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Design of Laboratory Procedures for General exercises and for Research Investigation.

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Abstract

Educating and preparing Petroleum Engineers for the 21st Century requires adequate changes in the style we teach and demonstrate knowledge, concepts and their application under complex conditions. The oil industry is undergoing fundamental changes globally, which needs to be transferred into the classroom, in order to enable future engineers to be prepared for contemporary issues in all aspects of oil and gas industry, especially exploration and production. One of the areas to be addressed at the UNIUYO Petroleum Engineering is getting a well-designed lab guide and exercises for students in the department. Also there is need for how we teach laboratory classes in order to prepare our students to easily adopt new safety requirements implemented in industry. Hence, for students to be competitive in the engineering market, they will not only need basic knowledge in engineering studies but also the technical skills that come from doing research and solving hands-on real life problems. To provide this guide for students in the department of Chemical/Petroleum Engineering, University of Uyo (UNIUYO), I used existing laboratory guides from other universities to create educational laboratory modules related to reservoir, drilling and production engineering research based on existing equipment in the petroleum laboratory. They focus on understanding the processes related to petroleum engineering experiments and how to use the equipment. This is designed to get students involved in the research being done in the area. The procedures were outlined in a simplified form which enables first time users of the equipment to be able to operate them successfully. The simplification of procedures involved a detailed theoretical background on the physics, chemistry and engineering principles on which each experimental parameter is based. The procedure for reporting laboratory results as well as general and specific precautions to be adhered to during each experiment was also included in the work. This is done in order to ensure that results and data emanating from experiments carried out with these equipment yields useful and acceptable results. Finally, detailed laboratory exercises with sample laboratory report sheets with formulas for calculations useful for student work were also included in the work. To improve the quality of the manual, a survey instrument in form of a questionnaire was added for the lab users to respond to. The photographs of all the equipment in the laboratory used in this work are included in the appendix. From the work, it is concluded that the laboratory guide is equivalent to the travellers compass in that it directs its user to reach a successful end in his or her research endeavor. Also, a meticulous use of this guide makes the user approach petroleum engineering laboratory experiments with improved confidence and reduce the burden of searching for procedures to use.

Table of Content

ACKNOWLEDGMENT	- - - - -	ii
ABSTRACT	- - - - -	iii
TABLE OF CONTENT	- - - - -	iv
LIST OF FIGURES	- - - - -	vii
LIST OF TABLES	- - - - -	ix
1.0 CHAPTER ONE: INTRODUCTION	- - - - -	1
2.0 CHAPTER TWO: EXISTING AND FUTURE LABS AT UNIUYO		
2.1 Equipment in a full-fledged laboratory	- - - - -	3
2.2 Equipment in UNIUYO petroleum laboratory	- - - - -	6
2.3 Difference between ordinary student labs and research labs for M.Sc.	- - - - -	9
3.0 CHAPTER THREE: LABORATORY MANUALS OF ALL THE EQUIPMENT WITH A DESCRIPTION OF PRINCIPLES OF EQUIPMENT USAGE AND MANAGEMENT WITHIN PETROLEUM ENGINEERING	- - - - -	10
3.1 Description and Usage of Equipment in Reservoir Engineering Courses	- - - - -	10
3.1.1 The Core Samples Drying Oven	- - - - -	10
3.1.2 The Vacuum Pump	- - - - -	14
3.1.3 The High and Low Speed Mixers	- - - - -	16
3.2 Description and Usage of Equipment in Drilling Engineering Courses	- - - - -	17
3.2.1 The Viscometer	- - - - -	17
3.2.2 The Electric Precision Balance	- - - - -	25
3.2.3 The Mud Balance	- - - - -	26
3.2.4 The Sand Content Kit	- - - - -	27
3.2.5 The Filter Press	- - - - -	29
4.0 CHAPTER FOUR: LABORATORY EXERCISES IN RELEVANT EXISTING AND FUTURE COURSES IN UNIUYO PETROLEUM ENGINEERING	- - - - -	40
4.1 Courses in Petroleum Engineering in UNIUYO	- - - - -	40
4.1.1 Courses offered in Undergraduate degree programme	- - - - -	40
4.1.2 Courses offered in Postgraduate degree programme	- - - - -	41
4.1.3 Courses offered in Undergraduate degree programme that requires course work	- - - - -	4
4.1.4 Description of courses in post graduate diploma programme needing	- - - - -	44
4.1.5 Courses offered in Master degree programme	- - - - -	46
4.2 Courses in Petroleum Engineering requiring lab work		
4.2.1 Courses and areas in Drilling Engineering requiring lab work		
4.2.2 Courses and areas in Reservoir Engineering requiring lab work		
4.2.3 Courses and areas in Production Engineering requiring lab work		

5.0	CHAPTER FIVE: LONG TERM PLAN OF MAINTENANCE AND SUPPORT ON THE EQUIPMENT FOR GOOD LABORATORY PRACTICES	-	-	-	-	-	-	-	49
5.1	Definition of Terms	-	-	-	-	-	-	-	49
5.2	Importance of Laboratory Maintenance	-	-	-	-	-	-	-	51
5.3	Types of Maintenance Programs	-	-	-	-	-	-	-	52
5.3.1	Reactive Maintenance	-	-	-	-	-	-	-	54
5.3.2	Preventive Maintenance	-	-	-	-	-	-	-	55
5.3.3	Predictive Maintenance	-	-	-	-	-	-	-	55
5.3.4	Reliability Centered Maintenance	-	-	-	-	-	-	-	57
5.3.5	Corrective maintenance	-	-	-	-	-	-	-	58
5.3.6	Comparison of Four Maintenance Programs	-	-	-	-	-	-	-	59
5.4	Proposed Long Term Maintenance Plan for the UNIUYO Lab	-	-	-	-	-	-	-	61
5.5	Equipment Management Plan Activities	-	-	-	-	-	-	-	65
5.6	Monitoring Overall Equipment Management Program Performance	-	-	-	-	-	-	-	67
6.0	CONCLUSION	-	-	-	-	-	-	-	68
7.0	NOMENCLATURE	-	-	-	-	-	-	-	69
8.0	REFERENCES	-	-	-	-	-	-	-	70
9.0	APPENDIX	-	-	-	-	-	-	-	72
	Appendix A - Design of the chemical/petroleum engineering laboratory	-	-	-	-	-	-	-	72
	Appendix B - General Laboratory Safety Procedures	-	-	-	-	-	-	-	73
	Appendix C - Procedure for reporting laboratory experiments	-	-	-	-	-	-	-	76
	Appendix D - Survey Instrument	-	-	-	-	-	-	-	82
	Appendix E - Photographs of all equipment in the UNIUYO Chemical / Petroleum Lab	-	-	-	-	-	-	-	84
	Appendix F - Lab exercises for Undergraduate Degree programme	-	-	-	-	-	-	-	92
	(a) Drilling Engineering courses	-	-	-	-	-	-	-	92
	(b) Reservoir Engineering courses	-	-	-	-	-	-	-	97
	(c) Production Engineering courses	-	-	-	-	-	-	-	102
	Appendix G – Lab exercises for Postgraduate Diploma programme	-	-	-	-	-	-	-	103
	(a) Drilling Engineering courses	-	-	-	-	-	-	-	103
	(b) Reservoir Engineering courses	-	-	-	-	-	-	-	103
	(c) Production Engineering courses	-	-	-	-	-	-	-	103
	Appendix H – Lab exercises for Master Degree programme	-	-	-	-	-	-	-	103
	(a) Drilling Engineering courses	-	-	-	-	-	-	-	104
	(b) Reservoir Engineering courses	-	-	-	-	-	-	-	126
	(c) Production Engineering courses	-	-	-	-	-	-	-	151
	Appendix I – Experiment by present author	-	-	-	-	-	-	-	151
	Experiment One - Measurement of Porosity by Saturation Method	-	-	-	-	-	-	-	151
	Aim of the experiment	-	-	-	-	-	-	-	151
	Test procedure	-	-	-	-	-	-	-	151
	Test results and discussion	-	-	-	-	-	-	-	152
	Experiment Two - Measurement of Wettability by the Amott Method	-	-	-	-	-	-	-	152

Aim of the experiment	-	-	-	-	-	-	-	-	152
Test apparatus for experiment	-	-	-	-	-	-	-	-	152
Test procedure	-	-	-	-	-	-	-	-	152
Test results and discussion	-	-	-	-	-	-	-	-	153

List of Figures

Figure 1.1:	UNIUYO Engineering Lab Directory	-	-	-	-	2
Figure 2.1:	Floor Plan of Reservoir Laboratory of the Department Of Chemical/Petroleum Engineering, UNIUYO	-	-	-	-	72
Figure 3.1:	The vacuum pump and its parts	-	-	-	-	15
Figure 3.2:	Vortexing Installation of the mixer	-	-	-	-	16
Figure 3.3:	High Speed Mixer shaft installation	-	-	-	-	17
Figure 3.4:	Gear Box Lever	-	-	-	-	20
Figure 3.5:	Rotor Removal / Installation	-	-	-	-	21
Figure 3.6:	Torsion Spring Removal and Replacement	-	-	-	-	21
Figure 3.7:	Dead Weight Calibration DW-3 Calibration Fixture	-	-	-	-	23
Figure 3.8:	The mud balance and its component	-	-	-	-	26
Figure 3.9:	The sand content kit and its parts	-	-	-	-	29
Figure 3.10:	CO ₂ Cartridge Holder Assembly	-	-	-	-	30
Figure 3.11:	Filter Press with Nitrogen Cylinder Pressure Source	-	-	-	-	31
Figure 3.12:	Dead-Weight Hydraulic Filter Press	-	-	-	-	33
Figure 3.13:	Dead Weight Hydraulic Assembly	-	-	-	-	33
Figure 3.14:	CO ₂ Pressure Assembly, Exploded View	-	-	-	-	34
Figure 3.15:	Regulator Assembly	-	-	-	-	34
Figure 3.16:	Filter Press and Cell Assembly, Exploded View	-	-	-	-	36
Figure 3.17:	Filtration Reduction Evaluation Device (FREAD)	-	-	-	-	37
Figure 3.18:	Filter Press, Standard Frame	-	-	-	-	38
Figure 3.19:	Filter Press, Standard Frame, W/ Regulator	-	-	-	-	39
Figure 3.20:	Filter Press, Standard Frame, W/ CO ₂ Pressure Source	-	-	-	-	39
Figure 4.1:	Overview of core petroleum engineering courses in UNIUYO	-	-	-	-	40
Figure 4.2:	Overview of core petroleum engineering courses offered in Post-graduate Diploma programme in UNIUYO	-	-	-	-	44
Figure 4.5:	Overview of core petroleum engineering courses offered in M. Eng programme in UNIUYO	-	-	-	-	47
Figure 5.1	Maintenance Information Loop	-	-	-	-	50
Figure 5.2	Component failure rate over time for component population	-	-	-	-	53
Figure 5.3	Plot of oil recovery with time from core sample	-	-	-	-	153
Figure 6:	Core samples drying oven	-	-	-	-	84
Figure 7:	Vacuum pump and accessories	-	-	-	-	84
Figure 8:	Desiccator and accessories, vacuum pump and accessories, vacuum Gauge, Oil Mist Filter EMF 10 plus filter, EMF 10 Spare Mist Element, Ultra Grade 19 Oil, connection tubes and fittings	-	-	-	-	85
Figure 9:	High speed and low speed mixers	-	-	-	-	85
Figure 10:	Amott cells and accessories	-	-	-	-	86
Figure 11:	Core cleaning apparatus and accessories.	-	-	-	-	86
Figure 12:	Condensers and 2000 ml round bottom flasks	-	-	-	-	87
Figure 13:	Soxhlet extractors	-	-	-	-	87
Figure 14:	Displacement pump and accessories	-	-	-	-	88
Figure 15:	Air permeameter	-	-	-	-	88
Figure 16:	Viscometers and accessories	-	-	-	-	89
Figure 17:	Electronic precision balance	-	-	-	-	89

Figure 18:	Drilling fluids test kits containing: Mud balance, Cup, Funnel, Sand Content kit, pH strips, Stop watch in carrying case E, marsh funnel	90
Figure 19:	Filter press	90
Figure 20:	Chemical supplies. Example: Methanol, Toluene, Bentonite, Barite, etc.	90
Figure 21:	Viscosity calculation chart	91
Figure A.1:	Schematic diagram of Soxhlet (a) and Dean- Stark (b) apparatus.	128
Figure A.2:	Vacuum distillation Apparatus.	128
Figure A.3:	Cubic packing (a), rhombohedra (b), cubic packing with two grain sizes (c), and typical sand with irregular grain shape (d).	132
Figure A.4:	Schematic diagram of helium porosimeter apparatus.	-
Figure A.5:	Mercury injection pump (a) and porosity through mercury injection (b).	136
Figure A.6:	Apparent formation factor versus water resistivity for clayey and Clean sands.	141
Figure A.7:	Water-saturated rock conductivity as function of porosity.	142
Figure A.8:	Formation factor as a function of water conductivity.	142
Figure A.9:	Resistivity index versus water saturation.	144
Figure A.10:	The electrical circuit of resistance measurements.	145
Figure A.11:	Interfacial tensions for water-oil-solid system at equilibrium	147
Figure A.12:	Imbibition cell with oil saturated core plug surrounded by Water (a) and water saturated core plug surrounded by oil (b).	150

List of Tables

Table 2.1:	Comparison between Analysis and Interpretation	-	-	-	78
Table 3.1:	Troubleshooting Table for Oven	-	-	-	13
Table 3.2:	Six-speed testing combinations model 35A and model 35SA	-	-	-	19
Table 3.3:	Twelve-Speed Testing Combinations Model 35A/SR12 and Model 35SA/SR12	-	-	-	20
Table 3.4:	Troubleshooting table for viscometer	-	-	-	24
Table 5.1:	Reliability centered maintenance element applications	-	-	-	58
Table 5.2:	Laboratory Maintenance Checklist	-	-	-	62
Table 5.3:	Maintenance priority matrix for RCM Development	-	-	-	64

Chapter One

Introduction

According to the National Science Foundation - an agency of the United States government that supports fundamental research and education in all the non-medical fields of science and engineering, there is an increasing concern that what is being taught at universities does not prepare students for real world challenges upon graduating (Sabatini 1997). In general, engineering homework and assignments given in the classroom tend to be very limited in scope compared to open ended work-related problems faced in real life (Sabatini 1997). For students to be competitive in the engineering market, they will not only need basic knowledge in engineering studies but also the technical skills that come from doing research and solving hands-on real life problems (Sabatini 1997). To provide this experience for students in the department of Chemical/Petroleum Engineering, University of Uyo (UNIUYO), I have created educational laboratory modules related to petroleum engineering research. They focus on understanding the processes related to petroleum engineering experiments and how to use the equipment. This is designed to get students involved in the research being done in the area.

The students in the department of Chemical/Petroleum Engineering are taught the basic principles of reservoir engineering by using textbook developed problems and solutions. In general, the data presented in these problems directly show the process under study and do not have accuracy or precision issues. I developed these laboratory modules to extend this learning experience to include field data and also provide students with an introduction to equipment usage and manuals in reservoir engineering research and methods.

However, the content of this work can provide students in the department of Chemical/Petroleum Engineering with an exposure to real data and an introduction to more open ended problems of the type that might be expected in actual projects after graduation. In order that the results generated from experiments done in this area could be acceptable and useful, the procedural steps for the experiment to be carried out needs to be carefully designed and procedures mapped out with assumptions made clearly defined, hence the need for a well-designed laboratory procedure. However, the procedural steps and their corresponding assumptions should be situated within the boundaries of known scientific principles.

Given the over-riding importance of good designed procedures for laboratory experiments, it is necessary for users of the laboratory in the Petroleum engineering programme to have an outline of procedures for experiments they want to carry out be it in drilling, reservoir or production engineering, hence the need for this work. This work primarily aims at introducing basic laboratory equipment and procedures used in Petroleum engineering courses and the theoretical aspect of the parameters. The work also includes detailed description of laboratory exercises useful for student work and could also serve as a guideline for laboratory users. In order to achieve the aim of this work, it would be following the sequence outlined below:

In order to achieve the objective of this work, it would follow the sequence:

- Gathering information on existing and relevant laboratory exercises and studies from other universities around the globe.
- Designing general laboratory exercises in relevant existing and future courses at UNIUYO
- Selecting an experimental investigation which utilizes existing equipment at UNIUYO and perform an in-depth study on selected scientific area
- Collecting laboratory manuals of all the equipment in order to describe the essential principles of Equipment Usage and Management
- Development of a long term plan of maintenance and support on the equipment for Good Laboratory Practices

Creating these laboratory exercises, will aid in students comprehension and better understanding of natural processes to provide a more complete learning environment.

To make this work unambiguous, Figure 1.1 shows the areas to be concentrated on in this work.

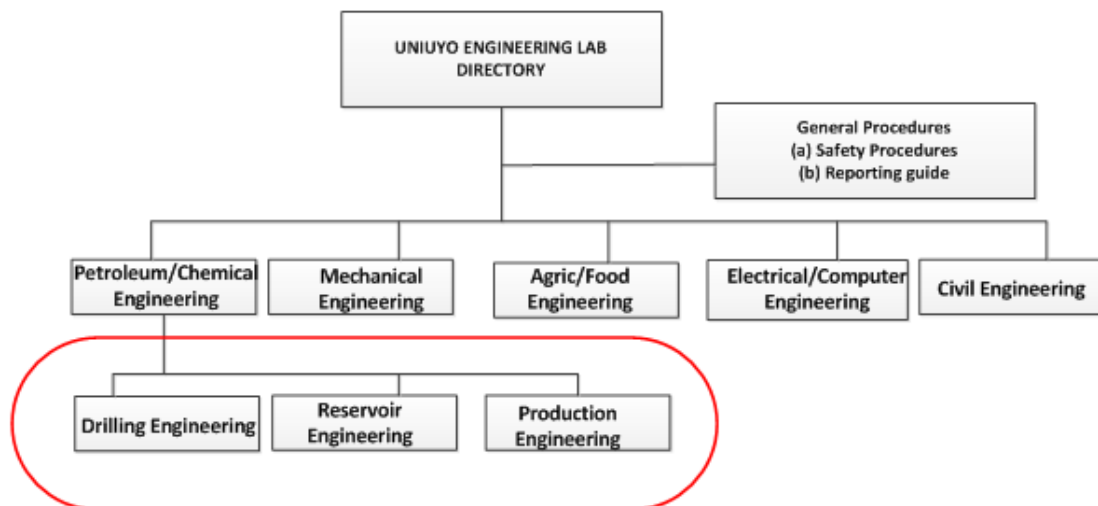


Figure 1.1: UNIUYO Engineering Lab Directory

In this work I would concentrate on the boxes in the red ring.

Chapter Two

2.0 Existing and Future Labs at Uniuyo

2.1 Equipment in a Full Fledged Petroleum Engineering Lab

This section makes an investigation into the equipment in the laboratory of UNIUYO and comparing it with laboratories from other universities in order to determine which equipment is demanded to beef up the UNIUYO lab. The labs in the universities of Alberta, U.S.A, and the lab in the University of New South Wales, Australia were used as case studies for the investigation. Below are the descriptions of what each lab look like.

Facilities at the University of Alberta Petroleum Lab

In the University of Alberta, There are a number of different laboratories, for petroleum engineering research. These laboratories, together with the major pieces of equipment to be found in each, are listed below.

- **Tertiary Gas Injection Laboratory**

This laboratory is equipped for tertiary recovery related-experiments. It contains camera-fitted equipment and data acquisition system for visualization and monitoring of laboratory tertiary-gas injection processes. The objective of the research performed with the equipment is to study the mechanisms of the gas injection/secondary water invasion which should help in development of practical set of screening criteria for selecting reservoirs which qualify for gravity assisted tertiary gas injection processes.

- **Immiscible Displacement Laboratory – Stability Lab**

This laboratory contains the followings for immiscible multiphase flow research: 1) Multiphase flow equipment for steady state and unsteady measurements: Capacitor-based saturation system, pressure transducers, FMI LAB pumping system, mass balances and data acquisition system. 2) Pressure calibration system. 3) Three personal computers. 4) Small collection of reference books.

- **Analytical Laboratory**

This is a general purpose analytical laboratory provided with equipment for standard core analysis and oil properties determination, including a Hooke rotational viscometer for high pressure, high temperature use. PVT equipment, interfacial tension measuring apparatus (including a spinning drop apparatus), ultra-high pressure pendant drop apparatus, high speed centrifuge, and so forth are also available for support of the research work as well as instructional work. This is an undergraduate laboratory but it is also used by graduate students.

- **Formation Evaluation Laboratory**

This lab is equipped with equipment for investigating the mechanism of cake formation. The laboratory at the department is equipped with the facilities necessary to conduct following experiments: Measuring the Density, specific gravity and API gravity using Hydrometers and Pycnometer. Measuring the viscosity using Brookfield Viscometer and U-tube viscometer. Measuring the kinematic viscosity using U-tube viscometer. Measuring the surface tension by Tensiometer. Determining the Flash point by Pensky-Martens Closed

Tester Method. Determination of Cloud and Pour point of crude oil. Determination of the water in crude oil by distillation and by the centrifuge. Determination of the total salts content of crude oil by conductivity method. Determination of natural gas composition using GC chromatography.

Facilities at the University of New South Wales, Australia

Facilities available to students studying at the School of Petroleum Engineering (SCOPE) include a large laboratory containing the latest equipment for industrial chemistry, geology, physics and mathematical analysis. These facilities give students practical experience of the application of the advanced technologies used in petroleum engineering. Two computer rooms and the latest software are available for training. Class sizes are small and SCOPE uses its own boardroom for presentations and seminars, both for students and representatives from industry.

SCOPE also has its own parking area.

- Fully equipped PVT laboratory for the study of fluid properties, minimum miscibility pressure, and heavy fraction characterization.
- Restored-state wettability determination, pendant drop apparatus for measurement of interfacial tension and spreading coefficients at reservoir conditions.
- Core flooding facilities, gravity stable gas flooding facilities.
- High-pressure glass micro model flooding and flow visualization facilities.
- Beckman L8-M rock ultracentrifuge equipped for high pressure, high temperature displacement experiments.
- Multicomponent apparatus for measuring mixed gas adsorption/desorption isotherms on coal.
- In-situ conditions apparatus for simultaneous measurement of porosity and permeability of coal and tight rock.
- Full range of CMG compositional and black-oil reservoir simulation software. CMG compositional and PVT software. In-house coal bed gas simulation software and phase behavior software. FEKETE well test analysis software.
- Silicon Graphics INDIGO2/IRIS workstations, direct access to University supercomputing facilities.
- Dynamic filtration apparatus to study formation damage of reservoir rock under simulated reservoir conditions.
- Mud lab consisting of FAN50 viscometer, high temperature high pressure filter press, and chemical analysis and API test equipment.
- API standard cement testing laboratories.
- Equipment to study petrophysical and mineralogical properties of reservoir rocks.
- Core preparation and cleaning laboratories.
- Laboratory scale drilling rig to study drilling parameters under bottom hole conditions.
- Liquid and gas pulse permeameter to study permeability of tight rocks (in the range of n-Darcy)
- Laboratory to study mud induced stresses in shales.
- BHA design capability for directional control in drilling deviated and horizontal wells.
- Drilling mud design capability for a range of drilling conditions: drilling through shales, hot wells, high pressure wells, etc.
- Design and optimization capability of oil well tubular goods.

- Capability to design chemical treatments for prevention and removal of formation damage.
- Summa graphics Microgrid II. In house software used for digitizing well logs, volumetric analysis of pay zones and calculating areal extent of reservoirs.
- Summa Sketch II. Graphics tablet for small scale accurate tracing of pictures, maps, drawings and photos
- In house software for the interpretation of well logs
- HP Draft Pro color plotter for draft size (A1) maps and diagrams
- State of the art geological modeling software STRATAMODEL
- Pseudo 3D fracture simulation model STIMPLAN.

The Petroleum Lab at West Virginia University, U.S.A

The Petroleum and Natural Gas Engineering Department (PNGE), with its state-of-the-art laboratories, is a world leader in fluid flow through porous media, reservoir characterization and stimulation by computational intelligence, natural gas storage, multi-phasic flow in pipes, drilling & production engineering, and environmental remediation.

- **Core Analysis Laboratory**

The purpose of this laboratory is to acquaint the students with the standard laboratory methods and techniques for measuring rock properties. Major pieces of equipment available in this facility include the core and brine resistivity measurement units, helium porosimeter, mercury porosimeter, capillary pressure unit, permeability measuring apparatus, acid flow test unit, relative permeability apparatus, desaturation capillary pressure unit, centrifuge extractor, drying oven, retorts, and core cutting and preparation units. With the exception of the mercury porosimeter and capillary pressure apparatus, all equipment is housed in one room.

- **Drilling Fluids Laboratory**

This laboratory is equipped with routine drilling fluid analysis instruments. Students are taught standard techniques for preparing and measuring drilling fluids properties. Equipment available includes blenders, mud balances, marsh balances, rheometers, pH meters, resistivity meters, and the filter press unit. An IBM- PC unit installed in this laboratory provides information on the properties of additives and mud calculations. Moreover, the Digitran RS 3000 Rig Floor Simulator permits the instructor to demonstrate normal and abnormal drilling conditions and the proper actions necessary to control kick conditions.

- **Gas Measurement Laboratory**

This laboratory gives the students hands-on experience in metering natural gas and testing procedures for determining accuracy of various meters. A number of natural gas meters including diaphragm, rotary, turbine, and orifice meters are used in this laboratory. Each meter is installed in an appropriate meter run equipped with pressure and flow regulator as well as temperature and pressure recorder. In addition, several provers including Bell, Sonic Nozzle, Low Pressure, and Transfer Provers are used for proving various meters. For utilization and safety, the laboratory and its equipment are excellent.

- **PVT (Fluid Analysis Laboratory)**

The PVT Laboratory course acquaints students with the laboratory techniques for measuring the important properties of hydrocarbon fluids, and thus, includes the required equipment for routine testing of hydrocarbons. Major pieces of equipment include long and short window PVT cells, a flash separation unit, mercury pumps, hydrometers, and viscometer. One faculty member is in charge of this laboratory to oversee all operations including safety and maintenance.

- **Rig Floor Simulator**

This unit provides the department with the capability to practice everyday oil and gas drilling operations using state-of-the-art equipment. All controls existing in a modern drilling unit are displayed at full scale giving students the feeling of an actual drilling rig. Our simulator also permits students to practice hazardous and life threatening operations without endangering either their lives or the environment. Such training is an important, integral part of a drilling operation.

2.2 Equipment in Uniuyo Petroleum Engineering Laboratory

Listed below are the equipment in the laboratory of the department of Chemical/Petroleum Engineering, University of Uyo. The equipment is listed in order of the courses requiring their use. The major equipment is listed but the accessories associated with them were basically left out.

Drilling Lab Equipment

1. Mud balance
2. Marsh funnel viscometer
3. Fann VG meter
4. HTHP filter press
5. LTLP filter press
6. Sand content kit
7. Blender
8. A set of sieves - 4mm-1, 2mm-1, 500 μ -1, 250 μ -1, 63 μ -1, 45 μ -1
9. Electronic balance
10. Triple beam balance
11. Digital oven
12. Resistivity meter
13. Rotary viscometer
14. Stop clock
15. pH meter
16. Sulphur determination apparatus
17. HTHP consistometer
18. Waring blender
19. Syscal resistivity meter
20. V –cart cement tester

21. Rock press

Reservoir/Production Laboratory

1. Sieve shaker
2. Retort kit
3. Water analysis kit
4. Distillation apparatus
5. Porosity cup (fabricated)
6. Permeability equipment (fabricated)
7. Salt in crude analysis tester
8. Flash point apparatus
9. Carbon residue apparatus
10. Osborne Reynolds apparatus
11. Hydraulic bench
12. Heat exchangers
13. Thermometers
14. Fume cupboard
15. Hydrometer
16. Stand by generators
17. Core porosimeter
18. Permeability tester
19. Quick fit distillation apparatus
20. Soxhlet distillation apparatus
21. Spatula

Glassware Furniture

1. Clamp and stand
2. Plastic cups
3. Plastic beaker
4. Glass beaker (different sizes)
5. Glass funnel (different size)
6. Burette (different size)
7. Pipettes (different size)
9. Volumetric flask (various sizes)
10. Measuring cylinder
11. Conical flask
12. Flat bottom flask
13. Round bottom flask
14. Side arm flask
15. Buchner funnel
16. Porcelain dish
17. Dropper
18. Glass rod

19. Test tube
20. Separating funnel
21. Reagent bottle
22. Plastic container
23. Glass jug
24. Wash bottle
25. Wooden cabinet
26. Work bench
27. Metallic shelf

Equipment Related to Reservoir Engineering Courses

1. Core samples drying oven
2. Vacuum pump
3. Core samples
4. Desiccator and accessories
5. Vacuum gauge
6. Oil Mist Filter EMF 10 plus filter
7. EMF 10 Spare Mist Element
8. Ultra Grade 19 Oil
9. Connection tubes and fittings
10. High speed and low speed mixers
11. Amott cells and accessories
12. Core cleaning apparatus and accessories.
13. Heating Element/Mantles WHM,
14. Round bottom flasks 2000 ml, with integrated power controller, power supply 230V.
15. Flasks, 2000 ML, DIN 12348,
16. Condensers T 45/40. Dimroth Condensers for Soxhlet 100-250 ml, L. 250 mm,
17. Clips for joints, Made of stainless (SCHLIFFEDER), ST 29/32-29/42 Pack.
18. Condensers and 2000 ml round bottom flasks for core cleaning apparatus
19. Soxhlet extractors for core cleaning apparatus and Examination gloves
20. Displacement pump and accessories
21. Air permeameter

Equipment Related to Drilling Engineering Courses

1. Viscometers and accessories
2. Electronic precision balance
3. Mud balance
4. Funnel
5. Sand content kit
6. pH strips
7. Stop watch
8. Marsh funnel
9. Filter press
10. Chemicals: Methanol, Toluene, Bentonite, Barite, etc.

Equipment Related to Production Engineering Courses

1. pH Meter
2. Conductivity Meter
3. Thermostatic cooling bath
4. Constant Temperature bath
5. Rotary Evaporator
6. API Hydrometer
7. Pour Point Apparatus
8. Spectrophotometer
9. Redwood Viscometer
10. Dean and Stark Distillation Apparatus
11. Reid Vapour Pressure Constant Temperature Bath
12. Rams bottom Carbon Residue Apparatus
13. Crude Petroleum Distillation Apparatus
14. Shell and Tube Heat Exchanger
15. Fabricated Osborne Reynolds Apparatus
16. Deionizer
17. Oven
18. Vacuum pump
19. Stop Clock
20. Hydraulic Beneli with accessories FI-17, F1-18, F1-21, F1-22
21. Smoke Point lamp
22. Refractometer
23. Fluid Mixing Apparatus
24. Osborne Reynolds Apparatus
25. Batch Reactor
26. Continuous Reactor Service Unit
27. Tubular Heat Exchanger
28. Heat Exchanger Service Unit
29. Melting Point Apparatus

2.3 Difference between ordinary student labs and Research labs for M.Sc.

There is a world of difference between ordinary student labs and research labs for MSc. This is indicated by the sophisticated nature of the equipment used for research. In the UNIUYO lab, there is need for more equipment for it to function optimally as a research lab. Hence the following equipment are in high demand and need to be constructed. They include: cutting flow loop equipment for cuttings transport experiments in Drilling engineering, In-situ conditions apparatus for simultaneous measurement of porosity and permeability of coal and tight rock for reservoir engineering etc.

CHAPTER THREE

3.0 Manuals of All the Equipment with a Description of the Essential Principles of Equipment Usage and Management

3.1 Description and Usage of Equipment in Reservoir Engineering Courses

3.1.1 The Core Samples Drying Oven

The drying oven is used in the laboratory for drying core samples. Manufacturers have developed several types of drying oven for that purpose: some operate by natural convection or by forced convection, others by gravity convection. In general, the ovens operate between room temperature and 350 °C. They are also known as hot air oven, or Poupinel or Pupinel.

The drying oven is used for drying core samples and metal materials used for examinations or tests performed in the laboratory. Dry heat sterilization of clean material is conducted at 180 °C for two hours in the oven. Upon being heated by high temperature dry air, humidity is evaporated from core samples and thus the possibility of any remaining fluid is eliminated.

Generally, drying ovens have an internal and an external chamber. The internal chamber is made of aluminium or stainless steel material with very good heat transference properties. It has a set of shelves made of stainless steel grids so that air circulates freely around objects requiring drying or dry heat sterilization. It is isolated from the external chamber by insulating material which maintains high temperature conditions internally and delays the transference of heat to the exterior. The external chamber is made of steel laminate, covered with a protective film of electrostatic paint. Heat is generated through sets of electrical resistors transferring this thermal energy to the chamber. These resistors are located in the lower part of the oven and heat is transferred and distributed by natural or forced convection (in oven with internal ventilators)

In order to be used, the drying oven requires the following:

1. A large, strong, levelled work table.
2. Free space of at least 5 cm around the oven and enough space to place the material to be processed.
3. An electrical outlet with a ground pole of appropriate size for supplying electrical power to the oven. It must be in good condition and comply with the national or international electrical standards used in the laboratory and must not be more than 1 m away from the equipment. The typical voltage used is 110 V or 220 V/60 Hz.
4. Verifying that the electrical circuit has the necessary protection devices for guaranteeing an adequate electrical feed

A series of precautions must be taken into account for the correct operation of the oven. Among the most important are the following:

1. Do not use flammable or explosive materials in the oven.
2. Avoid spills of acid solutions or corrosive vapours inside the oven to prevent corrosion of the surfaces and interior shelves.
3. Use personal protection elements (insulated gloves, safety glasses and tongs for placing or removing substances or materials inside the drying oven)

Operation routine

In general, the following procedure is performed:

1. Activate the main switch, pressing the button usually identified by the symbol [I].
2. Press the key identified as Program.
Select the operational temperature by pressing the key marked by the sign (+) until the selected temperature appears on the screen. The oven will start the heating process until reaching the selected temperature.
4. For programmable ovens, instructions must be followed as defined by the manufacturer for setting additional parameters such as time, types of warming and alarms.

It is possible to identify the following elements:

1. The main switch.
2. Screens for controlling the current and selected temperatures.
3. The parameter selection button (menu).
4. The button for programming operation cycles.
5. Buttons for increasing and decreasing the Temperatures

Each manufacturer supplies detailed instructions to operate these controls. In general, they are located on the lower part of the oven and are cooled by a ventilator which circulates ambient air inside the assembly space where other electronic components are installed.

Electric circuit

The following elements are outlined:

1. Main switch. It energizes or turns off the oven.
2. Control. It controls the oven's functions (temperature, time, type of heating and cooling, selected operation modes such as preheating, sterilization, dehydration, preparation, drying and even baking).
3. Resistors. Heating elements transforming electrical energy into thermal energy.
4. Indicator systems. Devices complementing the general control. These indicate if the oven is ON and in operation.

Routine Maintenance

The maintenance required by a drying oven is simple and no complex routine maintenance is necessary. General maintenance routines to carry out as necessary are described next. The procedures vary depending on the type of oven and designs from different manufacturers.

Warning: Before carrying out any maintenance routine on the oven, verify that it is at room temperature and disconnected from the electrical feed outlet. Access to electronic components

Frequency: Whenever necessary

The oven's electronic components are usually located in its lower part. In order to be able to check them, proceed as follows:

1. Disconnect the oven from the electrical feed outlet.
2. Move the oven forward until the front part of the base is aligned with the edge of the working space.

3. Place two wedges of approximately 3 cm in thickness below each front support. This will elevate the front part of the oven and facilitate the inspection of electronic elements once the lower cover is removed.
4. Remove the screws securing the lower cover and lift it. Next, check the electronic control components. In general, the following elements are located in this compartment.
 - a) The programmable control panel
 - b) A safety release
 - c) The main switch and circuit breaker (combined)
5. Replace the cover once checking has been completed.

Changing of the heating resistors

Frequency: Whenever necessary

The procedure explained next must be performed by personnel with a good knowledge of electricity.

