University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Environmental Technology/ Offshore Environmental Engineering	Spring semester, 2014 Restricted access
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Thesis title: SUPERHEATED STEAM DISTILLATION FOR TREATMENT OF DRILL CUTTINGS CONTAMINATED WITH OIL BASED DRILLING FLUIDS

Credits (ECTS): 30 ECTS

Key words: Superheated, steam, distillation, offshore, drill cuttings, treatment, oil, gas, environmental discharge, retained oil on cuttings, environmental regulations, Dalton's Law of Partial Pressures, Universal Gas Law, temperature, boiling point, immiscible, miscible, mixtures, vapor pressure, extraction	Pages: 85 + enclosure: 23 Stavanger, June 26, 2014

SUPERHEATED STEAM DISTILLATION FOR TREATMENT OF DRILL CUTTINGS CONTAMINATED WITH OIL BASED DRILLING FLUIDS

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2014

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ABSTRACT

Offshore drilling activities for the oil and gas industry produce massive quantities of waste material including drill cuttings contaminated with oil based drilling fluids/muds. In offshore Norway and other Oslo Paris Commission (OSPAR) signatory countries contaminated drill cuttings are permitted for discharge if they contain less than one percent retained oil on cuttings. There are very few currently available offshore treatment technologies that can meet the stringent retained oil on cuttings requirements. This thesis describes the utilization of the Ideal Gas Law and Dalton's Law of Partial Pressure in an oil distillation process using superheated steam. The overall objective is to develop a technology which can be used for offshore treatment of drill cuttings to remove retained oil on cuttings. In the thesis, the superheated steam distillation process is performed in a laboratory setup, and deviations between the standardized reference results and the results from the superheated steam trials are discussed. The results of the superheated steam distillation experiments clearly show that the base oil distillation rates using superheated steam are significantly increased when compared to conventional distillation at 100 $^{\circ}$C. The superheated steam distillation technology shows promise for potential use in the offshore treatment of drill cuttings to remove retained oil on cuttings.

ACKNOWLEDGEMENT

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NOMENCLATURE

^0C	Temperature, degrees Celsius
CO_2	Carbon Dioxide
ΔHvap	Enthalpy of Vaporization
ln P	Natural Log of Vapor Pressure
Kelvin (1/T)	Absolute Temperature in Kelvin
R	Universal Gas Constant [8.314 J/(mol·K)]
C	Y-intercept
T	Temperature in Kelvin,
P	Vapor Pressure
V	Volume
n	Number of moles
Pt	Total Vapor Pressure above the Liquid Mixture
XA	Mole fraction of Component "A"
nA	Number of moles of "A"
nt	Total Number of Moles
P_A	Partial Pressure of Component A ,
P_{total}	Total Vapor Pressure
P_A^O	Independent vapor pressure of pure component "A"
P_B^O	Independent vapor pressure of pure component "B"
m_s	Mass of Steam in the Vapor
m_o	Mass of oil in the vapor
P_s	Partial Pressure of steam
P_o	Partial Pressure of Oil
MW_s	Molecular Weight of Steam
MW_o	Molecular Weight of Oil
$M_{o/w}$	Mass Ratio of Oil Production Per Unit Water Production

C	Represents Carbons
H	Represents Hydrogen
n	Number of Carbons
mbar	Millibar

ABBREVIATIONS

OSPAR	Oslo Paris Commission
PAH	Polycyclic Aromatic Hydrocarbons
SBM	Synthetic Based Muds/Fluids
ROC	Retained Oil on Cuttings
OCNS	Offshore Chemical Notification Scheme
HOCNF	Harmonized Offshore Chemical Notification Format
HQ	Hazard Quotient
CHARM	Chemical Hazard and Risk Management
BCF	Bioaccumulation Factor
Acute L(E)C_{50}	Acute Toxicity Lethal Effect Concentration for 50 % of Test Subjects
USEPA	United States Environmental Protection Agency
NPDES	National Pollutant Discharge Elimination System
WBM	Water Based Mud/Fluid
SBM	Synthetic Based Mud/Fluid
OBM	Oil Based Mud/Fluid
LC50	Acute Toxicity Lethal Concentration for 50 % of Test Subjects
EMOBM	Enhanced Mineral Oil Based Mud/Fluid
EMP	Environmental Management Plan
IBAMA	Brazilian Institute of Environment and Renewable Natural Resources
OECD	Organization for Economic Cooperation and Development
log Pow	Bioaccumulation Potential
TCC	Thermomechanical Cuttings Cleaner
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
MSDS	Material Safety Data Sheet
GC-MS	Gas chromatography-mass spectrometry

1   CHAPTER ONE: INTRODUCTION

1.1   Problem of Offshore Drill Cuttings Contaminated with Oil Based Drilling Fluids/Muds

Offshore drilling activities for the oil and gas industry produce massive quantities of waste material including drill cuttings contaminated with oil based drilling fluids/muds. When drill cuttings become contaminated with oil based drilling fluids/muds they are considered hazardous waste. All hazardous waste must be handled and disposed of according to regional environmental regulatory standards. In offshore Norway and other Oslo Paris Commission (OSPAR) signatory countries contaminated drill cuttings are permitted for discharge if they contain less than one percent retained oil on cuttings [1]. There are very few currently available offshore treatment technologies that can meet the stringent retained oil on cuttings requirements [1]. As a result, the contaminated drill cuttings must be either transported to shore for treatment or reinjected into subterranean geological formations for disposal [1]. According to the Norwegian Environment Agency, in the year 2012 over 314,000 tons of hazardous waste was transported to shore for treatment and disposal [2]. As can be seen in Figure 1.1 below, the vast majority of this hazardous waste was drilling waste mostly comprised of contaminated drill cuttings [2].
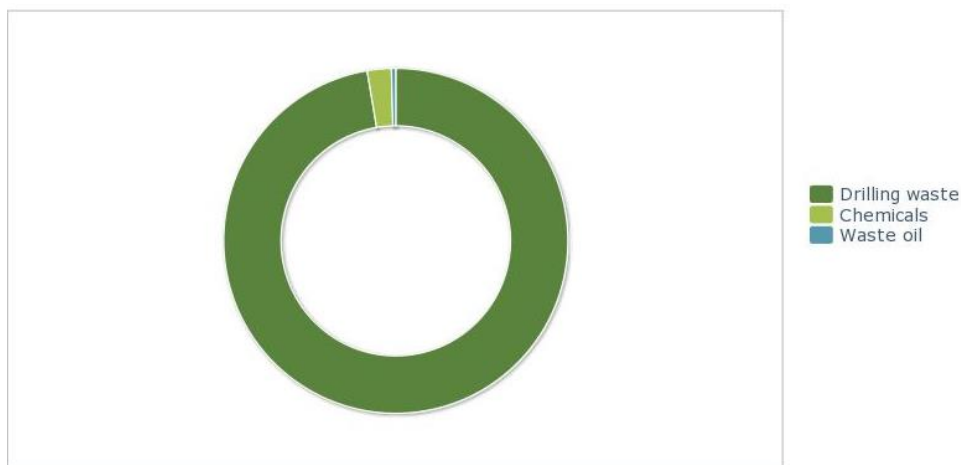
Figure 1.1: Diagram showing the composition of hazardous waste produced and transported to shore from offshore activities on the Norwegian shelf totaling 314,000 tons in 2012 [2]

Between the years of 1997-2012 there has been a tremendous increase in the amount of hazardous waste transported to shore in Norway as can be seen in Figure 1.2 below. This increase in hazardous waste transfers to shore is due to several operational factors. The driving factors include the increased use of oil based drilling fluids and problems encountered with reinjection of contaminated drill cuttings into geological formations[2].
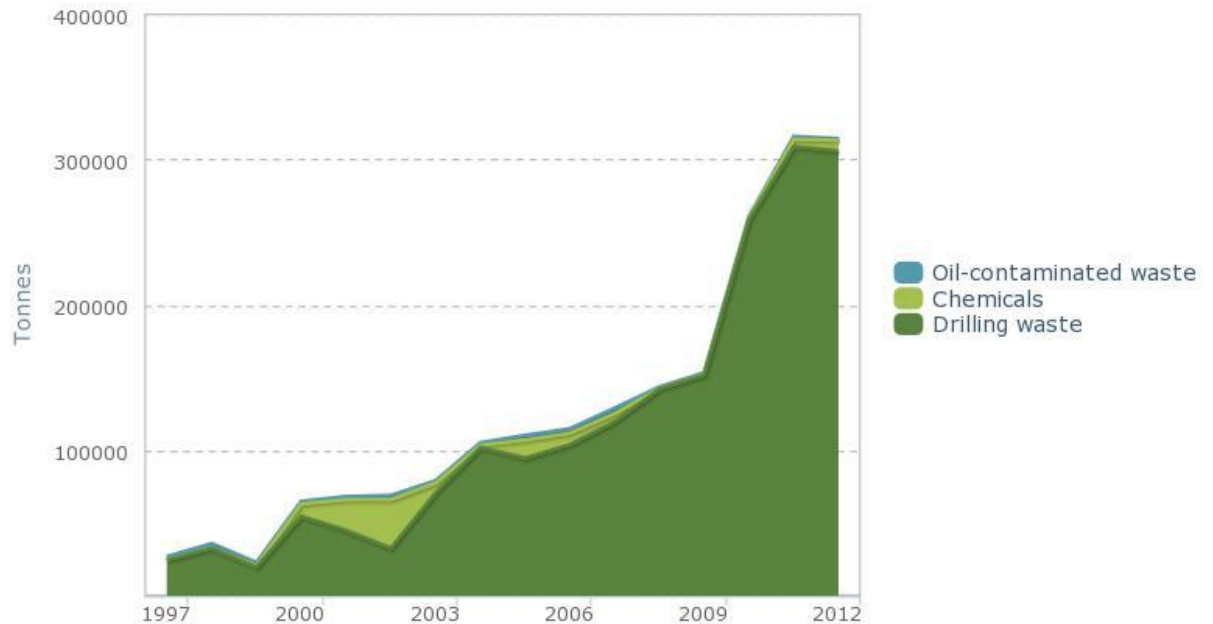
Figure 1.2: Graph showing tons of hazardous waste produced and transported to shore per year from oil and gas activities on the Norwegian shelf [3]

Transport of contaminated drill cuttings to shore is both expensive and has significant negative impacts on the environment. The equipment and ships used to transport the waste produce large quantities of greenhouse gasses as well as nitrogen oxides, sulphur oxides, ozone, and other air pollutants [3]. There is also a risk of spills and accidents which could cause environmental damage to ecologically sensitive areas [3]. Transport to shore involves many crane lifts and other potentially risky activities that could cause health and safety impacts to personnel [3].

Reinjection poses its own set of risks including fracturing of the geological formation and leakage of the contaminated drill cuttings and fluids into the environment [2]. In addition, discharge of contaminated drill cuttings that do not meet the one percent retained oil on

cuttings requirements is both illegal and damaging to the benthic communities [4, 5]. The effects of discharging contaminated drill cuttings are two fold and include both chemical toxicity as well as physical burial of benthic communities [4, 5]. The development of an effective offshore treatment technology that can meet the stringent environmental retained oil on cuttings requirements is of utmost importance.

1.2   Use of Superheated Steam Distillation for Offshore Treatment of Contaminated Drill Cuttings

There is limited published material on the use of superheated steam for distillation and it has yet to be extensively investigated for extraction of oil based drilling fluids from drill cuttings. Superheated steam distillation is a technology that could potentially be applied offshore for the treatment of contaminated drill cuttings. This technology has many advantages over conventional steam distillation including high thermal efficiency, high steam dryness, low density, high heat storage capacity, lack of condensate formation, and higher achievable distillation temperatures [6]. The predicted superheated steam distillation rates calculated using the Ideal Gas Law and Dalton's Law of Partial Pressure are significantly higher than conventional steam distillation rates. The development of such a technology could help solve the increasing problem of how to treat offshore contaminated drill cuttings in order to meet stringent environmental discharge regulations.

1.3   Objectives

This thesis describes the utilization of the Ideal Gas Law and Dalton's Law of Partial Pressure in an oil distillation process using superheated steam. The overall objective is to develop a technology which can be used for offshore treatment of drill cuttings to remove retained oil on cuttings. In the thesis, the superheated steam distillation process is performed in a laboratory setup, and deviations between the standardized reference results and the results from the superheated steam trials are discussed. The reason why it is of interest to investigate the use of superheated steam in such a process is because according to the gas laws, oil distillation rates will be significantly increased compared to normal steam distillation at 100 ⁰C.

2 CHAPTER TWO: OFFSHORE DRILL CUTTINGS THEORY

2.1 Offshore Drilling Process

Drilling a well offshore involves several key components such as the drill rig, drill bit, drilling fluids, and associated drill cuttings. Typically wells drilled offshore utilize a continuous rotary drilling process whereby a rotating drill bit crushes and breaks rock at the bottom of the hole. The continuous process is facilitated by the use of specially designed drilling muds/fluids which carry away cuttings and lubricate the drill bit. The offshore drill rig is a self-contained unit consisting of all machinery and equipment necessary to drill a well. A typical offshore drill rig contains mud tanks, mud pump, shale shaker, drilling derrick, draw-work, top drive, drill string, drill pipe, and associated drilling equipment. Figure 2.1 below shows a basic drilling rig schematic with typical rig equipment illustrated. The drilling derrick is the pyramidal structure that supports the drill string and block and tackle system which is the main lifting system for drilling operations. The draw-work is a large mechanical reel that is used to hoist cables through the block and tackle system for heavy lifting operations such as adding drill pipe to the drill string. The top drive rotates the drill string which transfers the rotational energy down to the drill bit. The shale shaker is the primary treatment system used to separate drill cuttings from drill mud/fluid. The drill cuttings then undergo further treatment to remove contaminants and the valuable mud/fluid is recycled to the drilling process [7].
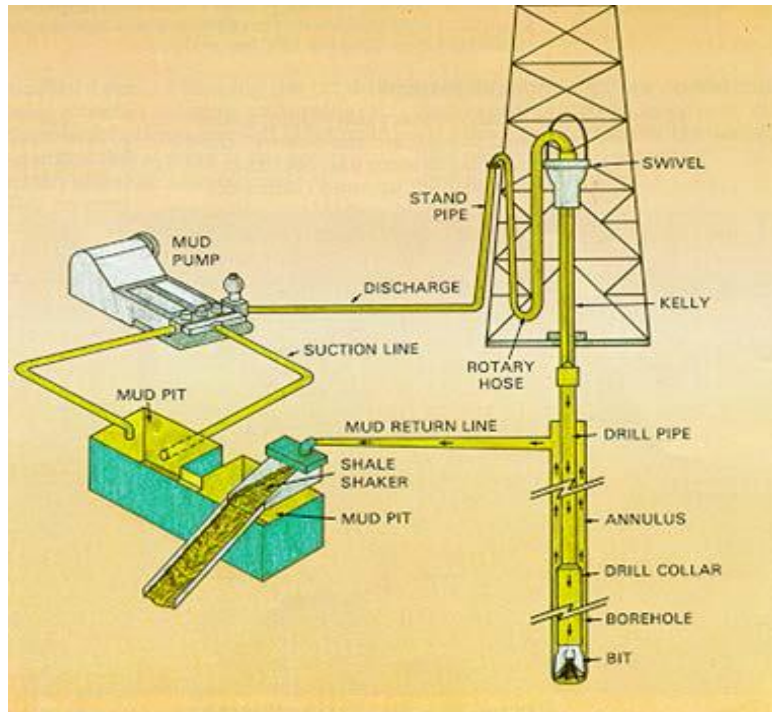
Figure 2.1: Drilling rig schematic [7]

Offshore drill rigs come in several different forms depending on operational needs and environmental conditions. Figure 2.2 shows several examples of typical offshore drilling rigs. The mobile drill rigs such as jack-up, drill-ship, and semisubmersible are generally used for exploration well drilling while fixed platforms are used for development well drilling [7]. A key factor differentiating offshore drill rigs from onshore drill rigs is the limited space and weight restrictions offshore. Onshore operations have essentially no space or weight restrictions and can therefore house extensive process and treatment facilities. Offshore facilities in contrast must be designed to minimize footprint and weight while maximizing efficiency and output. These design restrictions limit the processing capability of offshore facilities often leading to product or waste being shipped or piped to shore for further processing to meet requirements [1].

Figure 2.2: Examples of offshore drill rigs [7]

2.2   Drilling Muds/ Fluids

According to Encyclopaedia Britannica, the terms drilling mud and drilling fluid refer to the same thing and can be used interchangeably [8]. Therefore, throughout this thesis the terms drilling mud and drilling fluid refer to the same thing and are used interchangeably. Drilling muds/fluids play an integral role in the offshore drilling process. The key functions that they perform include cooling and lubrication of the drill bit/drill string, transport and suspension of drill cuttings, stabilization of wellbore, controlling formation pressure and preventing blowout, providing hydraulic energy transfer, and minimization of formation damage [9]. Figure 2.3 below illustrates how drilling muds/fluids are circulated through the drill string and up the well annulus in order to perform key operational functions.
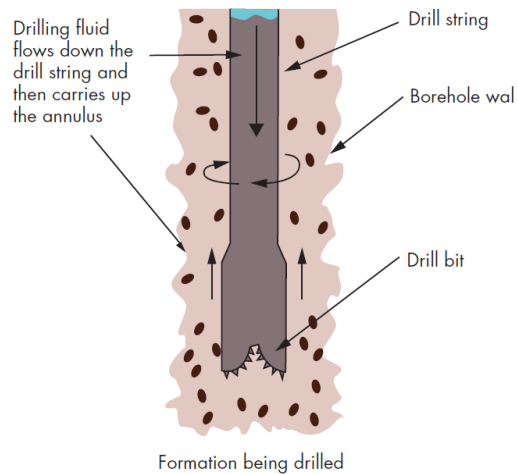
Figure 2.3: Illustration of down-hole drilling mud/fluid operations [10]
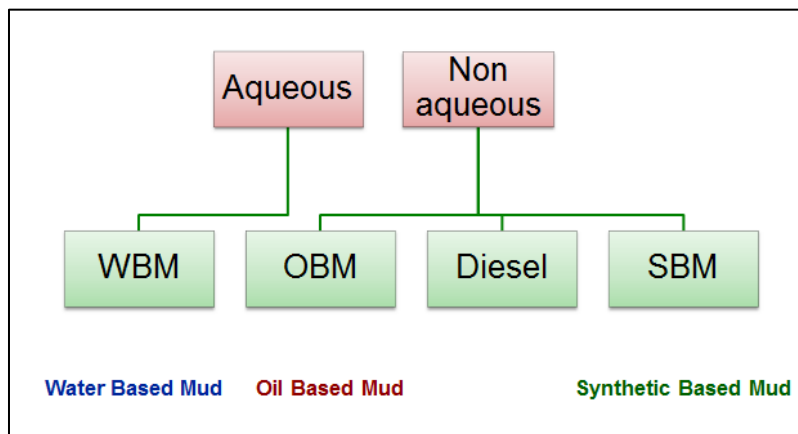
Figure 2.4: Classification of drilling muds/fluids [9].

Drilling muds/fluids are classified based on the composition of their base fluid either aqueous or non-aqueous as shown in Figure 2.4. The aqueous category of drilling fluids/muds includes all water based muds/fluids. Water based muds/fluids are made up of water mixed with weighting agents bentonite clay and barite. Chemicals such as thinners, filtration control agents, lubrication agents and others are added to water based mud/fluid to enhance drilling performance [10]. On a weight percent basis, a typical water based mud/fluid will contain 76 % water, 15 % barite, 7 % bentonite, and 1 % salts and other additives as shown in Figure 2.5 below [10].
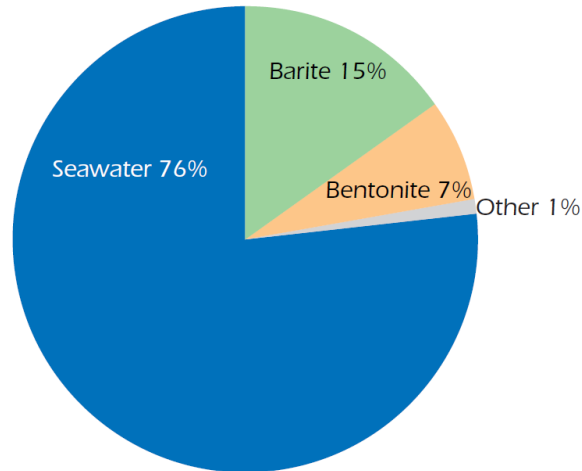
Figure 2.5: Diagram of typical aqueous drilling mud/fluid on a weight percent basis [11]

Non-aqueous drilling fluids/muds are essentially emulsions of oil, diesel, mineral oil, or synthetic hydrocarbons. Figure 2.6 below shows the typical composition of a non-aqueous drilling fluid/mud on a weight percent basis. These non-aqueous fluids/muds are broken down into three distinct groups based on aromatic content. Oil, diesel, and conventional mineral oil based muds/fluids typically have high aromatic content and are placed in group I. Low toxicity mineral oil based muds/fluids typically have medium aromatic content and are placed in group II. Muds/fluids with low aromatic content for example synthetic hydrocarbons and specially formulated mineral oils are placed in group III [1].
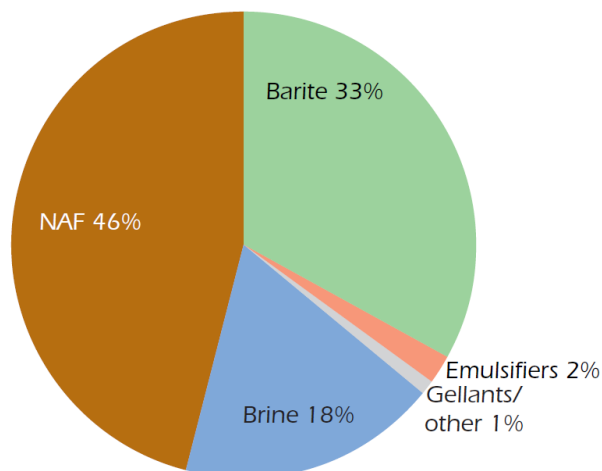
Figure 2.6: Diagram of typical non-aqueous drilling muds/fluids on a weight percent basis [11]

Group I oil based muds/fluids are made from processed crude oil. Since these muds/fluids are sourced from crude oil they contain hydrocarbon compounds such as olefins, paraffins, polycyclic aromatic hydrocarbons (PAHs), and aromatics. Diesel oil based muds/fluids normally have a PAH content between 2-4 % and conventional mineral oil contains between 1-2 % PAH [10]. These oil based muds/fluids contain highly toxic compounds such as fluorine, phenanthrene, biphenyls, alkylated benzenes and naphthalene [1]. Drill cuttings exposed to group I oil based mud/fluid are typically not permitted to be discharged into the environment unless treated to remove retained oil on cuttings [10].

Group II muds/fluids are usually made up of low toxicity mineral oils derived from crude oil. The PAH content of group II muds/fluids are significantly lower than group I through the use of distillation techniques [10]. These muds/fluids typically have a PAH content of between 0.001 % to 0.35 % [10]. The lower toxicity and low PAH content of these muds/fluids make them a good alternative to group I based muds/fluids in certain drilling applications[10].

Group III muds/fluids have a PAH of less than 0.001 % and are typically made from synthetic based muds/fluids(SBM) and highly processed mineral oils [10]. SBMs are made up of synthesized hydrocarbons such as paraffins, esters, and olefins [10]. These compounds are created from the combination of pure chemicals and therefore lack many

of the impurities and PAHs typically found in muds/fluids derived from processed crude oil. Another advantage of SBMs is their higher biodegradability and lower toxicity when compared to traditional oil based muds/fluids [1]. Some oil producing regions allow the offshore discharge of drill cuttings exposed to SBMs due to their low inherent environmental impacts [1]. The other Group III muds/fluids are made from highly processed mineral oil. These muds/fluids are derived from crude oil but the advanced processing and distillation removes most of the contaminants and PAHS [10]. The resulting drilling fluid has many characteristics resembling synthesized paraffins [10].

2.3   Aqueous versus Non-Aqueous Drilling Muds/Fluids

Aqueous drilling muds/fluids are generally less toxic, less expensive, more environmentally friendly, and easier to dispose of after use than non-aqueous drilling muds/fluids. Drill cuttings exposed to aqueous drilling muds/fluids can typically be discharged without treatment whereas cuttings exposed to non-aqueous drilling muds/fluids often require specialized treatment before disposal [10]. Despite the numerous environmental advantages of aqueous drilling muds/fluids they cannot fulfill all of the specialized drilling requirements needed in the offshore environment. The inability of aqueous drilling muds/fluids to perform optimally under certain drilling conditions is one of the main driving forces for the use of non-aqueous muds/fluids. Even though aqueous muds/fluids are less expensive than non-aqueous muds/fluids this cost savings is often nullified by lack of drilling performance [10].

There are numerous examples and situations where aqueous muds/fluids simply cannot compare to the performance of non-aqueous muds/fluids. An example is when drilling in clay or shale where the water component of the aqueous mud/fluid will interact with these formations and cause increased resistance to the rotation of the drill pipe [10]. Non-aqueous muds/fluids have far superior lubricating properties which reduce friction, prevent drill pipe from sticking to the well bore, and enhance energy transfer to the drill bit. These lubricating functions are critical when drilling horizontal or extended reach wells due to the increased distances and risks of fracturing the well [10]. Non-aqueous muds/fluids perform better at high temperatures greater than 350 °C and typically are

lighter than aqueous muds/fluids. These characteristics are critical when drilling deep wells or in geological formations susceptible to fracturing [10]. Other advantages of non-aqueous muds/fluids include reduced hydrate formation, shorter drilling time per well and reduced drilling waste [10]. Hydrate formation is reduced due to the lower water content and chemical makeup of the non-aqueous mud/fluid. The amount of time used and the quantity of waste produced per well is reduced due to better drilling performance of non-aqueous muds/fluids in shale and clay formations. Interactions of aqueous muds/fluids with these formations can cause the material surrounding the borehole to go into suspension and contribute to drilling waste. These same interactions can cause significant time delays due to reduced drilling efficiency and friction [10]. The recycle rates of non-aqueous muds/fluids are much higher than those of aqueous muds/fluids due to the decomposition of polymers and other components over time in aqueous muds/fluids [9]. This decomposition is exacerbated at high temperatures and pressures, therefore making aqueous muds/fluids unsuitable for deep drilling where these conditions are commonplace.

A combination of both mud/fluids types is typically used when drilling offshore wells. This is done in order to balance the environmental and economic benefits of aqueous muds/fluids with the superior drilling properties of the non-aqueous muds/fluids [10]. When both types of muds/fluids are used; the aqueous muds/fluids are typically used in the upper portion of the well and the non-aqueous muds/fluids are used in the lower portions of the well [10]. Aqueous muds/fluids are used in the upper portion of the well because this section has lower pressure and temperature thus enabling these muds/fluids to perform optimally. Non-aqueous muds/fluids are used once the temperatures and pressures become too great for optimum performance of aqueous muds/fluids. In addition to the lower portions of the well, non-aqueous muds/fluids are used when drilling through shale or clay and under high incline situations [10]. This optimization of the use of both muds/fluids translates into cost savings as well as increased drilling performance.

