Sudan University of Science & Technology

College of Graduate Studies and Scientific Research

Study of the Properties of Yemeni Crude Oil in Comparison with Some Sudanese Crude Oils

دراسة خصائص النفط الخام اليمني ومقارنته مع بعض عينات النفط السوداني

A Thesis submitted in fulfillment of Ph.D in chemistry

By

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بسم الله الرحمن الرحيم

قال تعالى:

﴿ أَفَرَأَيْتُمُ النَّارَ الَّتِي تُورُونَ (71) أَأَنْتُمْ أَنْشَأْتُمْ شَجَرَتَهَا أَمْ نَحْنُ الْمُنْشِئُونَ(72) ﴾

صدق الله العظيم

(سورة الواقعه الأية 71:72)

DEDICATION

To**:**

The soul of my father,

my mother,

my wife,

my Children: Ragad, Abdalkareem, Mohammed, Sunds Ahmed, and Salsabil.

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Praise to Allah, Almighty, who gave the strength and patience to conduct this work. I am greatly indebted to my principal supervisor Dr. Abdalsalam abdallah dafaallaa and my co-supervisor Dr. Kamal Mohammed Saeed for their keen guidance, suggestion, encouragement and assistance offered during this work.

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Abstract

Physicochemical parameters of crude oil obtained from some Yemeni fields (Jannah, Marib, Almaslah) and Sudanese (Nile blend, Dar blend, Moga) have been determined. The parameters studied were:, viscosity, specific and API gravity, pour point, acid no, sulphur content, and heavy metals namely: Ag, Ca, Cd, Co, Cd, Cr, Fe, K, Na, Ni, Pb and V. Determination of these parameters was done by ICP- Optically Emission Spectrometer, Universal of petroleum (UOP-915-92) was used to determine distribution of normal alkane and Gas Chromatography. Using standard procedures of American Society for Testing and Materials (ASTM).

The result of this study has shown that crude oils obtained from some fields in Yemen and Sudan contains low levels of sulphur. Most crude oils obtained from Yemen can thus be classified as light-sweet crude oils while Sudan crude oils can be classified as medium – sweet. Carbon preference Index (CPI) of Yemen and Sudan crude oils ranging about 1.00 (1.04-1.1), (1.17 – 1.65) these mean maturity Yemen and Sudan crude oils. pr/ph in this study <2 (0.4037-1.6585) these indicate Yemen crude oil including marine, within increasing maturity but Sudan crude oils Pr/Ph (2.005–2.32) describe mixed organic source matter terrestrial environments while Moga is terrestrial sediments crude oil Pr/Ph (25.57) with increasing maturity. The V/Ni decreases with the age of oil So Yemen and Sudan crude oils are young age and mature because V/Ni less than 1 and classify as paraffinic.This study presents the operational conditions for wax production from Safer Blend. Yemen's oil, characterized as sweet oil with a high level of wax content (39.67 wt %). The method of solvent extraction was employed using a Methyl Ethyl Ketone (MEK) - Toluene mixture as solvent. The study covered a wide range of mixing temperatures (40 to 60 ^{0}C).

المستخلص

تم قياس بعض الخصائص الفيزوكيميائية للنفط الخام لبعض الحقول اليمنية مثل جنة ومأرب والمسيلة والسودانية مثل مزيج النيل ومزيج الدار وموجا . والخصائص التي تم دراستها: اللزوجة والكثافة النوعية ودرجة النقاوة (API) ونقطة الإنسكاب والرقم الحمضي (TAN) ومحتوى الكبريت والمعادن الثقيلة مثل الفضة Ag والكالسيوم Ca والكادميوم Cd والكوبلت Co والكروم Cr والحديد Fe والبوتاسيوم K والصوديوم Na والنيكل Ni والرصاص Pb والفناديوم V، حيث قيست هذه الخصائص بواسطة تقنية مطياف الإنبعاث الضوئي (ICP) كما استخدمت الطريقة العالمية للبترول (UOP-915-92) لتحديد توزيع الالكانات العاديه وحللت بواسطة كروماتوغرافيا الغاز (GC) واستخدمت مواصفات الجمعية الأمريكية لاختبار المواد (ASTM). لوحظ من نتائج الدراسة للخامات اليمنية والسودانية انخفاض مستوى الكبريت في معظم خامات النفط التي تم تحليلها ويمكن وصف النفط اليمني بالحلو(الخفيف) بينما خامات النفط السوداني التي تم تحليلها يمكن وصفها بالحلو الوسط.

ذرة الكربون الممييزة للخام اليمني والسوداني تتراوح حول الواحد (1) (1.04- 1.1) و(1.17 -1.65) وهذا يعني نضوج الخامات اليمنية والسودانية.

نسبة البريستين إلى الفايتين للخامات اليمنية pr/ph (1.6585و0.4037) (اقل من 2) لذا يمكن وصفه بأنه بحري وعالي النضوج بينما نسبتها في الخام السوداني (2.32 و2.005) (أكبر من 2) لذا يمكن وصفه بأنه خليط من مواد عضوية برية وبحرية بينما موجا أصله سبخات بريه لأن نسبة البرستين إلى الفايتين كبيره جدا (25.57) مع زيادة النضوج.

نسبة الفناديوم إلى النيكل V/Ni تقل مع عمر النفظ الخام لذا الخامات اليمنية والسودانية عمرها صغير وناضجة لأن النسبه أقل من واحد كما يوصف الخام بأنه برافييني الأساس.

كما سعت هذه الدراسة إلى استخراج الشمع من مزيج صافر وهو خام يمني يتميز بأنه حلو ويحتوي على شمع نسبته حوالي (39.67) حيث استخدمت طريقة الاستخلاص بالمذيب لإزالته واستخدم فيها خليط من الميثيل إيثيل كيتون والتولوين كمذيب وغطت الدراسة مدى من درجات الحرارة يتراوح بين (40-60) درجة مئوية.

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WTI	West Texas Intermediate
API	American Petroleum institute
ASTM	American standard test material
DNO	Den Norske Oljeselskap
BOPD	Barrel oil per day
PSA	production sharing agreement
Bpd	Barrel per day
TWA	time-weighted average
STEL	short-term exposure limit
DMA	density is measured using an Anton Parr
TAN	Total acid number
FT-ICR MS	Fourier transform ion cyclotron resonance mass Spectrometry
ESI	electro spray ionization
VGO	vacuum gas oil
SPE	the Society of Petroleum Engineers
CPL	Central Petroleum Laboratories
DBS	Di-n-Butyl Sulfide
MOW	Mineral Oil, White
Pr/ph	Pyristane /Phytane
GC	Gas chromatography
CPI	Carbon Preference Index
Sp.Gr	Specific gravity
Cv	Correlation vector
ICP	Inductively coupled plasma
$Pr/n\text{-}C_{17}$	Pristine/ n-alkane C_{17}
$Ph/n\text{-}C_{18}$	Phytane/ n-alkane C_{18}
UCM	the unresolved complex mixture

MEK	Methyl ethyl keton

INTRODUCTION

Petroleum is a non-renewable source of energy, which is globally in demand. The depletion of petroleum industries; heating processes, transportation sectors, and domains Petroleum are a complex mixture of organic matters. The major constituent present in Petroleum is hydrocarbons, which is usually compounded with minor constituents like oxygen, nitrogen, and sulfur. In general, the petroleum is found in the land solids (Riazi, 2005). The crude oil and its liquid petroleum fractions are the main concern in this project initially, the reservoir fluid is extracted from the earth's crust, and then at the production site the oil is processed to separate the water and gases. Later, they bring the oil at atmospheric pressure and temperature. The product obtained is called crude oil which consists of hydrocarbons from light hydrocarbons to heavy hydrocarbons. The crude oil after field processing is sent to be refined where it is processed and produces different useful petroleum products. A petroleum refinery is a combination of different unit operations such as distillation towers, separators pumps, heat exchangers, etc. Before transferring any kind of crude oil to the refinery, the thermodynamic and physical properties of the crude oil and its petroleum fractions need to be known. Moreover, prior knowledge of boiling point ranges of petroleum fractions or products is also required before starting with the process of the crude oil in the refinery. The procedure of their generating the data for the crude oil at a laboratory scale is referred to as characterization of petroleum fluids crude oils i.e. the petroleum fractions are a complex mixture of compounds. Therefore, some physical properties are measured for mixtures, e.g. specific gravity at 15.5℃, but some properties such as average boiling point, molecular weights, and compositions cannot be measured easily. Furthermore, some properties which are not viable to measure because of time constraints and cost need to be predicted from the easily measured properties. Over the decades, chemical and petroleum engineers have developed a variety of simple methods and correlations to predict the properties of fractions from the easily measured properties. These correlations have developed in such way that it should require minimum input parameters, ease of use, and accurate in prediction of specific calculation of average boiling point, conversion of boiling point data from one type to another type, molecular weights, and composition of hydrocarbons (paraffin's-naphthenic-aromatics) of the fractions are referred to as the initial steps in characterization of petroleum fractions (Fahim, 2010). The determination of other properties such as density at specific temperatures, refractive index, critical properties, viscosities, CH ratio, a centric factor, sulfur content, aniline point, flash point, etc. are also part of the characterization of petroleum fractions. With the help of characterization one can not only estimate the parameters and properties of petroleum fractions, but also can determine the compositions of the fractions in order to ensure the quality of petroleum products (Riazi, 2005).

Generally, the characterization of crude oil is presented in terms of several narrow boiling cut with known composition and characterization parameters such as boiling point, molecular weight, specific gravity, and kinematic viscosity. Each narrow boiling point is considered as petroleum fraction. Therefore, the characterization of the crude oil depends upon the characterization of the petroleum fractions, which indirectly depends on the characterization of pure hydrocarbons and its properties. The accurate characterization of crude oil or its fraction is very important for a refinery especially during the design and operation of units. A small error in the prediction of any property can make big changes in design and operation specifications of units, which in turn effects on the plant cost, production cost, plant life, desire product specifications, and finally on the profit. Therefore, the use of appropriate characterization method to predict accurate properties of petroleum fractions can save a large portion of the additional investment West Texas Intermediate crude oil (WTI) is produced in Texas and southern Oklahoma of USA which is one of the world’s market crude used as benchmark for pricing other US crudes according to the data (Prasad and Mudga, 2011). Crude oil samples obtained from different oil fields vary in both physical and chemical properties. This is due to different proportions of the various molecular types, sizes of hydrocarbons and other elemental constituents in the crude mixture (Onyema, *et al.*, 2010 and Osuji *et al.*, 2005). Petroleum fluids are complex fluids, normally of undefined composition that require a characterization procedure to obtain relevant information (Hossain *et al.*, 2005). A ccording to (Odebunmi, *et al,* 2005); ever-increasing chemical utilization of crude oils and petroleum products call for the better knowledge of the composition, structure and properties of their fractions. Parameters often determined in crude oil include: density, API gravity, pour point, kinematic Viscosity, water content (%) salt content (%) sulphur content (%), asphaltene (%), ASTM distillation cracking point as well as metal/mineral contents.These important parameters are used in the specification and classification of crude oil (Oyekunle and Famakin, 2004).

Crude oil or petroleum is a naturally occurring mixture, consisting predominantly of hydrocarbons with another element such as sulphur, nitrogen, oxygen, etc. appearing in the form of organic compounds which in some cases form complexes with metals (Bland and Davidson, 1983). Elemental analysis of crude oil shows that it contains mainly carbon and nitrogen in the approximate ratio of six to one by weight (Allinson, 1980).

The mixture of hydrocarbons is highly complex. Appreciable property differences appear between crude oils as a result of the variable ratios of the crude oil components. For refiner dealing with crudes of different origins, a simple criterion may be established to group crudes with similar characteristics. Crude oils can be arbitrarily classified into three or four groups depending on the relative ratio of the hydrocarbon classes that predominate in the mixture. The following describes three types of crudes:

1. Paraffinic—the ratio of paraffinic hydrocarbons is high compared to aromatics and naphthenic.

2. Naphthenic—the ratios of naphthenic and aromatic hydrocarbons are relatively higher than in paraffinic crudes.

3. Asphaltic—contain relatively large amount of polynuclear aromatics, high asphalting content, and relatively less paraffin's than paraffinic crudes (Hatch, 2001)**.**

1.1-History of Oil Exploration in Yemen

The first trial in exploring oil in Yemen dates back to 1938 when the Iraqi petroleum firm IPC that were of originally a British identity executed some geology-physiological studies related to its plan of discoveries in north Hadramout - Al Mahara Zone. It exploration phase extended till the mid-fifties, though on a discontinuing basis It then left the area without managing to dig a single well. As a fact in noting such first trials that took place in Yemen even before the break of the Second World War, it is important to indicate its cause. This was because of the success achieved by some western petroleum companies in exploring oil during the second and third decades of the twentieth century, in the Arabian Peninsula and Gulf States on one hand, and their interests, on the other hand, to expand their exploration activities to other new regions. The second trials worthy of mentioning took place during 1952-1954 by a German GmbH called "Brackla and Deilaman". This oil group did some geological and geo-physiological survey (cross-sectional and magnetic survey works only) in Al-Saleif coastal line. Again, they left the area with no success.

Around various and distant dry and coastal regions of the Yemeni territory, petroleum firms of a world -wide fame began since the early sixties, and thereafter, numerous activities of crude -oil explorations. Their works in a concise form can be outlined as an indication of the activity related to discoveries (1969-1984) by the following systematic order:

- In the summer of 1984, Hunt Oil Company announced the first commercial discovery of oil in Yemen. Oil was found in Block 18, Ma’rb/Al-Jawaf. Following that, development of the block was done through building surface plants and constructing a pipeline to the Red Sea.
- In 1986, the production and export of the first oil shipment was executed from block 18.
- In 1987, it was announced that oil was discovered in three fields of Shabwah governorate by a (former) Russian company, Techno-Export. These were West Iyad, East Iyad and Amel fields (block 4). Developing of the block was done

through building its plants and construction of pipelines to Belhaf Port on the Arab Sea.

- In 1991, significant oil discoveries were made on Sona field Masilah block (block 14) by Canadian Occidental Petroleum (now Canadian Nexen Petroleum). Such discoveries were followed by more findings. Then, the block was developed by building its plants and construction of the oil pipeline to Al-Thabah area, Hadhramout governorate, on the Arab Sea.
- In September 1996, oil was discovered in Halayouh field Janah block 5. (It was discovered by a consortium of companies operating in the block). Then plants were built and the produced oil was carried by the pipeline of Hunt Yemen Company, the (former) operator of block 18, Ma'reb /Al-Jawaf. Hunt pipeline delivered oil the port on the Red Sea.
- In 1998, Total Yemen (Total Vienna Alf) made a number of oil discoveries in the following fields: Khareer, Atouf, and Wadi Taryah, East Shabwah block 10. Production was linked with Al-Masilah block 14.
- On December 18, 1999, DNO, a Norwegian company and operator of Hawreeh block 32, announced the discovery of oil. It started production and exporting oil through Al-Masilah pipeline in November 2001.
- In December 2001, production began in block 53.
- In April 2004, Block S1 started producing oil.
- November 2005 was the outset for oil production from block 51.
- In July 2005, oil production initiated from Block 43.
- Dec. 2005 was the beginning of producing oil from Malik block 9.
- In addition, oil discovery in block S1 was announced to have been done and production would possibly start in the second half of 2006 (*URL1*, 2014).

1.2- Production Blocks crude oil in Yemen

1.2-1-Marib– Blocks (18)

The first oil production block in the Republic of Yemen is Block (18), located in (Marib-Shabwa) basin, with area of (8,479) km^2. It is operated by Safer Exploration and production operation Company. It is one of the biggest oil blocks. The main reservoirs in the block are (Alif Sand) and (Seen Sand). In General it contains 14 fields with an average production of (35,000) barel oil per day (BOPD). Number of wells was 692 until Des. 2011. The block is connected with the export terminal of Ras Essa in Huddydah province by pipeline (long of 340 km and 24" diameter), with maximum capacity of 400,000 BOPD. The produced oil is light with density between (35-48 API), in addition to of big amount of gas as a reserve, which is neither invested nor exploited so far.

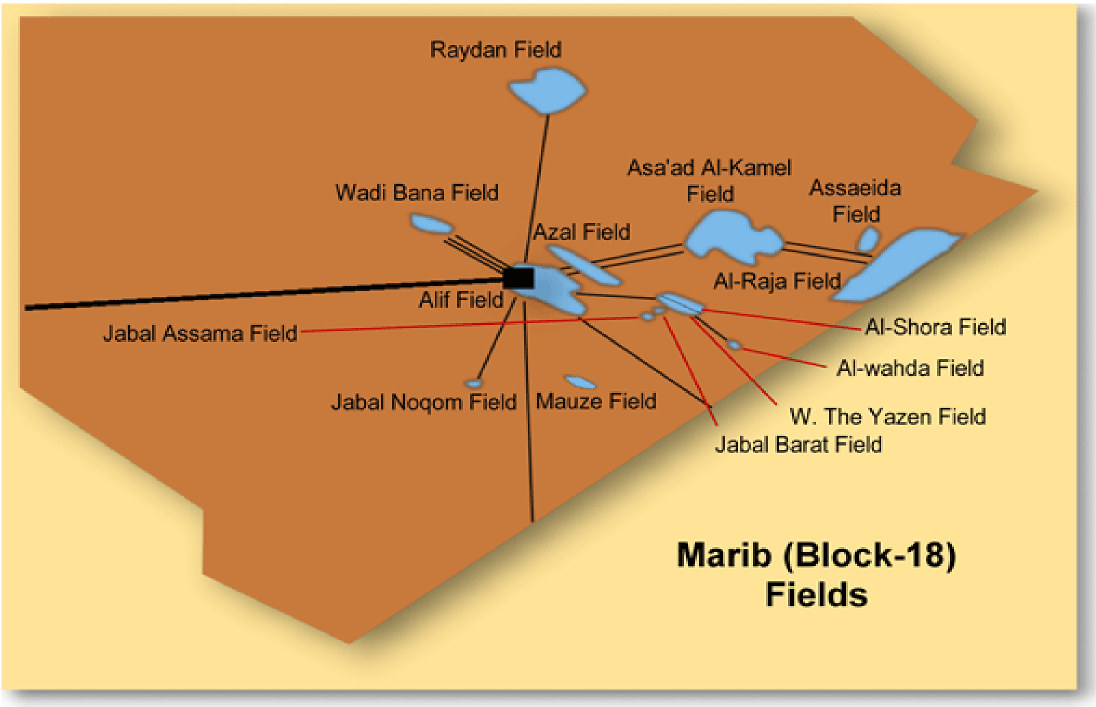


Figure (1.1): Marib fields (block 18)

1-2-2-Masilah - Blocks (14)

The second biggest oil blocks in the Republic of Yemen are Block (14), located in (Masilah-Sya'un) basin, with area of 1,257 km^2. It is operated by Canadian Nexen petroleum Company. Its main reservoirs are: Qishnclastic, Saar clastic, Saar carbonate, Basil sand and Madbi carbonate. The partners in the Production Sharing Agreement with the Yemeni government are: Nexen (52%), CCC, (10%) Occidental (38%). In General it contains 16 fields with an average production of (58,627 BOPD). The total number of wells was 639 until Des/ 2011.

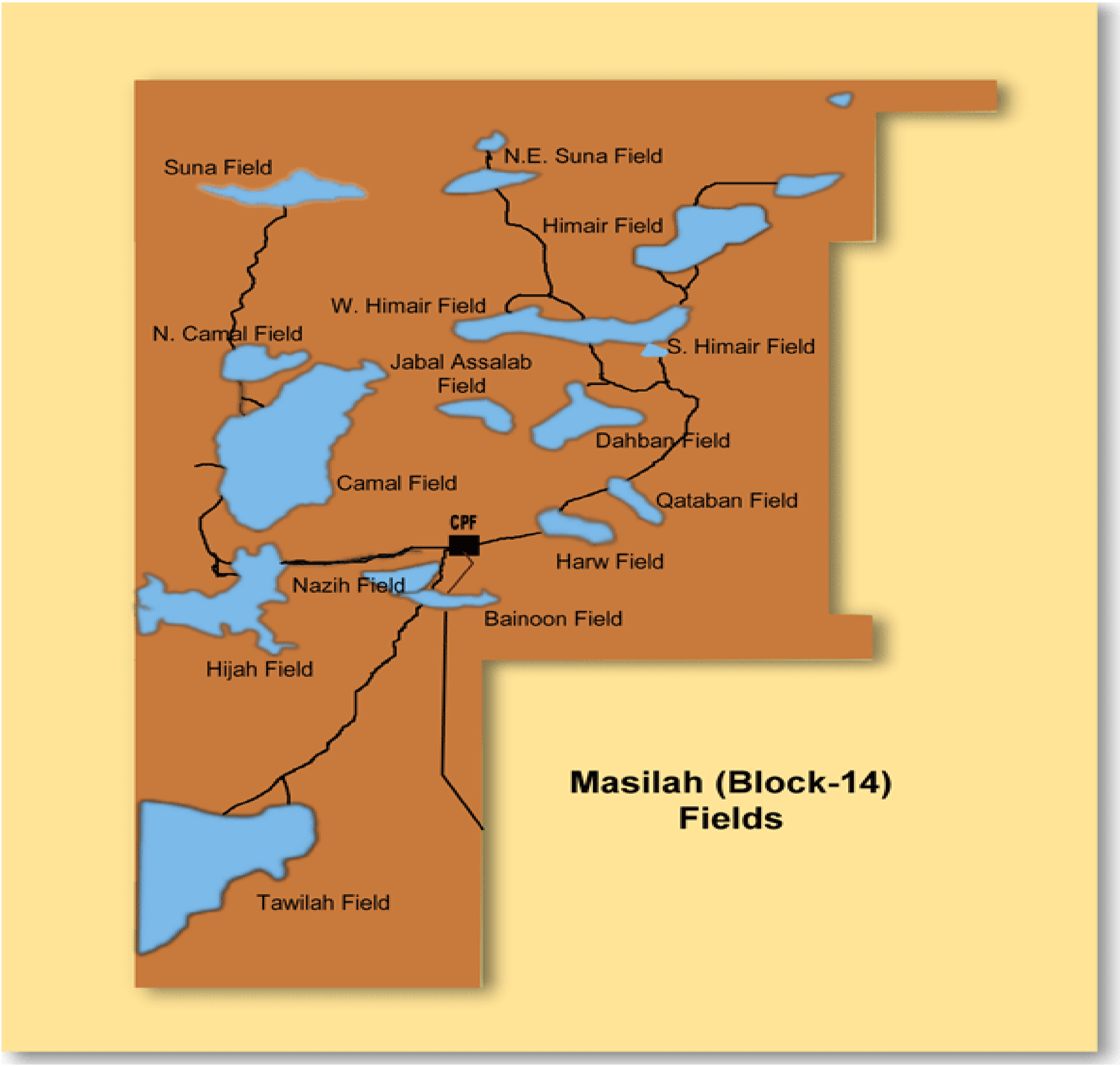


Figure (1.2): Masilah filed (block14)

The block is connected with the export Terminal of ASShihr in hadhramout province by pipeline (long of 138 Km and 24 inches diameter), with maximum capacity of 350,000 BOPD. The produced oil from the main reservoirs is intermediate in mass with density between (28-32 API), whereas the oil produced from Basement rocks is light with density about 41 (API) (*URL1*; 2013).

1-2-3-Block47

Resulting from the success of the Yaalen-1 well in the 7,606 km^2 onshore Block 47 (South Hood), Den Norske Oljeselskap (DNO) Yemen has confirmed that it will shortly spud Yaalen-2 testing a structure north of the discovery. The Yaalen-1 was suspended in February 2008 at a depth of 2,812 m after drilling the Basement section. The operator reported that oil had been observed while drilling through several intervals and samples had been retrieved from wire line fluids from both the Lower Cretaceous Qishn Formation sandstone as well as in Lower Jurassic Khulna Formation sandstones immediately above the Basement. A smaller rig is due to arrive shortly to undertake testing operations. DNO farmed in as operator of Block 47 in May 2006 and the current right holders are DNO (operator) 35%, Oil and Gas Mine Company 35% and the Yemen Oil and Gas Company 30%, but 12.5% carried (URL-1).

1-2-4- Block S-2.

Having received approval from the Yemeni authorities, Österreichische Mineralölverwaltung Aktiengesellschaft" (OMV) AG will begin the $250-300 million development of Block S2 (Al Uqlah) in the Shabwah province of eastern Yemen. Block S2, containing a complex fractured-basement reservoir, will be developed in two phases. Phase one will concentrate on acquisition of 3D seismic data, and Phase two entails full field development.

The area of the block to be developed covers 1.029 km^2. OMV will assess the hydrocarbon potential of the remainder of the block and, subject to government approval, explore the nearby Block 2 (Al Mabar), for which OMV on July 13, 2005, signed a production sharing agreement (PSA). Block S2 could begin oil production as early as the third quarter of this year. OMV will gradually increase production to 11,000 b/d by 2007-08. The field is expected to reach plateau production of 32,000 b/d by 2009-10. Proved reserves are estimated at 50 million bbl. Proved and probable reserves are estimated at 170 million bbl.

OMV discovered oil on Block S2 with the Al-Nilam-1 well in 2003. After a comprehensive block evaluation in 2004, the Habban-1 oil discovery was drilled in 2005. The Al-Nilam-ST1 tested the potential of the fractured basement in another compartment of Hobanfield.

OMV, operator, holds a 44% interest in Block S2. Sinopec International Petroleum Exploration and Production Corp. have 37.5%; Yemen General Corp. for Oil and Gas, 12.5%; and Yemen Resources Ltd., 6%.

1-2-5-Block 51

Located in Masilah- Say'un basin, with area of 2,004 km^2 Block (51) is operated by Canadian NEXEN Limited Yemen–Canadian Company. The main reservoirs in the block are: QishnClastic, Saar Sand, Saar Carbonate and expected to be produce from the fracture basement rocks in the future. The partners in the Production Sharing Agreement with the Yemeni government are NEXEN (87.5%) YCO (12.5%). The block has three fields, with an average production rate of (7,320) BOPD, the total number of wells ware 639 until Des. 2011. The block is connected with the main pipeline of block 14 (NEXEN) by 22 Km long, and 16" Diameter of the pipeline, the produced is intermediate oil with a density between (28-32 API).

1-2-6-Block 4

Shabwa province (Sector4) -Operating oil firm: till mid 1990, the Russian company Machino Import was working there-Since Second half of 1990 till now, it have been offered to Al-Namer Petroleum Company. -Work start: since 1986 by Machino-Import of Russia -First oil discovery: April 1987, Number of oil fields discovered: 3 -Start of production and average level: as from October 1987, by Machino-Import at the average level of 15,000 bpd. The production stopped in February 1990 due to the company's withdrawal. The production Te-continued in September 1992, with an average estimates 8, 5000 bpd. It depreciated till reaching 3, 5000 bpd, around May 1994. It then stopped about two-years. The production again started in June 1997, with an average of 2000 bpd. -Associated Units /Establishments: One crude- oil assembly unit; a pipeline 204 Kilometer long for oil exporting, and extending to Bier Ali on the Arabian Sea; and storage depots in the port of export. Estimated reserves: 520 million oil-barrels.

1-2-7-Block 5

Jannah region /Mareb -Shabwa (Sector 5) -Operating firm incorporation of companies comprising of: Total, Hunt, Exxon, Kovinpeck, and Russian Machino Import. -Starting of Work in March 1990 -First Oil Discovery in October 1991 -Number of digged rigs is 63 explorative and developing wells. -Start of production in October 1996 -Average level of production:- Started by 15,000 bpd. Currently reaching 25,000 pbd. -Estimated reserves:-

750 million barrels of oil, and 1.6 trillion Cubic feet of natural gas (*URL1*; 2014).

1-2-8-Block 32

The well was drilled to a total depth of 4,147 metres and encountered oil shows of 36º API in the Shuqra Formation, which was perforated over a 32-metre interval, acidised and tested, the Norwegian oil and gas company said. The well flowed naturally at an initial rate of 5,900 bpd before being held back at 3,400 bpd due to limited surface storage capacity. Block 32 also contains two producing oilfields - Godah and Tasour - whose gross output currently averages 2,500 bpd, company sources added. The well was spudded in July 2013 and it costed US$10mn to drill, complete and test.

BijanMossavar-Rahmani, executive chairman of DNO International, said, “Yemen continues to be an important focus area for DNO International and this discovery reflects our commitment to continue to build on our in-country knowledge, expertise and investments”. He added that the Salsala-1 well will be placed on an extended production test and that an appraisal well was scheduled in early 2014 as part of a fast track development of this discovery.

DNO International is the operator of Block 32 and holds a 38.95 per cent interest. Investment firm AnsanWikfs holds a 42.93 per cent, TransGlobe Energy Corporation a 13.12 per cent and Yemen Oil and Gas Corporation has the remaining five per cent interest in the block.

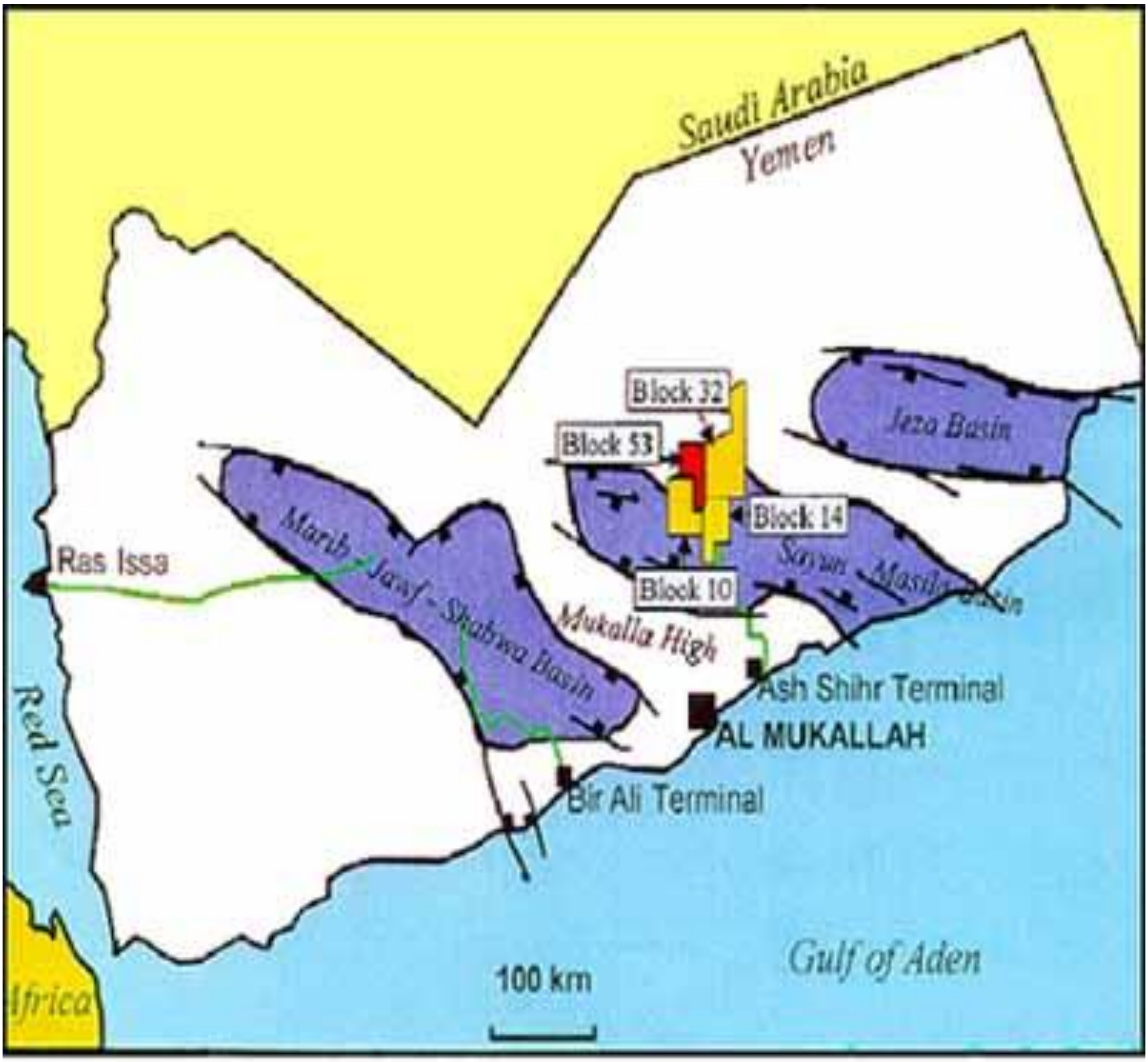


Figure (1.3): Major sector in Yemen and transportation pipeline

1-2-9-Block 9

Reserves attributable to Calvalley Petroleum Inc.'s 50% working interest in Block 9 in Yemen's Masilah basin fell to 12.5 million bbl at the end of (2012), from 14.7 million bbl a year earlier, the Calgary Company said. Company interest proved plus probable oil reserves of 25.2 million bbl declined from 29.3 million bbl in 2011.

Proved plus probable oil in place on Block 9 fell to 317 million bbl from 331 million bbl, due mainly to a technical revision of oil in place in RasNowmah field, The definition of the RasNowmah structure was updated by the current year drilling activity. The structure is still open in the northwest direction and will be evaluated by drilling in 2013. Activity in 2012, restricted by security and local issues, involved drilling two delineation wells at RasNowmah and a water injection well at Hiswah field. Early in 2013 the company achieved a cumulative production milestone of 1 million bbl from RasNowmah field (*URL 2*, 2013).

1-3-Definitions and Terminology

Petroleum is a naturally occurring mixture of hydrocarbons, generally in a liquid state, which may also include compounds of sulfur, nitrogen, oxygen, metals, and other elements. Petroleum has also been defined as

I. Any naturally occurring hydrocarbon, whether in a liquid, gaseous, or solid state
II. Any naturally occurring mixture of hydrocarbons, whether in a liquid, gaseous, or solid state
III. Any naturally occurring mixture of one or more hydrocarbons, whether in a liquid, gaseous, or solid state and one or more of the following: hydrogen sulfide, helium, and carbon dioxide.

The definition also includes any petroleum as defined in (I), (II), or (III) that has been returned to a natural reservoir (Speight and Laramie, 2006).

1-4-Composition of Crude Oils

The crude oil mixture is composed of the following groups:

I. Hydrocarbon compounds (compounds made of carbon and hydrogen).
II. Non-hydrocarbon compounds.
III. Organometallic compounds and inorganic salts (metallic compounds) (Sami, *et al*, 2001).

1-5- Elemental Composition of Crude Oils

With few exceptions, the proportions of carbon, hydrogen, nitrogen, oxygen, sulfur, and some metals in petroleum are as follows: Carbon (83.0- 87.0%), Hydrogen (10.0 - 14.0%), Nitrogen (0.1% - 2.0%), Oxygen (0.05- 1.5%), Sulfur (0 .05- 6.0%), Ni<1000 ppm and V<1000 ppm (Speight and Laramie, 2006)

1-6-Hydrocarbon Constituents

I. Paraffin's, which are saturated hydrocarbons with straight or branched chains, but without any ring structure.

II. Naphthene's, which are saturated hydrocarbons containing one or more rings, each of which may have one or more paraffinic side chains (more correctly known as alicyclichydrocarbons).

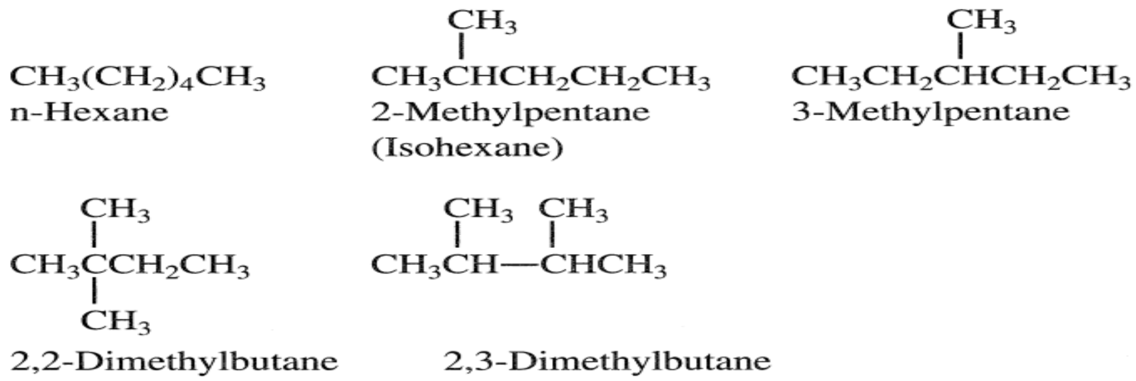
III. Aromatics, which are hydrocarbons containing one or more aromatic nuclei, such as benzene, naphthalene, and phenanthrene ring systems, which may be linked up with substituted naphthene rings or paraffinic side chains (Speight and Laramie, 2006).

1-6-1-Hydrocarbon Compounds

The principal constituents of most crude oils are hydrocarbon compounds. All hydrocarbon classes are present in the crude mixture, except alkenes and alkynes. This may indicate that crude oils originated under a reducing atmosphere. The following is a brief description of the different hydrocarbon classes found in all crude oils (Sami, *et al*, 2001).

1-6-1-1-Alkanes (Paraffins)

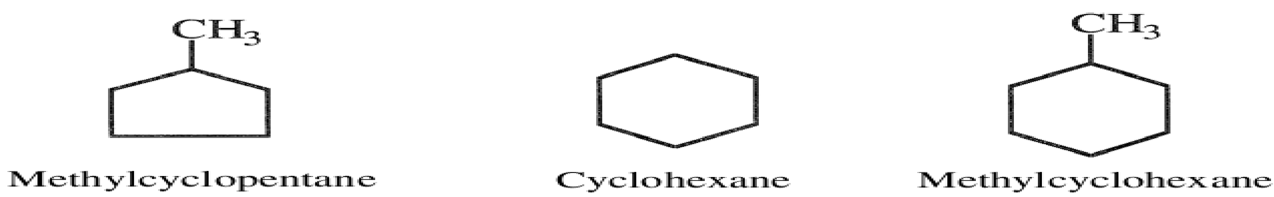
Alkanes are saturated hydrocarbons having the general formula C_nH_{2n+2}. The simplest alkane, methane (CH_4), is the principal constituent of natural gas. Methane, ethane, propane, and butane are gaseous hydrocarbons at ambient temperatures and atmospheric pressure. They are usually found associated with crude oils in a dissolved state. Normal alkanes (n-alkanes, n-paraffins) are straight-chain hydrocarbons having no branches. Branched alkanes are saturated hydrocarbons with an alkyl substituent or a side branch from the main chain. A branched alkane with the same number of carbons and hydrogens as an n-alkane is called an isomer. For example, butane (C_4H_{10}) has two isomers, n-butane and 2-methyl propane (isobutane). As the molecular weight of the hydrocarbon increases, the number of isomers also increases. Pentane (C_5H_{12}) has three isomers; hexane (C_6H_{14}) has five. The following shows the isomers of hexane:



An isoparaffin is an isomer having a methyl group branching from car-bon number 2 of the main chain. Crude oils contain many short, medium, and long-chain normal and branched paraffins. A naphtha fraction (obtained as a light liquid stream from crude fractionation) with a narrow boiling range may contain a limited but still large number of isomers (Sami, *et al,* 2001).