1. Disconnect the oven from the electrical feed outlet.
2. Remove the thermometer from the upper part of the chamber.
3. Open the door and remove the shelves
4. Disconnect the thermometer's probe.
5. Remove the screws that secure the lower panel.
6. Remove the lower panel.
7. Remove the screws that secure the resistor's electrical feed cables and disconnect the terminals fastening these to the resistors.
8. Remove the screws that secure the resistors as well as the external resistors.
9. Install new resistors with the same characteristics as the originals.
10. Reinstall the parts and reconnect the electrical components.

Changing the cooling ventilator

Frequency: Whenever necessary

To change the cooling ventilator (generally located in the lower part), these procedures must be followed:

1. Proceed as explained for opening the electronic compartment.
2. Disconnect the ventilator's electrical feed terminals.
3. Undo the screws that secure the ventilator.
4. Install a ventilator with the same specifications as the original; connect the wires feeding the ventilator to the terminals.
5. Replace the protective cover

Changing of the door gasket

Frequency: Whenever necessary

The door's gasket is usually made of silicone.

1. Turn off the oven and open the door.
2. Loosen the safety devices that keep the gasket in place.
3. Remove the gasket using a screwdriver for disengaging it from the retention guide. Avoid using excessive force which can distort the housing.
4. Install the replacement gasket starting from the upper part. Next, move the rest of the gasket towards the sides, securing it with the assembly elements which fasten it to the door. Finish the procedures on the lower part of the door in the same fashion.

Changing of the thermocouple

Frequency: Whenever necessary

1. Open the electronic control compartment.
2. Remove the thermocouple's connecting cables from their connection points on the control card.
3. Loosen the thermocouple assembly from the upper part of the oven. Move it towards the front part until a free length of at least 15 cm of connector cable is left exposed.
4. Cut the cable from the thermocouple to remove its wrapping.
5. Secure the cut ends of the defective thermocouple with the cables from the replacement. Use tape to prevent these from becoming loose.
6. Gently pull the defective thermocouple outside of the electronic compartment while keeping the electric wiring attached to use as a guide during its replacement
7. Disconnect the wires of the old thermocouple and place those of the new thermocouple into their respective connection terminals. Check that the original polarity is maintained.
8. Reassemble the protective cover.

Changing of the door hinges

Frequency: Whenever necessary

To change the door hinges, proceed as explained next:

1. Open the door and lift it from the hinges.
2. Remove the assembly screws of the defective hinges.
3. Remove the defective hinge(s).
4. Put the new hinge(s) in place and tighten with the assembly screws.
5. Reinstall the door.

Table 3.1: Troubleshooting Table for Oven

PROBLEM	PROBABLE CAUSE	SOLUTION
There is no power to the oven	The oven is not connected. The main switch is off.	Connect the oven to the electrical outlet.
	The circuit breaker is defective.	Change the circuit breaker.
	The control card is defective	Substitute the control card
	The connector cable is defective.	Check/repair connector cables
Erratic elevated temperature	The thermocouple is defective.	Substitute the thermocouple
	The control is defective.	Substitute the control.
The oven shows heating errors.	A temperature lower than that selected	Change the temperature selection. Wait until it reaches the selected temperature.
	The thermocouple is defective	Substitute the thermocouple
	The heating resistor is defective	Substitute the heating resistor.
	The control is defective	Replace the control.
The screen displays the message "open".	The thermocouple circuit is open	Verify the thermocouple connection or substitute the thermocouple

3.1.2 The Vacuum Pump

Instructions for Changing Vacuum Pump Oil

1. Operate vacuum pump until vacuum pump oil becomes warm.
2. Turn vacuum pump switch off and disconnect electrical cord plug from electrical outlet.
3. Place vacuum pump on a level surface. Unscrew and remove oil plug from bottom of pump housing and let oil drain from pump until all oil has drained.
4. Reinstall drain plug back into pump housing.
5. Remove oil fill plug in top of pump housing.
6. Add oil as noted on specification chart or an amount of FJC vacuum pump oil, part # 2200, to raise the oil level to the full oil level marks on the front of the vacuum pump housing on each side of the oil sight glass.
7. Reinstall oil fill plug.
8. Operate vacuum pump for a short period of time.
9. Check oil level through oil sight glass. (See Figure 3.1)
10. Operate vacuum pump for a short period of time.
11. Vapor from exhaust port is normal during operation. This is the result of moisture in A/C system and humidity in shop.
12. Check oil level through oil sight glass. (See Figure 3.1)
13. The vacuum pump will become hot during operation.
14. Remove electrical plug from outlet. Grasp plug and pull from outlet. Pulling wire to disconnect plug from outlet will damage electrical plug.

Troubleshooting/Management of Equipment

Pump will not run.

1. Check electrical outlet for low voltage or no voltage.
2. Check to ensure switch is turned on.

Pump does not pull low vacuum.

1. Check oil level.
2. Check for contaminated oil.
3. Check manifold and system servicing for leaks.
4. Check for low voltage at electrical outlet.
5. Check type of oil. If incorrect type of oil is used vacuum pump will not operate properly.

Essential Operating Instructions

1. Check oil level. Oil level in sight glass should be even with “oil level full” marks on each side of sight glass on front of vacuum pump. If oil level is low, add oil until oil level reaches full oil level marks. (See Figure 3.1)
2. Make sure vacuum pump electrical switch is turned off. (See Figure 3.1)
3. Plug electrical plug into a grounded 115 volt electrical outlet.
4. Connect yellow hose from manifold gauge set to inlet of vacuum pump. Make sure pressure in system is less than 5 psi. If pressure is over 5 psi vacuum pump may be damaged.
5. Turn switch to on. (See Figure 3.1)
6. Vapor from exhaust port is normal during operation. This is the result of moisture in A/C system and humidity in shop.
7. Allow pump to operate until desired vacuum is reached.
8. Close manifold gauge set valves.
9. Turn switch to off position. (See Figure 3.1)

10. Disconnect yellow hose from vacuum pump.
11. Remove electrical plug from outlet. Grasp plug and pull from outlet. Pulling wire to disconnect plug from outlet will damage electrical plug.

Set Up Instructions:

1. Read vacuum pump instructions.
2. Remove vacuum pump and vacuum pump oil from box.
3. Inspect vacuum pump and electrical cord for damage.
4. If damage is found, it should be immediately reported to the freight carrier.
5. Vacuum pump is shipped without oil – do not operate until oil is added.
6. Warranty is void if vacuum pump is operated without oil.
7. Place vacuum pump on a level surface. Remove oil fill plug from top of pump housing and add vacuum pump oil until oil level is even with oil level full marks on front of vacuum pump housing on each side of the oil sight glass.
8. Use only FJC vacuum pump oil or equivalent. If the wrong type of oil is used, the vacuum pump will not operate properly. (See Figure 3.1)
9. Reinstall oil fill plug. (See Figure 3.1)

Maintenance

Check oil level through oil sight glass before each use. The main cause of vacuum pump failure is low oil levels and contaminated oil. (See photo)

Always disconnect vacuum pump from electrical source before performing any maintenance.

Replace vacuum pump oil every week during heavy usage periods or after every service of a system with excess moisture. Keep vacuum pump in a clean dry place.

Use FJC vacuum pump oil Part # 2200 or equivalent.

Check electrical cord and plug for wear or damage each week. If damage or excessive wear is found, have cord replaced by a licensed electrical technician.

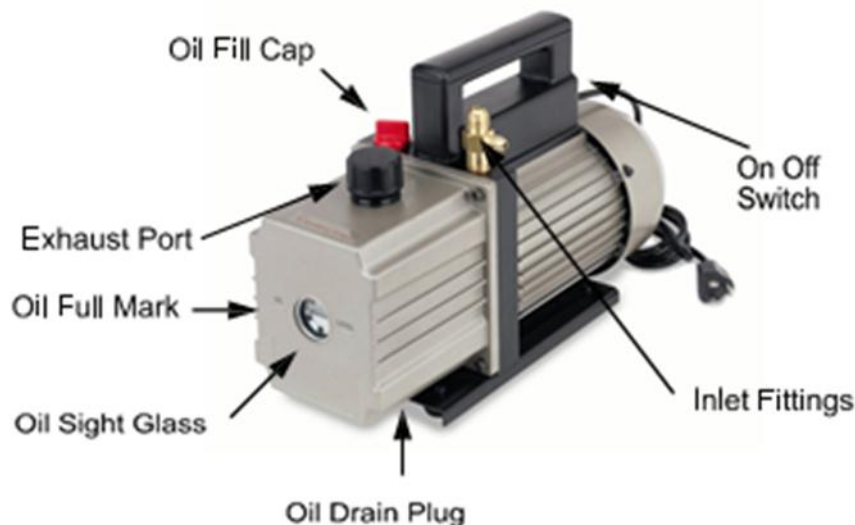


Figure 3.1: The vacuum pump and its parts

3.1.3 The High and Low Speed Mixers

Installation

Once location is decided on, chemical mixer needs to be securely mounted to frame or sturdy structure. Mixers may not be mounted directly to the wall of polyethylene tanks. Polyethylene is a flexible material and eventually will give way to the vibrations and weight of the mixer. Be sure that anchoring bolts and wiring comply with local building codes. The following diagrams will help provide the mixing needed

Mixer Orientation

How the mixer is oriented determines the type of mixing produced.

Blending Installation (shown to right)

Note: Mixer needs to be installed at 10-15 degrees from vertical and towards center of tank. This will force fluid movement from bottom to top of tank. The mounting brackets of the mixer facilitate a standard angled mounting. If vortexing (fluid funneling) appears, adjust the angle of the mixer towards the side wall



Figure 3.2: Vortexing Installation of the mixer

Note: Mixer needs to be installed vertically and in the center of the tank. This will create the best vortex and help draw in dry chemicals. Baffles can be added to the inside of the tank to decrease the vortexing. If Dry chemicals are not being drawn in, mixer may be undersized. If dry chemicals are settling at the bottom of the tank, the mixer shaft may be too short.

Mixer Shaft Installation

When installing the mixer shaft, align the red arrow and the setscrew dimple, and then hand tighten the shaft set screw with an Allen wrench.

Be sure to check all fasteners, mounting and set screws, before start up, to ensure proper mixer performance. *Do not use lock-tight on set screw, or shaft will not be able to be replaced.*



Figure 3.3: High Speed Mixer shaft installation

Routine Maintenance

Routine maintenance in this section is referred to as checking once a week until a maintenance schedule can be determined. All fasteners should be checked for proper operations. Maintenance and care will depend upon the usage and environment in which the chemical mixer is subject to.

Inspection of the mixer should include:

Balance – Be sure that the mixer is not shaking or wobbling

Mounting Hardware – Be sure that the mounting hardware is secure.

Shaft Integrity – Check the shaft for chemical attack.

Fluid Consistency – Check that the fluid is being mixed to your requirements

3.2 Description and Usage of Equipment in Drilling Engineering Courses

3.2.1 The Viscometer

The FANN Model 35 viscometer are direct reading instruments which are available in six speed and 12 speed designs for use on either 50 Hz or 60 Hz electrical power. The standard power source is 115 volts but all of the models may be fitted with a transformer which makes operation with 220/230 volts possible.

These are true Couette coaxial cylinder rotational viscometer since the test fluid is contained in the annular space (shear gap) between an outer cylinder and the bob. Viscosity measurements are made when the outer cylinder, rotating at a known velocity, causes a viscous drag to be exerted by the fluid. This drag creates a torque on the bob, which is transmitted to a precision spring where its deflection is measured and then compared with the test conditions and the instrument's constants. This system permits the true simulation of many of the significant flow process conditions encountered in industrial processing.

Viscosity as measured by a Couette type viscometer such as the Model 35 is a measure of the shear stress caused by a given shear rate. This relationship is a linear function for Newtonian Fluids, i.e. a plot of shear stress vs. shear rate is a straight line. In many

instances, while the fluid of interest may not be Newtonian, its rheology is near enough to Newtonian that this viscometer can be used and the viscosity calculated as though it were Newtonian. It should be noted that the recommended calibration of the Model 35 is a linear or Newtonian calibration. This means that if the sample fluid characteristics are extremely Non-Newtonian the linear method of calculating the viscosity cannot be used. In this case the Model 35 dial reading and speed along with the dimensional data on the rotor and bob used will have to be calculated using an appropriate formula for a non-linear shear stress / shear rate relationship that closely fits the characteristics of the fluid.

These instruments have been designed so that viscosity in centipoise (or mille-Pascal seconds) of a Newtonian fluid is indicated on the dial with the standard rotor, bob, and torsion spring operating at 300 rpm. Viscosities at other test speeds may be measured by using multipliers of the dial reading. The range of shear rates may be changed by selecting rotor speed and using various rotor-bob combinations. A variety of torsion springs are available and designed to be easily interchanged in order to broaden shear stress ranges and allow the measuring of viscosity in a wide variety of fluids.

Safety Considerations

A. Safe Operation

The safe operation of the FANN Model 35 Series Viscometer requires that the laboratory technician be familiar with the proper operating procedures and potential hazards associated with the instrument. This instrument is driven by 115 volt or 230 volt electrical power. Keep hands, clothes and other objects away from the rotating parts of the machine

The optional heated sample cups and recirculating sample cups are electrically heated. Make sure the power cord and other wiring associated with these cups is in good condition and properly grounded. Make sure the viscometer is turned off and unplugged from the source before cleaning or other repair or maintenance. Do not allow the Viscometer Base to get wet. If samples have been spilled or splattered, wipe clean with a damp cloth. Do not allow water to run into the base, as excessive water could cause damage to the electrical components.

B. Standard B1 Bob

The standard B1 Bob normally furnished with the Model 35 Series Viscometer is a hollow Bob and must not be used to test samples hotter than 200°F (93°C). Solid Bobs are available for this type testing.

C. Safe Operation of the Optional Heated Sample Cup

Precautions should be taken when testing heated samples using the optional heated sample cups to avoid possible burns from spilled hot sample, or from touching the hot sample cup.

When heated sample cups are being used, do not exceed 200°F

Viscosity Test

The stainless steel sample cup provided has a line at the proper 350 ml test fluid level. Fill the cup to that line with recently stirred test fluid. A scribed line on the rotor indicates proper immersion depth. Damage to the bob shaft bearings may occur if this immersion depth is exceeded. If other sample holders are used, the space between the bottom of the rotor and the bottom of the sample holder should be one-half inch (1.27cm) or greater.

Warning: the standard b1 bob is hollow and should never be used to test samples hotter than 200°f. (93°C).

A. Model 35A and Model 35SA

The Model 35A and 35SA viscometer are instruments with the ability to test at six different speeds. Their range is from 3 rpm up to 600 rpm with the speed being determined by a combination of speed switch setting and viscometer gear knob placement. To select the desired speed, set the speed switch located on the right side of the base to the high or low speed position as desired. Then turn the motor on and move the viscometer gear shift knob located in the center of the top of the instrument to its desired position.

Table 3.2 lists the proper positions for the viscometer switch and the gear knob combinations to obtain the desired speed. The viscometer gear shift knob may be engaged while the motor is running. Read the dial for shear stress values.

Table 3.2: Six-Speed Testing Combinations Model 35a and Model 35sa

SPEED RPM	Viscometer Switch	Gear Knob
600	High	Down
300	Low	Down
200	High	Up
100	Low	Up
6	High	Center
3	Low	Center

B. R-12 Model 35A/SR12 and 35SA/SR12

The Model 35A/SR12 and 35SA/SR-12 have twelve speed testing capabilities. To achieve this broader testing range (from 0.9 rpm up to 600 rpm) an additional gear box shift lever is used and it is located on the right side of the gear box. Position this lever to the Left or Right as determined from Table 3.3

Caution: never change this gear box shift lever while the motor is running. Gear damage will result.

Only the viscometer gear shift knob on the top of the instrument can be changed while the motor is running. After preparing the instrument for 12-speed testing by setting the gear

box shift lever, select the proper speed range with the speed shift switch on the right side of the base, then turn on the motor and set the viscometer gear knob on the top of the instrument. Refer to Table 3.3 for the correct combination of gear box shift lever setting; speed switch selection; and viscometer gear knob placement. The stress values will appear on the dial.

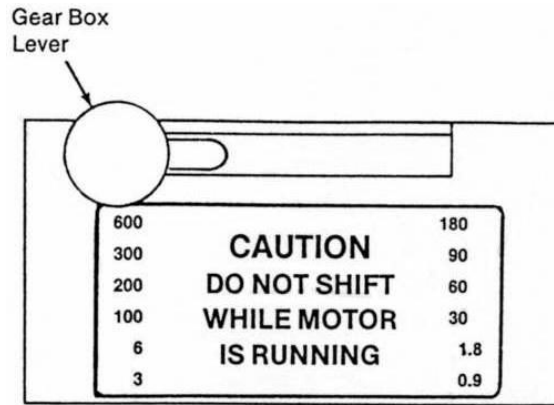


Figure 3.4: Gear Box Lever

Table 3.3: Twelve-Speed Testing Combinations Model 35A/SR12 and Model 35SA/SR12

RPM	Gear Box Lever	Speed Switch	Viscometer Gear Knob
600	Left	High	Down
300	Left	Low	Down
200	Left	High	Up
180	Right	High	Down
100	Left	Low	Up
90	Right	Low	Down
60	Right	High	Up
30	Right	Low	Up
6	Left	High	Center
3	Left	Low	Center
1.8	Right	High	Center

RPM	Gear Box Lever	Speed Switch	Viscometer Gear Knob
0.9	Right	Low	Center

C. GEL STRENGTH

Gel strengths are measured by first stirring the sample thoroughly at 600 rpm. Set gears to the neutral position and turn motor off. After desired wait period, turn gel knob, located below gear shift knob, refer to Figure 3.5, slowly counterclockwise and read the dial at instant of the gel break (Peak Dial Reading). Gel reading is in lbs./100 ft. 2.

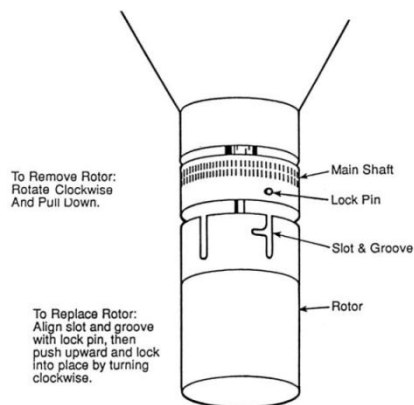


Figure 3.5: Rotor Removal / Installation

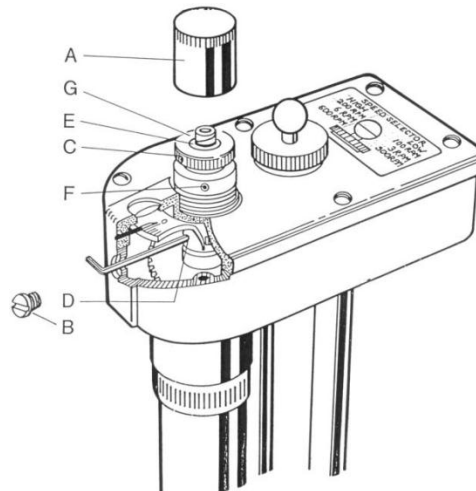


Figure 3.6: Torsion Spring Removal and Replacement

A = Dust cap, B= Plug screw, C = set screw, D= set screw, E= Top of clamp, F= set screw, G= Adjustable knob

Changing Rotors, Bobs, and Torsion Spring

The R1-B1-F1 rotor-bob-torsion spring combination is standard for all FANN viscometer. Other rotor-bob combinations may be used, provided shear rates are calculated for the fluid being tested. Use of rotor-bob combinations which result in large gap sizes can lead to shear stress dial readings not consistent with readings from a smaller gap.

A. Rotor removal and Replacement

The rotor can be removed from its socket by twisting counterclockwise, when viewed from above, while gently pulling straight down. Refer to Figure 3.6. The rotor may be replaced by aligning the rotor slot and groove with the lock pin in the main shaft socket. Push the rotor upward and lock it into position by turning it clockwise.

B. Bob removal and Replacement

The bob shaft end that fits into the Bob is tapered and fits into a matching tapered hole in the bob. To remove the bob twist the bob clockwise while pulling downward. To install the bob, twist it clockwise while pushing upward.

C. Torsion Spring Removal and Replacement

1. Remove the dust cap [A] and plug screw [B].
2. Loosen set screws [C] and [D] about 1/2 turn. The spring can now be lifted out. Be careful not to stretch the spring.
3. Insert the new spring, making sure the bottom mandrel is properly oriented and seated. Set screw [D] should line up with the point at which the spring leaves the bottom mandrel. A notch cut into the upper end of the bottom mandrel will help locate this point. Tighten set screw [D], so that it presses against the split ring to hold the bottom mandrel of the spring.

NOTE: Before tightening set screw [C] be positive that the top of the adjustable mandrel is flush with the top of clamp [E]. It may be necessary to slightly compress or stretch the spring to accomplish this.

4. Tighten set screw [C]. The slot in the top of the adjustable mandrel should line up with clamping set screw [C].
5. Loosen set screw [F] to zero dial under index, then rotate knob [G] as required for alignment, then adjust knob [G] vertically to allow the spring to be clamped in a free position, neither stretched nor compressed.
6. Tighten set screw [F] and replace the dust cap [A].

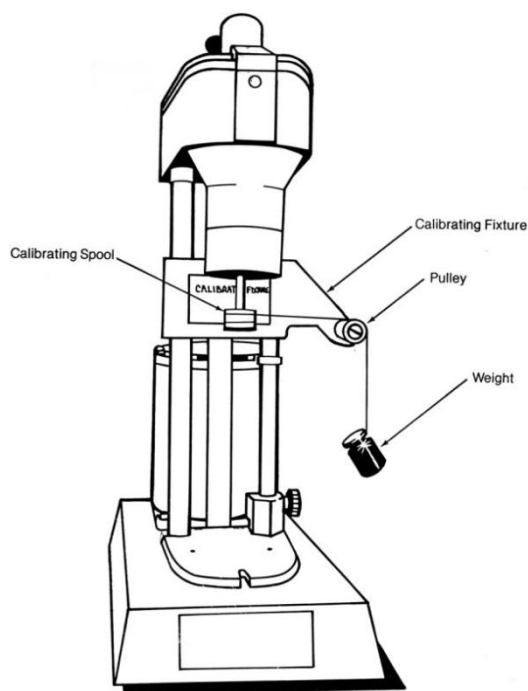


Figure 3.7: Dead Weight Calibration DW-3 Calibration Fixture

Instrument Calibration

Periodically the Model 35 Series Viscometer should be checked for proper calibration and if found in error the viscometer should be calibrated or repaired. Continued accuracy of measurements requires the instrument be properly calibrated. The calibration is checked by applying known torques to the bob shaft. For any applied torque, within the torque range of the spring, there should be a specific dial reading plus or minus a small tolerance. Two methods of calibration are described.

The Dead Weight Calibration is easier to perform and if the spring requires adjustment, the proper setting can easily be verified. The Standard Fluid Calibration check verifies the complete instrument is operating properly. It will determine problems of bent bob shaft, rotor eccentricity, and/or run out of the rotor or bob more effectively than the Dead Weight method.

A. Dead Weight Calibration Check Using Model DW3 Calibration Kit. Refer to Figure 3.7.

1. Remove rotor and bob. Be sure that the tapered end of the bob shaft is clean, and then install the calibrating spool.
2. Install the DW -3 calibrating fixture by clamping it onto the upper portion of the viscometer support legs.
3. Select a weight according to Table 3.3. Insert the bead at the end of the thread into the recess in the top of the calibrating spool. Wrap the thread a little more than once around the spool and then drape the thread over the pulley.

4. Hang the selected weight on the thread and adjust the calibrating fixture up or down until the thread from the spool to the pulley is horizontal. Compare the dial reading with the reading on Table 3. 3.
5. If necessary, adjust the torsion spring. "Adjusting Torsion Spring".

Factory tolerances for F1 spring only are $127 \pm 1/2^\circ$ for 50 g and $254 \pm 1/2^\circ$ for 100 g. A movement of $\pm 1/2^\circ$ is permissible when the main shaft is turning. This movement will generally be dampened out when a fluid is being tested. Check the linearity of the dial reading with at least three weights. If the spring appears to be non-linear it is usually a sign that the bob shaft is bent. An instrument with these characteristics needs additional service and/or repair.

Trouble Shooting and Maintenance

Table 3.4: Troubleshooting table for viscometer

Symptoms	Causes
Erratic dial motion	<ol style="list-style-type: none"> 1. Contaminated bob shaft bearings 2. Bent bob shaft 3. Rotor out of alignment 4. Incorrectly adjusted main shaft
Out of calibration	<ol style="list-style-type: none"> 1. Contaminated bob shaft 2. Bent bob shaft 3. Bent rotor 4. Friction in bob shaft bearings 5. Damaged or incorrectly installed torsion spring 6. Motor needs replacement
Excessive noise	<ol style="list-style-type: none"> 1. Lubrication failure or contamination in gears 2. Worn center shaft bushing 3. Top cover can create a bind in gear train if set improperly
Excessive run-out of rotor	<ol style="list-style-type: none"> 1. Damaged rotor 2. Contamination in main shaft recess
Sticking support legs	<ol style="list-style-type: none"> 1. Corrosion/contamination within support legs 2. Broken spring 3. Legs out of adjustment
Loose gear housing	<ol style="list-style-type: none"> 1. Bolts attaching gear housing to support legs are loose

Maintenance

The bob and rotor should be cleaned after each test and examined periodically for dents, abrasion or other damage. Oiling or greasing of the viscometer is not required in normal service. Always remove the bob from the bob shaft when transporting instrument to avoid bending bob shaft. Periodically test the bob shaft bearings. Operate the instrument at 3 or 6 rpm with no sample around the rotor and bob. Observe movement of the dial. It should not move more than +/- 1 division. Rough bob shaft bearings should be replaced.

Instrument should be serviced by qualified personnel only. If factory service is required, contact Fan for return authorization.

3.2.2 The Electric Precision Balance

The calibration of balances must be done by personnel specially trained for this activity. It should be highlighted that it must be done based on the alignments of the OIML or an equivalent body such as the American Society for Testing and Materials (ASTM), institutions which have developed methodologies for classifying standard weights. The reference weights classification used by the OIML is covered in the table opposite.

Any calibration process must be done using standard weights. The results obtained must be analyzed to determine if these are within the acceptable tolerances. The standard weights must be selected based on the balance's capacity. The above table complements the previous. It provides guidance in determining the standard weights to use in the calibration of a balance according to its capacity.

Routine Maintenance

The balance is characterized as an instrument of high precision. For this reason, the operator is only responsible for minimal maintenance limited to the following:

Daily Activities

1. Clean the weighing plate so that it is kept free of dust. Cleaning is done by using a piece of clean cloth which may be dampened with distilled water. If there is a stain, a mild detergent can be applied. Also a paintbrush with soft bristles can be used to remove particles or dust deposited on the weight plate.
2. Clean the weighing chamber, externally and internally. Verify that the glass is free from dust.
3. Verify that the adjustment mechanisms on the front door of the weighing chamber works adequately

Troubleshooting

PROBLEM, PROBABLE CAUSE, SOLUTION

The balance does not turn on. The interconnection cable is disconnected or maladjusted on the balance.

Check the connection. Adjust the cable connector if this is the case.

Electrical outlet has no power. Check electrical feed.

The weight reading is incorrect. The balance was not adjusted to zero before the reading.

Place the balance on zero; repeat the measurement.

The balance is incorrectly calibrated. Calibrate according to the procedure recommended by the manufacturer.

The balance is not levelled. Level the balance.

The balance does not show the desired units of measurement on the screen.

The units are incorrectly selected. Select the required measurement unit.

The unit required not available or not activated. Activate the measurement unit according to the procedure recommended by the manufacturer.

The menu may be locked. Check to see if the locking switch is activated. If this is the case, deactivate it.

The balance is incapable of keeping the selections or changes. process.

Verify that the changes and selections are done according to the manufacturer's instructions.

Repeat the selection or change.

The balance's reader is unstable. There is vibration on the surface of the table/counter.

The front door of the balance is open.

Place the balance on a stable surface.

Close the front door to measure.

The RS232 interface does not function. The interconnection cable is maladjusted. Check the connection of the interconnection cable.

The screen shows incomplete readings or is locked. The microprocessor is locked.

If the situation persists, seek technical assistance from the service representative.

The screen displays an error code. Verify the error codes in the balance's manual.

3.2.3 The Mud Balance

The Fann Four Scale Mud Balance is an accurate, self-contained measuring device used to determine the density of drilling fluid. It has a range of 7 to 24 pounds per gallon or Specific Gravity of 0.84 to 2.88. The Mud Balance consists of a constant-volume sample cup and lid, connected to a balance arm that has four graduated scales. On one side are scales for measuring density in pounds per gallon (LB/GAL) and specific gravity (SP GR- g/cm³). On the other side are scales for measuring pounds per square inch per 1000 feet of depth (LBS/SQ.IN./1000 FT). As shown in Figure 3.8, a rider is moved along the balance arm to indicate the scale readings. There is a knife edge attached to the arm near the balance cup, and a bubble level built into the knife edge to level the arm. A fulcrum is mounted on a base stand, if used, or in the plastic carrying case, if it is used

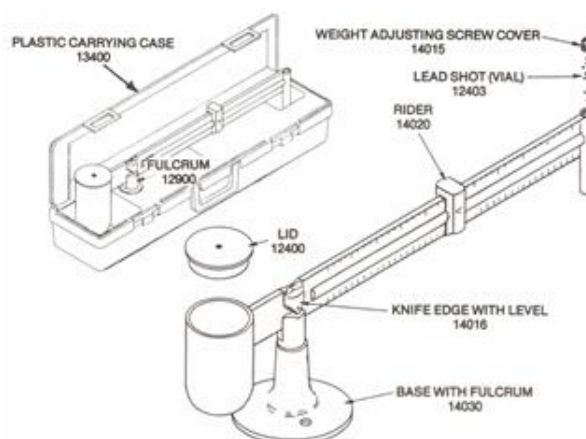


Figure 3.8: Mud balance and its components

Procedure

1. The balance cup should be clean and dry before it is filled with the drilling fluid sample.
2. Drilling Fluid samples containing large amounts of gas should be deaerated using the Fann Dearator before a density measurement is attempted.
3. Place the base stand or the carrying case on a surface that is approximately level.
4. Fill the balance cup with the sample to be tested. Tap the side of the balance cup several times to break up any entrained air or gases. Put the lid onto the balance cup by pushing it downward with a slow rotating motion until it is firmly seated. Make sure that some of the test sample is forced out through the vent hole in the lid. (This action will also help to rid the sample of any entrained air or gas.)
5. Clean any sample from the outside of the balance cup and lid.
6. Fit the knife edge of the balance arm into the fulcrum and balance the assembly by moving the rider along the arm. The Mud Balance is horizontal when the level bubble fluctuates on equal distance to either side of the center line.
7. Take the reading from the side of the rider nearest the balance cup. (The arrow on the rider is pointing to this side). The measurement reading should be reported to the nearest 0.1 lbs/gal, 0.5 lbs/cu ft, or 0.01 g/cm³ (which is equivalent to specific gravity).
8. Empty the sample from the cup. Clean and dry the entire assembly as soon as possible

Calibration

The Mud Balance calibration can be checked using fresh water. At 70F (21C) fresh water should give a reading of 1.00 on the specific gravity scale, 8.34 on the lbs/gal scale, and 62.3 on the lbs/cu ft scale. This spot on the balance arm is marked with a longer scale division line called the water line. Small amounts of mud on the balance arm or rider can cause improper readings. If the Mud Balance does not give the correct reading for fresh water, the instrument should be thoroughly cleaned.

NOTE: Replacing the lid on the balance cup with a new lid can cause the Mud Balance to be out of calibration. Check the calibration whenever a different lid is used and, if necessary, recalibrate using the new lid. If the Mud Balance continues to give improper readings for fresh water after cleaning, it should be recalibrated. This is done by removing the screw cover from the weight adjustment compartment and adding or removing lead shots until the Mud Balance is correctly calibrated.

PARTS LIST:

Part No.	Description	Part No.	Description
12400	Lid	14015	Cover Screw
12403	Lead Shot (Vial)	14016	Knife Edge
12900	Fulcrum	14020	Rider
13400	Plastic Carrying Case	14030	Base with Fulcrum (Not required the 13400 carrying case is used)

3.2.4 The Sand Content Kit

The Sand Content Kit is an easy, reliable, efficient, and proven means for determining the sand content of drilling fluid. The kit employs the sieve analysis method for determining the sand content. It uses a 200 mesh sand screen to trap the sand and other coarse particles in the drilling fluid. The Sand Content Kit contains the sand screen [a sieve mounted in a plastic cylinder, 2-1/4 inches (5.7cm) in diameter x 3-3/4 (9.5cm) long], a plastic funnel that

fits over the end of the screen cylinder with the small end fitting into a glass measuring tube, and a wash bottle. The measuring tube has a scale that is graduated from 0 to 20% to measure percentage of sand by the volume of drilling fluid.

The volume of sand, including the spaces between the grains, is expressed as a percentage of the volume of the drilling fluid. The value read from the measuring tube is reported as: "*% by Volume*".

Measuring the Sand Content of Drilling Fluids Procedure

1. Fill the measuring tube up to the line labeled "**Mud to Here**", and then use the wash bottle to add clear water (or diesel if oil drilling fluid) to the line labeled "**Water to Here**". Close the mouth of the tube with the thumb and shake vigorously.

NOTE: Use diesel oil instead of water in the wash bottle for oil based drilling fluids.

2. Pour the mixture in the tube through the screen. Continue adding wash bottle fluid to the tube, shaking it, and pouring the contents through the screen until all of the drilling fluid has been washed out of the tube.

NOTE: Do not stir or manually force the mixture through the screen. Tapping the side of the screen holder as the diluted drilling fluid is added will help the mixture pass through the screen.

3. Flush the screen with fluid from the wash bottle to wash away the remaining drilling fluid and shale particles until all that remains on the screen is sand.
4. Fit the large end of the funnel over the top of the screen holder and slowly invert the screen and funnel assembly, fitting the tip of the funnel into the mouth of the glass measuring tube.
5. Using a fine spray of fluid from the wash bottle, wash the sand from the screen back through the funnel into the glass measuring tube, and allow the sand to settle.
6. Note the quantity of sand that has settled and, using the scale on the outside of the tube, determine the percentage of the total mud volume that is sand. Report this value on the Drilling Fluid Report as "*% by Volume*" sand.

NOTE: If other coarse solids or lost circulation material are retained on the screen, report the presence of these materials on the Drilling Fluid Report.

Care of Equipment

After each use of the Sand Content Kit, wash any dirt or drilling fluid from the screen, the funnel, and the measuring tube, and dry all equipment. Take special care to clean and dry the screen thoroughly. Refill the wash bottle.

Components:

Left: Wash Bottle, 500 mL

Right: Funnel, Plastic

Center below: Graduated Tube, Glass, 0-20 %

Center Top: Carrying Case



Figure 3.9: The sand content kit and its parts

3.2.5 The Filter Press

Filtration and wall-building properties of drilling fluids and cement slurries are determined by a filter press. The filtration rate is a measure of fluid loss measured in milliliters [1 milliliter (ml) = 1 cubic centimeter (cm³)] under 100 pounds per square inch (psi) (690 kPa) of pressure through a special filter paper for 30 minutes. Wall-building characteristics are demonstrated by the thickness and consistency of the filter cake (the residue) deposited on the filter paper at the end of this period. The filter cake is measured to the closest 1/32" (0.8 mm). The low pressure filter press assemblies described in this booklet consists of a filter cell mounted in a frame, a pressure source, a filtering medium, and a graduated cylinder for receiving and measuring the filtrate.

The filter cell, or drilling fluid cell, is constructed of rustproof anodized aluminum and chrome plated brass, or stainless steel. Pressure sources deliver the required 100 ± 5 psi (690 ± 35 kPa) and may consist of compressed nitrogen or air in cylinders, CO₂ gas cartridges, high pressure air or water systems, or a dead-weight hydraulic pressure assembly.

Caution: *due to the hazard of explosion, compressed oxygen should not be used as a pressure source.*

The filtering medium normally is a filter paper that has been specially hardened for filtrate testing. The filtrate receiver is a 10 or 25 ml graduated cylinder.

NOTE: A filtration Reduction Evaluation Device (FREAD) is available for use in the Model 300 filter presses. This device adapts the filter press cell to hold a 1/4 inch (6.3 mm) porous ceramic filter which replaces the filter paper.