2.4   Drill Cuttings

As with any type of drilling operation used to create a bore-hole, material must be excavated and removed. This excavated material is what is known as drill cuttings and its composition is dependent on the subterranean geological formations present. Drill cuttings are formed by the rotational motion of the drill bit at the bottom of the hole which cuts and crushes rock into small pieces [10]. These drill cuttings are put into suspension by drilling muds/fluids and are carried up the well annulus to the drill rig. Figure 2.7 below shows a picture of clean drill cuttings under a 10 X microscope. As can be seen in Figure 2.7 a large proportion of the drill cuttings are made up of different types of shale and limestone. These sedimentary rocks typically make up a large proportion of drill cuttings because they are often found in oil bearing formations. Other components of drill cuttings can include sand, clay, fine silts, and pieces of rock the proportion of which is dependent on the type of formation being drilled [10].
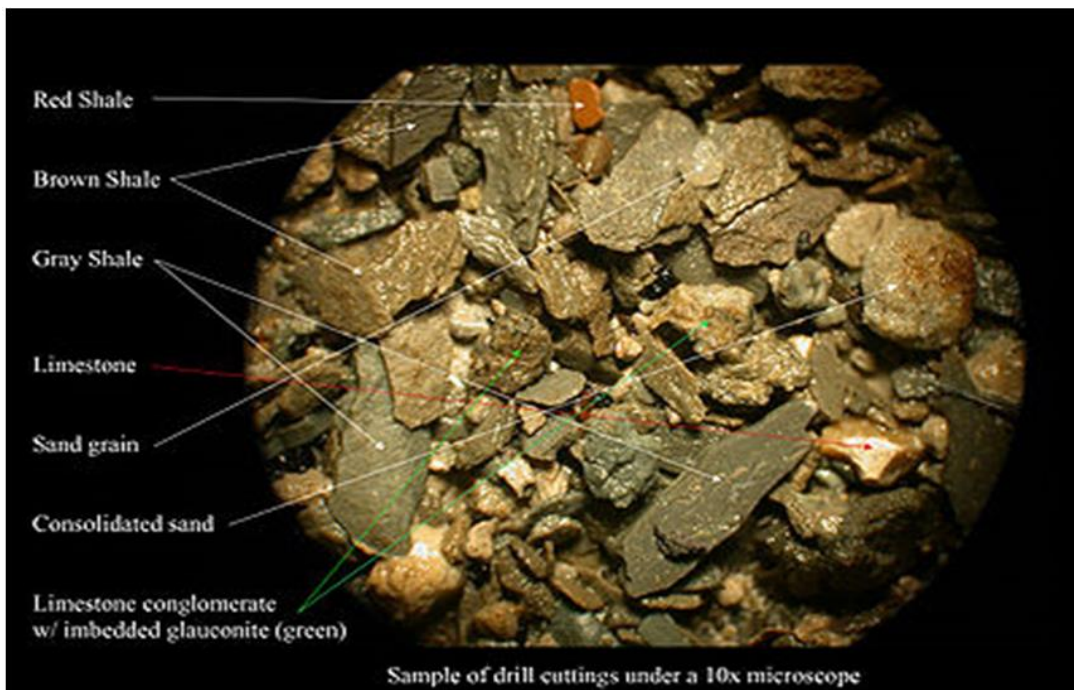
Figure 2.7: Clean drill cutting shown under 10 X microscope [9]

Clean drill cuttings are considered non-hazardous and are allowed for discharge. However, once they come into contact with formation oil or non-aqueous drilling muds/fluids they become a hazardous waste and must be treated accordingly[9]. Figure 2.8 below shows drill cuttings that have been exposed to non-aqueous oil based drilling mud/fluid. As can be seen in Figure 2.8 once the drill cuttings are exposed to oil based mud/fluid they take on a dark black/grey color similar to that of oil.

Figure 2.8: Drill cuttings exposed to oil based mud/fluid [9]

The extent to which formation oil or non-aqueous mud/fluid adheres to drill cuttings depends on many factors including the composition, particle size, and porosity of the exposed drill cuttings. Drill cuttings with small particle size have more surface area onto which oil or non-aqueous mud/fluid can adhere than large particle sized drill cuttings. Certain rock types such as those with high porosity have a higher propensity for oil adhesion. Oil or non-aqueous mud/fluid can flow into pores within the drill cuttings and become entrapped or attached to the pore surface. The viscosity, chemical composition, and type of formation oil or non-aqueous mud/fluid that comes into contact with drill cuttings can also affect the amount of oil retained on cuttings. Higher viscosity drilling

muds/fluids have a tendency to heavily coat and stick to drill cuttings yielding a higher amount of oil retained on drill cuttings. This high viscosity also decreases the effectiveness of solids separation equipment allowing oil and non-aqueous mud/fluid to follow the drill cuttings in the solid waste stream [10]. Certain ions present in oil or non-aqueous drilling fluids can interact with charges on the surface of drill cuttings causing a positive attraction where oil becomes attached to the surface of drill cuttings. All of these factors discussed contribute to the amount of retained oil on cuttings (ROC). The percent ROC is one of the main parameters that environmental regulators use to control the discharge of drill cuttings exposed to formation oil or non-aqueous mud/fluid [1].

2.5   Drill Cutting Environmental Discharge Regulations

Environmental regulators have established discharge limits on the percent by weight of retained oil on cuttings. These limits were established in order to prevent negative effects on the environment. Oily drill cuttings can have several negative environmental effects particularly impacting benthic biota. These benthic communities bear the greatest impacts because drill cuttings tend to settle to the bottom of the ocean in piles near the offshore discharge point. These piles of drill cuttings have both physical and chemical effects on the native populations. The chemical effects are due to the inherent toxicity of the oil retained on the cuttings as well as biodegradation of the oil and subsequent oxygen depletion. The physical effects are due to burial as well as changes in material size and composition [10]. The goal of environmental regulators is to minimize these negative environmental effects while still enabling exploitation of valuable oil resources. The specific limits of percent ROC and regulatory strategies vary between oil producing regions. This is due to various reasons such as geological conditions, environmental sensitivity, available technology, and perceived risk to the environment. The following section summarizes key environmental regulatory standards for discharge of drill cuttings in several oil producing regions [1].

2.5.1   Norway and the North Sea
The key regulatory drivers for discharges to the North are the Offshore Chemical Notification Scheme (OCNS), and the Oslo Paris Commissions (OSPAR) Harmonized Offshore Chemical Notification Format (HOCNF). The HOCNF ranks offshore

chemicals based on their inherent hazard risk. Each chemical is assigned a Hazard Quotient (HQ) determined through the use of a modeling system called CHARM (Chemical Hazard and Risk Management) [1]. The key chemical properties that contribute to a chemical's HQ are its persistency (Half-life 50 days), bioaccumulation factor (BCF >= 500), and toxicity (Acute L(E) C_{50} = < 1 mg/L). Non-aqueous drilling muds/fluids and formation oil fall under these guidelines and must be analyzed accordingly to determine their specific HQ. Currently it is permitted to discharge into the North Sea and Norwegian Sea drill cuttings contaminated with water based mud/fluid, oil based mud/fluid or synthetic based mud/fluid as long as they contain less than 1 % ROC. However, the retained oil must pass several tests that show it biodegrades within a specified time period and does not bioaccumulate [1].

2.5.2   United States and the Gulf of Mexico

Discharge of drill cuttings in the Gulf of Mexico is administered by the United States Environmental Protection Agency (USEPA) with the use of National Pollutant Discharge Elimination System (NPDES) permits [1]. These NPDES permits specify the discharge limitations of drill cuttings associated with water based mud/fluid (WBM), synthetic based mud/fluid (SBM), and oil based mud/fluid (OBM). Drill cuttings associated with WBM are permitted for discharge as long as they meet limits on free oil (Static sheen test), cadmium (3 mg/kg), mercury (1 mg/kg) in stock barite, suspended particulate toxicity (96 hour LC50 greater than 30,000 mg/kg) and discharge rate (1,000 bbl/h maximum) [1]. All discharges must be a minimum of 4.8 km from shore and a minimum of 1,000 m from biologically sensitive areas and ocean disposal sites [1]. Drill cuttings associated with SBM must meet the same limits as WBM cuttings in addition they must also meet limits relating to the base fluid and cuttings composition [1]. SBM cuttings must not exceed 6.9 % internal olefins and/or 9.4 % esters retained base fluid on cuttings. In addition, they must meet sediment toxicity standards and must meet limits on retained formation oil on cuttings [1]. The SBM base fluid must comply with limits on biodegradation rate, sediment toxicity, and PAH content [1]. Cuttings associated with OBM or enhanced mineral oil based mud/fluid (EMOBM) are not permitted for discharge in the U.S. [1].

2.5.3   Canada

In Canada, the offshore discharge of drilling mud/fluid and cuttings is governed by the Offshore Waste Treatment Guidelines, 2010 [12]. This document establishes guidelines for the management, evaluation, treatment, and monitoring of drilling muds/fluids and cuttings. All drilling muds/fluids must be pre-evaluated for toxicity before they are permitted to be used offshore in Canada. The use of WBM is encouraged and WBM is permitted for discharge offshore without treatment. Operators must obtain a permit for WBM discharge and must establish best management practices to reduce the total volumes discharged. SBMs and EMOBMs are not permitted for discharge except for small amounts retained on cuttings. As a result, these muds/fluids must be re-used, injected into a well, or shipped to shore for processing and disposal [1]. Oil base muds/fluids can only be used under extreme circumstances and are never permitted for discharge [12].

Drill cuttings resulting from WBM operations are permitted for discharge without any treatment. This is in contrast to drill cuttings exposed to SBM or EMOBM which should be re-injected below the surface or shipped to shore for processing and disposal. If the operator can prove that these disposal methods are not feasible, then drill cuttings must be treated with the best available technology to meet discharge requirements [12]. The discharge requirements for offshore Canada are based on a 48 hour weighted average where the ROC must be less than 6.9 g of oil per 100 g of wet cuttings [12]. Drill cuttings resulting from OBM operations are never permitted for discharge and must be either re-injected below the surface or shipped to shore for processing and disposal [12].

2.5.4   Australia

In Australia, offshore drilling waste regulations are administered by the Department of Industry and Resources. Operators must have an approved Environmental Management Plan (EMP). The EMP includes justification for drilling mud/fluid selection, environmental assessment of drilling mud/fluid to include bioaccumulation, biodegradation and toxicity results, environmental monitoring plan, and a drilling waste disposal plan [13]. Drill cuttings resulting from SBM operations are permitted for discharge if the ROC is less than 10 % by dry weight or 6.9 % by wet weight [1].

Australia has also established restrictions on the borehole size that SBM drill cuttings may be discharged from in order to encourage the use of WBM in larger upper bore sections. SBM drill cuttings are only permitted for discharge if they are sourced from 12 ¼ in diameter borehole or smaller. If OBM is to be used in lower well sections, then it must have an aromatics content of less than 1 %. Cuttings associated with OBM may be discharged if the ROC is less than 1 % [1].

2.5.5 Brazil

In Brazil, offshore drilling waste regulations are administered by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) [1]. OBM discharges are not permitted in Brazil. However, drill cuttings associated with SBM are permitted for discharge if they meet certain environmental performance criteria. These criteria include biodegradability (OECD 306 method), toxicity (Before and after drilling tests on organisms from four different phyla), PAH content, and bioaccumulation potential (log Pow) [1]. Cuttings associated with SBM must have a ROC of less than 6.9 % for paraffin and olefin, less than 9.4 % for ester, and less than 1 % for formation oil [1]. All SBM must contain less than 1 mg/kg mercury and less than 3 mg/kg cadmium in stock barite [1]. No discharges are permitted to waters with depths of less than 60 m. At water depths between 60-1000 m discharges are permitted if seabed and water column monitoring are conducted [1]. No monitoring is required if discharges are to waters with depths greater than 1000 m [1].

2.6 Conventional Drill Cuttings Treatment Technology

Conventional drill cuttings treatment technology can be divided into the primary separation of drill cuttings from drilling fluids and the secondary treatment to remove retained oil on cuttings. These systems aim to maximize the amount of valuable drilling fluid that can be recycled to the drilling process [1]. Figure 2.9 below shows a flow chart of the process where drilling fluids return topside to the oil rig for solids separation and fluid recycling. From Figure 2.9 it can be seen that separated drill cuttings (referred to as waste solids in Figure 2.9) have three options for disposal. These options include onshore disposal, reinjection, or discharge to sea [1]. Typically, conventional drill cuttings treatment cannot achieve the 1 % ROC required by OSPAR signatory countries for

discharge to sea. As a result, drill cuttings from these regions must be either reinjected or transported to shore for treatment [1]. This is in contrast to other oil producing regions with less stringent 6.9 % ROC requirements. These limits can be achieved through the use of conventional drill cutting treatment technologies [1].
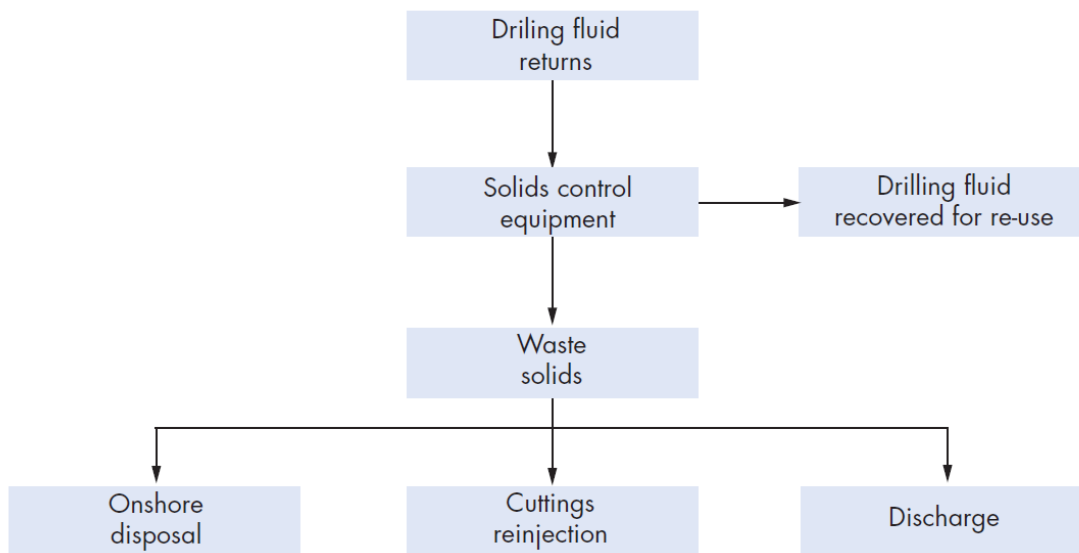
Figure 2.9: Flow chart of drilling fluid and conventional drill cuttings separation technology [10]

The type of solids control equipment used offshore depends on several factors such as the local discharge regulations, the type of formation being drilled, the cuttings characteristics, the size of the drill rig, and the type of drilling mud/fluid in operation [1]. Primary separation of drill cuttings from drilling fluids is typically accomplished through the use of shale shakers, centrifuges, and hydro cyclones. Conventional secondary treatment to remove retained oil on cuttings is most often done using cuttings dryers, high powered centrifuges, and onshore thermal desorption plants [10]. Figure 2.10 below shows a conventional combined primary and secondary drill cuttings treatment system. The system uses a series of progressively finer screened shale shakers for primary

separation of the drill cuttings. The separated drill cuttings are then sent for secondary treatment using a vertical cuttings dryer and a high powered centrifuge [10]. The individual components of the system shown in Figure 2.10 will be discussed in more detail in the following subsections.
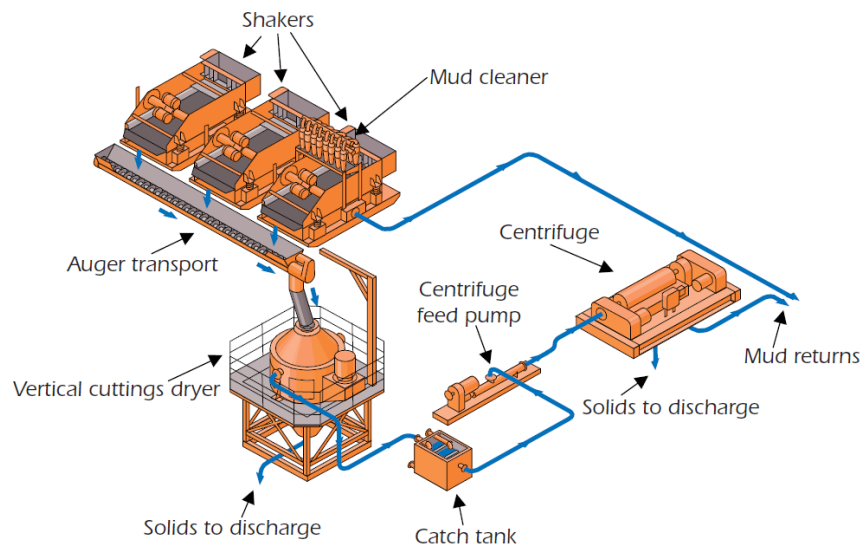
Figure 2.10: Example of a conventional drill cuttings treatment system [10]

2.6.1   Shale shakers

Shale shakers are typically the first piece of equipment that the drilling fluids come into contact with once they have reached the drilling rig. These systems are designed to physically separate drill cuttings from the drilling fluids through the use of vibrating screens. Figure 2.11 below shows a picture of a shale shaker produced by MI-SWACO. In the picture the black separation screens are visible in the center of the equipment. These screens retain the larger sized drill cuttings but unfortunately allow the finer grained solids (colloids and silts) to pass through and follow the drilling mud/fluid [1]. The finer grained solids must be removed later with the use of centrifuges or other similar equipment. Another drawback to shale shakers is that their fine screens will also retain barite weighting materials necessary for proper drilling mud/fluid function [9].

Figure 2.11: Picture of shale shaker produced by MI-SWACO [14]

Figure 2.12 below shows a shale shaker schematic with arrows indicating the flow of drilling fluids and separated cuttings. The vibrational motion of the shale shaker forces the retained solids towards the exit of the machine where they are sent on for further processing or disposal depending on the local regulations.
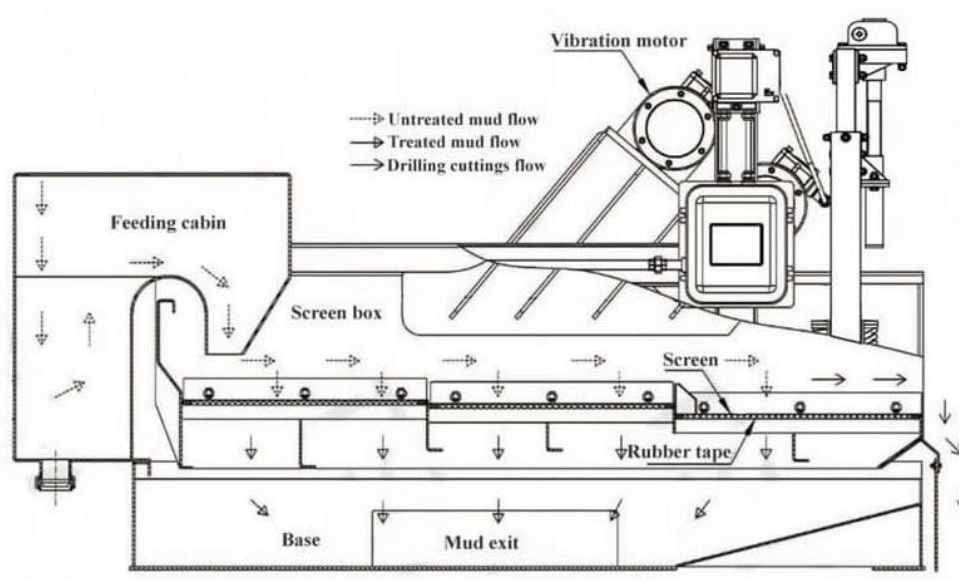
Figure 2.12: Schematic of shale shaker operational principle [15]

2.6.2   Hydro-cyclones

Hydro-cyclones are equipment designed to separate solids from drilling fluids through the use of centrifugal forces [1, 16, 17]. Figure 2.13 contains a working principle schematic of a hydro-cyclone showing the tangential inflow of drilling fluid and solids at the conical end of the unit [1]. Injecting the mixture tangentially at the conical end causes a rotational flow of the drilling fluids and solids.
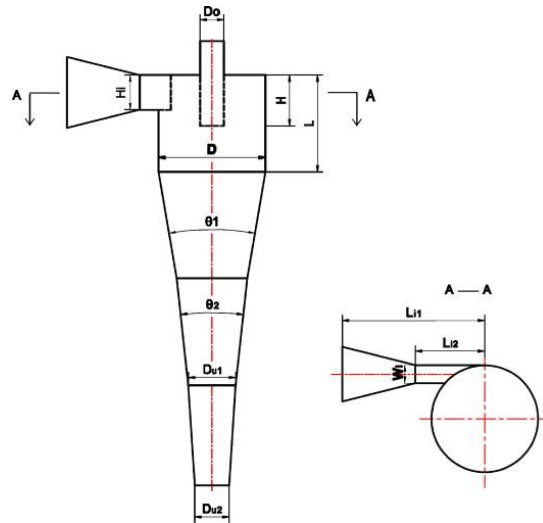
Figure 2.13: Schematic drawing of hydro-cyclone working principle [16]

This rotational flow induces centrifugal forces on the components in the mixture. The denser solid components are more influenced by the centrifugal forces than the lighter drilling fluid components and are thus driven to the perimeter of the hydro-cyclone. At the same time, the lighter components which are less influenced by the centrifugal forces accumulate in the center [1]. The solid components exit the cylindrical bottom of the hydro-cyclone and the lighter drilling fluid components exit the top of the hydro-cyclone as shown in Figure 2.14 below [1, 17]. The advantages of the hydro-cyclones are that they are robust, can handle large volumes, and do not contain complex moving parts. A disadvantage of the hydro-cyclones is that they are governed by Stokes law and therefore cannot efficiently separate solids of similar mass [17].
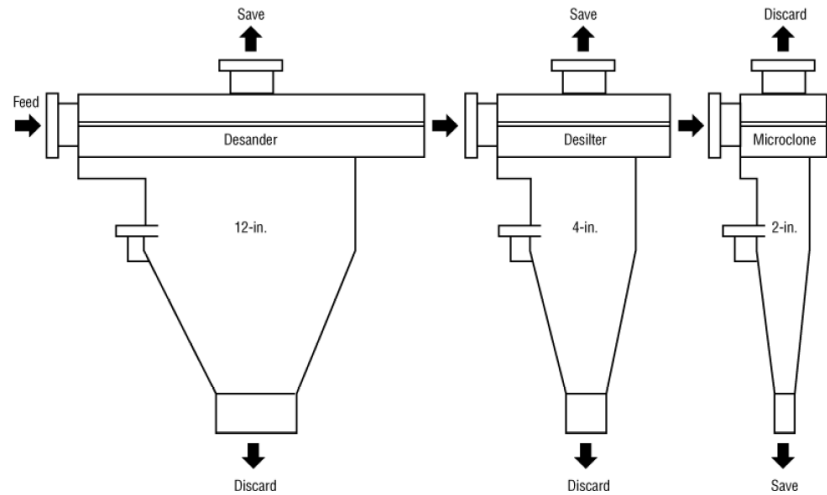
Figure 2.14: Illustration of hydro-cyclone inflow (feed) ,waste stream (Discard), and recycle stream (save) [17]

2.6.3 Decanting Centrifuges

Decanting centrifuges are equipment designed to separate solids from drilling fluids through the use of centrifugal forces [18]. The equipment produces strong centrifugal forces by the rotation of a drum which causes higher density solid components to be forced to the wall of the drum as shown in Figure 2.15 below [17, 18].
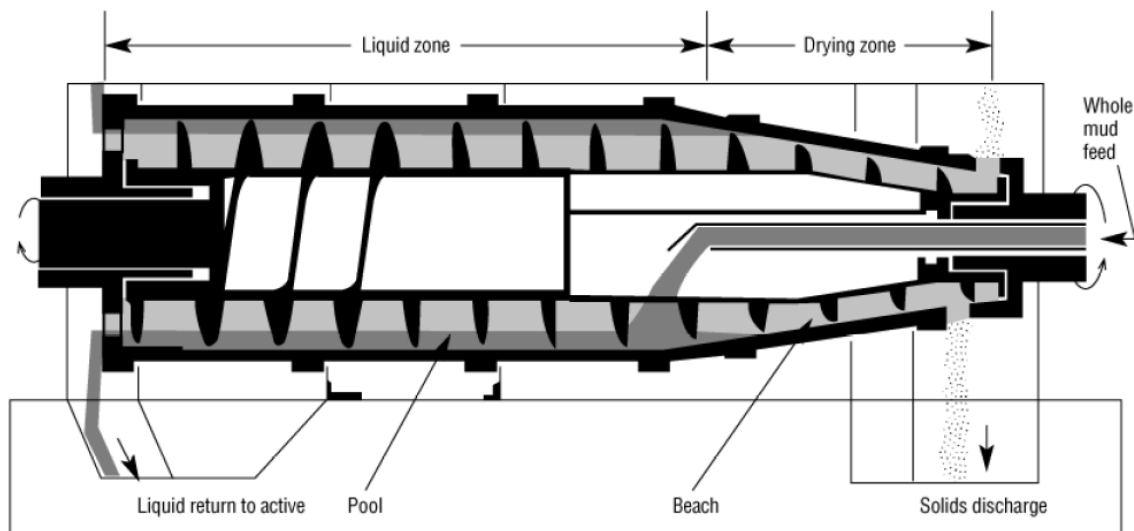
Figure 2.15: Schematic drawing of decanting centrifuge working principle [17]

These higher density solid components are then transported to the discharge port through the use of a rotating auger [18]. The lower density drilling fluids collect in the pool region shown in Figure 2.15 and are discharged at the opposite end of the decanting centrifuge unit [1]. The advantage of decanting centrifuges is that they can separate extremely fine solids due to the very high centrifugal forces generated [1]. A disadvantage of the centrifuge is the complexity of the moving parts which can necessitate significant maintenance and repair [1].

2.6.4   Cuttings Dryers

Cuttings dryers are typically used to process drill cuttings that have been separated by the shale shakers [1]. The cutting are fed into the top of the dryer as shown in Figure 2.16 below and are then subjected to high centrifugal forces in a rotating basket lined with a wire mesh [1]. The mesh retains the cuttings yet allows drilling fluids to pass through and be recycled into the drilling process [1].
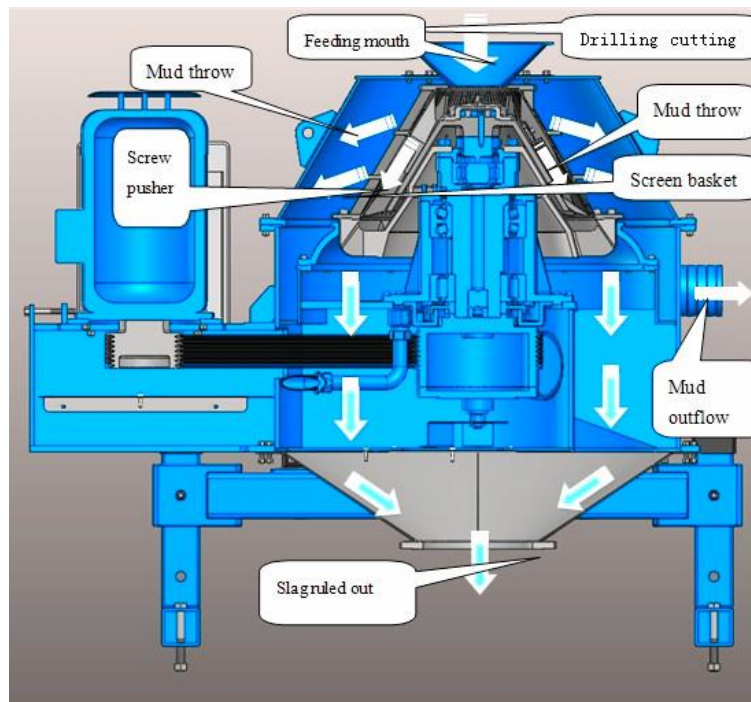
Figure 2.16: Schematic of vertical cuttings dryer working principle [19]

The dried solids are then discharged at the bottom of the unit as shown in Figure 2.16 above. A study of 72 wells is in the Gulf of Mexico by Jonston et al. found that the

average retained synthetic oil on cuttings level achieved with cuttings dyers was 4.93 % [20]. This ROC level meets the offshore Canada and U.S. Gulf of Mexico limitations of 6.9 % but does not comply with the Norwegian and North Sea limitations of 1 % ROC [1]. An advantage of cuttings dryers is that they are effective at significantly reducing the ROC. A disadvantage is that cuttings dryers allow significant amounts of fine solids to follow the recycled drilling fluids. These fine solids require dilution with added fluid thus contributing to increased waste production [17].

2.7   Transport of Cuttings Onshore for Treatment

The drill cuttings waste management option of transport to shore has increased due to the introduction of more stringent regulations on allowable ROC for discharge. Other contributing factors to this trend are the increased use of oil based drilling fluids and difficulties encountered with reinjection of drill cutting [3]. This trend can be seen in table 2.1 below where tonnage of waste shipments to shore have increased significantly between the years 2008 thru 2010 in Norway [21].

Table 2.1 Distribution of drill cuttings waste disposal per year in tons for offshore Norway [22]

Year	Waste to shore	WBM cuttings discharged	OBM cuttings injected
2008	142 142	70 199	228 743
2009	151 704	132 003	252 562
2010	258 482	207 655	125 123

The increase in transport to shore is due to the limited offshore treatment technologies that can meet the strict ROC discharge limits [22]. Transport to shore involves loading the drill cuttings into containers and then lifting them with a crane onto supply ships [9]. As shown in Figure 2.17 below, the supply ships transport the drill cuttings from the offshore production platforms to the onshore treatment bases [9]. This transport process involves many individual crane lifts which pose significant risks to the environment and the health and safety of personnel due to the potential for accidents and spills [21]. A drawback to the transport to shore option is that weather conditions can prevent supply

ships from being able to safely load the containers holding contaminated drill cuttings
[9].
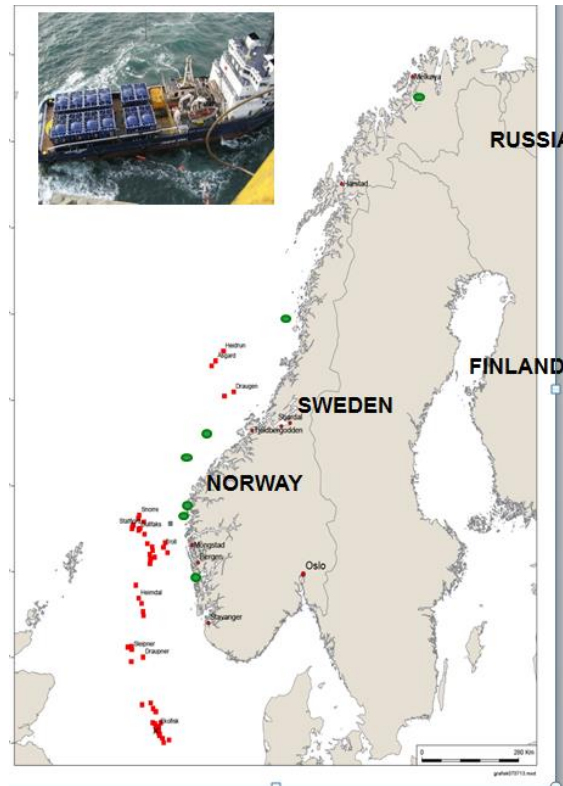
Figure 2.17: Map showing offshore drill cuttings production platforms in red and onshore drill
cutting treatment bases in green [9]

New specially designed cuttings transport systems such as the "CleanCut" by MI Swaco
can significantly reduce the amount of crane lifts required [23]. This system uses
specially designed transport containers which can be loaded with a pump system from the
drill rig. This eliminates the majority of crane lifts required to lift containers from the
drill rig to the supply ship [23]. The contaminated drill cuttings are transported to shore
for treatment by rotary kiln, thermal desorption, bioremediation or other processes
discussed in the following subsections.