1-6-1-2-Cycloparaffins (Naphthenes)

Saturated cyclic hydrocarbons, normally known as naphthenes, are also part of the hydrocarbon constituents of crude oils. Their ratio, however, depends on the crude type. The lower members of naphthenes are cyclopentane, cyclohexane, and their mono-substituted compounds. They are normally present in the light and the heavy naphtha fractions. Cyclohexanes, substituted cyclopentanes, and substituted cyclohexanes are important precursors for aromatic hydrocarbons.

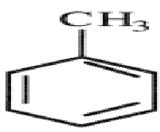


The examples shown here are for three naphthenes of special importance. If a naphtha fraction contains these compounds, the first two can be converted to benzene, and the last compound can dehydrogenate to toluene during processing. Dimethylcyclohexanes are also important precursors for xylenes. Heavier petroleum fractions such as kerosine and gas oil may contain two or more cyclohexane rings fused through two vicinal carbons (Sami, *et al*, 2001).

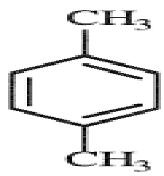
1-6-1-3-Aromatic Compounds

Lower members of aromatic compounds are present in small amounts in crude oils and light petroleum fractions. The simplest mononuclear aromatic compound is benzene (C_6H_6), Toluene (C_7H_8) and xylenes (C8H10) are also mononuclear aromatic compounds found in variable amounts in crude oils. Benzene, toluene, and xylenes (BTX) are important petrochemical intermediates as well as valuable gasoline components. Separating benzene, Toluene, and xylene (BTX) aromatics from crude oil distillates is not feasible because they are present in low concentrations. Enriching a naphtha fraction with these aromatics is possible through a catalytic reforming process. Binuclear aromatic hydrocarbons are found in heavier fractions than naphtha. Trinuclear and polynuclear aromatic hydrocarbons, in combination with heterocyclic compounds, are major constituents of heavy crudes and crude residues. Asphaltenes are a complex mixture of aromatic and heterocyclic compounds. The nature and structure of some of these compounds have been investigated (Speight; 1972). The following are representative examples of some aromatic compounds found in crude oils:

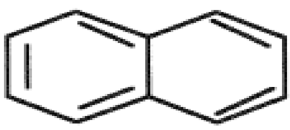
Benzene



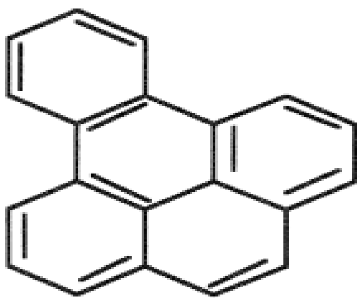
Toluene



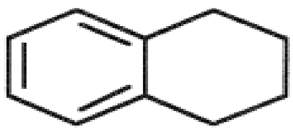
p-Xylene



Naphthalene



1,2-Benzopyrene



Tetralin

Only a few aromatic-cycloparaffin compounds have been isolated and identified. Tetralin is an example of this class.

1-6-2-Non-hydrocarbon Compounds

Various types of non-hydrocarbon compounds occur in crude oils and refinery streams. The most important are the organic sulfur, nitrogen, and oxygen compounds. Traces of metallic compounds are also found in all crudes. The presence of these impurities is harmful and may cause problems to certain catalytic processes. Fuels having high sulfur and nitrogen levels cause pollution problems in addition to the corrosive nature of their oxidization products (Sami, *et al*; 2001).

1-6-2-1-Sulfur Compounds

Sulfur in crude oils is mainly present in the form of organosulfur compounds. Hydrogen sulfide is the only important inorganic sulfur compound found in crude oil. Its presence, however, is harmful because of its corrosive nature. Organosulfur compounds may generally be classified as acidic and non-acidic. Acidic sulfur compounds are the thiols (mercaptans). Thiophene, dimethylsulfides, and dimethyldisulfides are examples of non-acidic sulfur compounds found in crude fractions. Extensive research has been carried out to identify some sulfur compounds in a narrow light petroleum fraction (Rall, *et al*; 1962) Examples of some sulfur compounds from the two types are:

Acidic Sulfur Compounds

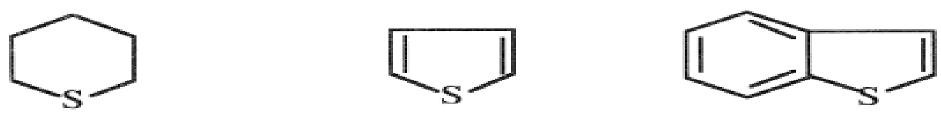
CH_3SH

Methyl mercaptan | Phenyl mercaptan | Cyclohexylthiol

Non-acidic Sulfur Compounds

CH_3SCH_3 | $CH_3S\text{-}SCH_3$

Dimethyl sulfide | Dimethyldisulfide

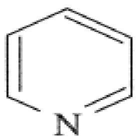


Thiocyclohexane | Thiophene | Benzothiophene

Sour crudes contain a high percentage of hydrogen sulfide. Because many organic sulfur compounds are not thermally stable, hydrogen sulfide is often produced during crude processing. High-sulfur crudes are less desirable because treating the different refinery streams for acidic hydrogen sulfide increases production costs.

1-6-2-2-Nitrogen Compounds

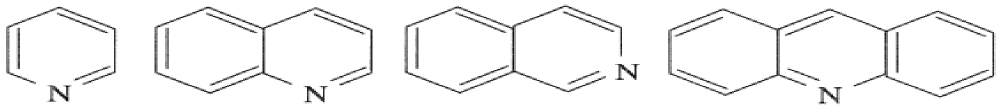
Organic nitrogen compounds occur in crude oils either in a simple heterocyclic form as in pyridine (C_5H_5N) and pyrrole (C_4H_5 N), or in a complex structure as in porphyrin. The nitrogen content in most crude is very low and rarely exceeds 0.1 wt%. In some heavy crude, however, the nitrogen content may reach up to 0.9 wt % (Speight, 1991). Nitrogen compounds are more thermally stable than sulfur compounds and accordingly are con-centrated in heavier petroleum fractions and residues. Light petroleum streams may contain trace amounts of nitrogen compounds, which should be removed because they poison many processing catalysts. During hydro treatment of petroleum fractions, nitrogen compounds are hydro denitrogenated to ammonia and the corresponding hydrocarbon. For example, pyridine is denitrogenated to ammonia and pentane:



$$+ 5H_2 \longrightarrow NH_3 + CH_3CH_2CH_2CH_2CH_3$$

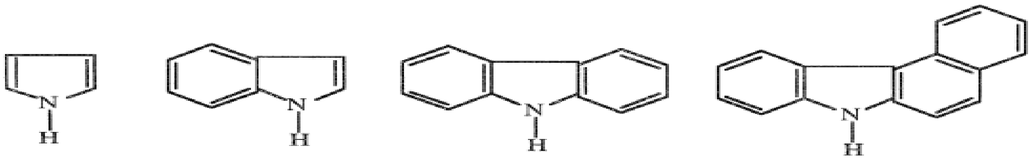
Nitrogen compounds in crude oils may generally be classified into basic and non-basic categories. Basic nitrogen compounds are mainly those having a pyridine ring, and the non-basic compounds have a pyrrole structure. Both pyridine and pyrrole are stable compounds due to their aromatic nature. The following are examples of organic nitrogen compounds:

Basic Nitrogen Compounds



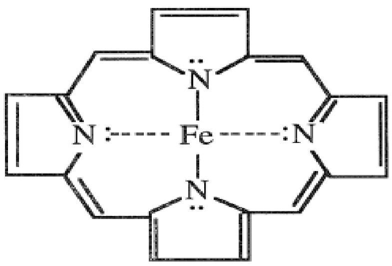
Pyridine Quinoline Isoquinoline Acridine

Non-Basic Nitrogen Compounds



Pyrrole Indole Carbazole Benzocarbazole

Porphyrins are non-basic nitrogen compounds. The porphyrin ring system is composed of four pyrrole rings joined by =CH-groups. The entire ring system is aromatic. Many metal ions can replace the pyrrole hydrogens and form chelates. The chelate is planar around the metal ion and resonance results in four equivalent bonds from the nitrogen atoms to the metal (Fessenden, and Fessenden, 1991). Almost all crude oils and bitumens contain detectable amounts of vanadyl and nickel porphyrins. The following shows a porphyrin structure:

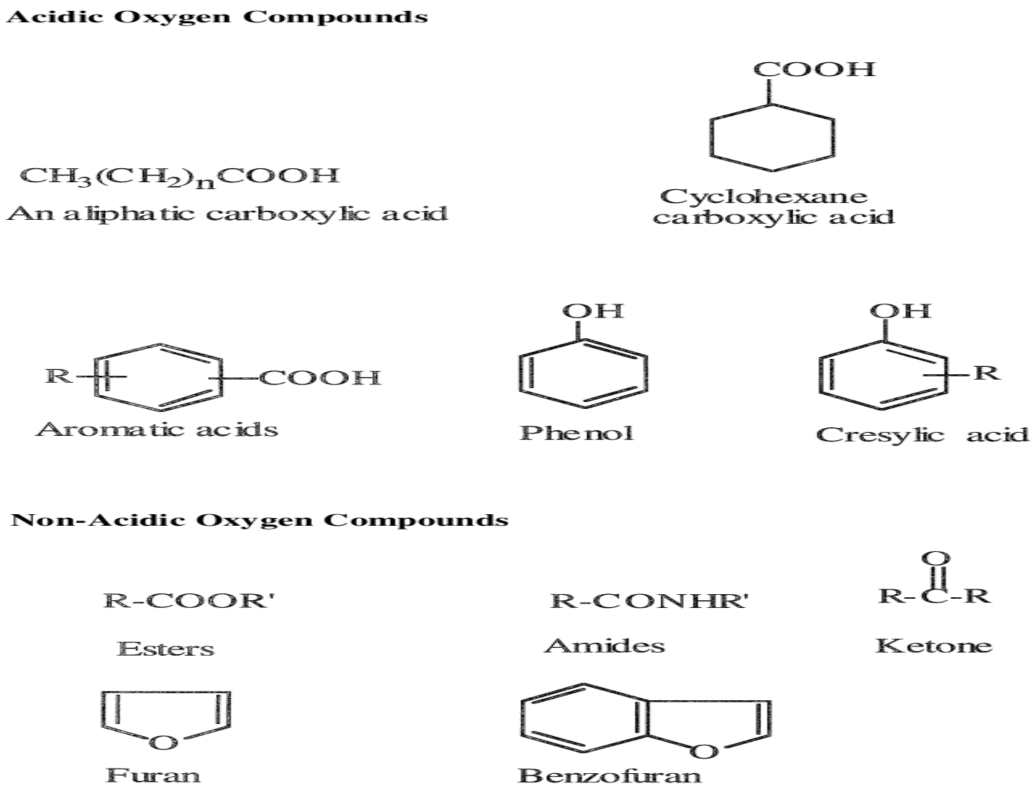


Separation of nitrogen compounds is difficult, and the compounds are susceptible to alteration and loss during handling. However, the basic low-molecular weight compounds may be extracted with dilute mineral acids.

1-6-2-3-Oxygen Compounds

Oxygen compounds in crude oils are more complex than the sulfur types. However, their presence in petroleum streams is not poisonous to processing catalysts. Many of the oxygen compounds found in crude oils are weakly acidic. They are carboxylic acids, cresylic acid, phenol, and naphthenic acid. Naphthenic acids are mainly cyclopentane and cyclohexane derivatives having a carboxyalkyl side chain.

Naphthenic acids in the naphtha fraction have a special commercial importance and can be extracted by using dilute caustic solutions. The total acid content of most crude oils is generally low, but may reach as much as 3%, as in some California crudes.Non-acidic oxygen compounds such as esters, ketones, and amides are less abundant than acidic compounds. They are of no commercial value. The following shows some of the oxygen compounds commonly found in crude oils:



1-6-3-Metals in Crude Oils

Crude oils primary constituents are organic but also contain trace concentrations of inorganic or metals in the range of subparts per billion (ppb) to tens and occasionally hundreds of parts per million (ppm). The trace content of metals in crude oil is of interest for the potential contamination of the environment. Environmental risks depend on the toxicity and concentration of each metal in the crude oil. High concentrations of metals in soil and water can be harmful to land, marine animals, and plants, upsetting delicate ecological balances and contaminating food sources (Carey, 2004), Crude oil is particularly rich in certain metals, such as vanadium, which reaches

2000ppm in Venezuelan crude oil. Most alkalis and alkaline earth metals are present in small amounts of order of ppm or less.

1-7-Properties of crude oils

Even though crude oils are a continuum of tens of thousands of different hydrocarbon molecules, the proportions of the elements in crude oils vary over fairly narrow limits. Nevertheless, a wide variation in properties is found from the lightest crude oils to the highly asphaltenic crudes. The carbon content normally is in the range 83-87%, and the hydrogen content varies between 10 and 14%. In addition, varying small amounts of nitrogen, oxygen, sulfur and metals (Ni and V) are found in crude oils (Speight; *et al*, 1999). Due to the complex composition of crude oils, characterization by the individual molecular types is not possible, and elemental analysis is unattractive because it gives only limited information about the constitution of petroleum due to the constancy of elemental composition. Instead, hydrocarbon group type analysis is commonly employed (Onyema; *et al*, 2010).

1-7-1-Viscosity

Crude oil viscosity is an import The viscosity, in general, is defined as the internal resistance of the fluid to flow. Viscosity is an extremely important property from processand reservoir simulations to the basic design of a pipeline. Experimental liquid viscosities ofpure hydrocarbons and their mixtures under pressure are important to simulating thebehavior of the fluid at reservoir conditions. Also, experimental measurements over a wide range of temperature and pressure are needed to test the effectiveness of semi-theoretical and empirical viscosity models (Salem and Al-Marri, 2009). Oil viscosity is a strong function of manythermodynamic and physical properties such as pressure, temperature, solution gas-oilratio, bubble point pressure, gas gravity and oil gravity. Usually oil viscosity is determined by laboratory measurements at reservoir temperature. Viscosity is usually reported in standard PVT analyses. Oil viscosity correlations all belong to three categories: deadoil, saturated oil and under saturated oil, viscosity correlation. Numerous correlations have beenproposed to calculate the oil viscosity. There have been a number of empirical correlationsdeveloped for medium and light crude oils (Abdulkareem and Kovo, 2006). However their applicability is limited to specific oils due to the complex formulation of the crude oils.

These correlations are categorized into two types, The first type which refers to black oil type correlations predict viscosities from available field-measured variables including reservoir temperature, oil APIgravity, solution gas- oil ratio, saturation pressure and pressure (Hossain, *et al*, 2005). The second type which refers to compositional models is derived mostly from the principle of corresponding states and its extensions. In these correlations beside previous properties, other properties such as reservoir fluid composition, pour point temperature, molar mass, normal boiling point, critical temperature and a centric factor of components are used (Kartoatmodjo and Schmidt, 1994).

Ideally, viscosity is experimentally measured in laboratory. When such direct measurements are not available, correlations fromthe literature are often used. Fundamentally, there aretwo different typesof correlations in the literature, The first group of correlations isdeveloped using randomly selected datasets (Houpemt *et al*, 1974). Such correlations could be called generic correlations. The second group of correlations, called specialized correlations, is developed using a certain geographical area or a certain class type of oil. Correlations using randomly selected datasets may not be suitable for certain type of oils, or certain geographical areas. Even though the authors of the generic correlations want to cover wide range of data, specialized correlations still work better for certain types of oils. Specialized correlations represent the properties of a certain type of oil or geographical area for which they are developed better than the general purpose correlations (Houpemt, 1974).

1-7-2-Water Content

Some of the oils analyzed by ESD contain substantial amounts of water. Because any process that would separate the oil and water would also change the composition of the oil, most properties were determined on the oils as received. Therefore, for those oils with significant water contents, >5%, many of the properties measured do not represent the properties of the "dry" oil.

At ESD, water contents were determined by Karl Fischer titration using a Metrohm 701 KF Automatic Titrator. A slightly modified version of ASTM method D 4377 was used (Annual book of ASTM standards, 1996).

1-7-3-Evaporation Equation

Evaporation is a major process which contributes to the weathering of spilled oil. While pure compounds evaporate at constant rates, oils, which are composed of thousands of compounds, do not. Rapid initial loss of the more volatile fractions is followed by progressively slower loss of less volatile components. It is not uncommon for 25% of the total volume of an oil spill to evaporate within one day of the spill (Fingas, 1979). Using a simple pan evaporation technique, evaporation rate equations have been developed for approximately 60 oils.

1-7-4-Flash Point

The flash point of a fuel is the temperature to which the fuel must be heated to produce a vapour/air mixture above the liquid fuel that is Ignitable when exposed to an open flame under specified test conditions. In North America, flash point is used as an index of fire hazard. As such, shipping regulations use flash point as (a criterion to establish labeling requirements). Flash point is an extremely important factor in relation to the safety of spill cleanup operations. Gasoline's and other light fuels can be ignited under most ambient conditions and therefore pose a serious hazard when spilled. Many freshly spilled crude oils also have low flash points until the lighter components have evaporated or dispersed.

There are several ASTM methods for measuring flash points. Methods (D 93/IP 34) Standard Test Methods for Flash Point by Pensky-Martens Closed Tester and (D 56) Standard Test Method for Flash Point by Tag Closed Tester are among the most commonly used. The Pensky-Martens tester has an integral stirrer, but no cooling bath. The minimum flash point that can be determined by method (D93/IP34) is 10 'C. The Tag closed tester has an integral cooling bath, but no stirring mechanism. Method (D-

56) is intended for liquids with a viscosity less than 9.5cSt at 25 'C. The flash points and fire points of lubricating oils can be determined by ASTM method (D 92/IP 36) Standard Test Method for Flash and Fire Points by Cleveland Open Cup (Annual book of ASTM standards, 1996).

Many fresh crude oils have flash points below 10 ºC and/or viscosities above 9.5cSt at 25 ºC. For this reason, at ESD a Sur Berlin TAG 2 automatic flash point tester, which has been modified by adding a stirring mechanism, is used to determine flash points. The mechanism operates in a similar fashion to a Pensky-Martens tester, but is of a more efficient design. The stirrer aids in producing more uniform heat transfer to oils that exceed the design viscosity, and in no way interferes with the test mechanism. Flash points measured by this instrument are generally repeatable to +/- 4 ºC.

1-7-5-Fire Point

Fire point is the lowest temperature, corrected to one atmosphere pressure (101.3 k Pa), at which the application of a test flame to the oil sample surface causes the vapor of the oil to ignite and burn for at least five seconds. For ordinary commercial lubricating oils, the fire point usually runs about 30 ºC above the flash point (Prasad and Mudga, 2011), the flash points and fire points of lubricating oils can be determined by ASTM method (D 92/IP 36) (Annual book of ASTM standards; 1996).

1-7-6-Reid Vapor Pressure

Vapor pressure is an important physical property of volatile liquids. It is the pressure that a vapor exerts on its surroundings. Its units are kilopascals, corrected to one atmosphere (101.3 k Pa). For volatile petroleum products, vapor pressure is used as an indirect measure of evaporation rate. Vapor pressure can be measured by a variety of methods including Reid, dynamic, static, isoteniscopic, vapor pressure balance, and gas saturation. The most commonly used method for crude oils has been the Reid vapor pressure, as determined by ASTM method D 323 - Standard Test Method for Vapor Pressure of Petroleum Products Reid Method (Annual Book of ASTM Standards, 1996). This test method determines vapor pressure at 37.8 'C (100 ºF) of petroleum products and crude oils with initial boiling point above 0 ºC (32 ºF). It is measured by saturating a known volume of oil in an air chamber of known volume and measuring the equilibrium pressure which is then corrected to one atmosphere (101.3 k Pa).

1-7-7-Hydrogen Sulphide

Unlike other sulphur compounds in crude oils, which tend to accumulate in the distillation residue, hydrogen sulphide is evolved during distillation or other heating processes. During an oil spill, this makes it a safety concern, as hydrogen sulphide is a toxic gas with a time-weighted average (TWA) exposure limit of 10 ppm and a short-term exposure limit (STEL) of 15 ppm (ACGIH; 1996).

1-7-8-Pour Point

The pour point of oil is the lowest temperature at which the oil will just flow, under standard test conditions. The failure to flow at the pour point is usually attributed to the separation of waxes from the oil, but can also be due to the effect of viscosity in the case of very viscous oils. Also, particularly in the case of residual fuel oils, pour points may be influenced by the thermal history of the sample, that is, the degree and duration of heating and cooling to which the sample has been exposed. From a spill response point of view, it must be emphasized that the tendency of the oil to flow will be influenced by the size and shape of the container, the head of the oil, and the physical structure of the solidified oil. The pour point of the oils is therefore an indication, and not an exact measure, of the temperature at which flow ceases (Dyroff, 1993).

1-7-9- Density

Density is defined as the mass per unit volume of a substance. It is most often reported for oils in units of g/mL or g/cm^3, and less often in units of kg/m^3. Density is temperature-dependent. Oil will float on water if the density of the oil is less than that of the water. This will be true of all fresh crude oils, and most fuel oils, for both salt and fresh water. Bitumen and certain residual fuel oils may have densities greater than 1.0 g/mL and their buoyancy behavior will vary depending on the salinity and temperature of the water. The density of spilled oil will also increase with time, as the more volatile (and less dense) components are lost. After considerable evaporation, the density of some crude oils may increase enough for the oils to sink below the water surface. Two density-related properties of oils are often used, specific gravity and American Petroleum Institute (API) gravity. Specific gravity (or relative density) is the ratio, at a specified temperature, of the oil density to the density of pure water.

The API gravity scale arbitrarily assigns API gravity of 10/ to pure water. API gravity is calculated as, Oils with low densities, and hence low specific gravities, have high API gravities. The price of a crude oil is usually based on its API gravity, with high gravity oils commanding higher prices. API gravity, and density or specific gravity at 15 /C, can be interconnected using Petroleum Measurement (American Petroleum Institute, 2009). At ESD, density is measured using an Anton Parr DMA 48 digital density meter, and following ASTM method D 5002 - Density and Relative Density of Crude Oils by Digital Density Analyzer (Annual Book of ASTM Standards, 1996). In this way, densities can be measured to 0.0001 g/ml with a repeatability of "0.0005 g/ml.

1-7-10- Waxes content

Waxes are predominately straight-chain saturates with melting points above 20 ºC (generally, the n-alkanes C_{18} and heavier).From a chemical science point of definition, wax are mixtures of n-alkanes usually of the homologous chain lengths. They are hydrocarbon classes similar in composition and physical properties to beeswax from natural beehive that deform above near-ambient conditions, insoluble in water but soluble in organic, non-polar solvents (Ajayi, 2013).

1-7-11-API Gravity

An American Petroleum Institute measure the density for petroleum as ºAPI.

$$^{o}\text{API} = \frac{141.5}{\text{specific gravity at } 15.6\,^{o}\text{C}} - 131.$$

Fresh water has a gravity of 10 ºAPI. The scale is commercially important for ranking oil quality. Heavy, inexpensive oils are $<$ 25 ºAPI; medium oils are 25 to 35 ºAPI; light, commercially-valuable oils are 35 to 45 ºAPI.

1-7-12-Total of acid content.

Components, such as naphthenic acids and phenols, whichare known to cause various operational problems, such ascorrosion/fouling of process units and water/oil emulsification[33-34]. Petroleum industry uses total acid number (TAN) as a measure of crude oil corrosively (Shi, *et al*; 2010). TAN is defined as1milligrams of potassium hydroxide (KOH) required to neutralize all acid compounds in 1g of oil sample (Standard Test Method for Acid Number of Petroleum Products; 2004).The higher the TAN, the more corrosive the crude oil (Qu, Zheng; et al; 2006). However, it is known that some crude oils with relatively low TAN exhibit high corrosives which are comparable to those of high TAN crudes (Laredo ; *et al*; 2004). The corrosively of crude oil is not linearly correlated to the TAN (Smith; *et al;* 2008), and is dependent on the size and structure of naphthenic acids and/or other acid-ice components in crude oil (Hsu; *et al*; 2000). Naphthenic acid corrosion is commonly known refinery to describe corrosion problems in heaters, distillation units, and pipes. Refinery corrosion was also related toothier feedstock properties such as sulfur content and process operating conditions: temperature and flow rate (Laredo; 2004). In the atmospheric distillation operation, corrosion ofside-stream gas oil product line was attributed to liquid-phase corrosion at 250–400 °C (Qian ; 2001). In recent years, the Fourier transform ion cyclotron resonance mass Spectrometry (FT-ICR MS) (Marshall; *et al*, 1998), which provides ultra-high resolving power and mass accuracy, has become a desired technique used for characterizing highly complex hydrocarbon mixtures. In coupling with theelectro spray ionization (ESI) which has high selectivity for ionizing trace polar compounds (Qian; *et al*; 2004), hasbeen widely used to characterize acidic and basic compounds include oil (Marshall; 1998). Stanford reported the acidic polar heteroatom molecular class composition of three distillate fractions of vacuum gas oil (VGO), showing different compositions of carboxylic acids and Oxygen-sulfur (S_x O_y) species in light, middle and heavy distillates (Lateefah, *et al*, 2004).

1-7-13-Resins

This fraction comprised of polar molecules often containing heteroatom such as nitrogen, oxygen or sulphur. The resin fraction is operationally defined as the fraction soluble in light alkanes such as pentane and heptane, but insoluble in liquid propane. Since the resins are defined as a solubility class, overlap both to the aromatic and the asphalting fraction is expected. Despite the fact that, the resin fraction is very important with regard to crude oil properties, little work has been reported on the characteristics of the resins, compared to for instance the asphaltenes. However, some general characteristics may be identified. Resins have a high H / C ratio than asphaltenes, 1.2 - 1.7 compared to 0.9 - 1.2 for the asphaltenes.

Resins are structurally similar to asphaltenes, but smaller in molecular weight (>1000g/mol). Naphthenic acids are commonly regarded as part of the resin fraction (Muhammad, *et al*, 2013)

1-7-14-Asphaltenes

The asphaltenes fraction, like the resins, is defined as a solubility class, namely, the fraction of the crude oil precipitating in light alkanes like pentane, the hexane or heptanes. This precipitate is soluble in aromatic solvents like the toluene and benzene. The asphaltenes fraction contains the largest percentage of heteroatom (O, S, and N) and organ metallic constituents (Ni, V, Fe) in the crude oil. Asphaltingis believed to be suspended as a micro colloid in the crude oil, consisting of particles of about 3mm each. The particles consist of one or more atomic sheets of asphalting monomers with absorbed resin acting as surfactants to stabilize the colloid at suspension (Muhammad, et al; 2013).

1-8-Literature review

A crude oil is a naturally occurring mixture, consisting predominantly of hydrocarbons, sulphur, nitrogen and metals (Bawazeer, and Zilouchian, 1997). The Quality of the petroleum products is playing the major role of consumer satisfaction and speaks about the performance of the refineries. To identify and predict the behavior of the crude oil and finished petroleum products in particular circumstances, it is necessary to measure physicochemical properties and to compare the measured values with International Standards (Robert, *et al*, 1995). The typical nature of crude oil from different sources is different or less identical. The same is true for crude oil also; the individual oil even from the same well at different time of extraction is differing in the characteristics in term of chemical composition and Physico-chemical behavior though the basic trend is almost same for each type of crude oil (Roussel and Boulet; 1995). It is known that crude oil, the basic raw material of refining industries is not only unique, but the entire organic chemistry can be studied. Crude oil contains almost all known hydrocarbons and non-hydrocarbons As it is drawn from the earth, it also contains impurities like water, mud and salts during its exploration and transportation Crude oils are complex but mainly paraffinic, napthenicand aromatic.Crude oils contain all normal alkenes from C1 to C120 (Wang, *et al*, 1994 and Khanorkar, 1996).

However, this percentage rises to 35% in highly paraffinic and decreases to zero in highly biograded oils (Ali, *et al,* 1989). Methane is predominant component of natural gas and alkanes ranging from pentan to pentadecane are the chief constituents of straight run (uncrackcd) gasoline or petrol. Above C 17, the alkanes are solid wax like substances and crude oils, which contain high concentrations of paraffin wax, will be viscous and have high cloud and pour points.These Paraffins consists of isoalkanes and methyl cycloalkanes. Most commonly found naphthenes are five and six membered rings and occasionally a few rings with seven carbon atoms among these, methyl derivatives are the most abundant compounds as compared with the parent bicycle compounds. Crude oils contains up to 50% of such 54 naphthenes.

Aromatic compounds rarely amount to more than 15% of the crude oils. Crude oil samples obtained from different oil fields vary both in physical and chemical properties. This is due to different proportions of the various molecular types, sizes of hydrocarbons and other elemental constituents in the crude mix (Onyema, *et al*, 2010). Petroleum fluids are complex fluids, normally of undefined composition that require a characterization procedure to obtain relevant information (Abdulkareem and Kovo, 2006).

According to (Odebunmi and Adeniyi, 2007) the ever-increasing chemical utilization of crude oils and petroleum products call for a better knowledge of the composition, structure and properties of their fractions. Parameters often determined in crudeoil include: Density, API gravity, Pour point, Kinematic Viscosity, Water content (%) Salt content (%) Sulphur content (%), Asphaltene (%), ASTM Distillation cracking point as well as Metal/mineral contents. These important parameters are used in specification and classification of crude oil blends (Oyekunle and Famakin, 2004). Specific gravity is often defined as ratio of densities for crude oil and water at 15.6 °C, although slight deviations from this may use other reference points, such as 0°C, 20°C or the maximum volumetric mass of water which is at 3.98°C. API gravity ranges from 0-60°, where dense oils have low values and highly viscous oils have high values. Condensates typically have API gravities over 45° and Canadian tar sands from the Athabasca can be found in the range of 6 -10° (Peters, et *al*., 2005). Oil with less than 10 °API is denser than water and may be called extra-heavy oil or natural bitumen. Depending on viscosity, Heavy oils have gravities of less than 20°API, but more than 10°API (USGS; 2006). Medium crudes can be found between 20°API and 30°API. Light crudes have more than 30°API (Robelius, 2007).

The API gravity classifica-tion is a simple system and worked well, as long as there was one dominating quality type of crude oil in use. As new oil fields were brought into production and new crude oil blends entered the market, the simple gravity classification scheme was insufficient to fully measure the quality of crude oil.

Even so, the API system is still in use for certain crude oils and products (Speight, 1999).

An improvement in classification can be performed by including the content of various important pollutants, especially sulphur. The sourness of crude oil refers to the sulphur content. The Society of Petroileum Engineers (SPE) defines sour crude oil as oil containing free sulphur or other sulphur compounds whose total sulphur content is in excess of 1 percent (Society of Petroleum Engineers; 2009). Crude oils with low sulphur content are commonly called sweet. It is more complicated to refine heavy and sour crude oils, and consequently, they are worth less on the market compared to the light and sweet crude oils. Heavy crude needs more processing to yield high quality products due to their low API-gravity, high viscosity, high initial boiling point, high carbon residue and low hydrogen content The most valuable oil is the light and sweet crude oil (Nygren, 2008).

Light, heavy and extra heavy Crude Oil As the terminology indicates, the character of the crude oil product is usually defined with respect to its density. In the early years of petroleum industry, density was the principal specification for petroleum and refinery products (Speight; 1998). Although the density gives no specific information about the chemical composition of the product, there are generally certain properties that directly or indirectly correlate to the density of the oil. The API (American Petroleum Institute) gravity indicates a transition from conventional to heavy oils at 20 API (0.934kg/m^3 at 60^{0}F/15.6 ^{0}C). Light oils have API gravity greater than 20, whereas extra heavy oils and bitumen have API gravity less than 10 (heavier than water).

Naphthenic acid consist of saturated acyclic, monocyclic and polycyclic carboxylic acids with the general chemical formula of $C_nH_{2n+Z}O_2$; where n is the carbon number and Z represents the hydrogen atoms lost as the structures form rings (Vaz deCampose MC; *et al;* 2006) Naphthenic acid problem had become a great concern to petroleum industry nowadays because of the corrosive properties of naphthenic acid tends to cause aggravated equipment corrosion, especially at high temperature (230-

400°C), andthis leads to high maintenance costs, may pose environmental disposal problems and low quality of the crude oils produced. There is no clear consensus on what constitutes a dangerous concentration of naphthenicacids, but corrosion will occur if the neutralization number is above 0.5 mg KOH /g of crude oil (Huang, *et al*, 2006) Asphaltenes are found in heavy crude oil and consist of positively charged complex large muttering hydrocarbon systems. They are in effect a solubility class, i.e. the fraction of the crude oil that is not soluble in paraffinic solvents, which are chained non-polar hydrocarbons (Masakatsu, *et al,* 2005 and Wiehe, 1996). They are known to aggregate in solutions in a micro-emulsion, where an asphaltene core is surrounded by resins (with fewer hydrocarbon rings), which are surrounded by smaller hydrocarbon ring molecules, which in turn are dissolved in the non-polar solvent This micro-emulsion structure allows the asphaltenes to dissolve in the crude oil (Wiehe, *et al,* 2005).

The salt elimination from produced crude oil is an important stage in oil field processing and it is considered as a compulsory requirement in the oil industry. In most cases, salt is found a dissolved component in the brine phase in contact with oil. Different compositions of various salts might exist in the brine; however, sodium chloride (NaCl) has the highest fraction in the solution. The water existing in the crude oil is seen as very small drops dispersed in the bulk of oil. In the current study, a simple predictive strategy for density determination of aqueous salty solution in crude oil as a function of salinity (in vole% of sodium chloride concentration), temperature, and pressure is proposed through combination of an Arrhenius-type asymptotic exponential function and the relationship introduced by (Spivey, *et al*, 2004).

The Jubilee and Salt pond crude oils are light (API>30) and sweet sulfur levels < 0.5%wt) quality crude oils with low water content (<1%), coupled with low sediments level (<1% This implies low or minimal microbial growth and reduced ability to serve as a collector of water soluble metals and salts This enhances the quality of the crude oils as it is devoid of fouling and corrosion at high temperatures

1-8-1 **Crude oils biomarkers**

Due to the variety of geological conditions and ages under which oil was formed, every crude oil exhibits a unique biomarker fingerprint. Crude oils compositions vary widely depending on the oil sources, the thermal regime during oil generation, the geological migration and the reservoir conditions. Crude oils can have large differences in:

I. Distribution patterns of the n-alkanes, iso-alkanes and cyclic-alkanes as well as the unresolved complex mixture (UCM) profiles
II. Relative ratios of isoprenoid to normal alkanes.

Most of these constituents undergo changes in their chemical structure by time as an effect of several factors among which are the biodegradation and weathering. Relative to other hydrocarbon groups in oil, there are some compounds that are more degradation-resistant in the environment as for example; Pristane, phytane, steranes, triterpanes and porphyrins. These undegradable compounds are known as Biomarkers (Moustafa and Morsi, 2012).

1-8-2-Normal -alkanes' characteristics

The distribution of n-alkanes in crude oils can be used to indicate the organic matter source (Duan and Ma, 2001). For example, the increase in the n-C_{15} to n-C_{20} suggests marine organic matters with contribution to the biomass from algae and plankton (Peters and Moldowan, 1993). Oil samples characterized by uniformity in n-alkanes distribution patterns suggest that they are related and have undergone similar histories with no signs of biodegradation (Duan, *et al*, 2000).

1-8-3-Carbon Preference Index (CPI)

Carbon preference index, obtained from the distribution of n-alkanes, is the ratio obtained by dividing the sum of the odd carbon-numbered alkanes to the sum of the even carbon-numbered alkanes. CPI is affected by both source and maturity of crude oils (Ficken, *et al*, 2000). CPI of petroleum oils ranging about 1.00 generally shows no even or odd carbon preference indicates mature samples. Also, it can be used in source identification; petroleum origin contaminants characteristically have CPI values close to one (Maioli, *et al*, 2011; Bray and Evans, 1961).

$$CPI = 0.5\left[\frac{C_{25}+C_{27}+C_{29}+C_{31}+C_{33}}{C_{24}+C_{26}+C_{28}+C_{30}+C_{32}} + \frac{C_{25}+C_{27}+C_{29}+C_{31}+C_{33}}{C_{26}+C_{28}+C_{30}+C_{32}+C_{34}}\right]$$

1-8-4-Degree of waxiness

The degree of waxiness can be expressed by the ΣC_{21}-$C_{31}/\Sigma C_{15}$-C_{20} ratios. The oils characterized by high abundance of n-C_{15} to n-C_{20} n-alkanes in the saturate fractions reflecting low waxy (Moldowan, 1994). Generally, the degree of waxiness <1 reveals low waxy nature and suggests marine organic sources (Peters, 1993) mainly of higher plants deposited under reducing condition.

1-8-5-Pristane/phytane ratio

Both pristine (2,6,10,14-tetramethylpentadecane) and phytane (2,6,10,14-tetramethylhexadecane) are derived from the phytol side chain of chlorophyll, either under reducing conditions (phytane) or oxidizing conditions (pristane). Also both pristane and phytane became dominant saturated hydrocarbon components of highly weathered crude oils until they are degraded (Moustafa, 2004). The pristane/phytane (Pr/Ph) ratio is one of the most commonly used correlation parameters which have been used as an indicator of depositional environment (Peters, *et al*; 2005). It is believed to be sensitive to diagenetic conditions; Pr/Ph ratios substantially below unity could be taken as an indicator of petroleum origin and/or highly reducing depositional environments. Very high Pr/Ph ratios more than 3 are associated with terrestrial sediments. Pr/Ph ratios ranging between 1 and 3 reflect oxidizing depositional environments (Hunt, 1996). Low Pr/Ph values < 2 indicate aquatic depositional environments including marine, fresh and brackish water (reducing conditions), intermediate values 2-4indicate mixed organic source matter terrestrial environments, whereas high values up to 10 are related to peat swamp depositional environments (oxidizing conditions) (Lijmbach, 1975).