Safety Considerations

Safe operation of Filter Presses requires that the laboratory technician or drilling fluids engineer be familiar with the proper operation and potential hazards associated with this equipment. Pressurizing the drilling fluid sample cell poses the potential hazards of the cell or associated pressurization equipment leaking and releasing sample or pressurizing fluid which could cause serious injury. Several precautions that should be observed are listed below:

1. Always use Nitrogen, Carbon Dioxide, or compressed air.
Never connect the Filter Press to Oxygen, natural gas, or any other non-recommended gas. If Nitrogen is used it must be supplied from an approved Nitrogen gas cylinder. Nitrogen Cylinders must be secured and meet all safety standards. Carbon Dioxide is normally supplied in small cartridges which contain about 900 psi (6206 kPa) pressure. They are primarily used for field operations. Do not allow these cartridges to be heated or exposed to fire. They can explode if overheated. If compressed air is used, its maximum pressure should not exceed 150 psi (1035 kPa).
2. Maintain pressure regulators in good condition. Never use oil on pressure regulators. Leaking pressurization systems should be repaired or replaced. Gauges, fittings and hoses should be kept in good condition and leaks should be found and corrected. Periodically test the safety relief valves on the pressurization manifolds to verify they will relieve if excessive pressure should occur. Never plug or bypass these safety valves.
3. When pressurizing the Cell always make sure the regulator is closed (Tee screw backed all the way out, counterclockwise), then open the supply pressure, then adjust the regulator. Do not attempt to pressurize higher than 100 psi. (694 kPa).

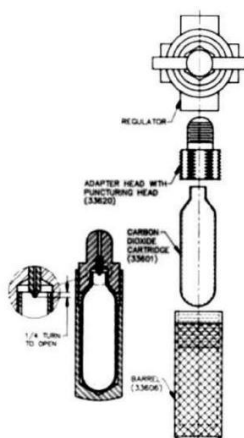


Figure 3.10: CO2 Cartridge Holder Assembly

Filter Press Pressure Sources

A. CO₂ Cartridge Pressure Source

Follow this procedure to pressurize the filter press with a CO₂ cartridge pressure source (Refer to Fig.3.11)

1. Remove the barrel from the CO₂ pressuring assembly and insert a fresh CO₂ cartridge.
2. After making sure the safety bleeder valve is closed, and the regulator adjusting screw is backed out to the closed position (maximum outward), turn the barrel loosely with the fingers until first contact with the puncturing pin is felt.
3. Advance the holder an additional 1/4 turn. The puncture pin, shown in Fig. 3.11, seals when the cartridge seats.
4. Screw the adjusting screw into the regulator to apply 100 ± 5 psi (690 kPa) pressure to the filter cell as indicated by the test-pressure gauge. Start 30-minute timing now.

Caution: when using systems with CO₂ cartridges as a pressure source, no inlet pressure gauge or valve is used. Use care when replacing spent CO₂ cartridges. There could be some pressure left in the cartridge. Keep CO₂ cartridges away from extreme heat.



Figure 3.11: Filter Press with Nitrogen Cylinder Pressure Source

B. Nitrogen Cylinder Pressure Source

Follow this procedure to pressurize the filter press with a Nitrogen cylinder pressure source (Refer to the assembly in Figure 3.11):

1. With the regulator adjusting screw backed out to the closed position (maximum outward), slowly open the pressure valve on the cylinder. The inlet pressure gauge should show the cylinder pressure. Be sure this is greater than 100 psi, (690 kPa).

2. Be sure the hose between the cylinder regulator and the cell is connected, all fittings are tight, and the safety-bleeder valve is closed.
3. Screw the regulator adjusting screw into the regulator to apply 100 ± 5 psi (690 kPa) pressure to the filter cell, as indicated by the test-pressure gauge. Start 30-minute timing now.

***Caution:** always screw the regulator adjusting screw to its maximum outward position before opening the release valve on the pressure source. If the full pressure of the pressure source is released to an open regulator, the regulator is put under a severe strain. If this causes the regulator to fail, the full tank pressure is released to the filter press and it may be damaged. As an added precaution, a safety bleeder valve, that releases at approximately 170 psi, is placed in the system between the regulator and the filter press.*

C. Dead-Weight-Hydraulics Pressure Source

The Dead-Weight -Hydraulic Filter Press is a Series 300 Filter Press equipped with a Dead-Weight Hydraulic Assembly. Refer to Fig. 3.12. The Dead Weight Hydraulic Assembly is shown in Fig. 3.13. Follow this procedure to pressurize the filter press with the dead-weight-hydraulic pressure source:

1. Fill the water reservoir and cylinder of the dead-weight assembly to the top with clean fresh water.
2. Open the bleed-off valve and place the piston, with the weight attached, in the cylinder. Allow the piston to travel full stroke.
3. Refill the reservoir with clean, fresh water and close the bleed-off valve.
4. Set the unit in place on the filter press frame and tighten the attaching set screws, if not previously attached.
5. Connect the air hose from the dead-weight assembly to the top cap pressure inlet, if not previously attached.
6. Raise the weight to the top of its stroke and allow it to settle. In about two-thirds of the stroke, the delivery pressure gauge will indicate 100 psi.
7. Lift the dead weight back to the top of the stroke. Start the timing of the test when the weight is released. One stroke of the piston will allow a maximum filtration loss of approximately 30 ml.



Figure 3.12: Dead-Weight Hydraulic Filter Press



Figure 3.13: Dead Weight Hydraulic Assembly

D. EXTERNAL PRESSURE SOURCE

Almost any compressed air source, with a reliable pressure of more than 100 psi, (690 kPa) is suitable to pressurize the filter press. However, there must be a suitable regulator, on this line so that the pressure to the cell can be regulated. A regulator such as 33700 or 34265 is suitable. A shutoff valve and a hose should be installed between the regulator and the filter press cell. Refer to Figures 3.13 and 3.14 and the following Note.

NOTE: The 33700 regulator is designed for a maximum inlet pressures of 1000 psi, (6940 kPa.) and the 34265 regulator is designed for inlet pressures between 1000 psi (6940 and 3000 psi (20820 kPa)).

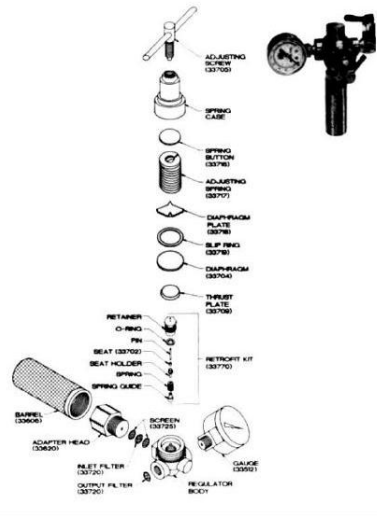


Figure 3.14: CO₂ Pressure Assembly, Exploded View

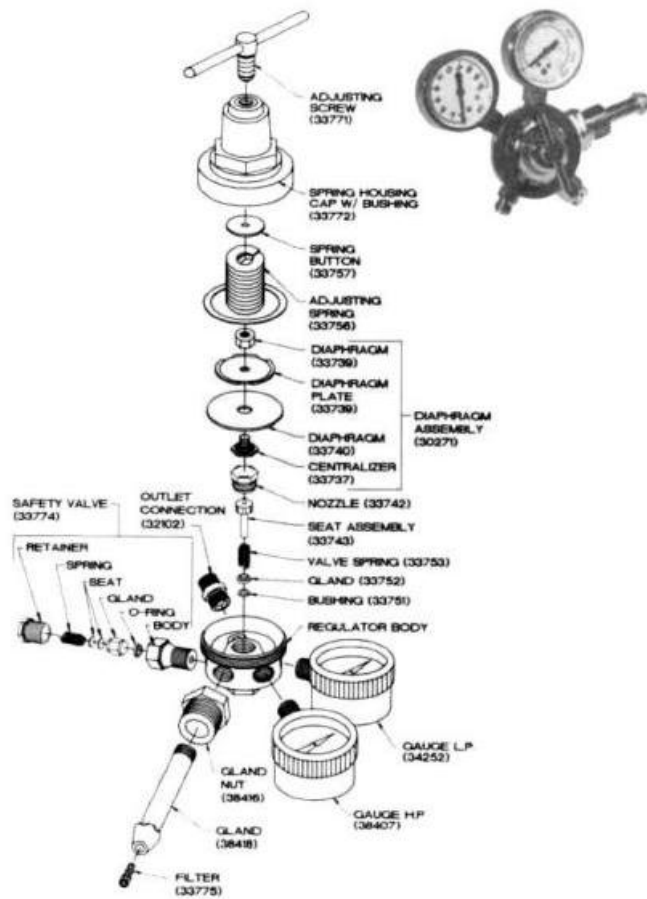


Figure 3.15: Regulator Assembly

Standard Filter Press Test Procedures

Follow the steps in this procedure to operate the filter press with a compressed gas or dead-weight hydraulic pressure source:

1. Assemble the clean, dry parts of the filter cell in the following order
Refer to Figure 3.16:
 - a. base cap
 - b. rubber gasket
 - c. screen
 - d. a sheet of filter paper
 - e. rubber gasket
 - f. filter cell
2. Secure the cell to the base cap by rotating it clockwise.
3. Fill the cell with the test sample to within approximately 1/4" (6mm) of the top. (Filling the cell to this level lessens the volume of pressurizing gas required from the pressure source.)
4. Set the filter press cell assembly in place within the frame.
5. Check the top cap to make sure the rubber gasket is in place. Place the top cap, already connected to the pressure source, onto the filter cell and secure the cell in place with the T-screw.
6. Place a dry graduated cylinder under the filtrate tube, either on the support or in the clip.
7. Depending upon the pressure source being used, apply pressure to the cell following the appropriate pressure source procedure.
8. At the end of 30 minutes (or 7-1/2 minutes - Refer to Note below), close the pressure source valve and back off the regulator, open the safety-bleeder valve. This releases the pressure on the entire system.
9. Measure the volume of filtrate collected in the graduated cylinder and record the filtrate loss in milliliters as the API (30 minute) filtrate loss of the drilling fluid, or milliliters x 2 for the 7-1/2 minute test.

NOTE: The amount of filtrate collected after 7-1/2 minutes can be noted and, when this amount is multiplied by two, it will give a rough estimate of the amount that will be collected in 30 minutes. The estimated value is usually one or more milliliters short of the actual value and this estimation procedure should not be attempted on drilling fluids having a filtrate loss of less than 5 ml in the 7-1/2 minute period.

10. Loosen the T-screw, remove the cell top, and then remove the cell from the frame.
11. Discard the drilling fluid.
12. Disassemble the filter cell and carefully remove the filter cake and filter paper from the base cap.
13. With a gentle stream of water (or, in the case of oil drilling fluids, with clean base oil), carefully wash excess drilling fluid from the cake.
14. Measure and record the thickness of the filter cake to the nearest 1/32" (0.8 mm).
15. If desired, record properties of the filter cake such as texture, hardness, flexibility, etc.

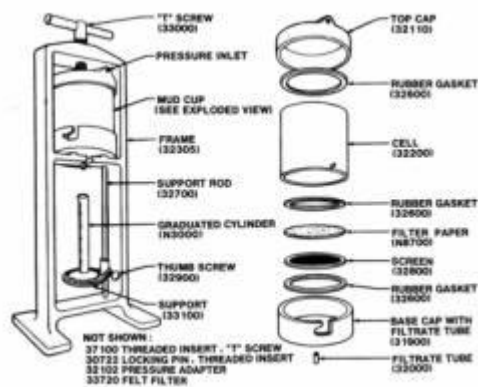


Figure 3.16: Filter Press And Cell Assembly, Exploded View

FREAD Filter Press Test Procedures

Follow this modified procedure if the FREAD ceramic disc adapter is to be used. Either compressed gas or the dead-weight-hydraulic unit can be used.

1. Assemble the Filtration Reduction Evaluation Device as follows, Refer to Figure 3.17:
 - a. Assemble the selected porosity ceramic filter disc into the Body Adapter (1).
 - b. Assemble "O" ring seal (5) into the Body Adapter.
 - c. Install Ring Seal (2) into Body Adapter fitting it over the "O" ring.
 - d. Screw the Seal Nut (3) onto the Body Adapter (1) and tighten hand tight.
 - e. Install «O" Ring (4) on the outside bottom of the Body Adapter.

2. Assemble the dry parts of the filter cell in the following order.
 - a. Base cap
 - b. Rubber gasket
 - c. FREAD assembly. Refer to Procedure 1 above.
 - d. Rubber gasket
 - e. filter cell Secure the cell to the base cap by rotating it clockwise.

3. Fill the cell with the test sample to within approximately 1/4" (6mm) of the top.(Filling the cell to this level lessens the pressure volume required from the pressure source.)

4. Set the filter press cell assembly in place within the frame.

5. Check the top cap to make sure the rubber gasket is in place.
Place the top cap, already connected to the pressure source, onto the filter cell and secure the cell in place with the T-screw.

6. Place a dry graduated cylinder under the filtrate tube, either on the support or in the clip.

7. Depending upon the pressure source being used, apply pressure to the cell following the appropriate pressure source procedure.

8. At the end of 30 minutes close the pressure source valve and back off the regulator, open the safety-bleeder valve. This releases the pressure on the entire system.
9. Measure the volume of filtrate collected in the graduated cylinder and records the filtrate loss in milliliters as the 30 minute filtrate loss of the drilling fluid using the FREAD adapter and the micron size of the filter used for the test.
10. Loosen the T-screw, remove the cell top, and then remove the cell from the frame.
11. Discard the drilling fluid.
12. Disassemble the filter cell and carefully remove the FREAD assembly with the cake.
13. With a gentle steam of water (or, in the case of oil drilling fluids, with diesel oil), carefully wash excess drilling fluid from the cake.
14. Measure and record the thickness of the filter cake to the nearest 1/32" (0.8 mm) and note that this test used the FREAD.

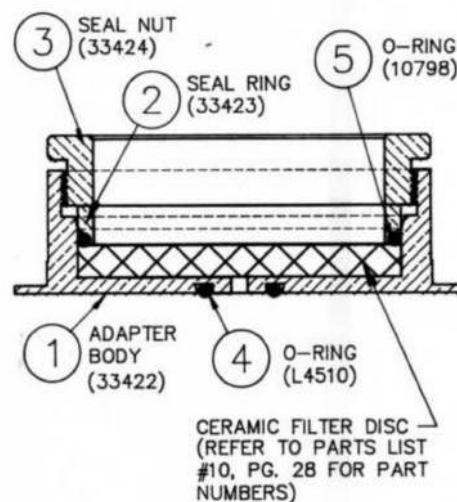


Figure 3.17: Filtration Reduction Evaluation Device (FREAD)

Care of Equipment

A. *Cleaning*

After each use, the filter press cell should be disassembled and cleaned of all drilling fluid by washing and thoroughly rinsing. Wipe off the rest of the filter press, and dry all parts completely. Replace the filter paper on the screen, and assemble the end cap onto the cell. Loosely reassemble the cell onto the frame for storage.

B. Pressure Regulator Maintenance and Repair

Most regulator troubles are caused by leaking fittings or faulty pins and seats. Rarely does a diaphragm rupture. If regulator will not hold pressure, check the fittings which are screwed into it. This is done by applying pressure to the system and looking for escaping gas in the form of bubbles. There are two methods of doing this. One method is to apply soap suds to the fitting areas, the other is to carefully immerse all but the pressure gauge in a container of water. If leaks are apparent, disassemble and apply tape thread sealant to the threads.

Caution: Do not use oil based thread dope or oil when assembling any regulator.

Replacing the seat and pin.

If regulator connections do not leak, the seat and pin probably need replacement. Use the following procedure.

1. using a wrench on the hex of the spring case, unscrew the spring case. All parts down to and including the diaphragm will remain in the spring case.
2. Remove the thrust plate.
3. Unscrew the retainer and remove the seat with the pin.
4. Clean and inspect the regulator for evidence of dirt or drilling fluid in the regulator body. An outlet filter (33720) is available to prevent this problem.
5. Replace the pin and seat.
6. Re-assemble the regulator.

C. Dead Weight Hydraulic Unit

Maintenance

Always protect the mirror finish of the stainless steel piston, especially when removing it. Clean the fine mesh screen on the bottom of the water reservoir. If the piston moves sluggishly during a test, remove the piston and O-ring from the cylinder. Clean the O-ring groove in the cylinder. Examine the O-ring carefully for torn or rough places, and, if the surface is damaged, replace it with a new O-ring. Before replacing the O-ring and the piston, apply a light film of high-grade, water-repellent grease. In subfreezing weather, the water in the dead-weight assembly can be replaced by an anti-freeze solution such as ethylene glycol and water; this does not adversely affect the operation of the unit.



Figure 3.18: Filter Press, Standard Frame



Figure 3.19: Filter Press, Standard Frame, W/ Regulator



Figure 3.20: Filter Press, Standard Frame, W/ CO2 Pressure Source

CHAPTER FOUR

4.0 Laboratory Exercises in Relevant Existing and Future Courses at Uniuyo Petroleum Engineering

This chapter basically shows the core petroleum engineering courses offered in the undergraduate, postgraduate diploma and master's degree levels. The courses are stated with their basic content and then the courses requiring lab work are isolated. The areas in the courses needing lab are identified and then lab exercises are developed in those areas.

4.1 Courses in Petroleum Engineering in UNIUYO

The following section would look at the courses offered in the undergraduate, Postgraduate Diploma and Masters Degree programmes in the department of Chemical/Petroleum Engineering, University of Uyo. For each programme, the entire courses offered with a breakdown of the course content of each work are included.

4.1.1 Courses Offered In Undergraduate Degree Programme

Below are the entire courses offered in the undergraduate programme in Petroleum Engineering. A breakdown of each course showing the course codes, the credits units as well as the entire content of the course is given. Figure 2.1 shows the core petroleum engineering courses offered in the programme. The courses in red rings are the courses that require lab work.

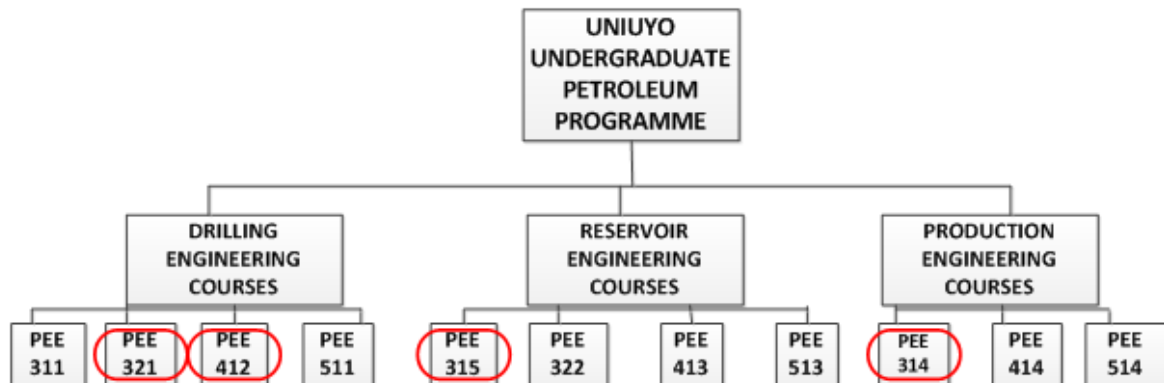


Figure 4.1: Overview of core petroleum engineering courses in UNIUYO. Courses in red rings need lab work.

(a) List of core Petroleum Engineering Courses in Undergraduate degree programme

Introduction to Petroleum Engineering (3 Credit Hours)
Drilling Engineering I (3 Credit Hours)
Petroleum Geology (3 Credit Hours)
Petroleum Production Engineering I (3 Credit Hours)
PEE 315: Reservoir Engineering I (3 Credit Hours)
PEE 321: Drilling Fluid Technology (3 Credit Hours)
PEE 322: Reservoir Engineering II (3 Credit Hours)
Industrial Studies I (2 Credit Hours)
Alternate Hydrocarbon Sources (2 Credit Hours)
Petroleum Rock Mechanics (3 Credit Hours)
Applied Geophysics in Petroleum Exploration (2 Credit Hours)
Drilling Engineering II (3 Credit Hours)
Reservoir Engineering III (3 Credit Hours)
Petroleum Production Engineering II (3 Credit Hours)
Formation Evaluation (3 Credit Hours)
Oil Pollution and Control (2 Credit Hours)
Drilling Engineering III (3 Credit Hours)
Natural Gas Engineering (3 Credit Hours)
Reservoir Modeling and Simulation (3 Credit Hours)
Petroleum Production Engineering III (3 Credit Hours)
Computer Applications in Petroleum Engineering (3 Credit Hours)
Well Completion and Workover (3 Credit Hours)
Natural Gas Processing (3 Credit Hours)
Petroleum Product Transport and Storage (2 Credit Hours)
Offshore Operations Engineering (2 Credit Hours)
Enhanced Oil Recovery (2 Credit Hours)
Petroleum Economics (2 Credit Hours)
Multiple Phase Flow in Pipes (3 Credit Hours)

4.1.2 Courses Offered in Undergraduate Degree Programme that requires course work

(A) DRILLING ENGINEERING

(i) Course: PEE 321: Drilling Fluid Technology (3 Credit Hours)

Course description: Mud properties, testing, classification and chemical analysis. Drilling and calculations control of mud properties. Well completion fluids, drilling and performance. Data for executing kick control, indications of kick; methods of circulating out a kick-balanced bottom hole pressure method (BBHP), driller's method; kick when tripping gas out mud.

Areas of PEE 321 needing lab work:

Mud properties, testing, classification and chemical analysis

Topics Designed for Experiment in the areas needing lab work:

- Testing of Drilling Mud Properties – Density, Gel strength, Filtration
- Hydrogen ion Calculation
- Drilling Mud Alkalinity
- Chloride ion determination
- Treatment of Contaminated drilling fluid
- Effects of Chemical dispersion in drilling fluid
- Hydraulic characteristics and control of drilling fluid properties
- Colloidal properties of clay

Experimental Work/Student Task: See Appendix F

Procedure for carrying out the experiments: See Appendix F

Safety Guidelines during experiment: See Appendix F

(ii) PEE 412: DRILLING ENGINEERING II (3 CREDIT HOURS)

Areas of PEE 412 needing lab work:

Properties of cements/additives, primary cementing operations including hole and pipe preparations, equipment (surface and down hole) used in primary cementing operation, operational techniques and evaluation, squeeze cementing open-hole and casing plugs, etc.

- Cementing

(B) RESERVOIR ENGINEERING

(ii) Course: PEE 315: Reservoir Engineering 1 (3 Credit Hours)

Course description: Introduction to petroleum reservoir engineering; physical properties of rocks and fluids (porosity, permeability of active and relative permeabilities, specific surface of rocks, compressibilities of rock and fluids, fluid saturation, wettability, surface tension, capillary forces, etc. Fluid flow through porous media, application of Darcy's Law. Reservoir drives and races. Hydrocarbon content of reservoirs, its composition, formation. Water and its physical properties. Gas behaviour binary and multi-component systems. Equilibrium constant and its application. Sampling for PVT analysis, other methods of determining reservoir fluid properties; evaluation and interpretation.

Areas of PEE 315 needing lab work:

Properties of rocks and fluids (porosity, permeability of active and relative permeabilities, specific surface of rocks, compressibilities of rock and fluids, fluid saturation, wettability,

surface tension, capillary forces, etc. Sampling for PVT analysis, other methods of determining reservoir fluid properties; evaluation and interpretation.

Topics Designed for Experiment in the areas needing lab work:

- Porosity measurement
- Measurement of liquid permeability of cores
- Measurement of gas permeability
- Fluid saturation measurement
- PVT analysis of fluid sample
- Core analysis
- Resistivity measurement

Experimental Work/Student Task: See Appendix F

Procedure for carrying out the experiments: See Appendix F

Safety Guidelines during experiment: See Appendix F

(B) PRODUCTION ENGINEERING

(ii) Course: PEE 314: Petroleum Production Engineering 1 (3 Credit Hours)

Areas of PEE 314 needing lab work:

Experimental Work/Student Task: See Appendix F

Procedure for carrying out the experiments: See Appendix F

Safety Guidelines during experiment: See Appendix F

4.1.3 Courses offered in Postgraduate degree programme

Below are the entire courses offered in the Postgraduate Diploma programme in Petroleum Engineering. A breakdown of each course showing the course codes, the credits units as well as the entire content of the course is given. Figure 4.2 shows the core petroleum engineering courses offered in the programme. The courses in red rings are the courses that require lab work.

Petroleum Engineering Systems (3 Credit Hours)

Applied Petroleum Geology (3 Credit Hours)

PEE 613: Petroleum Reservoir Engineering I (3 Credit Hours)

PEE 621: Drilling Fluid Technology (2 Credit Hours)

Petroleum Reservoir Engineering II (3 Credit Hours)

Natural Gas Engineering (3 Credit Hours)

Well Completion & Workover (3 Credit hours)
 Petroleum Rock Mechanics (2 Credit Hours)
 Petroleum Economics & Property Valuation (2 Credit Hours)
 Petroleum Engineering Laboratory/Field Practice II (1 Credit Hour)
 Drilling Engineering I (3 Credit Hours)
 Formation Evaluation (3 Credit Hours)
 Production Engineering I (3 Credit Hours)
 Oil and the Environment (2 Credit Hours)
 Reservoir Simulation (3 Credit Hours)
 Drilling Engineering II (3 Credit Hours)
 Enhanced Oil Recovery (3 Credit Hours)
 Production Engineering II (3 Credit Hours)
 Well Testing (3 Credit Hours)
 Research Project (6 Credit Hours)
 Alternate Hydrocarbon Sources (3 Credit Hours)
 Natural Gas Processing (3 Credit Hours)

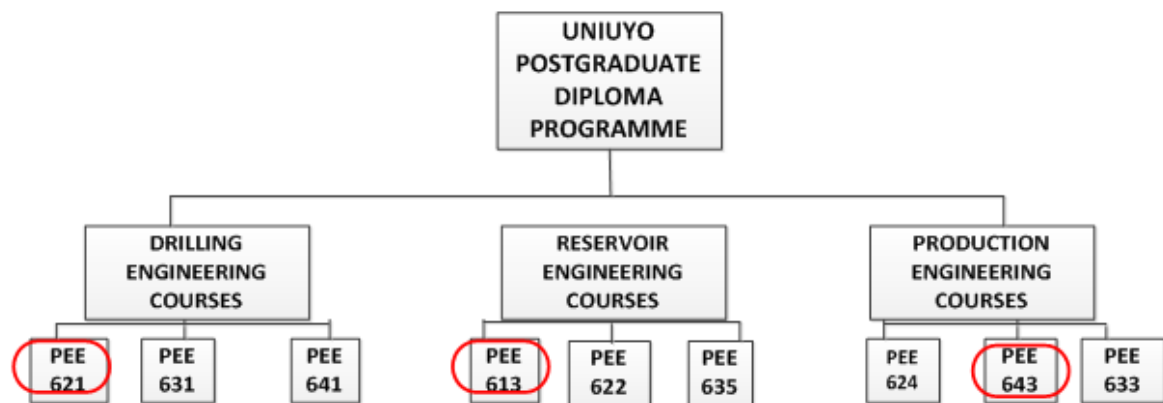


Figure 4.2: Overview of core petroleum engineering courses offered in Post graduate Diploma programme in UNIUYO
 (Courses in red rings need lab work)

4.1.4 Description of courses in Postgraduate Diploma Programme Needing lab

(A) Drilling Engineering

(i) Course: PEE 621: Drilling Fluid Technology (3 Credit Hours)

Areas of PEE 621 needing lab work:

Mud properties; testing, classification and chemical analysis. Drilling calculations and control of mud properties. Well completion fluids. Formation damage caused by drilling fluids and chemistry of reaction between fluid and formation.

Topics Designed for Experiment in the areas needing lab work:

- Testing of drilling and well completion fluids properties.
- Cements: types, properties and analysis.
- Laboratory observation of reactions between drilling and workover fluids on formation.
- Colloidal properties of clays.

Experimental Work/Student Task: See Appendix F

Procedure for carrying out the experiments: See Appendix F

Safety Guidelines during experiment: See Appendix F

(ii) PEE 631: Drilling Engineering I (3 Credit Hours)

Drilling fluids – functions, properties and testing. Types of drilling fluids and additives, drilling hydraulics, drilling cost analysis and control. Formation pressure prediction, fracture gradient prediction, formation damage, lost circulation, stock pipe. Cementing properties of cements and additives, cementing equipment, hole conditions, volume calculation and rate of circulation. Primary cementing operations squeeze cementing, cement plugs/ Fishing operations – causes control and prevention. Analysis of drill cuttings, determination of lithology

Topics Designed for Experiment in the areas needing lab work:

- Cements: types, properties and analysis.

Experimental Work/Student Task: See Appendix F

Procedure for carrying out the experiments: See Appendix F

Safety Guidelines during experiment: See Appendix F

(B) Reservoir Engineering

(ii) Course: PEE 613: Petroleum Reservoir Engineering 1 (3 Credit Hours)

Areas of PEE 613 needing lab work:

Core Analysis, measurement of porosity, liquid and gas permeability, fluid saturation. Rheological measurements Hydraulic characteristics and control of drilling fluid properties. Flow metering of liquids and gas. Determination of meter accuracy. Uses and operations of various pressure regulators. Pressure loss measurement along pipes. PVT analysis. Physical properties of rocks and fluids (porosity, permeability, compressibility of rocks and fluids, fluid saturation, wettability, etc.)

Experimental Work/Student Task: See Appendix F

Procedure for carrying out the experiments: See Appendix F

Safety Guidelines during experiment: See Appendix F

(B) PRODUCTION ENGINEERING

(ii) Course: PEE 643: Production Engineering 11 (3 Credit Hours)

Areas of PEE 643 needing lab work:

Topics Designed for Experiment in the areas needing lab work:

Experimental Work/Student Task: See Appendix F

Procedure for carrying out the experiments: See Appendix F

Safety Guidelines during experiment: See Appendix F

4.1.5 Courses offered in Master's Degree programme

Below are the entire courses offered in the Master's degree programme in Petroleum engineering. A breakdown of each course showing the course codes, the credits units as well as the entire content of the course is given. Figure 4.3 shows the core petroleum engineering courses offered in the programme. The courses in red rings are the courses that require lab work.

Advanced Petroleum Engineering Numerical Analysis (3 Credit Hours)

Advanced Rock and Fluid Properties (3 Credit Hours)

Advanced Formation Evaluation (3 Credit Hours)

Petroleum Economics & Risk Analysis (3 Credit Hours)

Advanced Computer Applications in Petroleum Engineering (3 Credit Hours)

Advanced Petroleum Production Engineering (3 Credit Hours)

Advanced Well Completion Work over (3 Credit Hours)

Advanced Petroleum Rock Mechanics (3 Credit Hours)

Artificial Lift (3 Credit Hours)

Drilling Optimization (3 Credit Hours)

PEE 726: Drilling Fluid Technology (3 Credit Hours)

Well Test Analysis (3 Credit Hours)

Reservoir Characterization and Geo-statistics (3 Credit Hours)

Advanced Reservoir Engineering (3 Credit Hours)

Advanced Reservoir modeling & Simulation (3 Credit Hours)

PEE 742: Fluid Flow in Porous Media (3 Credit Hours)

Natural Gas Engineering (3 Credit Hours)

Gas Production Engineering (3 Credit Hours)
 Coal Conversion Processes (3 Credit Hours)
 LNG Processing (3 Credit Hours)
 Petroleum and Energy Resources (3 Credit Hours)
 Oil and Gas Industry Accounting (3 Credit Hours)
 Renewable Energy Options (3 Credit Hours)
 Surface and Interfacial Phenomena in the Environment (3 Credit Hours)
 Environmental Control in Petroleum Engineering (3 Credit Hours)
 Pollution Control in Process Industries (3 Credit Hours)
 Environmental Impact Analysis & Management (3 Credit Hours)

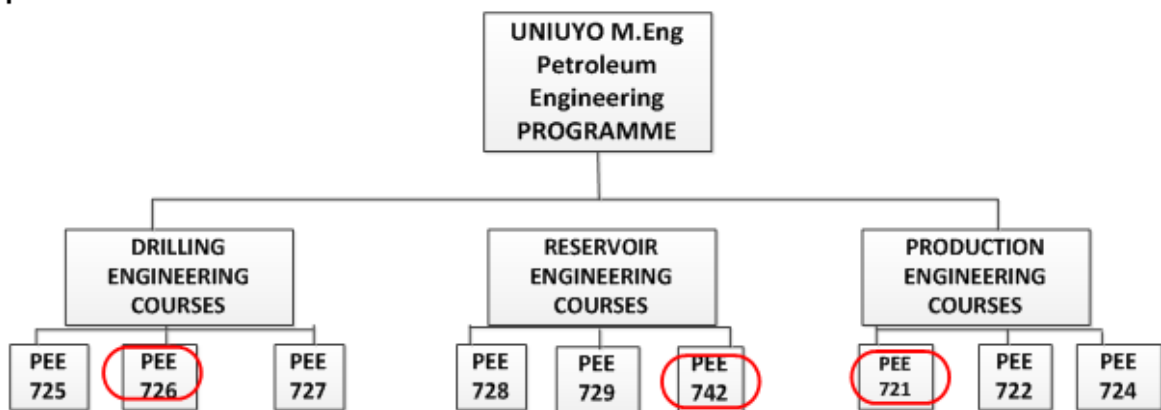


Figure 4.3: Overview of core petroleum engineering courses offered in B.Eng. programme in UNIUYO (Courses in red rings need lab work)

4.1.6 Description of Courses Needing Lab Work in Master's Degree Programme

(A) DRILLING ENGINEERING

(i) Course: PEE 726: Drilling Fluid Technology (3 Credit Hours)

Areas of PEE 726 needing lab work:

Experimental Work/Student Task: See Appendix F

Procedure for carrying out the experiments: See Appendix F

Safety Guidelines during experiment: See Appendix F

(B) RESERVOIR ENGINEERING

(ii) Course: PEE 742: Fluid flow in porous media (3 Credit Hours)

Areas of PEE 742 needing lab work:

Topics Designed for Experiment in the areas needing lab work:

Experimental Work/Student Task: See Appendix G

Procedure for carrying out the experiments: See Appendix G

Safety Guidelines during experiment: See Appendix G

(B) PRODUCTION ENGINEERING

(ii) Course: PEE 721: Advanced Petroleum Production Engineering (3 Credit Hours)

Areas of PEE 721 needing lab work:

Topics Designed for Experiment in the areas needing lab work:

Experimental Work/Student Task: See Appendix H

Procedure for carrying out the experiments: See Appendix H

Safety Guidelines during experiment: See Appendix H

CHAPTER FIVE

5.0 Long Term Plan of Maintenance and Support on the Equipment for Good Laboratory Practices

Maintaining laboratory equipment is crucial to the overall productivity of the lab, the long-term performance of equipment and the total cost of ownership.

Effective maintenance plans reflect the vision and mission of the organization, this includes an accurate assessment of existing equipment, incorporate the perspectives of various stakeholder groups, and focus on preventive measures that ensure that capital investment is managed responsibly. The purpose of this plan is to outline a long term laboratory Equipment Management Program that provides for the safe and reliable operation of the petroleum engineering laboratory equipment used in the analysis of petroleum engineering research. The Equipment Management Program will ensure that the equipment provides accurate, reliable information to the staff and students, that the equipment is safe for the use of its operators, and that the equipment is utilized to its fullest capacity in order to optimize laboratory care.

The plan will be based upon manufacturer recommended practice, organizational experience, as well as policies, standards, regulations and applicable laws that govern the UNIUYO petroleum engineering lab. The plan comprises issues from reservoir and drilling engineering. The Equipment Management plan looks at two branches of the Equipment Management Program namely: the Technical support and the Engineering support. Technical support of equipment includes, but is not limited to, incoming inspection, installation, monitoring, preventive maintenance, troubleshooting, repairs, and modification for improvement, reliability, and safety. Engineering support of lab equipment includes, but is not limited to, modification for improvement, reliability, safety, hazard alert/recall monitoring and notification, incident investigation, and research development.

All UNIUYO lab staff is responsible for adhering to the policies and procedures developed in support of the lab Equipment Management Program. Responsibilities include, but are not limited to, ensuring all equipment used within the patient care vicinity has been inspected prior to use, immediately reporting problems with lab equipment, and requesting education on the operation of unfamiliar equipment.