2.7.1   Rotary Kiln Thermal Desorption

Onshore rotary kiln desorption units are designed to remove retained oil on cuttings through the use of controlled indirect heating of cuttings in a large rotating vessel [24]. Figure 2.18 below shows an example of an onshore rotary kiln thermal desorption unit.

Figure 2.18: Onshore rotary kiln thermal desorption unit for treatment of drill cuttings [25]

The volatilized vapor from the rotary kiln process is condensed and separated into base oil and water fractions [1]. The advantages of the onshore rotary kiln process are that it can process large volumes of cuttings, it can achieve ROC's of less than 1 %, and the recovered base oil can be recycled [24]. The disadvantages of the system are that they require large footprints, they have high energy consumption, and have not been successfully applied offshore [1].

2.7.2   Land Treatment Bioremediation

Land treatment of drill cuttings is a method that utilizes naturally occurring soil microorganisms as well as biodegradation to reduce the oil content of contaminated drill cuttings waste [26]. The soil microorganisms are able to metabolize the base oil and organic compounds attached to the contaminated drill cuttings. The soil particles physically and chemically bind to chemical pollutants associated with the drill cuttings effectively locking them up and inhibiting their ability to leach [26]. The process involves incorporating the contaminated drill cuttings into the soil and providing favorable

conditions that promote rapid metabolism of chemical pollutants[27]. The advantages of land treatment of contaminated drill cuttings include the low cost, minimal energy consumption, and high efficacy of the process. The disadvantages include large footprints required, long process times, and unsuitability for use offshore [26].

2.7.3   Solidification and Stabilization

Solidification and stabilization is a method of drill cuttings treatment that involves encapsulation in cement, silica or other suitable materials [1, 28, 29]. The encapsulation of the drill cuttings waste locks the contamination in place and prevents dissolution and migration of the pollutants to the surrounding environment [28]. The process involves both physical and chemical stabilization of the contaminants associated with the drill cuttings [1]. A disadvantage of this method is the production of large solid blocks of encapsulated waste material. An improvement of the process has been developed which involves the use of a CO_2 to produce smaller easier to handle granulated material [28, 30]. Advantages of this method include low costs and effectiveness at neutralizing the contaminated drill cuttings. Disadvantages of the method include unsuitability for offshore application, large volumes of solid waste that must be disposed of properly, and the long term potential breakdown of the encapsulating material [1].

2.8   Emerging Drill Cuttings Treatment Technology

The following section discusses new emerging drill cuttings treatment technologies. The majority of these new technologies are still in the research and development stage except for the thermomechanical cuttings cleaner (TCC) which has been installed offshore [1]. These new technologies have the potential for offshore application once they have been sufficiently tested and developed.

2.8.1   Thermomechanical Cuttings Cleaner (TCC)

TCC is a drill cuttings treatment technology that works on the principle of friction based heating through the use of rapidly rotating hammers attached to a central drive shaft [31]. The rotating hammers produce frictional heat which is transferred to the drill cuttings in order to volatilize the oil and water associated with the contaminated drill cuttings [1]. The oil and water vapors are then recovered through the use of an oil condenser and

steam condenser located downstream from the TCC process mill [1]. This treatment technology has been successfully applied offshore in the U.K. and Kazakhstan. It is projected to be applied offshore in the near future in the United Arab Emirates, West Africa, and Norway [32]. In Norway, this technology has been effectively used onshore for treatment but has yet to be applied offshore [9, 32].
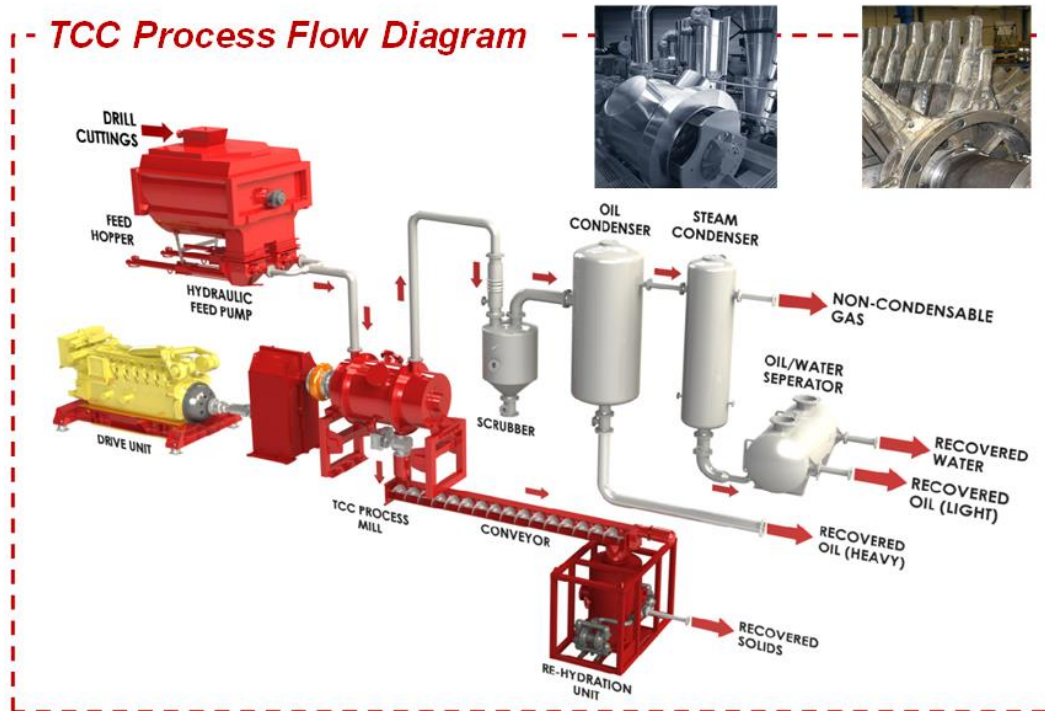
Figure 2.19: Diagram of TCC process [9]

The TCC treatment process can consistently achieve ROCs of less than 1 % thus meeting the OSPAR and other regional regulatory discharge requirements. Meeting these discharge requirements eliminates the need to transport the cuttings to shore for treatment [1, 31]. Figure 2.19 above shows a flow diagram of the TCC process from inflow of contaminated drill cuttings to the end product of recovered solids, oil fractions, gas and water. There are many advantages of the TCC process including low operational temperatures, efficient oil removal, and compact size suitable for offshore applications [1, 22, 31]. The relatively low desorption temperatures of between 260 °C-300 °C for the TCC process enables a high rate of oil recovery for the purpose of recycling due to minimization of heat degradation of the oil [1, 22, 31]. The direct thermomechanical

heating of the TCC process eliminates the need for complex external heating sources and minimizes the required energy input for desorption [31]. Some of the disadvantages of the TCC process include maintenance issues, footprint and weight additions to the oil rig, and complex moving parts [1, 9, 31].

2.8.2   **Microwave Cuttings Treatment**

Microwave drill cuttings treatment is a thermal desorption process that utilizes microwaves to vaporize associated oil and water [1, 33]. Figure 2.20 below shows a working principle drawing of a pilot scale microwave drill cuttings treatment system [34].
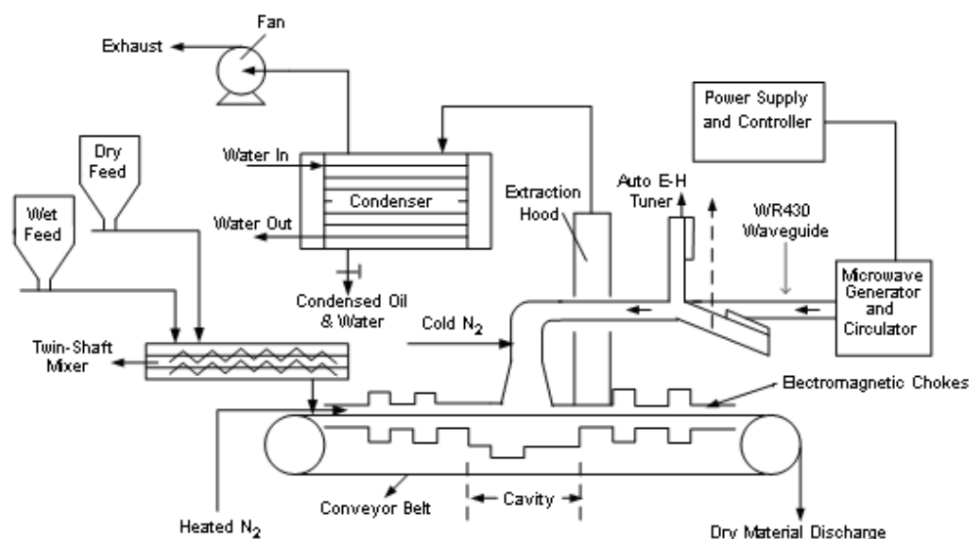
Figure 2.20: Working principle drawing of experimental microwave drill cuttings treatment system [34]

Microwave treatment systems work by heating water trapped in the pores of drill cuttings into steam which in turn distills the associated oil through steam distillation [34]. The advantage of microwave systems is that they directly heat the water components through electromolecular interactions as opposed to conventional systems which work via conduction or convection [34]. These systems are also relatively compact, efficient and can achieve ROC levels of less than one percent [33, 34]. Disadvantages of this treatment technology include the pretreatment requirements of the drill cuttings prior to

introduction to the system, as well as other improvements necessary before full scale offshore applications [1, 33, 34].

2.8.3   Supercritical CO_2 Extraction

Supercritical CO_2 extraction is a drill cuttings treatment technology that involves heating and pressurizing CO_2 above its critical pressure and temperature [1]. Under these conditions the CO_2 behaves as a supercritical fluid and can be used as an effective solvent to extract contaminants and oil from the drill cuttings waste [1]. The advantages of this treatment technology include its inflammable nature, non-toxicity, and strong oil extraction capabilities [35]. The disadvantages of this technology include the necessity of extensive pressurization equipment and the need for further research and development before full scale offshore applications [1].

2.8.4   Liquefied Gas Extraction

Liquefied gas extraction is a drill cuttings treatment technology that involves heating and pressurizing hydrocarbon gases above their critical pressure and temperature [1, 36]. Typically the types of hydrocarbon gases used in this process include propane and butane because they can be liquefied at low pressures and temperatures [1, 36]. Under these conditions, the hydrocarbon gases behave as supercritical fluids and can be used as solvents to extract contaminants and oil from the drill cuttings [1]. The advantages of this treatment technology include the lower required supercritical pressures and temperatures compared to CO_2 and achievable ROC values of less than one percent [1, 36]. A disadvantage of this treatment technology is that it is still in the early stages of development and needs significant research and development before offshore implementation [1, 36].

2.8.5   Chemical Washing and Surfactants

Chemical washing and surfactants is a drill cuttings treatment technology that uses anionic and nonionic surfactants to remove oil and contaminants from drill cutting waste [1, 37]. The anionic and nonionic properties of the surfactants chemically interact with and remove oil and contaminants attached to the surface of the drill cuttings [1, 37]. An advantage of this treatment technology is that it has been proven effective for onshore treatment of hydrocarbon contaminated soils [1, 37]. A disadvantage of this treatment

technology is that it needs significant research and development before offshore implementation [1, 37].

2.9   Cuttings Reinjection

Cuttings reinjection is an offshore method used to dispose of drill cuttings waste by injecting it into subterranean geological formations [1, 38]. The cuttings reinjection process is shown in Figure 2.21 below. Before the drill cuttings waste can be injected it must first be screened and made into slurry in order to ensure proper flow characteristics during injection. This is accomplished by milling the drill cuttings into fine particles and combining with seawater as shown in Figure 2.21 below [1, 38].
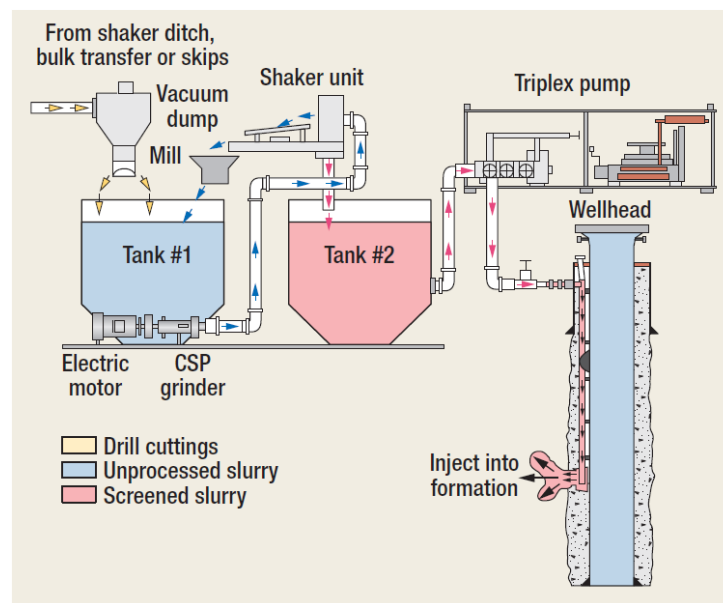
Figure 2.21: Illustration of drill cuttings reinjection system [39]

The drill cuttings slurry can then be injected into a suitable subterranean geological formation for disposal [1, 38] . The advantages of this waste disposal method include elimination of waste transport to shore, offshore disposal capabilities, cost savings, zero discharge to the environment, and high capacity [1, 38]. The disadvantages of this treatment technology include waste leakage from geological formations, potential for spills and accidents, long term monitoring, equipment issues, and formation plugging [1, 38]. According to the Norwegian Environment Agency, the oil and gas industry has

experienced difficulties with cuttings reinjection in recent years 2009-2012 [3]. The cuttings reinjection difficulties have resulted in an increase in the quantity of drill cuttings waste being transported to shore as shown in Figure 1.2 above [3].

3   CHAPTER THREE: STEAM DISTILLATION THEORY

3.1   Temperature and Vapor Pressure Relationship

Vapor pressure can be defined as the pressure resulting from the vaporization of a liquid. Evaporation of a liquid causes the formation of vapor which increases the surrounding pressure. Increasing the temperature of a liquid increases the amount of kinetic energy imparted to the liquid molecules. Once the molecules gain enough kinetic energy to break free of the bonds holding the liquid together they can escape into vapor form [40]. Figure 3.1 below shows visually how increased temperature affects the vapor pressure of a liquid in a closed container. The illustration on the right in Figure 3.1 shows how increased temperature indicated by the thermometer translates into increased vapor molecules and pressure.
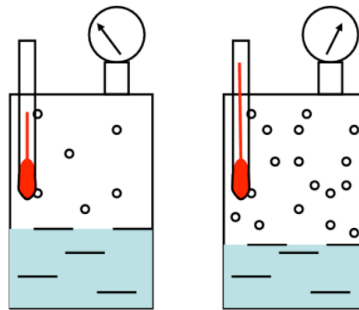
Figure 3.1: Illustration of increased vapor pressure due to heating [41]

Vapor pressure in relation to temperature is a characteristic property of a liquid [40]. Every liquid will have a specific vapor pressure at a given temperature. The temperature of a liquid at which the vapor pressure equals the surrounding pressure is known as the boiling point. At the boiling point, bubbles of vapor form within the liquid and rise to the

surface where they escape into the surrounding environment. The temperature of a boiling liquid will remain constant regardless of the amount of heat added. Any additional heat applied to a boiling liquid will increase the boiling rate and vaporization yet the temperature of the boiling liquid will remain constant [42]. Figure 3.2 below shows the exponential relationship between temperature and vapor pressure of a liquid. This non-linear relationship is due to vapor pressure's dependence on the proportion of liquid molecules with sufficient kinetic energy to escape the liquid which increases exponentially with temperature [40].
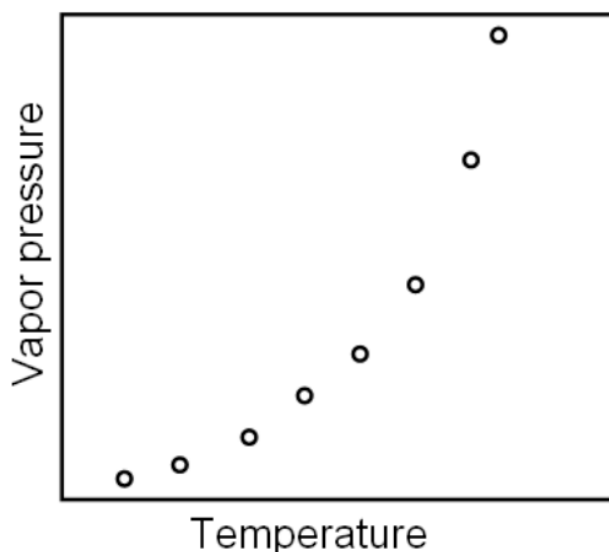
Figure 3.2: Graphical representation of the relationship between temperature and vapor pressure of a liquid [41]

3.2   Enthalpy of Vaporization

The amount of energy required to evaporate one mole of a liquid is defined as the enthalpy of vaporization ΔH**vap** [42, 43]. The enthalpy of vaporization increases with the strength of the bonds holding the liquid together. For example, water has hydrogen bonding between molecules therefore it requires more energy to break these bonds than liquids with no hydrogen bonding [43]. In order to calculate parameters such as enthalpy of vaporization or vapor pressure at varying temperatures it is useful to linearize the

graph of vapor pressure versus temperature. This can be accomplished by graphing the natural log of vapor pressure (ln P) versus the inverse of the absolute temperature in Kelvin (1/T) as can be seen in Figure 3.3 below. The resulting graph yields a straight line of Equation 3.1 and a slope equal to $(-\Delta H \text{vap}/R)$ [40].
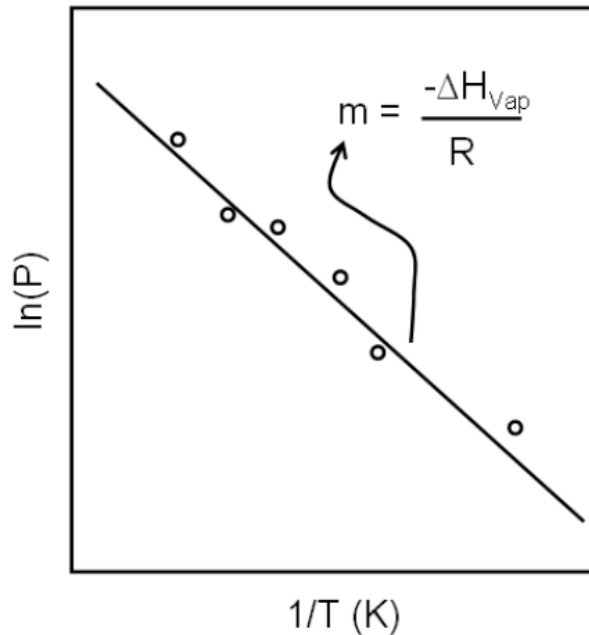
Figure 3.3: Linearized plot of vapor pressure versus temperature [41]

$$\ln P = \frac{-\Delta H_{\text{vap}}}{R} \left(\frac{1}{T} \right) + C$$

Equation for a straight line : $\quad y \quad = \quad mx \quad + \quad b$

Equation 3.1

In Equation 3.1 above, R is the universal gas constant [8.314 J/(mol·K)], C is the y-intercept, T is the temperature in Kelvin, P is vapor pressure, and ΔH_{vap} is the enthalpy of vaporization [40]. Equation 3.1 is known as the Clausius-Clapeyron Equation which can be rearranged into Equation 3.2 below to calculate ΔH_{vap} when the vapor pressure

and temperature at two points are known. If ΔH_{vap} is known, then Equation 3.2 can be used to calculate the vapor pressure at a specified temperature.

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{-\Delta H_{vap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$
<div align="right">Equation 3.2</div>

3.3 Ideal Gas Law

The Ideal Gas Law is an expression that combines the relationship of volume, pressure, temperature and quantity of a gas in a single equation [40].

$$PV = nRT$$
<div align="right">Equation 3.3</div>

Equation 3.3 is known as the Ideal Gas Law where P is pressure, V is volume, n is number of moles, R is the universal gas constant [8.314 J/(mol·K)], and T is the temperature in Kelvin [40]. The Ideal Gas Law can also be written in terms of molecular weight as shown in Equation 3.4 below.

$$PV = \frac{mRT}{MW}$$
<div align="right">Equation 3.4</div>

In Equation 3.4, m is the mass of gas in grams, and MW is the molecular weight of the gas.These equations are valid only for ideal gasses which when combined in a mixture do not interact with each other to cause attraction or repulsion [40]. Ideal gasses do not exist in nature but real gasses under most conditions do behave very similar to ideal gasses. Real gasses deviate from ideal gas behavior only when they are at low temperature or extremely high pressure. Therefore, the Ideal Gas Law can be used in most cases to approximate the behavior of real gasses [40]. If three parameters of the Ideal Gas Law

are known (e.g. n, T, and V), then the remaining variable (P) can be solved for using the Ideal Gas Law [40]. The Ideal Gas Law can also be used to calculate the end conditions of a gas after variables such as temperature, pressure, volume or quantity of moles are changed from the original conditions [40].

3.4   Dalton's Law of Partial Pressure

Another important concept for understanding the nature of vapor pressure and liquid mixtures is Dalton's Law of Partial Pressures described by Equation 3.5 below [40]. Dalton's Law of Partial Pressures states that "The vapor pressure above a liquid mixture is equal to the sum of the vapor pressures of the individual components" [44].

$$P_t = P_1 + P_2 + P_3 + \cdots + P_i \qquad \text{Equation 3.5}$$

In Equation 3.5 above, the variable Pt represents the total vapor pressure above the liquid mixture. The other variables in Equation 3.5 represent the vapor pressures of the individual constituents that make up the liquid mixture [40]. If the gasses making up the vapor pressure above a liquid mixture are considered ideal, then the Equation for total pressure can be written in terms of number of moles present as shown in Equation 3.6 below.

$$P_t = (n_1 + n_2 + n_3 + \cdots + n_i)\left(\frac{RT}{V}\right) \qquad \text{Equation 3.6}$$

In Equation 3.6 above, Pt is the total pressure, R is the universal gas constant [8.314 J/(mol·K)], T is temperature in Kelvin, V is volume in liters, and n is the number of moles of a particular gas in the mixture [40]. Equation 3.6 illustrates the concept that the

pressure of a gas mixture at constant temperature and volume is only reliant on the total number of moles of gas in the mixture [40].

3.5   Distillation of Liquid Mixtures

In general , liquid mixtures are classified as either miscible or immiscible [44]. The difference between these mixtures is the extent to which the liquids dissolve within each other. Miscible mixtures are made up of components that are completely soluble in each other whereas immiscible mixtures are comprised of liquids that are insoluble within each other [44]. An example of a miscible mixture is ethanol in water and an example of an immiscible mixture is oil in water. Both types of mixtures follow Dalton's Law of Partial Pressures but they differ in the manner to which each component contributes its partial pressure. As a result, their behavior under distillation varies greatly [44].

3.5.1   Miscible Mixtures

In miscible mixtures, the partial pressure contributed by a component is reliant on its independently measured vapor pressure and its relative quantity within the mixture [44] .The mole fraction of a component in a miscible mixture can be used to calculate its partial pressure contribution to the vapor pressure above the mixture. A component's mole fraction can be found by dividing the number of moles of the component in the mixture by the total number of moles in the mixture as shown in Equation 3.7 below [40].

$$\text{mole fraction of A} = X_A = \frac{\text{moles A}}{\text{total moles}} = \frac{n_A}{n_t} \qquad \text{Equation 3.7}$$

Equation 3.7 above designates a component of a miscible mixture as "A". In Equation 3.7, X_A is the mole fraction of "A", n_A is the number of moles of "A", and n_t is the total

number of moles in the mixture [40]. The mole fraction of component "A" calculated in Equation 3.7 can then be plugged into Raoult's Law shown in Equation 3.8 below. Raoult's Law can then be used to calculate the partial pressure of the component within the mixture [44].

$$P_A = P_A^o X_A$$

Equation 3.8

In Equation 3.8 above, P_A^O is the independently measured vapor pressure of pure component "A", X_A is the mole fraction of "A", and P_A is the partial pressure of component A in the mixture [40]. This means that the partial pressure of any component in a mixture can be found by multiplying its mole fraction by its independent vapor pressure [44]. Raoult's Law can be combined with Dalton's Law of Partial Pressure in order to calculate the total vapor pressure above a miscible mixture as shown in Equation 3.9 below [44].

$$P_{total} = P_A^o X_A + P_B^o X_B$$

Equation 3.9

In Equation 3.9 above P_{total} is the total vapor pressure above a miscible liquid mixture made up of components "A" and "B" [44]. When a liquid mixture is heated, the partial pressures of the components increase thereby increasing the total vapor pressure of the mixture. If P_{total} reaches the surrounding pressure, then the mixture will begin to boil [44]. The boiling point of a miscible mixture will be between the boiling points of the components making up the mixture [44]. Due to the nature of Raoult's Law, the vapor above a boiling miscible mixture will have a higher concentration of the component with lower boiling point [44]. This phenomenon enables relatively easy separation of miscible liquids using normal distillation. If the boiling points of the components making up the mixture are too similar, then fractional distillation must be used to separate the mixture. Fractional distillation involves modifying the normal distillation setup with a fractionating column designed to increase the surface area that comes in contact with the

distilled vapor. The increased surface area enables the vapor to condense then re-vaporize according to Raoult's Law causing enrichment of a particular component [44].

3.5.2   Immiscible Mixtures

In contrast to miscible mixtures, the partial pressure contribution of a component in an immiscible mixture is not reliant on its relative quantity within the mixture. Therefore, the partial pressure contributed by a component is equal to its independently measured vapor pressure [44].   Equation 3.10 below is an expression of Dalton's Law for an immiscible mixture made up of components "A" and "B" [44].

$$P_{total} = P_A^o + P_B^o$$ Equation 3.10

In Equation 3.10 above, P_{total} is the total vapor pressure above an immiscible mixture, P_A^O is the independent vapor pressure of pure component "A", and P_B^O is the independent vapor pressure of pure component "B" [44]. The boiling point of an immiscible mixture will be lower than the boiling point of any component within the mixture. This is a result of Dalton's Law where the individual vapor pressures of the components in the mixture add together resulting in an overall higher vapor pressure. This higher vapor pressure causes the mixture to reach the surrounding pressure faster than any of the components in the mixture would have alone [44].

A component's contribution to the vapor pressure of an immiscible mixture is independent of its relative quantity in the mixture. Therefore, a component will contribute the same amount of partial pressure to the total vapor pressure of the mixture regardless of how much of the component is present [44]. Also, when a mixture reaches its boiling point it does not matter which component contributes more partial pressure to the total vapor pressure of the mixture [44].

 In order for immiscible mixtures to obey Dalton's Law they must be thoroughly mixed so that all components have contact with the surrounding environment. If the mixture is not thoroughly mixed, then layering can occur. When layering occurs, only one

component is exposed to the surrounding environment and the other component is trapped beneath. In this case, the trapped component cannot contribute its partial pressure to the total vapor pressure of the mixture. As a result, the mixture will not obey Dalton's Law and the vapor above the mixture will not contain the trapped component or it will be greatly reduced [44].

