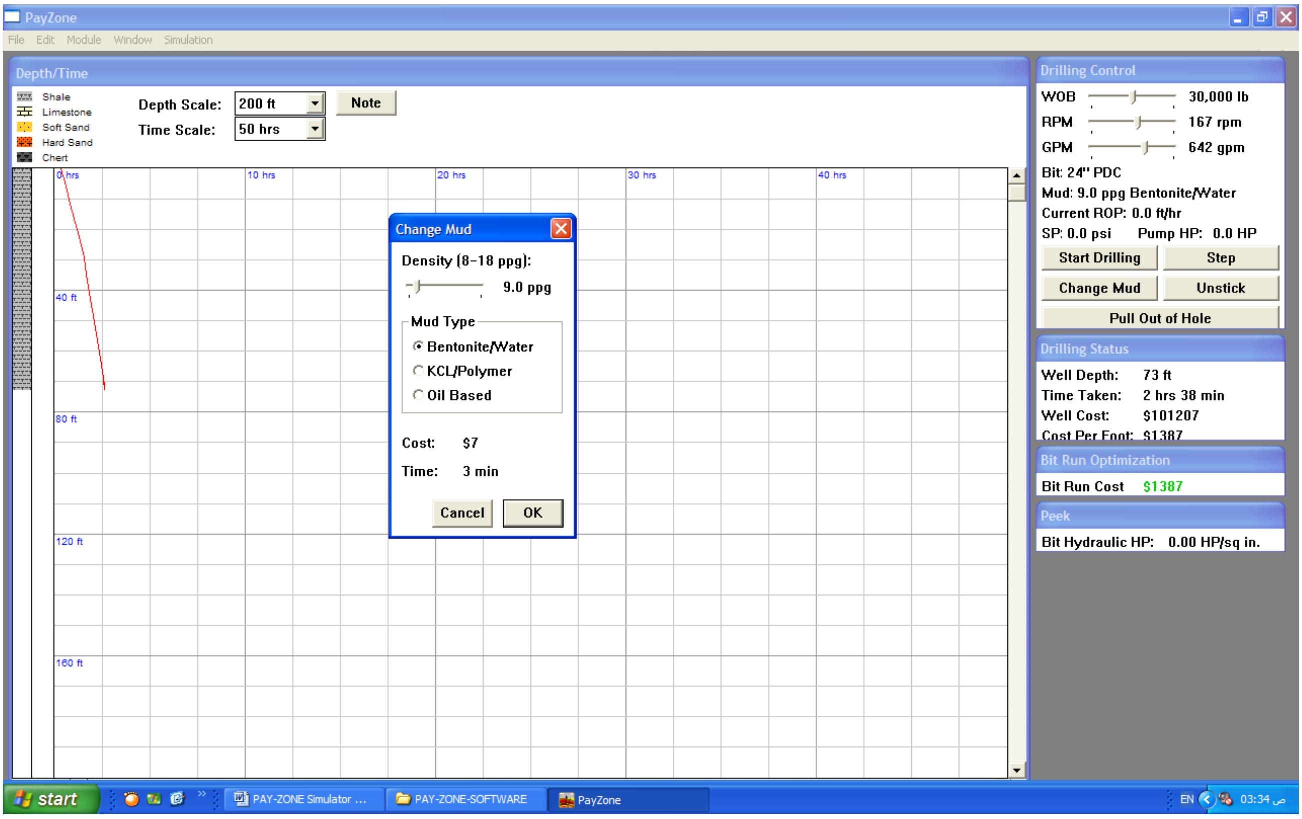
2- Open Setting Module and edit all variables including available logs, casing, bits, rig operations, well testing, etc.