1-8-6- Isopreniods/n-alkanes

By increasing maturity, n-alkanes are generated faster than iosprenoids in contrast to biodegradation. Accordingly, isopreniods/n-alkanes (Pr/n-C_{17} and Ph/n-C_{18}) ratios provide valuable information on biodegradation, maturation and diagenetic conditions. The early effect of microbial degradation can be monitored by the ratios of biodegradable to the less degradable compounds. Isoprenoid hydrocarbons are generally more resistant to biodegradation than normal alkanes. Thus, the ratio of the pristane to its neighboring n-alkane C_{17} is provided as a rough indication to the relative state of biodegradation. This ratio decreases as weathering proceeds (Waples, 1985). There are mainly two different methods for wax removal: solvent and catalytic. Solvent dewaxing is more selective for removing both heavier normal and non-normal hydrocarbons. Catalytic dewaxing removes the normal paraffins more evenly over the boiling range, while the light non-normal hydrocarbon is removed more selectively. Oil obtained from solvent dewaxing has higher yield and viscosity index than that of catalytic dewaxing (Robert and. Arthur; 1992). The removal of wax from oil by means of solvent extraction involves mixing crude oil with solvent to form a solution followed by cooling (chilling) the mixture (oil + solvent + wax) to form wax-crystal-lattice and, finally, separating the crystal lattice from the solution. The dewaxing is influenced by many parameters such as type of solvents, cooling rate, and temperature and solvent to oil ratio. Several pure solvents or mixtures of solvents have been in use for solvent dewaxing. These include Methylisobutylketone (MIBK), Dichloromethane, Trichlorethylene, and a mixture of Methyl Ethyl Ketone (MEK) and Toluene and MEK/Benzene. Pure Toluene is excellent oil solvent, and, has good solvent power for wax as well. If it is used alone, a tight lattice of wax will form that hinders filtration (Wauquier, 2000). In contrast, MEK shows low solvent power to paraffinic compound i.e., low selectivity and as such it precipitates the wax very well. Previous studies on Arabian light oil indicated that optimum wax separation occurs at MEK-toluene solvent composition ranges from 40–75 v% MEK (Wauquier, 2000 and Evans, 1962). Dewaxing of West Siberian crude with MEK-Toluene mixtures indicated that with increasing MEK in the mixture, the filtration time increases (i.e., the filtration viscosity increases) and the oil yield decreases. With increasing MEK, the viscosity of the oil index increases, but the solid point remains constant (Gryaznov, *et al;* 1982). In solvent dewaxing, most of the energy consumption goes into pumping and regeneration of solvent. Therefore, the current trend is to use lower solvent dilution ratios and smaller amounts of solvent in washing the precipitate (wax cake) on filters. At the other hand, an increase in solvent to oil ratio will enhance the filtration rate because solvent prompts the crystal growth and lowers the viscosity of the mixture (oil + solvent). It also increases the dewaxed oil yield and decreases the oil content in the wax yield. The previous literature indicates that the solvent \ oil ratio is: between 16\1 to 32\1 on mass basis (Meketta, 1992).

The rate of cooling (high or low) has a strong influence on crystal formation and particle characteristic. For example, a high cooling rate is found to promote the formation of small crystals but they are of the needle type that clogs the filter. Previous experiments showed that the optimum cooling rate varies between 0.56–4.4 ^{o}C per minute depending on the type of crude oil. The chilling or filtration temperature is usually in the order of -20 ^{o}C (Lei and Jin-Jun, 2007).

1-9- Aim of the study

Due to the importance of crude oil in the present time. The study aimed to study the characteristics of Yemeni crude oil for the purpose of improvement and then compared with some samples of Sudanese crude oils.

Objective

1- To investigate the properties of Yemeni crude oil fields.

2- To investigate the properties of some Sudanese crude oil fields.

3- To compare between Yemeni and Sudanese crude oils.

Materials and Methods

2-1-Sample Collection

The studied area in Yemen consists of three principle sectors: governorate Marib, Shabowh and Hadramout. Itis, Maarib-aljowf, Jannah, and Almasilah many oil sectors were discovered in Yemen and it is resave about one hundred and five field in 2014, but fourteen sectors only entered production at the end 2014, a total of twelve crude oil samples were collected from various Yemen crude oil sectors. Sample collection was done in collaboration with field technicians from the well heads of the various producing wells the oil samples include: S-2, 34, Jannah, Alnaser, Malik, 32, 43, Al-masilah, 51, 10, Dabah and Safer. These samples were properly labeled for easy identification. During sampling all bottles were rinsed properly with water and properly air-dried. The bottles were later rinsed with the crude oil to be sampled. The oil samples were coded according to name sector while Sudan crude oils samples Nile blend, Dar blend, Moga were provided by Central Petroleum Laboratories (CPL).

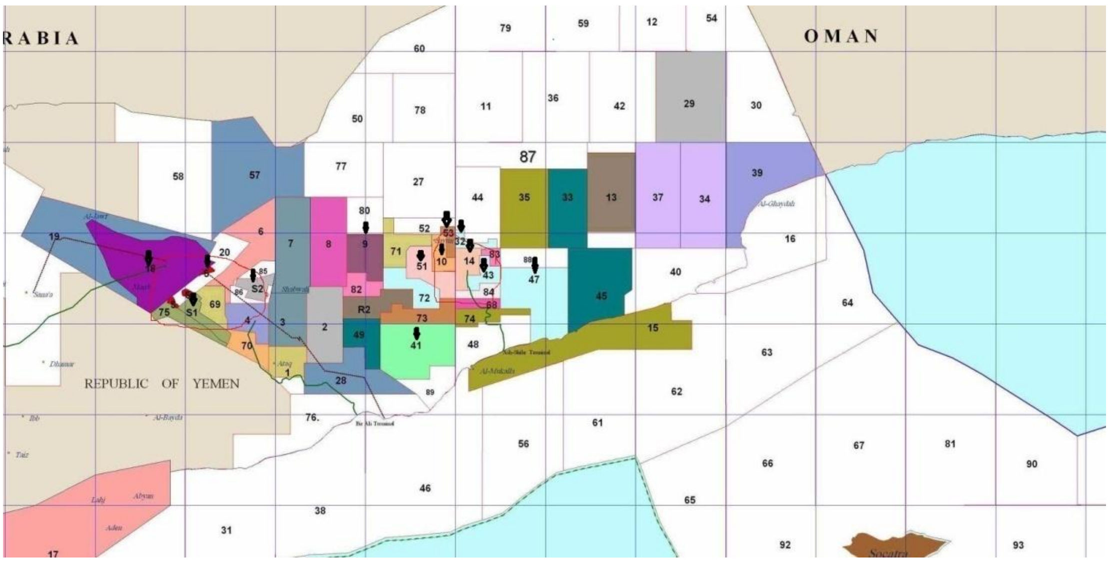


Figure (2.1): All fields of crude oil in Yemen

2**-2-Methods**

The physical and chemical properties of the crude oil samples are determined following well established standard procedures: Density, specific gravity, API gravity (Designation: ASTM, D 5002 –1999). Pour point (Designation: ASTM, D 5853-95; 2000), total sulphur (ASTM, D 4294), total acid number (ASTM, D 664), water by distillation (ASTM, D 664), Reid vapor pressure (ASTM, D 323 – 99). Wax content (UOP-46), wet degsition (ASTM, D 5708).

The Physical and chemical properties of these samples were tested in Central Petroleum Laboratories (CPL) according to following methods.

2-2-1-Determination of Density, Specific Gravity and API Gravity by (ASTM, D 5002) method.

0.5 ml of crude oil sample was introduced into an oscillating sample tube and the change in oscillating frequency caused by the change in the mass of the tube was used in conjunction with calibration data to determine the density of the sample.

2-2-2-Determination of API Gravity by (ASTM, D 5002) method.

$$°\text{API} = \frac{141.5}{\text{specific gravity at } 15.6\ ℃} - 131.$$

2-2-3-Determination of pour point by (ASTM, D 5853) method.

After preliminary heating to 50°C, the test specimen was cooled at a specified rate and examined at intervals of 3°C for flow characteristics. The lowest temperature at which movement of the test specimen was observed was recorded as the pour point.

2-2-4-Determination of sulfur content by (ASTM, D 4294) method.

10 ml of sample was placed in the beam emitted from an X-ray source. The resultant excited characteristic X radiation was measured, and the accumulated count was compared with counts from previously prepared calibration standards that bracket the sample concentration range of interest to obtain the sulfur concentration in mass %.

2-2-5- Determination of Metals content by wet digestion (ASTM, D 5708) method.

10 g of sample was weighed into a beaker and decomposed with concentrated sulfuric acid. The residual carbon was burned off by heating at 525°C in a muffle furnace. The inorganic residue was digested with nitric acid, and made up to 50 ml volume. The solution was nebulized into the plasma of an atomic emission spectrometer. The intensities of light emitted at characteristic wavelengths of the metals were measured simultaneously. These intensities are related to concentrations by the appropriate use of calibration data (Dusseault, 2001).

2-2-5-1- ICP- Optical Emission Spectoscopy Principle.

ICP, Inductively Coupled Plasma, is one method of optical emission spectrometry. When plasma energy is given to an analysis sample from outside, the component elements (atoms) is excited. When the excited atoms return to low energy position, emission rays (spectrum rays) are released and the emission rays that correspond to the photon wavelength are measured. The element type is determined based on the position of the photon rays, and the content of each element is determined based on the rays' intensity.To generate plasma, first, argon gas is supplied to torch coil, and high frequency electric current is applied to the work coil at the tip of the torch tube. Using the electromagnetic field created in the torch tube by the high frequency current, argon gas is ionized and plasma is generated. This plasma has high electron density and temperature (10000K) and this energy is used in the excitation-emission of the sample. Solution samples are introduced into the plasma in an atomized state through the narrow tube in the center of the torch tube.

2-2-6-Whole – Oil, Gas Chromatography.

The Crude oil samples were subjected to whole oil- Gas chromatographic analysis. This was achieved by using Varian CP 3800 Gas Chromatograph, equipped with Flame Ionization Detector; 50m × 0.2 mm film thickness 0.5µm fused silica capillary PONA column.

2-2-6-1-Whole – Oil, Gas Chromatography Analysis

The Crude oil samples were subjected to whole oil- Gas chromatographic analysis. The sample (1µl) was injected, Injector temperature was kept at 280°C and (FID) detector at 320°C. The oven temperature was programmed from 60 (Held 5 min) to 150°C at the rate 10°C /min, then to 300°C at rate 20°C/min (Held 60 min) finally to 310 at rate 20°C/min (Held 15 min). Helium flow 1.5 ml/min was used as carrier gas. The data were collected from retention time: 0-97 minutes.

2-2-7- Derermination of Wax Appearance Temperature by Differntial Scanning Calormetry.

Differential scanning Calorimetry (DSC) is a thermo analytical technique, in which the Difference in heat flow between the sample and a reference at the same temperature is recorded as a function of temperature. DSC is commonly used in studies of wax systems in order to determine the onset temperature of wax crystallization as well as the amount of crystallized waxes under quiescent conditions.

- In this system, the temperatures of the sample and reference are controlled by identical furnace.
- The system monitors the temperature in both sample and reference.
- A temperature difference between the sample and the reference is resulting from enthalpy or heat capacity changes in the sample.
- The temperature difference is recorded and related to enthalpy change in the sample by using calibration.
- About 1-10 mg sample is sealed into a small aluminum pan.
- The reference is usually an empty pan and cover.
- A flow of nitrogen gas is kept over the samples to create a reproducible and dry atmosphere.
- A typical plot of heat flow with respect to temperature of wax crystallization process is given in Figure blow.

. During the cooling of a sample, waxes start to crystallize at onset temperature (T1) and two peaks are present; the end point is at T2. The baseline (the dot line) links the onset and end points.

2-2-8- Standard Test Method for Water in Crude Oil by Distillation (ASTM, D 664).

The sample is heated under reflux conditions with water immiscible solvent which co-distills with the water in the sample. Condensed solvent and water is continuously separated in a trap the water settles in the graduated section of the trap, and the solvent returns to the distillation flask.

2-2-9- Derermination of Acid Number of Petroleum Products by Potentiometric Titration by (ASTM, D 664).

The sample was dissolved in a mixture of toluene and propan-2-ol containing a small amount of water and titrated potentiometrically with alcoholic potassium hydroxide using a glass indicating electrode and a reference electrode or a combination electrode. The meter readings are plotted manu-ally or automatically against the respective volumes of titrating solution and the end points are taken only at well-defined inflections in the resulting curve. When no definite inflections are obtained and for use oils, end points are taken at meter readings corresponding to those found for aqueous acidic and basic buffer solutions.

2-2-10-Determination of Viscosity of Petroleum For low temperature

- Transfer sample to be tested into a 4 oz bottle.

- Stir sample with the thermometer and condition in a bath to a temperature of 75°F. The sample should be free from entrapped air.

- Put the bottle with the sample on the jack stand under the brookfield Viscometer and maintain the sample temperature at 75°F.

-Choose the spindle for the measurement. To select the right spindle, the goal is to 4 obtain a Viscometer dial reading between 10 and 100, keeping in mind that the accuracy improves as the reading approaches 100.

- Examine the spindle for signs of pitting, dulled edges or other obvious defects. Use only clean brightly polished spindles. Mount spindle to Viscometer.

- Raise the sample bottle with the jack such that the solution level covers the mark on the spindle.

-Turn on the Viscometer and let the spindle rotate for about 30 seconds, noting the speed setting.

- Press lever located at the back of the Viscometer and turn off at the same time when peg becomes visible in the window.

- Record dial reading, spindle number and the speed used in the test.

- Refer to the chart located at the top front of the Viscometer or use the Brookfield Factor Finder. To locate the factor to convert the dial reading to viscosity, look for the spindle number (horizontal axis) and the speed in rpm (vertical axis).

2-2-11-Measurement of viscosities at high temperatures

- Mount the Thermosel alignment bracket to the Viscometer (Model LV DV-3) and place the thermo-container at the base of the Viscometer.
- Put the sample container in the thermo-container, mount the appropriate spindle and check for concentricity of spindle and sample chamber.
- Remove the sample chamber using the extracting tool.
- Set the temperature controller at the temperature desired for measurement. Allow the system to equilibrate.
- When the thermo-block is at temperature, pour enough sample into the sample chamber so that the spindle is covered or the line on the spindle is reached and mount the sample chamber on the thermo-block. Cover with insulating cap and turn on the Viscometer to aide the temperature equilibration process. The cap has a small opening for the spindle hanger or for the use of the LV4 spindle.
- Allow temperature to equilibrate for 15 minutes or longer.

- To make a viscosity measurement, allow dial reading to stabilize.

- Record the dial reading and multiply by a factor appropriate to the spindle and the speed.

- Remove the hot sample chamber using the extracting tool for easy and safe handling. Pour off the sample while it is hot and pourable.

- The thermo-container can be air-cooled or the cooling plug can be connected to a tap water supply and drain for rapid cooling (400°F/20 minutes).

-The Viscometer is checked for accuracy at intervals determined by the frequency of use and number of operators.

2-2-12- Detrermination of wax content by (UOP-46-96) method.

1. Weight 2 g of crude oil, Petroleum ether, crust flour and aceton are praperd.
2. Heating and mixing: added 300ml Petroleum ether, 15-30gm crust flour to the 2 g of oil and 100ml aceton. The flask is tightly closed and manually shaken then placed in the magmatic stirrer (the stirring ball is placed inside the flask). The mixing is done gradually; starting at low speed and increasing towards full speed. The mixing time is 20 minutes.
3. Chilling: two layers consist of top layer separate by filtration; it is placed in the ethanol bath of the thermostat. Since the desired chilling temperature is -20 ^{0}C, the thermostat is set at -20 ^{0}C. This is made to reduce the cooling time (increase the cooling rate). When the bulk temperature reaches -20 ^{0}C, the thermostat temperature is adjusted to and left for an additional one a hour at -20 ^{0}C.
4. Filtration: The wax formed in the mother solution was filtered under vacuum through glass wool in a Gooch crucible. The flask containing the mother solution was rinsed with 20 ml of fresh solvent at -20 ^{0}C to ensure that all components have been removed. The wax collected on the glass wool was washed with 100 ml of Naphtha.
5. Evaporation: The Naphtha and the traces of solvent were driven off under vacuum evaporation. The water bath temperature is maintained at 95 ^{0}C. The

wax in the flask is then left for 24 hours in a desiccator containing P2O5. This was made to dry the wax from the traces of Naphtha and solvent.

2-2-13-Dewaxing from crude oils

In the present work, there are eight parameters to be investigated, these are three temperatures (heating, cooling, and evaporation), two retention times (mixing and chilling), one mixing speed, one solvent to oil ratio, and one mixture concentration. If each parameter is varied twice in accordance with a 2^k factorial method, there will be 256 experiments. With a minimum replicate of three, this will be infeasible due to high cost and time. An alternative method of "fractional factorial designs" was used. Here, only the parameters that best describe the problem are studied. In this process, the mixing speed, chiller and evaporator temperatures, and chiller resident time are kept constant in this work. Each of the rest of the parameters is replicated at least three times. The number of experiments and their procedures are given as:

1. Material preparation: 27 samples each of 2 g of crude oil are prepared. MEK - Toluene mixtures of different concentrations (50, 75, and 100 %MEK) are prepared; a known amount of MEK is added to a known amount of Toluene.

2. Heating and mixing: The desired amount of solvent is added to the 2 g of oil. The flask is tightly closed and manually shaken then placed in the magmatic stirrer (the stirring ball is placed inside the flask). The mixing is done gradually; starting at low speed and increasing towards full speed. The mixing time is varied from 10–30 minutes with 10 minute intervals (3 replicates) at a temperatures range of 40 to 60 ^{0}C [40, 50 and 60 ^{0}C].

3. Chilling: After mixing and heating, the flask with its content is transferred to the chiller. It is placed in the ethanol bath of the thermostat. Since the desired chilling temperature is -22 ^{0}C, the thermostat is set at -22 ^{0}C. This is made to reduce the cooling time (increase the cooling rate). When the bulk temperature reaches -22 ^{0}C, the

thermostat temperature is adjusted to and left for an additional one a hour at -22 ^{0}C. It was observed that the bulk temperature reaches the desired level within one an hour minutes.

4. Filtration: The wax formed in the mother solution was filtered under vacuum through glass wool in a Gooch crucible. The flask containing the mother solution was rinsed with 20 ml of fresh solvent at -22 ^{0}C to ensure that all components have been removed. The wax collected on the glass wool was washed with 100 ml of Naphtha.

5. Evaporation: The Naphtha and the traces of solvent were driven off under vacuum evaporation. The water bath temperature is maintained at 95 ^{0}C. The wax in the flask is then left for 24 hours in a desiccator containing P2O5. This was made to dry the wax from the traces of Naphtha and solvent.

The extracted wax, here called yield X, is determined as a percentage of the total wax in crude oil as:

$$x = \frac{Wi}{W_T} \times 100\%$$

W_I is extracted wax in grams for experiment, and W_T is the total wax in the crude oil sample in grams.

2-2-14-Infrared Spectroscopy (IR / FTIR)

Infrared spectroscopy is a method of identifying and analyzing chemical compounds. An infrared beam is directed at a sample, and by measuring the radiation that is absorbed by the sample at different frequencies, one can tell what types of molecules make up the sample. The Fourier transform infrared (FTIR) spectrometer is the most common type of infrared spectrometer. It records the data collected and transforms the data into a spectrum. The spectrum is displayed with a graph that shows at which frequency and how much absorption occurred. Because different molecules absorb the radiation at specific frequencies in known amounts, the spectrum can be used to identify the sample at a molecular level.

Results and discussion

3-1- Results

Table(3-1): gives the physicochemical parameters of the crude oils, it shows a comparison of the API gravity and sulfur contents of Yemen crude oil with that of American Petroleum Institute (API) (2005) standard in figure (3. 23), (3. 24) respectively. The results showed range of values for physicochemical parameters obtained for the oil samples as follows: specific gravity (0.8010-0.916), API gravity (22.97-44.99), sulfur content (0.0849-0.859), water content (0.00-4.9),TAN (0.00-0.54); pour point (-33-18), density at 15^{0}C (0.8010-0.915), wax content (ND-68.72), R.V.P (12.5-45), Asphalten content (0.00-0.01), Kinamatic viscosity at 50^{o}C (1.632-107.5) Show figure (3-11).

Table(3- 2) shows the levels of heavy metals present in the crude oil For heavy metals, the range of values were Ag (0.0035-0.0846), Ca (3.24-1876), Cd (<0.0009-0.0162), Co (<0.0018-0.1632), Cr (<0.0013-1.776), Fe (<0.0062-94.3), K (<0.0360-17.52), Na (<0.0360-319.4), Ni (0.1649-4.005), Pb (0.015-402.2), V (0.0531-4.919) show figure (3. 12 - 3. 22) respectively.

Table (3. 1.1) parameter of physicochemical Properties of Yemeni Crude oils

	S-2	34	Jannah	Alnaser	Malik	32
Density at15^{0}C	0.8394	0.819	0.899	0.899	0.915	0.867
API	36.29	41.15	25.72	25.72	22.97	31.48
S.G	0.8402	0.820	0.9000	0.9000	0.9161	0.8682
TAN	0.00	0.00	0.54	0.12	0.00	0.00
Pour point	-21	-18	-18	-18	18	-18
Water content	0.00	0.00	0.00	0.00	0.05	0.30
Wax content	48.52	ND	30.95	51.10	29.99	39.19
Sulfur content	0.0966	0.0846	0.8598	0.8497	0.5884	0.4880
R.V.P	13.1	31.3	12.5	13.7	11.4	19.4
Asphalten cont	0.01	0.02	0.80	0.00	0.75	0.02
Kinamatic visc at50^{0}C	3.345	2.121	106.67	107.50	37.69	7.625

Table (3.1. 2) parameter of physicochemical Properties of Yemeni Crude oils

	43	Almasilah	51	10	Dabah	Safer
Density at15^{0}C	0.8671	0.8296	0.8368	0.8432	0.8364	0.8010
API	31.55	38.90	37.45	36.32	37.47	44.99
S.G	0.8678	0.8304	0.8375	0.8632	0.8374	0.8010
TAN	0.00	0.00	0.00	0.00	0.00	0.02
Pour point	-12	-24	-9	-6	-9	-33
Water content	0.90	4.9	0.25	0.00	0.00	0.00
Wax content	40.47	45.25	68.72	39.10	*	39.67
Sulfur content	0.4786	0.1371	0.1068	0.2835	0.2002	0.1270
R.V.P	21.6	27.7	20.7	28.9	20.4	45
Asphalten content	0.20	0.11	0.00	0.02	0.06	0.00
Kinamatic visc at 50^{0}C	6.728	2.724	2.785	4.543	3.172	1.632

Table (3. 2.1): The levels of heavy metals presnt in Yemeni crude oils

	S-2	34	Iannah	Alnaser	Malik	32
Ag	<0.0035	<0.0035	0.0614	0.0437	0.0846	<0.003
Ca	3.849	5.671	1876	1868	231	3.727
Cd	0.0041	<0.0009	0.0195	0.0162	<0.001	0.0047
Co	<0.0018	<0.0008	0.1615	0.1632	0.0147	<0.002
Cr	<0.0013	<0.0013	1.776	1.759	0.1619	<0.001
Fe	0.6345	0.3801	94.3	92.7	33.35	1.1020
K	1.262	0.4209	4.169	5.164	17.52	<0.036
Na	6.173	<0.0360	19.67	59.19	31.98	3.877
Ni	0.1611	0.1200	0.3915	0.3823	3.942	4.058
Pb	<0.015	0.7000	0.3915	402.2	0.1372	<0.015
V	0.0679	0.0531	0.2073	0.2109	4.919	3.582

Table (3. 2.2): The levels of heavy metals presnt in Yemeni crude oil

	43	Almasilah	51	10	Dabah.	Safer
Ag	<0.003	<0.003	<0.003	<0.003	0.003	0.003
Ca	14.66	83.41	13.81	3.240	9.863	6.900
Cd	<0.001	<0.001	0.0092	<0.001	0.001	0.001
Co	<0.002	<0.002	<0.002	<0.002	0.002	0.067
Cr	<0.001	0.0018	<.0013	<0.001	0.001	0.008
Fe	4.850	18.50	3.514	<0.006	3.2	1.684
K	0.1873	12.59	1.963	0.0360	1.132	0.320
Na	6.648	319.4	42.66	4.462	29.77	0.04
Ni	4.005	0.1894	0.1643	2.460	0.169	1.60
Pb	<0.015	0.0534	0.0086	<0.015	0.116	1.31
V	3.633	0.0667	0.0674	1.082	0.072	0.45

3-2-Properties of Yemen Crude oils

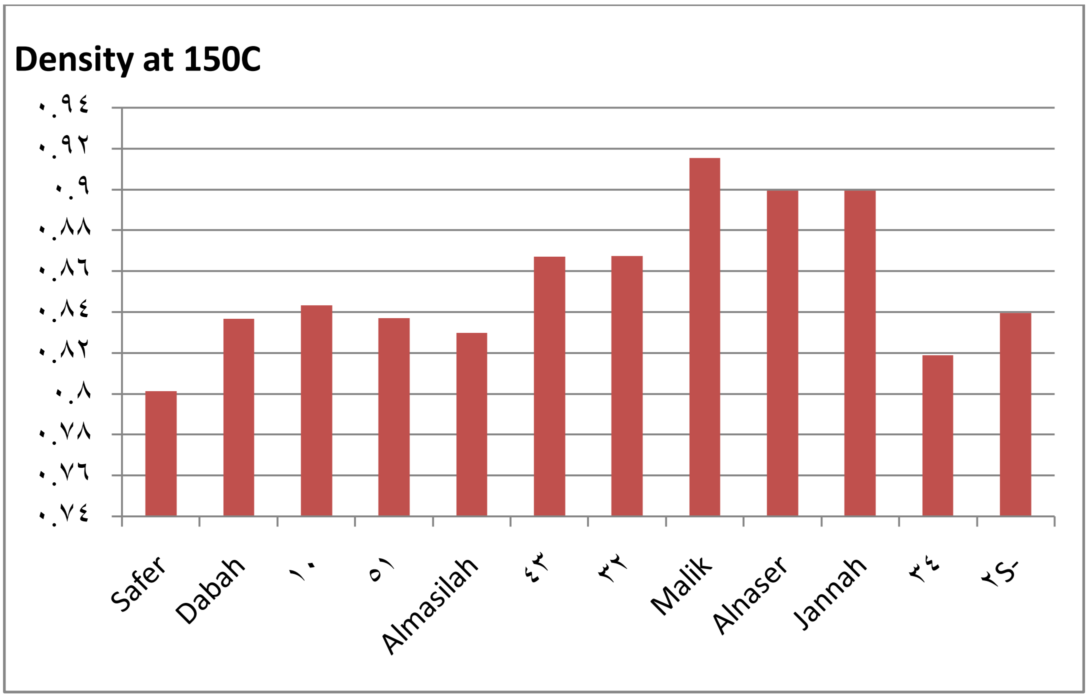


Figure (3.1): Density of Yemeni crudes oil

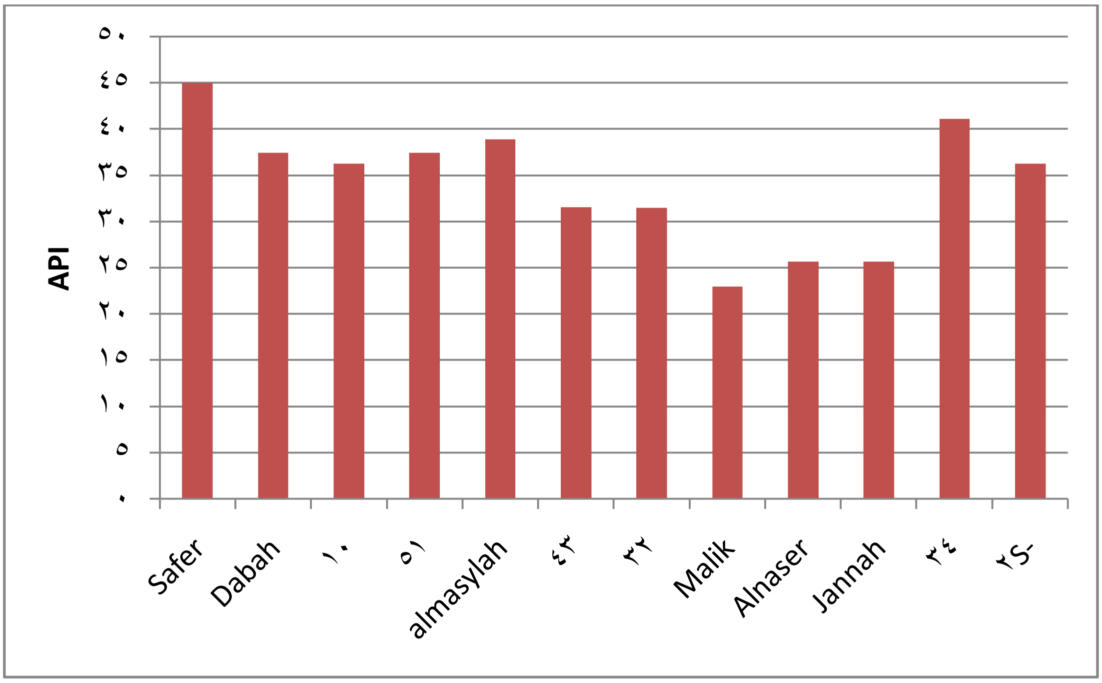


Figure (3.2): API of Yemeni crudes oil

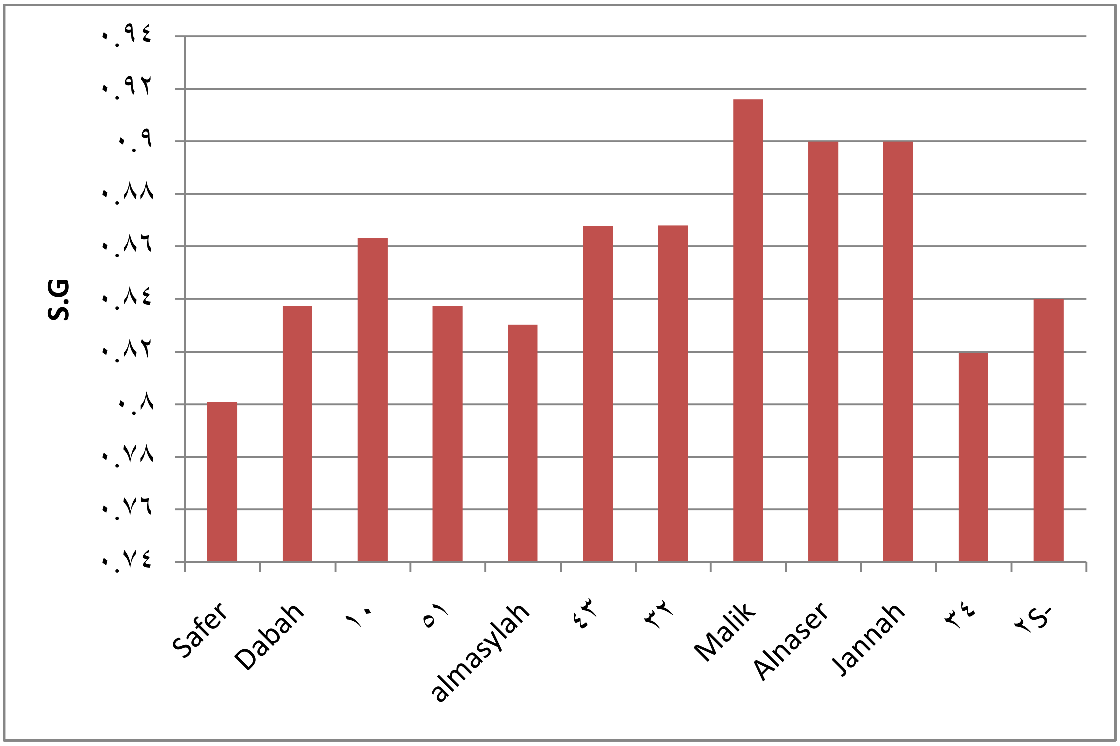


Figure (3.3): S.G of Yemeni crudes oil

S.G, density of Yemeni crude oil is low but API is high this mean its light crude oil

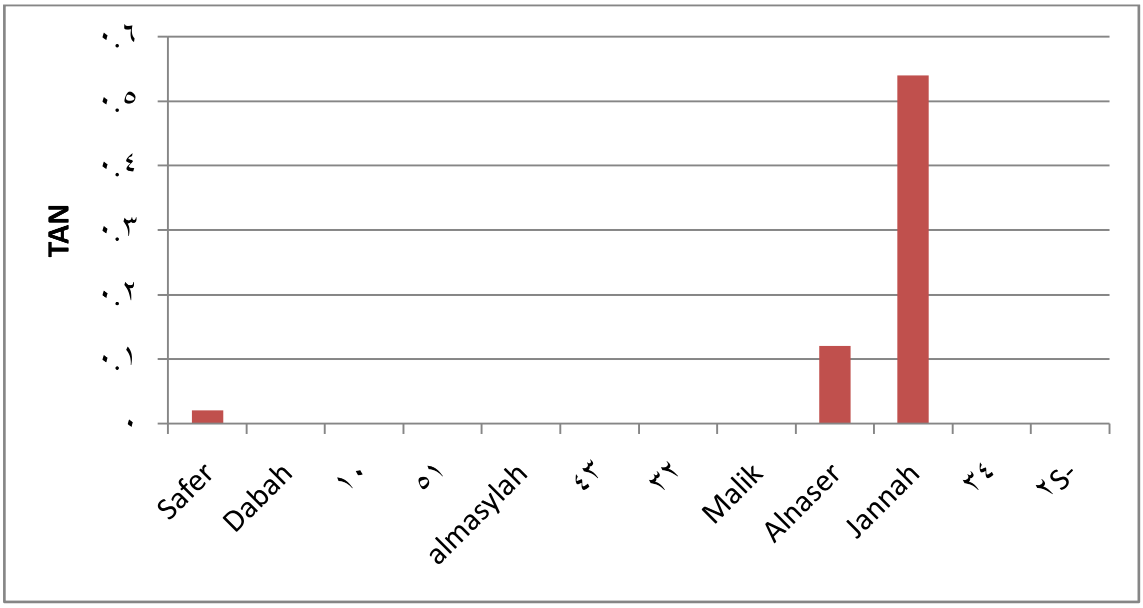


Figure (3.4): TAN of Yemeni crudes oil

TAN of Yemen crudes Oil is very low so no any corrosive

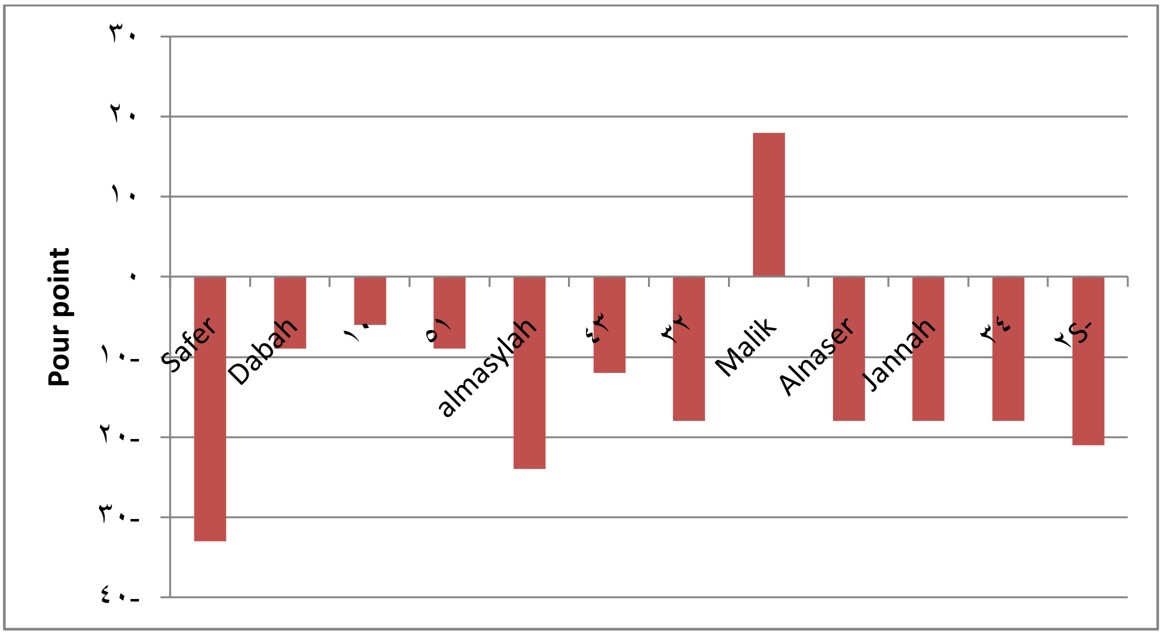


Figure (3.5): pour point of Yemeni crudes oil

Pour point of Yemeni crudes Oil very low so viscosity low too (flow easly).