Steam distillation is a process that takes advantage of Dalton's Law of immiscible mixtures in order to lower the boiling point of water insoluble substances. Oil is a common water insoluble substance that can be distilled with steam. The high vapor pressure of steam helps to significantly reduce the boiling point of the oil [44]. The condensed vapor of the oil steam distillation will contain both oil and water in proportions according to Dalton's Law and the Ideal Gas Law. The Ideal Gas Law (Equation 3.4) can be written in terms of partial pressures and rearranged to solve for the mass of steam and the mass of oil in the distilled vapor as shown in the Equations below.

$$P_s V = \frac{m_s RT}{MW_s} \qquad \text{Equation 3.11}$$

$$m_s = \frac{P_s \times V \times MW_s}{R \times T} \qquad \text{Equation 3.12}$$

$$P_o V = \frac{m_o RT}{MW_o} \qquad \text{Equation 3.13}$$

$$m_o = \frac{P_o \times V \times MW_o}{R \times T} \qquad \text{Equation 3.14}$$

In the equations above, m_s is the mass of steam in the vapor, m_o is the mass of oil in the vapor, P_s is the partial pressure of steam, P_o is the partial pressure of oil, MW_s is the molecular weight of steam, and MW_o is the molecular weight of oil. Dividing Equation 3.14 by Equation 3.12 yields the mass ratio of oil production per unit water production as shown in Equation 3.15 below. The terms V, T, and R cancel out when Equation 3.14 is

divided by Equation 3.12 because the steam distillation occurs at a standard temperature and volume.

$$M_{o/w} = \frac{P_o \times MW_o}{P_s \times MW_s} \qquad \text{Equation 3.15}$$

In Equation 3.15 above, $M_{o/w}$ is the mass ratio of oil production per unit water production. If the steam distillation is carried out at sea level with an atmospheric pressure of 1.013bar, then Dalton's Law of Partial Pressure becomes Equation 3.16 below.

$$1.013bar = P_o + P_s \qquad \text{Equation 3.16}$$

Solving Equation 3.16 for the partial pressure of steam yields Equation 3.17 shown below.

$$P_s = 1.013bar - P_o \qquad \text{Equation 3.17}$$

Plugging in the partial pressure of stream (P_s) from Equation 3.17 and the molecular weight of steam (18g/mol) into Equation 3.15 yields Equation 3.18 below.

$$M_{o/w} = \frac{P_o \times MW_o}{(1.013bar - P_o) \times 18g/mol} \qquad \text{Equation 3.18}$$

Equation 3.18 gives the mass ratio of oil production per unit water production in terms of the oil's partial pressure. This Equation can be solved for P_o yielding the partial pressure of oil in the steam distillation process.

3.6   Steam Distillation Description

Steam distillation is a method of extraction whereby the steam acts as an immiscible component in an immiscible mixture. The method is used to distill water insoluble substances with high boiling points such as oil. The advantage of steam distillation is the reduction in boiling point temperature of the mixture. This is because all components within the mixture contribute their individual pure vapor pressure to the overall vapor

pressure of the mixture. The components in the mixture exert their pure vapor pressure because they obey Dalton's law of Partial Pressure (Equation 3.5) [44, 45]. Figure 3.4 below shows an example of a steam distillation experimental setup.
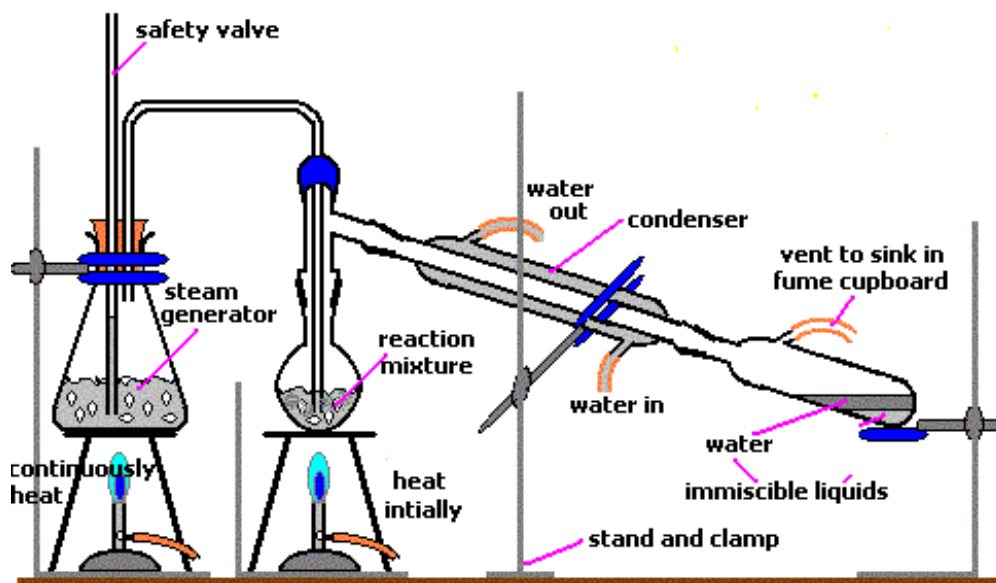
Figure 3.4: Example of a steam distillation setup [45]

A typical steam distillation setup includes a steam production unit, a distillation unit, a condensing unit, and a collection flask as shown in Figure 3.4 above [44, 45]. The steam production unit is designed to produce a steady rate of steam for the distillation process. The distillation unit is designed to maximize mixing of the immiscible mixture and minimize heat loss for enhanced distillation performance. The condensing unit is designed to efficiently cool and condense the vapors form the distillation unit. The collection flask finally captures the condensed liquid exiting the condensing unit [44, 45].

3.7   History and Applications of Steam Distillation

Steam distillation has a long history of use in the food and fragrance industry. It also has a more recent history of use in the petrochemical industry. The following subsections briefly describe the applications and uses in these industries.

3.7.1   Fragrance Industry

Steam distillation is used in the fragrance industry for extraction of essential oils and perfumes [45]. This process is well suited for extraction of fragrances because it is able to preserve the integrity of the volatile compounds [46, 47]. Preservation of the chemical integrity is critical in the formulation of fragrances and essential oils [46, 47]. Plant materials which contain these chemical compounds are exposed to steam and the condensed vapors are used in fragrance formulations [46, 47].

3.7.2   Food Industry

In the food industry steam distillation is used for de-acidification and deodorizing of cooking fats and oils [48]. It is also used for extraction of flavoring and oils used for culinary purposes [48]. Steam distillation is well suited for the food industry because it enables purification and extraction of flavorings and oils without causing heat degradation [48].

3.7.3   Petrochemical Industry

In the petrochemical industry steam distillation is used to strip various aromatic hydrocarbons from refinery waste fluids [49, 50]. This process is advantageous because it enables the effective extraction of Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX) and other aromatic contaminants at reduced temperatures [49, 50]. The steam acts as a solvent to strip the targeted aromatics from the complex refinery liquid waste mixture [49, 50].

3.8   Superheated Steam Uses and Applications Including Distillation

The three most common types of steam are unsaturated (wet) stream, saturated (dry) steam and superheated steam. Unsaturated steam is a type of steam that contains entrained water molecules that have not vaporized completely. Saturated steam is a type of steam that forms at equilibrium when the pressure and temperature conditions are such that water vaporizes at the same rate that it condenses [6]. The saturated steam conditions are shown in Figure 3.5 as the solid black line curve that separates the pink (superheated) region from the grey (solid) and blue (liquid) regions. This type of steam is referred to as

dry steam because it does not contain any non-vaporized water molecules [6]. Superheated steam is unsaturated or saturated steam that has been heated above the saturated steam point. In Figure 3.5 below, the superheated steam is represented by the pink region. The advantages of superheated steam include increased thermal efficiency, high steam dryness, low density, high heat storage capacity, lack of condensate formation, and higher achievable distillation temperatures [6]. Superheated steam is often used for propulsion in turbines and pistons [6]. This is because superheated steam does not form condensate droplets which can become projectiles that impact and damage turbine blades and pistons [6]. Another application of superheated steam is in the recovery of heavy oil reserves. The superheated steam is injected into the reservoir to heat and stimulate flow of viscous heavy oil for recovery [51]. Superheated steam can also be used for distillation of hydrocarbons due to its high thermal efficiency and high achievable distillation temperatures [52].
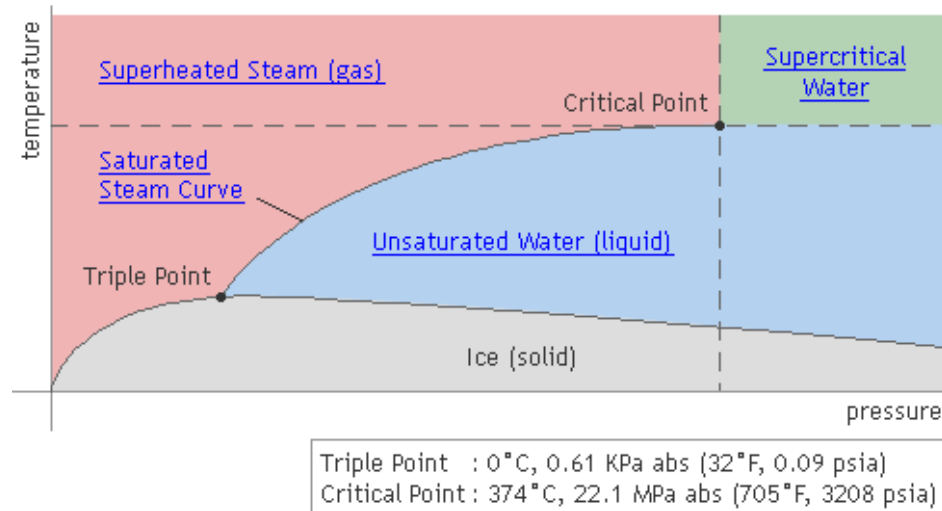
Figure 3.5: Relationship of pressure versus temperature for water and steam [6]

4 CHAPTER FOUR: EXPERIMENTAL MATERIALS, METHODS, AND RESULTS

4.1 Information on Oil Based Drilling Fluids Used for Experiments

Two different oil based drilling fluids were tested during the experimental portion of my Master's thesis. The base oils tested were SIPDRILL 2/0 manufactured by SIP LTD and Clairsol NS manufactured by Petrochem Carless [53] [54].

4.1.1 Chemical Composition and Molecular Formula of Base Oils

The base oils tested are made from processed mineral oils that contain very low amounts of aromatic hydrocarbons [10, 53, 54]. Mineral oils are derived from refined crude oil and are mostly made up of the aliphatic compounds alkanes and isoalkanes [55, 56]. The term aliphatic refers to a class of compounds that do not contain aromatic rings such as benzene [55]. Alkanes are straight chain hydrocarbons made up entirely of single bonded hydrogen and carbon atoms [55]. Isoalkanes are simple, branched alkanes of the form shown in Figure 4.1 below [57]. The structures of isoalkanes are unique in that they only contain single bonds at branch points, and at the branch points they contain at least two methyl groups and one hydrogen atom [57]. The general molecular formula for alkanes and isoalkanes is the same and is shown in Equation 4.1 below.

$$C_nH_{2n+2}$$

Equation 4.1

In Equation 4.1 above, C represents carbons, H represents hydrogen, and n is the number of carbons. Alkanes have the highest ratio of hydrogen to carbon and therefore they are referred to as saturated with regards to hydrogen [55]. Cycloalkanes are alkanes that contain rings made of carbon atoms [55]. Figure 4.1 below shows an example of a straight chain alkane, a branched isoalkane, and a simple, single ringed cycloalkane [58].
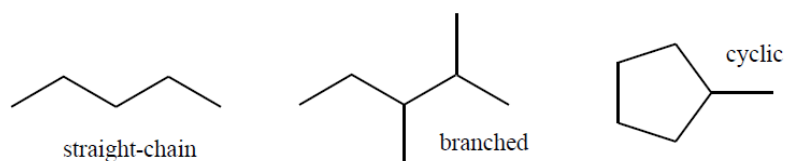
Figure 4.1: Structural representation of alkanes [58]

The general molecular formula for single ringed cycloalkanes is shown in Equation 4.2 below [55].

$$C_nH_{2n}$$
Equation 4.2

When comparing Equation 4.1 and 4.2 above; it is clear that the molecular formula for single ringed cycloalkanes has two less hydrogens than the molecular formula for straight chained or branched alkanes. This is a result of the formation of the ring which necessitates the loss of two hydrogens [55]. Cycloalkanes containing more than one carbon ring are called polycyclic [55]. The general molecular formula for polycyclic compounds is shown in Equation 4.3 below [55].

$$C_nH_{(2n+2-2m)}$$
Equation 4.3

In Equation 4.3 above, m is the number of rings in the compound and n is the number of carbons. From Equation 4.3 it can be seen that increasing the number of rings causes a decrease in the number of hydrogens in the compound. This results in polycyclic compounds having a lower hydrogen to carbon ratio than straight chain alkanes [55].

The base oils tested can also contain very small amounts of alkenes and alkynes. Alkenes are hydrocarbons which contain at least one double bond between carbons and alkynes are hydrocarbons which contain at least one triple bond between carbons [55]. As a result of the double bonding in alkenes, the amount of hydrogens in the molecular formula is reduced by two per double bond as shown in Equation 4.4 below.

$$C_nH_{2n}$$
Equation 4.4

In Alkynes, the triple bonding of carbon causes a reduction of four hydrogens per triple bond as shown in Equation 4.5 below.

$$C_nH_{2n-2}$$ Equation 4.5

In summary, the molecular formulas of the compounds making up the base oil samples vary only in their relative number of hydrogens. Hydrogen has a molecular mass of only 1 g/mol which is twelve times less than the molecular mass of carbon at 12 g/mol [40]. As a result, the molecular mass of the base oil samples is most dependent on the number of carbons contained in the oil [55]. The relative amounts of alkanes, cycloalkanes, alkenes, and alkynes has less influence on the molecular mass of the oil than the than the total number of carbons contained in the oil.

4.1.2   Factors Affecting Vapor Pressure and Boiling Point of the Base Oils

The relative strength of the intermolecular forces within the base oil has a significant impact on the vapor pressure and boiling point of the oil [42]. Strong intermolecular forces tightly bind the oil molecules together thus enabling few molecules to have sufficient kinetic energy to break the bonds and escape into the gas phase [59]. This phenomenon causes oils with strong intermolecular forces to have lower vapor pressure and higher boiling points [59]. The boiling point is increased because it takes more energy input to break the strong intermolecular forces holding the molecules together [59]. In the case of the base oils, the longer the hydrocarbon chain the stronger the intermolecular forces [60]. The reason for the increased intermolecular forces is due to the hydrocarbon chain interlocking and meshing together creating stronger bonds [61]. The length of the hydrocarbon chain can be equated with the number of carbons contained in the molecular formula of the base oil [60]. Shorter chained hydrocarbons do not have these additional intermolecular forces. Therefore, they have higher vapor pressure and lower boiling point than longer chained hydrocarbons [61]. These differences in vapor pressures and boiling points are utilized in petroleum refineries to separate hydrocarbons of varying carbon chain length [40].

4.1.3   SIPDRILL 2/0

The material safety data sheet (MSDS) for Sipdrill 2/0 located in Appendix-1 gives a thorough description of the chemical, physical and toxicological attributes of this base oil. The information of particular interest for the experimental portion of my master's thesis is the chemical composition, boiling point, vapor pressure, and relative density. From the MSDS it can be seen that the chemical composition of Sipdrill 2/0 is made up of 100 % aliphatic hydrocarbons that contain between ten and thirteen carbons yielding an average of twelve carbons. Therefore, the molecular mass of the Sipdrill 2/0 can be approximated by using the molecular formula for alkanes (Equation 4.1 above) and assuming an average carbon content of twelve. The boiling point in the MSDS is given as a range between 210-260 °C due to the chemical composition of the base oil. The lighter fractions of the oil boil at a lower temperature and the heavier fractions boil at a higher temperature. The Sipdrill 2/0 is a distilled petroleum product therefore it can have variations in composition depending on the refining process.

4.1.4   CLAIRSOL NS

The MSDS for Clairsol NS found in Appendix-2 contains the chemical, physical and toxicological characteristics of this base oil. The information of particular interest is the chemical composition, boiling point, vapor pressure, and relative density. The MSDS lists the chemical composition of Clairsol NS as a hydrocarbon containing between fourteen and eighteen carbons. The main chemical constituents are alkanes, isoalkanes, and to a lesser extent cycloalkanes. The MSDS also lists an aromatic content of less than two percent for Clairsol NS. Although the chemical composition of Clairsol NS is more complex than Sipdrill 2/0, an estimation of molecular mass can still be found by using the molecular formula for alkanes (Equation 4.1 above). The average carbon content of sixteen carbons can be plugged into Equation 4.1 above to give an estimate of the molecular mass. This molecular mass estimation may overestimate or underestimate the actual mass. This is because the equation assumes the hydrocarbon is saturated with regards to hydrogen which may or may not be the case for Clairsol NS. It also assumes the oil is made up entirely of alkanes with sixteen carbons even though it could contain up to eighteen carbons. The boiling point of Clairsol NS is given as a range between 230-335 °C. This is due to the oil's composition which contains both shorter and longer chain

hydrocarbons. The relative density is also listed as a range between 0.780-0.920 g/cm^3 .This is because Clairsol NS is a distilled product which can vary in chemical composition.

4.2   Standardized Vapor Pressure versus Temperature Experiment

Understanding the relationship between temperature and vapor pressure of a liquid gives insight into predicting its behavior under varying conditions. This relationship was established for the two base oils Clarisol NS and Sipdrill 2/0 in order to gain a better understanding of their behavior under several temperature and pressure situations. The results of these standardized tests can then be used to compare to the behavior of the oils under superheated steam distillation conditions. If the superheated steam distillation results follow the standardized test results, then they can be deemed valid. Of particular interest is using Dalton's Law of Partial Pressure and the Ideal Gas Law to determine the vapor pressures of the base oil samples under superheated steam distillation conditions. The vapor pressures calculated under superheated steam distillation conditions can then be compared with the standardized vapor pressure versus temperatures results found in the following lab.

The standardized vapor pressure versus temperature experiment was divided into two phases referred to as phase I and phase II. The goal of both phases was to determine the boiling point temperatures of the base oils at varying pressures. The boiling point temperature is of particular interest because at the boiling point, the liquid vapor pressure is equal to the surrounding pressure. Therefore, at the base oil's boiling point temperature, the applied surrounding pressure is equal to the vapor pressure of the base oil. These experiments were accomplished with the use of a rotary vapor machine and pump. This equipment enabled the surrounding pressure to be varied so that the corresponding boiling point temperature could be measured. Phase I and phase II are differentiated by the methods used to determine the boiling point temperatures of the base oil samples. Phase I estimated the base oil boiling point temperature based on the heating bath temperature. Phase II used a long temperature probe to determine the vapor temperature of the base oil at its boiling point.

4.2.1   Methods and Materials

1   Rotary Evaporator: VWR by IKA model RV10

2   Vacuum pump and control: Vacuubrand for VWR CVC 3000

3   Hot Plate: Heidolph 30001

4   Temperature Control Unit for Hot Plate: Heidolph EKT 3001

5   Stainless Steel Cooking Pot

6   Thermometer

7   Two Stage Vacuum Pump: Model VE 215

8   Pressure Gauge: Thyracont Model VD85

9   Flasks: Round Bottom tempered Glass

10   Boiling Chips

11   Clarisol NS Oil Sample

12   Sipdrill 2/0 Oil Sample

13   Silicone oil for heating baths
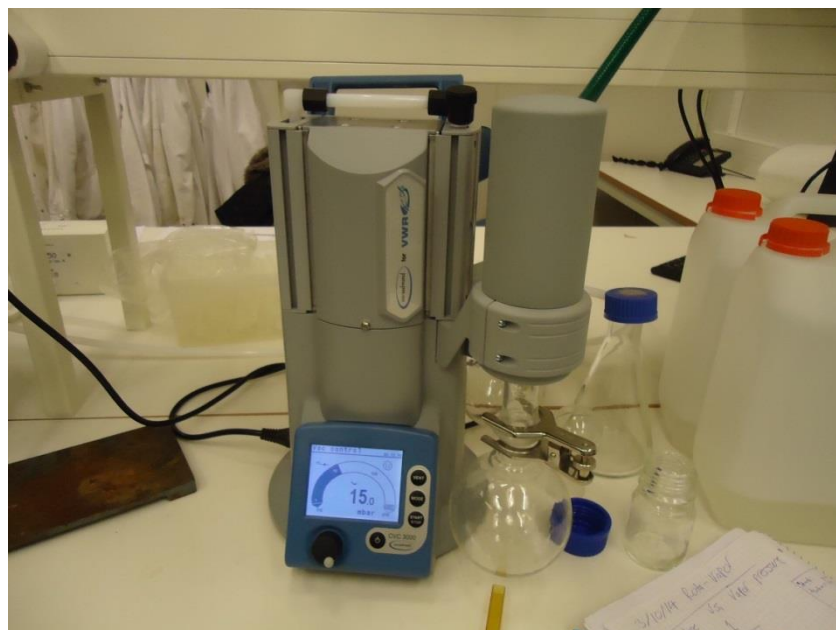
Figure 4.2: Photo of vacuum pump and control made by Vacuubrand for VWR model CVC 3000

Figure 4.3: Photo of phase I rotary evaporator experimental setup

The phase I setup utilized the standard rotary evaporator machine connected to its associated pump (Vacuubrand for VWR CVC 3000) as shown in Figures 4.2 and 4.3 above. The standard heating bath was replaced with a Heidolph 30001 hot plate and a stainless steel cooking pot filled with silicone oil in order to achieve higher temperatures. A sample of Sipdrill 2/0 was poured into a round bottomed sample flask filled with several boiling chips such that 1/3 of the flask was filled with base oil sample. The sample flask was then attached to the rotary evaporator machine and was rotated and heated in the silicone oil bath. The Vacuubrand pump was then activated and set to its minimum achievable pressure of 15 mbar. The sample was then heated until it reached a visual boiling point and the corresponding bath temperature measured using a mercury thermometer was noted. The visual boiling point was identified by uniform formation of large vapor bubbles at the bottom of the base oil sample. Once the boiling point bath temperature was noted at 15 mbar, the pressure was increased to 20 mbar and the corresponding boiling point bath temperature was noted. This procedure was repeated for numerous pressures reaching a maximum of 500 mbar. The same

phase I experiment was also carried out on the Clarisol NS Oil Sample. In order to achieve lower pressure, a high powered two stage vacuum pump was hooked up to the standard rotary evaporator machine as shown in Figure 4.4 below. The high powered pump was able to achieve a minimum pressure of 1.5 mbar as can be seen registered on the screen of the pressure gauge in Figure 4.5 below. The boiling point bath temperature of the two base oil samples were also measured at this low pressure of 1.5 mbar.

Figure 4.4: Photo of experimental setup with high powered two stage vacuum pump

Figure 4.5: Photo of pressure gauge (Thyracont Model VD85) associated with the high powered two stage vacuum pump

The phase II setup involved modifying the rotary evaporator machine to include a long temperature probe as can be seen in Figure 4.6 below.
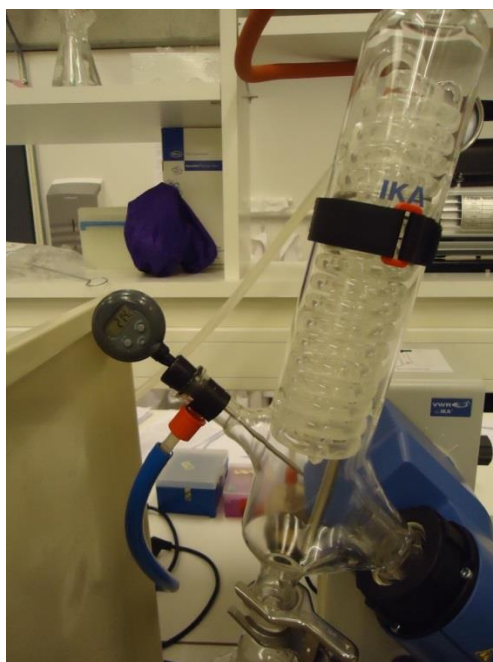
Figure 4.6: Photo of phase II experimental setup with long temperature probe

The long temperature probe was used to directly measure the vapor temperature of the base oil samples at their boiling point. Phase II involved heating the base oil samples until they boiled and began to vaporize. This initial vapor temperature was noted and the base oil sample was heated more until the entire sample was vaporized. Phase II resulted in a range of vapor temperatures from the initial vaporization temperature to the maximum vapor temperature. The reason for the range of vapor temperatures is due to the makeup of the base oils which include both shorter chain and longer chain hydrocarbons. The shorter chain hydrocarbons are vaporized at lower temperatures and the longer chain hydrocarbons vaporize at higher temperatures. The phase II experiments were also carried out at the low pressure of 1.5 mbar achieved by connecting the rotary evaporator to the high powered vacuum pump as shown in Figure 4.4 above.