5.1 Definition of Terms

Creating a maintenance plan is generally not difficult to do. But creating a comprehensive maintenance program that is effective poses some interesting challenges. It would be difficult to appreciate the subtleties of what makes a maintenance plan effective without understanding how the plan forms part of the total maintenance environment.

This section explains what makes the difference between an ordinary maintenance plan and a good, effective maintenance program. Maintenance practitioners across industry use many maintenance terms to mean different things. So to level the playing field, it is necessary to explain the way in which a few of these terms have been utilized throughout this document to ensure common understanding by all who read it. It must be emphasized, however, that

this is the author’s preferred interpretation of these terms, and should not necessarily be taken as gospel truth.

In sporting parlance, the maintenance policy defines the “rules of the game”, whereas the maintenance strategy defines the “game plan” for that game or season.

- **Maintenance policy** – Highest-level document, typically applies to the entire site.
- **Maintenance strategy** – Next level down, typically reviewed and updated every 1 to 2 years.
- **Maintenance program** – Applies to an equipment system or work center, describes the total package of all maintenance requirements to care for that system.
- **Maintenance checklist** – List of maintenance tasks (preventive or predictive) typically derived through some form of analysis, generated automatically as work orders at a predetermined frequency.
- **Short-term maintenance plan** (sometimes called a “schedule of work”) – Selection of checklists and other ad-hoc work orders grouped together to be issued to a workshop team for completion during a defined maintenance period, typically spanning one week or one shift.
- **Long term maintenance plan** - Activities required or undertaken to conserve as nearly, and as long, as possible the original condition of an equipment while compensating for normal wear and tear.

The Maintenance Information Loop

Figure 5.1 below describes the flow of maintenance information and how the various aspects fit together.

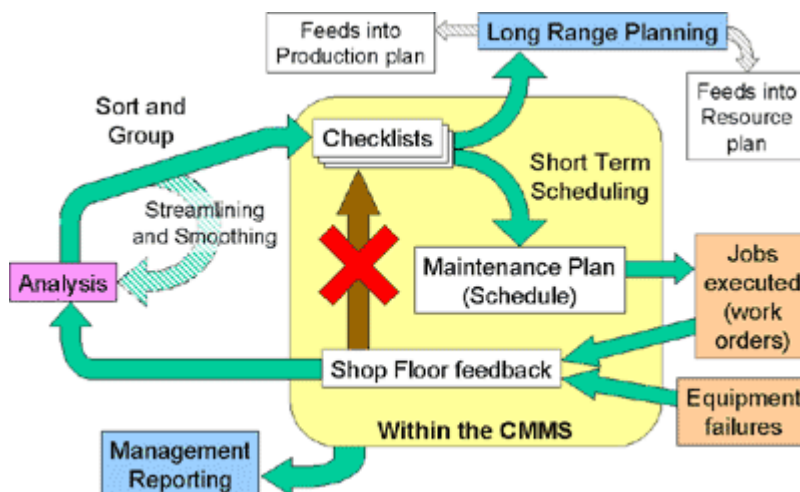


Figure 5.1 – Maintenance Information Loop

The large square block indicates the steps that take place within the computerized maintenance management system, or CMMS.

It is good practice to conduct some form of analysis to identify the appropriate maintenance tasks to care for your equipment. RCM2 is probably the most celebrated methodology, but there are many variations.

The analysis will result in a list of tasks that need to be sorted and grouped into sensible chunks, which each form the content of a checklist. Sometimes it may be necessary to do some smoothing and streamlining of these groups of tasks in an iterative manner.

The most obvious next step is to schedule the work orders generated by the system into a plan of work for the workshop teams.

Less common, however, is to use this checklist data to create a long-range plan of forecasted maintenance work. This plan serves two purposes:

- The results can be used to determine future labour requirements, and
- They feed into the production plan.
- The schedule of planned jobs is issued to the workshop and the work is completed. Feedback from these work orders, together with details of any equipment failures, is captured in the CMMS for historical reporting purposes.

A logical response to this shop floor feedback is that the content of the checklists should be refined to improve the quality of the preventive maintenance, especially to prevent the recurrence of failures. A common mistake however, is to jump straight from the work order feedback and immediately change the words on the checklists. When this happens, the integrity of the preventive maintenance programme is immediately compromised because the revised words on the checklist have no defensible scientific basis. This should be avoided wherever possible. The far better approach to avoid this guessing game is to route all the checklist amendments through the same analysis as was used originally to create the initial checklists. This means that the integrity of the maintenance program is sustained over the long term. Implicit in this approach, however, is the need to have a robust system in which the content of the analysis can be captured and updated easily.

Finally, all the information that gets captured into the CMMS must be put to good use otherwise it is a waste of time. This is the value of management reports that can be created from maintenance information.

5.2 Importance of Laboratory Maintenance

When scientific instrumentation stops working the entire laboratory can be thrown into chaos. Research grinds to a halt as the scientists figure out how to fix the instrument and wait for the service technician to come in and make the repair. The entire process of returning the laboratory to its regular operation can be quite expensive in terms of both time and money. A well-designed maintenance program can help reduce loss of time and money when instrumentation in the laboratory breaks down.

Developing a fully integrated instrument maintenance program is an excellent way to increase the productivity of the laboratory. Productivity in the laboratory is most easily understood by asking how much of the scientist's time and the company's money is consumed for the laboratory to produce value in the form of data or compounds. Having a well-designed maintenance program in place can save both time and money. In some

situations it is even possible to eliminate distractions for the scientists so that they can focus even more on producing results. However, it is important that these gains not come at the expense of the value that the laboratory is producing. The condition of your laboratory maintenance program can also serve as a leading indicator for the health of the laboratory as a whole. If instrument maintenance is well handled, you can be confident that the rest of the laboratory is well organized for long term success.

The first step in setting up a maintenance plan is to fully understand how all of the individual instruments contribute to the success of the laboratory. In order to fully understand the level of disruption that a particular instrument failure would cause, it is critical to understand the importance of the instruments function and how easily it can be quickly replaced by other resources in the lab.

Once all the laboratories scientific instrumentation has been characterized you can build maintenance plan that safeguards all the laboratory's capabilities for the lowest possible cost. This can be done by negotiating agreements with service providers that provide high priority service for the most important instrumentation while providing slower service for the instruments that are not as vital. The well-designed maintenance plan will also include a mechanism to track down time for each individual instrument for both future planning and continuous improvement efforts.

While it takes considerable effort to fully design and implement a comprehensive instrument maintenance program, the long term benefits are invaluable to any company that relies on an efficient and cost effective laboratory. The best maintenance programs are set up to be self-sustaining so that the benefits are preserved far into the future.

As with any successful management endeavor, good equipment maintenance plans integrate best practices of planning, implementation, and evaluation.

In the experimental research arena, the phrase *good laboratory practice* or GLP specifically refers to a quality system of management controls for research laboratories and organizations to try to ensure the uniformity, consistency, reliability, reproducibility, quality, and integrity.

5.3 Types of Maintenance Programs

What is maintenance and why is it performed? The dictionary defines maintenance as follows: "the work of keeping something in proper condition; upkeep." This would imply that maintenance should be actions taken to prevent a device or component from failing or to repair normal equipment degradation experienced with the operation of the device to keep it in proper working order. Unfortunately, data obtained in many studies over the past decade indicates that most laboratories in public universities in Nigeria do not expend the necessary resources to maintain equipment in proper working order. Rather, they wait for equipment failure to occur and then take whatever actions are necessary to repair or replace the equipment. Nothing lasts forever and all equipment has associated with it some predefined life expectancy or operational life. For example, equipment may be designed to operate at full design load for 5,000 hours and may be designed to go through 15,000 starts and stop cycles. The need for maintenance is predicated on actual or impending failure – ideally, maintenance is performed to keep equipment and systems running

efficiently for at least design life of the component(s). As such, the practical operation of a component is time-based function. If one were to graph the failure rate a component population versus time, it is likely the graph would take the “bathtub” shape shown in Figure 5.2 In the figure the Y axis represents the failure rate and the X axis is time. From its shape, the curve can be divided into three distinct: infant mortality, useful life, and wear-out periods. The initial infant mortality period of bathtub curve is characterized by high failure rate followed by a period of decreasing failure. Many of the failures associated with this region are linked to poor design, poor installation, or misapplication. The infant mortality period is followed by a nearly constant failure rate period known as useful life. There are many theories on why components fail in this region, most acknowledge that poor O&M often plays significant role. It is also generally agreed that exceptional maintenance practices encompassing preventive and predictive elements can extend this period. The wear-out period is characterized by a rapid increasing failure rate with time. In most cases this period encompasses the normal distribution of design life failures.

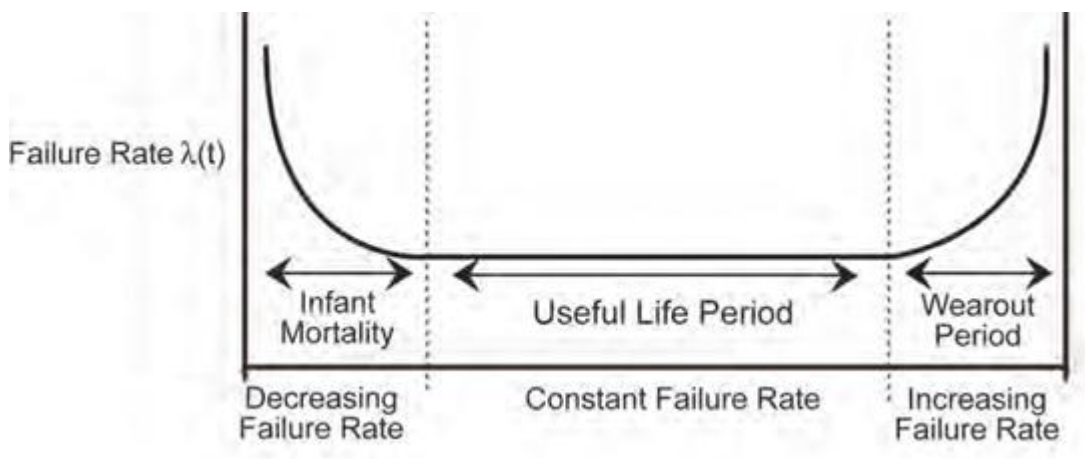


Figure 5.2: Component failure rate over time for component population

The design life of most equipment requires periodic maintenance. Belts need adjustment, alignment needs to be maintained, proper lubrication on rotating equipment is required, and so on. In some cases, certain components need replacement, (e.g., a wheel bearing on a motor vehicle) to ensure the main piece of equipment (in this case a car) last for its design life. Anytime we fail to perform maintenance activities intended by the equipment’s designer, we shorten the operating life of the equipment. But what options do we have? Over the last 30 years, different approaches to how maintenance can be performed to ensure equipment reaches or exceeds its design life have been developed in the United States. In addition to waiting for a piece of equipment to fail (reactive maintenance), we can utilize preventive maintenance, predictive maintenance, or reliability centered maintenance.

5.3.1 Reactive Maintenance

Reactive maintenance is basically the “run it till it breaks” maintenance mode. No actions or efforts are taken to maintain the equipment as the designer originally intended to ensure design life is reached. Studies as recent as the winter of 2000 indicate this is still the predominant mode of maintenance in the United States. The referenced study breaks down the average maintenance program as follows:

- >55% Reactive
- 31% Preventive
- 12% Predictive
- 2% Other

Note that more than 55% of maintenance resources and activities of an average facility are still reactive.

Advantages to reactive maintenance can be viewed as a double-edged sword. If we are dealing with new equipment, we can expect minimal incidents of failure. If our maintenance program is purely reactive, we will not expend manpower dollars or incur capital cost until something breaks. Since we do not see any associated maintenance cost, we could view this period as saving money. The downside is reality. In reality, during the time we believe we are saving maintenance and capital cost, we are really spending more dollars than we would have under a different maintenance approach. We are spending more dollars associated with capital cost because, while waiting for the equipment to break, we are shortening the life of the equipment resulting in more frequent replacement. We may incur cost upon failure of the primary device associated with its failure causing the failure of a secondary device. This is an increased cost we would not have experienced if our maintenance program was more proactive. Our labour cost associated with repair will probably be higher than normal because the failure will most likely require more extensive repairs than would have been required if the piece of equipment had not been run to failure. Chances are the piece of equipment will fail during off hours or close to the end of the normal workday. If it is a critical piece of equipment that needs to be back on-line quickly, we will have to pay maintenance overtime cost. Since we expect to run equipment to failure, we will require a large material inventory of repair parts. This is a cost we could minimize under a different maintenance strategy.

Advantages

- Low cost.
- Less staff.

Disadvantages

- Increased cost due to unplanned downtime of equipment.
- Increased labor cost, especially if overtime is needed.
- Cost involved with repair or replacement of equipment.

- Possible secondary equipment or process damage from equipment failure.
- Inefficient use of staff resources.

5.3.2 Preventive Maintenance

Preventive maintenance can be defined as follows: Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level.

The U.S. Navy pioneered preventive maintenance as a means to increase the reliability of their vessels. By simply expending the necessary resources to conduct maintenance activities intended by the equipment designer, equipment life is extended and its reliability is increased. In addition to an increase in reliability, dollars are saved over that of a program just using reactive maintenance. Studies indicate that this savings can amount to as much as 12% to 18% on the average. Depending on the facilities current maintenance practices, present equipment reliability, and facility downtime, there is little doubt that many facilities purely reliant on reactive maintenance could save much more than 18% by instituting a proper preventive maintenance program.

While preventive maintenance is not the optimum maintenance program, it does have several advantages over that of a purely reactive program. By performing the preventive maintenance as the equipment designer envisioned, we will extend the life of the equipment closer to design. This translates into dollar savings. Preventive maintenance (lubrication, filter change, etc.) will generally run the equipment more efficiently resulting in dollar savings. While we will not prevent equipment catastrophic failures, we will decrease the number of failures. Minimizing failures translate into maintenance and capital cost savings.

Advantages

- Cost effective in many capital-intensive processes.
- Flexibility allows for the adjustment of maintenance periodicity.
- Increased component life cycle.
- Energy savings.
- Reduced equipment or process failure.
- Estimated 12% to 18% cost savings over reactive maintenance program.

Disadvantages

- Catastrophic failures still likely to occur.
- Labor intensive.
- Includes performance of unneeded maintenance.
- Potential for incidental damage to components in conducting unneeded maintenance

5.3.3 Predictive Maintenance

Predictive maintenance can be defined as follows: Measurements that detect the onset of system degradation (lower functional state), thereby allowing causal stressors to be

eliminated or controlled prior to any significant deterioration in the component physical state. Results indicate current and future functional capability.

Basically, predictive maintenance differs from preventive maintenance by basing maintenance need on the actual condition of the machine rather than on some preset schedule. You will recall that preventive maintenance is time-based. Activities such as changing lubricant are based on time, like calendar time or equipment run time. For example, most people change the oil in their vehicles every 3,000 to 5,000 miles traveled. This is effectively basing the oil change needs on equipment run time. No concern is given to the actual condition and performance capability of the oil. It is changed because it is time. This methodology would be analogous to a preventive maintenance task. If, on the other hand, the operator of the car discounted the vehicle run time and had the oil analyzed at some periodicity to determine its actual condition and lubrication properties, he/she may be able to extend the oil change until the vehicle had traveled 10,000 miles. This is the fundamental difference between predictive maintenance and preventive maintenance, whereby predictive maintenance is used to define needed maintenance task based on quantified material/equipment condition.

The advantages of predictive maintenance are many. A well-orchestrated predictive maintenance program will all but eliminate catastrophic equipment failures. We will be able to schedule maintenance activities to minimize or delete overtime cost. We will be able to minimize inventory and order parts, as required, well ahead of time to support the downstream maintenance needs. We can optimize the operation of the equipment, saving energy cost and increasing plant reliability. Past studies have estimated that a properly functioning predictive maintenance program can provide a savings of 8% to 12% over a program utilizing preventive maintenance alone. Depending on a facility's reliance on reactive maintenance and material condition, it could easily recognize savings opportunities exceeding 30% to 40%. In fact, independent surveys indicate the following industrial average savings resultant from initiation of a functional predictive maintenance program:

- Return on investment: 10 times
- Reduction in maintenance costs: 25% to 30%
- Elimination of breakdowns: 70% to 75%
- Reduction in downtime: 35% to 45%
- Increase in production: 20% to 25%.

On the down side, to initially start into the predictive maintenance world is not inexpensive. Much of the equipment requires cost in excess of \$50,000. Training of in-plant personnel to effectively utilize predictive maintenance technologies will require considerable funding. Program development will require an understanding of predictive maintenance and a firm commitment to make the program work by all facility organizations and management.

Advantages

- Increased component operational life/availability.
- Allows for preemptive corrective actions.
- Decrease in equipment or process downtime.
- Decrease in costs for parts and labor.
- Better product quality.
- Improved worker and environmental safety.
- Improved worker morale.
- Energy savings.
- Estimated 8% to 12% cost savings over preventive maintenance program.

Disadvantages

- Increased investment in diagnostic equipment.
- Increased investment in staff training.
- Savings potential not readily seen by management.

5.3.4 Reliability Centered Maintenance

Reliability centered maintenance (RCM) magazine provides the following definition of RCM: “a process used to determine the maintenance requirements of any physical asset in its operating context.” Basically, RCM methodology deals with some key issues not dealt with by other maintenance programs. It recognizes that all equipment in a facility is not of equal importance to either the process or facility safety. It recognizes that equipment design and operation differs and that different equipment will have a higher probability to undergo failures from different degradation mechanisms than others. It also approaches the structuring of a maintenance program recognizing that a facility does not have unlimited financial and personnel resources and that the use of both need to be prioritized and optimized. In a nutshell, RCM is a systematic approach to evaluate a facility’s equipment and resources to best mate the two and result in a high degree of facility reliability and cost-effectiveness. RCM is highly reliant on predictive maintenance but also recognizes that maintenance activities on equipment that is inexpensive and unimportant to facility reliability may best be left to a reactive maintenance approach. The following maintenance program breakdowns of continually top-performing facilities would echo the RCM approach to utilize all available maintenance approaches with the predominant methodology being predictive.

- <10% Reactive
- 25% to 35% Preventive

- 45% to 55% Predictive.

Because RCM is so heavily weighted in utilization of predictive maintenance technologies, its program advantages and disadvantages mirror those of predictive maintenance. In addition to these advantages, RCM will allow a facility to more closely match resources to needs while improving reliability and decreasing cost.

Advantages

- Can be the most efficient maintenance program.
- Lower costs by eliminating unnecessary maintenance or overhauls.
- Minimize frequency of overhauls.
- Reduced probability of sudden equipment failures.
- Able to focus maintenance activities on critical components.
- Increased component reliability.
- Incorporates root cause analysis.

Disadvantages

- Can have significant startup cost, training, equipment, etc.
- Savings potential not readily seen by management.

Table 5.1 below highlights guidance on RCM development by equipment application (adapted from NASA 2000). It is important to both define the equipment criticality and cost of down-time when determining the optimal mix of maintenance elements. Once defined, the equipment can be prioritized in the developing a functional RCM program.

Table 5.1: Reliability centered maintenance element applications

Reliability Centered Maintenance Hierarchy		
Reactive Element Applications	Preventive Element Applications	Predictive Element Applications
Small parts and equipment	Equipment subject to wear	Equipment with random failure patterns
Non-critical equipment	Consumable equipment	Critical equipment
Equipment unlikely to fail	Equipment with known failure	Equipment not subject to wear
Redundant systems	Manufacturer recommendations	Systems which failure may be induced by incorrect preventive maintenance

5.3.5 Corrective Maintenance

Corrective maintenance typically falls into one of two categories. The first category is when equipment that has been well maintained simply breaks or fails to some degree that it

requires maintenance. Corrective maintenance to make any needed repairs is scheduled and performed.

The second corrective maintenance category is when equipment is run to failure deliberately before any corrective maintenance is scheduled and performed. This is what we'll call the run-to-failure model. As indicated earlier, some managers have hard percentage numbers for the relationship between corrective maintenance and preventive maintenance. A typical scenario would be 60% of maintenance work hours are scheduled for preventive maintenance and the remaining 40% of scheduled hours would be for corrective maintenance.

5.3.6 Comparison of Four Maintenance Programs (Piotrowski 2001)

Reactive Maintenance (Breakdown or Run-to-Failure Maintenance)

Basic philosophy

- Allow machinery to run to failure.
- Repair or replace damaged equipment when obvious problems occur.

Cost: \$18/hp/yr.

This maintenance philosophy allows machinery to run to failure, providing for the repair or replacement of damaged equipment only when obvious problems occur. Studies have shown that the costs to operate in this fashion are about \$18 per horsepower (hp) per year. The advantages of this approach are that it works well if equipment shutdowns do not affect production and if labor and material costs do not matter.

Preventive Maintenance (Time-Based Maintenance)

Basic philosophy

- Schedule maintenance activities at predetermined time intervals.
- Repair or replace damaged equipment before obvious problems occur.

Cost: \$13/hp/yr

This philosophy entails the scheduling of maintenance activities at predetermined time intervals, where damaged equipment is repaired or replaced before obvious problems occur. When it is done correctly, studies have shown the costs of operating in this fashion to be about \$13 per hp per year. The advantages of this approach are that it works well for equipment that does not run continuously, and with personnel who have enough knowledge, skills, and time to perform the preventive maintenance work.

Predictive Maintenance (Condition-Based Maintenance)

Basic philosophy

- Schedule maintenance activities when mechanical or operational conditions warrant.

- Repair or replace damaged equipment before obvious problems occur.

Cost: \$9/hp/yr.

This philosophy consists of scheduling maintenance activities only if and when mechanical or operational conditions warrant-by periodically monitoring the machinery for excessive vibration, temperature and/or lubrication degradation, or by observing any other unhealthy trends that occur over time. When the condition gets to a predetermined unacceptable level, the equipment is shut down to repair or replace damaged components so as to prevent a more costly failure from occurring. In other words, “Don’t fix what is not broke.” Studies have shown that when it is done correctly, the costs to operate in this fashion are about \$9 per hp per year. Advantages of this approach are that it works very well if personnel have adequate knowledge, skills, and time to perform the predictive maintenance work, and that it allows equipment repairs to be scheduled in an orderly fashion. It also provides some lead-time to purchase materials for the necessary repairs, reducing the need for a high parts inventory. Since maintenance work is only performed when it is needed, there is likely to be an increase in production capacity.

Reliability Centered Maintenance (Pro-Active or Prevention Maintenance)

Basic philosophy

- Utilizes predictive/preventive maintenance techniques with root cause failure analysis to detect and pinpoint the precise problems, combined with advanced installation and repair techniques, including potential equipment redesign or modification to avoid or eliminate problems from occurring

Cost: \$6/hp/yr.

This philosophy utilizes all of the previously discussed predictive/preventive maintenance techniques, in concert with root cause failure analysis. This not only detects and pinpoints precise problems that occur, but ensures that advanced installation and repair techniques are performed, including potential equipment redesign or modification, thus helping to avoid problems or keep them from occurring. According to studies, when it is done correctly, operating in this fashion costs about \$6 per hp per year. One advantage to this approach is that it works extremely well if personnel have the knowledge, skills, and time to perform all of the required activities. As with the predictive-based program, equipment repairs can be scheduled in an orderly fashion, but additional improvement efforts also can be undertaken to reduce or eliminate potential problems from repeatedly occurring. Furthermore, it allows lead-time to purchase materials for necessary repairs, thus reducing the need for a high parts inventory. Since maintenance work is performed only when it is needed, and extra efforts are put forth to thoroughly investigate the cause of the failure and determine ways to improve machinery reliability, there can be a substantial increase in production capacity.

5.4 Proposed Long Term Maintenance Plan for the Uniuyo Lab

Some laboratories enjoy the luxury of having regular, fixed maintenance plan built into the production plans. For example, it could be agreed that every Tuesday morning Production Unit 1 will stop production and the equipment will be made available to the maintenance crew for six hours. During this six-hour period, the maintenance crew has the opportunity to assign as many people as required to complete all the planned maintenance activities in that work center. Thereafter, the system is handed back to the production team until the next week.

In many cases however, there is no such regular routine in place. Opportunities for the maintenance teams to conduct planned maintenance need to be negotiated and agreed with the production teams on an “as-needed” basis. Unfortunately, this is very often reduced to the maintenance department begging for access to the equipment. Furthermore, this plea is often met with the unsympathetic response from the production teams that they have to run the equipment in order to meet their targets and they therefore cannot afford to release it for maintenance. This is a very short-sighted view in my opinion.

The generation of a long-range maintenance plan that shows the number of hours of preventive maintenance work to be done in each work center over an 18- to 24-month horizon is a valuable tool. It gives the production schedulers visibility of the amount of time that is required for this preventive maintenance so that they can proactively plan to release the equipment for those periods. This makes the job of planning the maintenance activities so much simpler. Of all the maintenance plans, the Reliability Centered Maintenance plan is the best to be adopted for the UNIUYO lab. It follows the order below:

1. Develop a Master equipment list identifying the equipment in the lab. (*Equipment audit*)

Things change. It is a fact of life and of lab facilities maintenance planning. The lusters of new equipment are sure to fade over time.

And as facilities age, their condition changes as well. But change isn't always a bad thing. For example, a two-year-old air-handling system might perform better than a new system because its operators have had 24 months to learn how to use it and “get out the kinks.” Of course, this assumes that the operators have maintained the equipment responsibly along the way—changing filters and belts as needed. If, however, the same air handler is operating well after 10 years of service, it is safe to assume that more extensive maintenance efforts have been undertaken—valves and gaskets will have been replaced and the compressor pump serviced (probably more than once).

Because the definition of what constitutes “proper maintenance” changes over the life of the equipment or building, knowing the age and condition of a facility or piece of equipment is a prerequisite for maintaining it properly.

Otherwise, maintenance efforts are a hit-or-miss situation—some things only get fixed when they break while others get “maintained” on a routine basis whether they need it or not.

When an education organization knows the status of its facilities and equipment, the need for maintenance, repairs, and upgrades becomes much clearer—after all, it is tough to argue against good data!

Most of what is required for an equipment management plan you are already doing. What you may not be doing is documenting this maintenance or completing it on a regular schedule. Needless to say, no one wants that. Documentation is every bit as important as actually doing the work. First thing you want to do is to make an inventory of all of the equipment in your lab that requires any amount of care. Be sure to include anything that runs on electricity or air and anything that has moving parts. Also include anything that uses filters or needs sharpening. As you can see, this list will soon become fairly long.

Once you have your list, refer to the owner’s manuals for maintenance information and make a note of it on your list. You did save the owner manuals, right? If not, try to get the information online or by calling the company that produced the equipment. Sometimes with older equipment, none of these options may be possible and you just have to make comparative studies of similar equipment. If all else fails, it is better to make an educated guess than to do nothing.

Laboratory Equipment Maintenance Checklist

Provided here is a template which may be adapted by laboratory supervisors for use in such a system of maintenance and safety checks. Supervisors could review what is required in the laboratory and modify the template accordingly to suit. Supervisors may need to expand the instruction detail for many items.

Table 5.2: Laboratory Maintenance Checklist

UNIUYO Laboratory		Issue Date:
Name:	Signature:	Date:
Participants:		
Maintenance Item	Done	
Work Bench - Clear and clean bench tops. Return materials to their rightful place		
Floor - sweep or swab floor if necessary.		
Eyewash Station - test that eyewash works. Let run for a while to flush line.		
Emergency Shower Station - test that shower works.		
Fire and Emergency Equipment - check that fire extinguishers, fire blanket, first aid kit are present and in order.		
Sharps Containers - if bin is more than half full, seal and take to disposal area.		
Glass Bins - if bin is more than half full, carefully tip contents into a study box. Tape the box shut, label it as "BROKEN GLASS" and take to the dumper.		
Core samples drying oven -		
Vacuum pump		
Core samples		
Desiccator and accessories		
Centrifuges - remove rotor, wash and clean rotor, buckets and adaptors. Check O-rings.		

Balances - Clean balances. Clean bench around balance. Return bottles to correct storage. Ensure balance is level.	
pH Meter - turn it off if not in use. Check electrode is filled internally and sensing tip is covered with buffer.	
Chemical Waste - if chemical discard containers are more than half full, date them and take to the chemical stores branch for disposal.	
Chemical Storage - ensure chemicals are correctly segregated into dangerous goods classes and stored correctly.	
Fume Cupboard - Remove items being stored in work zone. Check that cupboard controls work and unit performs satisfactorily.	
Biosafety Cabinet - (Laminar/Clean work station, Class I or II). Remove items being stored in work zone. Check that cabinet controls work and unit performs satisfactorily. Clean internal surfaces with disinfectant.	
Vacuum gauge	
Hand Disinfectant - clean the sink and dispenser. Replace or refill the hand disinfectant bottle.	
Paper Towel - ensure that the paper towel roll is at least half full. Obtain a spare roll to place beside the dispenser.	
Oil Mist Filter EMF 10 plus filter.	
High speed and low speed mixers	
Gas Cylinder - Return unused or empty cylinders to store. Mark empty cylinders. with M/T. Ensure cylinders are always correctly restrained.	
Radioactive Wastes - check date of store date for those wastes being left to decay. If past the anticipated date, check the count and discard in the industrial waste if count is not significant.	
Major Instrument - Ensure maintenance protocol for instrument is followed. Ensure use log is current and faults are reported.	
Liquid Nitrogen - If local Dewar has less than 20% LN2 capacity, refill Dewar from main store. Record levels before and after filling. Record filling date.	
Media Plates and Flasks - Dispose of (autoclave) used plates, bottles etc. as soon as possible. Use small discard containers and dispose of contents when at 3/4 level or less. Carry material to disposal area in sturdy, spill proof containers.	
Amott cells and accessories	
Viscometers and accessories	
Air permeameter	
Displacement pump and accessories	
Soxhlet extractors	
Sand content kit	
Stop watch	
Filter press	
Marsh funnel	

Comments / problems / suggestions:

2. Prioritize the listed components based on importance or criticality to operation, process, or mission – see table 5.3 highlighting priority schemes.

The list can be delivered in several ways, but most programs use some form of the probability and consequence table to determine the category. This involves a determination that quantifies the probability of equipment failing and the consequences associated with the failure.

Consider a 1-to-10 scale with 10 being a low probability and 1 being the highest failure probability. Management needs to assign the actual scale numbers to use for this determination. Most equipment in an engineering lab facility has a low failure probability, or else it wouldn't have been purchased and installed in the first place. Even so, there will be some equipment with a higher failure probability than others, and these receive a higher probability rating. Because probability failures are normally low, the consequence of a failure number assigned to the piece of equipment carries more weight than the probability. But we need to use both numbers in our run-to failure versus maintenance performance equation. We'll use the same 1-to-10 scale for the consequence, with 10 being low-to-no consequence and 1 being high negative consequence.

Table 5.3: Maintenance priority matrix for RCM Development

Priority Weighting	Description	Application
1	Emergency	Life, health, safety risk-mission criticality
2	Urgent	Continuous operation of facility at risk
3	Priority	Mission support/project deadlines
4	Routine	Prioritized: first come/first served
5	Discretionary	Desired but not essential
6	Deferred	Accomplished only when resources allow

3. Assign components into logical groupings.

Now arrange the equipment in an orderly checklist and assign each a date and a task: inspect oil, sharpen, and clean, and so on. These checklists, or logs, should be set up so that it makes sense for you in your lab. Although there are several standard forms you can acquire, it is best to make your own list as it pertains to your lab and your specific needs. Designate an area where the log can be stored and can be accessed easily and will not get lost.

Assign a person whose job it is to maintain the equipment. That person should refer to this log when servicing equipment and record the actions

4. Determine the type and number of maintenance activities required and periodicity using:
 - a. Manufacturer technical manuals
 - b. Machinery history
 - c. Root causes analysis findings - Why did it fail?
 - d. Good engineering judgment
5. Assess the size of maintenance staff.
6. Identify tasks that may be performed by operations maintenance personnel.
7. Analyze equipment failure modes and impacts on components and systems.
8. Identify effective maintenance tasks or mitigation strategies.

5.5 Equipment Management Plan Activities

Selection and acquisition of equipment: Each of the two branches of the Equipment Management Program actively participates in the selection and acquisition of equipment. Activities revolving around the identification of the need for equipment replacement include, but are not limited to, submitting planned capital equipment requests based on depreciation schedules, monitoring approved capital equipment and construction projects, monitoring hazard alerts/product recalls, and reactively replacing equipment based on inability to further maintain. Assistance provided during the selection process includes, but is not limited to, identifying technical specifications, writing Requests For Proposals, reviewing bids, verifying performance specifications, benchmarking with similar institutions, consulting external agencies that focus on equipment safety (e.g. AAMI, ECRI, FDA, etc.), performing site visits, and negotiating with vendors. Assistance provided during the acquisition process includes, but is not limited to, coordinating construction activities to prepare the site for the equipment, coordinating installation efforts, performing acceptance testing, and coordinating training of lab staff/service personnel.

Preventive maintenance inspections: In conjunction with the evaluation of equipment for inclusion in the Equipment Management Program, each classification of device should be assigned a preventive maintenance inspection strategy and schedule. The preventive maintenance inspections for most equipment included in the Equipment Management Program are interval-based; however some are meter-based (note, interval-based preventive maintenance inspections are still assigned to meter-based devices to ensure that the device's meter is checked). The frequency for interval-based preventive maintenance inspections is determined based upon manufacturer recommendations, risk levels, and past organizational experience. Preventive maintenance work orders are generated on a monthly basis, with expectations that the work orders be completed in a timely manner. Additional preventive maintenance work orders may be generated for those devices that have missed their previous preventive maintenance inspections (e.g. device could not be located, device was

in use, etc.), or that came due for preventive maintenance off-cycle (e.g. meter-based inspections).

Repairs: All repairs should be prioritized and performed in a timely manner. To assure the continuation of lab researches care in the event of equipment failure, backup devices should be available for most critical devices. In addition, the department should maintain individualized emergency procedure plans for critical equipment and/or systems

Review of hazard alerts and product recalls: Notification of hazard alerts and product recalls come from a variety of sources (e.g. manufacturers and vendors, etc.). All hazard alerts and product recalls should be promptly reviewed, acted upon, and documented, regardless of their origination. To aid this process, a written hazard should be pasted on the body of the equipment to notify the user of the hazard that could emanate from the misuse of such equipment. This can be exemplified by posting “don’t drink” on a bottle containing acid.

Data collection/management: The primary tool and resource for data collection/management should be a computerized maintenance management system. This system should incorporate the equipment inventory, all service history records for equipment in the inventory, a work order system, and the preventive maintenance schedules/procedures. This system is used as an administrative tool to track equipment, to initiate work orders, to measure performance indicators, to determine equipment failure trends, to identify training needs, and to produce management reports.

Orientation and continuing education (users of equipment): Users of equipment require orientation to equipment either upon initial hire, upon reassignment to new job responsibilities, upon introduction of new equipment, or upon individualized recognition of need. Upon initial hire or reassignment to new job responsibilities, each department is responsible for providing orientation to employees to provide them with the skills needed to safely utilize the equipment in their work environment. Educational plans shall address initial orientation needs as well as ongoing continuing education, if appropriate. Ongoing continuing education needs are typically specified in departmental annual competency programs. Training conducted upon individualized recognition of need can be provided either by an employee’s supervisor/mentor who recognizes need through daily activity or by service maintenance department personnel who recognize operator error problems through repair calls.

Orientation and continuing education (maintainers of equipment): Maintainers of equipment require orientation to equipment either upon initial hire, upon reassignment to new job responsibilities, or upon introduction of new equipment. Upon initial hire or reassignment to new job responsibilities, the service maintenance department managers provide orientation to employees to provide them with the skills needed to maintain and/or repair equipment in their work environment. Orientation may be provided through a combination of supervisor review with the employee at the direct worksite, staff cross-training, and service school attendance. Upon introduction of new equipment, service maintenance department managers assess what is the most appropriate methodology for

obtaining the skills needed to maintain and/or repair the new equipment and pursue training as appropriate. Typically, significant capital equipment purchases include negotiations for training service personnel.

5.6 Monitoring Overall Equipment Management Program Performance

An Equipment Management Committee should be set up and should be saddled with the responsibility of monitoring the overall Equipment Management Program in several ways.

First, Equipment Management committee is expected to report to the Head of Department on a quarterly basis preventive maintenance completion, product problems/hazard alerts that impact the facility, current quality improvement indicators, and any other equipment management issues. The committee reviews the reports to ensure the facility is maintaining compliance with policies, standards, regulations and applicable laws that govern the UNIUYO, as well as identify program deficiencies and implement corrective action to eliminate any identified deficiencies.