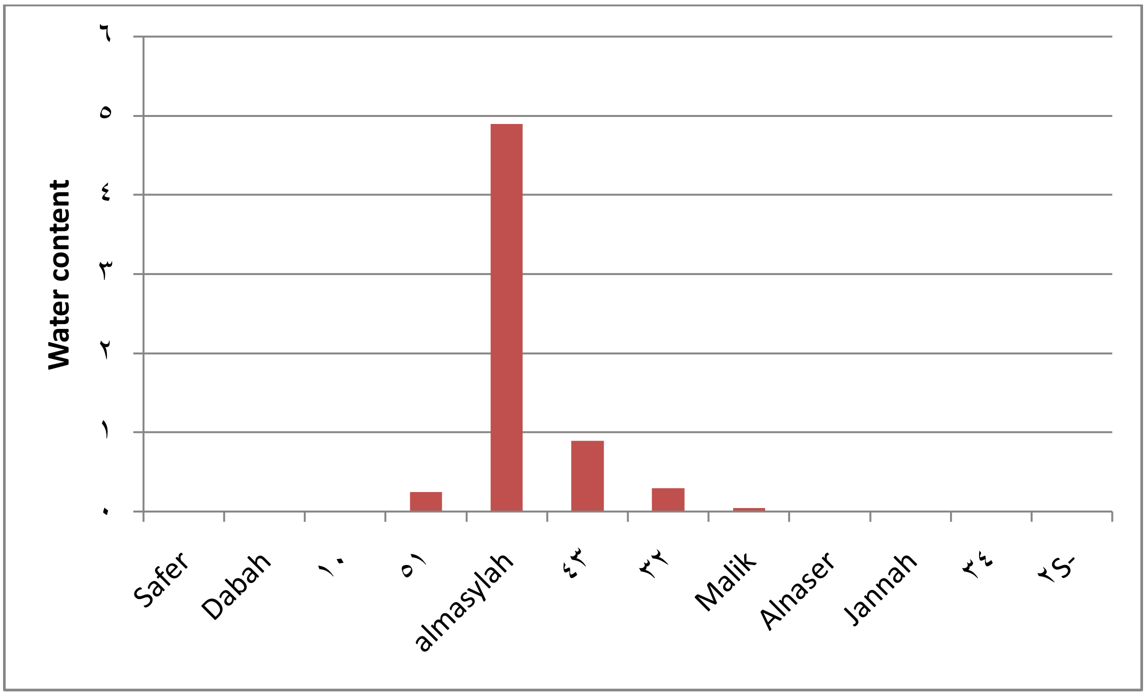


Figure (3.6): water content of Yemeni crudes oil

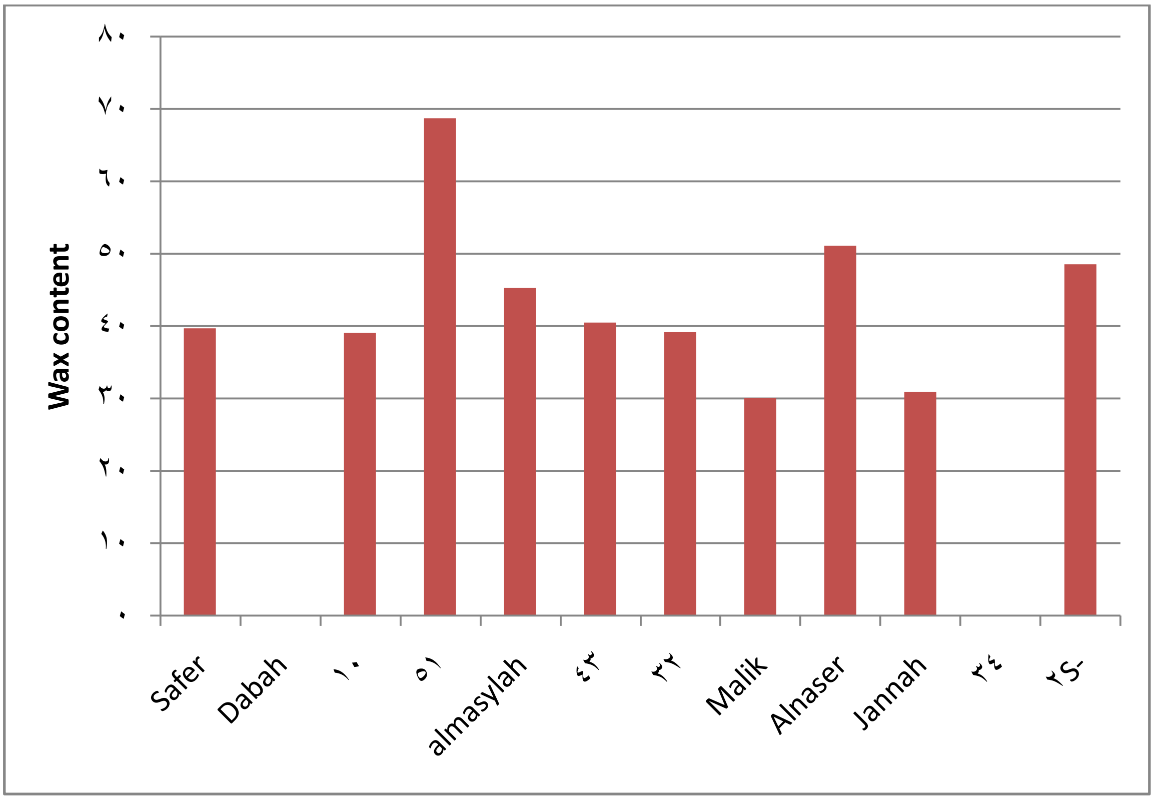


Figure (3.7): wax content of Yemeni crudes oil

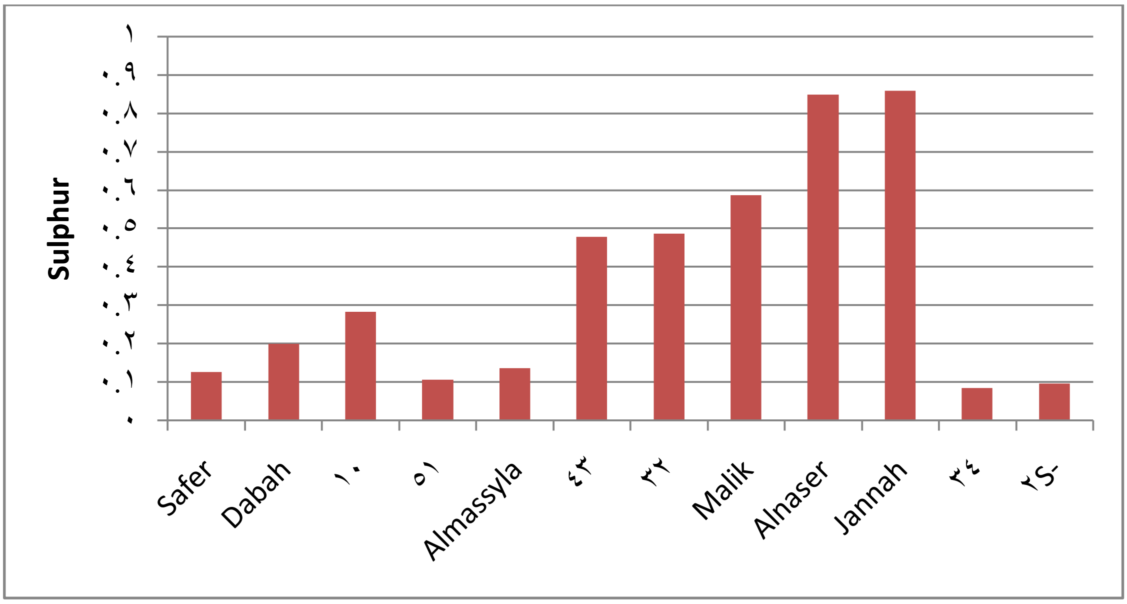


Figure (3.8): Sulphur content of Yemeni crudes oil

Sulphur content of Yemeni crudes oil is low so can be classfy sweet.

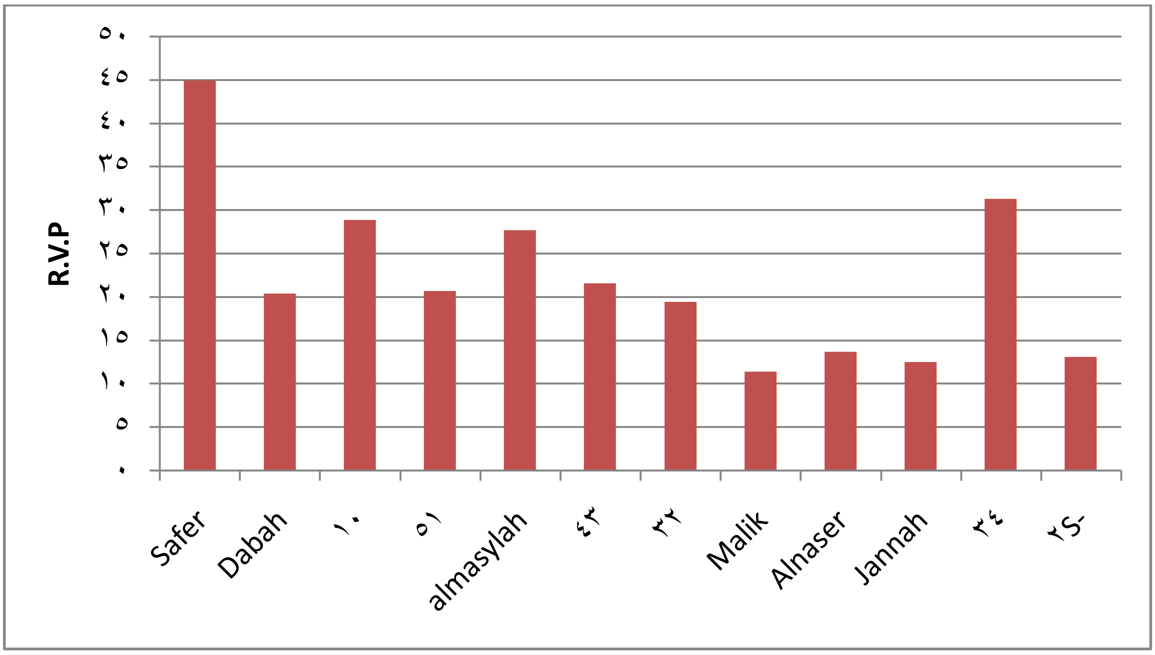


Figure (3.9): R.V.P of Yemeni crudes oil

R.V.P of Yemeni crudes Oil is high so light compound is volatile.

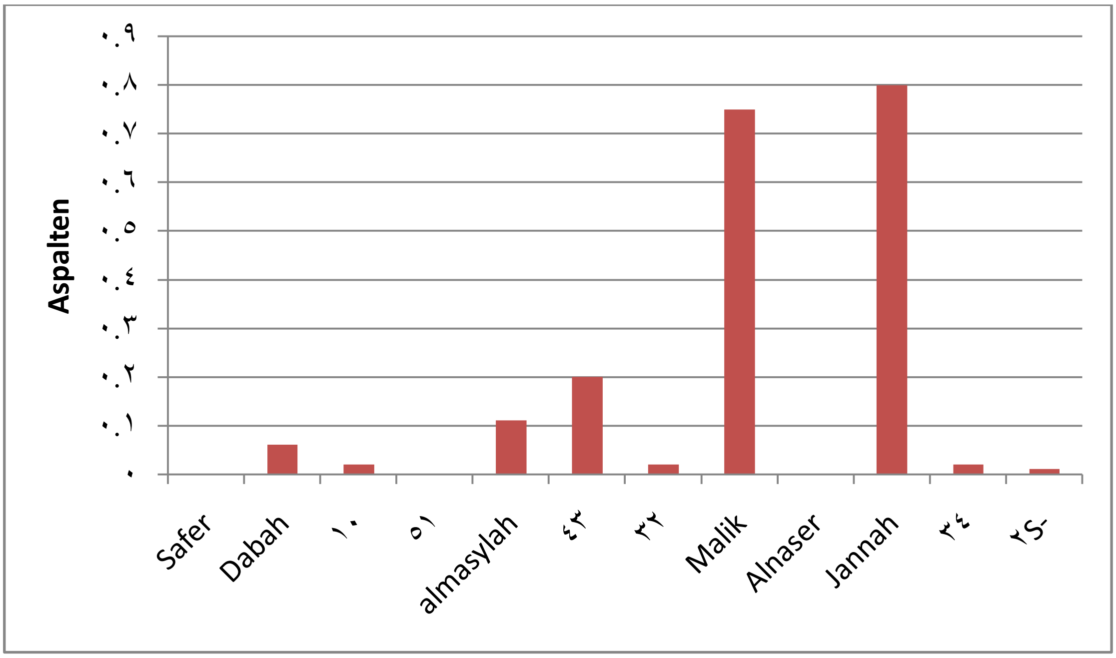


Figure (3.10): Asphaltenof Yemeni crudes oil

A sphalten in Yemen crudes Oil is low thesae mean no aromatic.

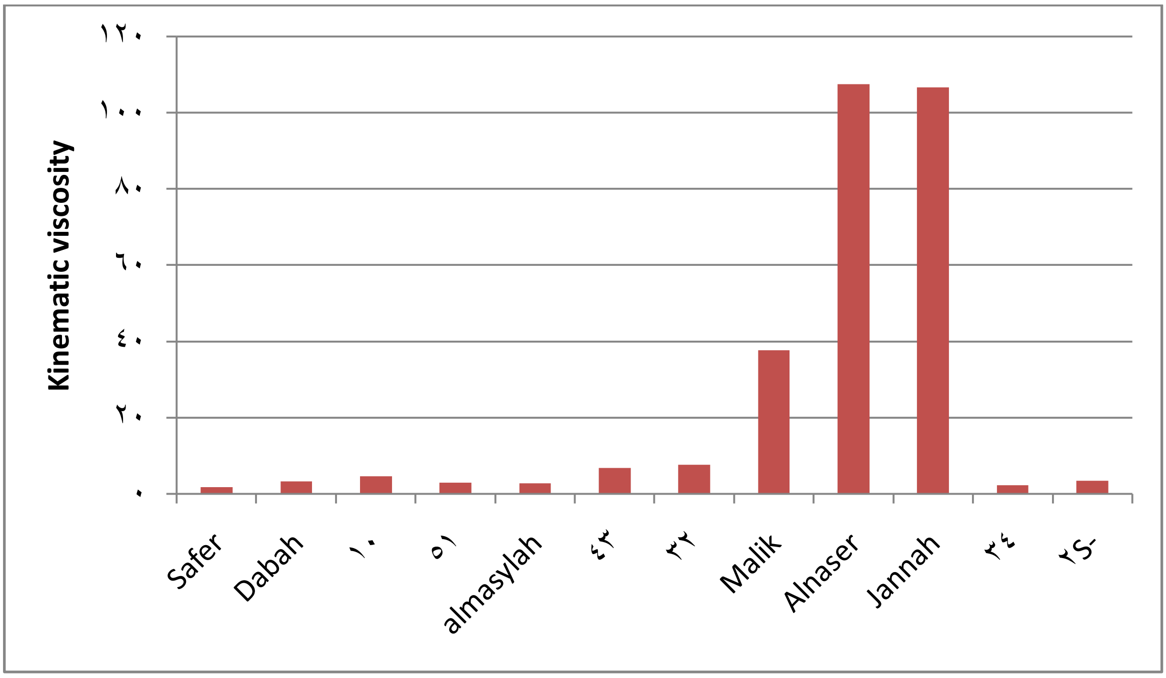


Figure (3.11): Kinematic viscosity of Yemeni crudes oil

Kinematic viscosity of Yemeni crudes Oil is low (flow easly).

3-3-Heavy metals in Yemeni crude oils.