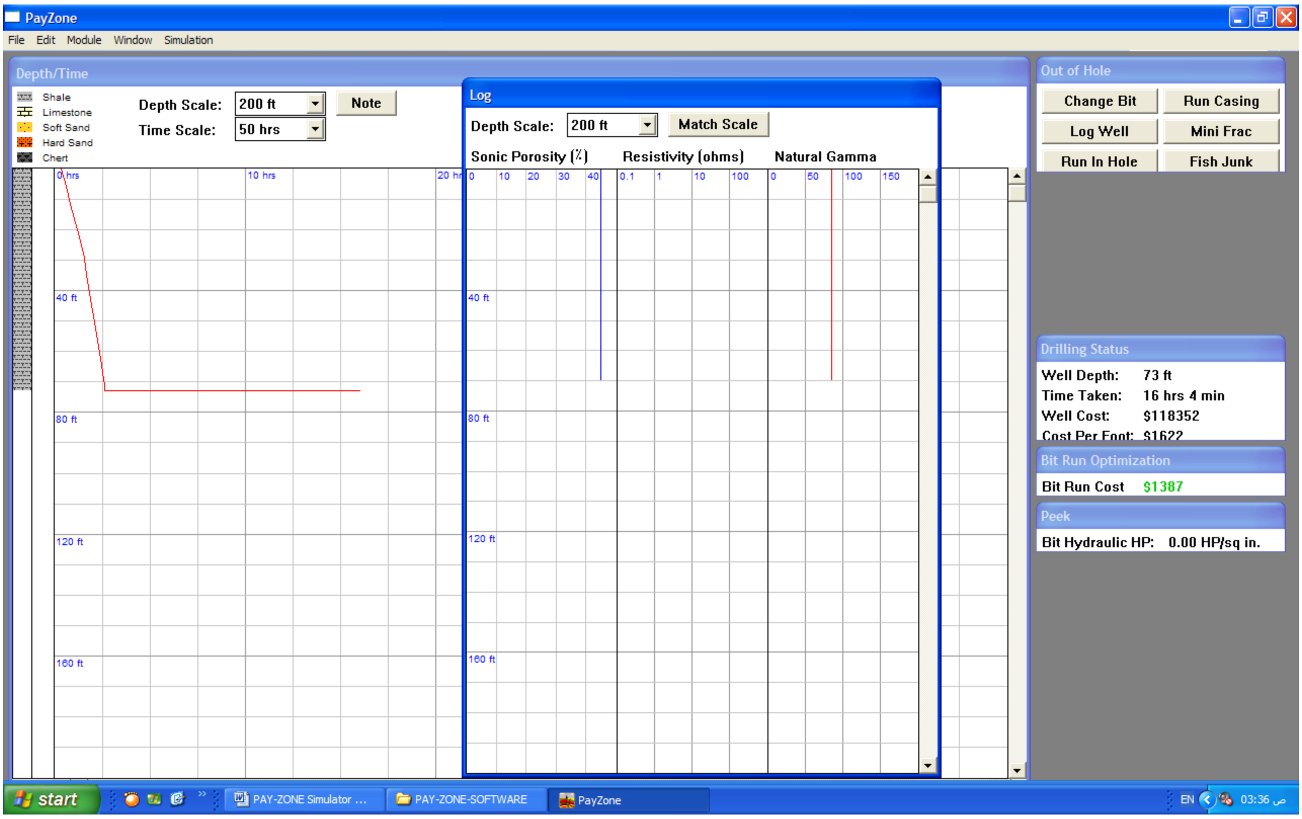


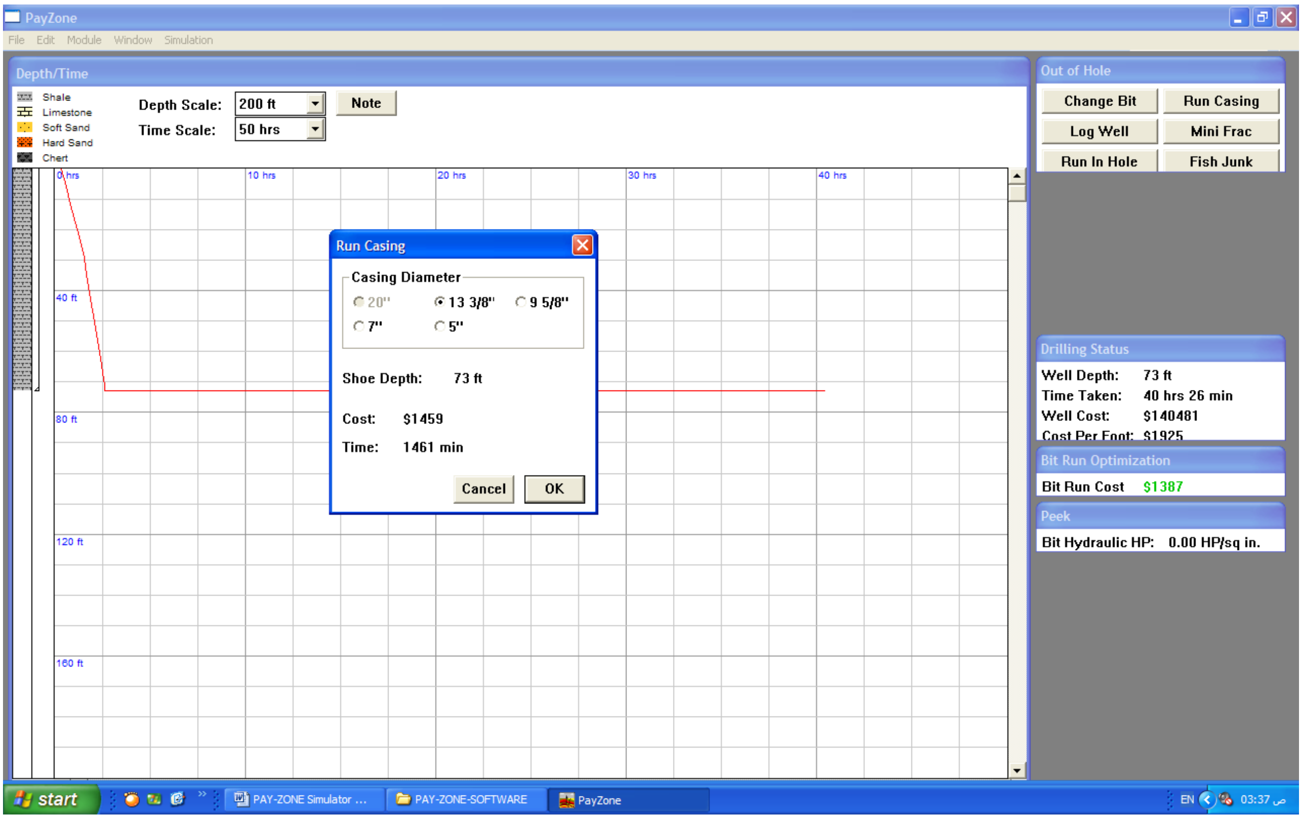
3- After setting are variables, go to Module Chooser and select "Drilling Simulator Module" and select "Run in Hole" to start drilling process. At any time you can pull out from the well and make and change in drilling parameters.