4.2.2   Results

The phase I results for the two base oils Sipdrill 2/0 and Clarisol NS are presented in Figures 4.7 and 4.8 below. The results are plotted as vapor pressure versus boiling point bath temperature yielding an exponential relationship. Figures 4.9 and 4.10 show the Sipdrill 2/0 and Clairsol NS phase I and phase II results plotted on the same graph.
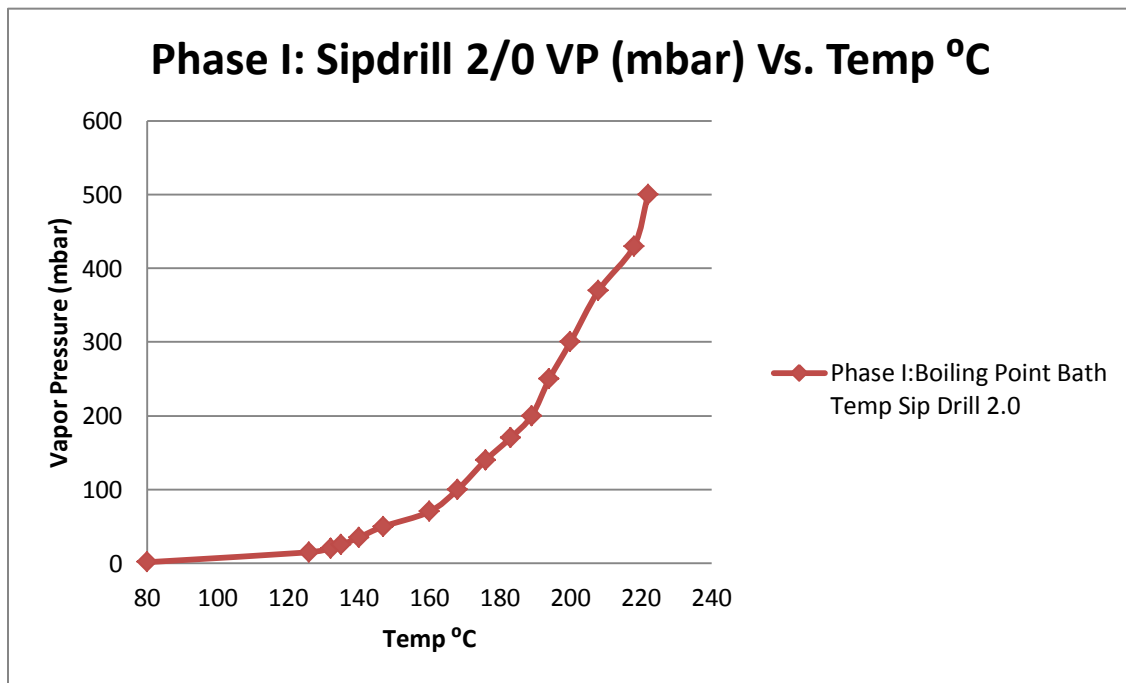
Figure 4.7: Phase I plot of vapor pressure versus boiling point bath temperature for the base oil Sipdrill 2/0
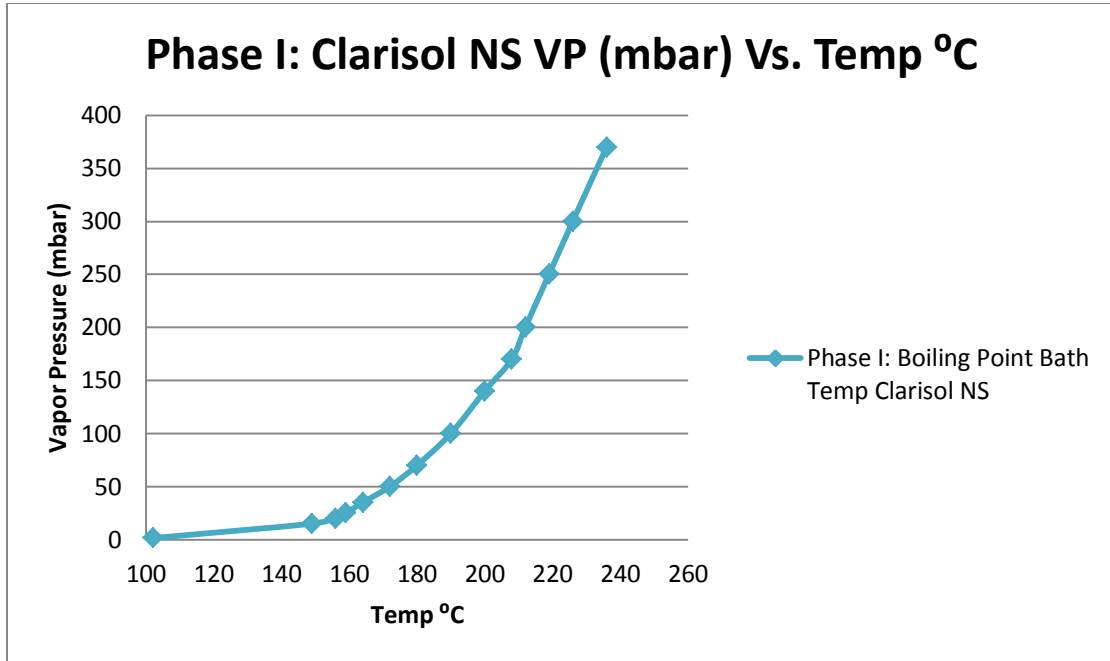
Figure 4.8: Plot of phase I vapor pressure versus boiling point bath temperature for the base oil Clarisol NS
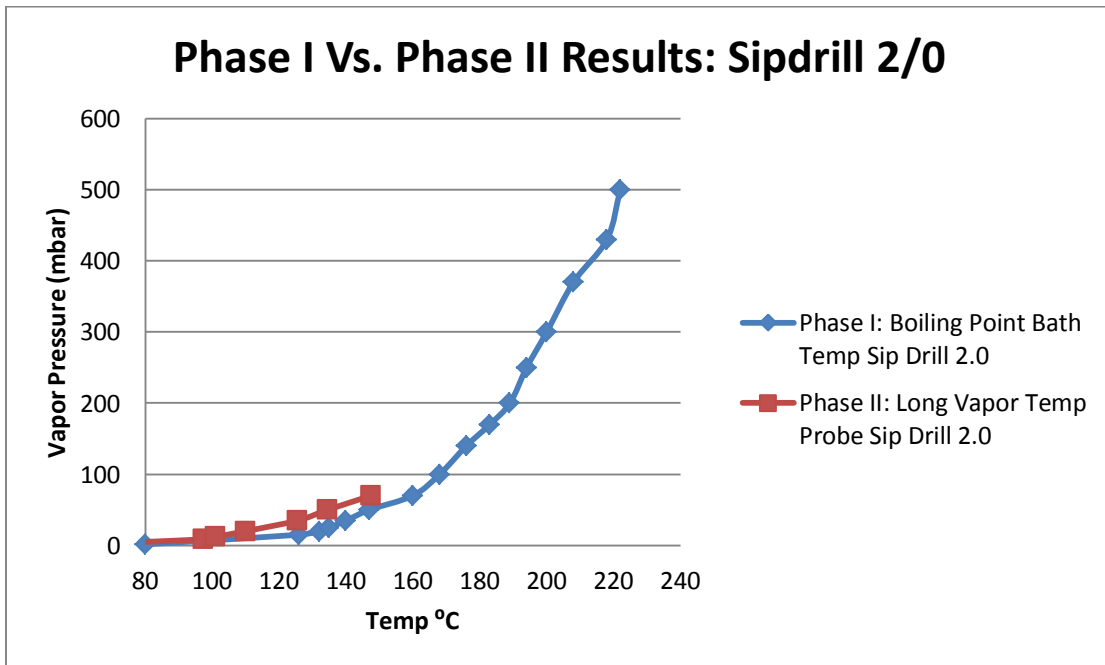
Figure 4.9: Plot of phase I versus phase II results for the base oil Sipdrill 2/0
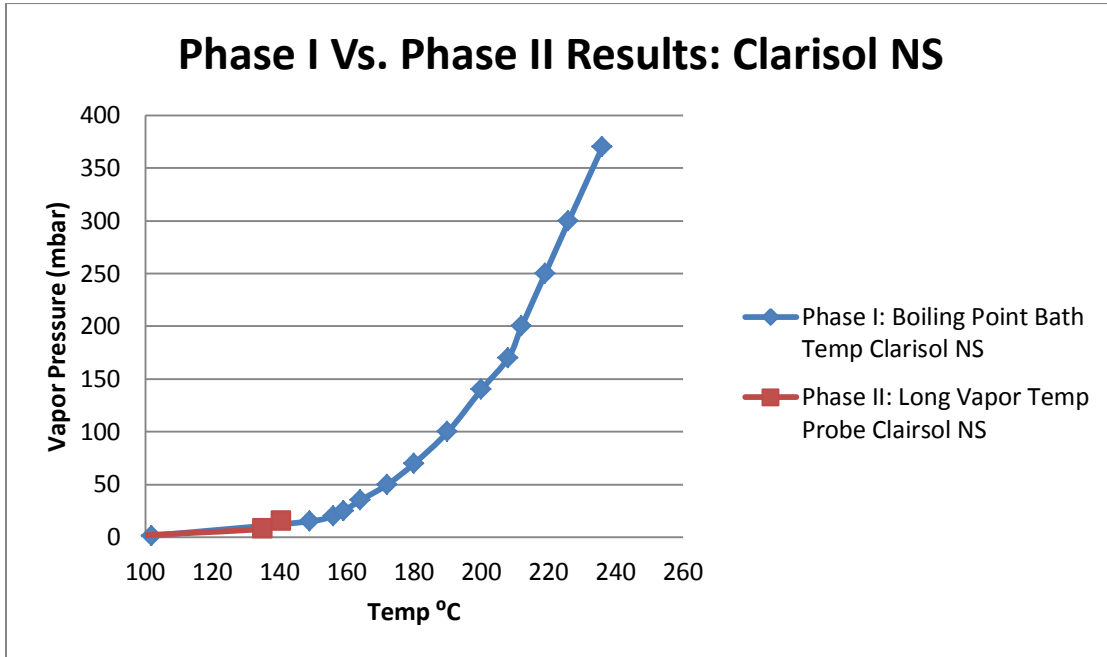
Figure 4.10: Plot of phase I versus phase II results for the base oil Clairsol NS

Due to the limited amount of Phase II results, it was decided to linearize the phase II and phase I results in order to compare their linear equations. The results have been linearized by plotting the natural log of vapor pressure (ln P) versus the inverse of the absolute temperature in Kelvin (1/T) as can be seen in Figures 4.11 and 4.12 below. The resulting graph yields a straight line of Equation 3.1 and a slope equal to $(-\Delta H_{vap}/R)$ [40]. The phase II results are plotted together with the phase I results in order to show how closely their linear equations resemble each other. The equations of the lines have been presented in Figures 4.11 and 4.12 below because they can be used in further experiments to determine the base oils enthalpy of vaporization ΔH_{vap} or vapor pressure at varying temperatures. In addition, all of the raw data and results for the phase I and phase II experiments can be found in Appendix-3.
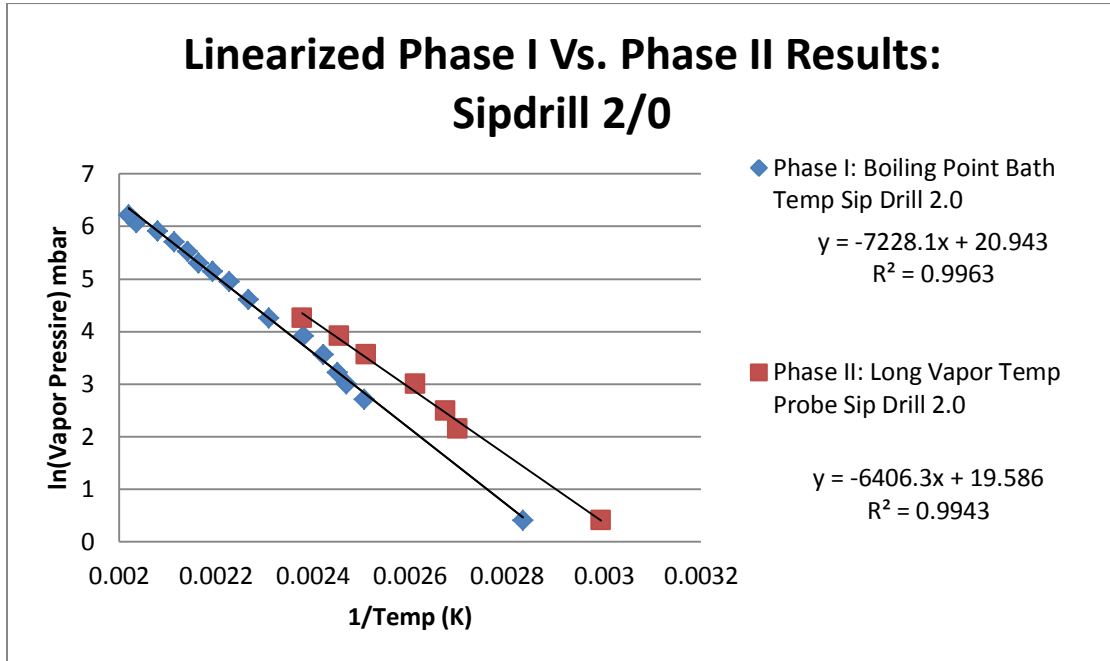
Figure 4.11: Linearized plot of phase I and phase II results for Sipdrill 2/0
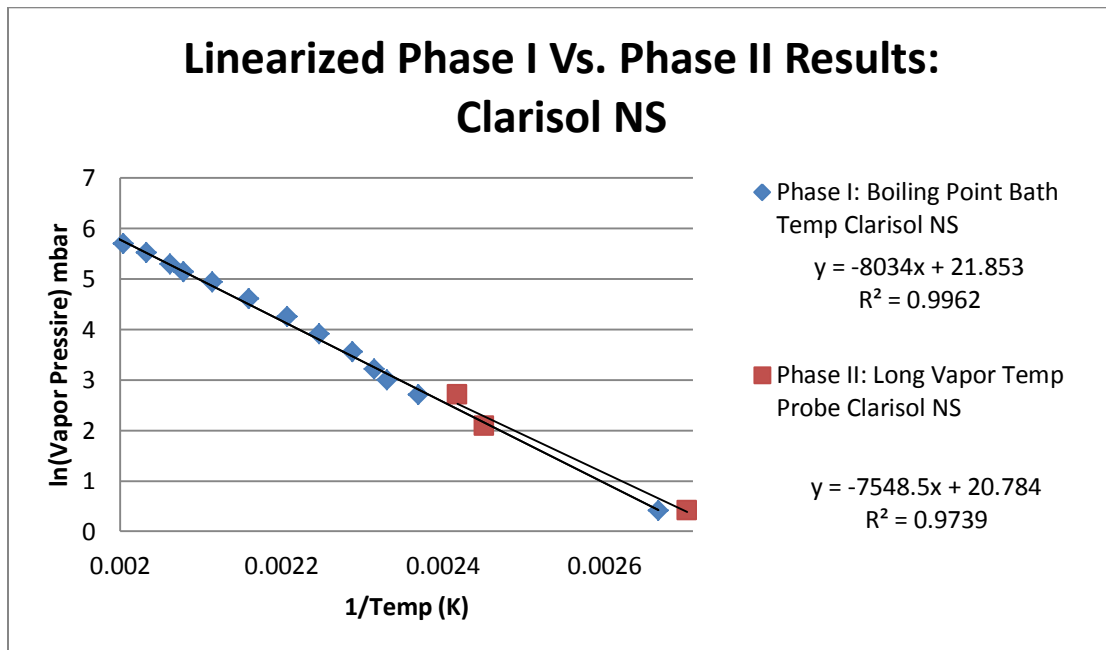
Figure 4.12: Linearized plot of phase I and phase II results for Clarisol NS

4.3   Superheated Steam Distillation Experiment

An experiment was developed in order to test the behavior of the base oils Sipdrill 2/0 and Clairsol NS under superheated steam distillation conditions. The setup included a steam production unit, a steam superheating unit, a distillation unit, and a condensing unit. The relative volumes of oil and water produced in the condensed distillate were measured. The measured volumes were used in the Ideal Gas Law and Dalton's Law of Partial Pressure to calculate the vapor pressures of the base oils. The calculated vapor pressures from these experiments were compared to the standardized Rota vapor reference results.

4.3.1   Methods and Materials

1   Large stainless steel cooking pot and lid

2   Copper tubing 10 mm diameter

3   Fittings and connectors for copper tubing

4   Erlenmeyer flask 2 liter size

5   Two Hot Plates: Heidolph 30001

6   Temperature Control Unit for Hot Plate: Heidolph EKT 3001

7   Rubber stoppers

8   Three temperature probes

9   Three retort stands and clamps

10   Glass 3-way distillation connection adaptor 29/32

11   Round bottomed tempered glass flask

12   Boiling Chips and stir bars

13   Clarisol NS Oil Sample

14   Sipdrill 2/0 Oil Sample

15   Glass condenser

16   Glass Y-adaptor

17   Plastic neck clamps

18   Glass end adaptor for condenser

19   Graduated cylinder 100 ml size

20   Two heat guns

21   Drill

22   Galvanized steel wire mesh

23   Aluminum foil and wire

24   Fiberglass insulation

25   Electronic balance

The experimental setup shown in Figure 4.13 below was constructed in order to test the behavior of base oils Clairsol NS and Sipdrill 2/0 under superheated steam distillation conditions.

Figure 4.13: Photo of experimental setup for superheated steam distillation

The experimental setup shown in Figure 4.13 is comprised of the following four main components, the steam production unit, the steam superheating unit, the distillation unit, and the condensing unit. The steam production unit was designed to produce a steady rate of steam through the use of an adjustable Heidolph 30001 hotplate. Stir bars and boiling chips were added to the two liter Erlenmeyer flask in order to ensure controlled boiling of

the water used to produce steam. A rubber stopper was drilled in order to insert a copper tube to collect the steam and transport it to the steam superheating unit. Figure 4.14 shows the steam production unit in operation.
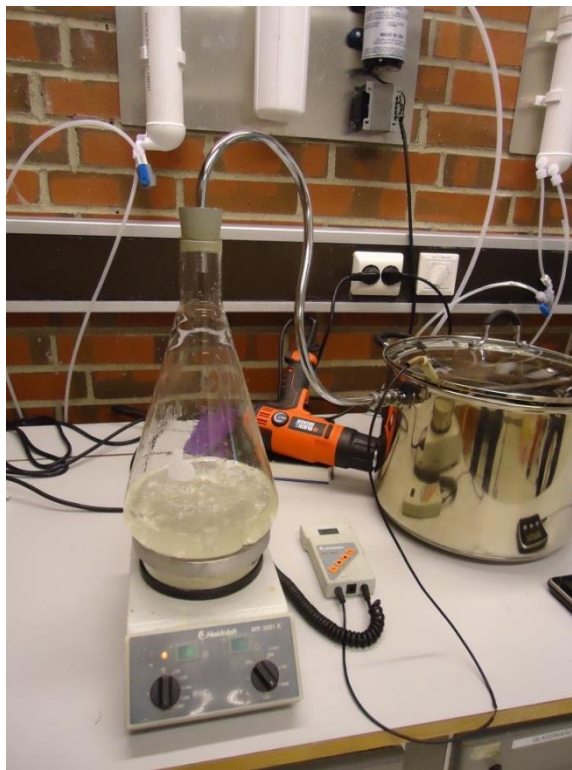
Figure 4.14: Photo of steam production unit in operation

The steam superheating unit was designed to superheat the steam through the use of a heat gun and a closed stainless steel cooking pot. The copper tubing carrying the steam was coiled within the cooking pot in order to maximize the surface area exposed to the hot air provided by the heat gun as shown in Figure 4.15.
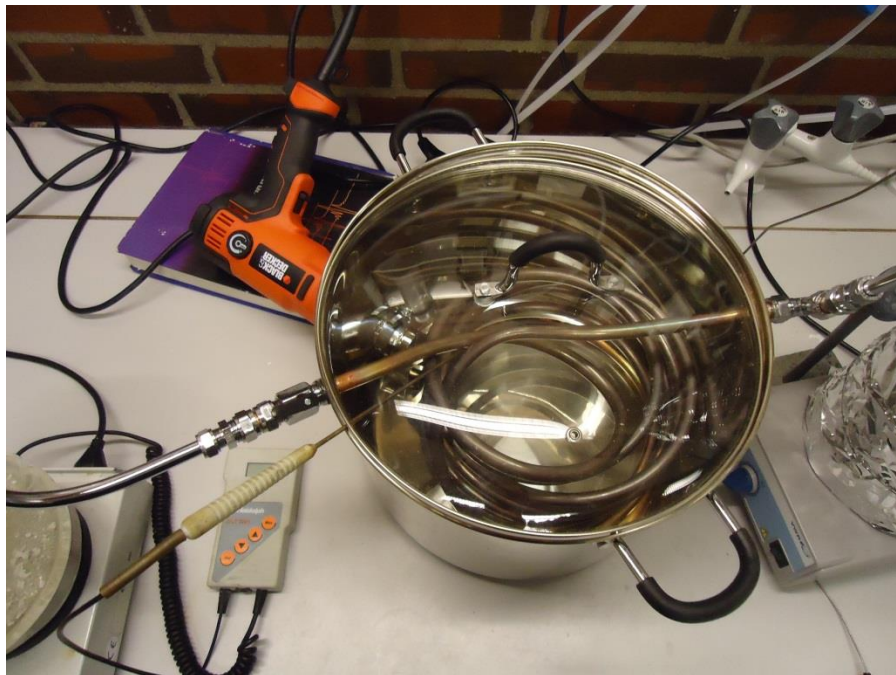
Figure 4.15: Photo of steam superheating unit with heat gun and temperature control unit for Heidolph 30001 hot plate

The temperature within the steam superheating unit was measured using the temperature control unit for the Heidolph 30001 hotplate as shown in Figure 4.15 above. The temperature of the superheated steam leaving the unit was measured using a temperature probe inserted into the copper steam tube. After the temperature reading, the superheated steam was transported to the distillation unit shown in Figure 4.16 below. The distillation unit was designed to provide thorough mixing of the superheated steam and oil sample in order to maximize distillation efficiency. Superheated steam was injected at the bottom of the flask containing the oil sample and was vigorously mixed using a stir bar. The oil and steam mixture was heated with a hot plate in order to aid in the distillation process and avoid heat loss. The temperature of the oil and steam mixture in the flask was measured using a long temperature probe as shown in Figure 4.16 below. A temperature probe located at the top of the distillation unit was used to measure the temperature of the distilled vapor exiting the distillation unit as shown in Figure 4.16 below.

Figure 4.16: Photo of distillation unit

The four temperature probes mentioned previously were installed at various stages of the experimental setup in order to assist in maintaining steady state conditions during the distillation process.

Due to significant heat loss from the glass tubing of the distillation unit, it was decided to insulate the unit with fiberglass building insulation. The fiberglass insulation was found to be insufficient to prevent excessive heat loss. An effective solution was found by building a wire mesh housing around the unit and covering it with aluminum foil as shown in Figures 4.17 and 4.18 below. Hot air was then supplied into the housing with the use of a heat gun as shown in Figure 4.18 below. This solution was very effective at preventing heat loss and it enabled tighter control of steady state conditions during distillation. The heat gun could be adjusted to either increase or decrease the heating rate of the oil and steam mixture in the flask.
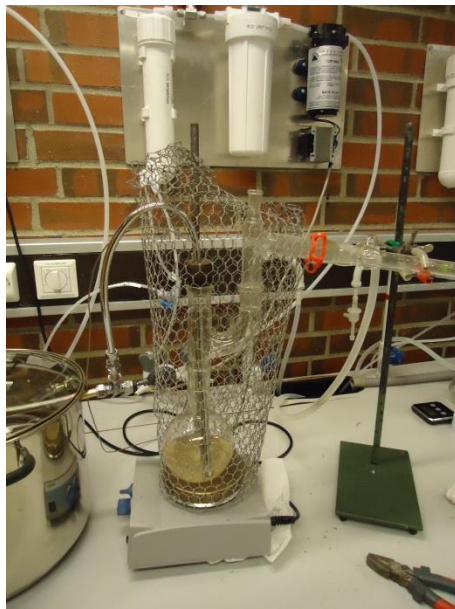
Figure 4.17: Photo of wire mesh housing built around distillation unit
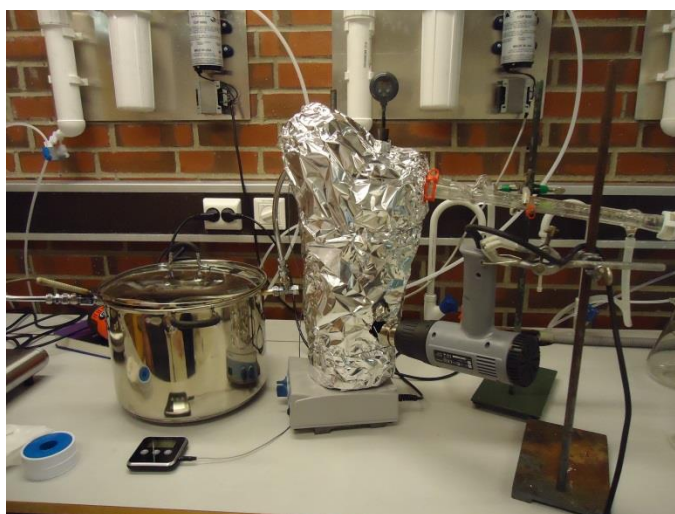
Figure 4.18: Photo of wire mesh and aluminum foil housing built around distillation unit with heat gun

The final component of the experimental setup was the condensing unit shown in Figure 4.19 below. The condensing unit consisted of a glass-jacketed water cooled condenser that efficiently condensed the vapors from the distillation unit. The condensed vapors were then collected in a 100 ml graduated flask as shown in Figure 4.20 below. The relative volumes of oil and water could then me measured by visual inspection.
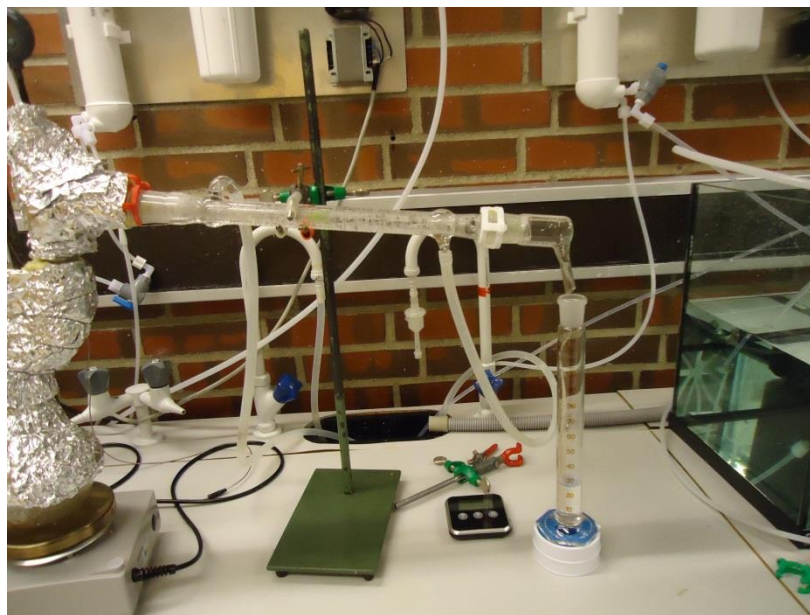
Figure 4.19: Photo of condensing unit of experimental setup

Figure 4.20: Photo of graduated cylinder used to capture condensed vapors

The experimental procedure involved first filling the flask in the distillation unit with a sample of base oil and then heating it to around 95 °C with vigorous stirring. It was critical to keep the oil sample temperature below 100 °C until the steam from the steam

production unit had been sufficiently heated and dried by the steam superheating unit. If the steam was not completely dried, then small water droplets entrained in the steam could flash boil explosively when they came in contact with oil above 100 ⁰C. While the oil was slowly heated, the steam production unit was initiated and the steam superheating unit was heated up. Once the steam temperature leaving the steam superheating unit was safely above 100 ⁰C, then the oil sample could be heated above 100 ⁰C. The oil sample was heated using a combination of the superheated steam, the hotplate under the sample flask and the heat gun associated with the distillation housing. The cooling water for the condensing unit was turned on at this stage in order to condense any vapors leaving the distillation unit. A measurement of the distillate was taken once the experimental setup had reached an equilibrium state for a period of time. An equilibrium state was established once the four temperature probes throughout the process had stabilized. The distillate separated into two distinct layers with the base oil on the top and water on the bottom. Both volumes were visually measured using the graduated cylinder and the results were noted. The experiment was repeated for both base oil samples and was conducted over a range of temperatures. Figure 4.21 shows the final experimental setup during operation.

Figure 4.21: Photo of final experimental setup during operation

In addition to the superheated steam distillation experiments, the density of the base oils was also experimentally determined. The density of both Sipdrill 2/0 and Clairsol NS was measured at 15 ℃ and 30 ℃ using a graduated cylinder and an electronic balance. These temperatures were selected because the densities listed in the MSDS's of the base oils were measured at 15 ℃ and the distillate from the superheated steam experiments was measured at 30 ℃.