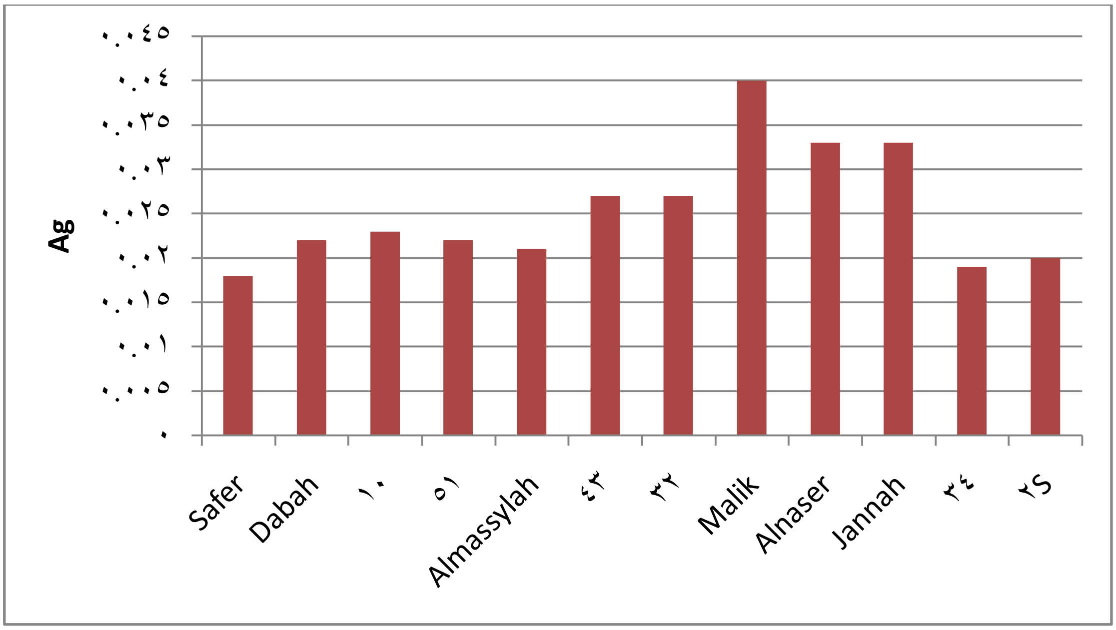


Figure (3.12): Ag of Yemeni crude oils

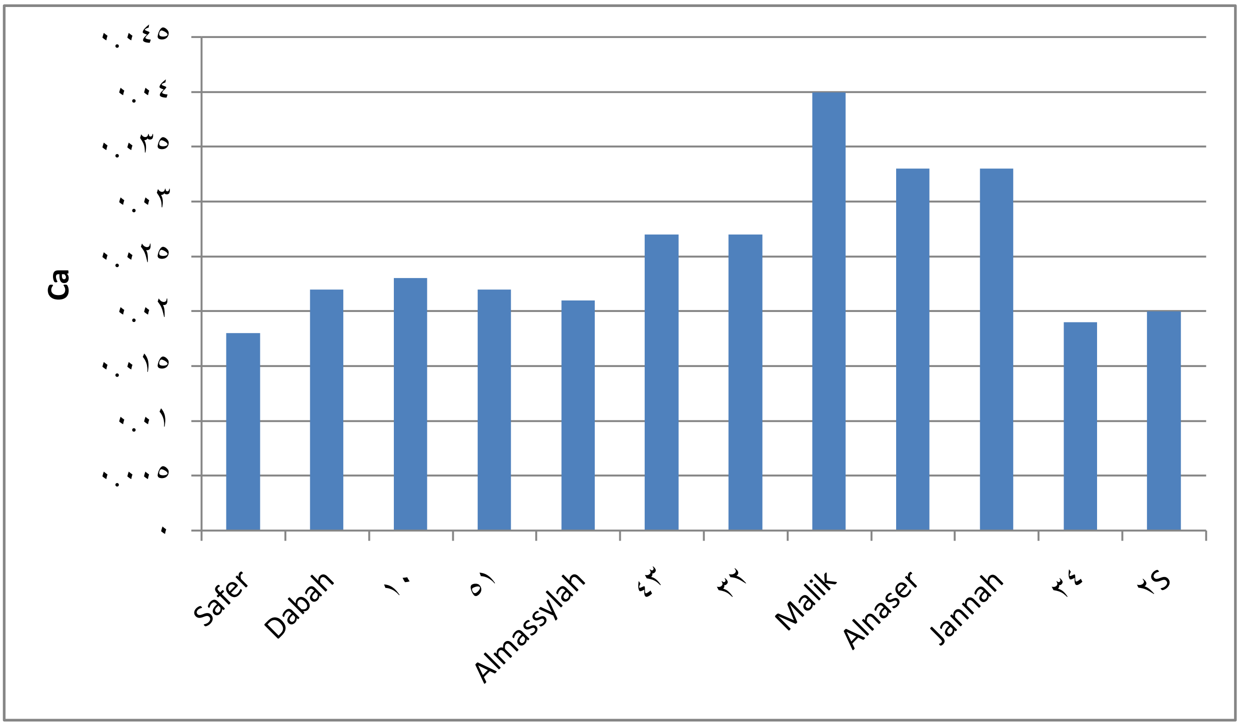


Figure (3.13): Ca of Yemeni crude oils

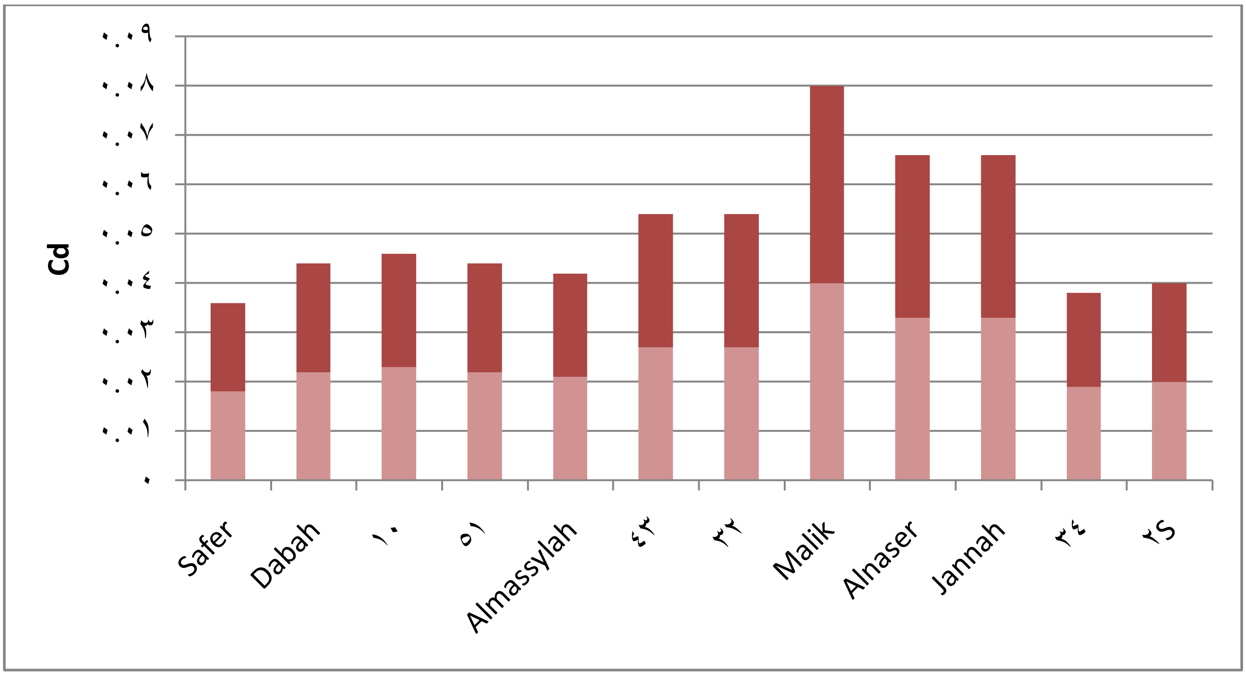


Figure (3.14): Cd of Yemeni crude oil

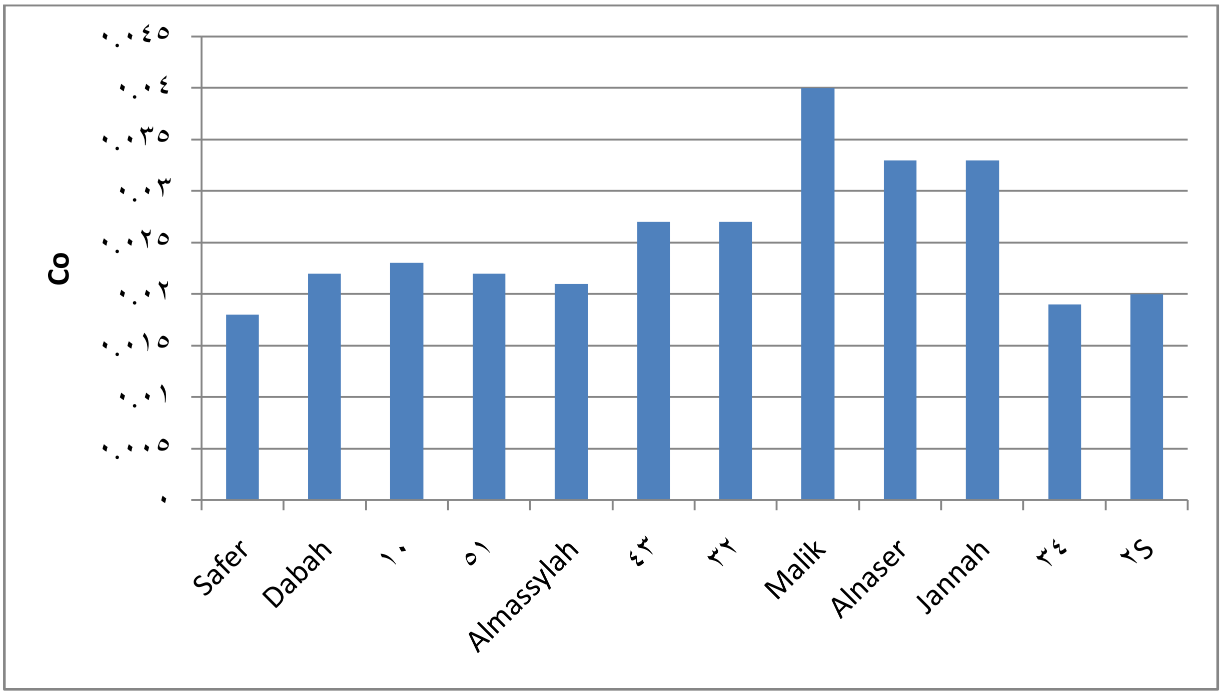


Figure (3.15): Co of Yemeni crude oil

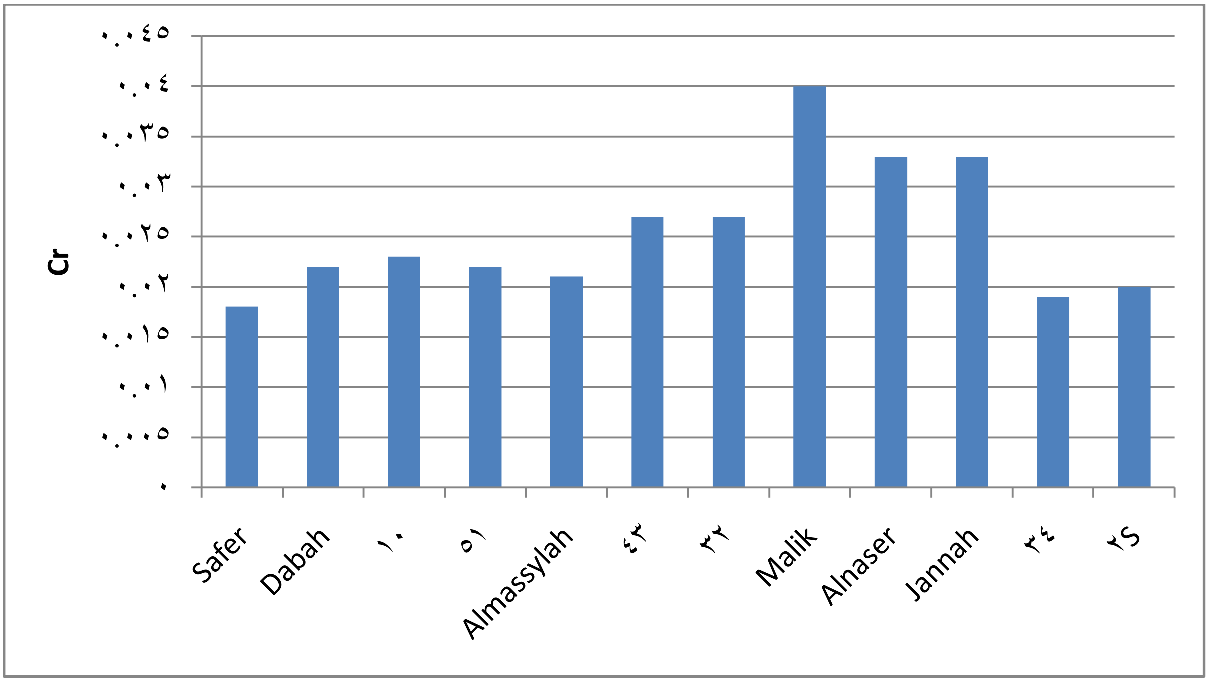


Figure (3.16): Cr of Yemeni crude oil

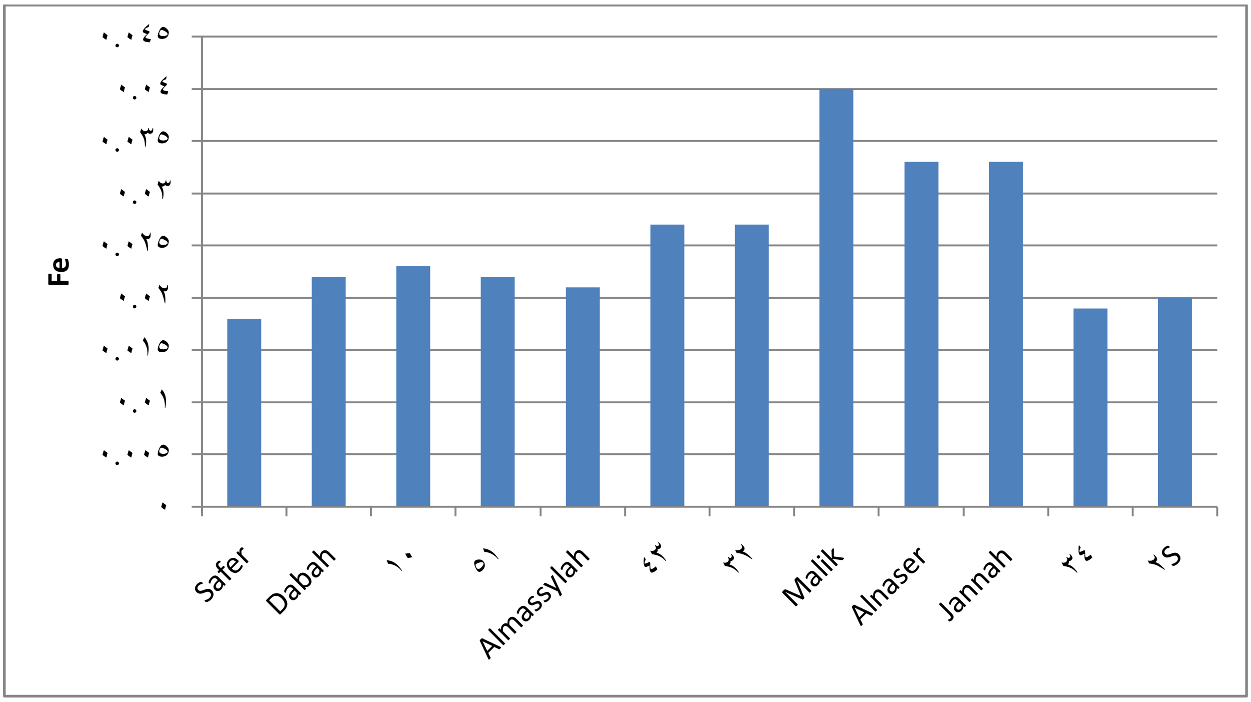


Figure (3.17): Fe of Yemeni crude oil

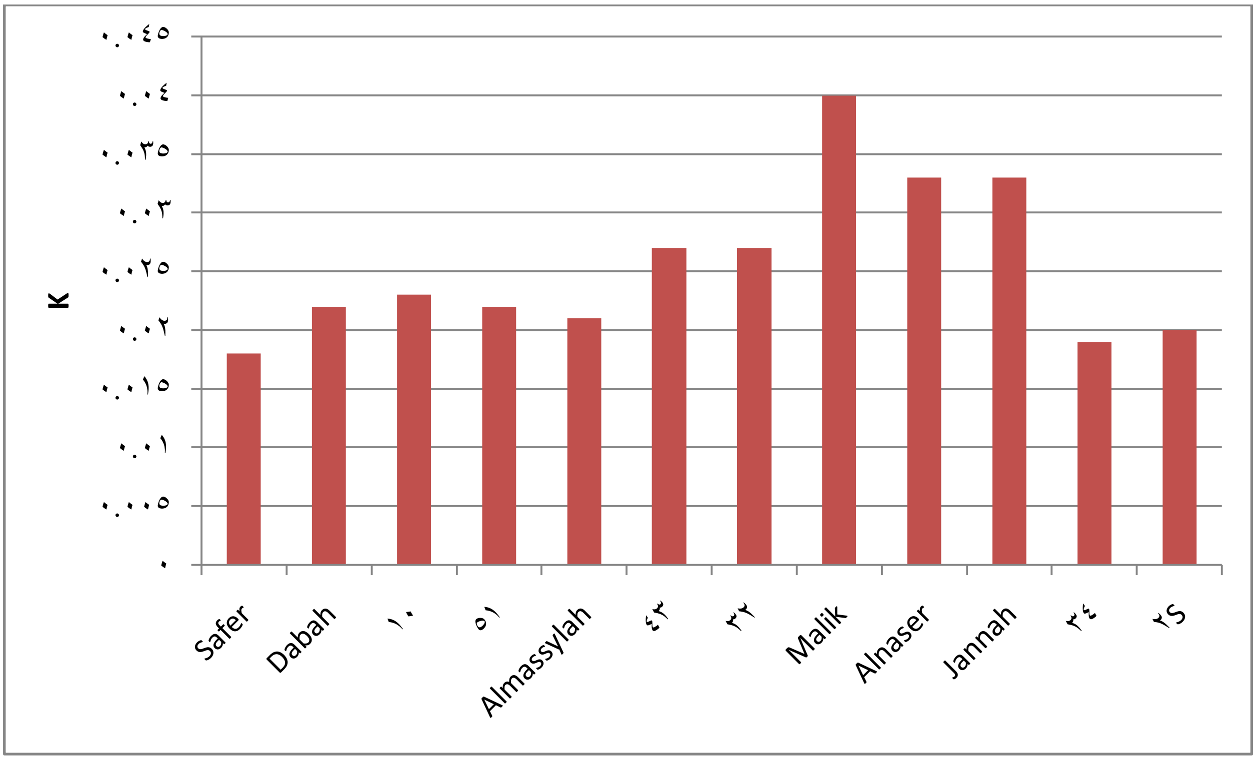


Figure (3.18): K of Yemeni crude oil

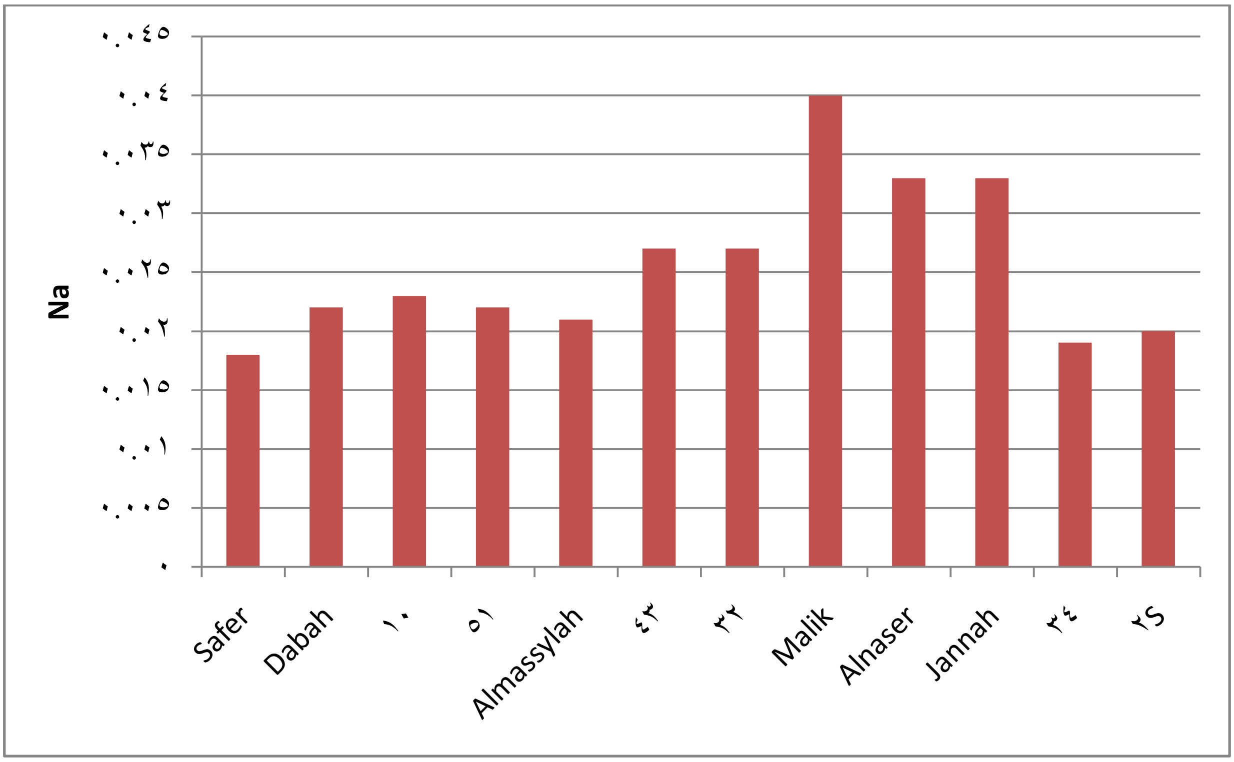


Figure (3.19): Na of Yemeni crude oil

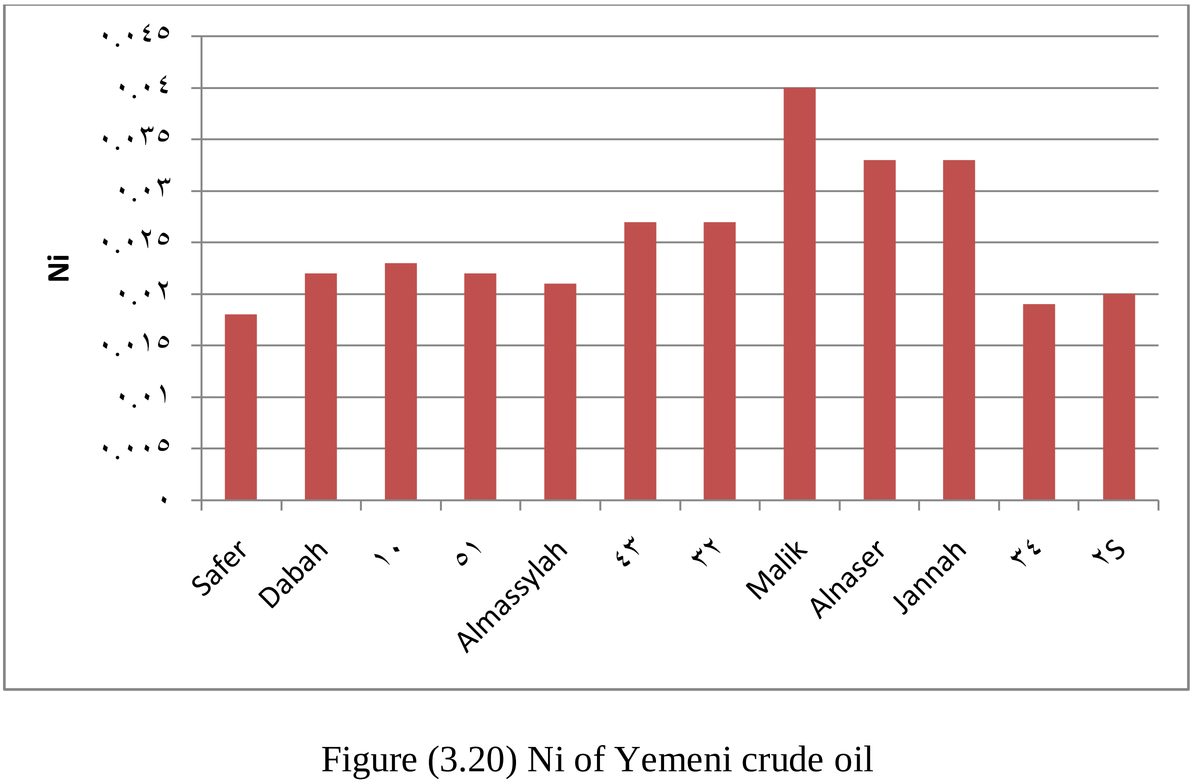


Figure (3.20) Ni of Yemeni crude oil

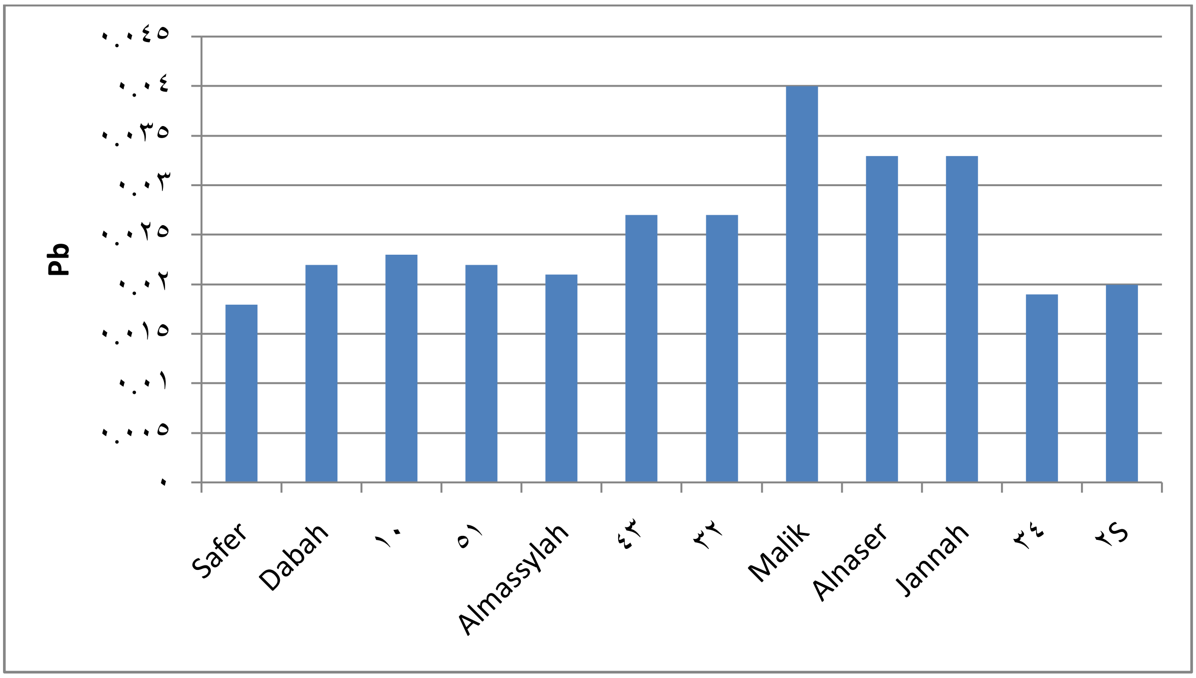


Figure (3.21): Pb of Yemeni crude oil

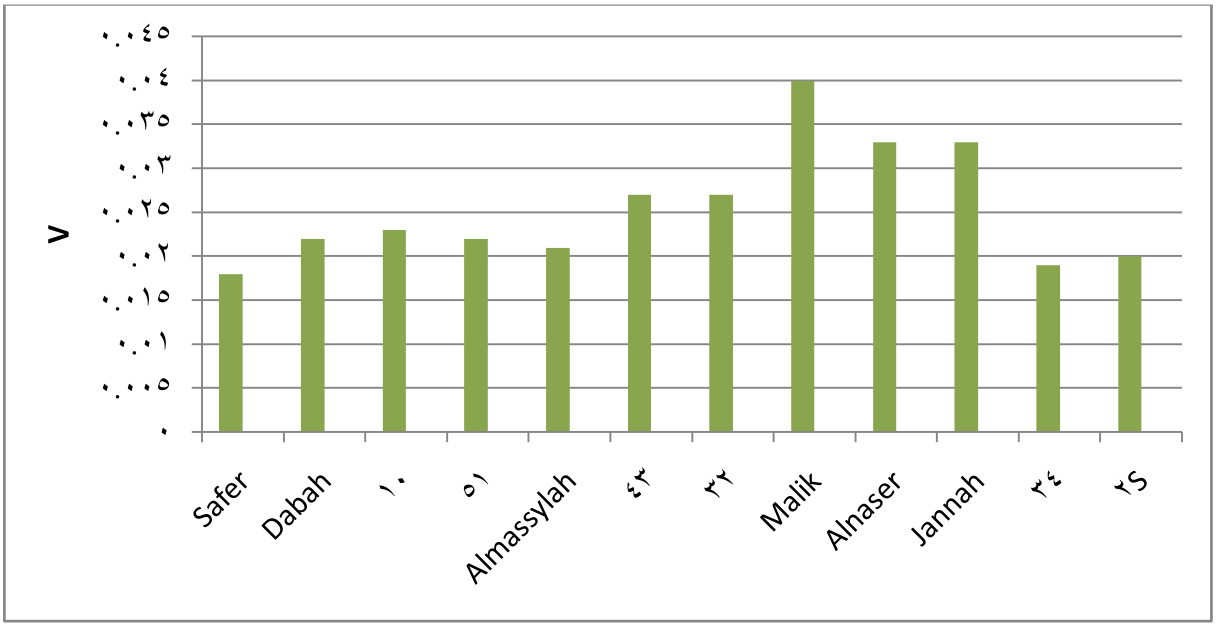


Figure (3. 22): V of Yemeni crude oil

All heavy metals in Yemeni crude Oil are very low (light crude).

3-4- Compare between API standard and API of Yemeni crude oils.

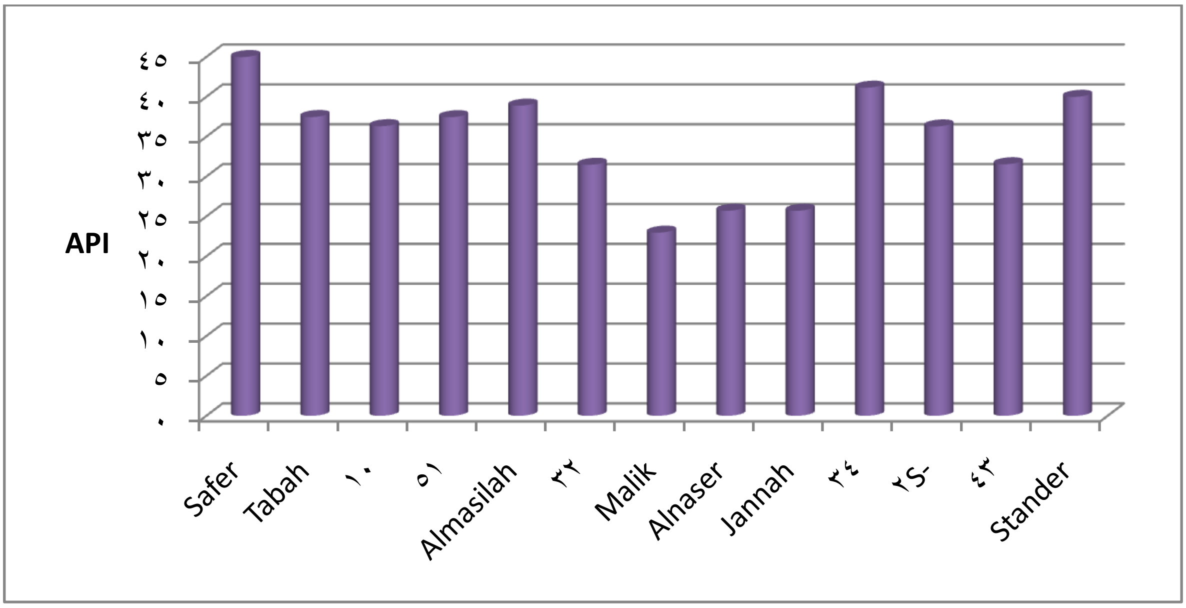


Figure (3.23): compare between API standard and API of Yemeni crude oils

API of Yemeni crude oils agree with API standard (light)

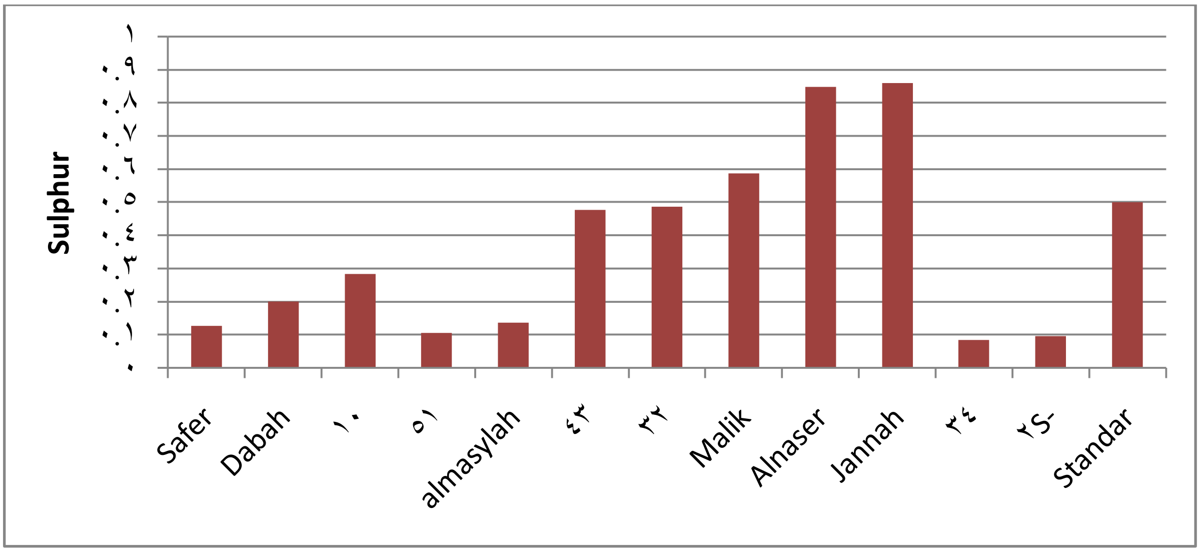


Figure (3.24): compares between Sulphure standard and Sulphure of Yemeni crude oil

Sulphure of Yemeni crude oils is less than standard in most samples (sweet).

Table (3.3): Comparison between Shabwah, East Shabwah, Almasilah, Maarb.

	Shabwah	East Shabwah	Almasylah	Maarb
Mean of density	0.8576	0.8832	0.8365	0.8010
Mean API	32.22	28.66	37.55	44.99
Mean S.G	0.8649	0.884	0.8437	0.8010
Mean sulfur	0.472	0.518	0.175	0.1270
Mean asphalten	0.2075	0.32	0.04	0.00

At take all filed as four major sectors we found result in table (3.3), figure (3. 25-3. 29) and map (2). As following: density (0.8010-0.8832), API (28.66-44.99), S.G (0.8010-0.884), sulfur (0.12-0.518), asphalten (0.00-0.32).

3-5-Comparison between Shabwah, East Shabwah, Almasilah and Maarb crude oils.

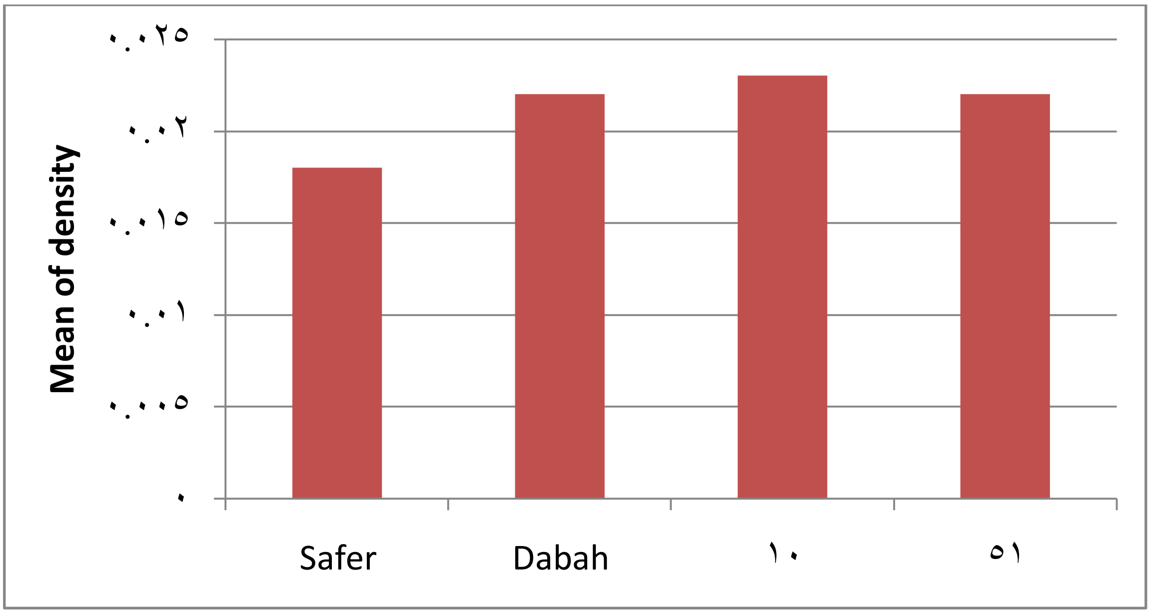


Figure (3.25): comparison between crude oil density Shabwah, east Shabwah, ALmasilah and Marib.

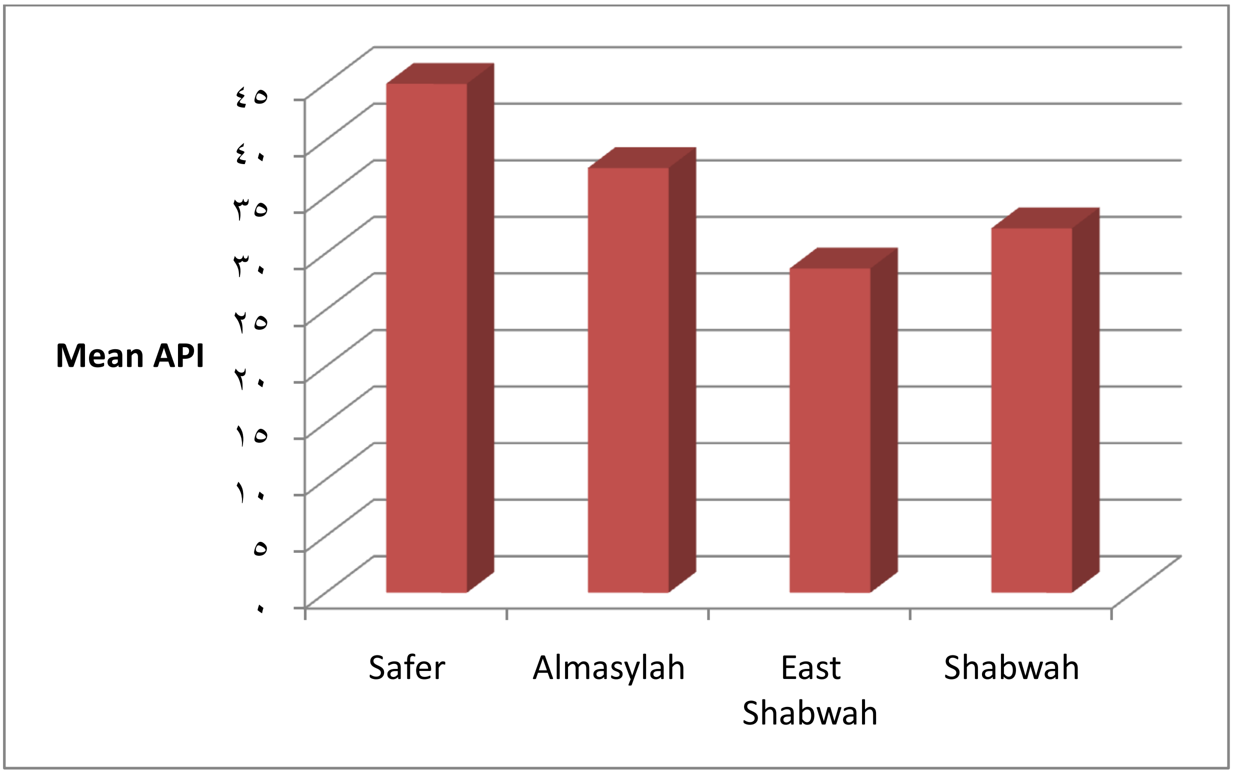


Figure (3.26): Comparison between API of crude oil Shabwah, East Shabwah, Almasilah and Marib.

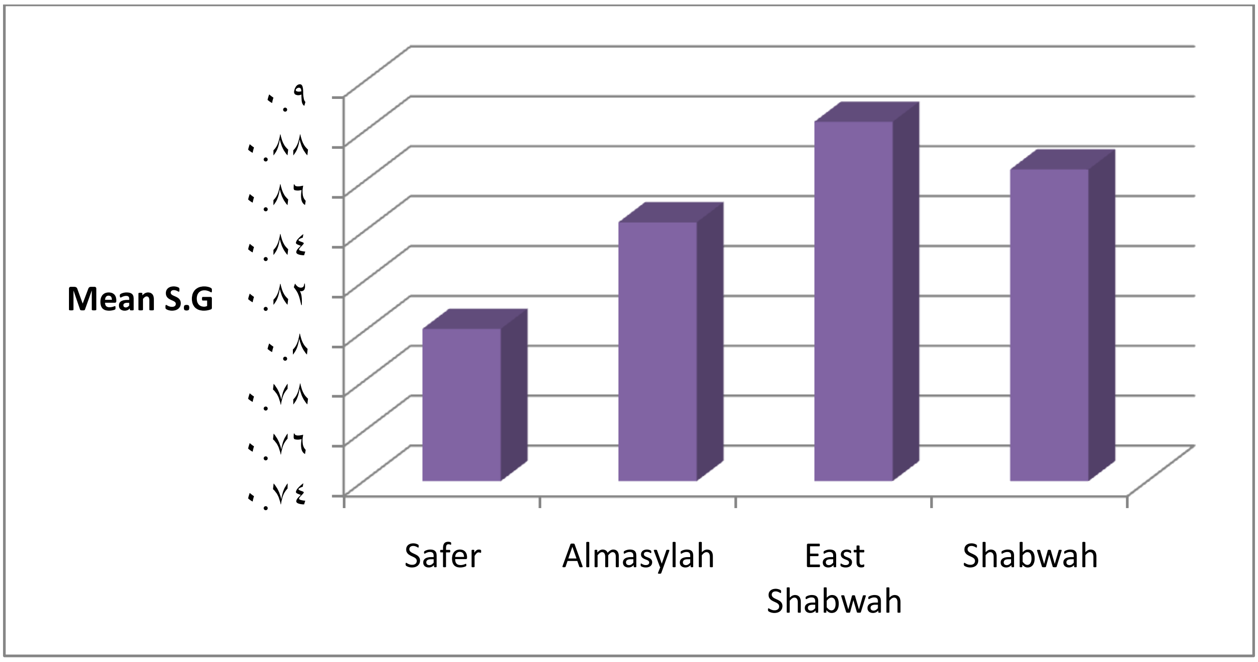


Figure (3.27): Comparison between S.G of crude oil Shabwah, East Shabwah, Almasilah andMarib

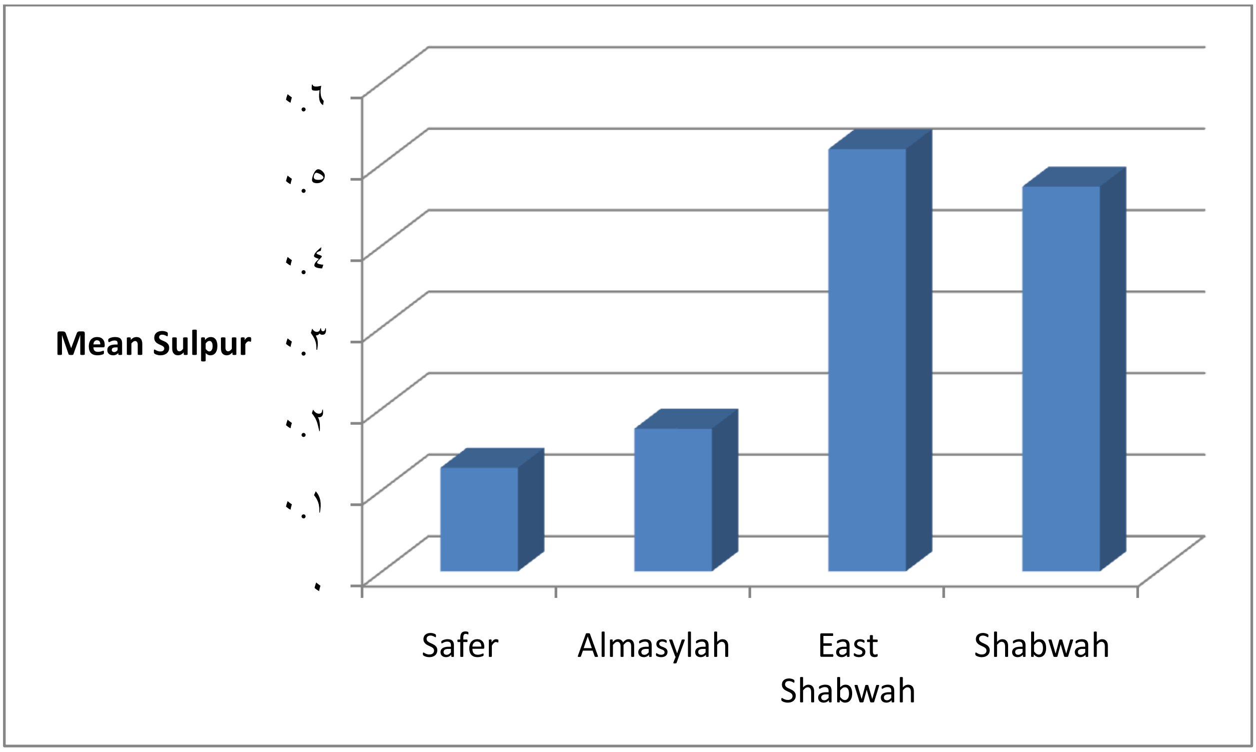


Figure (3.28): Comparison between Sulfur of crude oil Shabwah, East Shabwah, Almasylah and Marib.

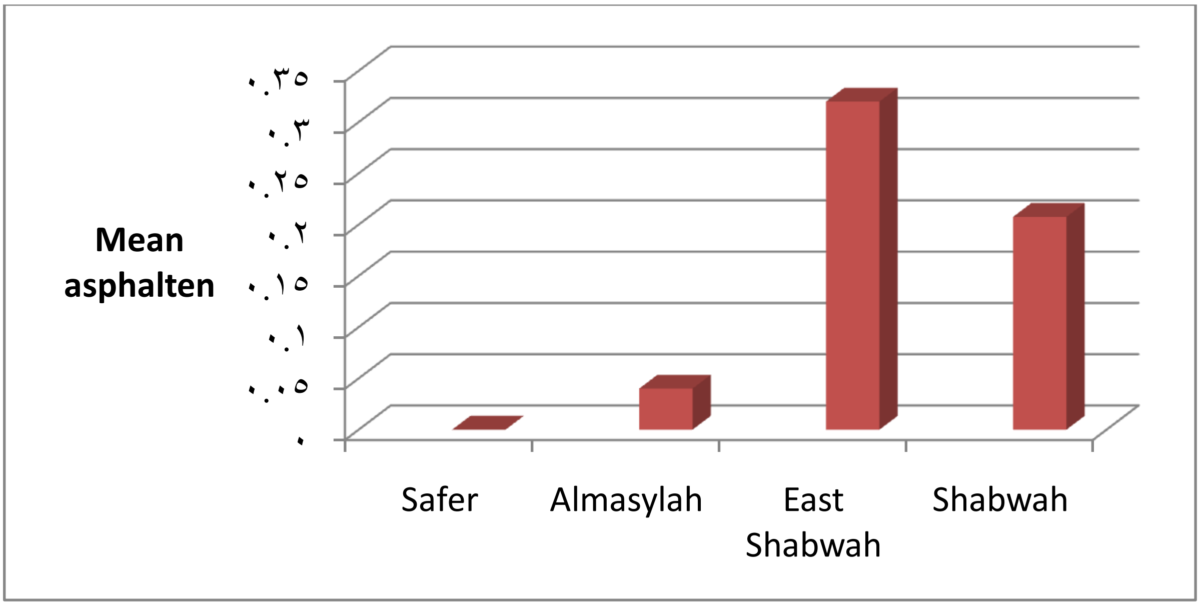


Figure (3.29): Comparison between Mean Asphaltene of crude oil Shabwah, East Shabwah, Almasylah and Marib.

Almasilah and Marib crude oils more quality than Shabwah, East Shabwah crudeoils.

Table (3. 4) Comparison between properties of Yemeni and Sudanese crude oil

	Yemen crude Oils			Sudan crude Oils		
Field	Jannah	Almasilah	Safer	Dar blend	Nile blend	Moga
Density @ $15C^0$	0.8992	0.8364	0.8010	0.9135	0.8793	0.9338
API	25.72	37.47	44.99	23.25	29.28	19.89
S.G	0.9000	0.8374	0.8010	0.9144	0.8801	0.9346
TAN	0.54	0.00	0.02	4.18	0.32	2.70
Wax content	30.95	*	39.67	20	30.31	25.25
WAT	-7.02	43.40	14.48	62.38	57.60	25.45
Dynamic visco at75^0C	44.99	3.33	1.67	141.64	20	187.30
Kinematic visco at75^0C	50.03	3.98	2.08	155	22.74	200.57
Ag	0.0614	<0.0035	<0.0035	0.0395	<0.0035	0.0231
Ca	1876	9.863	6.900	22.49	5.030	729.6
Cd	0.195	<0.0009	<0.0009	0.0080	<0.0009	0.0074
Co	0.1615	<0.0018	0.0686	1.847	0.2365	0.2261
Cr	1.776	<0.0013	0.0084	0.0145	0.0062	0.1014
Fe	94.3	3.2	1.684	7.291	1.844	44.64
K	4.169	1.132	0.3198	2.107	0.1165	0.8054
Na	19.67	29.77	<0.0360	20.79	2.748	22.94
Ni	0.3915	0.1649	1.6010	68.29	7.01	12.59
Pb	408.1	0.1162	1.312	<0.0150	<0.0150	<0.0154
V	0.2073	0.0722	0.4591	0.9098	0.2174	0.2754

At compare some samples from Yemeni with some Sudanese crude oils we found result as the following Table (3- 4): gives the physicochemical parameters of the crude oils. And shows levels of heavy metals present in the crude oil, shows a comparison of the propeties of some field Yemen (Jannah, Marib, Almasilah) and Sudanese (Nile blend, Dar blend, Moga) crude oil, The results showed range of values for physicochemical parameters obtained for the Yemeni crude oil samples as follows: specific gravity (0.8010-0.9000), API gravity (25.72-44.99), TAN(0.00-0.54); density at 15^{0}C (0.8010-0.915), wax content (ND-39.67), R.V.P (12.5-45), Dynamic viscosity at 75^{o}C (1.67-44.99) and Kinematic viscosity at 75(2.08 – 50. 03). For heavy metals, the range of values were Ag (0.0035-0.0846), Ca (3.24-1876), Cd (<0.0009-0.0162), Co (<0.0018-0.1632), Cr (<0.0013-1.776), Fe (<0.0062-94.3), K (<0.0360-17.52), Na (<0.0360-319.4), Ni (0.1649-4.005), Pb (0.015-402.2), V (0.0531-4.919) respectively. while The results showed range of values for physicochemical parameters obtained for the Sudanese oil samples as follows: specific gravity (0.8801-0.9346), API gravity (19.89-29.28), TAN(0.32-4.18); density at 15^{0}C (0.8793-0.9338), wax content (20-30.31), Dynamic viscosity at 75^{o}C (20-187.3), and Kinematic viscosity at 75 (22.74 – 200. 57), For heavy metals, the range of values were Ag (0.0035-0.0395), Ca (5.030-729.6), Cd (<0.0009-0.0074), Co (22.61-1.847), Cr (0.0062-0.1014), Fe (1.84-44.64), K (0.1165-2.107), Na (2.748-22.94), Ni (7.01-68.29), Pb (<0.0150-<0.0154), V (0.2174-0.9098) show figure (3. 30-3.48).