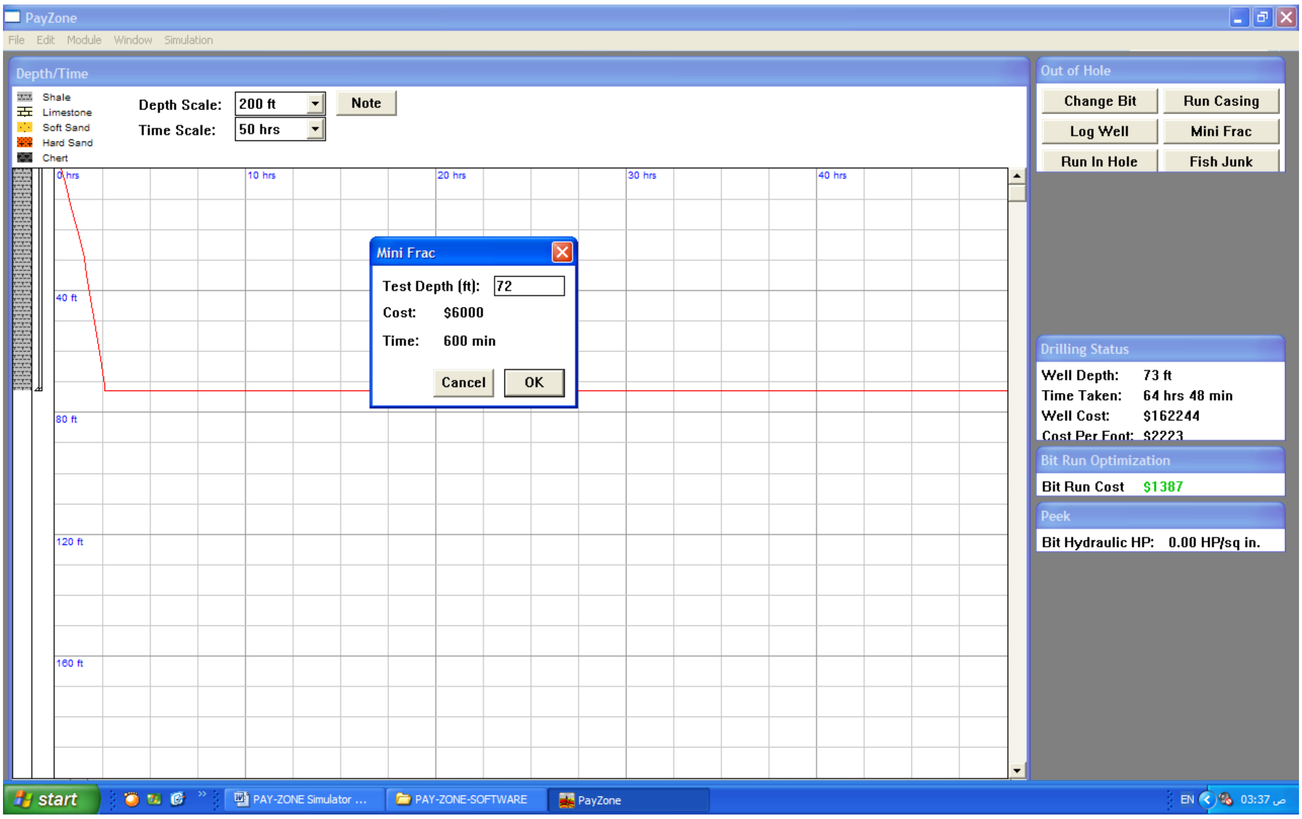


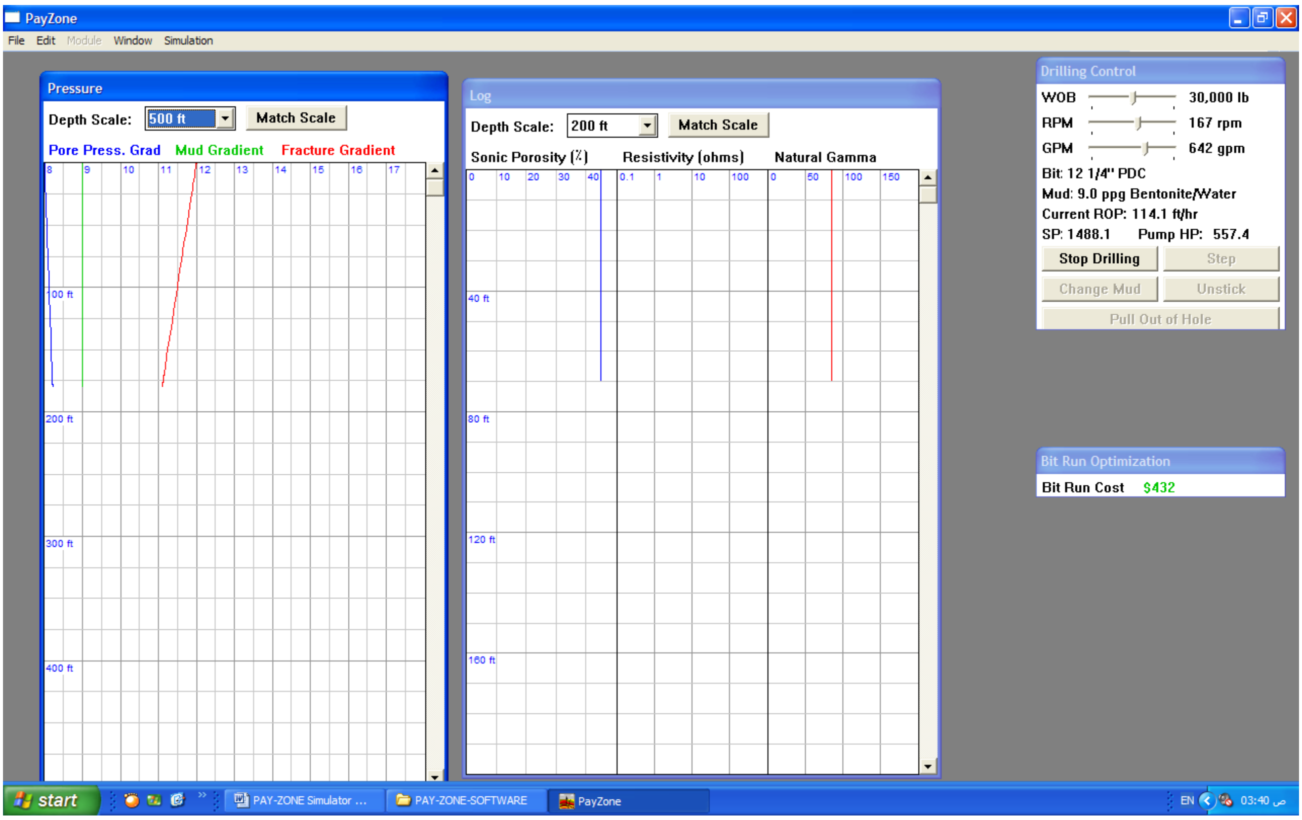

PayZone
File Edit Module Window Simulation
Depth/Time
Shale
Limestone
Soft Sand
Hard Sand
Chert
Depth Scale: 200 ft
Time Scale: 50 hrs
Note
0 hrs
10 hrs
20 hrs
30 hrs
40 hrs
40 ft
80 ft
120 ft
160 ft
Drilling Control
WOB 20,000 lb
RPM 167 rpm
GPM 642 gpm
Bit: 24" PDC
Mud: 9.0 ppg Bentonite/Water
Current ROP: 39.1 ft/hr
SP: 1333.7 Pump HP: 499.6
Stop Drilling
Step
Change Mud
Unstick
Pull Out of Hole
Drilling Status
Well Depth: 35 ft
Time Taken: 1 hrs 42 min
Well Cost: $100420
Cost Per Foot: $2862
Bit Run Optimization
Bit Run Cost $2862
Peek
Bit Hydraulic HP: 1.06 HP/sq in.
start
PAY-ZONE Simulator ...
PAY-ZONE-SOFTWARE
PayZone
EN 03:33


PayZone
File Edit Module Window Simulation
Depth/Time
Shale
Limestone
Soft Sand
Hard Sand
Chert
Depth Scale: 200 ft
Time Scale: 50 hrs
Note
0 hrs
10 hrs
20 hrs
30 hrs
40 hrs
40 ft
80 ft
120 ft
160 ft
Change Mud
Density (8-18 ppg):
9.0 ppg
Mud Type
Bentonite/Water
KCL/Polymer
Oil Based
Cost: $7
Time: 3 min
Cancel
OK
Drilling Control
WOB 30,000 lb
RPM 167 rpm
GPM 642 gpm
Bit: 24" PDC
Mud: 9.0 ppg Bentonite/Water
Current ROP: 0.0 ft/hr
SP: 0.0 psi Pump HP: 0.0 HP
Start Drilling
Step
Change Mud
Unstick
Pull Out of Hole
Drilling Status
Well Depth: 73 ft
Time Taken: 2 hrs 38 min
Well Cost: $101207
Cost Per Foot: $1387
Bit Run Optimization
Bit Run Cost $1387
Peek
Bit Hydraulic HP: 0.00 HP/sq in.
start
PAY-ZONE Simulator ...
PAY-ZONE-SOFTWARE
PayZone
EN 03:34