Second, a member of the Committee is expected to report to the committee on a quarterly basis a summary of incident investigation activity. The committee reviews the summary to ensure the facility is maintaining compliance with policies, standards, regulations and applicable laws that govern UNIUYO, as well as identify program deficiencies and implement corrective action to eliminate any identified deficiencies.

Finally, the committee conducts an annual review and evaluation of the Equipment Management Plan, including plan objectives, scope, performance, and effectiveness. Effectiveness will be determined by evaluating the program's ability to have:

- (a) Met all core objectives, scopes, and performance denoted in the prior year plan, and
- (b) Made progress on areas for improvement denoted in the prior year's annual evaluation.

The following are the ways the head of department can monitor current performance improvement indicators:

Operator Errors: Lab staff knowledge of proper equipment operation and maintenance will be assessed by monitoring the number of work orders associated with operator errors compared to the total number of repair work orders for a given month.

Inventorying Incoming Equipment: The accuracy of capturing incoming equipment will be assessed by monitoring the number of work orders associated with a maintenance/repair call for an item not previously inventoried.

CHAPTER SIX

6.0 Conclusion

Following the necessity of well-designed laboratory procedures for experimental studies, this work has been able to isolate detailed procedural steps for conducting basic petroleum engineering experiments in the department of Chemical/Petroleum Engineering of the University of Uyo. The thesis work discusses laboratory exercises I developed for students' classes in petroleum engineering. The main goal of this effort was to introduce the students to research methods and expose them to actual laboratory methods to provide a more complete learning experience. Obtaining feedback from students after performing the laboratory exercises is very important to determine if I met these goals. For that reason I have attached a questionnaire to each user of the laboratory. The findings would indicate whether the students found the manuals and exercises included in this work were effective in giving them a more professional experience. This would shape my thoughts for a more improved work in the future.

The following are the conclusions drawn based on the research work:

- An effective maintenance program is based on a critical equipment list developed through a rigorous analysis of the probability of failure and the consequences of failure.
- Multiple sources of data are available for quantifying the probability and consequences.
- The details of the resulting maintenance program needs to be reviewed no less than annually to accommodate changes in equipment condition and technology.
- Including laboratory exercises in educational courses, even if they do not provide the expected benefits, should not interfere with traditional education techniques. Implementing real life problems into the curriculum expands the knowledge and extent of thinking for students. Interaction between students working in groups in the laboratory present a real life situation to better prepares them for future work.
- For an experiment to be carried out there must be an availability of the equipment to be used. Besides, a procedure for calibrating the said equipment has to be outlined for the results generated from such equipment to be of standard and acceptable value.
This should also be coupled with knowledge of the basic theoretical background of the experimental parameters.
- Finally, the procedure for the experiment should be detailed and even the minutest of details shouldn't be left out. This procedure is best understood by users when written in chronological order. Also, the basic reporting style for each experiment is also of great importance.

Nomenclature

CMMS	=	Computerized maintenance management system
DF	=	Drilling Fluid
FREAD	=	Filtration Reduction Evaluation Device
GLP	=	Good Laboratory Practices
O&M	=	Operation and Maintenance
RCM	=	Reliability Centered Maintenance

Symbols

\$/ hp/ year	=	Dollar per horse power per year
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Appendix

This appendix is made up of 8 appendices (A – I). It showcases the design of the UNIUYO petroleum lab, lab safety procedures, the procedure for reporting lab experiments, the survey questionnaire to be used in evaluating the success or otherwise of this manual, the photographs of the equipment in the UNIUYO lab, and also the various exercises developed for the undergraduate, postgraduate diploma and master’s degree programmes in drilling, reservoir, and production engineering and the lab experiments carried out by the author.

Appendix A - Design of the Chemical/Petroleum Engineering laboratory

Theories taught in petroleum engineering courses requires practical confirmation so that students have a firm grip of how real life problems could be tackled in the field through simple laboratory experiments. Through a close collaboration with Afren Oil, Nigeria and the Norwegian University of Science and Technology, Trondheim, the department has been able to set up a laboratory and install state of the art facilities in it. The laboratory is used primarily for basic research in reservoir and drilling engineering as a support base for basic petroleum engineering courses taught at the undergraduate and postgraduate levels. There are still opportunities for more sophisticated equipment to be installed in the laboratory through the collaboration agreement with these two organizations.

The floor plan design of the laboratory is as shown in Figure 2.1. The plan essentially consists of good floor space arrangement with a large entrance/exit, stores for chemicals, office, and three work benches on which two bear the equipment. The lab is designed such that there is a steady supply of water and gas for heating purposes.

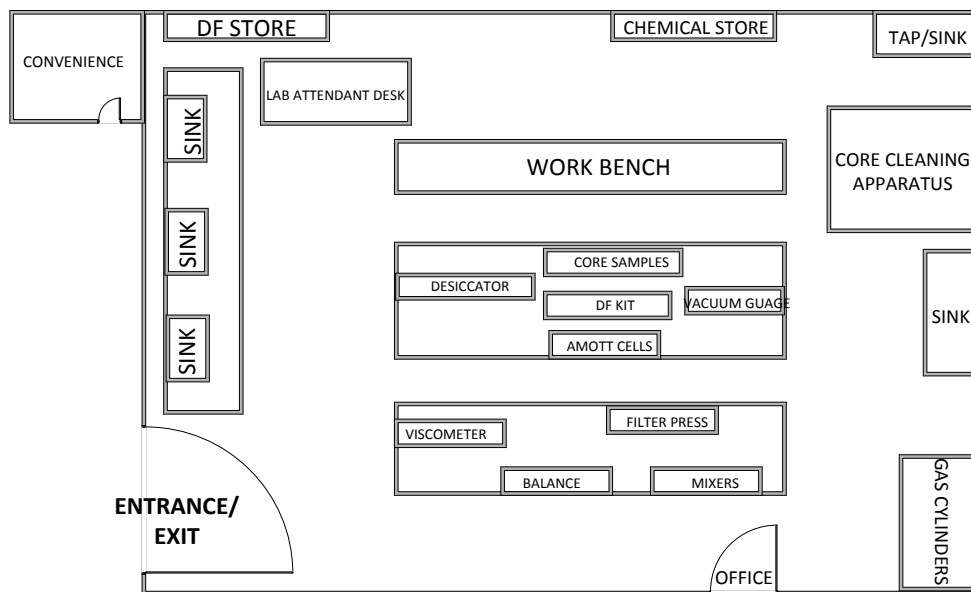


Figure 2.1: Floor plan of reservoir laboratory of the department of chemical/petroleum engineering, UNIUYO (Drawn by author)

Appendix B -General Laboratory Safety Procedures (as adapted from the Harvard University Lab safety procedures)

All lab users must read and understand the information in this document with regard to laboratory safety and emergency procedures prior to the first laboratory session. Your personal laboratory safety depends mostly on YOU. Effort has been made to address situations that may pose a hazard in the lab but the information and instructions provided cannot be considered all-inclusive. Lab users must adhere to written and verbal safety instructions throughout the academic term. Since additional instructions may be given at the beginning of laboratory sessions, it is important that all lab users arrive at each session on time. With good judgment, the chance of an accident in this course is very small. Nevertheless, research and teaching workplaces are full of potential hazards that can cause serious injury and or damage to the equipment. Working alone and unsupervised in laboratories is forbidden if you are working with hazardous substances or equipment. With prior approval, at least two people should be present so that one can shut down equipment and call for help in the event of an emergency.

Safety training and/or information should be provided by a faculty member, teaching assistant, lab safety contact, or staff member at the beginning of a new assignment or when a new hazard is introduced into the workplace. The following procedure is as adapted from the Harvard University Lab safety procedures from the university website online.

Emergency Response

1. It is your responsibility to read safety and fire alarm posters and follow the instructions during an emergency
2. Know the location of the fire extinguisher, eye wash, and safety shower in your lab and know how to use them.
3. Notify your instructor immediately after any injury, fire or explosion, or spill.
4. Know the building evacuation procedures.

Common Sense

Good common sense is needed for safety in a laboratory. It is expected that each student will work in a responsible manner and exercise good judgment and common sense. If at any time you are not sure how to handle a particular situation, ask your Teaching Assistant or Instructor for advice. Do not touch anything with which you are not completely familiar! It is always better to ask questions than to risk harm to yourself or damage to the equipment.

Personal and General laboratory safety

1. Never eat, drink, or smoke while working in the laboratory.
2. Read labels carefully.
3. Do not use any equipment unless you are trained and approved as a user by your supervisor.

4. Wear safety glasses or face shields when working with hazardous materials and/or equipment.
5. Wear gloves when using any hazardous or toxic agent.
6. Clothing: When handling dangerous substances, wear gloves, laboratory coats, and safety shield or glasses. Shorts and sandals should not be worn in the lab at any time. Shoes are required when working in the machine shops.
7. If you have long hair or loose clothes, make sure it is tied back or confined.
8. Keep the work area clear of all materials except those needed for your work. Coats should be hung in the hall or placed in a locker. Extra books, purses, etc. should be kept away from equipment that requires air flow or ventilation to prevent overheating.
9. Disposal - Students are responsible for the proper disposal of used material if any in appropriate containers.
10. Equipment Failure - If a piece of equipment fails while being used, report it immediately to your lab assistant or tutor. Never try to fix the problem yourself because you could harm yourself and others.
11. If leaving a lab unattended, turn off all ignition sources and lock the doors.
12. Never pipette anything by mouth.
13. Clean up your work area before leaving.
14. Wash hands before leaving the lab and before eating.

Electrical safety

1. Obtain permission before operating any high voltage equipment.
2. Maintain an unobstructed access to all electrical panels.
3. Wiring or other electrical modifications must be referred to the Electronics Shop or the Building Coordinator.
4. Avoid using extension cords whenever possible. If you must use one, obtain a heavy-duty one that is electrically grounded, with its own fuse, and install it safely. Extension cords should not go under doors, across aisles, be hung from the ceiling, or plugged into other extension cords.
5. Never, ever modify, attach or otherwise change any high voltage equipment.
6. Always make sure all capacitors are discharged (using a grounded cable with an insulating handle) before touching high voltage leads or the "inside" of any equipment even after it has been turned off. Capacitors can hold charge for many hours after the equipment has been turned off.
7. When you are adjusting any high voltage equipment or a laser which is powered with a high voltage supply, use only one hand. Your other hand is best placed in a pocket or behind your back. This procedure eliminates the possibility of an accident where high voltage current flows up one arm, through your chest, and down the other arm.
8. Distinguish between 110V and 220 V appliances to avoid equipment damage.

Mechanical safety

1. When using compressed air, uses only approved nozzles and never direct the air towards any person.
2. Guards on machinery must be in place during operation.
3. Exercise care when working with or near hydraulically- or pneumatically-driven equipment. Sudden or unexpected motion can inflict serious injury.

Chemical safety

1. Treat every chemical as if it were hazardous.
2. Make sure all chemicals are clearly and currently labeled with the substance name, concentration, date, and name of the individual responsible.
3. Never return chemicals to reagent bottles. (Try for the correct amount and share any excess.)
4. Comply with fire regulations concerning storage quantities, types of approved containers and cabinets, proper labeling, etc. If uncertain about regulations, contact the building coordinator.
5. Use volatile and flammable compounds only in a fume hood. Procedures that produce aerosols should be performed in a hood to prevent inhalation of hazardous material.
6. Never allow a solvent to come in contact with your skin. Always use gloves.
7. Never "smell" a solvent!! Read the label on the solvent bottle to identify its contents.
8. Dispose of waste and broken glassware in proper containers.
9. Clean up spills immediately.
10. Do not store food in laboratories.

Additional Safety Guidelines

- Never do unauthorized experiments.
- Never work alone in laboratory.
- Keep your lab space clean and organized.
- Do not leave an on-going experiment unattended.
- Always inform your instructor if you break a thermometer. Do not clean mercury yourself!!
- Never taste anything. Never pipette by mouth; use a bulb.
- Never use open flames in laboratory unless instructed by Teaching Assistant.
- Check your glassware for cracks and chips each time you use it. Cracks could cause the glassware to fail during use and cause serious injury to you or lab mates.
- Maintain unobstructed access to all exits, fire extinguishers, electrical panels, emergency showers, and eye washes.
- Do not use corridors for storage or work areas.
- Do not store heavy items above table height. Any overhead storage of supplies on top of cabinets should be limited to lightweight items only. Also, remember that a 36" diameter area around all fire sprinkler heads must be kept clear at all times.

- Areas containing lasers, biohazards, radioisotopes, and carcinogens should be posted accordingly. However, do not post areas unnecessarily and be sure that the labels are removed when the hazards are no longer present.
- Be careful when lifting heavy objects. Only shop staff may operate forklifts or cranes.

Appendix C -Procedure for reporting laboratory experiments (as adapted from Penn state university laboratory procedures.)

Verbal communication is temporal and easily forgotten, but written reports exist for long periods and yield long-term benefits for the author and others. A good lab report does more than present data; it demonstrates the writer's comprehension of the concepts behind the data. Merely recording the expected and observed results is not sufficient; you should also identify how and why differences occurred, explain how they affected your experiment, and show your understanding of the principles the experiment was designed to examine. Bear in mind that a format, however helpful, cannot replace clear thinking and organized writing. You still need to organize your ideas carefully and express them coherently.

Typical Components

- Title Page
- Abstract
- Introduction
- Methods and Materials (or Equipment)
- Experimental Procedure
- Results
- Discussion
- Conclusion
- References
- Appendices
- Further Reading

1. The Title Page needs to contain the name of the experiment, the names of lab partners, and the date. Titles should be straightforward, informative, and less than ten words (i.e. Not "Lab #2" but "Lab #2: Sample Analysis using the Dean Stark Method").

2. The Abstract summarizes four essential aspects of the report: the purpose of the experiment (sometimes expressed as the purpose of the report), key findings, significance and major conclusions. The abstract often also includes a brief reference to theory or methodology. The information should clearly enable readers to decide whether they need to read your whole report. The abstract should be one paragraph of 100-200 words.

The abstract should be written concisely in normal rather than highly abbreviated English. The author should assume that the reader has some knowledge of the subject but has not read the paper. Thus, the abstract should be intelligible and complete in itself; particularly it should not cite figures, tables, or sections of the paper. The opening sentence or two should,

in general, indicate the subjects dealt with in the paper and should state the objectives of the investigation. It is also desirable to describe the treatment by one or more such terms as brief, exhaustive, theoretical, experimental, and so forth.

The body of the abstract should indicate newly observed facts and the conclusions of the experiment or argument discussed in the paper. It should contain new numerical data presented in the paper if space permits; otherwise, attention should be drawn to the nature of such data. In the case of experimental results, the abstract should indicate the methods used in obtaining them; for new methods the basic principle, range of operation, and degree of accuracy should be given.

3. The introduction is more narrowly focused than the abstract. It states the objective of the experiment and provides the reader with background to the experiment. State the topic of your report clearly and concisely, in one or two sentences: A good introduction also provides whatever background theory, previous research, or formulas the reader needs to know. Usually, an instructor does not want you to repeat the lab manual, but to show your own comprehension of the problem. If the amount of introductory material seems to be a lot, consider adding subheadings such as: Theoretical Principles or Background.

Note on Verb Tense

Introductions often create difficulties for students who struggle with keeping verb tenses straight. These two points should help you navigate the introduction:

- The experiment is already finished. Use the past tense when talking about the experiment.

"The objective of the experiment was..."

- The report, the theory and permanent equipment still exist; therefore, these get the present tense:

"The purpose of this report is..."

"Darcy's Law for filtration is ..."

"The scanning electron microscope produces micrographs ..."

The "Introduction" of a laboratory report identifies the experiment to be undertaken, the objectives of the experiment, the importance of the experiment, and overall background for understanding the experiment. The objectives of the experiment are important to state because these objectives are usually analyzed in the conclusion to determine whether the experiment succeeded. The background often includes theoretical predictions for what the results should be.

4. Methods and Materials (or Equipment) can usually be a simple list, but make sure it is accurate and complete. In some cases, you can simply direct the reader to a lab manual or standard procedure: "Equipment was set up as in PEE 316 manual."

5. Experimental Procedure describes the process in chronological order. Using clear paragraph structure, explain all steps in the order they actually happened, not as they were supposed to happen. If your professor says you can simply state that you followed the procedure in the manual, be sure you still document occasions when you did not follow that

exactly (e.g. "At step 4 we performed four repetitions instead of three, and ignored the data from the second repetition"). Historically, laboratory procedures have been written as first-person narratives as opposed to second-person sets of instructions. Because your audience expects you to write the procedures as a narrative, you should do so.

Achieving a proper depth in laboratory procedures is challenging. In general, you should give the audience enough information that they could replicate your results. For that reason, you should include those details that affect the outcome. Consider as an example the procedure for using a manometer and strain indicator to find the static calibration of a pressure transducer. Because calibrations are considered standard, you can assume that your audience will have access to many details such as possible arrangements of the valves and tubes. What you would want to include, then, would be those details that might cause your results to differ from those of your audience. Such details would include the model number of the pressure transducer and the pressure range for which you calibrated the transducer. Should you have any anomalies, such as unusual ambient temperature, during your measurements, you would want to include those.

6. Results are usually dominated by calculations, tables and figures; however, you still need to state all significant results explicitly in verbal form, for example:

Using the calculated permeability parameter gives, then, $k = 4mD$.

Graphics need to be clear, easily read, and well labeled (e.g. Figure 1: Wettability concept and capillary pressure Value). An important strategy for making your results effective is to draw the reader's attention to them with a sentence or two, so the reader has a focus when reading the graph. In most cases, providing a sample calculation is sufficient in the report. Leave the remainder in an appendix. Likewise, your raw data can be placed in an appendix. Refer to appendices as necessary, pointing out trends and identifying special features.

7. Discussion is the most important part of your report, because here, you show that you understand the experiment beyond the simple level of completing it. Explain. Analyze. Interpret. Some people like to think of this as the "subjective" part of the report. By that, they mean this is what is not readily observable. This part of the lab focuses on a question of understanding "What is the significance or meaning of the results?" To answer this question, use both aspects of discussion:

Table 2.1: Comparison between Analysis and Interpretation

Analysis	Interpretation
What do the results indicate clearly? What have you found? Explain what you know with certainty based on your results and draw conclusions:	What is the significance of the results? What ambiguities exist? What questions might we raise? Find logical explanations for problems in the data:
Since none of the samples reacted to the Silver foil test, therefore sulfide, if present at all, does not exceed a concentration of	Although the water samples were received on 14 August 2000, testing could not be started until 10 September 2000. It is normally desirably to test

Analysis	Interpretation
approximately 0.025 g/l. It is therefore unlikely that the water main pipe break was the result of sulfide-induced corrosion.	as quickly as possible after sampling in order to avoid potential sample contamination. The effect of the delay is unknown.

More particularly, focus your discussion with strategies like these:

Compare expected results with those obtained.

If there were differences, how can you account for them? Saying "human error" implies you're incompetent. Be specific; for example, the instruments could not measure precisely, the sample was not pure or was contaminated, or calculated values did not take account of friction.

Analyze experimental error.

Was it avoidable? Was it a result of equipment? If an experiment was within the tolerances, you can still account for the difference from the ideal. If the flaws result from the experimental design explain how the design might be improved.

Explain your results in terms of theoretical issues.

Often undergraduate labs are intended to illustrate important physical laws, such as Darcy's filtration law, or the Müller-Lyer illusion. Usually you will have discussed these in the introduction. In this section move from the results to the theory. How well has the theory been illustrated?

Relate results to your experimental objective(s).

If you set out to identify an unknown metal by finding its lattice parameter and its atomic structure, you'd better know the metal and its attributes.

Compare your results to similar investigations.

In some cases, it is legitimate to compare outcomes with classmates, not to change your answer, but to look for any anomalies between the groups and discuss those.

Analyze the strengths and limitations of your experimental design.

This is particularly useful if you designed the thing you're testing

8. Conclusion can be very short in most undergraduate laboratories. Simply state what you know now for sure, as a result of the lab:

Example: The Debye-Sherrer method identified the sample material as nickel due to the measured crystal structure (fcc) and atomic radius (approximately 0.124nm).

Notice that, after the material is identified in the example above, the writer provides a justification. We know it is nickel because of its structure and size. This makes a sound and sufficient conclusion. Generally, this is enough; however, the conclusion might also be a

place to discuss weaknesses of experimental design, what future work needs to be done to extend your conclusions or what the implications of your conclusion are.

In longer laboratory reports, a "Conclusion" section often appears. Whereas the "Results and Discussion" section has discussed the results individually, the "Conclusion" section discusses the results in the context of the entire experiment. Usually, the objectives mentioned in the "Introduction" are examined to determine whether the experiment succeeded. If the objectives were not met, you should analyze why the results were not as predicted. Note that in shorter reports or in reports where "Discussion" is a separate section from "Results," you often do not have a "Conclusion" section.

9. References include your lab manual and any outside reading you have done. Organize references in a way appropriate to your field. More especially use the SPE Style Guide for referencing.

10. Appendices typically include such elements as raw data, calculations, graphs pictures or tables that have not been included in the report itself. Each kind of item should be contained in a separate appendix. Make sure you refer to each appendix at least once in your report. For example, the results section might begin by noting: "Program Results from the MATLAB code are contained in Appendix A." Another type of appendix that often appears in laboratory reports presents tangential information that does not directly concern the experiment's objectives. If the appendix is "formal," it should contain a beginning, middle, and ending. For example, if the appendix contains tables of test data, the appendix should not only contain the tabular data, but also formally introduce those tables, discuss why they have been included, and explain the unusual aspects that might confuse the reader. Because of time constraints, your instructor might allow you to include "informal" appendices with calculations and supplemental information. For such "informal" situations, having a clear beginning, middle, and ending is not necessary. However, you should still title the appendix, place a heading on each table, place a caption beneath each figure, and insert comments necessary for reader understanding.

IMPORTANCE OF A LABORATORY REPORT

Laboratory report is one way we use during or after an experiment in a laboratory to subtly record and discuss the experiment. During a laboratory work, we sometimes can observe only the physical part of the experiment, or may be some visible chemical changes. These changes indicate that the experiment we do is successful or not. However, in order to understand and achieve more from just simply doing the experiment, we write laboratory reports to more profoundly understand the internal meanings of the experiment we do, and the eventual purpose of the lab. Doing a laboratory report is also essential to making corrections for further experiments similar to previously done ones. Past experiences can help improve and better the new lab in many ways such as the procedure. We can make the procedure clearer and more precise. By doing so, we can do our best to limit the possibility of ingredients that may alternate final results popping up during a laboratory work. Without a precise data and purpose, a lab would not be a lab because it has no means of proving

anything that we don't know of. Too many alternating factors always cause a lab to be useless because we cannot focus on the specific thing we are looking at. Thus, a lab report is essential not just for the lab that the report is for, but essential for bettering future similar experiences.

Laboratory Notebooks

Because of the importance of the laboratory report, the methods and procedures used in recording the report have been long established. Among the most important of these procedures is the use of a laboratory notebook. All laboratory reports are recorded in a laboratory notebook. The notebook is the laboratory researcher's first line of defense. In an academic research situation, a research notebook is used to back up announced results. Based on the notebook, disputes over who made a key discovery first can be settled. Major award committees frequently request copies of the research notebook in order to verify the work performed and allow confirmation of discoveries contained within. Government agencies require laboratory notebooks be kept in order to verify compliance with regulations and safety precautions. In industry, the laboratory notebook is a key step in the patent process. Copies of the notebook are required to prove the validity of the discovery. As in the academic world, notebooks also play a vital role in guaranteeing governmental compliance.

For this reason the structure of the laboratory notebook is fairly well defined:

- All entries in the notebook must be made in ink.
 - When a change or correction is made to an earlier entry, the change is made in ink and then initialed and dated. This is done by drawing a line through the earlier entry in such a way that the original entry is still legible. Entries that are made in pencil, illegible, erased or whited out invalidate the notebook and can imperil the acceptance of any findings based on that notebook.
 - Every page of the notebook must be numbered sequentially, and no pages can be missing from the notebook.
 - At the very least, the last page of every experiment must be signed and dated by the researcher. Some academic and industrial labs require that every page be signed and dated.
- In addition to containing the experiments conducted, laboratory notebooks can also contain a table of contents, lists of any machinery used, and descriptions of any chemical or biological mixtures made. The machinery is described in sufficient detail to allow other researchers to on figure similar equipment in order to verify the experimental results. This includes make and model number, and any particular settings or modifications that have been made to the equipment. The description of the chemical or biological mixtures must state every step involved in making the mixture, and description of the ingredients should include manufacturer and lot number. By including these descriptions and recipes in one place, the experimenter can refer back to these pages, and note any changes made in the description of the experiment itself.

Appendix D – Survey Instrument

This appendix shows the questionnaire that would be used to improve the quality of this manual in future. This would be administered to every user of the laboratory and the response would be evaluated in a period of six months.

Question Block

Dear lab user,

Thank you for taking this survey. The results of this survey will be used to evaluate the effectiveness of improving the laboratory in the department of Chemical/Petroleum Engineering.

Please be honest and accurate in your response as they would be completely anonymous, we will receive confirmation that you completed the survey.

This survey would not take more than 5 minutes to complete.

To respond, tick on the option you wish by marking the answer button this way:

Thank You!

1. Have you ever used the laboratory in the department of Chemical/Petroleum Engineering before?

- Yes
- No

2. As a first time user of the laboratory, did the manual included here provide sufficient basic support to help you through the instructions?

- The manual included all the support I needed
- The manual included some support but I needed some extra help
- The manual did not include any support for me as a first time user of the lab

3. How long did it take you to finish the lab with the aid of the manual?

- Less than 30 minutes
- 30 minutes to an hour
- More than one hour

APPENDIX E – PHOTOGRAPHS OF EQUIPMENT IN THE LABORATORY

This appendix shows the pictures of all the equipment in the laboratory. The equipment and their accessories are also included.



Figure 6: Core samples drying oven



Figure 7: Vacuum pump and accessories



Figure 8: Desiccator and accessories, vacuum pump and accessories, vacuum gauge, Oil Mist Filter EMF 10 plus filter, EMF 10 Spare Mist Element, Ultra Grade 19 Oil, connection tubes and fittings

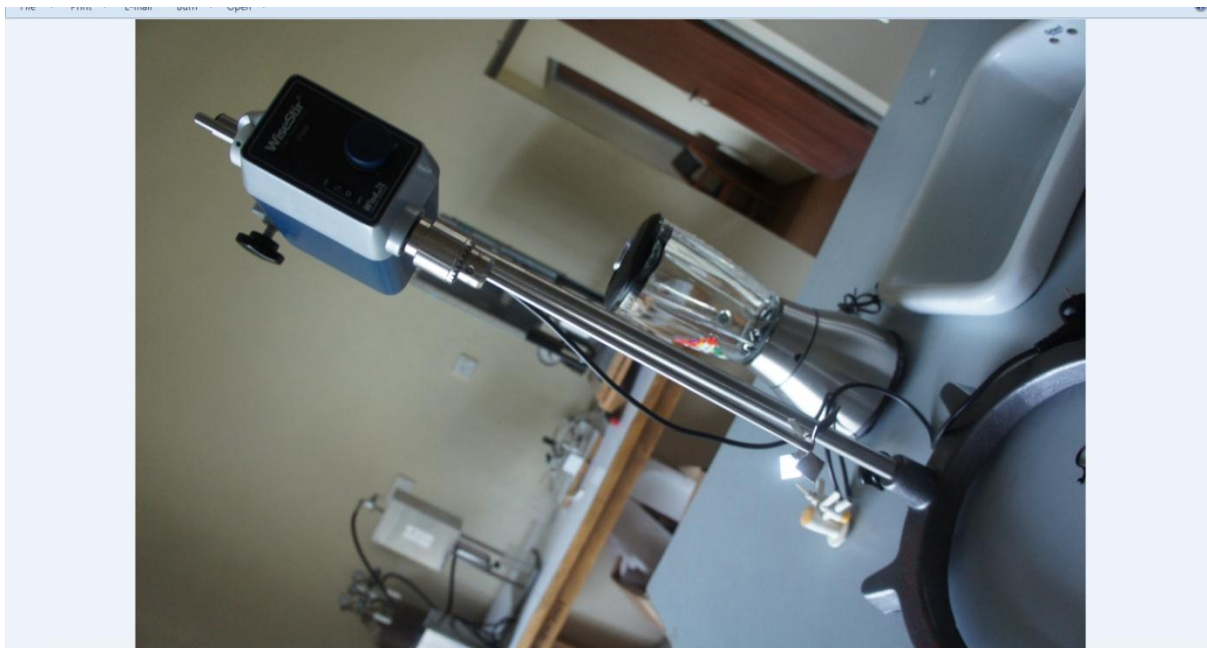


Figure 9: High speed and low speed mixers



Figure 10: Amott cells and accessories



Figure 11: Core cleaning apparatus and accessories.



Figure 12: Condensers and 2000 ml round bottom flasks



Figure 13: Soxhlet extractors



Figure 14: Displacement pump and accessories



Figure 15: Air permeameter



Figure 16: Viscometers and accessories



Figure 17: Electronic precision balance

Viscosity Computation

Viscosity can be computed in several ways:

- In terms of an overall instrument constant

$$\eta = Kf \frac{\theta}{N}$$

where K is the overall instrument constant
 $\left(\frac{\text{dyne sec}}{\text{cm}^2} \right) \left(\frac{\text{rpm}}{\text{degrees deflection}} \right)$

f is the torsion spring factor
 θ is the Fann Viscometer reading
 N is the rate of revolution of the outer cylinder
 η will be in centipoise

- In terms of three instrument constants for torsion spring, bob surface, and shear gap.

$$\eta = \frac{k_1 k_2}{k_3} (100) \frac{\theta}{N}$$

where k_1 is the torsion constant in dyne-cm/degree deflection
 k_2 is the shear stress constant for the effective bob surface, cm^3
 k_3 is the shear rate constant, sec^{-1} per rpm
 100 is a conversion factor
 1 poise = 100 cP
 η will be in centipoise

- In terms of shear stress divided by shear rate

$$\eta = \frac{\tau}{\dot{\gamma}}$$

where τ is the shear stress in dynes/cm²

$\tau = k_1 k_2 \theta$

$\dot{\gamma} = k_3 N$

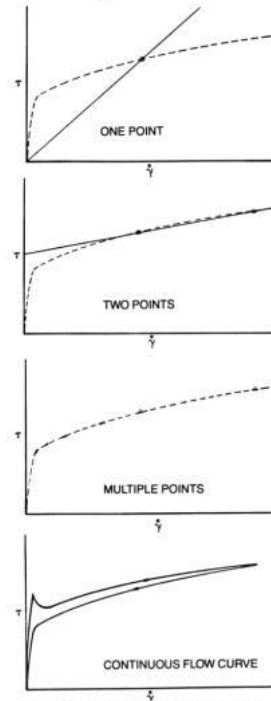
η will be in poise

1 poise = 100 cP

Torsion Springs

TORSION SPRING ASSEMBLY	TORSION SPRING CONSTANT k_1 (dyne-cm/deg. defl)	f	MAXIMUM SHEAR STRESS WITH B1 BOB (dynes/cm ²)	COLOR CODE
F0.2	77.2	0.2	307	Green
F0.5	193	0.5	766	Yellow
F1	386	1	1,533	Blue
F2	772	2	3,066	Red
F3	1,158	3	4,600	Purple
F4	1,544	4	6,132	White
F5	1,930	5	7,665	Black
F10	3,860	10	15,330	Orange

Viscosity Measurements



Viscosity measurements of a fluid (dotted rheogram) with different instruments: one-point; two-point; multiple points; continuous flow curve.

Conversion Factors

SI UNITS	SYMBOL	UNIT	ABBR.	CONVERSION
Shear Stress	τ	Pascal = 1 Newton/meter ²	Pa	1 Pa = 10 dynes/cm ²
Shear Rate	$\dot{\gamma}$	Reciprocal Second	s ⁻¹	1 s ⁻¹ (no change)
Viscosity	η	Pascal Second or Mill Pascal Second	Pa · s or mPa · s	1 Pa · s = 10 poise 1 mPa · s = 1 cP
OILFIELD UNITS (F1 Rotor, B1 Bob and F1 Torsion Springs)				
Shear Stress (exact)	τ	dynes/cm ²	—	1° Fann = 5.11 dynes/cm ²
Shear Stress (exact)	τ	lb/100 ft ²	—	1° Fann = 1.065 lb/100 ft ²
Shear Stress (approx.)	τ	lb/100 ft ²	—	1° Fann = 1 lb/100 ft ²
Shear Rate	$\dot{\gamma}$	Reciprocal Second	1/sec	1/sec = 1.7023 N
Viscosity	μ	centipoise	cP	$\mu = \frac{5.11 \theta}{1.70 N} (100) = 300 \frac{\theta}{N}$
Effective Viscosity	μ_e	centipoise	cP	$\mu_e = 300 \frac{\theta}{N}$
Plastic Viscosity	PV	centipoise	cP	PV = $\frac{\theta_{200} - \theta_{100}}{100}$
Yield Point	YP	lb/100 ft ²	—	YP = $\frac{\theta_{200}}{100} - PV$

Figure 21: Viscosity calculation chart

Appendix F –Lab exercises for Undergraduate Degree programme

This appendix looks at undergraduate student exercises in drilling, reservoir and production engineering. The aim of these exercises is for the students to apply the laboratory procedures stated in this work and to ensure they understand by evaluating them after the test. All the exercises are developed utilizing existing equipment in the Petroleum laboratory of the department of Chemical/Petroleum Engineering, University of Uyo.

(a) Drilling Engineering Courses – PEE 321

EXPERIMENT 1

TITLE: MEASUREMENT OF DENSITY USING ANALYTICAL BALANCE

APPARATUS/MATERIALS

- Triple beam balance
- Measuring cylinder
- Bentonite
- Water
-

PROCEDURE:

1. Add 20g of bentonite in 750cm³ of water
2. Stir the mixture
3. Pour the content into a measuring cylinder
4. Note the weight of the measuring cylinder
5. Weigh the measuring cylinder with content
6. Keeping the volume of water content at 750cc, repeat the experiment by adding 40g, 60g, 80g, 100g, 120g, and 140g of bentonite.
7. Tabulate your result.
8. Plot a graph of weight of bentonite versus density of mud. Explain your result.
9. From your graph determine the value of bentonite if the density of mud is 11ppg. Also compute the density of mud in 750cc of water if the weight of bentonite is 150g.
10. Report your result in pounds per barrel.

Report as follows:

Weight of Bentonite	Weight of mud	Volume of mud	Mud density

Note: Density = $\frac{\text{Mass}}{\text{Volume}}$

EXPERIMENT 2

TITLE: DETERMINATION OF GEL STRENGTH

APPARATUS

Fann VG Meter
Blender
Stop Clock

PROCEDURE

1. Stir sample thoroughly at 60rpm. 15 seconds will do
2. Slowly lift gear shift to first position. (Centre position) then shot motor off.
3. Wait for 10sec., then turn motor switch to low. (3rpm).
4. Read dial at maximum deflection units 1b.100sq. ft as the initial gel.
5. Max. deflection units (i.e. at gel breaks, to get the 10-mm gel).

EXPERIMENT 3

TITLE: FILTRATION

APPARATUS AND MATERIALS

Fan filter press assembly
25-cc Graduate
Stop Clock
Mud Sample
Air Compressor
Thermometer

PROCEDURE

1. Disconnect mud cell from filter press frame by pulling the cell toward operator with a slight twisted motion.
2. Remove bottom of filter cell as illustrated by the instructors. Fill to within ½ in of gasket ledge with fluid to be tested; being sure that cell lip is clean and large O-ring is in place before inserting filter paper. Replace button and tighten screw.
3. Place a 25-cc gradual under filter tube adjust regulator to 100psi and back of the dual needle valve.
4. After 130min, repeat the dual needle valve and bleed pressure gently, backing off the upper half of the valve.
5. Report the volume of filtrate in cc (to 0.1cc) as filter loss of 100psi at average temperature of the mud. During the test in degrees Fahrenheit. Report filters cake thickness in thirty seconds of an inch.
6. Class instrument immediately when you finish a run,. Place a fresh place of paper in place to prevent screen from sticking to gasket.