3-6-Comparison between properties of Yemeni and Sudanese crude oil

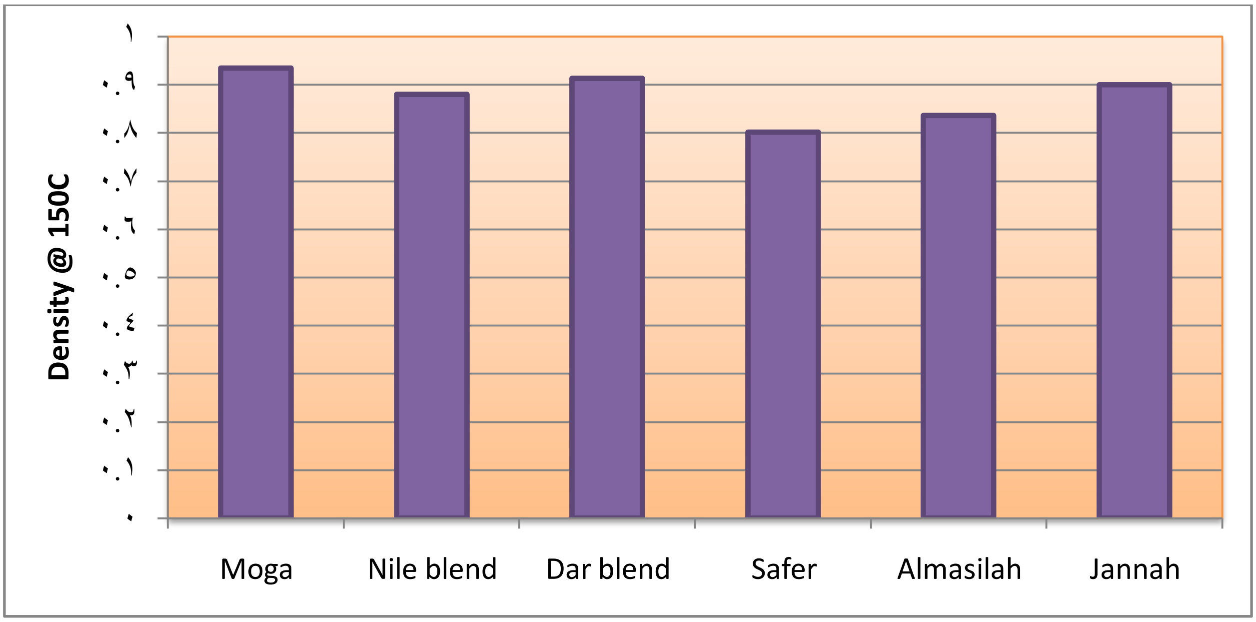


Figure (3.30): comparisons between density of Yemeni and Sudanese crude oils

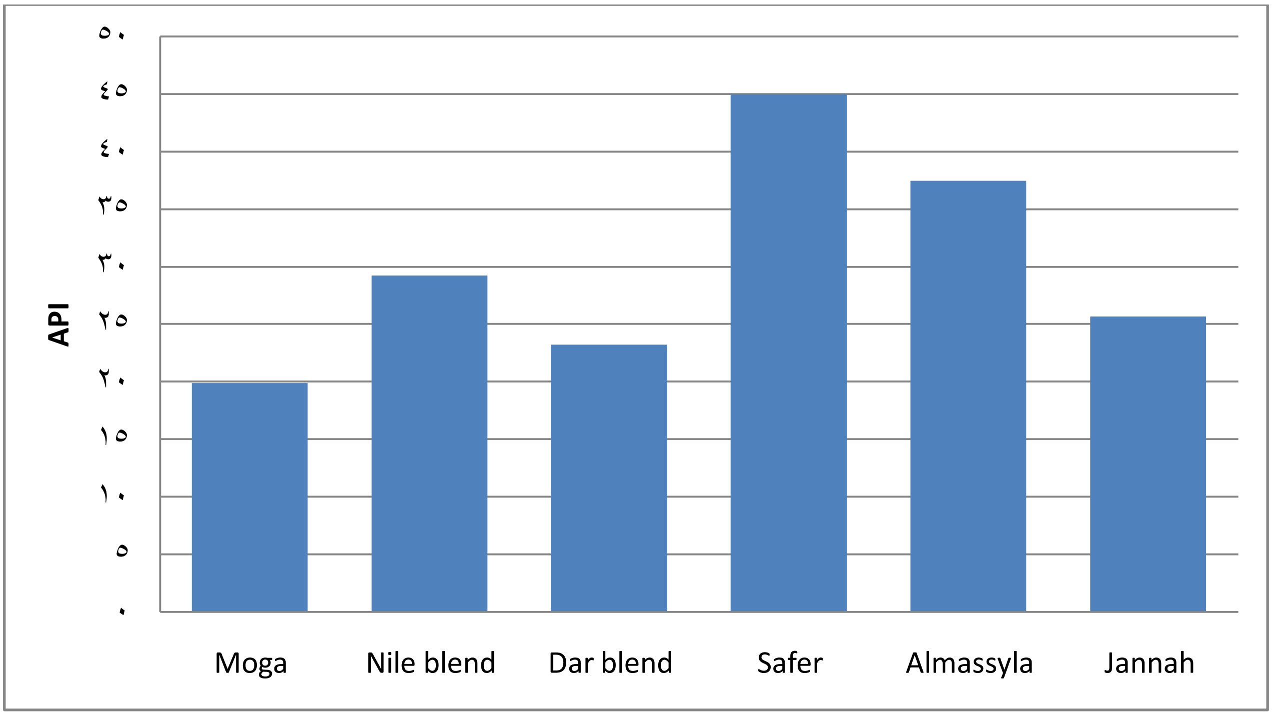


Figure (3. 31): comparisons between API of Yemeni and Sudanese crude oils

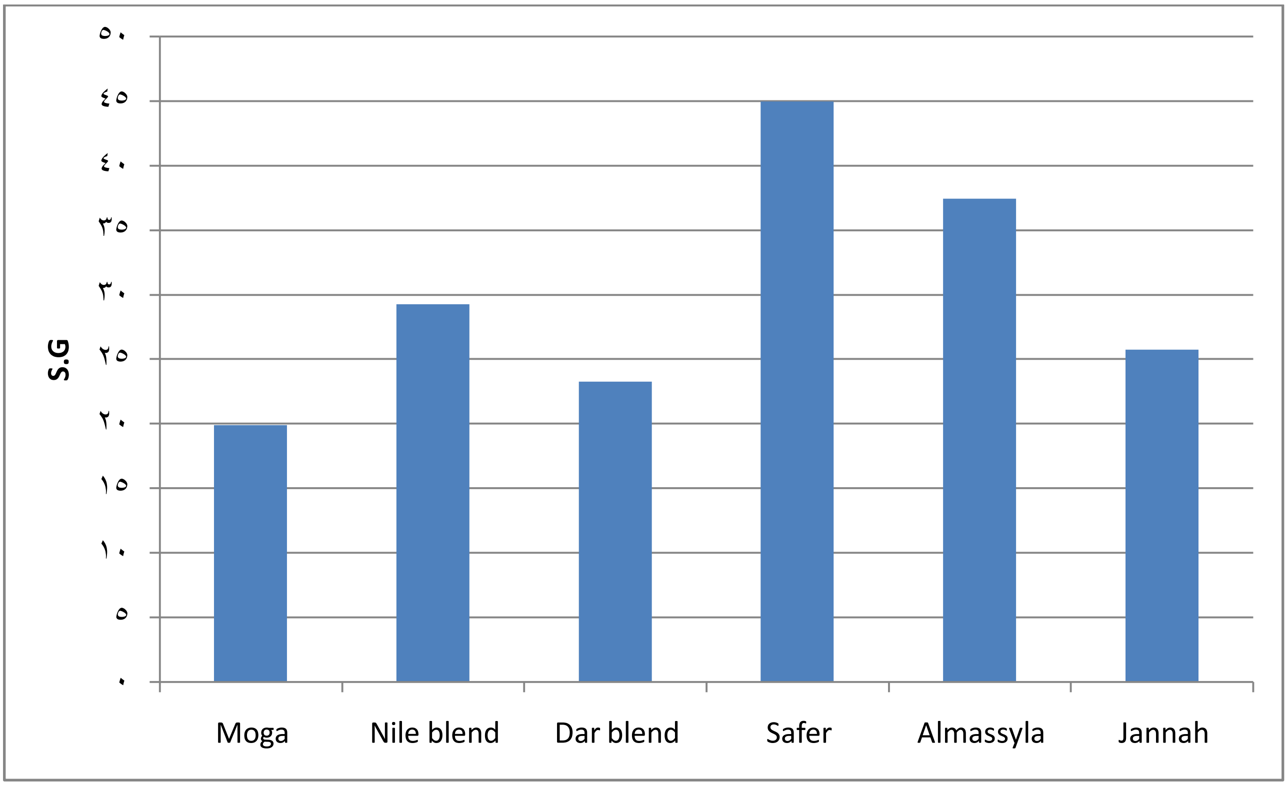


Figure (3. 32):Comparison between S.G of Yemeni and Sudanese crude oils

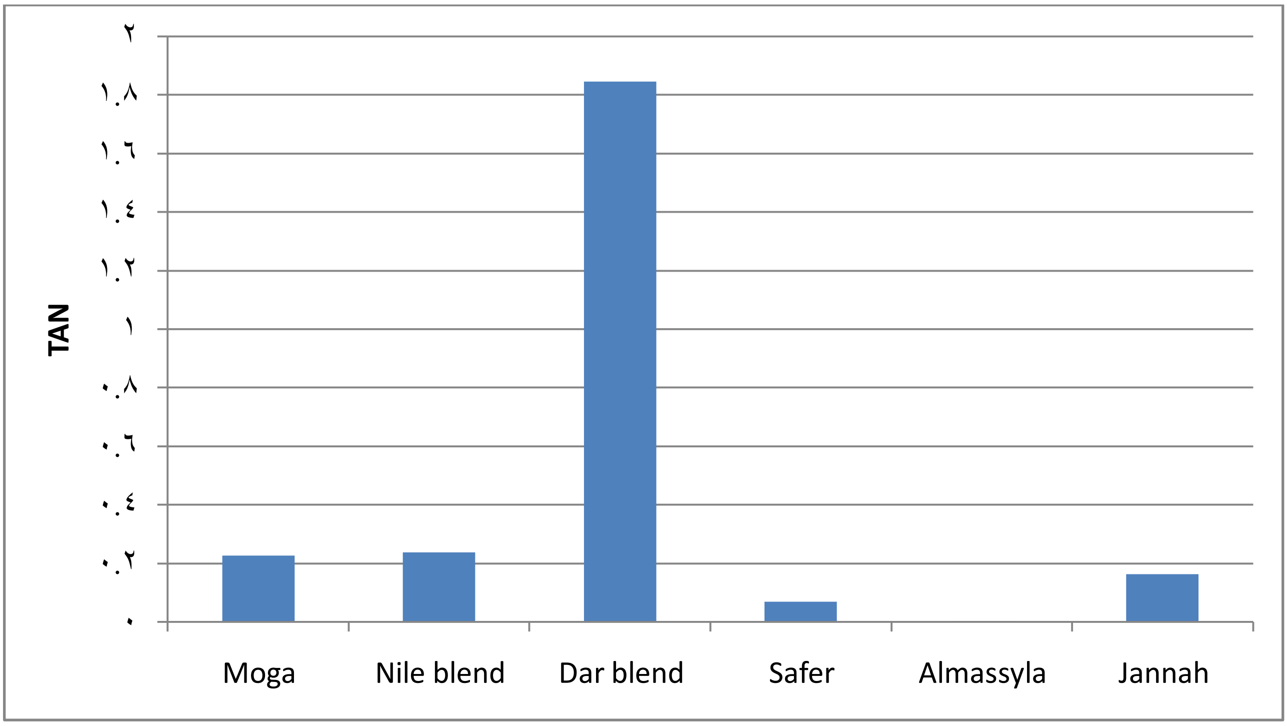


Figure (3. 33): comparison between TAN of Yemeni and Sudanese crude oils

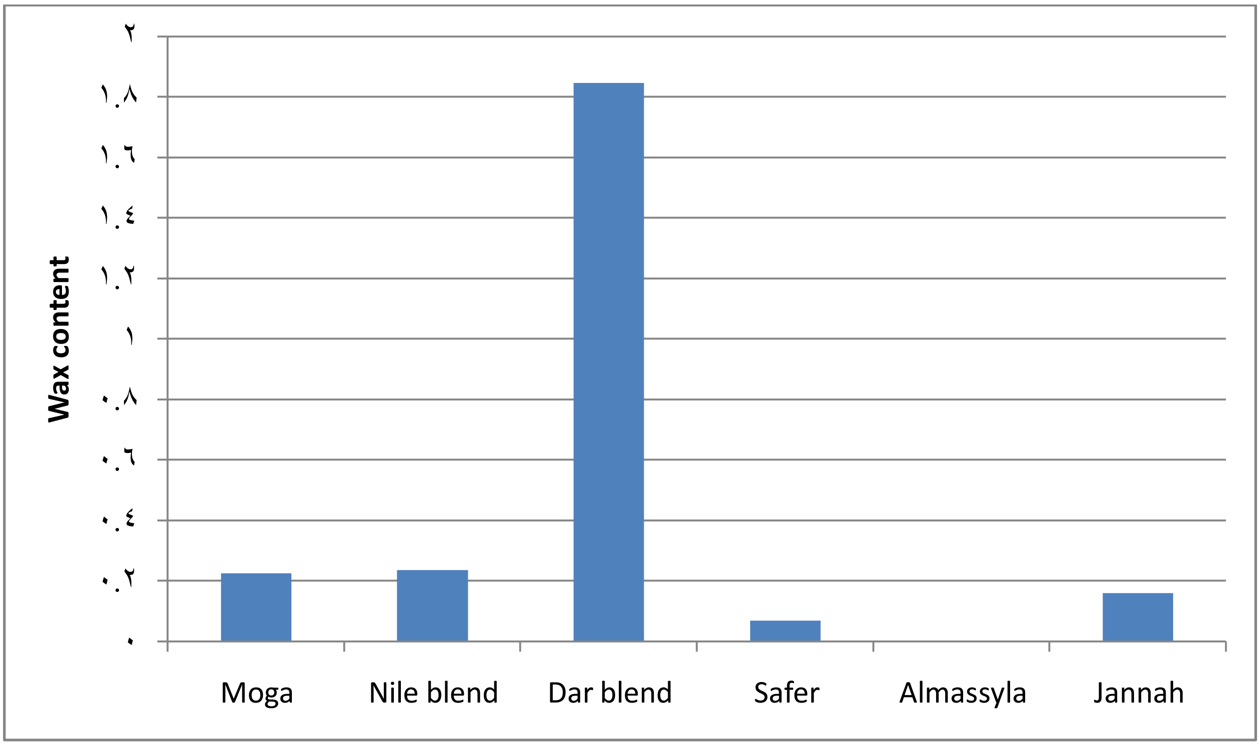


Figure (3.34): comparisons between wax content of Yemeni and Sudanese crude oils

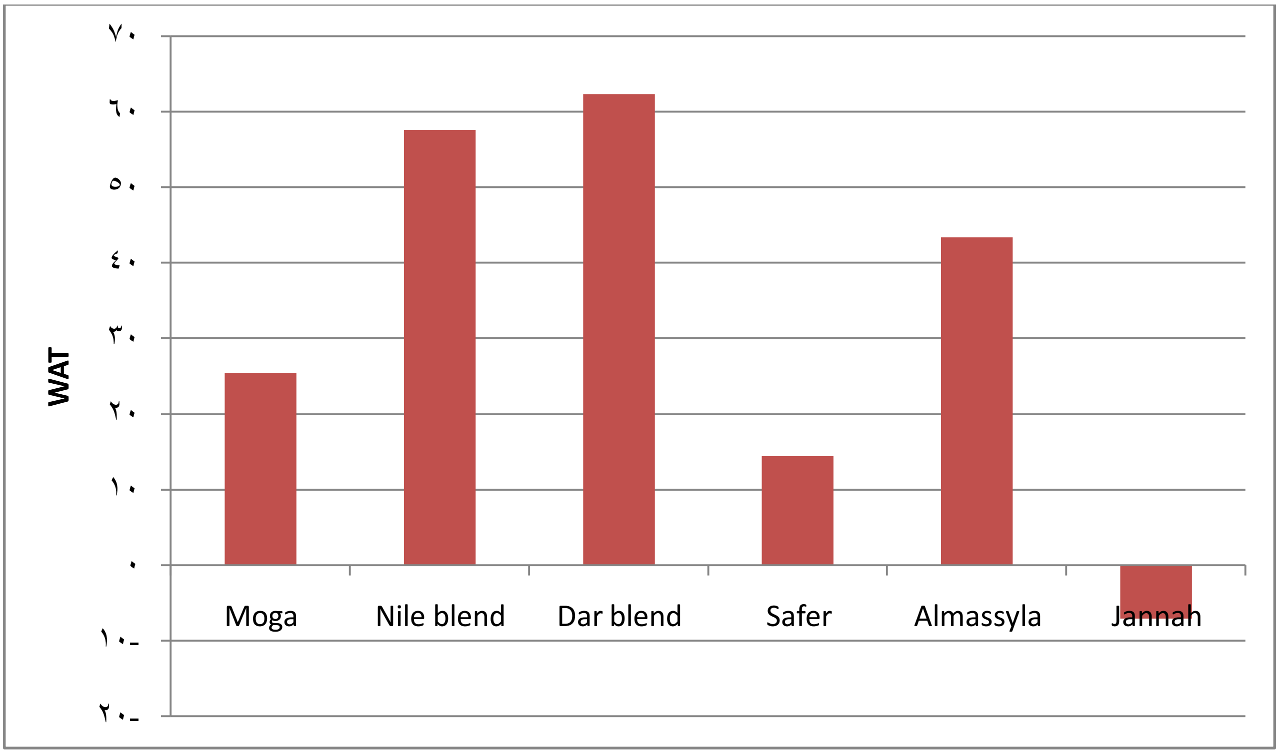


Figure (3.35): comparisons between WATof Yemeni and Sudanese crude oils

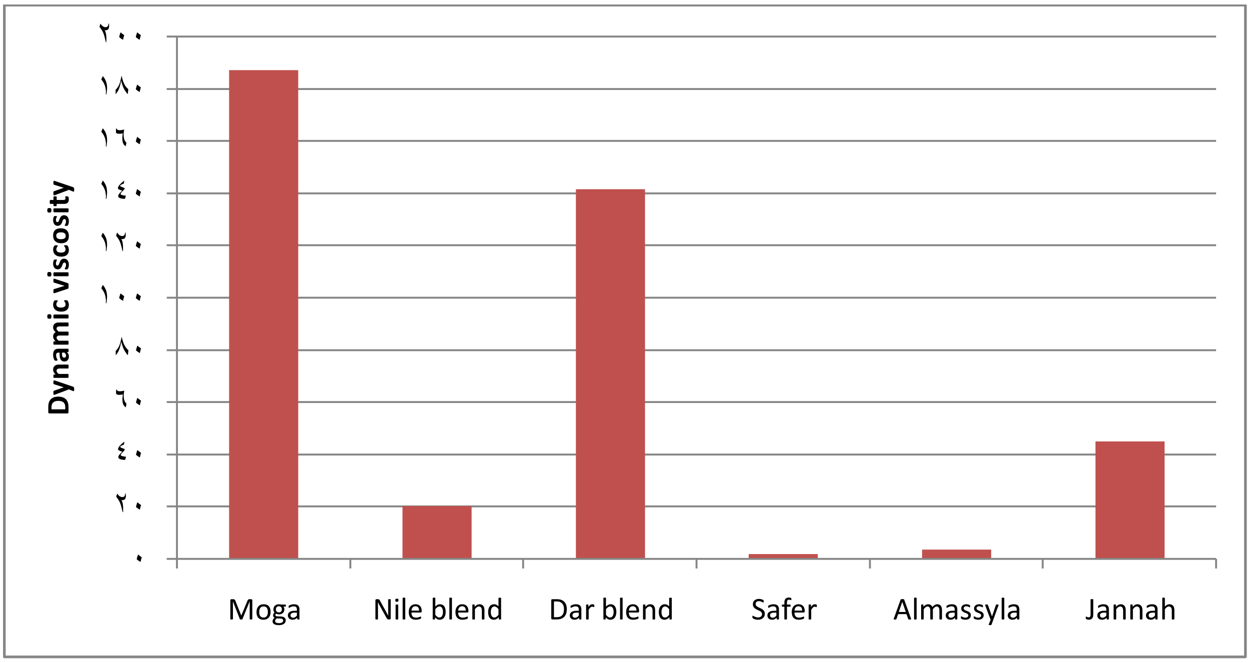


Figure (3.36): comparisons between Dynamic viscosity at 75 °Cof Yemeni and Sudanese crude oils

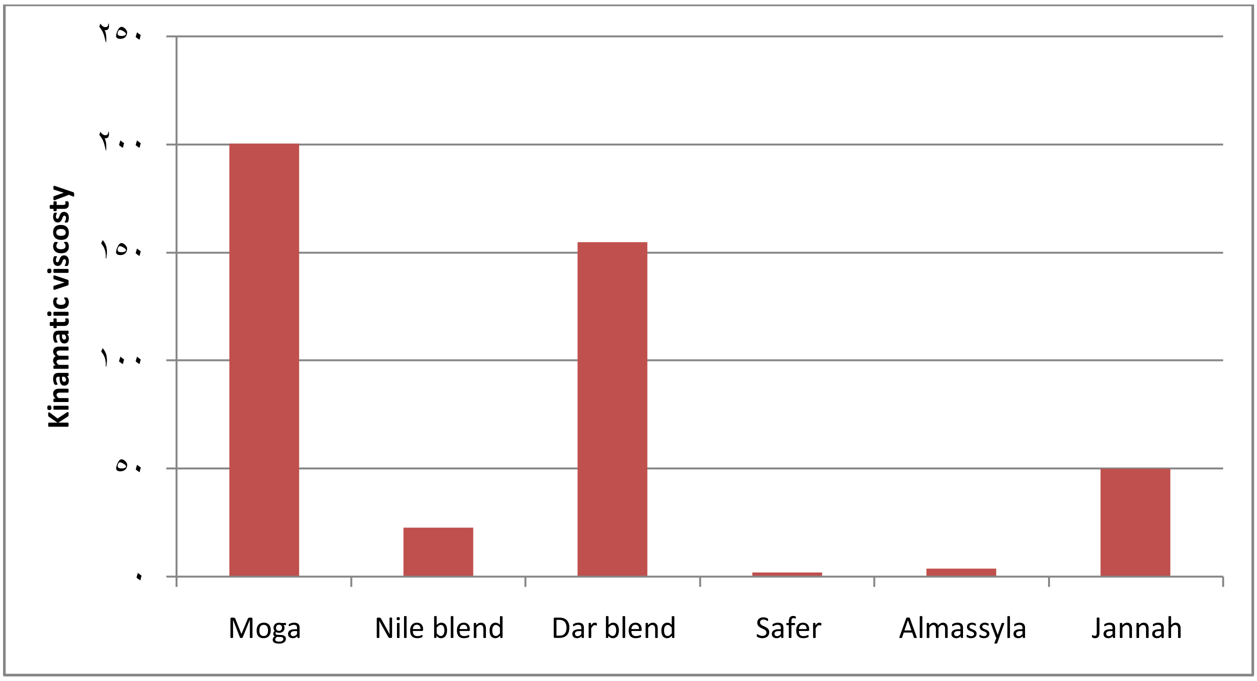


Figure (3.37): comparisons between kinematic viscosity at 75°Cof Yemeni and Sudanese crude oils

Properties of Yemeni crude oils better slightly from Sudanese crude oils in above.