4.3.2 Results

All of the base oil vapor pressures for the superheated steam distillation experiments were calculated using Equation 3.18 below.

$$M_{O/w} = \frac{P_O \times MW_O}{(1.013bar - P_O) \times 18g/mol} \qquad \text{Equation 3.18}$$

Equation 3.18 was rearranged and solved for P_o which was the vapor pressure of the oil sample. The variable $M_{o/w}$ was the experimentally determined mass ratio of oil produced per unit water in the distillate. The molecular weight of the oil MW_o was calculated using Equation 4.1 below.

$$C_n H_{2n+2} \qquad \text{Equation 4.1}$$

Equation 4.1 assumes that the base oils are composed entirely of alkanes which have the highest hydrogen to carbon ratio. Figure 4.22 below shows the experimental results for Sipdrill 2/0 assuming an average hydrocarbon length of twelve carbons for the molecular mass calculation. In addition, Figure 4.23 below shows the experimental results for Clairsol NS assuming an average hydrocarbon length of sixteen carbons for the molecular mass calculation. Both Figures 4.22 and 4.23 show the results of the superheated steam experiments one and two versus the standard Rota-vapor results.
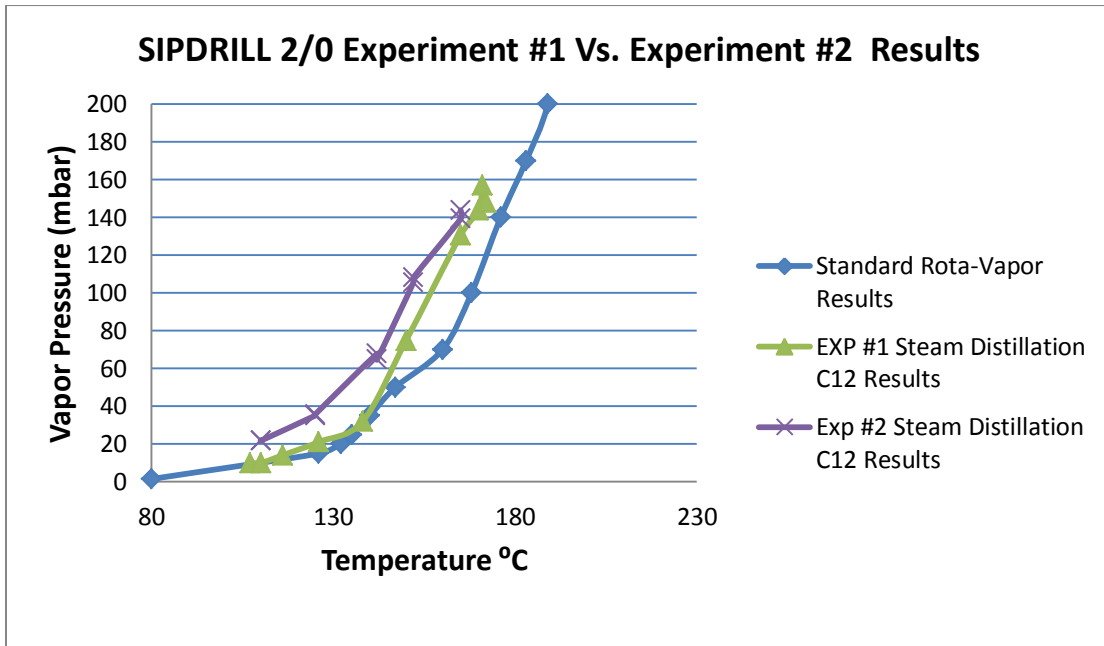
Figure 4.22: Plot of Sipdrill 2/0 vapor pressure versus temperature results for superheated steam experiments 1 and 2 compared to standard Rota-vapor results
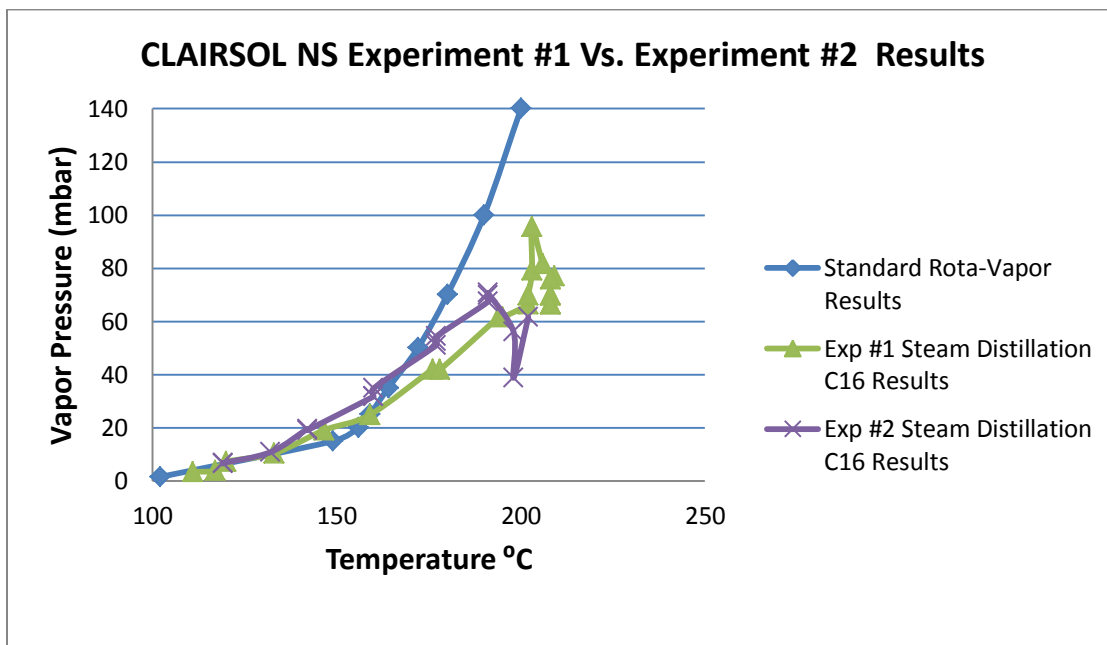
Figure 4.23: Plot of Clairsol NS vapor pressure versus temperature results for superheated steam experiments 1 and 2 compared to standard Rota-vapor results

Figures 4.24 and 4.25 below show the Sipdrill 2/0 superheated steam results for experiments one and two. They also show the variation in vapor pressure assuming the

shortest, average, and longest carbon chain lengths listed in the MSDS for Sipdrill 2/0 found in Appendix-1.
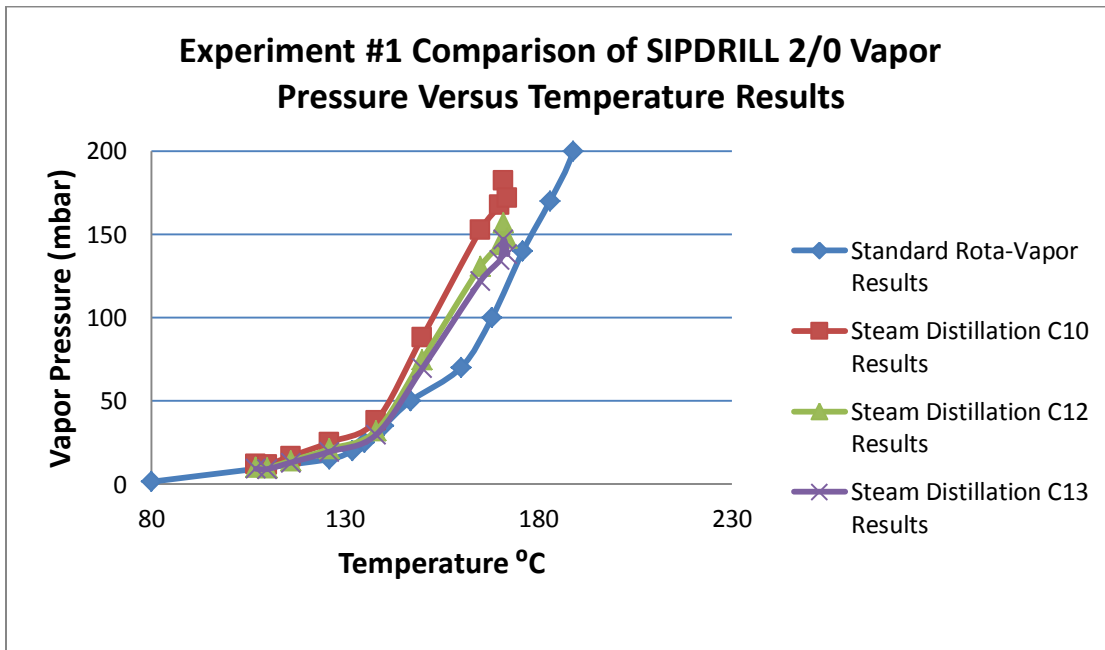
Figure 4.24: Plot of Sipdrill 2/0 experiment one results showing vapor pressure variation assuming different carbon chain lengths
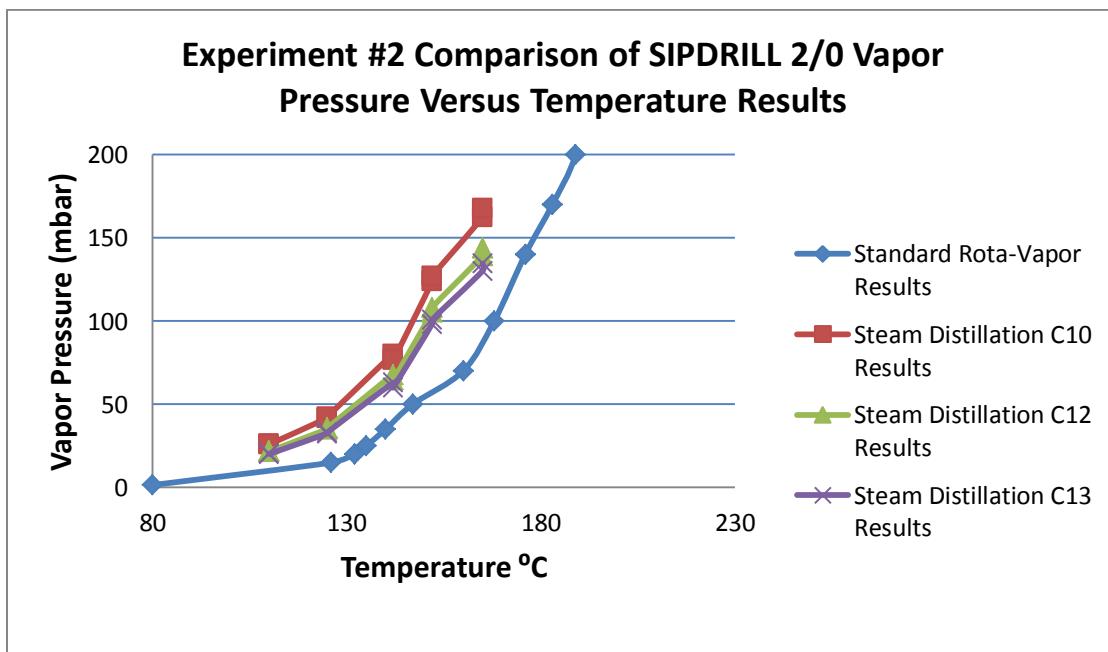
Figure 4.25: Plot of Sipdrill 2/0 experiment two results showing vapor pressure variation assuming different carbon chain lengths

Figures 4.26 and 4.27 below show the Clairsol NS superheated steam results for experiments one and two. They also show the variation in vapor pressure assuming the shortest, average, and longest carbon chain lengths listed in the MSDS for Clairsol NS found in Appendix-2.
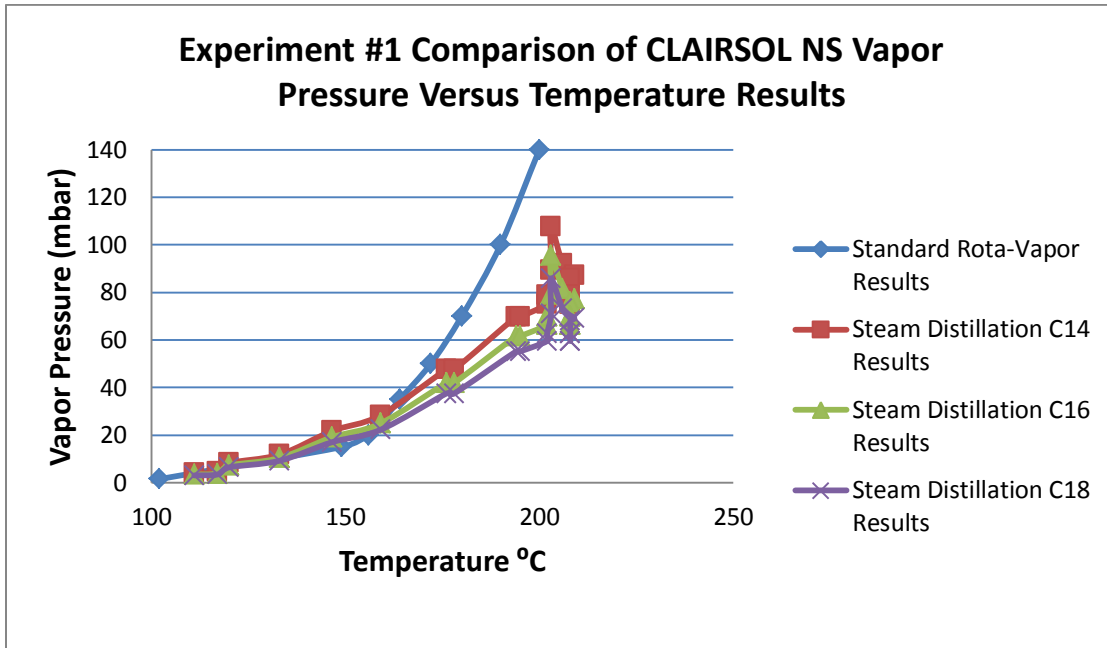
Figure 4.26: Plot of Clairsol NS experiment one results showing vapor pressure variation assuming different carbon chain lengths
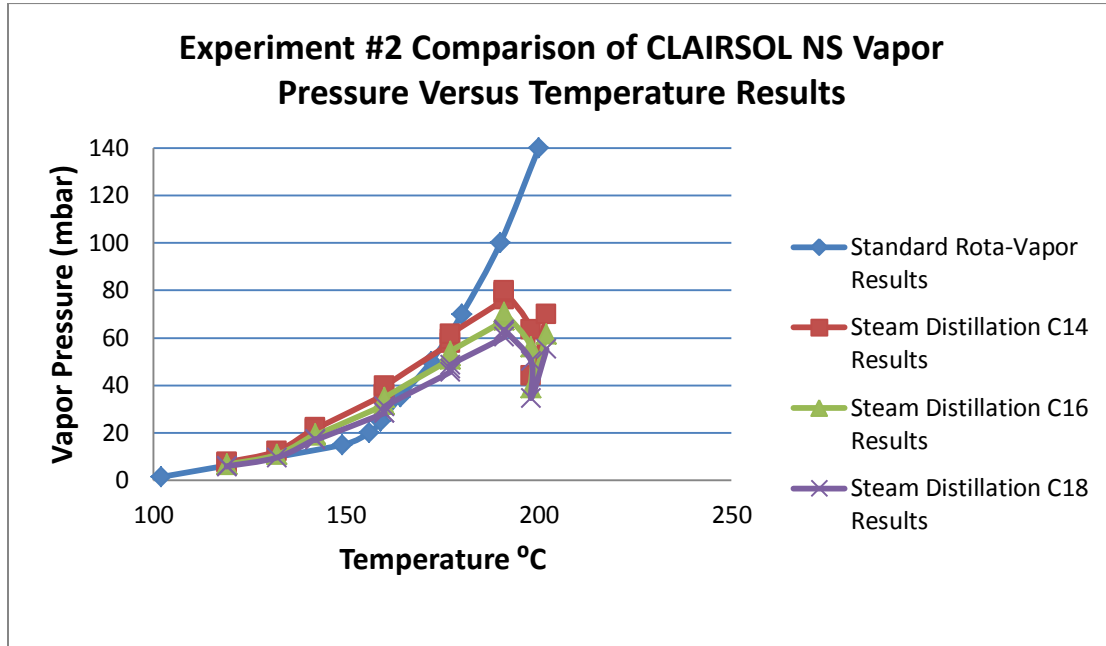
Figure 4.27: Plot of Clairsol NS experiment two results showing vapor pressure variation assuming different carbon chain lengths

Figures 4.28 and 4.29 below show the base oil distillation rates for Sipdrill 2/0 and Clairsol NS during the superheated steam distillation experiments one and two. The distillation rate is expressed as the volume ratio of oil produced per unit water in the distillate as a function of temperature. The results of experiments one and two are presented in Figure 4.28 for Sipdrill 2/0 and Figure 4.29 for Clairsol NS.
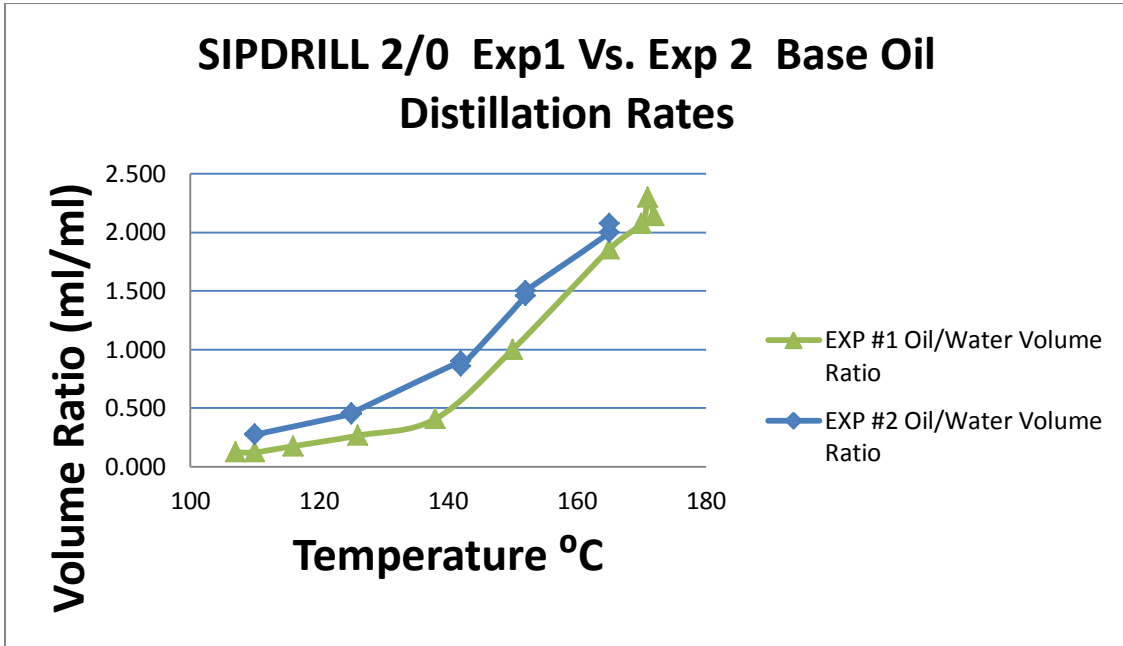
Figure 4.28: Plot of Sipdrill 2/0 distillation rates expressed as the volume ratio of oil/water produced in the distillate as a function of temperature for experiments one and two
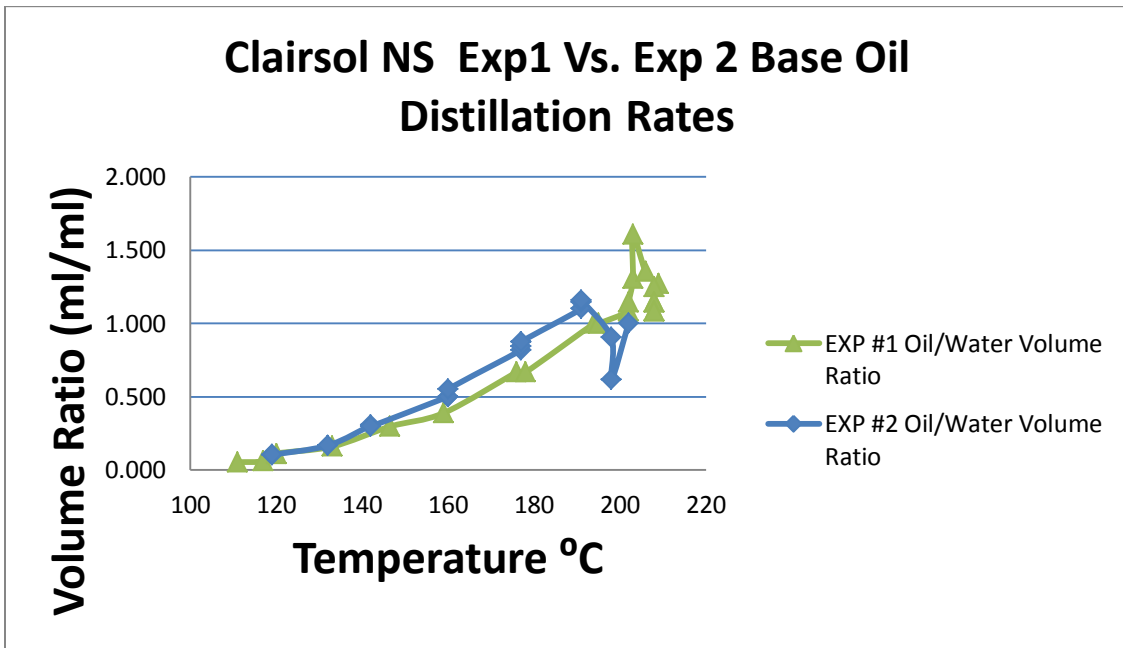
Figure 4.29: Plot of Clairsol NS distillation rates expressed as the volume ratio of oil/water produced in the distillate as a function of temperature for experiments one and two

All of the data and vapor pressure calculations for the superheated steam distillation experiments can be found in Appendix-4. The results of the density experiments for Sipdrill 2/0 and Clairsol NS are presented in Tables 4.1 and 4.2 below. In addition, the raw data and results from the oil density experiments can also be found in Appendix-4.

Table 4.1: Results of density experiments for Sipdrill 2/0

Density Experiment: SIPDRILL 2/0			
Average Density at 15^0C (g/ml)	Average Density at 30^0C(g/ml)	Density at 15^0C given in MSDS (g/ml)	Standard deviation of results
0.757	0.749	0.760	0.005

Table 4.2: Results of density experiments for Clairsol NS

Density Experiment: CLAIRSOL NS			
Average Density at 15^0C (g/ml)	Average Density at 30^0C(g/ml)	Density at 15^0C given in MSDS (g/ml)	Standard deviation of results
0.816	0.807	0.780-0.920	0.005

5   CHAPTER FIVE: DISCUSSION

5.1   Standardized Vapor Pressure versus Temperature Discussion

This section discusses the results of the standardized vapor pressure versus temperature experiments. The discussion is divided into two subsections where the phase I and phase II results are discussed in detail.

5.1.1   Phase I Experimental Results Discussion

The phase I results have some inherent error because they assume that the heating bath temperature is equal to the temperature of the base oil sample at its boiling point. This assumption is not completely accurate because of thermodynamic heat loss between the silicone heating oil and the base oil sample. The heat from the silicone oil must transfer through the glass sample flask and into the base oil. This process is highly complex and difficult to model therefore a secondary method for measuring the base oil temperature at boiling was developed in phase II.

5.1.2   Phase II Experimental Results Discussion

The phase II method eliminated this heat transfer error by directly measuring the base oil vapor temperature with a long temperature probe. During phase II it was found that the boiling point was a temperature range as opposed to a single temperature point. The reason for the boiling temperature range is due to the composition of the base oil samples which contain both shorter and longer chain hydrocarbons. The shorter chain hydrocarbons boil at lower temperatures and the longer chain hydrocarbons boil at slightly higher temperatures. In phase II, the Sip Drill 2/0 oil samples were heated until the entire sample was vaporized and there was almost nothing left in the sample flask. This was not possible with the Clarisol NS base oil possibly due to its composition which includes longer chain hydrocarbons that do not vaporize easily.

The minimum vapor temperature which can be found in Tables 3 and 4 of Appendix-3 is the temperature of the base oil vapor when vaporization was initiated. The maximum vapor temperature which can also be found in Tables 3 and 4 of Appendix-3 is the

maximum base oil vapor temperature observed throughout the experiment. Generally, the base oil vapor reached a maximum temperature and did not increase despite more heat added to the sample. This follows the expected results as mentioned in the theory section that a liquid at its boiling point will not increase in temperature despite increased heat added.

In order to compare the phase I and phase II results it was necessary to take the average of the phase II base oil vapor temperature range. The average yielded a single boiling point temperature for phase II which could then be compared to the boiling point temperature found in Phase I as can be seen in Figures 4.9 and 4.10 above. Based on the close resemblance of phase I and phase II results, the assumption can be deemed acceptable.

The amount of data points that could be obtained for phase II was limited by the heat capacity of the silicon oil bath which began to smoke at high temperatures and had to be stopped. Phase II required higher heating bath temperatures in order to produce sufficient base oil vapor to obtain a temperature reading. Due to the limited amount of phase II data available, it was decided to linearize the data yielding a linear relationship that could be easily compared with phase I results as can be seen in Figures 4.11 and 4.12 above. The linearized Phase I and Phase II results in Figures 4.11 and 4.12 correlate closely.

5.2   Superheated Steam Distillation Discussion

This section discusses the superheated steam distillation experimental results. The discussion is divided into several subsections where the results are discussed in detail.

5.2.1   Sipdrill 2/0 Experimental Results Discussion

The Sipdrill 2/0 superheated steam distillation results closely correlate with the standard vapor pressure versus temperature results henceforth referred to as the standard Rota-vapor results. They both demonstrate a very similar exponential growth relationship as shown in Figure 4.22 above. Although there is a close correlation of the results, the superheated steam results are shifted slightly to the left of the standard Rota-vapor results. This slight deviation could be due to errors incurred during the steam distillation

experiments or during the standard Rota-vapor experiments. A possible source of error in the superheated steam distillation experiments could be from visually measuring the relative volumes of oil and water produced in the distillate. It was difficult to determine the exact interface between the oil and water for accurate volume measurements. This error may have impacted the experimentally determined masses of oil and water in the distillate. These values were used in the vapor pressure calculations, thus resulting in potential deviations from the standard Rota-vapor results.

The other possible source of error came from the inherent error in the standard Rota-vapor results. This inherent error is because the Rota-vapor results approximated the temperature of the oil samples by assuming they were equal to the temperature of the heating oil bath. This is not completely accurate due to the thermodynamic heat losses between the heating oil bath and the oil samples. This error caused the temperatures measured in the Rota-vapor results to be higher than the actual oil sample temperatures. In the superheated steam distillation experiments, the oil vapor temperatures were measured directly with a temperature probe. The direct measurement of the oil vapor temperatures resulted in lower temperature values at a given vapor pressure when compared to the standard Rota-vapor results. This resulted in a shift of the superheated steam results to the left of the standard Rota-vapor results. The shift can be seen in both the Sipdrill 2/0 results as well as the Clairsol NS results presented in Figures 4.22 and 4.23 above.

5.2.2　　　　Experiment One versus Experiment Two Discussion

There is an observable leftward shift between the results of experiments one and two as can be seen in Figures 4.22 and 4.23 above. The experiment two results for both Sipdrill 2/0 and Clairsol NS are shifted slightly to the left of the experiment one results. It was observed in experiment one that the temperature of the oil vapor leaving the distillation unit was higher than the oil in the distillation flask. This temperature variance was due to superheating of the oil vapor after the distillation flask. The source of the superheating was the heat gun associated with the insulation housing built around the distillation unit. During experiment two an effort was made to reduce the superheating of the oil vapor.

This was accomplished by tight control of the heat gun to ensure that the temperature of the oil in the distillation flask was always equal to or higher than the oil vapor temperature. The reduction in superheating of the oil vapor caused the experiment two results to have lower temperature values at a given vapor pressure when compared to experiment one results. This resulted in the experiment two results shifting to the left of the experiment one results as shown in Figures 4.22 and 4.23 above.

5.2.3 Clairsol NS Experimental Results Discussion

At lower temperatures, the Clairsol NS superheated steam results closely correlate with the standard Rota vapor results as can be seen in Figure 4.23 above. The Clairsol NS results begin to deviate from the standard Rota vapor results at temperatures above roughly 170 °C as shown in Figure 4.23 above. The possible reasons why the Clairsol NS results deviate at high temperatures could be due to insufficient mixing and the presence of heavier oil fractions. Clairsol NS contains longer chain hydrocarbons which possess strong intermolecular forces. These heavier oil fractions are more resistant to distillation and require higher energy input for vaporization. Towards the end of the experiment, most of the lighter hydrocarbon fractions had vaporized leaving behind the heavier more resistance hydrocarbons. The Rota vapor results do not reflect this phenomenon because the Clairsol NS oil samples were not completely vaporized in the Rota vapor experiments. At the end of the Rota vapor experiments there was still a small volume of Clairsol NS oil sample left in the sample flask. This is in contrast to the superheated steam distillation experiments which were run until all of the Clairsol NS was vaporized and there was nothing left in the sample flask. The complete distillation of these heavier fractions is evident by the deviation of the superheated steam results from the Rota vapor results at high temperatures. This irregularity was not observed with the Sipdrill 2/0 results. The reason is because both the Sipdrill 2/0 superheated steam experiments and the Rota vapor experiments were carried out until the base oil samples were completely vaporized. Also, Sipdrill 2/0 has a more uniform composition of lighter fraction hydrocarbons which are easier to distill and vaporize.

The incomplete mixing of the Clairsol NS and steam towards the end of the experiments may also have contributed to the deviations from the standard Rota vapor results. At the end of the experiments there was very little Clairsol NS left in the sample flask. As a result, it was difficult to completely mix the steam and Clairsol NS. This incomplete mixing reduced the effectiveness of the distillation process thereby contributing to the deviations from the standard Rota-vapor results. The incomplete mixing effect was not as pronounced in the Sipdrill 2/0 results. This is most likely due to the lighter chemical composition and higher vapor pressure of the Sipdrill 2/0.

5.2.4 Base Oil Molecular Weight Discussion

For the purpose of calculating the molecular weights of the base oils, it was decided to use the chemical compositions listed in the MSDSs for Clairsol NS and Sipdrill 2/0. Gas chromatography-mass spectrometry (GC-MS) was not carried out on the base oils because the results of such an analysis would be difficult to interpret due to the complex compositions of the base oils. The chemical compositions and carbon contents listed in the MSDS's of the base oils were deemed sufficient to calculate the molecular weights of the base oils. The molecular weights were calculated using Equation 4.1 which assumes the base oils are composed entirely of alkanes. This molecular formula was used to approximate the molecular weights because the base oils are primarily composed of alkanes. The MSDS for Sipdrill 2/0 in Appendix-1 lists a chemical composition of one hundred percent aliphatic hydrocarbons with between ten and thirteen carbons. Therefore, the results presented in Figure 4.22 above show the vapor pressures for the superheated steam results calculated assuming an average carbon content of twelve carbons. The MSDS for Clairsol NS in Appendix-2 lists a chemical composition made up primarily of alkanes with an aromatic content of less than two percent. The carbon content of Clairsol NS is listed as a range between fourteen and eighteen carbons. Therefore, the vapor pressures of the Clairsol NS superheated steam results in Figure 4.23 are calculated assuming an average carbon content of sixteen carbons. Figures 4.24, 4.25, 4.26, and 4.27 above show how the calculated vapor pressures vary when different carbon contents listed in the MSDS's of the base oils are assumed. From these Figures it is clear that the

calculated vapor pressures do not vary significantly when different carbon contents are assumed for the base oils in the vapor pressure calculations. Therefore, Figures 4.22 and 4.23 above are good approximations of the average base oil vapor pressures during the superheated steam distillation experiments.

5.2.5   Distillation Rate Discussion

Figures 4.28 and 4.29 above clearly show that the base oil distillation rates using superheated steam are significantly increased when compared to normal distillation at 100 ^{o}C. From Figures 4.28 and 4.29 above it can be seen that the volume ratio of oil produced per unit water in the distillate increases significantly at temperatures above 100 ^{o}C. This higher oil production per unit water definitively indicates an increased base oil distillation rate when superheated steam is utilized. In Figures 4.28 and 4.29 above there is an observable leftward shift of the experiment two results relative to the experiment one results. This leftward shift is due to the reduction in superheating of the oil vapor during experiment two as explained earlier. In addition, at temperatures above 190 ^{o}C the Clairsol NS results in Figure 4.29 above show deviation from the normal data trend. This deviation is most likely due to insufficient mixing and the presence of heavier oil fractions as discussed earlier.

5.2.6   Density Experiment Discussion

The results of the base oil density experiments are shown in Tables 4.1 and 4.2 above. These results closely match the listed densities in the MSDSs for Sipdrill 2/0 and Clairsol NS found in Appendices 1 and 2 respectively. The density results show that there was very little variation between the densities measured at 15 ^{o}C and those measured at 30 ^{o}C. The distillate collected at the end of the superheated steam experiments was measured to be 30 ^{o}C. Therefore, the base oil densities measured at 30 ^{o}C during the density experiments were used for the vapor pressure calculations.