EXPERIMENT 4

TITLE: COLLOIDAL PROPERTIES OF CLAY

The purpose of this experiment is to determine the yield, gel and the wall building properties of commercial clays used in a fresh water mud.

Apparatus

Fann V-G Meter

Stop Clock

Filter Press Assembly

Salt Water Clay (Attapulgate)

Chemical Balance

Hamilton Beach Mixer

PROCEDURE

1. Obtain 4 quarts (2,838 ml) of water.
2. Add zeogel (attapugite) in the amount of 1lb./gallon of water. Stir for 10 minutes.
3. Determine viscosity, yield value, gel and wall building characteristics. Record the 100,200,300 and 600 rpm readings.
4. Repeat step 2&3 for 3 more additions of # of zeogel per gallon of water.
5. Repeat steps 1-4 for bentonite in amounts of 25 lb/gallon of water.

In your report include the following graphs and their interpretation

- (a) Rpm (or shear rate) vs (dial reading) (shear stress).
- (b) Yield vs pounds of zeogel per gallon the water. Use yield values from your graphs.
- (c) Repeat (a) and (b) for the bentonite mud.
- (d) Plastic viscosity (cp) vs pounds or commercial clay per gallon of water

EXPERIMENT 5

EFFECTS OF MUD-TREATING AGENTS ON A FRESH WATER DRILLING FLUID

In the experiment you will study the effect of water and chemical treatment on the physical characteristics of drilling fluids. The best stock is a natural and without contamination.

APPARATUS MATERIALS & MATERIALS

Hamilton breach mixer, Fann V-G meter, 500-ml measuring cup; glass; Magcogal, High yield Clay. Sodium acid pyrophosphate solution (10gm/10ml); caustic soda quebracho (10gm/100ml); miscellaneous Glass ware.

Procedure

1. Number jars # 1 through #5. Pour 1-bbl, equivalents of the base stock into the numbered jars
2. To sample # 1 do the following (a) Add 1cc of distilled water, stir on the mixer for 1 minutes and determine the apparent viscosity, plastic viscosity. Add another 1ml of distilled water to give a cumulative total of 2ml.
(b) Add another 1ml of distilled water give a cumulative total of 2ml.
(c) Stir for 1 minute and re-determine the same values as in step (a)
(d) Repeat steps (b) and (c) for cumulative additions of 5, 10, 20ml of distilled water.

- 3.(a) To sample #2 add on a cumulative basis: 0.1,0.2,0.4,1.0,1.5,2.0#/bbl, increments of sodium acid pyrophosphate solution = (one #/bbl = on eg/350ml). (b) Stir for 1 minute and record the apparent viscosity, plastic viscosity
4. To sample #4, repeat the procedure of step 3 using 10% magcophers as the dispersant.
5. To sample #4, repeat the procedure of step 3 using 5/10 caustic-quesbracho as dispersant.
6. Plot data on regular graph paper as follows:
 - (i) Cc pf water added versus apparent viscosity
 - (ii) #/bb of treating chemicals added versus apparent viscosity, plastic viscosity, and yield value.

EXPERIMENT 6

TITLE: CHEMICAL EFFECT ON YIELD VALUE

PROCEDURE

1. Using 1bbl equivalent of the suspension, add the calculated amount of Magcogar of increase the mud, weight to 10,0ppg. Stir for 3 minutes.
2. Immediately measure and record the 600 and 300rpm dial readings.
3. add 11b/bbl of cc-16 and stir for 3 minutes
4. Immediately measure and record the 600 and 300rpm dial readings.
5. Plot the two consistency curves from the data obtained to show the change in the intercept without appreciably altering slope of the curve.
6. Calculate the yield value and plastic viscosity before and after chemical treatment.

CALCIUM DETERMINATION- QUANTITATIVE

Water containing dissolved calcium and magnesium salt is referred to as "hard water". The common evidence of hardness in water is the difficulty of producing lather with soap. In some ill fields, water available for use is quite hard. The harder the water the more the bentonite required to make a satisfactory gel mud.

EQUIPMENT

1. Standard versenate solution (1mg CaCO₃)
2. Hardness butter solution
3. Hardness indicator solution
4. Titration vessel
5. 2-graduated pipettes. One 5ml and one 10ml
6. Graduated cylinder, 50ml
7. Distilled water

QUESTION

1. List the 3 factors acting in a clay suspension, which contribute to apparent viscosity.
2. Which of these factors contribute to plastic viscosity and which to yield point?
3. What is the different between the two types of colloidal solids used in drilling mud? Give an example of each.
4. Explain the acting of complex phosphates and tenantes on yield point, water loss, and wall cake.
5. If mixed in a chemical barrel, how much water is required to mix 100 # of each used in the experiment.
6. In what pH range do the minimum viscosities of drilling mud normally occur?

EXPERIMENT 7

TITLE: TREATMENT OF CONTAMINATED DRILLING FLUIDS

A SALT CONTAMINATION OF PREHYDRATED AND POST HYDRATED MATERIALS

PROCEDURE

1. Determine viscosity, plastic flow properties, initial gel, 10-minute gel, pH, fluid loss, supplies.
2. Pour 6 barrels equivalents of the bentonite suspension into glass jars. Accurately add to each the correct amount of.
3. Plot a contamination curve showing viscosity, yield point and fluid loss vs PPM NaCl for both the prehydrated and post hydrated samples

B. CALCIUM CONTAMINATION-CEMENT

It is usually know beforehand when cement is to be drilled mud unless the mud has been pretreated or is the calcium-treated kind the contaminated mud returns will have high funnel viscosity gel strengths water loss and cake thickness cement acts as a flocculating agent for clays increases gel strength and damages filtration properties. The extent of contamination depends upon the amount and condition of cement. If the cement is treated out with chemicals, best results are obtained by retreating for the contamination.

PROCEDURE

1. Obtain 8 barrels equivalents of the Bentonite suspension of 10-15cp in glass jars.
2. Pretest four of the samples as follows:
 - a. To No. 1 add 1#/bbl quebracho
 - b. To No. 2 add 1#/bbl S.A.A.P
 - c. To No.3 add 1#/bbl sodium bicarbonate.
 - d. To Bo.4 add ½ #/bbl quebracho and 1 #/bbl soda ash.
3. Add 1 #/bbl cement to each of the 8 samples.
4. Stir each sample for 3 minute, measures and compare with the properties of step No. 1 of salt contamination procedure.
5. Treat the samples that contain only cement with the same chemicals are were used for pre-treating. Attempt to restore the apparent viscosity, yield point and gel strengths to the uncontaminated or blank values.
6. If you find the viscosity unsatisfactory in the pre-treated samples, add small amount of additional-ad
S.A.A.P. to sample No. 1, quebracho to sample No.2 and 3, and mixture of quebracho and soda ash to sample Np.4.

Question

1. Give the principal characteristics of each type of contamination.
2. If 8cc of 0.10N silver Nitrate is required to titrate 2cc of filtrate, what is the ppm NaCl content? What percent salt is this?
3. What two icons are measured in total hardness?
4. How could you tell if salt was being picked up from strings or from salt water flow?
5. Why does continue treatment with soda ash for anhydrite or gypsum sometimes cease to be effective? Why so when treating for cement would you stop a salt-water flow? What is the danger involved here?

EXPERIMENT 8

TITLE: HYDRAULIC CHARACTERISTICS AND CONTROL OF DRILLING FLUID PROPERTIES

APPARATUS AND MATERIALS

Fann VG Meter, Hamilton Beach Mixer, Interval Timer, Bentonite, Barite, Lime, Magcogel, Quebracho. Miscellaneous Glassware.

SAMPLE PREPARATION

Prepare 5 barrels equivalents of 9% bentonite suspension and age 24 hours, stir well and measure the apparent viscosity, plastic viscosity, yield value and mud weigh. All chemicals are added dry.

(b) Reservoir Engineering Courses

Experiments in PEE 315

CORE ANALYSIS

This is a way of measuring well conditions down hole by studying samples of reservoir rocks. Core analysis gives the most accurate insight into the porosity and permeability among other characteristics of the work.

A core is a sample of rock in the shape of a cylinder taken from the side of a drilled oil or gas well. Core analysis is used to define not only porosity and permeability of the reservoir rock but also to unearth the fluid saturation and grain density.

Experiment

Determination of fluid saturation

Cores or underground rock samples when brought to the surface are universally found to have entrained in their pores varying amounts of liquid. An important phase of core analysis is the determination of the nature and amount of this liquid content.

APPARATUS

Retort kit assembly
Measuring cylinder
Crusher
Weighing balance

Procedure

1. Take 100 to 200g of rock sample and break into small pieces.
2. Pour the sample into the retort cup.
3. Pack a wad of No. steel wool into the chamber to approximately 3/16in (4.76mm) above the treads. Use only enough steel wool to prevent a boiling over of solids into liquid receiver.
4. Lubricate the threads on the sample cup with a light coat of Never-seez.
5. Carefully hand tightens the retort cup onto the chamber and connects the assembly to the condenser. Carefully insert the retort chamber tube into the ultra-tour connection and hand tightens. Place the chamber into the heating jacket and close the insulating lid.
6. Place a clean dry liquid receiver under the condenser discharge tube.

7. Insert the thermometer into the unit. Observe the liquid exiting the condenser. Continue heating for 10 minutes beyond the time that no more condensate is being collected. Allow the test to run for a minimum of 45 minutes.
8. Remove the liquid receiver and allow it to cool. Read and record the volumes of the total liquid received oil volume and water volume at ambient temperature.
9. Heat the connect to between 350 to 400°f (177 to 204°C) for about 40 minutes to 1 hour.
10. Allow to cool.

EXPERIMENT 9

MEASUREMENT OF POROSITY

$$\text{POROSITY} = \frac{\text{pore volume}}{\text{bulk volume}}$$

APPARATUS

Porosity cup
 Burette
 Measuring cylinder
 Funnel
 Rubber hose

MATERIALS

Paraffin
 Formation samples – Sandstone, Laterite, Clay etc.

PROCEDURE

1. Set up the apparatus
2. Take the dimension of the cup
3. Pour dry sandstone into the cup
4. Connect the burette to the cup using the rubber hose
5. Pour the paraffin oil into the burette to full capacity. Note the volume.
6. Repeat the procedure until the cup is saturated with the paraffin ensuring that no excess paraffin escapes.
7. Record pore volume as sum total of burette readings.
8. Calculate bulk volume using the parameters of the cup
9. Calculate porosity as the percentage of the pore volume to the bulk volume
10. Repeat the experiment using other soil sample
11. Compare your results
12. How does this agree with the origin porosity of the material
13. List the various equipment used in determining the porosity of a soil sample and state the techniques used.

EXPERIMENT 10

TITLE: Permeability test

APPARATUS

Permeability equipment

Measuring tape

AIM: To determine permeability of sandstone.

PROCEDURE

1. Measure length and diameter of pipe.
2. Connect the permeability apparatus to tap water.
3. Close the two valves.
4. Open the inlet valve to allow water flow into the system which the outlet valve remains closed.
5. After about 1 minute gently open the outlet valve
6. Collect water at the outlet for 15 sec.
7. Note the volume of water.
8. Read pressure p_1 and p_2 from the inlet and outlet gauges respectively.
9. Repeat the experiment 4 more times.
10. Tabulate your results as follows:

TIME/SEC	VOLUME OF WATER	P1	P2	P	FLOW RATE (Q)

11. Calculate permeability of sandstone using the formula

$$K = \frac{q\mu p}{A\Delta P}$$

Where q = volumetric flow rate, cm^3

μ = viscosity, cm^3

l = length of medium, cm

A = cross sectional area of medium, cm^2

P = $p_2 - p_1$ (1 atm = 14.7 psi)

K = permeability, Darcie's

Compare your result with original permeability of sandstone relative to water.

EXPERIMENT 11

TITLE: PRESSURE BUILD-UP EXPERIMENT

APPARATUS

Permeability equipment

Stop Clock

PROCEDURE

1. Set up the apparatus as in experiment
2. Close the upstream valve V_2 .
3. With valve 2 closed open the downstream valve V_1 .
4. Open tap and allow water to flow into the system.
5. Read the initial pressures at the 2 gauges.
6. Read pressure at the two gauges at intervals of 5 seconds until a stable pressure is obtained.
7. Tabulate your results as follows:

Time/s	P_1 /psi	P_2 /psi
5		
10		
15		
20		
25		

8. Plot a graph of
 - (i) P_2 versus time
 - (ii) ΔP versus time ($P=P_2-P_{si}$)
 - (iii) ΔP versus time ($P=P_1-P_{1i}$)
 - (iv) ΔP versus time ($P=P_2-P_1$)
8. What can you deduce from your graphs?

EXPERIMENT 12

TITLE: RESISTIVITY-FILTRATE AND MUD

APPARATUS AND MATERIALS

Resistivity Meter

Filtrate

PROCEDURE

1. Fill cell with fluid, being careful to remove all air bubbles (fill and exhaust fluid two or three times to thoroughly wet the surface).
2. Connect cell to the Resistivity meter.
3. Press the black button and adjust for full scale reading on the meter.
4. While keeping the black button depressed, press the red button.
5. The reading on the meter is the resistivity of the fluid (when testing mud, it may be necessary to allow 3 to 5 minutes after putting mud in the cell before taking a reading to allow the cell mud to reach temperature equilibrium).
6. Record the resistivity reading and the temperature of the cell.
7. Remove the cell and clean with distilled water. (Pipe cleaner can with water)

8. Compare the resistivity with that of a standard mu sample

EXPERIMENT 13

TITLE: DETERMINATION OF SAND CONTENT

Sand is not desirable in drilling operations. It is abrasive to pumps, hose and water courses in the bits. There is also the danger of sand settling in the hole and sticking the drill stem when the pumps are shut down. It weights the mud unduly and is particularly objectionable where then is a tendency to lose circulation in near-surface information. Control of sand content to a maximum of about 1^{1/2} by volume is generally considered acceptable.

APPARATUS AND MATERIALS

Sand Screen set
Mud Sample
Water

PROCEDURE

- Fill the glass tube with given mud sample to mark labeled “Mud to Here”. Add water to the next mark labeled, “Water to Here”
- Cover the mouth of the tube with the thumb and shake vigorously
- Pour the mixture onto the screen; add more water to the tube. Shake, and again pour onto the screen. Repeat until the wash water is clean. Wash the sand retained on the screen to free 1 to any remaining mud. If necessary tap the side of the filter to facilitate the pouring of the mud and water mixture through the screen.

CAUTION: Do not mash or force the material retained on the screen.

Think of two reasons why this precaution is necessary.

1. Fit the funnel down over the top of the screen, invert slowly, turning tip of funnel mouth of tube and wash sand back into the tube with a fine spray of clear water on the back side of the screen. Allow the sand to settle.
2. Record the quantity of sand settled in settled in the graduate tube as the sand content of the mud it percent by volume.

QUESTION:

Give at least two common methods used to reduce sand content of drilling mud.

EXPERIMENT 14

TITLE: DETERMINATION OF REYNOLDS NUMBER (RE) AND THE PRESSURE DROP (ΔP) IN A CIRCULAR PIPE.

MATERIALS/ APPARATUS

Hydro-pressure pipeline system (HPPS), water, measuring cylinder, stop watch

PROCEDURE

1. Close valve V_3 and Open values V_1 and V_2 .
2. Fill the reservoir with water to the full capacity.
3. Put a 2000ml measuring cylinder under the outlet nozzle of the pipeline system.
4. Open V_3 and start the stop watch simultaneously to all some water flow into the cylinder for 20 seconds.

5. Read and record the volume of water in the cylinder.
6. Repeat the experiment four times, ensuring that the reservoir is full to its capacity in each experiment.
7. Tabulate your results as shown below:

Density of water, ρ = 998 kg/m³
 Length of the pipe, L = 10m
 Internal diameter D = 0.05m

S/N	VOLUME V(CM ³)	TIME (SEC.)
1	50	20
2	53	20
3	52	20
4	57	20

Find the average volume

Calculate the following:

- (i) Kinematic Viscosity ν
- (ii) Volumetric flow rate
- (iii) Mass flow rate,
- (iv) Flow Velocity
- (v) Records numbers, $Re = \frac{\rho DV}{\mu}$
- (vi) Is the flow Laminar or turbulent?
- (vii) If Laminar calculate the friction factor of the pipe $f = \frac{64}{Re}$
- (viii) If turbulent, calculate the pipe friction coefficient from
- (ix) Calculate the pressure loss $P = 2f L \rho u^2$
- (x) Shear stress at the well.
 $T_w = \frac{\Delta P D}{4L}$

(c) Production Engineering Courses

EXPERIMENT 15

TITLE: TO DETERMINE THE PERCENTAGE OF BASIC SEDIMENTS AND WATER IN A GIVEN OIL SAMPLE.

APPARATUS: Centrifuge Machine Centrifuge tubes, Crude Samples Solvent if necessary e.g. Toluene or any other e.g. Demulsified.

PROCEDURE: Couple the apparatus properly and set it up making sure that is well positioned on the work bench. Slain your tubes, wash and dry with clean soap water.

Rinse with the sample and then fill tube with the appropriate quantity of sample, say 10ml, 15ml, 20ml, 25ml and 30ml, depending on the capacity of the working centrifuge tube.

If sample is too viscous, dilute with half volume of solvent. If sample is an emulsion, add an appropriate volume of a demulsified and in each case shake very well for solvent or demulsified to act properly.

Place tube and sample in the centrifuge tube holder; make sure it is properly fitted to avoid accident while spinning.

Turn on the mains if you are using the electric machine or the crank for a manual machine and while say for 1-20 minutes at 100rpm for an electric machine. Turn of mains.

Bring out the tube read off the various levels of fractions and water the separate out as oil and sediments from the graduated body of the tube.

Record your results and then calculate the percentage of each fraction to the original volume and submitted your write up.

Note: Yore observations tabulate your result, calculate percentage BS and W. write down the significance of the test.

EXPERIMENT 16

TITLE: LIGHT WEIGHT EMULSION DRILLING FLUIDS

The purpose of this experiment is to study the characteristic of a light weight, low viscosity oil emulsion frilling fluid.

APPARATUS AND MATERIALS

- ❖ Testing Apparatus
- ❖ Emulsifier
- ❖ Crude oil
- ❖ Discos
- ❖ Bentonite Fresh water Mud

PROCEDURE

1. Mix 1.85 16/bbl of viscose to one gallon of water. Stir until completely dissolved. Add 350 cc of prepared bentonite mud, stir 10 minutes then determine the physical characteristic.
2. Ass 15cc of emulsifier (spersene) to 200cc of diesel oil, mix thoroughly
3. Mix 1&2 above, stir vigorously for 10 minutes then determine the physical characteristic.

Appendix G – Lab exercises for Postgraduate Diploma programme

This section shows the exercises designed for lab work in drilling, reservoir, and production engineering in the Postgraduate diploma programme. In the UNIUYO curriculum, the basic undergraduate lab work is essentially the same for the postgraduate diploma students, hence the lab exercises developed for the undergraduate programme is to be used here.

(a) Drilling Engineering courses: See Appendix F

(b) Reservoir engineering courses: See Appendix F

(c) Production engineering courses: See Appendix F

Appendix H – Lab exercises for Master’s Degree programme

This appendix looks at Master’s Degree student exercises in drilling, reservoir and production engineering. The aim of these exercises is for the students to apply the laboratory procedures stated in this work and to ensure they understand by evaluating them after the test. The laboratory exercises are described individually in the following sections. The

laboratory exercises are designed strictly on the availability of the equipment in the laboratory of the department.

(a) Drilling Engineering courses

The exercises used in this section are culled from the King Fahd University of Petroleum & Minerals, Department Of Petroleum Engineering drilling laboratory manual.

The exercises consists of seven experiments for 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 treatment techniques for, common contaminants on drilling fluid characteristics. Additionally, there are experiments for studying physical properties of Portland cement such as free water separation, normal and minimum water content and thickening time.

It is hoped that the material in this manual will effectively supplement the theory aspect presented in the main course.

EXPERIMENT NO. 1

MUD WEIGHT, MARSH FUNNEL VISCOSITY AND pH

(A) MUD WEIGHT OR DENSITY TEST:

Theory

The density of the drilling fluid must be controlled to provide adequate hydrostatic head to prevent influx of formation fluids, but not so high as to cause loss of circulation or adversely affect the drilling rate and damaging the formation.

Normal pressure gradient by water is equal to (0.433 psi/ft) and equal to 433 psi/1000 ft.

Test Equipment

The Baroid Mud Balance as shown below is used to determine density of the drilling fluid. The instrument consists of a constant volume cup with a lever arm and rider calibrated to read directly the density of the fluid in ppg (water 8.33), pcf (water 62.4), specific gravity (water = 1.0) and pressure gradient in psi/1000 ft. (water 433 psi/1000 ft.)

Calibration

1. Remove the lid from the cup, and completely fill the cup with water.
2. Replace the lid and wipe dry.
3. Replace the balance arm on the base with knife-edge resting on the fulcrum.
4. The level vial should be centered when the rider is set on 8.33. If not, add to or remove shot from the well in the end of the beam.

Test Procedure

1. Remove the lid from the cup, and completely fill the cup with the mud to be tested.
2. Replace the lid and rotate until firmly seated, making sure some mud is expelled through the hole in the cup.
3. Wash or wipe the mud from the outside of the cup.
4. Place the balance arm on the base, with the knife-edge resting on the fulcrum.
5. Move the rider until the graduated arm is level, as indicated by the level vial on the beam.
6. At the left-hand edge of the rider, read the density on either side of the lever in all desired units without disturbing the rider.
7. Note down mud temperature corresponding to density.

(B) MUD VISCOSITY:

Theory

The viscosity of a fluid is defined as its resistance to flow. The desired viscosity for a particular drilling operation is influenced by several factors, including mud density, hole size, pumping rate, drilling rate, pressure system and requirements, and hold problems. The indicated viscosity as obtained by any instrument is valid only for that rate of shear and will differ to some degree when measured at a different rate of shear.

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 Stormer viscometer is still, however, used to some extent for single point (apparent) viscosity and 0-10 min. gel.

Test Equipment

The Marsh Funnel is a device that is common to every drilling rig.

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 $70\text{ F} + 0.5\text{oF} = 26 + 0.5\text{ sec}$. The Marsh Funnel measures the apparent viscosity.

Calibration

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

Test Procedure

1. 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).
2. 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.
3. Report the result to the nearest second as Marsh Funnel Viscosity at the temperature of the measurement in degrees Fahrenheit or Centigrade.

(C) HYDROGEN ION CONCENTRATION (pH):

Theory

The acidity and the alkalinity of the drilling fluid can be measured by the concentration of the (H⁺) ion in the fluid. As for instance, if H⁺ is large (1×10^{-1}), then the (OH⁻) hydroxyl concentration is very low (1×10^{-13}), the solution is strongly acidic. If the (OH⁻) concentration is (1×10^{-1}) very high then (H⁺) concentration is very low then the solution is strongly alkaline. The pH of a solution is the logarithm of the reciprocal of the (H⁺) concentration in grams moles per liter.

Therefore, if the pH of a mixture drops from 7.0 to 6.0, the number of (H⁺) increase ten times. 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.

Methods of measuring pH in the laboratory:

1. The pH Paper: 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.
2. 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.

EXPERIMENT

The Laboratory Test:

1. Take 2 samples of mud from each of the mud tanks.
2. Stir the samples for 2 minutes and determine:
 - (a) The Mud Weight
 - (b) Marsh Funnel Viscosity in seconds
 - (c) pH value using - pH meter - Hydrion papers 7

RESULTS OF MUD PROPERTIES TEST WATER BASED MUD

QUESTIONS ON EXPERIMENT NO. 1

Answer the following:

1. List any five (5) very important functions of the drilling fluid?
2. What requirements should a drilling fluid meet?
3. Using the mud weights (ppg) obtained for Samples #1 and 2 of your experiment, calculate, how much hydrostatic pressure that each sample will exert on a formation at a depth of 10,000 ft.
4. What is the difference between Over-balance and Under-balance?
5. Estimate the mud weight needed to balance a formation pressure equivalent to 10,000 ft. depth with 0.561 psi/ft. pressure gradient. 9

EXPERIMENT NO. 2

MUD RHEOLOGY TEST

Viscosity, Gel Strength and Yield Point

Introduction

Rheology refers to the deformation and flow behavior of all forms of matter. Certain rheologic 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:

Theory

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:

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

Test Equipment

The Baroid (Model 286) Rheometer is a coaxial cylindrical rotational viscometer, used to determine single or multi-point viscosities. It has fixed speeds of 3 (GEL), 100, 200, 300 and 600 RPM that are switch selectable with the RPM knob.

Additionally, the same switch set to the VAR position enables speed selection of between 3 and 625 RPM, by manual adjustment of the variable knob.

VISCOSITY MEASUREMENT PROCEDURE

1. Place a recently agitated sample in the cup, tilt back the upper housing of the rheometer, locate the cup under the sleeve (the pins on the bottom of the cup fit into the holes in the base plate), and lower the upper housing to its normal position.
2. Turn the knurled knob between the rear support posts to raise or lower the rotor sleeve until it is immersed in the sample to the scribed line.
3. Stir the sample for about 5 seconds at 600 RPM, then select the RPM desired for the best.
4. Wait for the dial reading to stabilize (the time depends on the sample's characteristics).
5. Record the dial reading and RPM.

RHEOLOGICAL CALCULATIONS

1. Plastic viscosity (in centipoise-up):

$$\text{Plastic Viscosity} = \mu_p = 600 \text{ RPM reading} - 300 \text{ RPM Reading}$$

2. Apparent Viscosity (in centipoise-cp): $\text{Apparent Viscosity} = \mu_a = 600 \text{ RPM Reading}$

3. Yield Point (in lb/100 ft²):

$$\text{Yield Point} = Y. P. = 300 \text{ RPM Reading} - \text{Plastic Viscosity}$$

(B) GEL STRENGTH:

Theory

The Baroid Rheometer 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, Therefore, the viscosity of plastic fluid will depend on the rate of shear at which the measurements were taken.

Gel Strength Measurement Procedures

1. Stir a sample at 600 RPM for about 15 seconds.
2. Turn the RPM knob to the STOP position.
3. Wait the desired rest time (normally 10 seconds or 10 minutes).
4. Switch the RPM knob to the GEL position.
5. Record the maximum deflection of the dial before the Gel breaks, as the Gel strength in lb/100 ft². (lb/100 ft² x 5.077 = Gel strength in dynes/cm²).

(C) YIELD POINT:

Theory

This is the measure of the electro-chemical or attractive forces in the mud under flow (dynamic) conditions. These forces depend on (1) surface properties of the mud solids, (2) volume concentrations of the solids and (3) electrical environment of the solids. The yield point of the mud reflects its ability to carry drilled cuttings out of the hole.

Measurement:

$$YP = 300 \text{ RPM} - \text{Plastic Viscosity}$$

Experimental Procedure

1. Obtain a recently agitated mud sample from each of mud tanks (1) and (2).
2. Using the Baroid Rheometer, obtain dial readings at 3, 300 and 600 RPM.
3. By means of the rheological calculations procedure, determine the Apparent and Plastic Viscosities, Yield Point and initial 10 sec. and final 10-minute Gel Strength parameters.
4. Tabulate your results as in the given table below:

MUD RHEOLOGY TEST WATER BASE MUD

QUESTIONS ON EXPERIMENT NO. 2

1. (a) What is Plastic Viscosity?
(b) What does it characterize?
(c) What is the difference between the Plastic Viscosity and Apparent Viscosity of a drilling fluid?
2. Which role does Gel Strength play in the drilling process?
3. What type of fluids does drilling fluid belong to?

4. (a) What is the Yield Point?
(b) What does it characterize?
(c) What is the difference between Gel Strength and Yield Point of a drilling mud?
5. Explain what you know about one point and two points curve fluids?

Give one example of each type of fluid.

EXPERIMENT NO. 3

FILTRATION, WALL BUILDING, AND RESISTIVITY

(A) FILTRATION:

Theory

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. $V \propto t$

The two commonly determined filtration rates are the low-pressure, low temperature and the high-pressure high-temperature.

Test Equipment

The low pressure test is made using standard cell under the API condition of 100 + 5 psi for 30 minutes at room temperature. Another special cell, will be used to measure filtration rate at elevated temperatures and pressure. Filter press used for filtration tests consists of four independent filter cells mounted on a common frame.

Each cell has its own valve such that any or all the cells could be operational at the same time. Toggle valve on the top of each cell could be operated independently for the supply of air for each individual cell. Special high pressure and high temperature filtration tests are run in the laboratory simulating formation temperature and formation back- pressure.

TEST PROCEDURE FOR FILTRATION RATE AT 100 PSI & ROOM

TEMPERATURE

1. Detach the mud cell from filter press frame.
2. Remove bottom of filter cell, place right size filter paper in the bottom of the cell.
3. Introduce mud to be tested into cup assembly, putting filter paper and screen on top of mud tighten screw clamp.

4. With the air pressure valve closed, clamp the mud cup assembly to the frame while holding the filtrate outlet end finger tight.
5. Place a graduated cylinder underneath to collect filtrate.
6. Open air pressure valve and start timing at the same time.
7. Report cc of filtrate collected for specified intervals up to 30 minutes.
8. Tabulate the results in an appropriate table.

(B) WALL BUILD:

MEASUREMENT PROCEDURE FOR MUD CAKE THICKNESS

It 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.

Results on mud cake thickness should be reported in whole number.

Example: 0.75/32" should be reported as 1/32. i.e. closest to the whole number. Likewise 1.75/32" should be reported as 2/32" 18

(C) MUD RESISTIVITY:

Theory

The resistivity (W_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.

Test Equipment

Equipment used is the Baroid Resistivity Meter (Fig. 3.3).

(i) MEASUREMENT PROCEDURE FOR MUD CAKE RESISTIVITY

1. Remove excess water from filter cake.
2. Fill the slot on top of the cell with mud cake.
3. Press black button and adjust for full scale.
4. While keeping the black button depressed, press red button.
5. Reading on the meter is the resistivity of mud cake.

6. Record the resistivity of the mud cake and the temperature of the cell.
7. Remove the cell and clean thoroughly with distilled water.

(ii) MEASUREMENT PROCEDURE FOR MUD FILTRATE RESISTIVITY

1. Fill cell with mud and remove excess mud from the top of the cell surfaces).
2. Connect cell to the resistivity meter.
3. Press black button and adjust for full scale reading on the meter.
4. While keeping the black button depressed, press the red button.
5. The reading on the meter is the resistivity of the mud (when testing mud it may be necessary to allow 3-5 minutes after putting mud in the cell before taking a reading to allow cell and the mud filtrate to reach temperature equilibrium).
6. Record the resistivity reading and the temperature of the cell.
7. Remove the cell and clean with distilled water. (Pipe cleaner can be used to remove particles of mud filtrate that cannot be flushed out with water). 20

QUESTIONS ON EXPERIMENT NO. 3

1. By comparing the Spurt Loss of Sample # 1 and Sample #2 in part A of your experimental results, determine which of the two samples plugs the filter paper faster and explain why.
2. Describe how the filter cake is formed on the walls of a hole during a normal drilling operation.
3. What are the factors controlling the rate of filtration?
4. What is sloughing of shale and how can it be controlled?

EXPERIMENT NO. 4

CONTROL OF MUD WEIGHT

(A) EFFECT OF ADDING BENTONITE ON MUD PROPERTIES FOR FRESH AND SALT WATER BASE MUD:

Procedure

1. Add to every 400 c.c batch of fresh water base mud 2, 4, 6 and 8 grams of bentonite and stir for 10 minutes.

2. Measure the density lb/gal, viscosity c.c. (apparent and plastic) and yield point lb/100 ft, using the Rheometer for every batch.
3. Add 20.6 ml of 10% by weight salt water to every batch. Stir for 5 minutes and repeat step (2).
4. Report all the results (density, viscosities, yield) for every batch in a convenient table. Plot them versus the amount of bentonite in gram in two plots, one for fresh water and the other for salt water.

Discussion:

Include the following points in your discussions:

1. Discuss the effect of adding bentonite on density.
2. Discuss the effect of adding bentonite on the rheological properties.
3. Correlate and justify the results obtained for fresh and salt water.
4. What is the effect on yield point?

(B) EFFECT OF ADDING WEIGHT MATERIAL (BARITE):

Theory

Barite was first used, in California, in a well being re-drilled with cable tools in 1923. According to that case, density of the mud was raised to 90 lb/ft³ (1.44 gr/cm³ to control gas in flow and to stop caving. One function of barite has developed - the preparation of a temporary high density plug formed from slurry of a barite in water (2.65 SG). Such slurry contains the maximum concentration of barite that is used - about 750 lb/bbl (2100 kg/cm³). The minimum concentration of barite might be as low as 10 lb/bbl (28 kg/m³), although usually it would be substantially higher. The quantity of barite required to raise the density of a given volume of mud a specific amount can be readily calculated from the relation, in consistent units:

Test Procedure

1. Calculate and list the amount of barite required to increase the density of each batch from 8.6 ppg to 9, 10, 11 and 12 ppg.
2. Obtain 400 cc of original base mud (density 8.6)
3. Add the calculated amount of barite to each batch, stir for about 2 minutes and measure the Apparent and Plastic Viscosities and Yield Point.
4. Repeat step 3 for Salt water-base mud.
5. Tabulate the results and plot the density (ppg), viscosity (apparent and plastic) and yield point versus the amount of barite added

(C) WATER-BACK (ADDING WATER TO A CHEMICALLY TREATED MUD):

1. Obtain a 350 c.c. of water base mud of 13.5 ppg weight and 9.5 pH.
2. Add water incrementally and measure the Mud weight every time to reach 10.5 ppg and same (9.5) pH.
3. Measure the viscosity and gel-strength and check if any change occurred.
4. List your results in an appropriate table. 24

QUESTIONS ON EXPERIMENT NO. 4

1. List the advantages obtained by adding weighting material to mud.
2. List three (3) names of weighting material.
3. What are the disadvantages of adding solids to the water based mud?
4. Give reasons for adding water to your mud. 25

EXPERIMENT NO. 5

DRILLING FLUID CONTAMINATION TEST

Introduction

In preparing a bentonite slurry using fresh water, the bentonite will hydrate and agitation furnished by a mixer is sufficient to separate the hydrated clay platelets and result in a viscosity and gel strength increase, if the bentonite is placed in salty water or water containing dissolved hardness (calcium or magnesium) the hydration and subsequent dispersion by agitation is reduced. The question arises, what occurs when salt or hardness is added to a dispersed bentonite drilling fluid and what is necessary to return the slurry to an acceptable condition for drilling?

In this test we will study the effect of contamination of monovalent chemicals (NaCl and KCl) and divalent chemicals that cause contamination are calcium sulfate (CaSO₄), cement (Ca (OH)₂), and Gypsum (CaSO₄ - 2H₂O). These soluble salts are commonly encountered during drilling, completion or workover operations.

TEST PROCEDURE FOR MUD CONTAMINATION

1. Test base mud for weight ppg, plastic viscosity cp, apparent viscosity c.p. yield point lb/100 ft².
2. Add to 400 ml base mud, 0.75, 1.5, 2.5, 3.5 and 5.0 grams NaCl and repeat step (1) after each addition (stir every time).
3. Add to a new 400 ml base mud 0.75, 1.5, 2.5, 3.5 and 5.0 grams Gypsum (CaSO₄ - 2H₂O) and repeat step (1) after each addition (stir every time).
4. Add to a new 400 ml base mud 0.75, 1.5, 2.5, 3.5 and 5.0 grams anhydrite (CaSO₄) and repeat step (1) after each addition (stir every time).
5. Report the results in a convenient table for the three contaminants and plot in three different plots the effect of contamination with salt, gypsum and anhydrite on mud density and viscosities and yield point.

TREATMENT OF THE CONTAMINATED DRILLING FLUID

(A) SALT CONTAMINATION:

Test Procedure

1. Test 525 ml of the base mud sample for weight ppg, viscosity cp, yield point lb/100 ft² and pH.
2. Add 27 ml of 10% by wt. salt water (NaCl) to the base mud sample (525 ml) stir 2 minutes after adding salt. Age for about 15 minutes and stir again for 2 minutes. Determine its viscosity, density and pH.
3. Add to the contaminated sample 1/2 cc increments until the original viscosity is restored.
4. Continue to add (SAPP) in 1/2 cc increments until the original viscosity is restored.
5. Plot the result on a curve showing the viscosity and pH as a function of (SAPP) concentration.