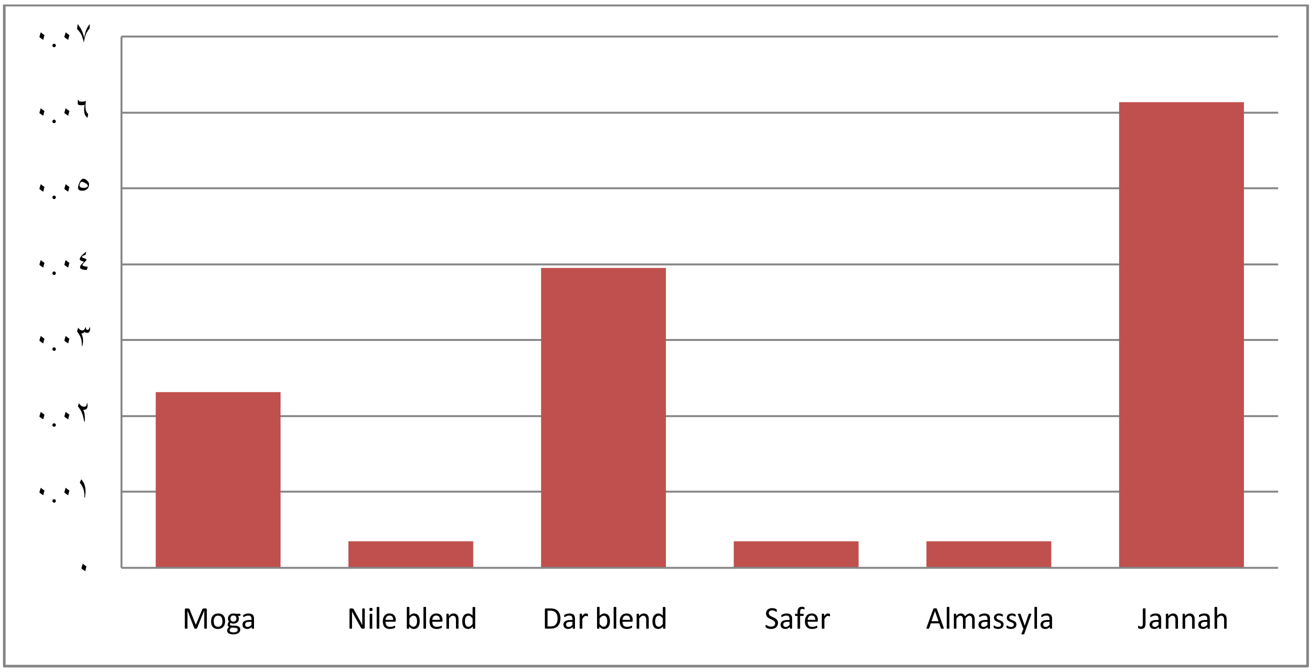


Figure (3.38): comparisons between Ag of Yemeni and Sudanese crude oils

3-7-Comparisons between heavy metals of Yemeni and Sudanese crude oils

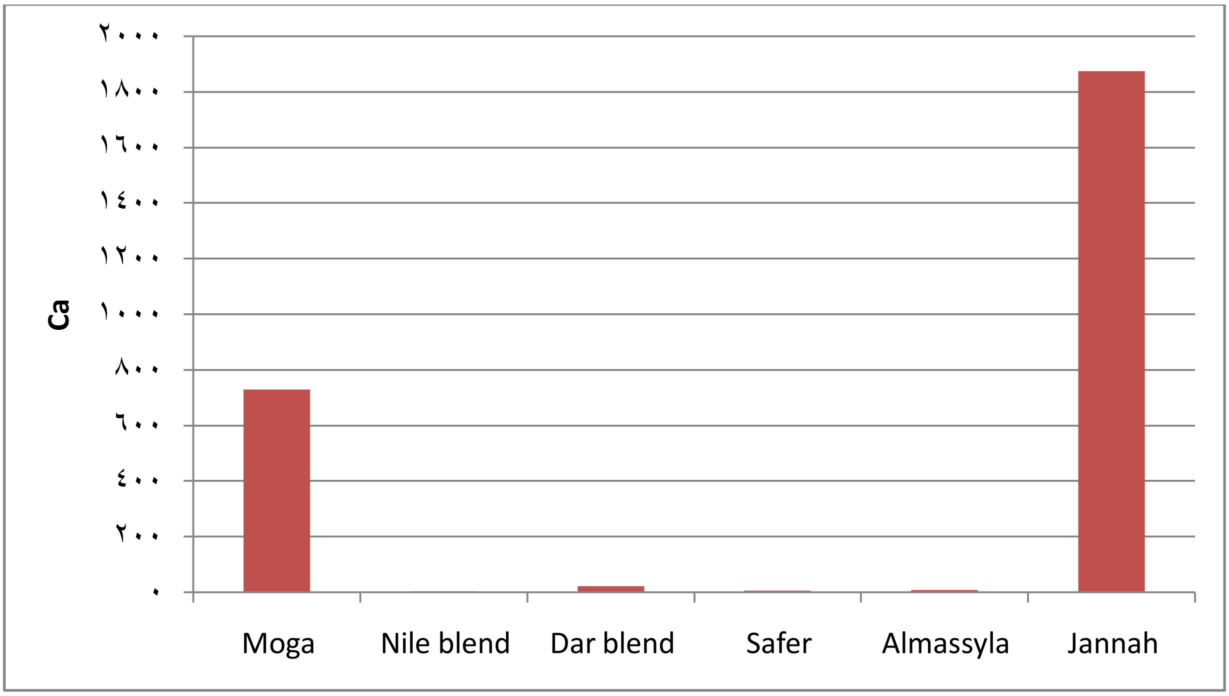


Figure (3. 39): comparisons between Ca of Yemeni and Sudanese crude oils

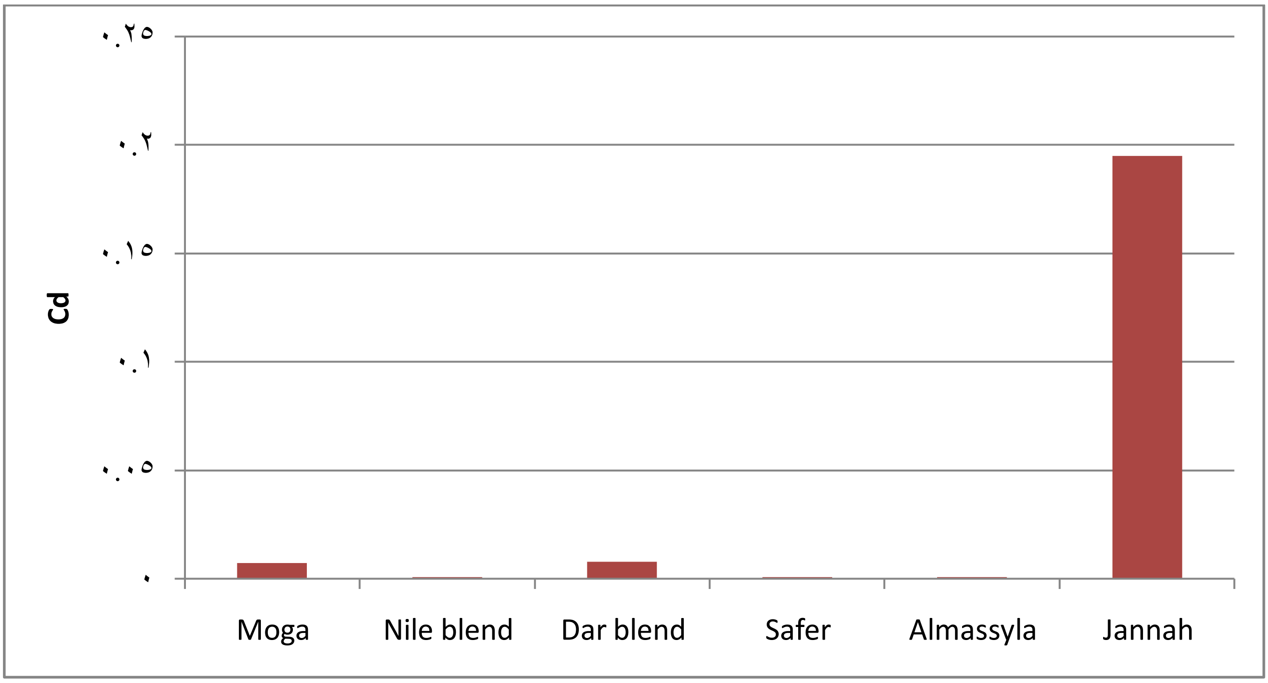


Figure (3. 40): comparisons between Cd of Yemeni and Sudanese crude oils

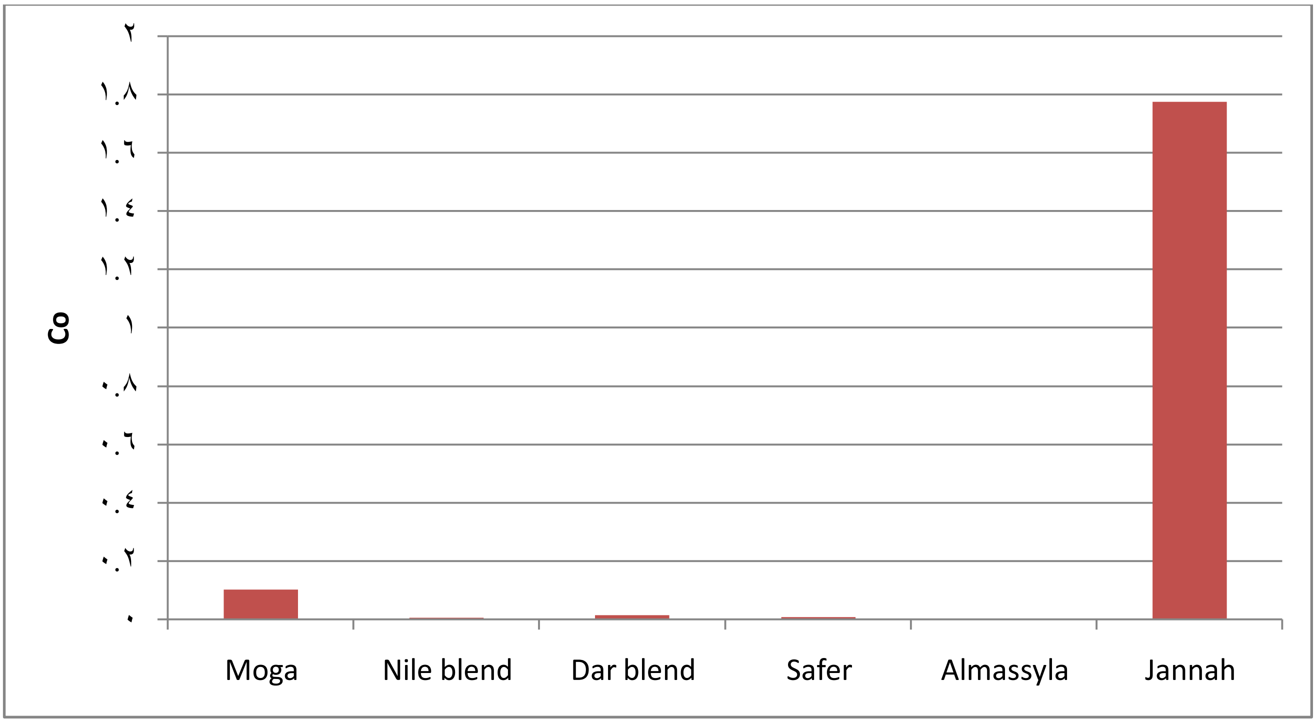


Figure (3. 41): comparisons between Co of Yemeni and Sudanese crude oils

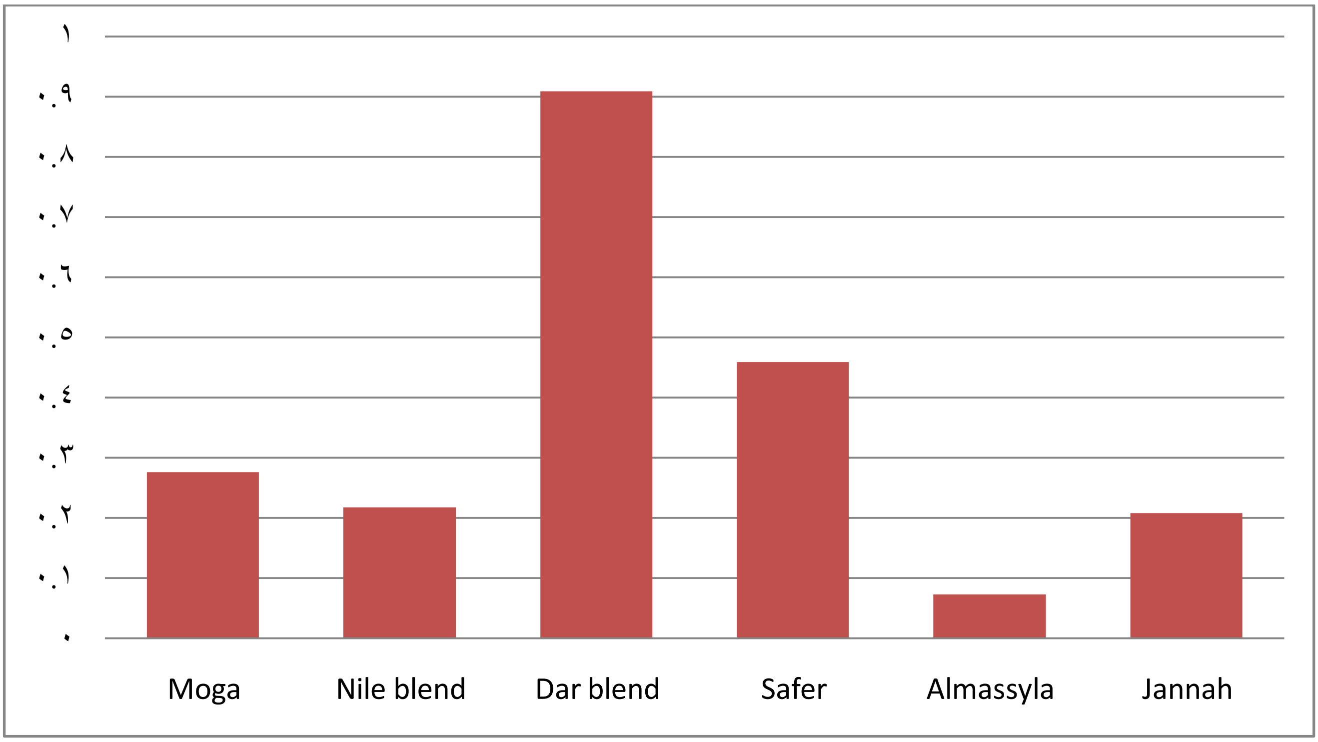


Figure (3. 42): comparisons between Cr of Yemeni and Sudanese crude oils

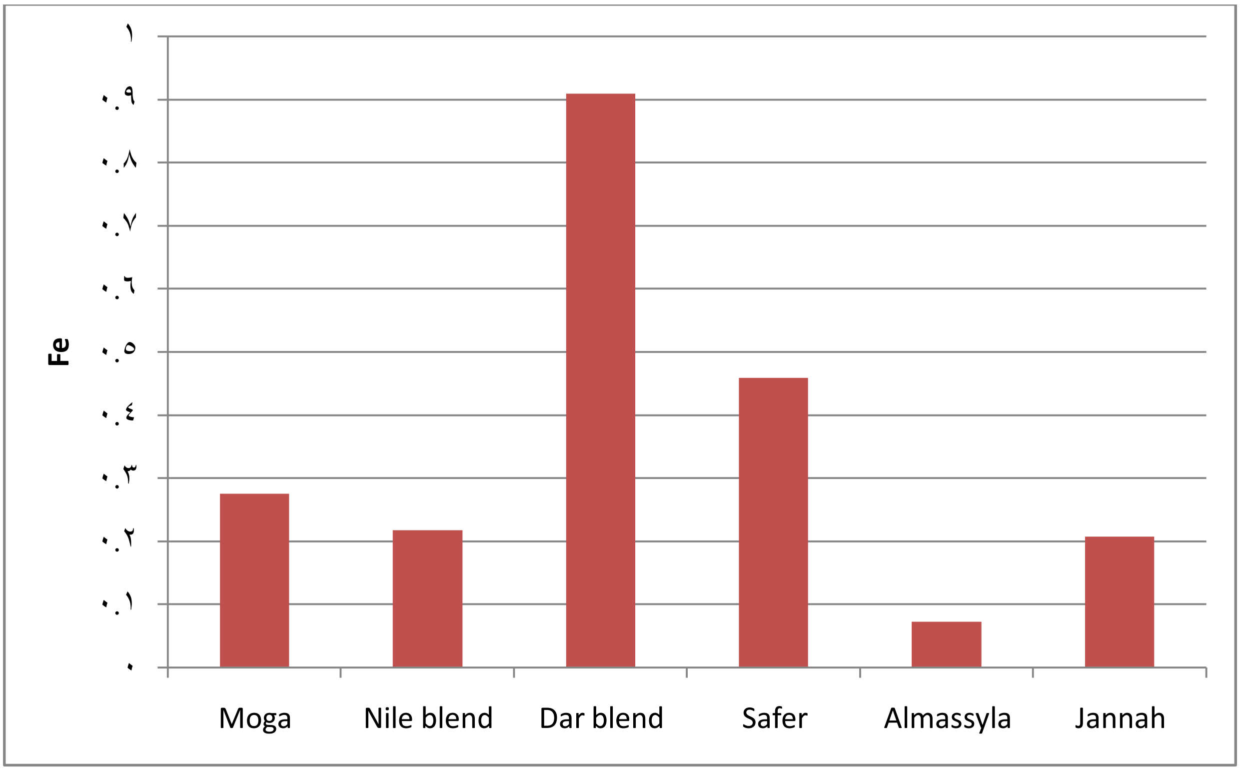


Figure (3. 43): comparisons between Fe of Yemeni and Sudanese crude oils

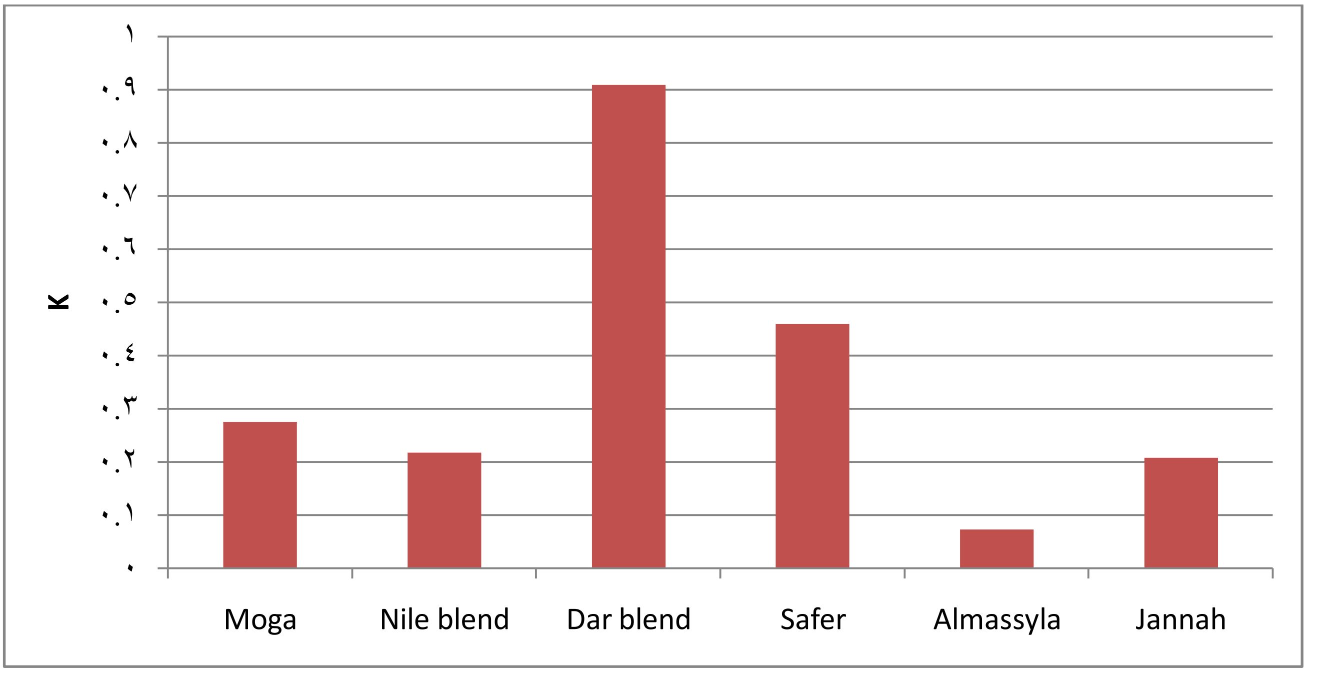


Figure (3.44): comparisons between K of Yemeni and Sudanese crude oils

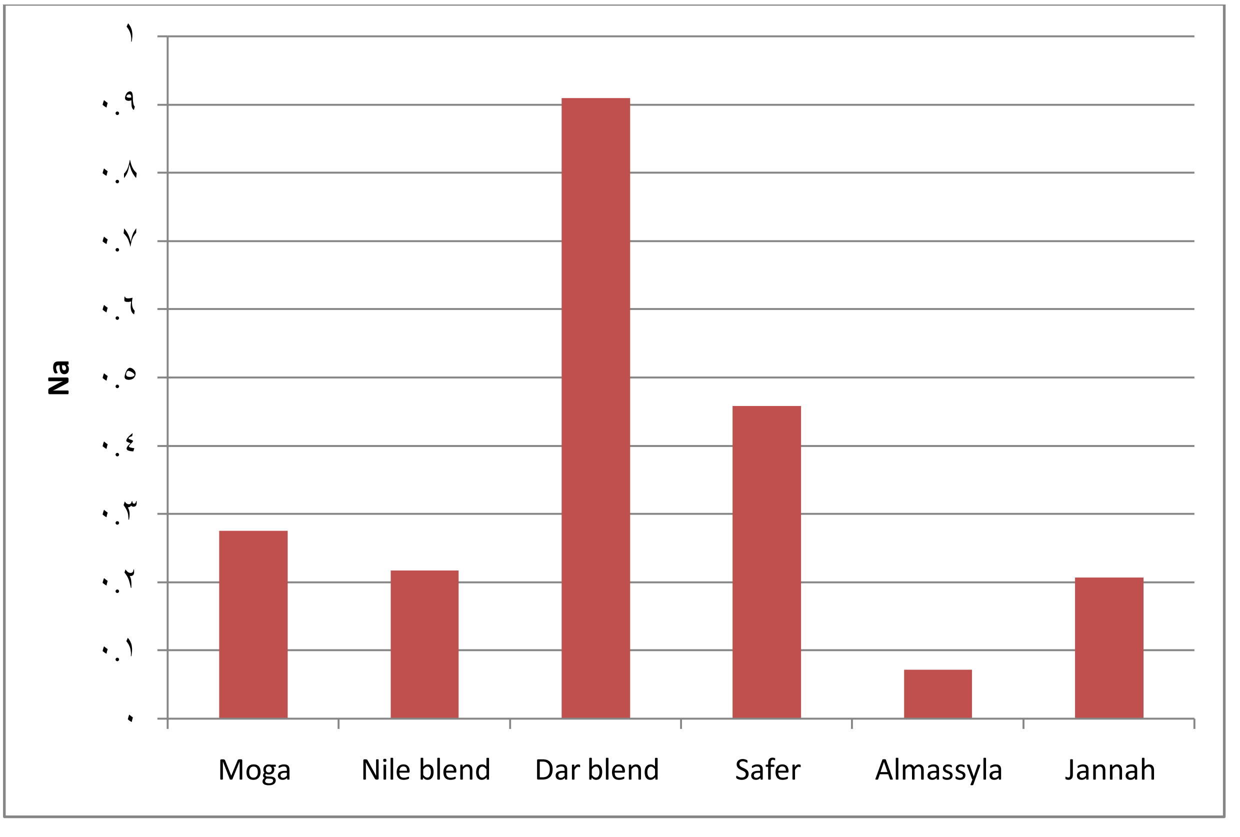


Figure (3.45): comparisons between Na of Yemeni and Sudanese crude oils

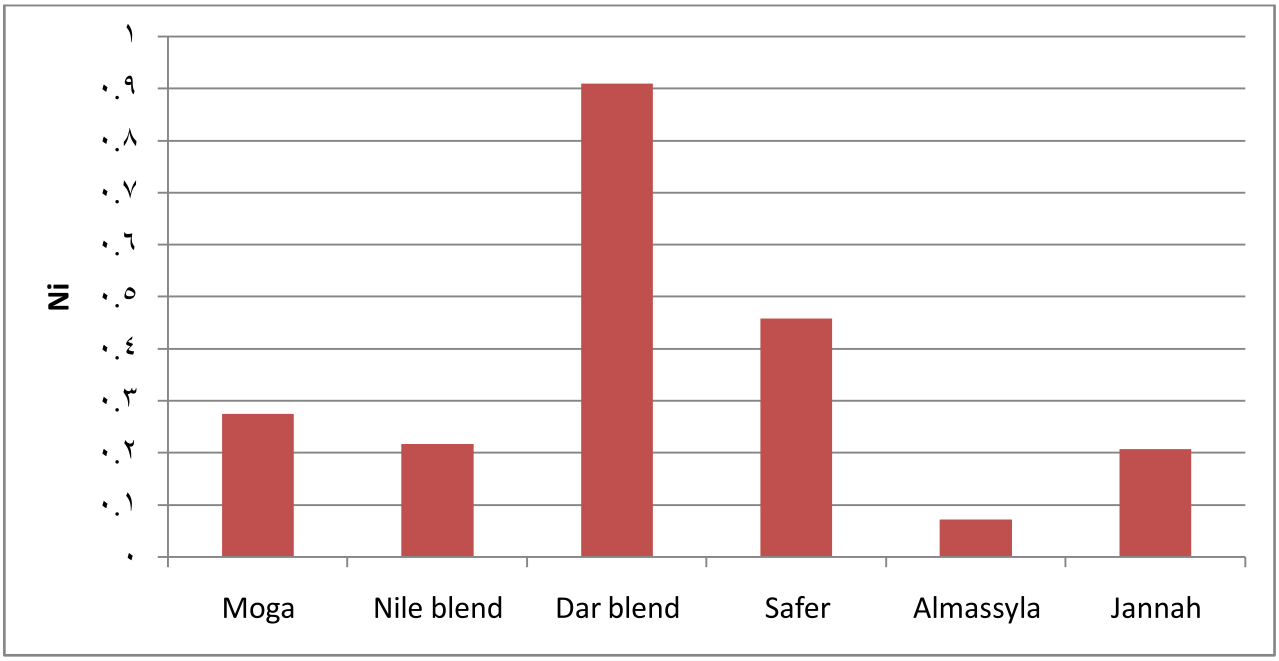


Figure (3. 46): comparisons between Ni of Yemeni and Sudanese crude oils

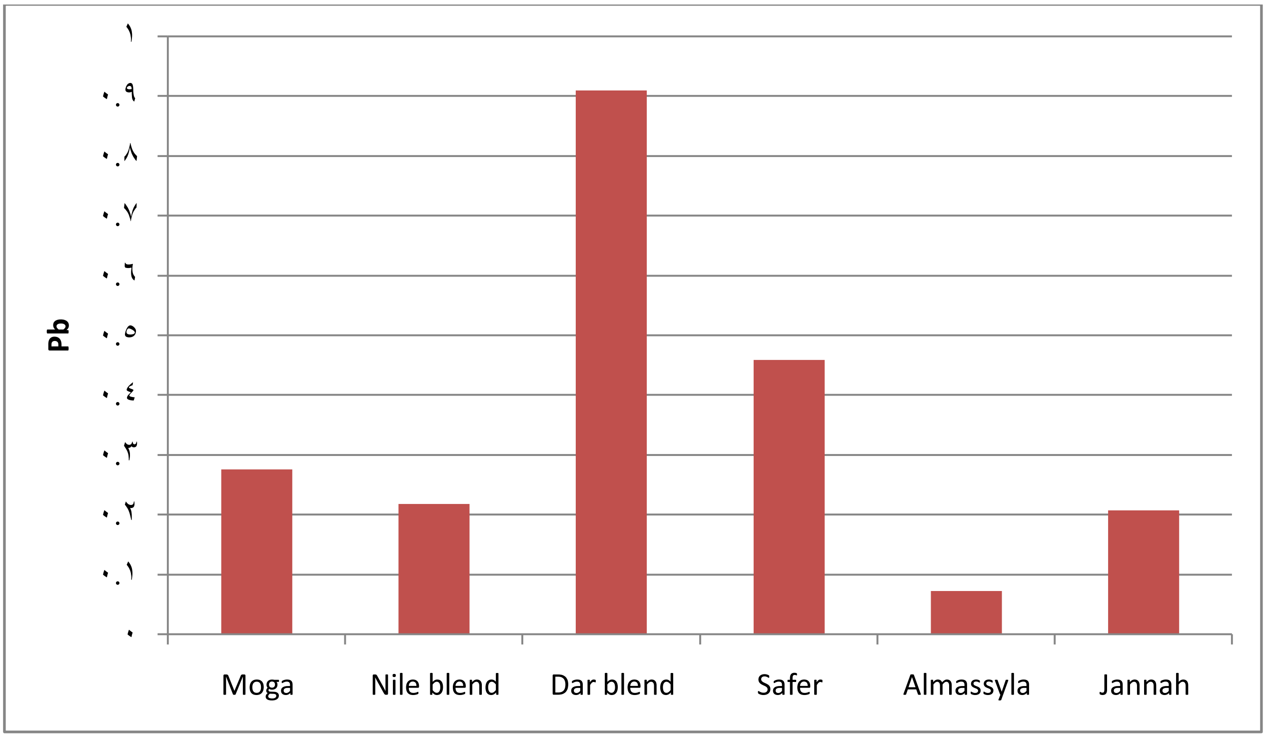


Figure (3. 47): comparisons between Pb of Yemeni and Sudanese crude oils

Generaly all heavy metals inYemeni and Sudanese crude oil was low.

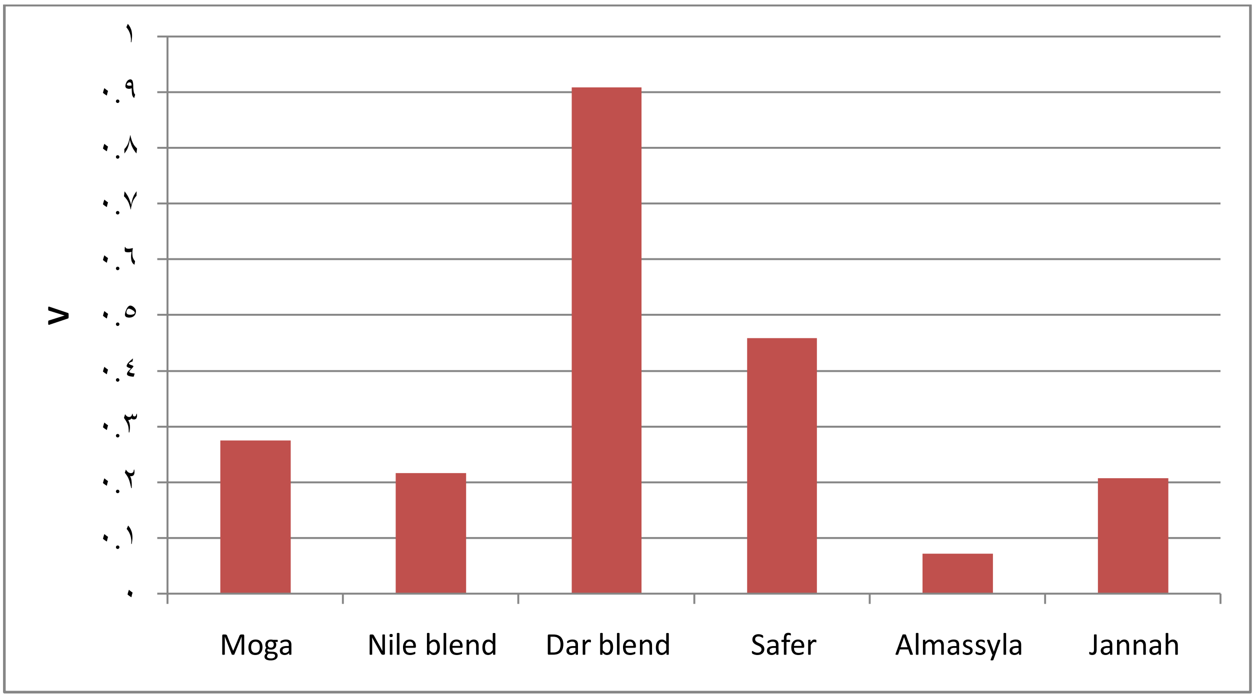


Figure (3. 48): comparisons between V of Yemeni and Sudanese crude oils

Table (3. 5): Normal alkanes/isoprenoid ratios

Sample	Pr/Ph	Pr/n-C17	Ph/n-C18	n-C25/n-C18	CPI	Pr+C17/ Ph+C18
Gannah	0.4037	0.4152	0.4737	0.5635	1.0476	o.4423
Almassyla	1.6585	0.4947	0.4484	0.1622	1.1645	1.7153
Safer	1.6030	0.5834	0.4921	0.2695	1.09	1.5643
Dar blend	2.005	0.1976	0.1066	1.0918	1.0276	1.1716
Nile blend	2.3210	0.3278	0.2165	0.6369	1.0995	1.4250
Moga	25.5738	0.3602	.o174	0.9032	1.1219	1.6546

From table (3-5) the range of Normal alkanes/isoprenoid ratios in Yemeni crude oils Pr/ph (0.4037- 1.6585), pr/n-C17 (0.4158-0.5834), ph /n-C18 (0.4484-0.4921), n-C25/n-C18 (0.1622-0.5635), CPI (1.09-1.1645), Pr+n-C17/Ph+n-C18 (0.4423-1.7153).The rang of Normal alkanes/isoprenoid ratios in Sudanese crude oils Pr/ph

(2.005-25.5738), pr/n-C17 (0.1976-0.3602), ph /n-C18 (0.0174-0.2165), n-C25/n-C18 (0.6369-1.0918), CPI (1.0276-1.1219), Pr+n-C17/Ph+n-C18 (1.1716-1.6546).

Table (3.6) Ratio Saturated to Aromatic between Yemeni and Sudanese crude oil sample

	Saturated %	Aromatic%
Jannah	80.8914	19.1086
Almassyla	90.7421	9.2579
Maarb	87.6247	12.3735
Moga	97.6077	2.1490
Dar blend	90.1050	1.8442
Nile blend	99.4393	0.5607

From table (3-6) Ratio Saturated to Aromatic between Yemeni and Sudanese crude Oil samples (80.8914 – 90.7421) to (9.25 – 19.1086), (90.1050– 99.4393) to (10.607 – 0.58442) show figure (3. 49) respectively.

Ratio Saturated to Aromatic between Yemeni and Sudanese crude oil.

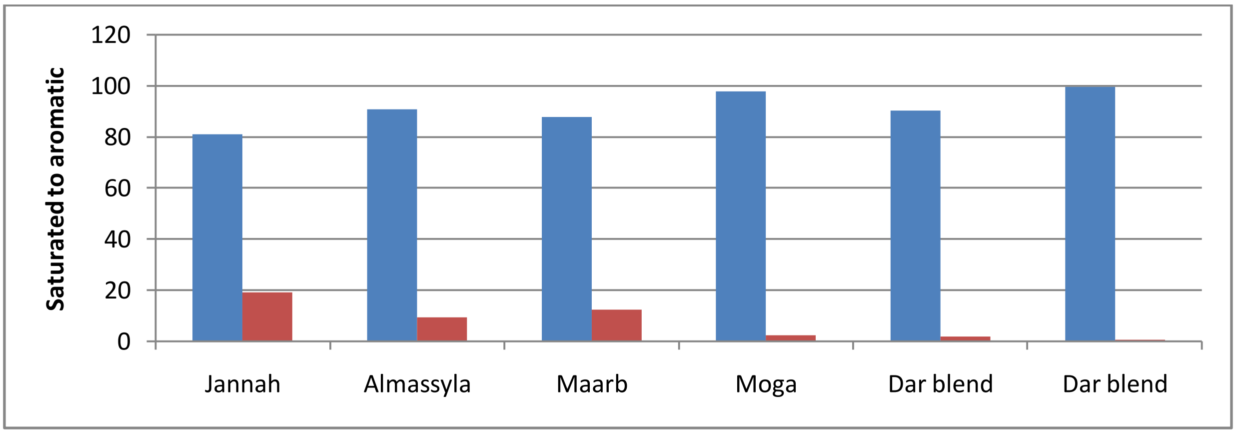


Figure (3. 49): Ratio Saturated to Aromatic between Yemeni and Sudanese crude oil sample.

Table (3.7) Wax Appearance Temperature of Yemeni and Sudanese crude oils

	WAT ^{0}C	Wt-mg
Jannah	-7.02	9.4
Almassyla	43.40	9.1
Marib	14.48	8.1
Dar blend	62.38	9
Nile blend	57.60	7.8
Moga	25.49	6.4

From table (3-7) wax appearance temperature (WAT ^{0}C) jannah (-7.02), Almasilah (43.40), Marib (14.48), Dar blend (62.38), Nile blend (57.60), Moga (25.49) show figure (3.50-3.55).

3-8-Wax Appearance Temperature of Yemeni and Sudanese crude oil

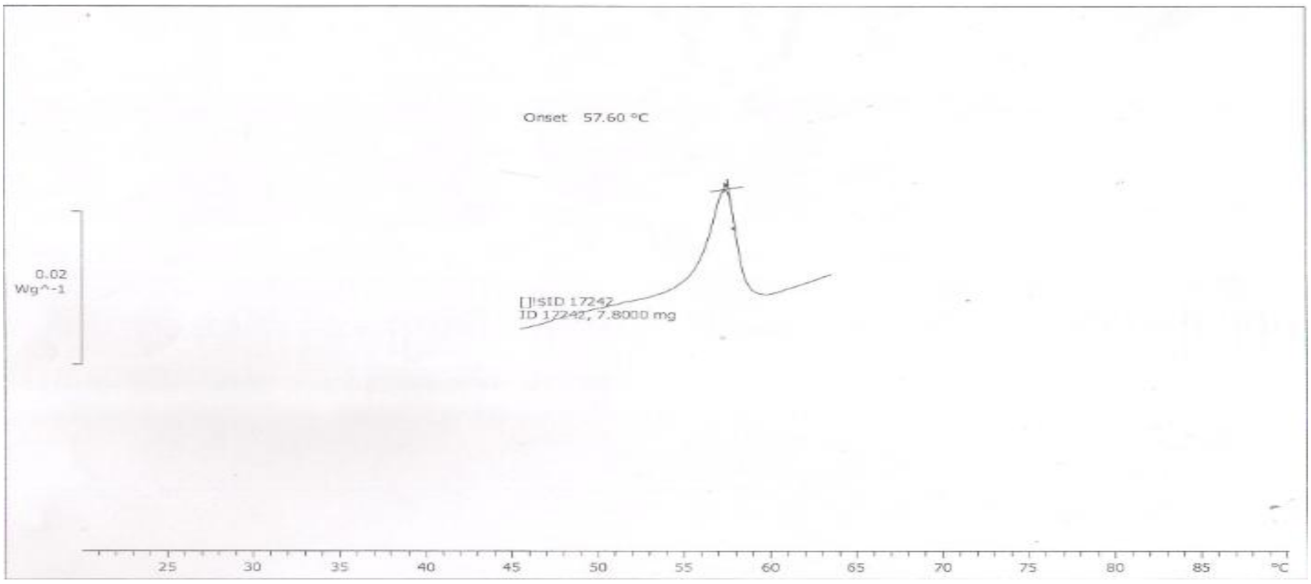


Figure (3. 50): WAT of Nile blend

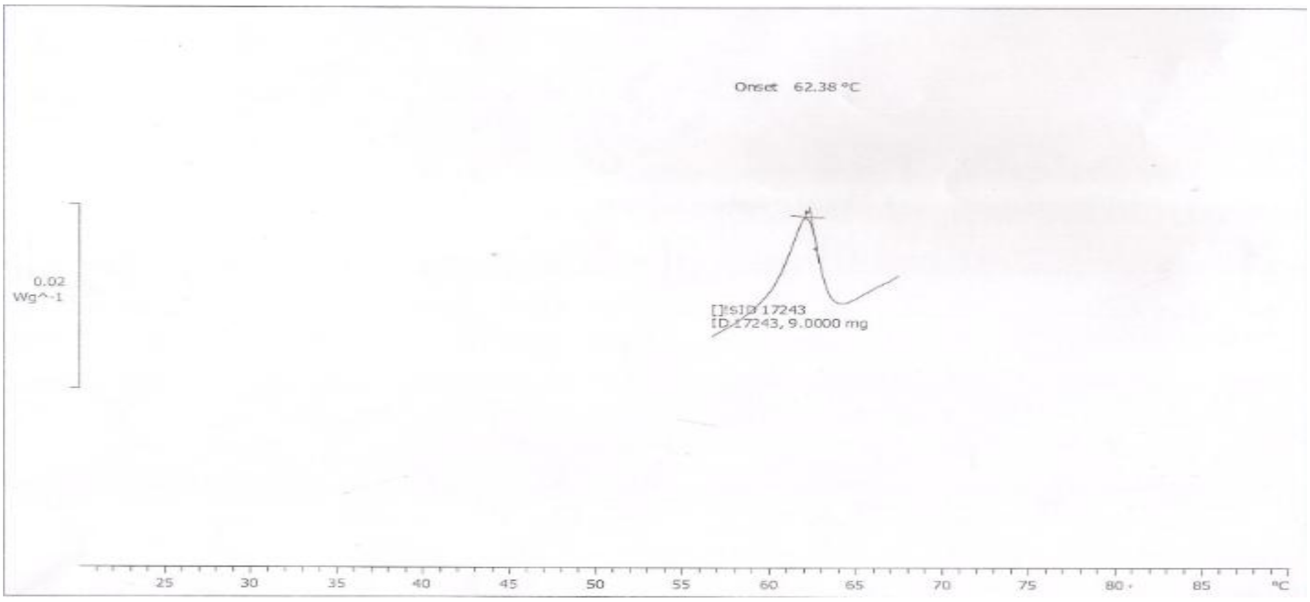


Figure (3. 51): WAT of Dar blend

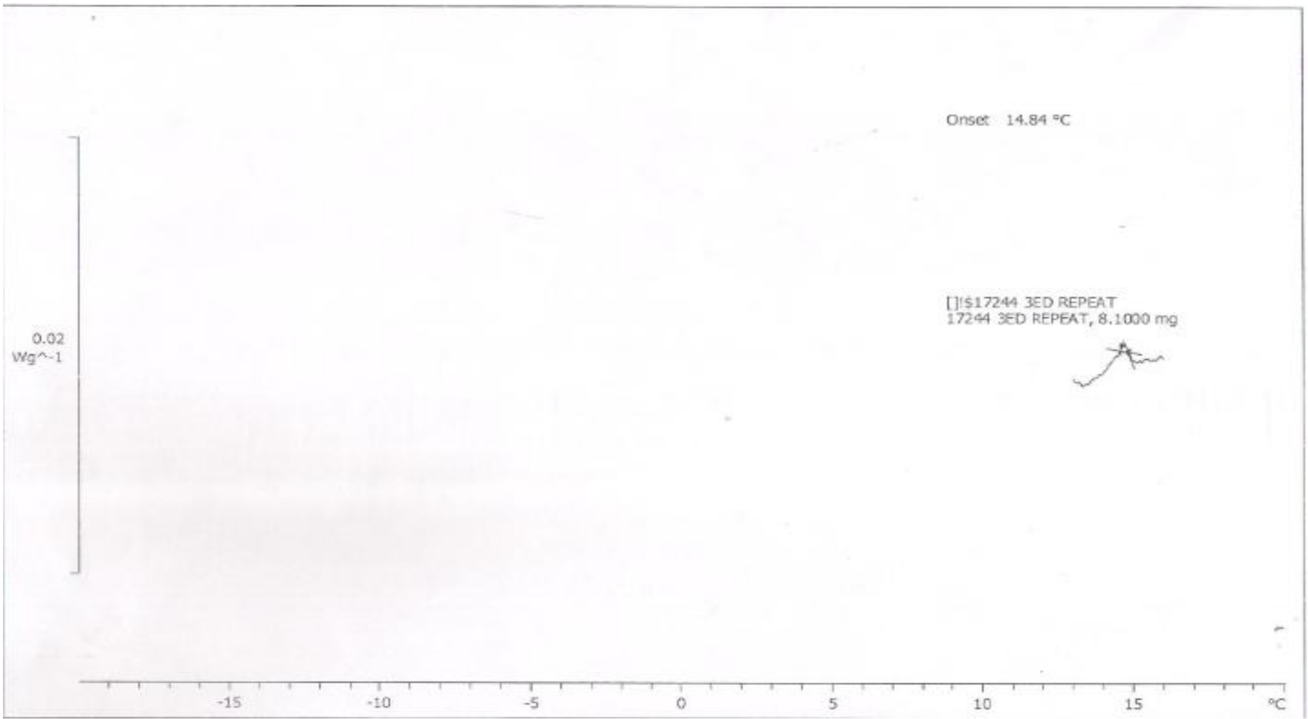


Figure (3. 52) WAT of Marib blend

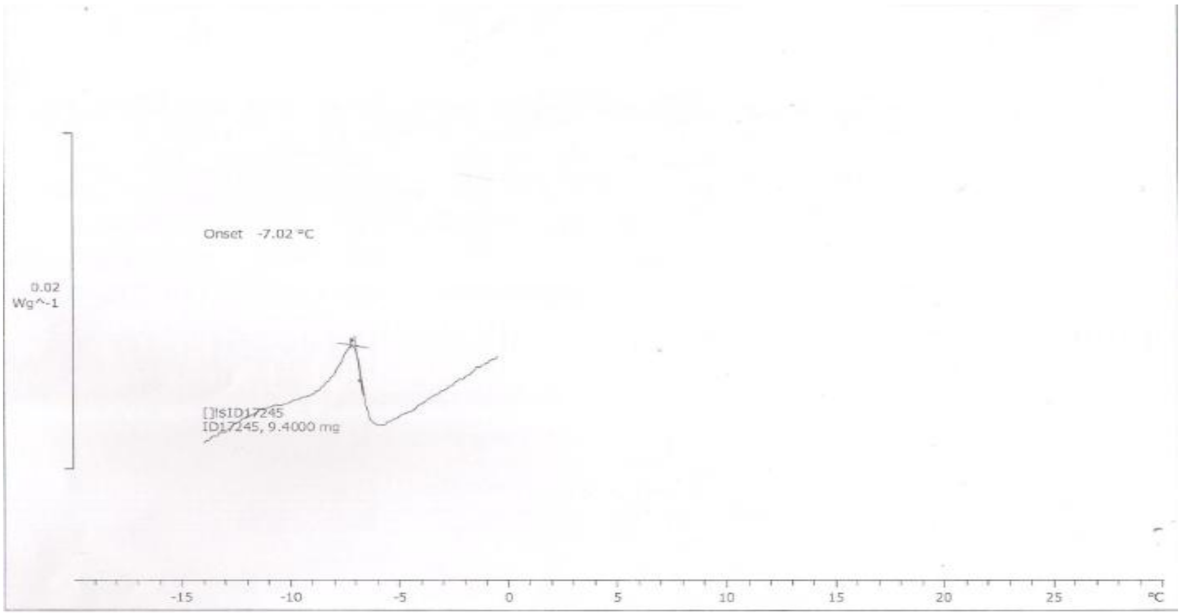


Figure (3. 53): WAT of Jannah blend

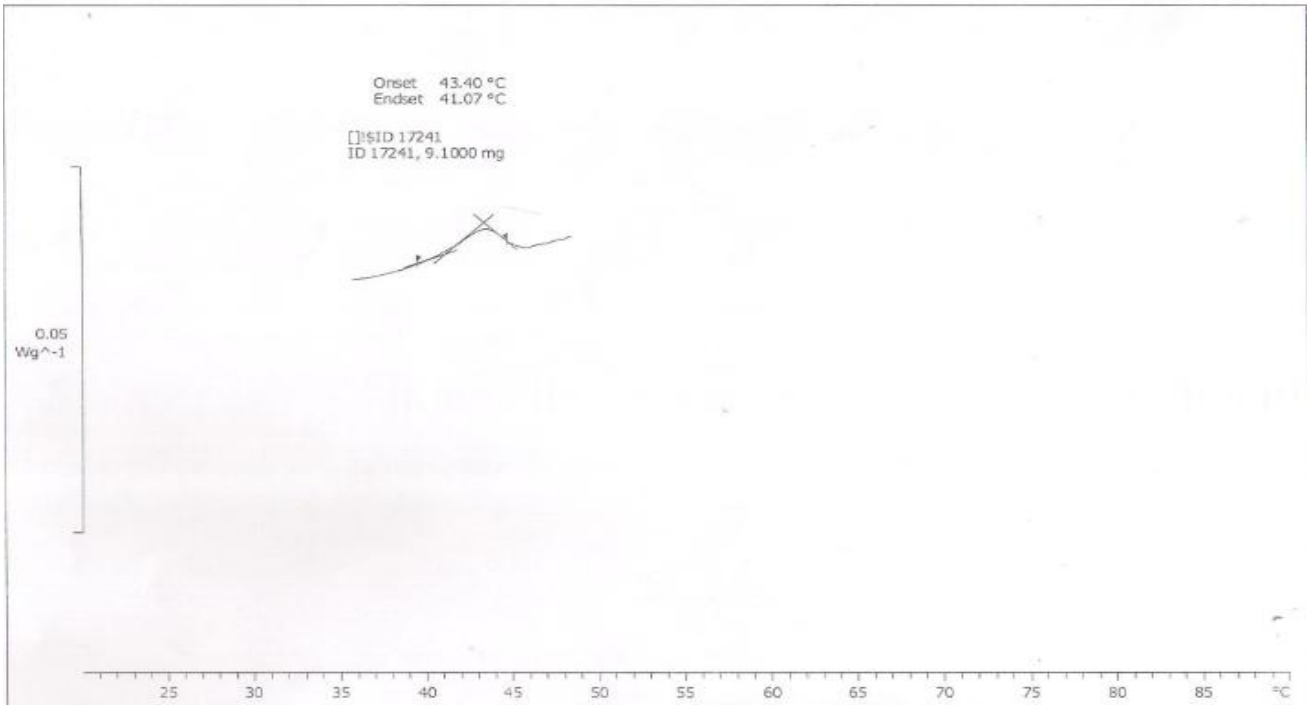


Figure (3. 54): WAT of Moga crude oil

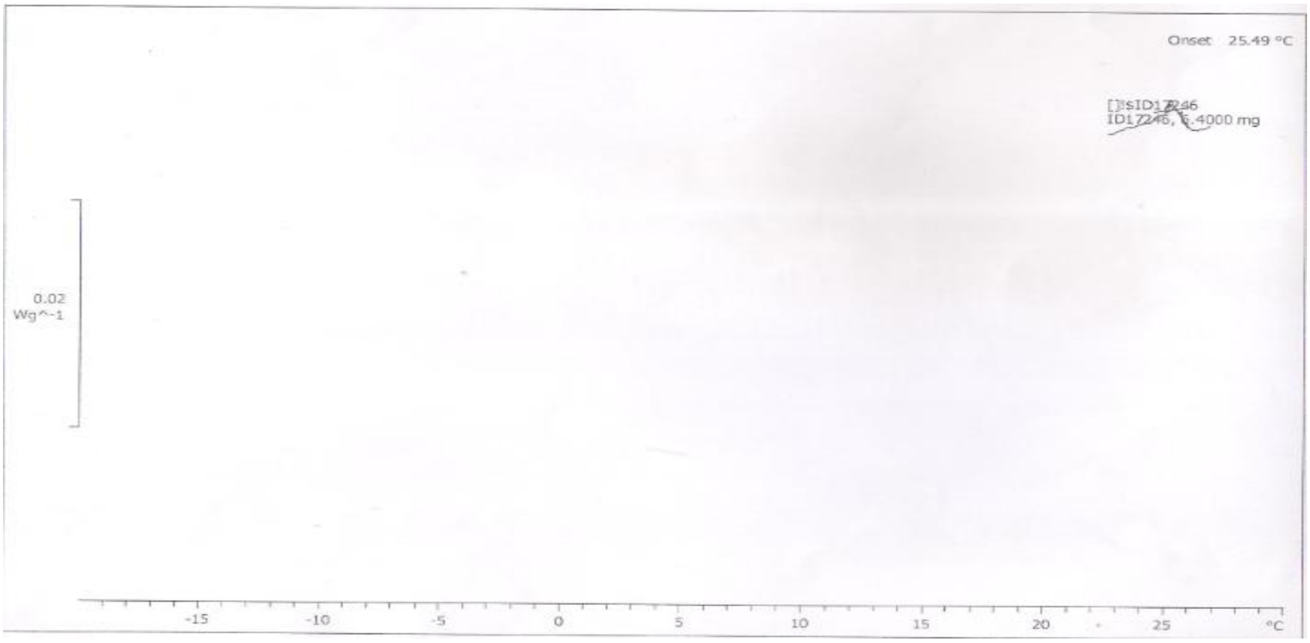


Figure (3. 55): WAT of Al -Masilah blend

Table (3-8) IR spectrum of Yemeni and Sudanese crude oil (cm^{-1}).

	OH Water	CH Alkan	CH_2 Alkan	CH_3 Alkyl	C=C Alkene	CO Carbonyl
Nile blend	3380.79	2851.55-2921.74	720.29-873.29	1462.49-1377.06	1603.11	1033.64
Dar blend	3373.26	2849-2919.83	720.29-873.29	1367.87-1460.65	1601.23	
Moga	3373.24	2852.34-2919	721.12-873.26	1367.87-1460.65	1601.53	1033.97
Marib	3382.71	2853.34	674.83-833.20	1377.51-1458.76	1605.06	1034.92
Jannah		2726.75-2919.32	722.02-873.02	1376.76-1462.08	1602.74	1032.53-115,516
Dabah	3381.63	2853.49-2925.10	726.76-873.27	1377.22-1458.60	1604.62	1032.85

From table (3-8) and figure (3. 56 - 3. 61). IR spectrum show as folowing Nile blend: pike absorption as following (3380.79) (OH) water, 2851.55-2921.74 (C-H) alkan, 1603.11(C=C) alkene, 1462.49-1377.06 alkan, 1033.64 (CO) carbonyl, 720.29-873.29 (CH_2) alkan long chain. Dar blend: 3373.26 (OH) water, 2849-2919.83 (C-H) alkan, 1601.23(C=C) alken, 1461.89-1383.59 (-CH) alkan, 720.29-873.29 (CH_2) alkan long chain.Moga: 3373.24 (OH) water, 2852.34-2919 (CH) alkan 1601.53 (C=C) alken, 1367.87-1460.65 (CH_3) alkan, 1033.97(CO) carbonyl, 721.12-873.26 (CH_2) long chain. Marib: 3382.71 (OH) water, 2853.34 (CH) alkan, 1605.06 (C=C) alken, 1377.51-1458.76 (CH) alkan, 1034.92 (CO) carbonyl, 674.83-833.20 (CH2) most long chain. Jannah: no found (OH), 2726.75-2919.32 (CH) alkan, 1602.74 (C=C) alken, 1376.76-1462.08 (CH_3) methyl (alkan), 1032.53-115516 (CO), 722.02-873.02 (CH_2) long chain. Almasilah: 3381.63 (OH) water, 2853.49-2925.10 (CH) alkan, 1604.62 (C=C) alken, 1377.22-1458.60 (CH) alkan, 1032.85 (CO), 726.76-873.27 (CH2) long chain figure (3.56-3.61) and (3.76-3.80).

3-9-IR spectrum of Yemeni and Sudanese crude oil (cm^{-1}).

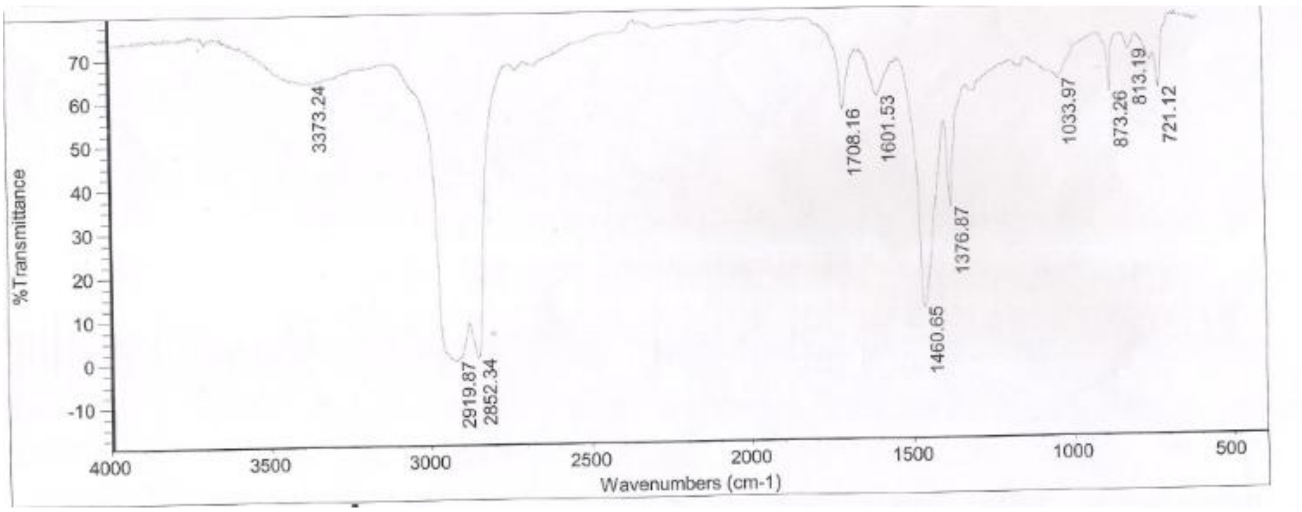


Figure (3. 56): IR spectrum of Moga crude oil.

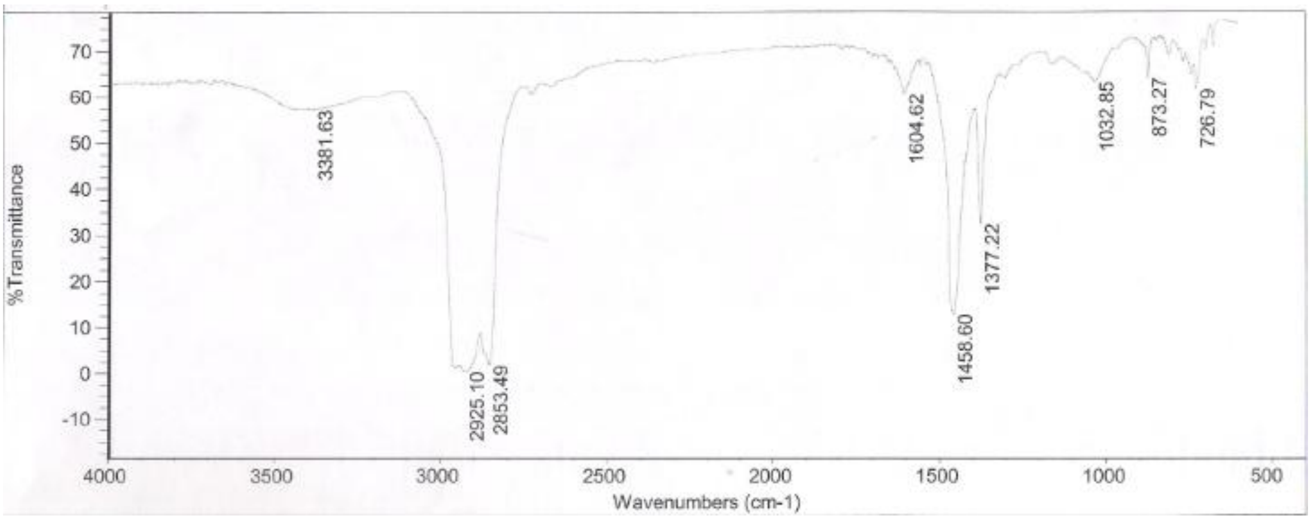


Figure (3. 57): IR spectrum of almasilah crude oil

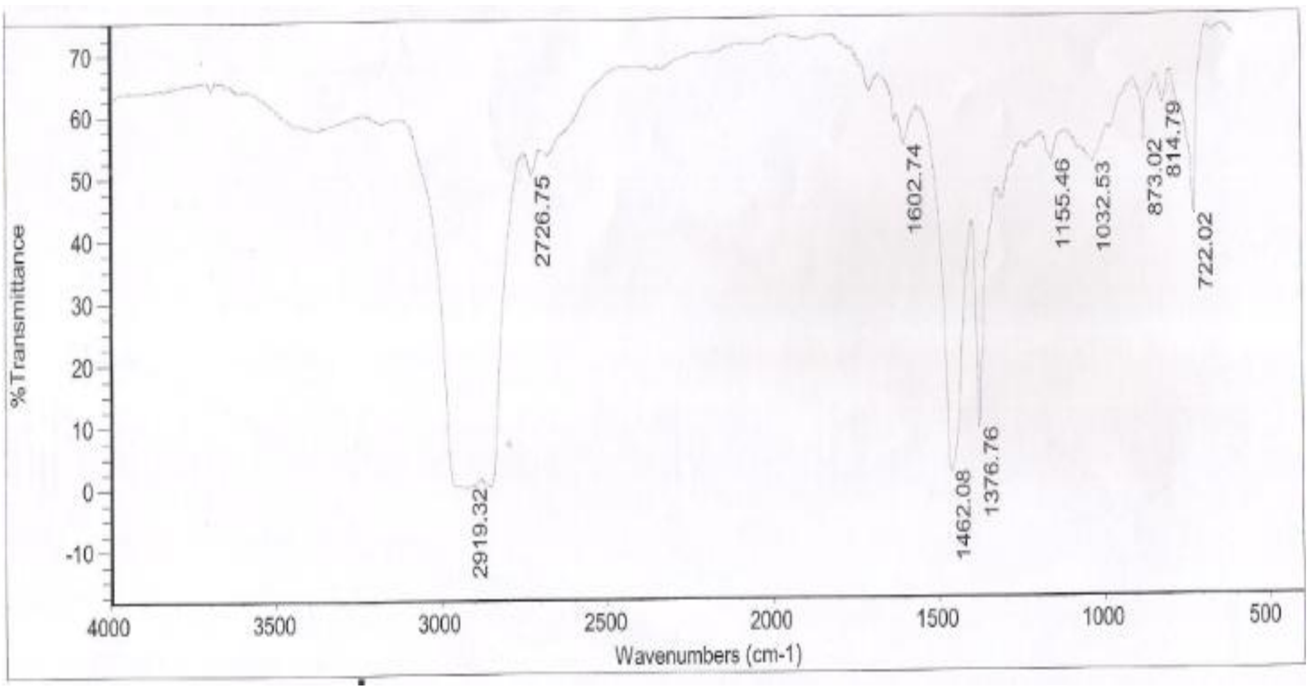


Figure (3. 58): IR spectrum of Jannah crude oil.