6   CHAPTER SIX: CONCLUSIONS AND FUTURE STUDIES

6.1   Conclusions from Standardized Vapor Pressure versus Temperature Rota Vapor Experiments

In conclusion, the standardized vapor pressure versus temperature Rota vapor data obtained in the phase I experiments is comparable to the data found in phase II. This conclusion is based upon the close correlation of the linearized graphical representation of the phase I and phase II data. The equations representing the lines of the two data sets are similar enough that they can be deemed analogous to each other. The close resemblance of the phase I and phase II data means they can be used as standard reference results in future experiments with the two base oils Sip Drill 2/0 and Clarisol NS.

6.2   Conclusions from Superheated Steam Distillation Experiments

The base oil vapor pressures calculated using the Ideal Gas Law and Dalton's Law of Partial Pressure for the superheated steam experiments closely correlate with the standardized Rota vapor reference results. There are some slight deviations of the experimental results from the reference results but these deviations are considered minor. The deviations from the reference results were due to differences in experimental procedures applied in the superheated steam experiments as well as differences in the chemical compositions of the base oils. The Clairsol NS results do not correlate as closely with the reference results as do the Sipdrill 2/0 results. This is due to the effect of up concentration of heavier distillation resistant components in the Clairsol NS towards the end of the superheated steam experiments. The results of the superheated steam distillation experiments clearly show that the base oil distillation rates using superheated steam are significantly increased when compared to normal distillation at 100 ⁰C.

6.3   Future Studies

The results of the superheated steam distillation experiments show promise for potential use in the offshore treatment of drill cuttings to remove retained oil on cuttings. The

superheated steam technology should be tested on actual drill cuttings contaminated with drilling base oil. The results of such a future study will provide insight into the effectiveness of this technology to remove retained oil on cuttings.

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SUPERHEATED STEAM DISTILLATION FOR TREATMENT OF DRILL CUTTINGS
CONTAMINATED WITH OIL BASED DRILLING FLUIDS

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Appendix-1

Appendix-1: Material Safety Data Sheet for Base Oil – SIPDRILL 2/0

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BAKER HUGHES **SIKKERHETSDATABLAD** **BAKER HUGHES**
BASE OIL - SIPDRILL 2/0

Seksjon 1: Identifikasjon av stoffet / blandingen og av selskapet / foretaket

Utgitt dato	19.03.2008
Revisjonsdato	30.07.2012

1.1. Produktidentifikasjon

Kjemikaliets navn	BASE OIL - SIPDRILL 2/0
CAS-nr.	64771-72-8
EC-nr.	265-233-4

1.2. Relevant identifiserte bruksområder for stoffet eller blandingen og bruk det fraådes mot

Kjemikaliets bruksområde	Olje-boringskjemikalie.

1.3. Nærmere opplysninger om leverandøren av sikkerhetsdatabladet

Distributør

Firmanavn	Baker Hughes Norge
Besøksadresse	Tanangerveien 501
Postadresse	Tanangerveien 501
Postnr.	4056
Poststed	TANANGER
Land	Norway
Telefon	+47 51 71 75 00
Telefaks	+47 51 71 75 01
E-post	NorwayHS&ETeam@bakerhughes.com
Hjemmeside	http://www.bakerhughes.com

1.4. Nødtelefon

Nødtelefon	Giftinformasjonen:22 59 13 00
	Beredskapstelefon:+47 51 69 46 24

Seksjon 2: Fareidentifikasjon

2.1. Klassifisering av stoff eller blanding

Klassifisering i henhold til 67/548/EEC eller 1999/45/EC	Xn; R65
	R66
Klassifisering i henhold til CLP (EC) No 1272/2008 [CLP/GHS]	Asp. tox 1; H304
Stoffets/blandingens farlige egenskaper	Kan være dødelig ved svelging om det kommer ned i luftveiene. Gjentatt eksponering kan gi tørr eller sprukken hud.

2.2. Etikettinformasjon

Farepiktogrammer (CLP)

Sammensetning på merkeetiketten	N-PARAFIN C10-C13, (alifatiske hydrokarboner): 100 %
Signalord	Fare
Faresetninger	H304 Kan være dødelig ved svelging om det kommer ned i luftveiene.

Dette Sikkerhetsdatablad er utarbeidet i ECO Publisher (ECOonline)   Revisjonsdato 30.07.2012

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Sikkerhetssetninger	P301 + P310 VED SVELGING: Kontakt umiddelbart et GIFTINFORMASJONSSENTER eller lege.
	P331 IKKE framkall brekning.
	P405 Oppbevares innelåst.
	P501 Innhold/beholder skal avhendes i henhold til lokale lover og regler.
Supplerende etikett informasjon	EUH 066 Gjentatt eksponering kan gi tørr eller sprukket hud.

2.3 Andre farer

PBT / vPvB	PBT-/vPvB-vurdering ikke utført.
Helseeffekt	Kan virke irriterende på øyne, nese, svelg og lunger.
Miljøeffekt	Danner oljefilm på vannflater som kan skade organismer som lever i vann og forstyrre oksygentransporten i grensesjiktet luft/vann.

Seksjon 3: Sammensetning / opplysning om innholdsstoffer

3.1. Stoffer

Komponentnavn	Identifikasjon	Klassifisering	Innhold
N-PARAFIN C10-C13, (alifatiske hydrokarboner)	CAS-nr.: 64771-72-8 EC-nr.: 265-233-4	Xn; R65 R66 Asp. tox 1; H304	100 %
Komponentkommentarer	Se seksjon 16 for forklaring av R- og H-setninger.		

Seksjon 4: Førstehjelpstiltak

4.1. Beskrivelse av førstehjelpstiltak

Generelt	I tvilstilfelle bør lege kontaktes.
Innånding	Sørg for frisk luft, varme og ro, helst i behagelig halvsittende stilling. Kontakt lege hvis ikke alt ubehag gir seg.
Hudkontakt	Fjern tilsølt tøy. Vask straks huden med såpe og vann. Skyll huden grundig med vann. Kontakt lege hvis ikke alt ubehag gir seg.
Øyekontakt	Skyll straks med rikelige mengder vann i opptil 15 minutter. Fjern evt. kontaktlinser og åpne øyet godt opp. Ved lengre tids skylling, anvend lunkent vann for å unngå skade på øyet. Kontakt lege hvis ubehaget vedvarer.
Svelging	Gi fløte eller matolje. FREMKALL IKKE BREKNING! Kontakt lege umiddelbart.

4.2. Viktigste symptomer og effekter, både akutt og forsinket

Informasjon til helsepersonell	Risiko for kjemisk lungebetennelse (pneumonitt) ved aspirasjon ved og etter svelging.
Forsinkede symptomer og virkninger	Ved svelging kan det utvikles kjemisk lungebetennelse som gir symptomer som frysninger, feber, smerter i brystet og hoste.
	Innånding av løsemiddeldampe kan være skadelig og overeksponering kan gi hodepine, kvalme, oppkast og rus symptomer.

4.3. Informasjon om umiddelbar legehjelp og spesiell behandling som eventuelt er nødvendig

| Annen informasjon | Ingen spesiell, se seksjon 4.1. |

Seksjon 5: Tiltak ved brannslukning

5.1. Brannslukningsmidler

| Passende brannslukningsmidler | Pulver, karbondioksid (CO2), vanntåke, alkoholresistent skum. |
| Uegnet brannslukningsmidler | Bruk ikke samlet vannstråle. |

5.2. Spesielle farer som stoffet eller blandingen kan medføre

| Brann- og eksplosjonsfarer | Produktet er brennbart, men ikke brannfarlig. |
| Farlige forbrenningsprodukter | Ved brann eller høy temperatur dannes: Karbonmonoksid (CO). Karbondioksid (CO2). Tett røyk. |

5.3. Anvisninger for brannmannskaper

Dette Sikkerhetsdatablad er utarbeidet i ECO Publisher (ECOonline)

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Personlig verneutstyr	Bruk friskluftmaske når produktet er involvert i brann. Ved rømning brukes godkjent rømningsmaske. Se forøvrig seksjon 8.
Annen informasjon	Beholdere i nærheten av brann flyttes straks eller kjøles med vann. Forhindre utslipp av slukningsvann ned i avløpet.

Seksjon 6: Tiltak ved utilsiktet utslipp

6.1. Personlige forholdsregler, verneutstyr og nødprosedyrer

Generelle tiltak	Fjern alle tennkilder. Sørg for god ventilasjon.
Sikkerhetstiltak for å beskytte personell	Benytt personlig verneutstyr som angitt i seksjon 8.

6.2. Sikkerhetstiltak for å beskytte ytre miljø

Sikkerhetstiltak for å beskytte ytre miljø	Forhindre utslipp til kloakk, vassdrag eller grunn.

6.3. Metoder for opprydding og rengjøring

Metoder for opprydding og rengjøring	Absorber i vermikulitt, tørr sand eller jord og fyll i beholdere. Samles opp i egnede beholdere og leveres som farlig avfall i henhold til seksjon 13. Vask det forurensede området med vann og la det tørke.

6.4. Referanse til andre seksjoner

Andre anvisninger	Se også seksjon 8 og 13.

Seksjon 7: Håndtering og lagring

7.1. Forholdsregler for sikker håndtering

Håndtering	Sørg for tilstrekkelig ventilasjon. Unngå kontakt med huden og øynene. Unngå innånding av damp og oljetåke.

Beskyttende tiltak

Tiltak for å hindre brann	Ta forholdsregler mot utladning av statisk elektrisitet. Holdes adskilt fra antennelseskilder.
Råd om generell yrkeshygiene	Det må ikke spises, drikkes eller røykes under arbeidet. Vask hendene etter hvert skift, og før spising, røyking eller bruk av toalett.

7.2. Betingelser for sikker oppbevaring, inklusiv eventuelle uforenligheter

Oppbevaring	Lagres i tett lukket emballasje i kjølig, godt ventilerte rom, beskyttet mot direkte sollys.
Råd angående samlagring	Lagres adskilt fra: Oksidasjonsmidler.
Kommentar, Lagringstemperatur	Oppbevares ved romtemperatur.

7.3 Spesifikk bruk

Spesielle bruksområder	Identifiserte bruksområder for dette produktet er beskrevet i punkt 1.2.

Seksjon 8: Eksponeringskontroll / personlig verneutstyr

8.1. Kontrollparametere

Administrative normer

Komponentnavn	Identifikasjon	Verdi	Norm år
Oljedamp		8 t.: 50 mg/m³	2009

8.2 Begrensning av eksponering på arbeidsplassen

Begrensning av eksponering på arbeidsplassen	Sørg for tilstrekkelig ventilasjon. Personlig verneutstyr bør velges i henhold til CEN-standard og i samarbeid med leverandøren av personlig verneutstyr.

Åndedrettsvern

Åndedrettsvern	Ved utilstrekkelig ventilasjon brukes maske med filter A mot løsemiddeldamper. Bruk kombinasjonsfilter A/P2 ved aerosoldannelse.

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Referanser til relevante standarder	NS-EN 136 . NS-EN 143.

Håndvern

Håndvern	Benytt hansker som er hensiktsmessige for arbeidsoperasjonen.
Egnede materialer	Nitril.
Gjennomtrengningstid	Gjennombruddstiden er ikke kjent. Det angitte hanskemateriale er foreslått etter en gjennomgang av enkeltstoffene i produktet og kjente hanskeguider.
Ytterligere håndbeskyttelsestiltak	Skift hansker ofte!

Øye- / ansiktsvern

Øyevern	Bruk sprutsikre vernebriller dersom det er mulighet for direkte øyekontakt.
Ytterligere øyeverntiltak	Øyedusj bør være på arbeidsplassen. Enten en fast øyedusjenhet koblet til drikkevann (temperert vann ønskelig) eller en bærbar disponibel enhet (øyespyleflaske).

Hudvern

Annet hudvern enn håndvern	Benytt hensiktsmessige verneklær for beskyttelse mot hudkontakt.

Annen informasjon

Annen informasjon	Mulighet for øyeskylling bør finnes på arbeidsplassen. Det oppgitte verneutstyr er veiledende. Risikovurderingen (Faktisk risiko) kan føre til andre krav.

Seksjon 9: Fysiske og kjemiske egenskaper

9.1. Informasjon om grunnleggende fysiske og kjemiske egenskaper

Tilstandsform	Væske
Farge	Klar
Lukt	Oljelukt
Kommentarer, Luktgrense	Ikke angitt.
Kommentarer, pH (handelsvare)	Ikke angitt.
Kommentarer, Smeltepunkt / smeltepunktsintervall	Ikke angitt.
Kokepunkt / kokepunktintervall	Verdi: 210-260 °C
Flammepunkt	Verdi: > 85 °C
	Testmetode: COC
Kommentarer, Fordampningshastighet	Ikke angitt.
Antennelighet (fast stoff, gass)	Ikke relevant.
Kommentarer, Eksplosjonsgrense	Ikke angitt.
Damptrykk	Verdi: < 1 mmHg
	Test temperatur: 20 °C
Damptetthet	Verdi: > 3
	Referansegass: Luft=1
Kommentarer, Damptetthet	v/ 101,3 kPa
Relativ tetthet	Verdi: 0,76 g/cm³
	Test temperatur: 15 °C
Løselighet i vann	Ikke løselig.
Kommentarer, Fordelingskoeffisient: n-oktanol / vann	Ikke angitt.
Selvantennelighet	Verdi: > 200 °C
Kommentarer, Dekomponeringstemperatur	Ikke angitt.
Viskositet	Verdi: < 2 cSt
	Test temperatur: 40 °C

Fysikalske farer

Eksplosive egenskaper	Ikke angitt.
Oksiderende egenskaper	Ikke angitt.

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9.2 Annen informasjon

Flytepunkt   Verdi: < -3 °C

Andre fysiske og kjemiske egenskaper

Fysiske og kjemiske egenskaper   Polysykliske aromater: <0,1%

Seksjon 10: Stabilitet og reaktivitet

10.1. Reaktivitet

Reaktivitet   Det er ingen kjent reaktivitetsrisiko forbundet med dette produktet.

10.2. Kjemisk stabilitet

Stabilitet   Stabil under normale temperaturforhold og anbefalt bruk.

10.3. Risiko for farlige reaksjoner

Risiko for farlige reaksjoner   Oppstår ved kontakt med forhold og materialer som skal unngås (seksjon 10.4
                                                     og 10.5)

10.4. Forhold som skal unngås

Forhold som skal unngås   Unngå varme, flammer og andre antennelseskilder.

10.5. Materialer som skal unngås

Materialer som skal unngås   Sterke oksidasjonsmidler.

10.6 Farlige spaltningsprodukter

Farlige spaltningsprodukter   Ingen kjente.

Seksjon 11: Toksikologisk informasjon

11.1 Informasjon om toxiologiske effekter

Toksikologisk informasjon

LD50 oral   Verdi: > 5000 mg/kg
                                                     Forsøksdyreart: Rotte

LC50 innånding   Verdi: > 1300 ppm
                                                     Forsøksdyreart: Rotte

Potensielle akutte effekter

Innånding   Damp kan irritere luftveier og lunger. Innånding av løsemiddeldamper er
                                                     skadelig. Symptomene på overeksponering er hodepine, tretthet, kvalme,
                                                     brekninger, bevisstløshet, beruselse.

Hudkontakt   Gjentatt eksponering kan gi tørr eller sprukken hud.

Øyekontakt   Kan virke irriterende og kan fremkalle rødhet og svie.

Svelging   Hvis en ved oppkast får produktet i lungene, vil det utvikles kjemisk
                                                     lungebetennelse som kan være livstruende. Inntak kan forårsake irritasjon i
                                                     mage- og tarmsystemet.

Aspirasjonsfare   Kan være dødelig ved svelging om det kommer ned i luftveiene.

Forsinket / Repeterende

Allergi   Kriteriene for klassifisering er på grunnlag av de tilgjengelige data ikke ansett
                                                     å være oppfylt.

Kroniske effekter   Langvarig og gjentatt kontakt med løsningsmidler over lang tid kan gi varige
                                                     helseskader.

Kreftfremkallende, mutagene og reproduksjonstoksiske

Kreft   Kriteriene for klassifisering er på grunnlag av de tilgjengelige data ikke ansett
                                                     å være oppfylt.

Arvestoffskader   Kriteriene for klassifisering er på grunnlag av de tilgjengelige data ikke ansett
                                                     å være oppfylt.

Fosterskadelige egenskaper   Kriteriene for klassifisering er på grunnlag av de tilgjengelige data ikke ansett
                                                     å være oppfylt.

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Reproduksjonsskader	Kriteriene for klassifisering er på grunnlag av de tilgjengelige data ikke ansett å være oppfylt.

Seksjon 12: Miljøopplysninger

12.1. Toksisitet

Akutt akvatisk, fisk	Verdi: > 5000 mg/l Testmetode: LC50 Fiske art: Pimephales promelas Varighet: 96 timer
Akutt akvatisk, fisk. Kommentar	Hentet fra Prevent databasen.
Økotoksisitet	Produktet er ikke klassifisert som miljøskadelig.

12.2. Persistens og nedbrytbarhet

Biologisk nedbrytbarhet	Verdi: 74 % Testperiode: 28 dager Testmetode: OECD 306
Persistens og nedbrytbarhet	Produktet forventes å være bionedbrytbart.

12.3. Bioakkumulasjonspotensial

Bioakkumulasjonspotensial	Forventes ikke å bioakkumulere.
Biokonsentrasjonsfaktor (BCF)	Verdi: 81,28 Testmetode: OECD 305 A-E
Kommentar, BCF	Hentet fra Prevent databasen.

12.4. Mobilitet i jord

Mobilitet	Flyter på vann.
Overflatespenning	Verdi: 28 mN/M
Kommentar, Overflatespenning	ved 25 ºC.
Kommentar, Vannløselighet	Produktet er uløselig i vann.

12.5. Resultater av PBT og vPvB vurdering

PBT vurderingsresultat	PBT-vurdering ikke utført.
vPvB vurderingsresultat	vPvB-vurdering ikke utført.

12.6. Andre skadevirkninger

Andre skadevirkninger / annen informasjon	Danner oljefilm på vannflater som kan skade organismer som lever i vann og forstyrre oksygentransporten i grensesjiktet luft/vann.

Seksjon 13: Fjerning av avfall

13.1. Metoder for avfallsbehandling

Egnede metoder til fjerning av kjemikaliet	Leveres som farlig avfall til godkjent behandler eller innsamler. Koden for farlig avfall (EAL-kode) er veiledende. Bruker må selv angi riktig EAL-kode hvis bruksområdet avviker.
Produktet er klassifisert som farlig avfall	Ja
Avfallskode EAL	EAL: 16 50 76 rene kjemikalier/kjemikalierester u/halogen og tungmetaller EAL: 16 03 05 organisk avfall som inneholder farlige stoffer
NORSAS	7042 Organiske løsemidler uten halogen

Seksjon 14: Transportinformasjon

14.1. UN-nummer

Kommentar	Ikke farlig i forbindelse med transport under UN, IMO, ADR/RID og IATA/ICAO regler.

14.2. UN varenavn

Kommentar	Ikke relevant.

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14.3. Transport fareklasse
Kommentar   Ikke relevant.

14.4. Emballasjegruppe
Kommentar   Ikke relevant.

14.5. Miljøfarer
Kommentar   Ikke relevant.

14.6. Spesielle forholdsregler for bruker
Spesielle forholdsregler   Ikke relevant.

14.7. Transport i bulk i henhold til vedlegg II til MARPOL 73/78 og IBC-koden

Andre relevante opplysninger
Andre relevante opplysninger   Ikke relevant.

Seksjon 15: Opplysninger om lover og forskrifter
EC-nr.   265-233-4

15.1. Forskrift / regelverk om stoff eller blanding i forhold til sikkerhet, helse og miljø
Referanser (Lover/Forskrifter)   Forskrift om klassifisering, merking og emballering av stoffer og stoffblandinger (CLP) datert 16.06.2012.
Stoffene er klassifisert iht. Vedlegg VI til CLP-forordningen, (EU) nr. 1272/2008, den til enhver tid gjeldende utgave.
Utkast til implementering av Kommisjonens (EU) forordning Nr 453/2010 om endring av Forordning (EF) Nr 1907/2006 fra Europa-Parlamentet og Rådet om registrering, vurdering, godkjenning og begrensning av kjemikalier (REACH), Annex II Sikkerhetsdatablad.
Veiledning om administrative normer for forurensning i arbeidsatmosfære fra Direktoratet for Arbeidstilsynet, den til enhver tid gjeldende utgave.
Avfallsforskriften, FOR 2004-06-01 nr 930, fra Miljøverndepartementet.
ADR/RID veg-/jernbanetransport av farlig gods 2011, Direktoratet for samfunnssikkerhet og beredskap.

Sikkerhetsdatabladet er utarbeidet med basis i opplysninger gitt av produsenten.

15.2. Vurdering av kjemikaliesikkerhet
Vurdering av kjemikaliesikkerhet er gjennomført   Ja

Seksjon 16: Andre opplysninger
Leverandørens anmerkninger	Informasjonen i dette dokument skal gjøres tilgjengelig til alle som håndterer produktet.
Liste over relevante R-setninger (i seksjon 2 og 3).	R65 Farlig: kan forårsake lungeskade ved svelging. R66 Gjentatt eksponering kan gi tørr eller sprukken hud
Liste over relevante H-setninger (i seksjon 2 og 3).	H304 Kan være dødelig ved svelging om det kommer ned i luftveiene.
Utfyllende opplysninger	Forkortelser og akronymer: PBT: Persistent, Bioakkumulerende og Toksisk (giftig) vPvB: veldig Persistent og veldig Bioakkumulerende
Viktigste kilder ved utarbeidelsen av Sikkerhetsdatabladet (ikke norske)	Sikkerhetsdatablad fra Baker Hughes datert 19.03.2008.
Opplysninger som er nye, slettet eller revidert	Tidligere utgitt i annet format. Versjon: 2. Seksjoner endret: 1-16.

For tidligere revisjonshistorikk se forrige versjon av dette sikkerhetsdatabladet.

Dette Sikkerhetsdatablad er utarbeidet i ECO Publisher (ECOonline)   Revisjonsdato 30.07.2012

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Kvalitetssikring av informasjonen	Dette sikkerhetsdatabladet er kvalitetssikret av Teknologisk Institutt as, som er sertifisert iht. ISO 9001:2008.
Ansvarlig for Sikkerhetsdatablad	Baker Hughes Norge
Utarbeidet av	Teknologisk Institutt as v/ Stine Bækkelund

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Appendix-2

Appendix-2: Material Safety Data Sheet for Base Oil – CLAIRSOL NS

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Faresetninger	H304 Kan være dødelig ved svelging om det kommer ned i luftveiene.
Sikkerhetssetninger	P301 + P310 VED SVELGING: Kontakt umiddelbart et GIFTINFORMASJONSSENTER eller lege.
	P331 IKKE framkall brekning.
Supplerende etikett informasjon	EUH 066 Gjentatt eksponering kan gi tørr eller sprukket hud.

2.3 Andre farer

PBT / vPvB	Ikke PBT / vPvB.
Fysiokjemiske effekter	Produktet er brennbart, men ikke brannfarlig.
Helseeffekt	Gjentatt eksponering kan gi tørr eller sprukken hud.
Miljøeffekt	Danner oljefilm på vannflater som kan skade organismer som lever i vann og forstyrre oksygentransporten i grensesjiktet luft/vann.

Seksjon 3: Sammensetning / opplysning om innholdsstoffer

3.1. Stoffer

Kjemisk renhet   Aromatinnhold er <2%.

Komponentnavn	Identifikasjon	Klassifisering	Innhold
Hydrokarboner, C14-C18, n-alkaner, isoalkaner, sykliske, <2% aromater	CAS-nr.: 64742-47-8 EC-nr.: 927-632-8 Registreringsnummer: 01-2119457736-27	Xn; R65 R66 Asp. tox 1; H304	60 - 100 %

Komponentkommentarer   Se seksjon 16 for forklaring av R- og H-setninger.

Seksjon 4: Førstehjelpstiltak

4.1. Beskrivelse av førstehjelpstiltak

Generelt	I tvilstilfelle bør lege kontaktes.
Innånding	Sørg for frisk luft, varme og ro, helst i behagelig halvsittende stilling. Kontakt lege hvis ikke alt ubehag gir seg.
Hudkontakt	Fjern tilsølt tøy. Vask straks huden med såpe og vann. Skyll huden grundig med vann. Kontakt lege hvis ikke alt ubehag gir seg.
Øyekontakt	Skyll straks med rikelige mengder vann i opptil 15 minutter. Fjern evt. kontaktlinser og åpne øyet godt opp. Ved lengre tids skylling, anvend lunkent vann for å unngå skade på øyet. Kontakt lege hvis ubehaget vedvarer.
Svelging	Gi fløte eller matolje. FREMKALL IKKE BREKNING! Kontakt lege umiddelbart. Gi aldri væske til en bevisstløs person. Ved brekninger må hodet holdes så lavt at mageinnholdet ikke kommer ned i lungene.

4.2. Viktigste symptomer og effekter, både akutt og forsinket

Informasjon til helsepersonell	Risiko for kjemisk lungebetennelse (pneumonitt) ved aspirasjon ved og etter svelging.
Forsinkede symptomer og virkninger	Ved svelging kan det utvikles kjemisk lungebetennelse som gir symptomer som frysninger, feber, smerter i brystet og hoste. Innånding av løsemiddeldamper kan være skadelig og overeksponering kan gi hodepine, kvalme, oppkast og rus symptomer.

4.3. Informasjon om umiddelbar legehjelp og spesiell behandling som eventuelt er nødvendig

Annen informasjon	Symptomatisk behandling.

Seksjon 5: Tiltak ved brannslukning

5.1. Brannslukningsmidler

Passende brannslukningsmidler	Pulver, karbondioksid (CO2), vanntåke, alkoholresistent skum.
Uegnet brannslukningsmidler	Bruk ikke samlet vannstråle.

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5.2. Spesielle farer som stoffet eller blandingen kan medføre

Brann- og eksplosjonsfarer   Produktet er brennbart, men ikke brannfarlig.

Farlige forbrenningsprodukter   Ved brann eller høy temperatur dannes: Karbonmonoksid (CO). Karbondioksid (CO2). Tett røyk.

5.3. Anvisninger for brannmannskaper

Personlig verneutstyr   Bruk friskluftmaske når produktet er involvert i brann. Ved rømning brukes godkjent rømningsmaske. Se forøvrig seksjon 8.

Annen informasjon   Beholdere i nærheten av brann flyttes straks eller kjøles med vann. Forhindre utslipp av slukningsvann ned i avløpet.

Seksjon 6: Tiltak ved utilsiktet utslipp

6.1. Personlige forholdsregler, verneutstyr og nødprosedyrer

Generelle tiltak   Fjern alle tennkilder. Sørg for god ventilasjon.

Sikkerhetstiltak for å beskytte   Benytt personlig verneutstyr som angitt i seksjon 8. Unngå innånding av
personell   damper og kontakt med hud og øyne.

6.2. Sikkerhetstiltak for å beskytte ytre miljø

Sikkerhetstiltak for å beskytte ytre   Forhindre utslipp til kloakk, vassdrag eller grunn.
miljø

6.3. Metoder for opprydding og rengjøring

Metoder for opprydding og   Absorber i vermikulitt, tørr sand eller jord og fyll i beholdere. Samles opp i
rengjøring   egnede beholdere og leveres som farlig avfall i henhold til seksjon 13. Vask med vann og såpe.

Opprydding   Vær oppmerksom på glatte gulv og overflater.

6.4. Referanse til andre seksjoner

Andre anvisninger   Se også seksjon 8 og 13.

Seksjon 7: Håndtering og lagring

7.1. Forholdsregler for sikker håndtering

Håndtering   Sørg for tilstrekkelig ventilasjon. Unngå kontakt med huden og øynene. Unngå innånding av damp og oljetåke. Bruk angitt verneutstyr, se seksjon 8.

Beskyttende tiltak

Tiltak for å hindre brann   Ta forholdsregler mot utladning av statisk elektrisitet. Holdes adskilt fra antennelseskilder.

Råd om generell yrkeshygiene   Det må ikke spises, drikkes eller røykes under arbeidet. Vask hendene etter hvert skift, og før spising, røyking eller bruk av toalett.

7.2. Betingelser for sikker oppbevaring, inklusiv eventuelle uforenligheter

Oppbevaring   Lagres i tett lukket emballasje i kjølig, godt ventilerte rom, beskyttet mot direkte sollys.

Egnet emballasje   Lagres i originalbeholder.

Råd angående samlagring   Lagres adskilt fra: Oksidasjonsmidler. Sterke syrer.

7.3 Spesifikk bruk

Spesielle bruksområder   Se seksjon 1.2.