(B) GYPSUM CONTAMINATION:

Test Procedure

1. Repeat step No. 1 in (A).
2. Contaminate the base mud by (525 ml) with 6 gr of Gypsum, stir for 3 minutes. Age the sample for 15 minutes and stir again for 2 - 3 minutes.

Determine the viscosity cp and density ppg and pH.

3. Add 3 gr soda ash (Na₂CO₃) to remove the hardness from sample in step # 2. Stir for 10 minutes and test. 27

4. Add 4 gr Carbonox and 1 gr of Caustic Soda to sample in step # 3. Stir 10 minutes and test.
5. Add 4 gr Gypsum to a 525 ml sample of base mud and stir 10 minutes and add 5 gr Q-Broxin and 3/4 of Caustic Soda. Stir 10 minutes and test.

(C) CEMENT CONTAMINATION:

Test Procedure

1. Repeat Step No. 1 in (A).
2. Contaminant the base mud (525 ml) by 1.0 PPB and stir for two minutes. Age for 15 minutes. Stir and test.
3. Add to the contaminated sample 1/2 cc (SAPP).
4. Continue to add SAPP in 1/2 cc increments until the original viscosity is restored measure pH every time.
5. Plot the result on a curve showing the viscosity and pH as function of (SAPP) concentration.
6. Add to the base mud 1.5 cc (SAPP) and 1.0 Sodium Bicarbonate and stir for 10 minutes.
7. Add 1.0 gr of cement while mixing the sample after aging and test.

Experimental Results

Tabulate all results in the appropriate table and present graphs where necessary. 28

QUESTIONS ON EXPERIMENT NO. 5

1. Would it be better to treat the mud before or after cement contamination?

Discuss this question using your experimentally obtained data.

2. Discuss and compare the effectiveness of various materials in treating contaminated muds.
3. Did the CARBONEX treated Gypsum contaminated mud or the QBROXIN treated Gypsum contaminated mud exhibit better flow properties? State why? 29

EXPERIMENT NO. 6

SOLID & LIQUID CONTENT AND EMULSION CHARACTERISTICS OF DRILLING FLUID

(A) SAND CONTENT DETERMINATION:

Theory

Periodic sand content determination of drilling mud is desirable, because excessive sand may result in the deposition of a thick filter cake on the wall of the hole, or may settle in the hole about the tools when circulation is stopped, thus interfering with successful operation of drilling tools or setting of casing. High sand content also may cause excessive abrasion of pump parts and pipe connections.

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.

Experiment Equipment : Baroid Sand Content Set:

The Baroid Sand Content Set consists of a 200-mesh sieve, funnel, and a glass measuring tube calibrated from 0 to 20% to read directly the percentage sand by volume.

Test Procedure

1. Pour mud into the Baroid 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.
2. 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.
3. 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.
4. Observe the quantity of sand settled in the calibrated tube as the sand content of the mud.

Results

Report the sand content of the mud in percent by volume (% by volume). Take into account coarse solids obtained on the screen.

Care of instrument

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.

Remarks

1. In step 2 of the procedure, the pouring of the mud and water mixture through the screen can be facilitated by tapping the side of the screen with a spatula handle.
2. Contents retained on the screen in Step 2 of the procedure should not be mashed, stirred, or mutually forced through the screen with a finger, 31 pencil, or the like, as this will give an erroneous reading and may pull the screen loose from the side of the container.

(B) EMULSION TEST

Theory

Emulsion testers are used to indicate the stability and type of emulsion whether water-in-oil or oil-in-water. They are used in the evaluation of inverted emulsion drilling fluids, cements, and fracturing fluids. Time stability and resistance to electrolyte contamination of these systems can be predicted from a measurement of relative emulsion stability.

Test Equipment

Test Procedure

1. The Fann Emulsion Tester may be operated from self-contained batteries, external 12 volt DC or from 115-volt AC 50-60 cycle current. Select power source desired and set power switch accordingly (D.C. position is for either self-contained battery or for external storage battery).
2. Set meter multiplier switch at the X1 position with the voltage control knob at zero.
3. Immerse probe in well-stirred sample so that electrodes are covered. 32
4. Raise voltage slowly by turning control clockwise and watch the flag indicator below meter. When movement of the red flag occurs, indicating current flow between electrodes, read breakdown voltage on meter. If breakdown does not occur, set range switch to X2 or to X4 position and repeat above steps.
5. Clean probe carefully after each use, using care not to alter the spacing of electrode.
6. When internal batteries are depleted (indicated by a marked fall-off in output voltage as shown on the meter) remove panel from carrying case and replace the 8 No. 2 flashlight cells. Only leak-proof batteries should be used.

Caution

1. Do not touch bare metal of electrodes when instrument is turned on.
2. Do not short out electrodes.

(C) OIL, WATER, SOLID & CLAY CONTENT DETERMINATION:

Theory

Knowledge of the liquid and solids content of a drilling mud is essential for good control of the mud properties. Such information will often explain poor performance of the mud and indicate whether the mud can best be conditioned by the addition of water or whether treatment with chemical thinner or the removal of the contaminant is required. Similarly, proper control of an oil emulsion mud depends upon knowledge of the oil content.

For muds containing only water and solids, the quantity of each can be determined from the mud density and from the evaporation of a weighed sample of mud. Oil and water content can also be obtained measuring the liquid fraction. The latter method is only applicable to oil emulsion muds.

Test Equipment

The Baroid Oil and Water Retort Kit

The apparatus required to determine the oil, water and solids content of the mud is included in the Baroid Oil and Water Retort Kit (See figure below).

Test Procedure

1. Lift retort assembly, out of insulator block. Using the spatula as a screwdriver, remove the mud chamber from the retort.
2. Pack the upper chamber with very fine steel wool.
3. Fill mud chamber with mud and replace lid, allowing excess to escape. (This is a point where error is often introduced. Be sure that no air is trapped in the chamber. An accurate charge of mud is essential).
4. Wipe off excess mud and screw mud chamber into upper chamber.
5. Replace retort in insulator block and put insulation cover in place. 34
6. Add a drop of wetting agent to graduate and place under drain of condenser; then turn heater on.
7. Heat mud until oil stops coming over or until the pilot light goes out on thermostatically controlled units. For diesel oil this time will be about 15 minutes with the thermo stated retorts and about 20 minutes in the uncontrolled units at 110 volts. Low or high voltage will cause variations in time required. Crude oils may require longer heating periods.

NOTE:

Nearly 100% recovery of refined oil will be obtained with this retort. If the mud is made up with crude oil, calibration runs should be made on mud containing a known percentage of the crude used. Recovery on some crudes may be as low as 60%. If the distillation is

being carried on for more than 30 minutes, the retort should be removed occasionally in the uncontrolled units and observed for temperature. In any case, the retort should never be heated above a DULL RED HEAT. The heater will burn out if left on too long.

8. Read the volume of oil and of water. (A drop of wetting agent at this time will often improve the menisci for easier reading).
9. Where the new style thermostated retort is used faster heating can be obtained and the temperature is controlled to prevent overheating.

Care of Equipment

Before each retorting the following should be done:

1. Use the spatula to scrape the dried mud from the mud chamber and lid to assure correct volume.
2. Remove and replace any mud-caked steel wool.
3. Clean the retort drain tube and condenser with a pipe cleaner. 35

THEORY AND CALCULATIONS OF SOLID CONTENT

The solid phase of a drilling mud unit of two components, i.e. (i) High specific gravity solids with a specific gravity of 4.3 and (ii) Low specific gravity solids with a specific gravity of 2.5.

The total solids phase, in volume %, is found by the Baroid Oil and Water

Retort.

The information (data) from the retort test can be used to calculate the average specific gravity of solids, the % of different types of solids, and the % solids by weight in the mud, as shown below:

NOTE:

The accuracy of your calculations depends on the retort test data. These care should be taken while running the equipment to ensure good results.

Presentation of Experimental Results

1. Using your calculated results of the average specific gravity of solids, determine the solid content of each of the samples (either directly or by interpolation, whichever is applicable).
2. Present the results of your findings in (1) in an appropriate table.

QUESTIONS ON EXPERIMENT NO. 6

- (1) From the results of your experiment in part (A), is there a correlation between the mud weight of the sample and the % sand by volume? Explain.
- (2) What problems are you likely to encounter during drilling operations if you have a high sand content in your drilling mud?
- (3) What is the importance of conducting Emulsion Stability tests on drilling fluids?
- (4) From the results of your experiment in part (C), which of the samples has the highest clay content?

OIL WELL CEMENTING, PROPERTIES AND FUNCTIONS 2

The cement used for oil well cementing differs from concrete or masonry work in that it consists of thin slurry of primarily cement and water. The cement used in oil wells must possess three primary properties. They must possess a proper water-to-cement ratio, a sufficient fluid time to allow placement, and must develop enough strength in a minimum time to bond the pipe to the formation.

HYDRATION OF CEMENT

Hydration (reaction with water) begins when water is added to cement. The cement slurry gradually sets to a solid as hydration continues. After hydration begins, which initiates the setting, the process slows, and the strength of the set cement continues to increase for many days.

ACCELERATION AND RETARDATION

Anything that will have an effect on the chemical reaction influences the degree of acceleration. Factors that could influence the reaction rate are: pressure, temperature, concentration of each chemical or ionized particles present, and the chemical nature of the combined chemicals present. Cement setting is retarded by use of an additive either at the time of manufacture or at the time of use. The retardation of slow set cements is due chiefly to the addition of chemical retarders such as borax and starch, which are added at the time of manufacture. Another method is to adjust the particle size (grind) of the cement. The cement will set more slowly if it is coarsely ground. Cement is accelerated about the same way that it is retarded by the manufacturer. It is performed by composition adjustment, particle size adjustment, and by the addition of a chemical accelerator. The addition of a chemical accelerator is the most effective way to accelerate the setting of cement.

Calcium is the most effective and economical accelerator for Portland cement. Calcium Chloride slightly reduces the viscosity of Portland cement slurries. The more calcium chloride added to cement, the more pronounced the acceleration. Optimum concentration of calcium chloride for early strength is reached between 2% and 4% by weight of the dry cement. More or less will not produce higher strength. Any strength greater than 5% lowers

strength. The usual effect of 2% Calcium Chloride is to reduce the thickening time by one half and to double the twenty-four hour strength.

COMMONLY MEASURED CEMENT PROPERTIES

There are several properties of Portland cement, which are commonly measured. These properties are thickening time, compressive strength, slurry volume, free water separation, and hydraulic flow properties. The thickening time is the amount of time necessary for the slurry to reach a consistency of 100 poises at different well temperature, depth, and pressure conditions. The compressive strength is the force per unit internal cross-sectional area in psi necessary to crush the cement specimen. The free water separation is the measurement of the water loss of the cement expressed in volume per unit time. It is directly proportional to the water to cement ratio. The hydraulic flow properties are the rheological properties of the cement necessary to make critical velocity calculations. The calculation of slurry volumes will usually be based upon water to cement ratios. The water to cement ratio is the ratio of the weight of water to a unit weight of dry cement. The ratio of water to cement is important because cementing material must contain sufficient water to make it pumpable, yet not have setting with free water separation. The two terms used for water ratios are maximum and minimum. Maximum water is the greatest amount that can be mixed with cement and produce a set volume equal to the slurry volume. Minimum water is the least amount that can produce pumpable slurry. The specific gravity of the cement is calculated to be 3.15.

A commonly used water to cement ratio is 0.46, which means 46 grams of water to 100 grams of dry cement. The results of the thickening time tests on the Consistometer. The Consistometer readings are plotted on common graph paper with the consistency as the ordinate and time as the abscissa. The general shape of the consistency time curve plotted as previously described presents a picture of a particular cement as far as its setting characteristics are concerned. There are certain features common to all consistency-time curves. As the cement is introduced, it generally has a fairly low consistency. This value usually drops a little as the stirring is begun. It then begins to increase at a very gradual rate. As time goes on, the rate of increase of the consistency is accelerated to such an extent that the latter part of the curve is very steep. This acceleration varies with different cements and with different temperature of testing. The two main flow properties of a cement slurry are shear rate and shear stress. These properties permit the determination of two slurry properties: (1) Flow Behavior Index, n' , and (2) Consistency Index, K' . These factors will then allow estimation of the pumping rate for turbulence of slurry in the annulus, frictional pressure drop of slurry in the annulus and pipe, and hydraulic horsepower necessary to overcome friction losses for non-Newtonian fluids. The flow curve, which is constructed to obtain the Flow Behavior Index and the Consistency Index, is prepared using a Fann V-G meter by plotting shear stress (pounds force/square foot) on the ordinate and the shear rate (sec⁻¹) on the abscissa on logarithmic coordinate paper. Shear Stress = Dial Reading of Viscometer x N x 1.066 / 100 where N = range extension factor of the torque spring

Shear Rate = (1.703) x (RPM of Viscometer) When the data points do not form a straight line flow curve, the best straight line through these values should be drawn and extrapolated

to the shear stress axis. The Flow Behavior Index is equal to the slope of the flow curve and is dimensionless. The Consistency Index is equal to the intercept of the flow curve at the unity rate of shear with the units (lb-sec' /ft²).

EXPERIMENT NO. 7

OIL WELL CEMENTING EXPERIMENT

WATER RATIOS FOR PORTLAND CEMENT SLURRY

Objective

To show the effects of varying amounts of mixing water on the physical properties of Portland cement. These properties are Free Water Separation, Normal and Minimum Water Content and Thickening Time.

Test Equipment

The Atmospheric Consistometer

The Atmospheric Consistometer consists of a Stainless Steel Water bath that houses the slurry containers. An instrument panel houses components that allow control of the bath at any temperature from ambient to 93oC, 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. The entire instrument has overall dimensions of 15" (39 cm) wide x 15" (38 cm) deep x 19" (48 cm) high.

EXPERIMENTATION

(A) FREE WATER SEPARATION:

Test Procedure

1. 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 + oF.
2. Prepare 170 cc, 190 cc and 210 cc of sweet 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.

3. 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.
4. Pour 225 c.c. of slurry into 250 c.c.- graduated cylinder. Tightly cover them with aluminum foil. Allow to stand for two hours.
5. Carefully decant the free water and measure in a 10 c.c. graduated cylinder. Do this for each slurry. Calculate the per cent (%) free water upon settling.

(B) NORMAL & MINIMUM WATER CONTENT OF CEMENT SLURRY:

Test Procedure

1. Prepare 4 slurry samples of varying water to cement ratios, as described in part (A) 1 & 2.
2. Pour the samples immediately into an Atmospheric Consistometer and stir for a period of 20 minutes, under ambient conditions.
3. Record the Consistency immediately after 20 minutes of stirring has elapsed.
4. Determine the Normal and Minimum Water Content.

DEFINITIONS

Normal Water Content

This is the water content of slurry yielding a consistency of 11 Bc.

Minimum Water Content

This is the water content of slurry yielding a consistency of 30 Bc.

(C) THICKENING TIME TEST:

Definition

This is the amount of time necessary for the cement slurry to reach a consistency of 100 Bc or poises, at different well temperature, depth and pressure conditions. It also represents the length of time the slurry is pumpable.

Test Procedure

1. After the cement slurry (Sample 1 Part (B)) is prepared, pour it immediately into the Atmospheric Consistometer and begin stirring.
2. Record the consistency after every 4 minutes. Tabulate the results in the appropriate table.
3. Plot the Consistency in Bc versus time on a log-log paper and extrapolate the straight time to 100 Bc, to determine the thickening time.

(b) Reservoir Engineering Courses

These exercises are culled from Torsæter, O. and Abtahi, M. (2003) Experimental Reservoir Engineering Laboratory Work Book. Department of Petroleum engineering and Applied Geophysics, Norwegian University of Science and Technology, January, 2003.

2.0 CLEANING AND SATURATION DETERMINATION

2.1 Definitions

Before measuring porosity and permeability, the core samples must be cleaned of residual fluids and thoroughly dried. The cleaning process may also be a part of fluid saturation determination.

Fluid saturation is defined as the ratio of the volume of fluid in a given core sample to the pore volume of the sample

$$S_w = \frac{V_w}{V_p} \quad S_o = \frac{V_o}{V_p} \quad S_g = \frac{V_g}{V_p} \quad (2.1)$$

$$S_w + S_o + S_g = 1 \quad (2.2)$$

where V_w , V_o , V_g and V_p are water, oil, gas and pore volumes respectively and S_w , S_o and S_g are water, oil and gas saturations. Note that fluid saturation may be reported either as a fraction of total porosity or as a fraction of effective porosity. Since fluid in pore spaces that are not interconnected cannot be produced from a well, the saturations are more meaningful if expressed on the basis of effective porosity. The weight of water collected from the sample is calculated from the volume of water by the relationship

$$W_w = \rho_w V_w \quad (2.3)$$

where ρ_w is water density in g/cm^3 . The weight of oil removed from the core may be computed as the weight of liquid less weight of water

$$W_o = W_L - W_w \quad (2.4)$$

where W_L is the weight of liquids removed from the core sample in gram. Oil volume may then be calculated as W_o/ρ_o . Pore volume V_p is determined by a porosity measurement, and oil and water saturation may be calculated by Eq. (2.1). Gas saturation can be determined using Eq. (2.2)

2.2 Measurement Methods

2.2.1 Direct Injection of Solvent

The solvent is injected into the sample in a continuous process. The sample is held in a rubber sleeve thus forcing the flow to be uniaxial.

2.2.2 Centrifuge Flushing

A centrifuge which has been fitted with a special head sprays warm solvent onto the sample. The centrifugal force then moves the solvent through the sample. The used solvent can be collected and recycled.

2.2.3 Gas Driven Solvent Extraction

The sample is placed in a pressurized atmosphere of solvent containing dissolved gas. The solvent fills the pores of sample. When the pressure is decreased, the gas comes out of solution, expands, and drives fluids out of the rock pore space. This process can be repeated as many times as necessary.

2.2.4 Soxhlet Extraction

A Soxhlet extraction apparatus is the most common method for cleaning sample, and is routinely used by most laboratories. As shown in Figure 2.1a, toluene is brought to a slow boil in a Pyrex flask; its vapors move upwards and the core becomes engulfed in the toluene vapors (at approximately 110°C). Eventual water within the core sample in the thimble will be vaporized. The toluene and water vapors enter the inner chamber of the condenser, the cold water circulating about the inner chamber condenses both vapors to immiscible liquids. Re-condensed toluene together with liquid water falls from the base of the condenser onto the core sample in the thimble; the toluene soaks the core sample and dissolves any oil with which it come into contact. When the liquid level within the Soxhlet tube reaches the top of the siphon tube arrangement, the liquids within the Soxhlet tube are automatically emptied by a siphon effect and flow into the boiling flask. The toluene is then ready to start another cycle.

A complete extraction may take several days to several weeks in the case of low API gravity crude or presence of heavy residual hydrocarbon deposit within the core. Low permeability rock may also require a long extraction time.

2.2.5 Dean-Stark Distillation-Extraction

The Dean-Stark distillation provides a direct determination of water content. The oil and water are extracted by dripping a solvent, usually toluene or a mixture of acetone and chloroform, over the plug samples. In this method, the water and solvent are vaporized, recondensed in a cooled tube in the top of the apparatus and the water is collected in a calibrated chamber (Figure 2.1b). The solvent overflows and drips back over the samples. The oil removed from the samples remains in solution in the solvent. Oil content is calculated by the difference between the weight of water recovered and the total weight loss after extraction and drying.

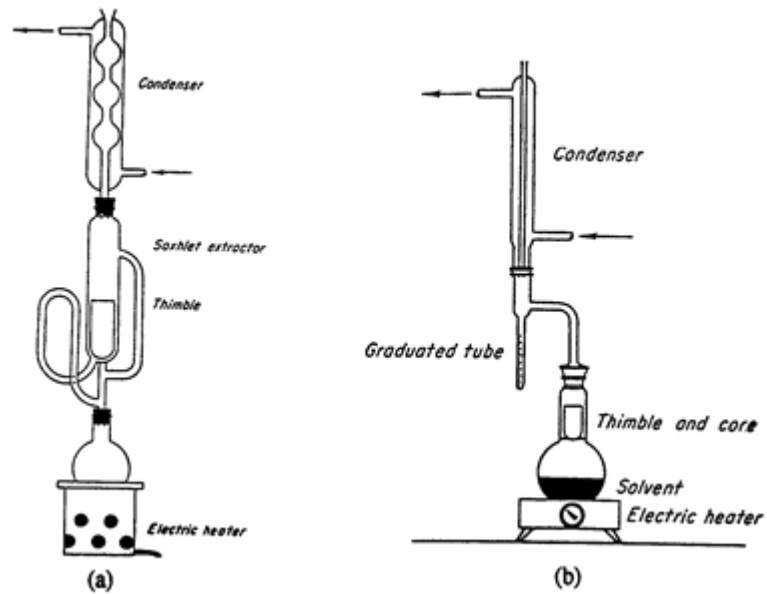


Fig. A.1: Schematic diagram of Soxhlet (a) and Dean- Stark (b) apparatus.

2.2.6 Vacuum Distillation

The oil and water content of cores may be determined by this method. As shown in Figure 2.2, a sample is placed within a leak-proof vacuum system and heated to a maximum temperature of 2300C. Liquids within the sample are vaporized and passed through a condensing column that is cooled by liquid nitrogen.

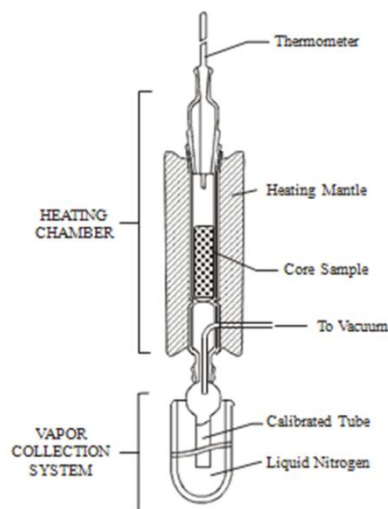


Fig. A.2: Vacuum distillation Apparatus.

2.2.7 Summary

The direct-injection method is effective, but slow. The method of flushing by using centrifuge is limited to plug-sized samples. The samples also must have sufficient mechanical strength to withstand the stress imposed by centrifuging. However, the procedure is fast. The gas driven-extraction method is slow. The disadvantage here is that it is not suitable for poorly consolidated samples or chalky limestone's. The distillation in a Soxhlet apparatus is slow, but is gentle on the samples. The procedure is simple and very accurate water content determination can be made. Vacuum distillation is often used for full diameter cores because the process is relatively rapid. Vacuum distillation is also frequently used for poorly consolidated cores since the process does not damage the sample. The oil and water values are measured directly and dependently of each other.

In each of these methods, the number of cycles or amount of solvent which must be used depends on the nature of the hydrocarbons being removed and the solvent used. Often, more than one solvent must be used to clean a sample. The solvents selected must not react with the minerals in the core. The commonly used solvents are:

- Acetone
- Benzene
- Benzen-methol Alcohol
- Carbon-tetrachloride
- Chloroform
- Methylene Dichloride
- Mexane
- Naphtha
- Tetra Chloroethylene
- Toluene
- Trichloro Ethylene
- Xylene

Toluene and benzene are most frequently used to remove oil and methanol and water is used to remove salt from interstitial or filtrate water. The cleaning procedures used are specifically important in special core analysis tests, as the cleaning itself may change wettability.

The core sample is dried for the purpose of removing connate water from the pores, or to remove solvents used in cleaning the cores. When hydratable minerals are present, the drying procedure is critical since interstitial water must be removed without mineral alteration. Drying is commonly performed in a regular oven or a vacuum oven at temperatures between 50⁰C to 105⁰C. If problems with clay are expected, drying the samples at 60⁰C and 40 % relative humidity will not damage the samples.

2.3 *Experiments*

2.3.1 Saturation Determination, Dean-Stark Distillation Method

Description:

The objective of the experiment is to determine the oil, water and gas saturation of a core sample.

Procedure:

1. Weigh a clean, dry thimble. Use tongs to handle the thimble.
2. Place the cylindrical core plug inside the thimble, and then quickly weigh the thimble and sample.
3. Fill the extraction flask two-thirds full with toluene. Place the thimble with sample into the long neck flask.
4. Tighten the ground joint fittings, but do not apply any lubricant for creating tighter joints. Start circulating cold water in the condenser.
5. Turn on the heating jacket or plate and adjust the rate of boiling so that the reflux from the condenser is a few drops of solvent per second. The water circulation rate should be adjusted so that excessive cooling does not prevent the condenser solvent from reaching the core sample.
6. Continue the extraction until the solvent is clear. Change solvent if necessary.
7. Read the volume of collected water in the graduated tube. Turn off the heater and cooling water and place the sample into the oven (from 105⁰C to 120⁰C), until the sample weight does not change. The dried sample should be stored in a desiccator.
8. Obtain the weight of the thimble and the dry core.
9. Calculate the loss in weight W_L , of the core sample due to the removal of oil and water.
10. Measure the density of a separate sample of the oil.
11. Calculate the oil, water and gas saturations after the pore volume V_p of the sample is determined.

Data and calculations:

Sample No:

Porosity,:

W_{org} g	W_{dry} g	ρ_w g/cm ³	ρ_o g/cm ³	V_w cm ³	W_o g	V_o cm ³	V_p cm ³	S_o	S_w	S_g

Where

W_{org} : Weight of original saturated sample

W_{dry} : Weight of saturated and dry sample

Equations:

$$W_L = W_{org} - W_{dry}$$

$$W_o = W_L - W_w$$

$$V_b = \pi(D/2)^2 L$$

$$V_p = \phi V_b$$

where D and L are diameter and length of the core sample, respectively.

POROSITY

3.1 Definitions

From the viewpoint of petroleum engineers, the two most important properties of a reservoir rock are porosity and permeability. Porosity is a measure of storage capacity of a reservoir. It is defined as the ratio of the pore volume to bulk volume, and is may be expressed as either a percent or a fraction. In equation form

$$\phi = \frac{\text{pore volume}}{\text{bulk volume}} = \frac{\text{bulk volume} - \text{grain volume}}{\text{bulk volume}}$$

Two types of porosity may be measured: total or absolute porosity and effective porosity. *Total porosity* is the ratio of all the pore spaces in a rock to the bulk volume of the rock. *Effective porosity* e is the ratio of interconnected void spaces to the bulk volume. Thus, only the effective porosity contains fluids that can be produced from wells. For granular materials such as sandstone, the effective porosity may approach the total porosity, however, for shales and for highly cemented or vugular rocks such as some limestone's, large variations may exist between effective and total porosity.

Porosity may be classified according to its origin as either primary or secondary. *Primary or original porosity* is developed during deposition of the sediment. Secondary porosity is caused by some geologic process subsequent to formation of the deposit. These changes in the original pore spaces may be created by ground stresses, water movement, or various types of geological activities after the original sediments were deposited. Fracturing or formation of solution cavities often will increase the original porosity of the rock.

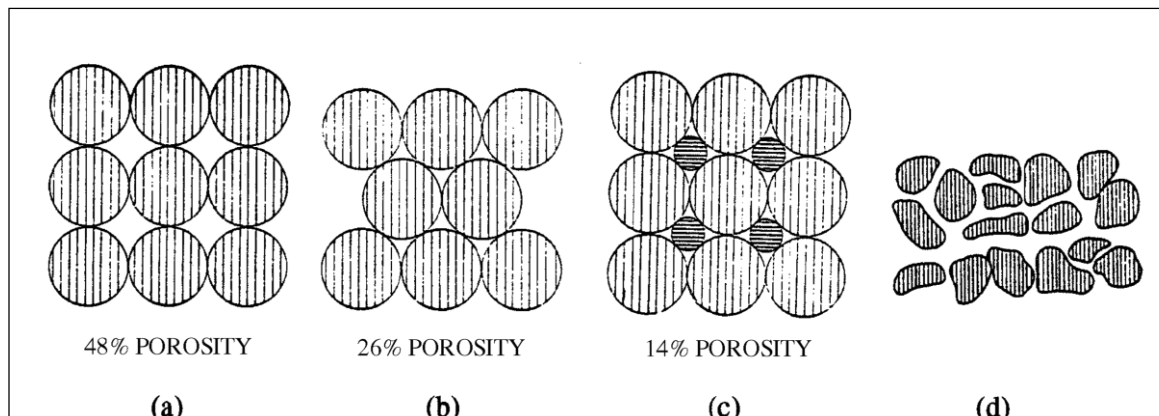


Fig. A.3: Cubic packing (a), rhombohedra (b), cubic packing with two grain sizes (c), and typical sand with irregular grain shape (d).

For a uniform rock grain size, porosity is independent of the size of the grains. A maximum theoretical porosity of 48% is achieved with cubic packing of spherical grains, as shown in Fig. A.3a. Rhombohedra packing, which is more representative of reservoir conditions, is shown in Fig. A.3 b; the porosity for this packing is 26%. If a second,

smaller size of spherical grains is introduced into cubic packing (Fig. 3.1c), the porosity decreases from 48% to 14%. Thus, porosity is dependent on the grain size distribution and the arrangement of the grains, as well as the amount of cementing materials. Not all grains are spherical, and grain shape also influences porosity. A typical reservoir sand is illustrated in Fig. 3.1d.

3.2 *Effect of Compaction on Porosity*

Compaction is the process of volume reduction due to an externally applied pressure. For extreme compaction pressures, all materials show some irreversible change in porosity.

This is due to distortion and crushing of the grain or matrix elements of the materials, and in some cases, recrystallization. The variation of porosity with change in pressure can be represented by

$$\phi_2 = \phi_1 e^{c_f(P_2 - P_1)} \quad 3.1$$

Where ϕ_2 and ϕ_1 are porosities at pressure P_2 and P_1 respectively, and c_f is formation compressibility. Formation compressibility is defined as summation of both grain and pore compressibility. For most petroleum reservoirs, grain compressibility is considered to be negligible. Formation compressibility can be expressed as

$$c_f = \frac{1}{V} \frac{dV}{dP} \quad 3.2$$

Where dP is change in reservoir pressure. For porous rocks, the compressibility depends explicitly on porosity.

3.3 Porosity Measurements on core plugs

From the definition of porosity, it is evident that the porosity of a sample of porous material can be determined by measuring any two of the three quantities: Bulk volume, pore volume or grain volume. The porosity of reservoir rock may be determined by

- Core analysis
- Well logging technique
- Well testing

The question of which source of porosity data is most reliable cannot be answered without reference to a specific interpretation problem. These techniques can all give correct porosity values under favourable conditions. The core analysis porosity determination has the advantage that no assumption need to be made as to mineral composition, borehole effects, etc. However, since the volume of the core is less than the rock volume which is investigated by a logging device, porosity values derived from logs are frequently more accurate in heterogeneous reservoirs.

In the following sections we will discuss how to estimate pore-, grain-, and bulk-volumes from core plugs.

3.3.1 Bulk Volume Measurement

Although the bulk volume may be computed from measurements of the dimensions of a uniformly shaped sample, the usual procedure utilizes the observation of the volume of fluid displaced by the sample. The fluid displaced by a sample can be observed either *volumetrically* or *gravimetrically*. In either procedure it is necessary to prevent the fluid penetration into the pore space of the rock. This can be accomplished (1) by coating the sample with paraffin or a similar substance, (2) by saturating the core with the fluid into

which it is to be immersed, or (3) by using mercury.

Gravimetric determinations of bulk volume can be accomplished by observing the loss in weight of the sample when immersed in a fluid or by change in weight of a pycnometer with and without the core sample.

3.3.2 Pore Volume Measurement

All the methods measuring pore volume yield effective porosity. The methods are based on either the extraction of a fluid from the rock or the introduction of a fluid into the pore spaces of the rock.

One of the most used methods is the helium technique, which employs Boyle's law. The helium gas in the reference cell isothermally expands into a sample cell. After expansion, the resultant equilibrium pressure is measured. The Helium porosimeter apparatus is shown schematically in Fig. 3.2.

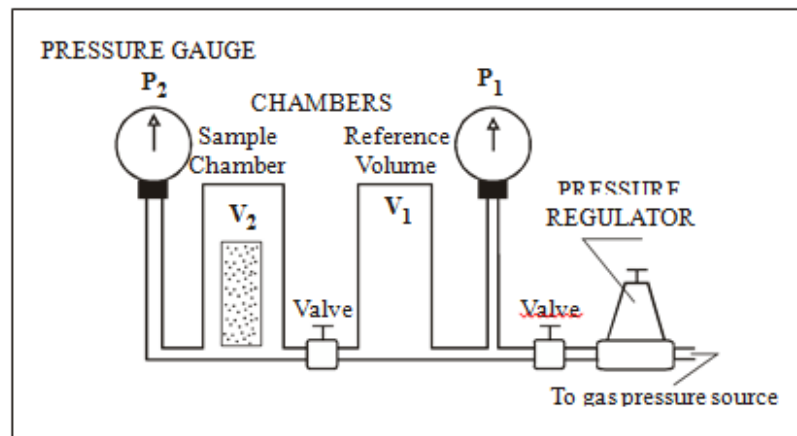


Fig. A.4: Schematic diagram of helium porosimeter apparatus.

Helium has advantages over other gases because: (1) its small molecules rapidly penetrated small pores, (2) it is inert and does not adsorb on rock surfaces as air may do, (3) helium can be considered as an ideal gas (i.e., $z = 1.0$) for pressures and temperatures usually employed in the test, and (4) helium has a high diffusivity and therefore affords a useful means for determining porosity of low permeability rocks.

The schematic diagram of the helium porosimeter shown in Fig. 3.2 has a reference volume V_1 , at pressure p_1 , and a matrix cup with unknown volume V_2 , and initial pressure p_2 . The reference cell and the matrix cup are connected by tubing; the system can be brought to equilibrium when the core holder valve is opened, allowing determination of the unknown volume V_2 by measuring the resultant equilibrium pressure p . (Pressure p_1 and p_2 are controlled by the operator; usually $p_1 = 100$ and $p_2 = 0$ psig). When the core holder valve is opened, the volume of the system will be the equilibrium volume V , which is the sum of the volumes V_1 and V_2 . Boyle's law is applicable if the expansion takes place isothermally. Thus the pressure-volume products are equal before and after opening the core holder valve:

$$p_1V_1 + p_2V_2 = p(V_1 + V_2) \quad 3.3$$

3.3

Solving the equation for the unknown volume, V_2 :

$$V_2 = \frac{(P - P_1)V_1}{P_2 - P} \quad 3.4$$

Since all pressures in equation (5.4) must be absolute and it is customary to set $p_1 = 100$ *psig* and $p_2 = 0$ *psig*, Eq. (5.4) may be simplified as follows:

$$V_2 = \frac{V_1(100 - p)}{p} \quad 3.5$$

where V_2 in cm^3 is the unknown volume in the matrix cup, and V_1 in cm^3 is the known volume of the reference cell. p in *psig* is pressure read directly from the gauge.

Small volume changes occur in the system, including the changes in tubing and fittings caused by pressure changes during equalization. A correction factor, G , may be introduced to correct for the composite system expansion. The correction factor G is determined for porosimeters before they leave the manufacturer, and this correction is built into the gauge calibration in such a way that it is possible to read the volumes directly from the gauge.

Another method of pore volume determination is to saturate the sample with a liquid of known density, and noting the weight increase (gravimetric method).

When a rock has a small fraction of void space, it is difficult to measure porosity by the mentioned methods. At this case, mercury injection is used. The principle consists of forcing mercury under relatively high pressure in the rock pores. A pressure gauge is attached to the cylinder for reading pressure under which measuring fluid is forced into the pores. Fig.A. 5 b shows a typical curve from the mercury injection method. The volume of mercury entering the core sample is obtained from the device with accuracy up to 0.01 cm^3 .