PayZone
File Edit Module Window Simulation
Depth/Time
Shale
Limestone
Soft Sand
Hard Sand
Chert
Depth Scale: 200 ft
Time Scale: 50 hrs
Note
Log
Depth Scale: 200 ft
Match Scale
Sonic Porosity (%)
Resistivity (ohms)
Natural Gamma
Out of Hole
Change Bit
Run Casing
Log Well
Mini Frac
Run In Hole
Fish Junk
Drilling Status
Well Depth: 73 ft
Time Taken: 16 hrs 4 min
Well Cost: $118352
Cost Per Foot: $1622
Bit Run Optimization
Bit Run Cost $1387
Peek
Bit Hydraulic HP: 0.00 HP/sq in.
start
PAY-ZONE Simulator ...
PAY-ZONE-SOFTWARE
PayZone
03:36


PayZone
File Edit Module Window Simulation
Depth/Time
Shale
Limestone
Soft Sand
Hard Sand
Chert
Depth Scale: 200 ft
Time Scale: 50 hrs
Note
Run Casing
Casing Diameter
20"
13 3/8"
9 5/8"
7"
5"
Shoe Depth: 73 ft
Cost: $1459
Time: 1461 min
Cancel
OK
Out of Hole
Change Bit
Run Casing
Log Well
Mini Frac
Run In Hole
Fish Junk
Drilling Status
Well Depth: 73 ft
Time Taken: 40 hrs 26 min
Well Cost: $140481
Cost Per Foot: $1925
Bit Run Optimization
Bit Run Cost $1387
Peek
Bit Hydraulic HP: 0.00 HP/sq in.
start
PAY-ZONE Simulator ...
PAY-ZONE-SOFTWARE
PayZone
03:37


PayZone
File Edit Module Window Simulation
Depth/Time
Shale
Limestone
Soft Sand
Hard Sand
Chert
Depth Scale: 200 ft
Time Scale: 50 hrs
Note
0 hrs
10 hrs
20 hrs
30 hrs
40 hrs
40 ft
80 ft
120 ft
160 ft
Mini Frac
Test Depth (ft): 72
Cost: $6000
Time: 600 min
Cancel
OK
Out of Hole
Change Bit
Run Casing
Log Well
Mini Frac
Run In Hole
Fish Junk
Drilling Status
Well Depth: 73 ft
Time Taken: 64 hrs 48 min
Well Cost: $162244
Cost Per Foot: $2223
Bit Run Optimization
Bit Run Cost $1387
Peek
Bit Hydraulic HP: 0.00 HP/sq in.
start
PAY-ZONE Simulator ...
PAY-ZONE-SOFTWARE
PayZone
03:37


PayZone
File Edit Module Window Simulation
Pressure
Depth Scale: 500 ft
Match Scale
Pore Press. Grad
Mud Gradient
Fracture Gradient
100 ft
200 ft
300 ft
400 ft
Log
Depth Scale: 200 ft
Match Scale
Sonic Porosity (%)
Resistivity (ohms)
Natural Gamma
40 ft
80 ft
120 ft
160 ft
Drilling Control
WOB 30,000 lb
RPM 167 rpm
GPM 642 gpm
Bit: 12 1/4" PDC
Mud: 9.0 ppg Bentonite/Water
Current ROP: 114.1 ft/hr
SP: 1488.1 Pump HP: 557.4
Stop Drilling
Step
Change Mud
Unstick
Pull Out of Hole
Bit Run Optimization
Bit Run Cost $432
start
PAY-ZONE Simulator ...
PAY-ZONE-SOFTWARE
PayZone
03:40

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REFERENCES

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6. Pay-Zone Drilling Simulator Manual, G. A. Cooper and A. G. Cooper, 1996.