Seksjon 8: Eksponeringskontroll / personlig verneutstyr

8.1. Kontrollparametere

Administrative normer

Komponentnavn	Identifikasjon	Verdi	Norm år
Hydrokarboner, C14-C18, n-alkaner, isoalkaner, sykliske, <2% aromater	CAS-nr.: 64742-47-8 EC-nr.: 927-632-8	8 t.: 50 ppm 8 t.: 275 mg/m³	2011

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Registreringsnummer: 01-
2119457736-27

8.2 Begrensning av eksponering på arbeidsplassen

Begrensning av eksponering på
arbeidsplassen

Sørg for tilstrekkelig ventilasjon. Personlig verneutstyr bør velges i henhold til
CEN-standard og i samarbeid med leverandøren av personlig verneutstyr.

Åndedrettsvern

Åndedrettsvern

Ved utilstrekkelig ventilasjon brukes maske med filter A mot løsemiddeldamper.
Bruk kombinasjonsfilter A/P2 ved aerosoldannelse.

Håndvern

Håndvern | Benytt hansker som er hensiktsmessige for arbeidsoperasjonen.

Egnede materialer | Nitril.

Gjennomtrengningstid | Gjennombruddstiden er ikke kjent. Det angitte hanskemateriale er foreslått
etter en gjennomgang av enkeltstoffene i produktet og kjente hanskeguider.

Ytterligere håndbeskyttelsestiltak | Skift hansker ofte!

Øye- / ansiktsvern

Øyevern | Bruk sprutsikre vernebriller dersom det er mulighet for direkte øyekontakt.

Ytterligere øyeverntiltak | Øyedusj bør være på arbeidsplassen. Enten en fast øyedusjenhet koblet til
drikkevann (temperert vann ønskelig) eller en bærbar disponibel enhet
(øyespyleflaske).

Hudvern

Annet hudvern enn håndvern | Benytt hensiktsmessige verneklær for beskyttelse mot hudkontakt.

Passende miljømessige eksponeringskontroll

Begrensing av miljøeksponering | Forhindre utslipp til kloakk, vassdrag eller grunn.

Annen informasjon

Annen informasjon | Nøddusj skal være tilgjengelig på arbeidsplassen. Det oppgitte verneutstyr er
veiledende. Risikovurderingen (Faktisk risiko) kan føre til andre krav.

Seksjon 9: Fysiske og kjemiske egenskaper

9.1. Informasjon om grunnleggende fysiske og kjemiske egenskaper

Tilstandsform	Klar væske
Farge	Fargeløs
Lukt	Mild
Kommentarer, Luktgrense	Ikke angitt.
Kommentarer, pH (handelsvare)	Ikke angitt.
Smeltepunkt/smeltepunktsintervall	Verdi: < -5 °C
Kokepunkt / kokepunktintervall	Verdi: 230-335 °C
Kommentarer, Kokepunkt / kokepunktintervall	760 mmHg
Flammepunkt	Verdi: > 93 °C
	Testmetode: CC
Kommentarer, Fordampningshastighet	Ikke angitt.
Antennelighet (fast stoff, gass)	Ikke relevant.
Eksplosjonsgrense	Verdi: 0,5-7,0 %
Damptrykk	Verdi: 0,001 kPa
	Test temperatur: 20 °C
Kommentarer, Damptetthet	Ikke angitt.
Relativ tetthet	Verdi: 0,780-0,920 g/cm³
	Test temperatur: 15 °C
Løselighet i vann	Ikke eller lite løselig.
Kommentarer, Fordelingskoeffisient:	Ikke relevant.

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n-oktanol / vann	
Selvantennelighet	Verdi: > 200 °C
Kommentarer,	Ikke angitt.
Dekomponeringstemperatur	
Viskositet	Verdi: 2,8-15,0 mm²/s
	Test temperatur: 20 °C

Fysikalske farer

Eksplosive egenskaper	Ikke angitt.
Oksiderende egenskaper	Ikke angitt.

9.2 Annen informasjon

Andre fysiske og kjemiske egenskaper

Fysiske og kjemiske egenskaper	Molekylvekt: 235,36.

Seksjon 10: Stabilitet og reaktivitet

10.1. Reaktivitet

Reaktivitet	Ingen testresultater tilgjengelig.

10.2. Kjemisk stabilitet

Stabilitet	Stabil under normale temperaturforhold og anbefalt bruk.

10.3. Risiko for farlige reaksjoner

Risiko for farlige reaksjoner	Polymerisering vil ikke forekomme.

10.4. Forhold som skal unngås

Forhold som skal unngås	Unngå varme, flammer og andre antennelseskilder.

10.5. Materialer som skal unngås

Materialer som skal unngås	Oksidasjonsmidler. Sterke syrer.

10.6 Farlige spaltningsprodukter

Farlige spaltningsprodukter	Ingen kjente. Se også seksjon 5.2.

Seksjon 11: Toksikologisk informasjon

11.1 Informasjon om toxiologiske effekter

Toksikologisk informasjon

LD50 oral	Verdi: 5000 mg/kg
	Forsøksdyreart: Rotte
LD50 dermal	Verdi: > 2000 mg/kg
	Forsøksdyreart: Kanin
LC50 innånding	Verdi: 5000 mg/m³
	Forsøksdyreart: Rotte
	Varighet: 4 timer

Potensielle akutte effekter

Innånding	Damp kan irritere luftveier og lunger. Innånding av løsemiddeldamper er skadelig. Symptomene på overeksponering er hodepine, tretthet, kvalme, brekninger, bevisstløshet, beruselse.
Hudkontakt	Gjentatt eksponering kan gi tørr eller sprukken hud.
Øyekontakt	Kan virke irriterende og kan fremkalle rødhet og svie.
Svelging	Hvis en ved oppkast får produktet i lungene, vil det utvikles kjemisk lungebetennelse som kan være livstruende. Inntak kan forårsake irritasjon i mage- og tarmsystemet.
Aspirasjonsfare	Kan være dødelig ved svelging om det kommer ned i luftveiene.

Forsinket / Repeterende

Allergi	Ikke klassifisert som allergifremkallende for hud eller ved innånding.

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	Klassifiseringskriteriene er ikke oppfylt.
Spesifikke målorgantoksisitet - enkelt eksponering	Kriteriene for klassifisering er på grunnlag av de tilgjengelige data ikke ansett å være oppfylt.
Spesifikke målorgantoksisitet - gjentatt eksponering	Kriteriene for klassifisering er på grunnlag av de tilgjengelige data ikke ansett å være oppfylt.

Kreftfremkallende, mutagene og reproduksjonstoksiske

Kreft	Kriteriene for klassifisering er på grunnlag av de tilgjengelige data ikke ansett å være oppfylt.
Arvestoffskader	Kriteriene for klassifisering er på grunnlag av de tilgjengelige data ikke ansett å være oppfylt.
Fosterskadelige egenskaper	Kriteriene for klassifisering er på grunnlag av de tilgjengelige data ikke ansett å være oppfylt.
Reproduksjonsskader	Kriteriene for klassifisering er på grunnlag av de tilgjengelige data ikke ansett å være oppfylt.

Seksjon 12: Miljøopplysninger

12.1. Toksisitet

Akutt akvatisk, fisk	Verdi: > 1028 mg/l Testmetode: LC50 Varighet: 96 timer
Akutt akvatisk, alge	Verdi: > 10000 mg/l Testmetode: IC50 Varighet: 72 timer
Akutt akvatisk, Daphnia	Verdi: > 3000 mg/l Testmetode: EC50 Varighet: 48 timer
Økotoksisitet	Produktet er ikke klassifisert som miljøskadelig. Dette utelukker imidlertid ikke muligheten for at store eller hyppige utslipp kan være miljøskadelige.

12.2. Persistens og nedbrytbarhet

Biologisk nedbrytbarhet	Verdi: 74 % Testperiode: 28 dager
Persistens og nedbrytbarhet	Produktet forventes å være bionedbrytbart.

12.3. Bioakkumulasjonspotensial

Bioakkumulasjonspotensial	Data om bioakkumulasjon er ikke tilgjengelig.

12.4. Mobilitet i jord

Mobilitet	Ikke eller lite løselig i vann.
Overflatespenning	Verdi: ~ 28 mN/m

12.5. Resultater av PBT og vPvB vurdering

PBT vurderingsresultat	Ikke PBT.
vPvB vurderingsresultat	Ikke vPvB.

12.6. Andre skadevirkninger

Andre skadevirkninger / annen informasjon	Danner oljefilm på vannflater som kan skade organismer som lever i vann og forstyrre oksygentransporten i grensesjiktet luft/vann.

Seksjon 13: Fjerning av avfall

13.1. Metoder for avfallsbehandling

Egnede metoder til fjerning av kjemikaliet	Leveres som farlig avfall til godkjent behandler eller innsamler. Koden for farlig avfall (EAL-kode) er veiledende. Bruker må selv angi riktig EAL-kode hvis bruksområdet avviker.
Produktet er klassifisert som farlig avfall	Ja

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Avfallskode EAL	EAL: *16 50 76 rene kjemikalier/kjemikalierester u/halogen og tungmetaller
NORSAS	7042 Organiske løsemidler uten halogen

Seksjon 14: Transportinformasjon

14.1. UN-nummer

Kommentar	Ikke farlig i forbindelse med transport under UN, IMO, ADR/RID og IATA/ICAO regler.

14.2. UN varenavn

Kommentar	Ikke relevant.

14.3. Transport fareklasse

Kommentar	Ikke relevant.

14.4. Emballasjegruppe

Kommentar	Ikke relevant.

14.5. Miljøfarer

Kommentar	Ikke relevant.

14.6. Spesielle forholdsregler for bruker

Spesielle forholdsregler	Ikke relevant.

14.7. Transport i bulk i henhold til vedlegg II til MARPOL 73/78 og IBC-koden
Andre relevante opplysninger

Andre relevante opplysninger	Ikke relevant.

Seksjon 15: Opplysninger om lover og forskrifter

EC-nr.	927-632-8

15.1. Forskrift / regelverk om stoff eller blanding i forhold til sikkerhet, helse og miljø

Referanser (Lover/Forskrifter)	Forskrift om klassifisering, merking og emballering av stoffer og stoffblandinger (CLP) datert 16.06.2012. Utkast til implementering av Kommisjonens (EU) forordning Nr 453/2010 om endring av Forordning (EF) Nr 1907/2006 fra Europa-Parlamentet og Rådet om registrering, vurdering, godkjenning og begrensning av kjemikalier (REACH), Annex II Sikkerhetsdatablad. Veiledning om administrative normer for forurensning i arbeidsatmosfære fra Direktoratet for Arbeidstilsynet, den til enhver tid gjeldende utgave. Avfallsforskriften, FOR 2004-06-01 nr 930, fra Miljøverndepartementet. ADR/RID veg-/jernbanetransport av farlig gods 2011, Direktoratet for samfunnssikkerhet og beredskap. Sikkerhetsdatabladet er utarbeidet med basis i opplysninger gitt av produsenten.
Deklarasjonsnr.	44142

15.2. Vurdering av kjemikaliesikkerhet

Vurdering av kjemikaliesikkerhet er gjennomført	Ja

Seksjon 16: Andre opplysninger

Leverandørens anmerkninger	Informasjonen i dette dokument skal gjøres tilgjengelig til alle som håndterer produktet.
Liste over relevante R-setninger (i seksjon 2 og 3).	R65 Farlig: kan forårsake lungeskade ved svelging. R66 Gjentatt eksponering kan gi tørr eller sprukken hud
Liste over relevante H-setninger (i	H304 Kan være dødelig ved svelging om det kommer ned i luftveiene.

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seksjon 2 og 3).

Brukte forkortelser og akronymer	EC50: Konsentrasjonen av et stoff som påvirker 50% av en populasjon på et gitt tidspunkt
	IC50: Konsentrasjonen av et stoff som hemmer veksten av algeceller med 50%
	LC50: Konsentrasjonen av et stoff som dreper 50% av en populasjon på et gitt tidspunkt
	LD50: Dødelig dose, den dosen som dreper 50% av en populasjon
	PBT: Persistent, Bioakkumulerende og Toksisk (giftig)
	vPvB: veldig Persistent og veldig Bioakkumulerende
Viktigste kilder ved utarbeidelsen av Sikkerhetsdatabladet (ikke norske)	Sikkerhetsdatablad fra Petrochem Carless (NO) datert 11.04.2011.
	Sikkerhetsdatablad fra Petrochem Carless (UK) datert 11.04.2011.
	Sikkerhetsdatablad fra Baker Hughes Norge datert 17.12.2009.
Opplysninger som er nye, slettet eller revidert	Tidligere utgitt i annet format. Versjon: 3. Seksjoner endret: 1-16. Ansvarlig: SBA.
Kvalitetssikring av informasjonen	Dette sikkerhetsdatabladet er kvalitetssikret av Teknologisk Institutt as, som er sertifisert iht. ISO 9001:2008.
Ansvarlig for Sikkerhetsdatablad	Baker Hughes Norge
Utarbeidet av	Teknologisk Institutt as v/ Stine Bækkelund

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Appendix-3

Appendix -3 Table 1: Phase I vapor pressure versus temperature data for Sipdrill 2/0

Pressure Vs. Boiling Point Bath Temp: Sip Drill 2.0

Pressure (mbar)	Boiling Point Bath Temp (°C)	Temp (K)	1/T (K)	ln(VP)
1.5	80	353	0.00283	0.40547
15	126	399	0.00251	2.70805
20	132	405	0.00247	2.99573
25	135	408	0.00245	3.21888
35	140	413	0.00242	3.55535
50	147	420	0.00238	3.91202
70	160	433	0.00231	4.2485
100	168	441	0.00227	4.60517
140	176	449	0.00223	4.94164
170	183	456	0.00219	5.1358
200	189	462	0.00216	5.29832
250	194	467	0.00214	5.52146
300	200	473	0.00211	5.70378
370	208	481	0.00208	5.9135
430	218	491	0.00204	6.06379
500	222	495	0.00202	6.21461

Appendix-3 Table 2: Phase I vapor pressure versus temperature data for Clarisol NS

Pressure Vs. Boiling Point Bath Temp: Clarisol NS

Pressure (mbar)	Boiling Point Bath Temp (°C)	Temp (K)	1/T (K)	ln(VP)
1.5	102	375	0.00267	0.40547
15	149	422	0.00237	2.70805
20	156	429	0.00233	2.99573
25	159	432	0.00231	3.21888
35	164	437	0.00229	3.55535
50	172	445	0.00225	3.91202
70	180	453	0.00221	4.2485
100	190	463	0.00216	4.60517
140	200	473	0.00211	4.94164
170	208	481	0.00208	5.1358
200	212	485	0.00206	5.29832
250	219	492	0.00203	5.52146
300	226	499	0.002	5.70378
370	236	509	0.00196	5.9135

Appendix-3 Table 3: Phase II vapor pressure versus temperature data for Sipdrill 2/0

Long Vapor Temperature Probe: Sip Drill 2.0							
Pressure (mbar)	Boiling Point Bath Temp (°C)	Min Vapor Temp (°C)	Max Vapor Temp (°C)	Average Vapor Temp (°C)	Average Vapor Temp (K)	Average 1/T (K)	ln(VP)
1.5	80	57	65	61	334	0.00299	0.40547
8.5	99	92	103	97.5	370.5	0.0027	2.14007
12	105	96	106	101	374	0.00267	2.48491
20	119	107	113	110	383	0.00261	2.99573
35	140	125	126	125.5	398.5	0.00251	3.55535
50	146	132	137	134.5	407.5	0.00245	3.91202
70	160	145	150	147.5	420.5	0.00238	4.2485

Appendix-3 Table 4: Phase II vapor pressure versus temperature data for Clarisol NS

Long Vapor Temperature Probe: Clarisol NS							
Pressure (mbar)	Boiling Point Bath Temp (°C)	Min Vapor Temp (°C)	Max Vapor Temp (°C)	Average Vapor Temp (°C)	Average Vapor Temp (K)	Average 1/T (K)	ln(VP)
1.5	110	83	111	97	370	0.0027	0.40547
8	133	124	146	135	408	0.00245	2.07944
15	150	129	152	140.5	413.5	0.00242	2.70805

Appendix-4

Appendix -4 Table 1: Sipdrill 2/0 experiment one data

Experiment #1 Steam Distillation: SIPDRILL 2/0

Trial #	Steam + oil vapor temp °C	Oil temp in flask °C	Steam temp °C	Copper coil pot temp °C	Volume of oil distilled ml	Volume of water distilled ml	Volume Ratio Oil/Water
1	107	99	146	170	5	40	0.125
2	110	110	183	204	11	89	0.124
3	116	108	190	206	15	85	0.176
4	126	116	195	210	8	30	0.267
5	138	120	195	210	29	71	0.408
6	138-162	166	196	212	20	20	1.000
7	165	166	196	212	13	7	1.857
8	170	180	198	213	27	13	2.077
9	171	180	198	213	23	10	2.300
10	172	180	198	213	60	28	2.143

Appendix -4 Table 2: Clairsol NS experiment one data

Experiment #1 Steam Distillation: CLAIRSOL NS

Trial #	Steam + oil vapor temp °C	Oil temp in flask °C	Steam temp °C	Copper coil pot temp °C	Volume of oil distilled ml	Volume of water distilled ml	Volume Ratio Oil/Water
1	111	106	185	208	2.5	47.5	0.053
2	117	116	185	216	3	50.5	0.059
3	120	124	186	216	3	27	0.111
4	133	138	189	215	5.5	34.5	0.159
5	146.5	148	198	214	8	27	0.296
6	159	156	198	217	7	18	0.389
7	176	174	198	214	10	15	0.667
8	178	178	198	214	16	24	0.667
9	194	184	198	214	10	10	1.000
10	195	186	198	214	15	15	1.000
11	202	200	198	214	13	12	1.083
12	202	200	198	214	16	14	1.143
13	203	202	198	214	17	13	1.308
14	203	202	198	214	37	23	1.609

15	206	200	198	214	23	17	1.353
16	209	200	198	214	14	11	1.273
17	208	205	198	214	25	20	1.250
18	208	208	198	214	16	14	1.143
19	208	214	198	214	16	14	1.143
20	208	214	198	214	13	12	1.083
21	208	210	198	214	26	24	1.083

Appendix -4 Table 3: Sipdrill 2/0 experiment two data

Experiment #2 Steam Distillation: SIPDRILL 2/0

Trial #	Steam + oil vapor temp °C	Oil temp in flask °C	Steam temp °C	Copper coil pot temp °C	Volume of oil distilled ml	Volume of water distilled ml	Volume Ratio Oil/Water
1	110	112	170	202	5	18	0.278
2	110	112	170	202	5.5	20	0.275
3	125	129	175	201	9	20	0.450
4	125	129	175	201	11	24	0.458
5	142	152	176	202	9	10	0.900
6	142	152	176	202	12	14	0.857
7	152	162	178	203	17.5	12	1.458
8	152	162	178	203	21	14	1.500
9	165	174	179	204	24	12	2.000
10	165	174	179	204	27	13	2.077

Appendix -4 Table 4: Clairsol NS experiment two data

Experiment #2 Steam Distillation: CLAIRSOL NS

Trial #	Steam + oil vapor temp °C	Oil temp in flask °C	Steam temp °C	Copper coil pot temp °C	Volume of oil distilled ml	Volume of water distilled ml	Volume Ratio Oil/Water
1	119	120	164	188	2.5	25	0.100
2	119	120	164	188	3	29	0.103
3	132	144	166	189	5	30	0.167
4	142	156	170	190	7	23	0.304
5	142	156	170	190	8	27	0.296
6	160	172	178	192	7.5	15	0.500

7	160	172	178	192	8	16	0.500
8	160	172	178	192	11	20	0.550
9	177	180	178	196	9	11	0.818
10	177	180	178	196	16	19	0.842
11	177	180	178	196	14	16	0.875
12	191	196	206	243	11	10	1.100
13	191	196	206	243	16	14	1.143
14	191	196	206	243	22	19	1.158
15	198	208	196	231	19	21	0.905
16	198	208	196	231	8	13	0.615
17	202	215	210	236	7.5	7.5	1.000

Appendix -4 Table 5: Sipdrill 2/0 experiment one vapor pressure calculations

														Vapor pressure	Vapor pressure	Vapor pressure	
	Density of SIPDRILL 2/0	Density of water at	Mass of oil	Mass of water	Mass ratio of oil production	1.013bar x Mass ratio of oil	MW of C10 alkane	MW of C12 alkane	MW of C13 alkane	MW	MW	MW	assuming	assuming	assuming	Steam + oil vapor
Trial #	at 30°C (g/ml)	30°C(g/ml)	distilled(g)	distilled (g)	oil/water (kg/kg)	production	(g/mol)	(g/mol)	(g/mol)	C10/18	C12/18	C13/18	C10 (mbar)	C12 (mbar)	C13 (mbar)	temp °C
1	0.750	0.996	3.750	39.840	0.094	0.095	142.000	170.000	184.000	7.889	9.444	10.222	11.944	9.996	9.243	107
2			8.250	88.644	0.093	0.094							11.811	9.885	9.140	110
3			11.250	84.660	0.133	0.135							16.781	14.055	13.000	116
4			6.000	29.880	0.201	0.203							25.145	21.090	19.516	126
5			21.750	70.716	0.308	0.312							38.012	31.949	29.589	138
6			15.000	19.920	0.753	0.763							88.268	74.803	69.502	150
7			9.750	6.972	1.398	1.417							152.534	130.651	121.906	165
8			20.250	12.948	1.564	1.584							167.598	143.916	134.419	170
9			17.250	9.960	1.732	1.754							182.359	156.978	146.764	171
10			45.000	27.888	1.614	1.635							172.015	147.818	138.104	172

Appendix -4 Table 6: Clairsol NS experiment one vapor pressure calculations

Experiment #1 Vapor Pressure Calculations: CLAIRSOL NS																	
Trial #	Density of CLAIRSOL NS at 30°C (g/ml)	Density of water at 30°C(g/ml)	Mass of oil distilled(g)	Mass of water distilled (g)	Mass ratio of oil production oil/water (kg/kg)	1.013bar x Mass ratio of oil production	MW of C14 alkane (g/mol)	MW of C16 alkane (g/mol)	MW of C18 alkane (g/mol)	MW C14/18	MW C16/18	MW C18/18	Vapor pressure assuming C14 (mbar)	Vapor pressure assuming C16 (mbar)	Vapor pressure assuming C18 (mbar)	Steam + oil vapor temp °C
1	0.810	0.996	2.025	47.310	0.043	0.043	198.000	226.000	254.000	11.000	12.556	14.111	3.926	3.442	3.063	111
2			2.430	50.298	0.048	0.049							4.430	3.883	3.456	117
3			2.430	26.892	0.090	0.092							8.254	7.238	6.446	120
4			4.455	34.362	0.130	0.131							11.800	10.353	9.222	133
5			6.480	26.892	0.241	0.244							21.715	19.075	17.008	146.5
6			5.670	17.928	0.316	0.320							28.311	24.890	22.206	159
7			8.100	14.940	0.542	0.549							47.584	41.932	37.481	176
8			12.960	23.904	0.542	0.549							47.584	41.932	37.481	178
9			8.100	9.960	0.813	0.824							69.737	61.623	55.200	194
10			12.150	14.940	0.813	0.824							69.737	61.623	55.200	195
11			10.530	11.952	0.881	0.892							75.118	66.421	59.530	202
12			12.960	13.944	0.929	0.942							78.924	69.819	62.598	202
13			13.770	12.948	1.063	1.077							89.303	79.103	70.994	203
14			29.970	22.908	1.308	1.325							107.674	95.593	85.949	203
15			18.630	16.932	1.100	1.115							92.112	81.620	73.273	206
16			11.340	10.956	1.035	1.049							87.121	77.149	69.226	209
17			20.250	19.920	1.017	1.030							85.697	75.875	68.073	208
18			12.960	13.944	0.929	0.942							78.924	69.819	62.598	208
19			12.960	13.944	0.929	0.942							78.924	69.819	62.598	208
20			10.530	11.952	0.881	0.892							75.118	66.421	59.530	208
21			21.060	23.904	0.881	0.892							75.118	66.421	59.530	208

Appendix -4 Table 7: Sipdrill 2/0 experiment two vapor pressure calculations

Experiment #2 Vapor Pressure Calculations: SIPDRILL 2/0																
Trial #	Density of SIPDRILL 2/0 at 30°C (g/ml)	Density of water at 30°C(g/ml)	Mass of oil distilled(g)	Mass of water distilled (g)	Mass ratio of oil production oil/water (kg/kg)	1.013bar x Mass ratio of oil production	MW of C10 alkane (g/mol)	MW of C12 alkane (g/mol)	MW of C13 alkane (g/mol)	MW C10/18	MW C12/18	MW C13/18	Vapor pressure assuming C10 (mbar)	Vapor pressure assuming C12 (mbar)	Vapor pressure assuming C13 (mbar)	Steam + oil vapor temp °C
1	0.750	0.996	3.750	17.928	0.209	0.212	142.000	170.000	184.000	7.889	9.444	10.222	26.165	21.949	20.313	110
2			4.125	19.920	0.207	0.210							25.910	21.734	20.114	110
3			6.750	19.920	0.339	0.343							41.720	35.086	32.502	125
4			8.250	23.904	0.345	0.350							42.460	35.713	33.085	125
5			6.750	9.960	0.678	0.687							80.139	67.824	62.984	142
6			9.000	13.944	0.645	0.654							76.612	64.801	60.163	142
7			13.125	11.952	1.098	1.112							123.780	105.517	98.267	152
8			15.750	13.944	1.130	1.144							126.874	108.209	100.795	152
9			18.000	11.952	1.506	1.526							162.386	139.318	130.079	165

Appendix -4 Table 8: Clairsol NS experiment two vapor pressure calculations

Experiment #2 Vapor Pressure Calculations: CLAIRSOL NS

Trial #	Density of CLAIRSOL NS at 30°C (g/ml)	Density of water at 30°C (g/ml)	Mass of oil distilled(g)	Mass of water distilled (g)	Mass ratio of oil production oil/water (kg/kg)	1.013bar x Mass ratio of oil production	MW of C14 alkane (g/mol)	MW of C16 alkane (g/mol)	MW of C18 alkane (g/mol)	MW C14/18	MW C16/18	MW C18/18	Vapor pressure assuming C14 (mbar)	Vapor pressure assuming C16 (mbar)	Vapor pressure assuming C18 (mbar)	Steam + oil vapor temp °C
1	0.810	0.996	2.025	24.900	0.081	0.082	198.000	226.000	254.000	11.000	12.556	14.111	7.434	6.519	5.805	119
2			2.430	28.884	0.084	0.085							7.689	6.743	6.004	119
3			4.050	29.880	0.136	0.137							12.330	10.819	9.638	132
4			5.670	22.908	0.248	0.251							22.292	19.584	17.462	142
5			6.480	26.892	0.241	0.244							21.715	19.075	17.008	142
6			6.075	14.940	0.407	0.412							36.112	31.778	28.373	160
7			6.480	15.936	0.407	0.412							36.112	31.778	28.373	160
8			8.910	19.920	0.447	0.453							39.582	34.847	31.123	160
9			7.290	10.956	0.665	0.674							57.781	50.983	45.616	177
10			12.960	18.924	0.685	0.694							59.372	52.396	46.888	177
11			11.340	15.936	0.712	0.721							61.550	54.333	48.631	177
12			8.910	9.960	0.895	0.906							76.187	67.375	60.391	191
13			12.960	13.944	0.929	0.942							78.924	69.819	62.598	191
14			17.820	18.924	0.942	0.954							79.880	70.674	63.371	191
15			15.390	20.916	0.736	0.745							63.512	56.079	50.203	198
16			6.480	12.948	0.500	0.507							44.083	38.830	34.696	198
17			6.075	7.470	0.813	0.824							69.737	61.623	55.200	202

Appendix -4 Table 9: Sipdrill 2/0 density experiment data

Density Experiment: SIPDRILL 2/0

Trial #	Mass of empty flask (g)	Mass of flask + Oil (g)	Mass of oil (g)	Volume of oil (ml)	Density (g/ml)	temp °C	Average Density at 15°C (g/ml)	Average Density at 30°C(g/ml)	Standard deviation of results	Density at 15°C given in MSDS (g/ml)
1	42.2376	80.1342	37.8966	50	0.757932	15	0.756538	0.748645	0.0047055	0.76
2	42.4084	80.1656	37.7572	50	0.755144	15				
3	42.2902	79.7397	37.4495	50	0.74899	30				
4	42.2902	79.7052	37.415	50	0.7483	30				

Appendix -4 Table 10: Clairsol NS density experiment data

Density Experiment: CLAIRSOL NS

Trial #	Mass of empty flask (g)	Mass of flask + Oil (g)	Mass of oil (g)	Volume of oil (ml)	Density (g/ml)	temp °C	Average Density at 15°C (g/ml)	Average Density at 30°C(g/ml)	Standard deviation of results	Density at 15°C given in MSDS (g/ml)
1	42.312	83.1623	40.8503	50	0.817006	15	0.816474	0.807077	0.005449	0.780-0.920
2	42.312	83.1091	40.7971	50	0.815942	15				
3	42.2967	82.6667	40.37	50	0.8074	30				
4	42.2967	82.6344	40.3377	50	0.806754	30				