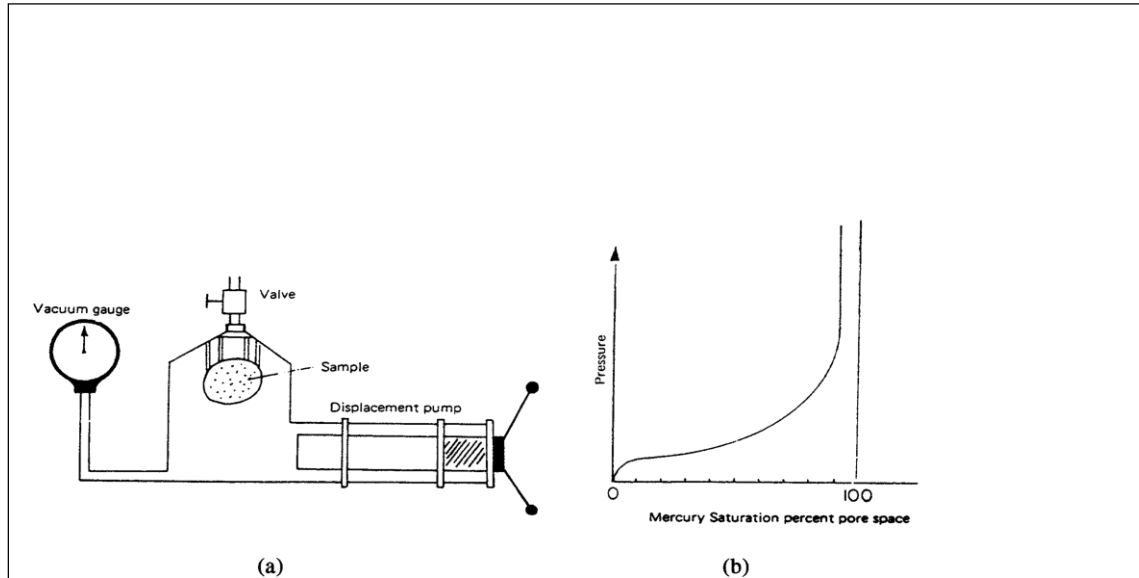


Fig. A.5: Mercury injection pump (a) and porosity through mercury injection (b).

3.3.3 Grain Volume Measurement

The grain volume of pore samples is sometimes calculated from sample weight and knowledge of average density. Formations of varying lithology and, hence, grain density limit applicability of this method. Boyle's law is often employed with helium as the gas to determine grain volume. The technique is fairly rapid, and is valid on clean and dry sample.

The measurement of the grain volume of a core sample may also be based on the loss in weight of a saturated sample plunged in a liquid.

Grain volume may be measured by crushing a dry and clean core sample. The volume of crushed sample is then determined by (either pycnometer or) immersing in a suitable liquid.

3.4 Experiments

3.4.1 Effective Porosity Determination by Helium Porosimeter Method

Description

The helium porosimeter uses the principle of gas expansion, as described by Boyle's law. A known volume (reference cell volume) of helium gas, at a predetermined pressure, is isothermally expanded into a sample chamber. After expansion, the resultant equilibrium pressure is measured. This pressure depends on the volume of the sample chamber minus the rock grain volume, and then the porosity can be calculated.

Procedure:

1. Measure the diameter and length of the core using caliper.
2. Give the porosimeter a helium supply, 10 bar.
3. Determine the volume of the matrix cup with core, V_2 :
 - 3.1 Put the cleaned, dried core inside the matrix cup, and mount the cup in the cup holder.
 - 3.2 Open “source” and then “supply”.
 - 3.3 Regulate the needle at 100.
 - 3.4 Close “source” and then “supply”.
 - 3.5 Open “core holder”.
 - 3.6 Take the reading on TOP SCALE, $V_2 = cm^3$.
4. Determine the volume of the matrix cup without core, V_1 :
 - 4.1 Take out the core from the matrix cup, and mount the cup in the cup holder.
 - 4.2 Open “source” and then “supply”.
 - 4.3 Open “cell 1”.
 - 4.4 Regulate the needle at 100.
 - 4.5 Close “source and then “supply”.
 - 4.6 Open core “holder”.
 - 4.7 Take the reading on MIDDLE SCALE, $V_1 = cm^3$.

Calculations and report

1. Calculate and fill the data form.

Core No.: D : cm , L : cm .

$V_1 (cm^3)$	$V_2 (cm^3)$	$V_g (cm^3)$	$V_b (cm^3)$	e

4. RESISTIVITY

4.1 Definitions

Porous rocks are comprised of solid grains and void space. The solids, with the exception of certain clay minerals, are nonconductors. The electrical properties of a rock depend on the geometry of the voids and the fluid with which those voids are filled. The fluids of interest in petroleum reservoirs are oil, gas, and water. Oil and gas are nonconductors. Water is a conductor when it contains dissolved salts, such as NaCl, MgCl₂, KCl normally found in formation reservoir water. Current is conducted in water by movement of ions and can therefore be termed *electrolytic conduction*.

The *resistivity* of a porous material is defined by

$$R = \frac{rA}{L} \quad 4.1$$

where r = resistance,
 A = cross-sectional area, m^2
 L = length, m

and resistivity is expressed in Ohm-meter ($\Omega \cdot m$). However, for a complex material like rock containing water and oil, the resistivity of the rock depends on

- Salinity of water
- Temperature
- Porosity
- Pore geometry
- Formation stress
- Composition of rock.

The resistivity of an electric current in porous rock is due primarily to the movement of dissolved ions in the brine that fills the pore of the rock. The resistivity varies with temperature due to the increased activity of the ions in solution as temperature increases.

Due to the conductivity properties of reservoir formation water, the electrical well-log technique is an important tool in the determination of water saturation versus depth and thereby a reliable resource for in situ hydrocarbon evaluation.

The theory of the electrical resistivity log technique generally applied in petroleum engineering was developed by Archie in 1942, the so called Archie's equation. This empirical equation was derived for clean water-wet sandstones over a reasonable range of water saturation and porosities. In practice, Archie's equation should be modified according to the rock properties: clay contents, wettability, pore distribution, etc. The following is a brief presentation of the main electrical properties of reservoir rocks and related parameters.

Formation Factor: The most fundamental concept considering electrical properties of rocks is the formation factor F , as defined by Archie:

$$F = \frac{R_o}{R_w} \quad 4.2$$

Where

R_o = the resistivity of the rock when saturated 100% with water, $\Omega.m$

R_w = the water resistivity, $\Omega.m$.

The formation factor shows a relationship between water saturated rock conductivity and bulk water conductivity. Obviously, the factor depends on the pore structure of the rock.

Resistivity Index: The second fundamental notion of electrical properties of porous rocks containing both water and hydrocarbons is the resistivity index I .

$$I = \frac{R_t}{R_o} \quad 4.3$$

Where

R_t = the resistivity of the rock when saturated partially with water, $\Omega.m$

R_o = the resistivity of the same rock when saturated with 100% water, $\Omega.m$.

Tortuosity: Wyllie (52) developed the relation between the formation factor and other properties of rocks, like porosity and tortuosity. Tortuosity can be defined as $(L_a/L)^2$, where L is the length of the core and L_a represents the effective path length through the pores. Based on simple pore models the following relationship can be derived:

$$F = \frac{\tau}{\phi} \quad 4.4$$

Where F = formation factor

τ = tortuosity of the rock

ϕ = porosity of the rock.

Cementation factor: Archie suggested a slightly different relation between the formation factor and porosity by introducing the cementation factor:

$$F = \phi^{-m} \quad 4.5$$

Where

ϕ = porosity of the rock

m = Archie's cementation factor.

Archie reported that the cementation factor probably ranged from 1.8 to 2.0 for consolidated sandstones and for clean unconsolidated sands was about 1.3.

Saturation Exponent: The famous Archie's equation gives the relationship of resistivity index with water saturation of rocks

$$I = \frac{R_t}{R_o} = S_w^{-n}$$

Where

S_w = water saturation

n = saturation exponent, ranging from 1.4 to 2.2 ($n = 2.0$ if no data are given).

In this equation, R_t and R_o can be obtained from well logging data, saturation exponent n is experimentally determined in laboratory. Therefore, the in situ water saturation can be calculated with Archie's equation. Based on the material balance equation for the formation, $S_w + S_o + S_g = 1.0$, the hydrocarbon reserve in place may be calculated.

4.2 Effect of Conductive Solids

The clay minerals present in a natural rock act as a separate conductor and are sometimes referred to as "conductive solids". Actually, the water in the clay and the ions in the water act as the conducting materials. Fig. 4.1 shows variation of formation factor versus water resistivity for clean and clayey sands. The effect of the clay on the resistivity of the rock is dependent upon the amount, type and manner of distribution of the clay in the rock.

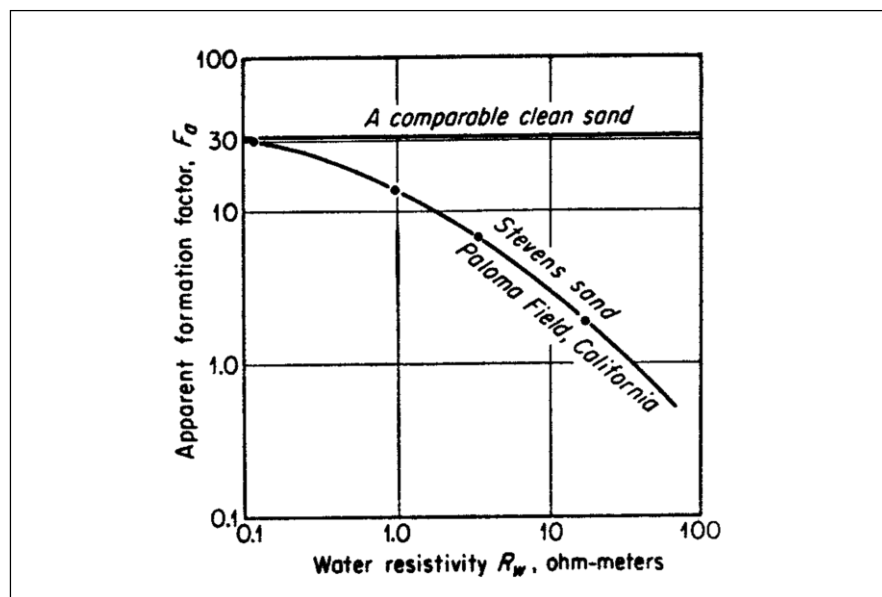


Fig. A.6: Apparent formation factor versus water resistivity for clayey and clean sands.

The formation factor for clay-free sand is constant. The formation factor for clayey sand increases with decreasing water resistivity and approaches a constant value at a water resistivity of about 0.1 Ω m. The apparent formation factor F_a was calculated from the definition of the formation factor and observed values of R_{oa} and R_w ($F_a = R_{oa}/R_w$). Wyllie proposed that the observed effect of clay minerals was similar to having two electrical circuits in parallel: the conducting clay minerals and the water-filled pores. Thus

$$\frac{1}{R_{oa}} = \frac{1}{R_c} + \frac{1}{FR_w}$$

Where R_{oa} is the resistivity of shaly sand when 100% saturated with water of resistivity R_w . R_c is the resistivity due to the clay minerals. FR_w is the resistivity due to the distributed water, and F is the true formation factor of the rock (the constant value when the rock contains low-resistivity water).

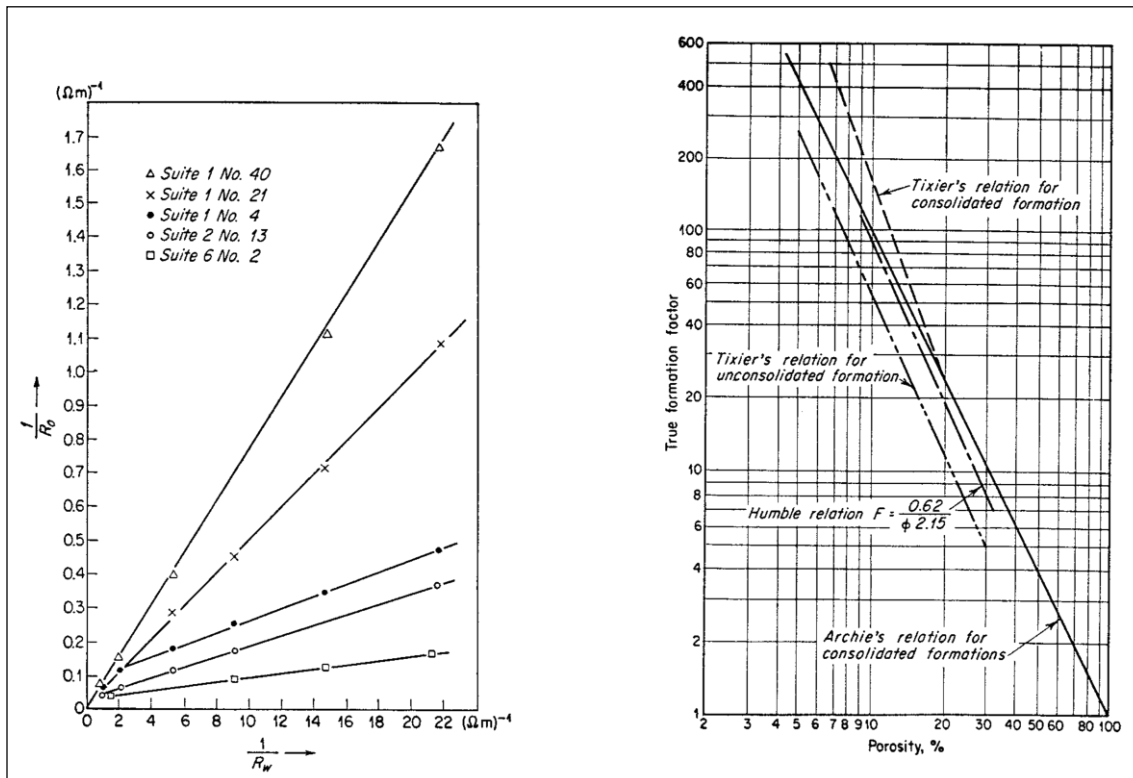


Fig. A.7: Water-saturated rock conductivity as a function of water conductivity.

Fig.A.8: Formation factor as a Function of porosity.

The data presented at the Fig.4.2 represent graphically the confirmation of the relationship expressed in Eq. (4.7). The plots are linear and are of the general form

$$\frac{1}{R_{oa}} = C \frac{1}{R_w} + b \tag{4.8}$$

where C is the slope of the line and b is the intercept. Comparing Eq. (4.7) with Eq. (4.8), it may be noted that $C = 1/F$ and $b = 1/R_c$. The line in which $b = 0$ indicates a clean sand, then

$$\frac{1}{R_{oa}} = C \frac{1}{R_w} + b$$

Eq. (4.7) can be rearranged to express the apparent formation factor in term of R_c and FR_w

$$R_{oa} = \frac{R_c R_w}{R} \quad \text{and} \quad F_a = \frac{R_c}{R}$$

As $R_w \rightarrow 0$, $\lim_{R_w \rightarrow 0} F_a = \frac{R_c}{R_c} = F$. Therefore F_a approaches F as a limit as R_w become small.

This was observed in Fig. 4.1.

4.3 Effect of Overburden Pressure on Resistivity

Confinement or overburden pressure may cause a significant increase in resistivity. This usually occurs in rocks that are not well cemented and in lower porosity rocks. Archie, as mentioned before, reported results of correlating laboratory measurements of formation factor with porosity in the form

$$F = \phi^{-m} \tag{4.11}$$

Wyllie investigated the influence of particle size and cementation factor on the formation factor of a variety of materials. He concluded that the cemented aggregates exhibit a greater change in formation factor with a change in porosity than the unconsolidated aggregates. Then, the general form of the relation between formation factor and porosity should be

$$F = a\phi^{-m} \tag{4.12}$$

where m is a constant depending on cementation and a a constant controlled by the porosity of the unconsolidated matrix prior to cementation. A comparison of some suggested relationships between porosity and formation factor is shown in Fig. 4.3.

4.4 Resistivity of Partially Water-Saturated Rocks

When oil and gas are present within a porous rock together with a certain amount of formation water, its resistivity is larger than R_o since there is less available volume for the flow of electric current. This volume is a function of the water saturation S_w . Eq. (4.6) indicates that the resistivity index is a function of water saturation and the path depth. From the theoretical development, the following generalization can be drawn:

$$I = C' S_w^{-n} \tag{4.13}$$

where $I = R_t/R_o$ is the resistivity index, C' is some function of tortuosity and n is the saturation exponent. In Archie's equation n is 2.0 and in Williams relation 2.7 (Fig. 4.4). All the equations fitted to the experimental data have assumed that both C' and n of Eq. (4.13) were constants and furthermore that $C' = I$.

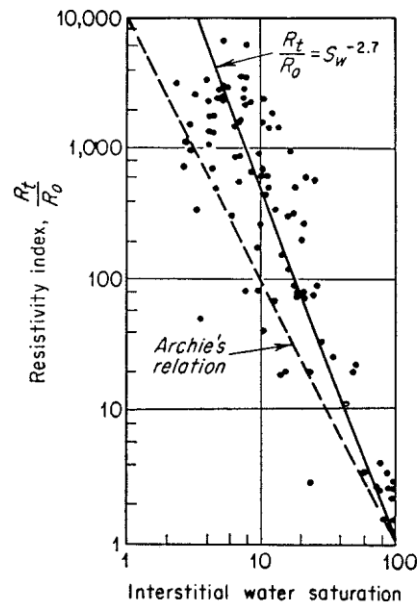


Fig. A.9: Resistivity index versus water saturation.

The generally accepted formation which relates water saturations and true resistivity R_t is that of Archie, which may be written in the following different form:

$$S_w = \sqrt{\frac{R_t}{R_o}} = \sqrt{\frac{FR_o}{R_t}} = \sqrt{\frac{R_o}{R_t} a}$$

where a is unique property of the rock and n is the saturation exponent, which in most cases is assumed to be 2.0.

4.5 Experiments

4.5.1 Resistivity Measurements of Fluid-Saturated Rocks

Description:

The objective of this experiment is to measure the main electrical properties of porous rock like water resistivity, formation factor, tortuosity, cementation factor, resistivity index and saturation exponent.

Procedure:

Resistance measurements in our laboratory are a *ratio of voltage decrease method* that is the ratio of voltage decrease between a reference resistor and a sample (to be measured) in series (Fig. 4.5). Then, the resistance of the sample is calculated and the resistivity of the sample can be developed when the size of the sample is known.

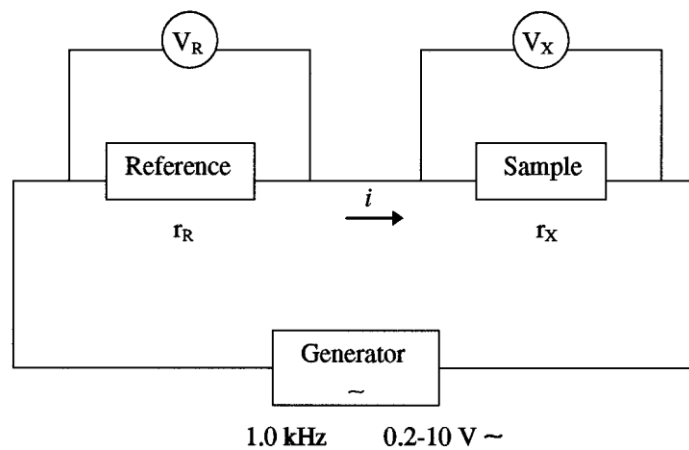


Fig. A.10: The electrical circuit of resistance measurements.

Calculations and report:

1. Calculate water resistivity, R_w

Equation:

$$R_w = \frac{r_x A}{L} = \frac{r_x \pi D^2}{4L}$$

Reference resistance (r_R):

V_x/V_R :

Water	Cell diameter D (m)	Cell length L (m)	Cell resistance, r_x ()	Water resistivity R_w (.m)
36 g NaCl/l				

2. Calculate formation factor, F , tortuosity, τ , and cementation factor, m

Reference resistance (r_R):, V_X/V_R :

Core No.	Core D (m)	Core L (m)	r_x ()	R_o (.m)	Porosity	Cementation factor, m	Formation Factor, F	Tortuosity,
R_w is equal to the value of R_w in (1).								

3. Calculate resistivity index, I , saturation exponent, n

Reference resistance (r_R):, V_X/V_R :

Core No.	Core D (m)	Core L (m)	r_x ()	R_t (.m)	R_o (.m)	S_w	Resistivity Index, I	Saturation exponent, n

R_o is equal to the value of R_o in (2).

5. CONTACT ANGLE AND WETTABILITY

5.1 Definitions

When a liquid is brought into contact with a solid surface, the liquid either expand over the whole surface or form small drops on the surface. In the first case the liquid will wet the solid completely, whereas in the latter case a contact angle $\theta > 0$ will develop between the surface and the drop.

When two immiscible fluids contact a solid surface, one of them tends to spread or adhere to it more so than the other. For example, for water-oil-solid system at equilibrium, the following equation (known as Young's equation) can be expressed

$$\sigma_{SO} - \sigma_{SW} = \sigma_{WO} \cos \theta$$

Where σ_{SO} is the interfacial tension between the oil and solid, σ_{SW} between the water and solid, σ_{WO} between the oil and water. θ is the contact angle measured through the water phase (Fig. 5.1).

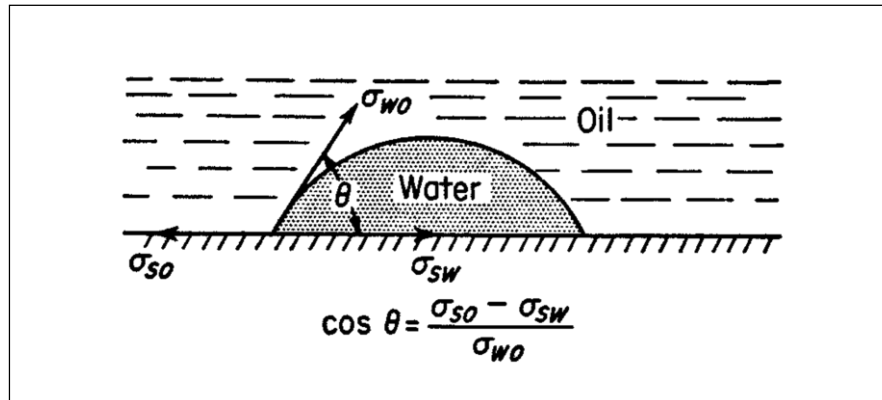


Fig. A.11: Interfacial tensions for water-oil-solid system at equilibrium.

Adhesion tension, which is a function of the interfacial tension, determines which fluid preferentially wets the solid. In the case of water-oil-solid, the adhesion tension A_T is defined as

$$5.2 \quad A_T = \sigma_{SO} - \sigma_{SW} = \sigma_{WO} \cos \theta$$

A positive adhesion tension A_T indicates that water preferentially wets the solid surface (water wet). An A_T of zero indicates that both phases have an equal affinity for the surface (neutral system). A negative A_T indicates the oil wets the solid surface (oil wet). The magnitude of the adhesion tension determines the ability of the wetting phase to adhere to the solid and to spread over the surface of the solid.

Wettability of a reservoir rock-fluid system is defined as the ability of one fluid in the presence of another to spread on the surface of the rock. Wettability play an important role in the production of oil and gas as it not only determines initial fluid distributions, but also is a main factor in the flow processes in the reservoir rock. The degree of wetting of solid by liquids is usually measured by the contact angle that a liquid-liquid interface makes with a solid.

Based on the contact angle, the *wetting index* *WI* is defined according to the tabulation below:

Wetting Index cos	Contact angle	Wetting condition
1.0	0°	completely water wetted
0	90°	neutral system
-1.0	180°	completely oil wetted

The limits of the scales are not definite, since a system with contact angle in the range of about 70° to 110° is considered neutral.

Another definition related to wetting is spreading *wetting*. In spreading wetting the adhesion forces between the liquid and the solid are greater than the cohesive forces between the liquid molecules, and the liquid will spread on the surface as a thin film. The spreading coefficient *S* is defined by the expression

$$S = -\frac{dG}{dA} = \sigma_{so} - (\sigma_{sw} + \sigma_{ow})$$

Where *dG* is the free energy increase due to spreading and *dA* is change in interfacial area. The liquid spreads spontaneously over the solid surface when *S* is positive or zero. When *S* is negative the liquid remains as a drop having a definite angle of contact with the solid surface. The equilibrium contact angle is such that the total surface free energy of the system is minimum.

To illustrate that, the quantitative relation between interfacial tension, contact angle and spreading coefficient are tabulated below:

Relative values		<i>S</i>
$\sigma_{so} < \sigma_{sw}$	$90^\circ < \theta < 180^\circ$	$S < 0$
$\sigma_{so} = \sigma_{sw}$	$\theta = 90^\circ$	$S < 0$
$\sigma_{sw} < \sigma_{so} < \sigma_{sw} + \sigma_{ow}$	$0^\circ < \theta < 90^\circ$	$S < 0$
$\sigma_{so} = \sigma_{sw} + \sigma_{ow}$	$\theta = 0^\circ$	$S = 0$
$\sigma_{so} > \sigma_{sw} + \sigma_{ow}$	does not exist	$S > 0$

The wettability of a reservoir rock system will depend on the following factors

- Reservoir rock material and pore geometry
- Geological mechanisms (accumulation and migration)
- Composition and amount of oil and brine
- Physical conditions; pressure and temperature
- Mechanisms occurring during production; i.e. change in saturations, pressure and composition.

Note that it is difficult to make a general model of wettability including all these factors. Although a lot of work has been done on wettability, it is not fully understood how the wettability of a porous rock surface is composed.

5.2 Measurement of Wettability

No satisfactory method exists for in situ measurement of wettability, and therefore it is necessary to estimate the wettability from laboratory measurements.

To obtain representative information on wetting preferences in the reservoir from laboratory experiments, the following conditions should be fulfilled:

- The method should not damage the surface properties of the rock.
- The method should enable differentiation of entire range of wettability from very Water-wet to very oil-wet.
- The results should include the effects of micro-heterogeneities of the rock (except where ideal systems are used).
- The results should not depend on parameters such as rock permeability and fluid viscosity unless these parameters can be isolated.
- The results should be reproducible both with respect to a given core sample and also between different cores having the same rock properties.

One way in which this can be done directly is by using the method of contact angle measurement by photographing a drop. Other indirectly methods are based on measurement on core samples. Three methods have been found worth discussing in more detail. These methods are:

- The Amott method
- The centrifuge method
- The contact angle method.

5.2.1 Measurements on Core Samples

In porous media the contact angle is determined indirectly. The methods are mainly based on measurements during displacement tests. But the problem is that no valid theory is developed for the relationship between displacement pressure and wetting preference.

The most common methods for measuring wettability on core samples are

- Displacement test with two different fluids
- Capillary pressure measurements
- Measurements of nuclear magnetic relaxation rate
- Measurement of dye absorption
- Imbibition measurements
- Imbibition and displacement (Amott method).

The test developed by Amott seems to be most accepted and widely used test in the oil industry.

5.2.1.1 The Amott Method

In principle, a core sample is chosen and saturated with oil. The oil-saturated sample is then placed in an imbibition cell surrounded by water. The water is allowed to imbibe into the core sample displacing oil out of the sample until equilibrium is reached (Fig. 5.2a). The volume of water imbibed is measured.

The core sample is then removed and the remaining oil in the sample is forced down to residual saturation by displacement with water. This may be done either in a centrifuge or displaced with a pump in a sealed core holder. The volume of oil displaced may be measured directly or determined by weight measurements.

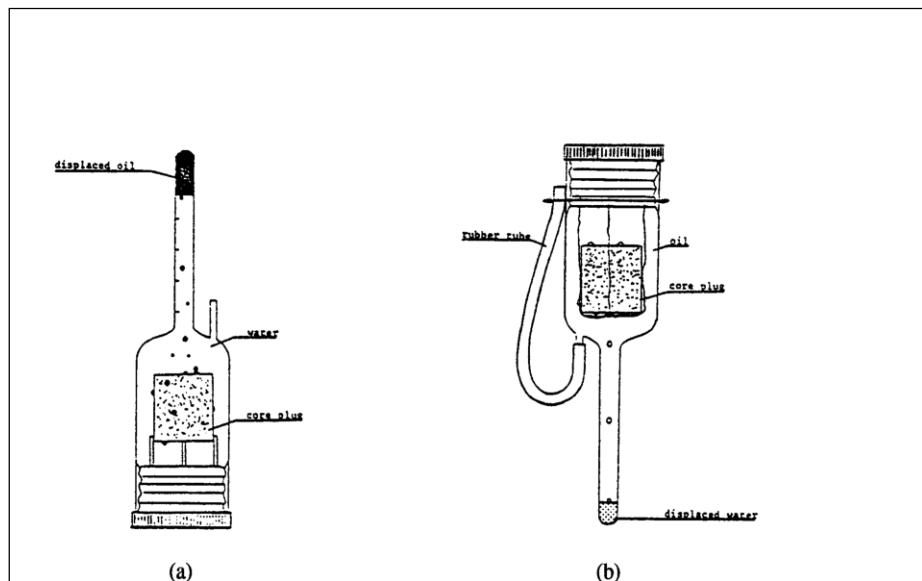


Fig. A.12: Imbibition cell with oil saturated core plug surrounded by water (a) and water saturated core plug surrounded by oil (b).

The core, now saturated with water at residual oil saturation, is placed in an imbibition cell and surrounded by oil. The oil is allowed to imbibe into the core displacing water out of the sample (Fig.A.12b). The volume of water displaced is measured (equal to volume of oil imbibed). The core is removed from the cell after equilibrium is reached, and remaining water in the core is forced out by displacement in a centrifuge. The volume of water displaced is measured. By recording all volumes produced, it is possible to calculate a wettability-index WI

$$WI = \frac{V_{O1}}{V_{O1} + V_{O2}} - \frac{V_{W1}}{V_{W1} - V_{W2}} = r_w - r_o$$

Where V_{O1} = volume of oil produced during water imbibition

V_{O2} = volume of oil produced during water flooding

V_{W1} = volume of water produced during oil “imbibition”

V_{W2} = volume of water produced during oil flooding

R_w = displacement-with-water-ratio

r_o = displacement-with-oil-ratio.

The wettability index will be a number between -1.0 and 1.0 where

$WI = 1.0$ completely water wetting

$WI = 0.0$ neutral

$WI = -1.0$ completely oil wetting.

The test is a fully empirical test but is based on some theoretical reasoning. A drawback is that the tests are difficult to perform at reservoir pressure and temperature.

APPENDIX I – Experiments Done By Author

This section looks at two reservoir engineering experiments in the laboratory done by the author by utilizing existing equipment in the Petroleum laboratory of the department of Chemical/Petroleum Engineering, university of Uyo. In this instance, two reservoir based experiments were conducted and reported. The first experiment would be measurement of porosity of core samples in the laboratory and the second would be the measurement of wettability using the Amott method.

EXPERIMENT ONE

TITLE OF EXPERIMENT: Measurement of Porosity by Saturation Method

AIM OF THE EXPERIMENT

The purpose of this experiment is to determine the porosity of the core samples in the petroleum engineering laboratory of the University of Uyo by the saturation method

TEST APPARATUS

The following are the basic apparatus used for the test: Core samples, Desiccator, Vacuum pump, Weighing balance, Vernier calliper, Exxsol D-60 oil

TEST PROCEDURE

- (a) Measure core dimensions
- (b) Measure dry weight of core samples
- (c) Put the core sample in desiccator connected to vacuum pump for 30 minutes
- (d) Saturate the core with Exxsol D-60
- (e) Calculate the pore volume (PV)
- (f) Calculate porosity

TEST RESULTS

(a) Dimensions of core sample

Length of core sample = 5cm, Diameter of core sample = 3.8 cm

(b) Weight of dry core sample = 112g

(c) Weight of saturated core = 120g

(d) Density of Exxsol D-60 oil = 0.88g/cm³

CALCULATIONS

$$\begin{aligned}\text{Bulk volume (BV) of core} &= \Pi r^2 h \\ &= \frac{22}{7} * \left(\frac{3.8^2}{2^2}\right) * 5 = 56.7 \text{ cm}^3\end{aligned}$$

$$\text{Weight of oil} = 120\text{g} - 112\text{g} = 8\text{g}$$

$$\text{Density of oil} = \frac{\text{Mass of oil}}{\text{Pore Volume}}; 0.88 = \frac{8}{PV}; PV = 9.09 \text{ cm}^3$$

$$\text{Porosity } (\phi) = \frac{PV}{BV} = \frac{9.09}{56.7} = 0.16 = 16\%$$

Conclusion: The porosity of the core samples in the petroleum engineering laboratory in the University of Uyo is 0.16.

Experiment Two

Title of Experiment: Measurement of Wettability by the Amott Method

Aim of the Experiment

The purpose of this experiment is to determine the wettability index of the core samples in the petroleum engineering laboratory of the University of Uyo by the Amott method

Test Apparatus

The following are the basic apparatus used for the test: Core samples, Desiccator, Vacuum pump, Weighing balance, Vernier calliper, Exxsol D-60 oil, Amott cell, stop watch, core holder, measuring beaker

Test Procedure

Saturate the chosen core sample with oil. The oil-saturated sample is then placed in an imbibition cell surrounded by water. The water is allowed to imbibe into the core sample displacing oil out of the sample until equilibrium is reached. The volume of water imbibed is measured. The core sample is then removed and the remaining oil in the sample is forced down to residual saturation by displacement with water. The volume of oil displaced may be measured directly.

The core, now saturated with water at residual oil saturation, is placed in an imbibition cell and surrounded by oil. The oil is allowed to imbibe into the core displacing water out of

the sample. The volume of water displaced is measured (equal to volume of oil imbibed). The core is removed from the cell after equilibrium is reached, and remaining water in the core is forced out by displacement. The volume of water displaced is measured. By recording all volumes produced, it is possible to calculate a wettability-index WI

TEST RESULTS

Table 6.1: Recovery of oil from core sample
PV = 9 cc, $P_{ovb} = 10$ bars, $q_{in} = 5$ cc/hr

Time (Minutes)	V_o (cc)	Recovery (%)
0.0	0.0	0.0
2.0	1.1	12
4.0	1.2	13
6.0	1.3	14
8.0	1.4	16
10.0	1.6	18

$$V_{o, sp} = 6.3 \text{ cc}$$

$$V_{o, f} = 0$$

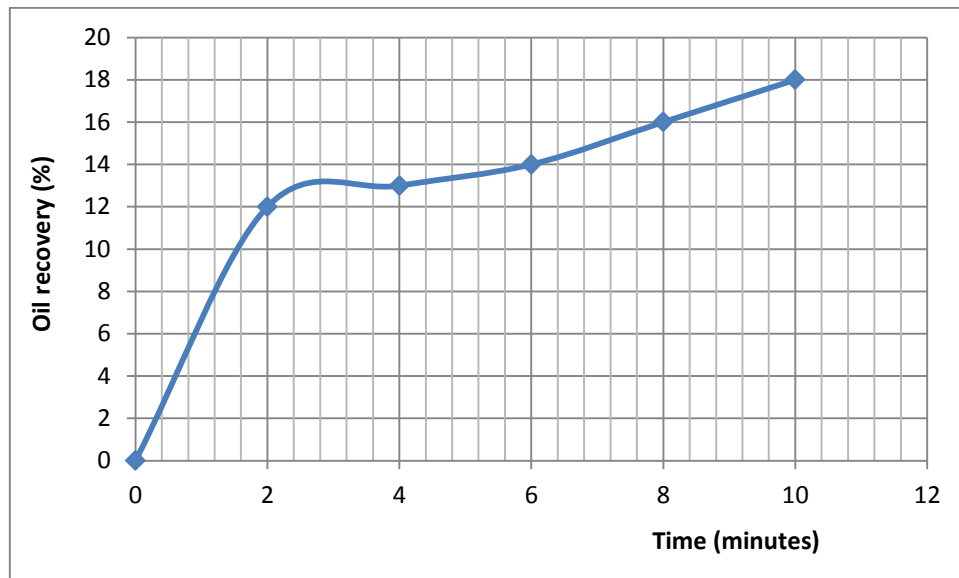


Figure 5.3: Plot of oil recovery with time from core sample

CALCULATIONS

$$I_W = \frac{V_{O,SP}}{V_{O,SP} + V_{O,F}}$$

$$I_W = \frac{6.3}{6.3+0} = 1$$

$$I_W = 1$$

Discussion/Conclusion: The plot in figure 5.3 shows the oil recovered in percentage from the saturated core sample. It is observed that the rate of oil recovery increases with time. On the

other hand, since $I_w = 1$, from the calculations done, then the core samples in the petroleum engineering laboratory in the University of Uyo is strongly water wet.

Sources of Error:

In both experiments measuring specific weights of core on balances, use of the stop were required and may have led to error in the results. Precision in the amount of water, oil displaced during imbibition and drainage processes may have been slightly off the desired amount. Also how well the equipment was cleaned between each run may have affected the results. Reading values of the volumes of oil or water recovered is up to the person taking the readings due to meniscus and may result in slightly different results being found.