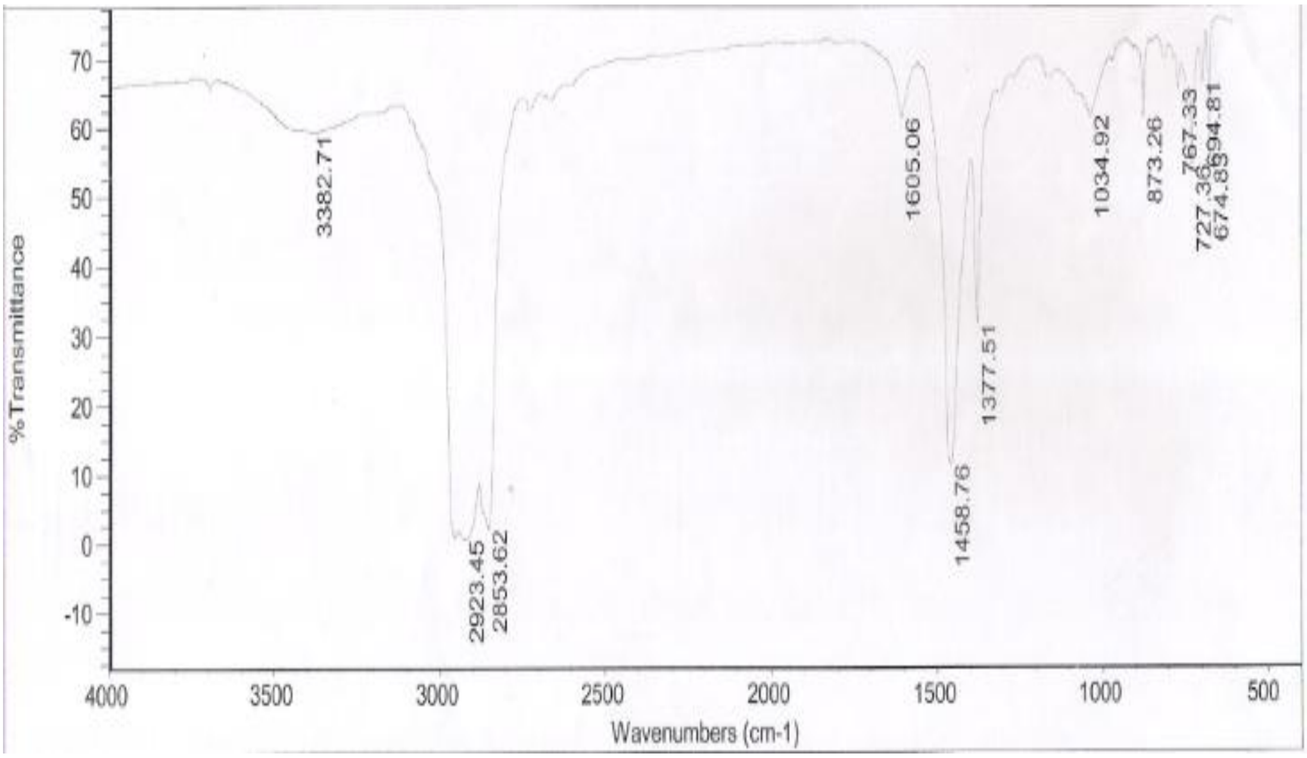


Figure (3. 59): IR spectrum of Marib crude oil.

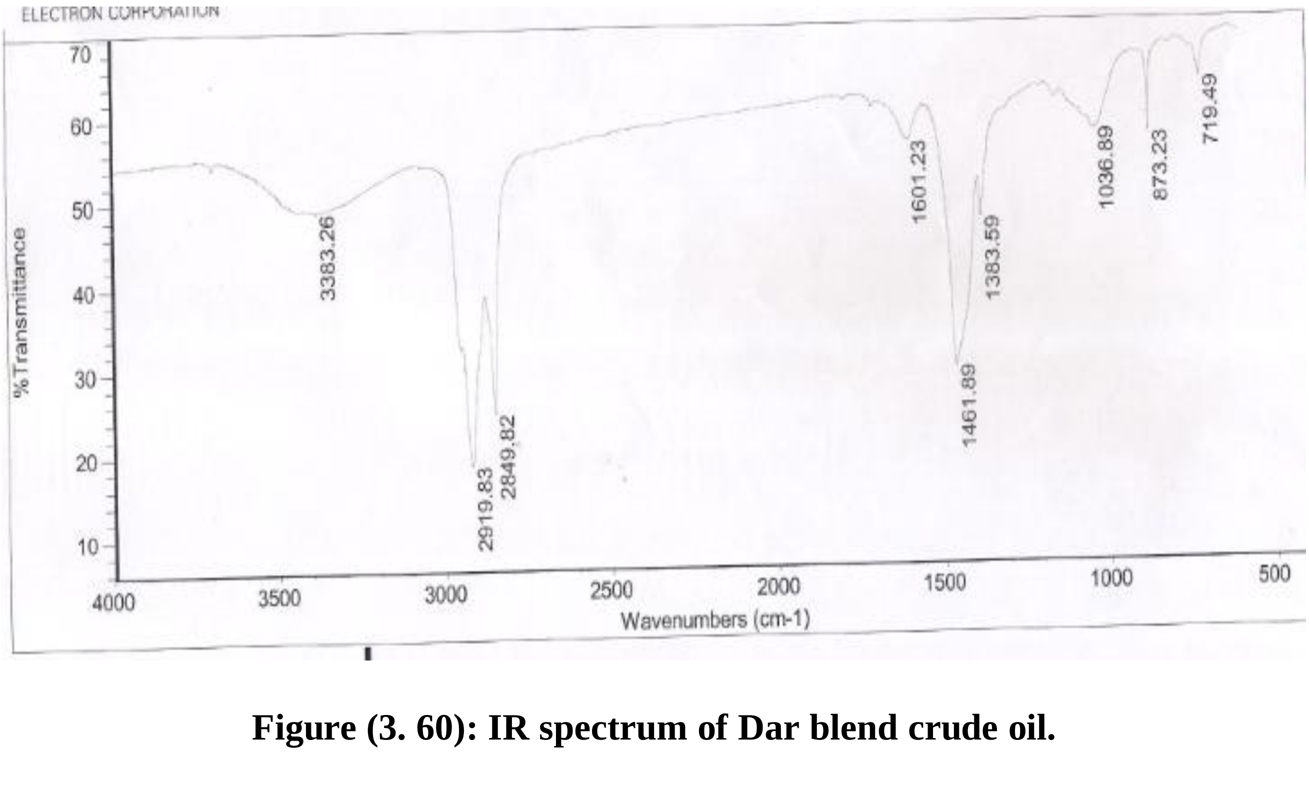


Figure (3. 60): IR spectrum of Dar blend crude oil.

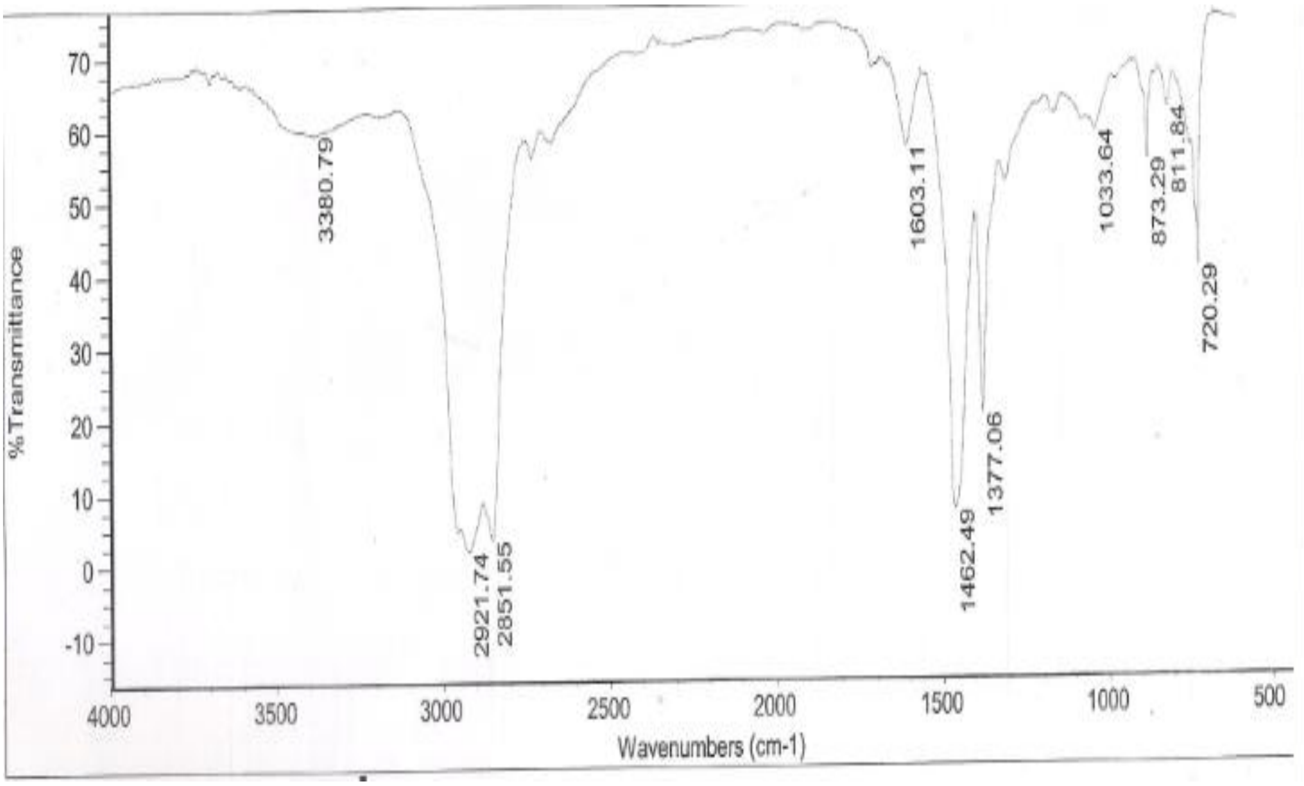


Figure (3. 61): IR spectrum of Nile blends crude oil.

Table (3. 9.1) Viscosity versus temperature in Yemeni and Sudanese crude oil

Jannah		Almasilah		Safer		Dar Blend		Nile Blend		Moga	
Viscosity (cP)	Temperature (ºC)	Viscosity (cP)	Temperature (ºC)	Viscosity (cP)	Temperature ((ºC)	Viscosity (cP)	Temperature (ºC)	Viscosity (cP)	Temperature (ºC)	Viscosity (cP)	Temperature (ºC)
49.99	75	3.33	75	1.67	74.9	141.64	75	20	75	178.30	74.9
51.66	74	3.33	74	1.67	74	143.30	74.1	21.66	74	178.30	74
53.32	72	3.33	71.9	1.67	72	148.30	72.2	20	71.8	178.30	73.8
56.65	69.9	3.33	69.8	1.67	69.8	154.97	69.9	21.66	70.1	181.63	73.1
58.32	67.9	3.33	67.7	1.67	68.1	163.30	68.2	21.66	68.1	183.29	71.9
61.65	66.2	3.33	66.2	1.67	66	174.96	66.1	23.33	66	184.96	71.2
64.99	64.2	3.33	64	1.67	64	188.29	64	23.33	64	191.63	70
69.99	62.1	3.33	62.2	1.67	62.2	206.62	61.9	24.99	61.9	194.96	69.2
74.98	60.1	3.33	59.9	1.67	59.8	226.62	59.8	26.66	59.8	201.62	67.9
81.65	58.2	3.33	57.9	1.67	58.2	248.28	58.2	28.33	57.9	208.29	67.1
86.65	56.1	3.33	55.8	1.67	56.2	281.61	56.2	31.66	55.9	214.95	66.2
94.98	54.1	3.33	54	1.67	53.8	318.27	54.1	33.33	53.9	223.29	64.9
103.31	52.2	5	52	3.33	52.2	358.26	52.2	36.66	52	231.62	64.1
113.31	49.9	5	49.9	3.33	50.3	403.25	50.2	39.99	50.1	239.95	63.2
123.31	48.1	5	48.1	3.33	48.1	468.23	48	44.99	47.9	253.28	61.9
138.30	45.9	5	46.1	3.33	46.1	531.55	46.1	49.99	46	263.28	61.1
153.30	43.9	5	44	3.33	44.1	623.20	44.1	58.32	44	273.28	60.2
168.30	42.1	5	42.1	3.33	41.9	748.17	41.9	66.65	41.9	289.94	59.1
184.96	40.1	5	40.1	3.33	40	968.13	39.9	78.32	40	301.60	58.2
209.96	38	5	38.1	3.33	38	1441.3	38.1	98.31	38.1	321.60	57
233.28	36.1	5	36.1	3.33	36			141.64	35.9	334.93	56.2
261.61	34	5	34.1	3.33	34.1			213.29	34.1	356.59	55
334.93	32	6.67	32	3.33	32			401.58	32	373.25	54.1
356.59	30.1	6.67	30.1	3.33	30			918.14	30	398.25	52.9

Table (3. 9.2) Viscosity versus temperature in Yemeni and Sudanese crude oil

Jannah		Almasilah		Safer		Nile Blend		Moga	
Viscosity (cP)	Temperature (ºC)	Viscosity (cP)	Temperature (ºC)	Viscosity (cP)	Viscosity (cP)	Viscosity (cP)	Temperature (ºC)	Viscosity (cP)	Temperature (ºC)
394.92	28	6.67	28	3.33	28.1	1523.01	29.1	416.58	52.1
399.91	27	8.33	27.8	3.33	27.9			444.91	50.9
406.58	27	8.33	27.5	5	27.6			464.90	50.2
411.58	27	8.33	27.2	3.33	27.4			498.23	49.1
416.58	27	8.33	27	3.33	27.1			534.89	47.9
422.24	26	8.33	26.4	3.3	26.6			601.54	46.1
429.91	26.5	8.33	26.1	3.33	26.4			648.20	45
436.57	26.2	8.33	25.8	3.33	26.1			696.52	44
441.57	26	8.33	25.6	3.33	25.9			751.51	42.9
448.24	25.8	8.33	25.3	3.33	25.9			809.83	41.9
456.57	25.5	8.33	25.1	3.33	25.6			871.48	40.9
463.23	25.3	8.33	24.8	3.33	25.4			939.80	39.9
469.90	25	8.33	24.5	3.33	25.1			1013.1	38.9
478.23	24.8	10	24.3	3.33	24.9			1093.1	37.9
484.90	24.5	10	24.1	3.33	24.6			1176.4	37
491.56	24.3	10	23.7	3.33	24.3			1268.1	36.1
499.89	24	10	23.5	3.33	24.1			1369.7	35.1
508.22	23.8	10	23.2	3.33	23.9			1521.3	33.9
514.89	23.6	10	23	3.33	23.7			1647.1	33
521.56	23.3	10	22.7	3.33	23.5				
529.89	23.1	11.66	22.5	3.33	23.2				

Table (3.9.3): Viscosity versus temperature in Yemeni crude oils

Jannah		Almasilah		Safer	
Viscosity (cP)	Temperature(^{0}C)	Viscosity(cP)	Temperature(^{0}C)	Viscosity(cP)	Temperatu^{0}C
539.88	22.9	11.66	22.2	3.33	23
546.55	22.6	11.66	22	3.33	22.8
554.88	22.4	11.66	21.8	3.33	22.5
564.88	22.2	11.66	21.5	3.33	22.3
571.54	21.9	11.66	21.3	3.33	21.1
581.54	21.7	13.33	21	3.33	21.8
589.87	21.5	13.33	20.8	3.33	21.6
599.87	21.3	13.33	20.6	5	21.4
608.20	21	13.33	20.3	3.33	21.2
616.54	20.8	13.33	20.1	3.33	21
628.20	20.6	15	20	5	20.7
636.53	20.4	15	19.8	5	20.5
646.53	20.2	16.66	19.6	3.33	20.3
656.53	20	16.66	19.2	3.33	20.1
666.52	19.8	16.66	19.1	3.33	20
676.52	19.6	16.66	18.9	3.33	19.7
686.52	19.4	16.66	18.7	3.33	19.5
696.52	19.1	18.33	18.2	3.33	19.2
718.18	18.7	18.33	18	3.33	18.8
728.18	18.5	20	17.8	3.33	18.6
741.51	18.3	20	17.6	5	18.3
751.51	18.1	20	17.4	3.33	18.2
763.17	17.9	21.66	17.2	3.33	18
774.83	17.7	21.66	17	3.33	17.8
786.50	17.5	21.66	16.8	3.33	17.6
796.50	17.3	12.66	16.6	3.33	17.4

Table (3.9.4): Viscosity versus temperature in Yemeni crude oil

Jannah		Almasilah		Safer	
Viscosity (cP)	Temperature(^{0}C)	Viscosity(cP)	Temperature(^{0}C)	ViscositycP	Temperature^{0}C
821.49	16.9	23.33	16.2	5	17
834.82	16.7	23.33	15.9	5	16.8
844.82	16.5	24.99	15.8	5	16.6
858.15	16.3	24.99	15.6	5	16.4
869.81	16.1	26.66	15.4	5	16.2
883.14	15.9	26.66	15.3	3.33	16
894.81	15.7	26.66	15.1	5	15.9
908.14	15.5	26.66	14.9	5	15.6
921.47	15.3	28.33	14.8	3.33	15.5
933.13	15.3	28.33	14.5	5	15.7
946.46	15.1	28.33	14.3	5	15.2
959.80	14.9	28.33	14.2	5	15
973.13	14.8	29.99	14	5	14.8
864.46	14.6	29.99	13.8	5	14.7
999.79	14.4	33.33	13.6	5	14.5
1013.12	14.2	31.66	13.4	5	14.3
1026.45	14.1	31.66	13.3	5	14.1
1039.78	13.9	33.33	13.1	5	13.9
1053.11	13.8	33.33	12.9	5	13.8
1068.11	13.6	33.33	12.8	5	13.6
1081.44	13.4	34.99	12.6	5	13.5
1094.77	13.3	34.99	12.4	5	13.3
1111.43	13.1	34.99	12.3	5	13.1
1124.76	13	36.66	11.9	5	12.9
1153.09	12.6	36.66	11.7	5	12.6

Table (3.9.5): Viscosity versus temperature in Yemeni crude oils

Jannah		Almasilah		Safer	
Viscosity (cP)	Temperature ^{0}C	Viscosity (cP)	Temperature^{0}C	Viscosity cP	Temperat^{0}C
1181.41	12.4	38.33	11.4	5	123
1196.41	12.1	38.33	11.2	5	12.2
1211.41	12	38.33	11.1	6.67	12
1226.40	11.8	39.99	10.9	5	11.9
1239.74	11.7	39.99	10.8	5	11.7
1256.40	11.5	39.99	10.6	5	11.5
1273.06	11.4	41.66	10.4	6.67	11.4
1286.39	11.2	41.66	10.4	5	11.2
1301.39	11.1	41.66	10.4	5	11.1
1316.39	10.9	41.66	10.2	5	10.9
1333.05	10.8	43.32	10	5	10.7
1349.71	10.7	43.32	9.9	5	10.6
1363.04	10.5	43.32	9.8	6.67	10.5
1378.04	10.4	43.32	9.6	6.67	10.4
139637.	10.4	43.32	9.5	5	10.4
1411.37	10.3	44.99	9.4	5	10.3.
1426.36	10.1	44.99	9.1	6.67	10.1
1443.03	10	44.99	9	6.67	9.9
1459.69	9.9	46.66	8.9	6.67	9.9
1474.69	9.7	48.32	8.7	5	9.7
1489.68	9.6	48.32	8.6	5	9.5
1509.68	9.5	48.32	8.5	6.67	9.4
1524.67	9.3	48.32	8.3	6.67	9.3
1541.34	9.2	48.32	8.1	6.67	9.2
1556.33	9	49.99	8	6.67	9
1576.33	8.9	49.99	7.9	6.67	8.8

Table (3.9.6): Viscosity versus temperature in Yemeni crude oil

Jannah		Al Masilah		Safer	
ViscositycP	Temperature(^{0}C)	Viscosity (cP)	Temperature(^{0}C)	Viscosity cP	Temperatu^{0}C
1591.33	8.8	49.99	7.8	6.67	8.7
1606.32	8.7	49.99	7.6	6.67	8.6
1624.65	8.5	51.66	7.5	6.67	8.5
1642.98	8.4	51.66	7.4	6.67	8.3
1656.31	8.4	53.32	7.2	6.67	8.2
		53.32	7	6.67	8
		53.32	6.9	6.67	7.8
		53.32	6.8	6.67	7.7
		54.99	6.7	6.67	7.6
		54.99	6.6	6.67	7.4
		54.99	6.5	6.67	7.3
		54.99	6.4	6.67	7.2
		56.65	6.2	6.67	7.1
		56.65	6.1	6.67	7
		56.65	6	6.67	6.9
		58.32	5.9	6.67	6.8
		58.32	5.8	6.67	6.7
		58.32	5.7	8.33	6.6
		58.32	5.6	6.67	6.4
		58.32	5.7	8.33	6.3
		59.99	5.6	8.33	6.2
		59.99	5.5	6.67	6.1
		59.99	5.4	6.67	6.1
		59.99	5.3	6.67	5.9
		61.65	5.2	8.33	5.8
		61.65	5.1	8.33	5.7

Table (3.9.7): Viscosity versus temperature in Yemeni crude oils

Al Masilah		Safer	
Viscosity (cP)	Temperature (^{0}C)	Viscosity (cP)	Temperature(^{0}C)
61.65	5.1	6.67	5.6
61.65	5	8.33	5.7
63.32	4.8	8.33	5.7
61.65	4.8	8.33	5.5
63.32	4.7	8.33	5.4
63.32	4.7	8.33	5.3
63.32	4.5	6.67	5.3
63.32	4.5	8.33	5.1
64.99	4.4	8.33	5
64.99	4.3	8.33	4.9
64.99	4.2	8.33	4.8
64.99	4.1	8.33	4.7
66.65	4.1	8.33	4.5
66.65	3.9	8.33	4.4
66.65	3.8	8.33	4.4
66.65	3.7	8.33	4.3
66.65	3.6	8.33	4.2
68.32	3.6	8.33	4.2
68.32	3.5	8.33	4
69.99	3.5	8.33	4
68.32	3.4	8.33	3.8
69.99	3.3	8.33	3.8
69.99	3.3	8.33	3.6
69.99	3.2	8.33	3.6
69.99	3.1	8.33	3.5

Table (3.9.8): Viscosity versus temperature in Yemeni crude oil

Al Masilah		Safer	
Viscosity (cP)	Temperature(^{0}C)	Viscosity (cP)	Temperature(^{0}C)
69.99	3	8.33	3.5
71.65	3	8.33	3.3
71.65	2.9	8.33	3.4
71.65	3	10	3.2
71.65	2.8	8.33	3.2
71.65	2.8	8.33	3.2
73.32	2.7	8.33	3
73.32	2.8	8.33	2.9
73.32	2.6	8.33	2.9
73.32	2.5	8.33	2.8
73.32	2.4	8.33	2.8
74.98	2.5	10	2.7
74.98	2.4	8.33	2.7
74.98	2.3	8.33	2.6
74.98	2.3	10	2.5
74.98	2.3	10	2.5
74.98	2.3	8.33	2.4
74.98	2.2	10	2.4
76.65	2.2	10	2.4
76.65	2	8.33	2.3
76.65	2		
76.65	1.9		
76.65	1.9		
76.65	1.9		
78.32	1.9		

Table (3.9.9): Viscosity versus temperature in Yemeni crude oil

Al Masilah	
Viscosity (cP)	Temperature(^{0}C)
78.32	1.9
78.32	1.9
78.32	1.9
78.32	1.9
78.32	1.9
78.32	1.9
78.32	1.8
78.32	1.7
78.32	1.6
78.32	1.6
78.32	1.5
78.32	1.5
78.32	1.4
78.32	1.4
79.98	1.3
79.98	1.4
79.98	1.3
79.98	1.3
79.98	1.2
79.98	1.1
79.98	1.1
79.98	1.1
79.98	1.1
81.65	1.1
81.65	1.1
81.65	1.1

Table (3.9.10): Viscosity versus temperature in Yemeni crude oil

AlMasilah	
Viscosity (cP)	Temperature(^{0}C)
81.65	0.9
81.65	0.8
81.65	0.9
83.32	1
83.32	1
81.65	0.9
83.32	0.9
81.65	0.8
83.32	0.8
83.32	0.8
83.32	0.8
83.32	0.7
83.32	0.8
83.32	0.8
83.32	0.8
83.32	0.8
83.32	0.8
83.32	0.7
83.32	0.8
83.32	0.8
83.32	0.8
83.32	0.8
83.32	0.9
84.98	0.9
83.32	1
83.32	1.1
83.32	1.1

Table (3.9.11): Viscosity versus temperature in Yemeni crude oil

Al Masilah	
Viscosity (cP)	Temperature(^{0}C)
83.32	1.1
83.32	1.1
83.32	1.1
83.32	1
83.32	0.9
83.32	1
83.32	0.9
83.32	1
83.32	1.1
83.32	1.1
83.32	1.1
83.32	1
83.32	0.9
83.32	0.9
83.32	0.9
83.32	0.9
83.32	0.8
83.32	0.8
83.32	0.8
83.32	0.7
83.32	0.6
83.32	0.6
83.32	0.6
83.32	0.6
83.32	0.6
83.32	0.5
83.32	0.5

Table (3.9.12): Viscosity versus temperature in Yemeni crude oil

Al Masilah	
Viscosity (cP)	Temperature(^{0}C)
83.32	0.4
83.32	0.4
83.32	0.3
83.32	0.3
83.32	0.3
84.98	0.2
83.32	0.2
83.32	0.2
83.32	0.1
83.32	0.1
83.32	0.1
84.98	-0.1
84.98	1
84.98	-0.3
86.65	-0.4
84.98	-0.5
86.65	-0.6
86.65	-0.7
88.31	-0.9
89.98	-0.9

From table (3-9.1) to (3-9-12) Figure (62-67) shows Viscosity versus temperature in some Yemeni

3-10-Viscosity versus temperature in some Yemeni and Sudanese crude oils.

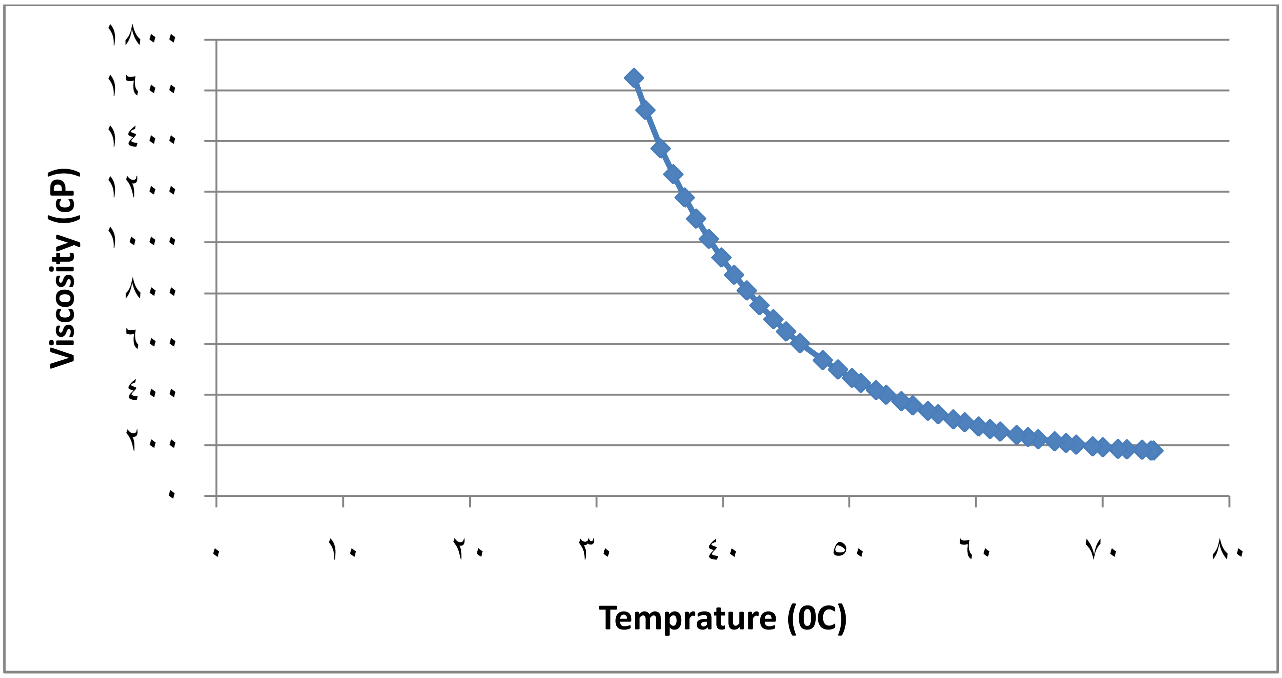


Figure (3. 62): Viscosity Vs Temperature of Moga crude oil.

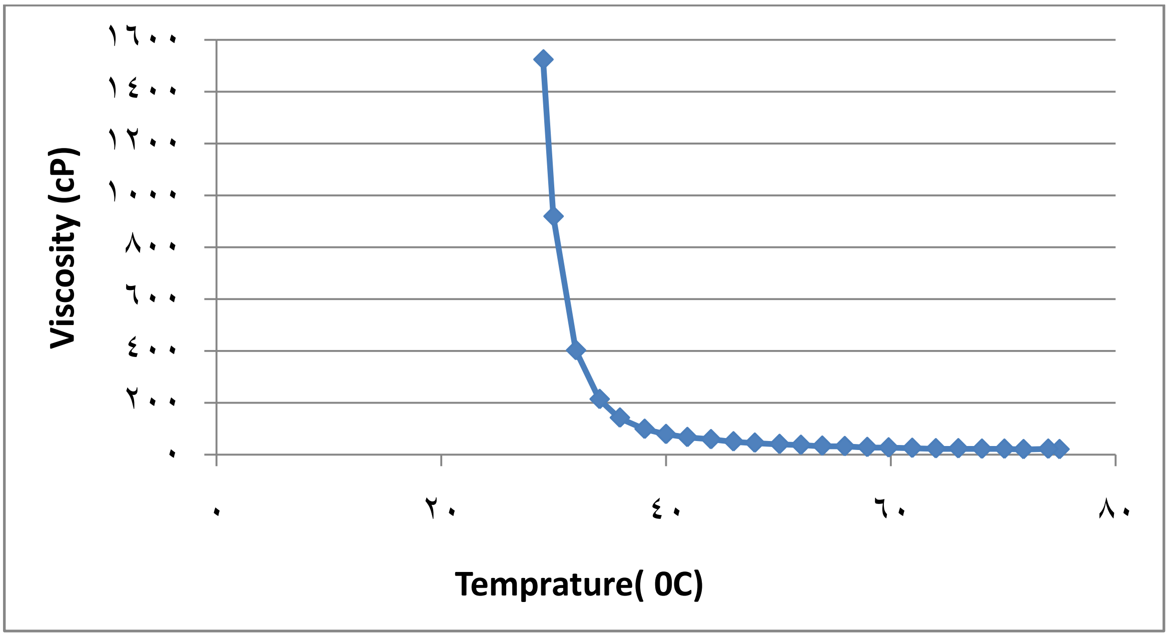


figure (3. 63): Viscosity Vs Temperature of Nile blend crude oil

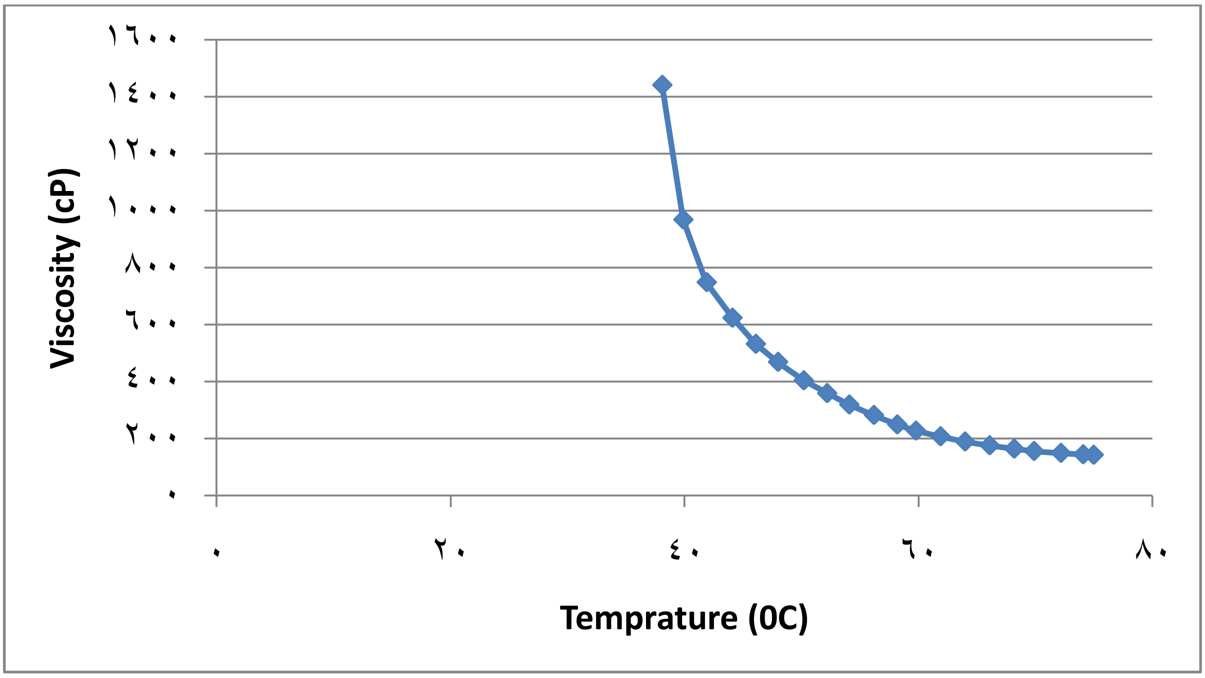


figure (3. 64): Viscosity Vs Temperature of Dar blend crude oil

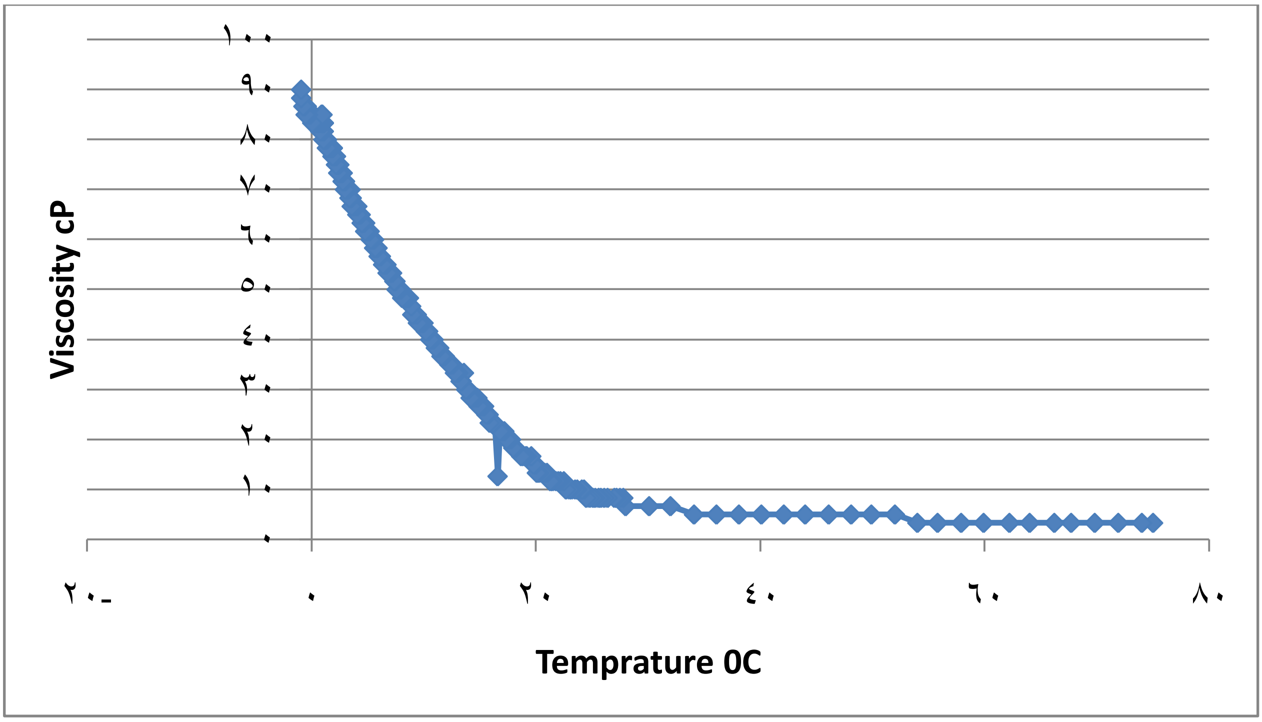


Figure (3. 65): Viscosity VS Temperature of Almasilah crude oil

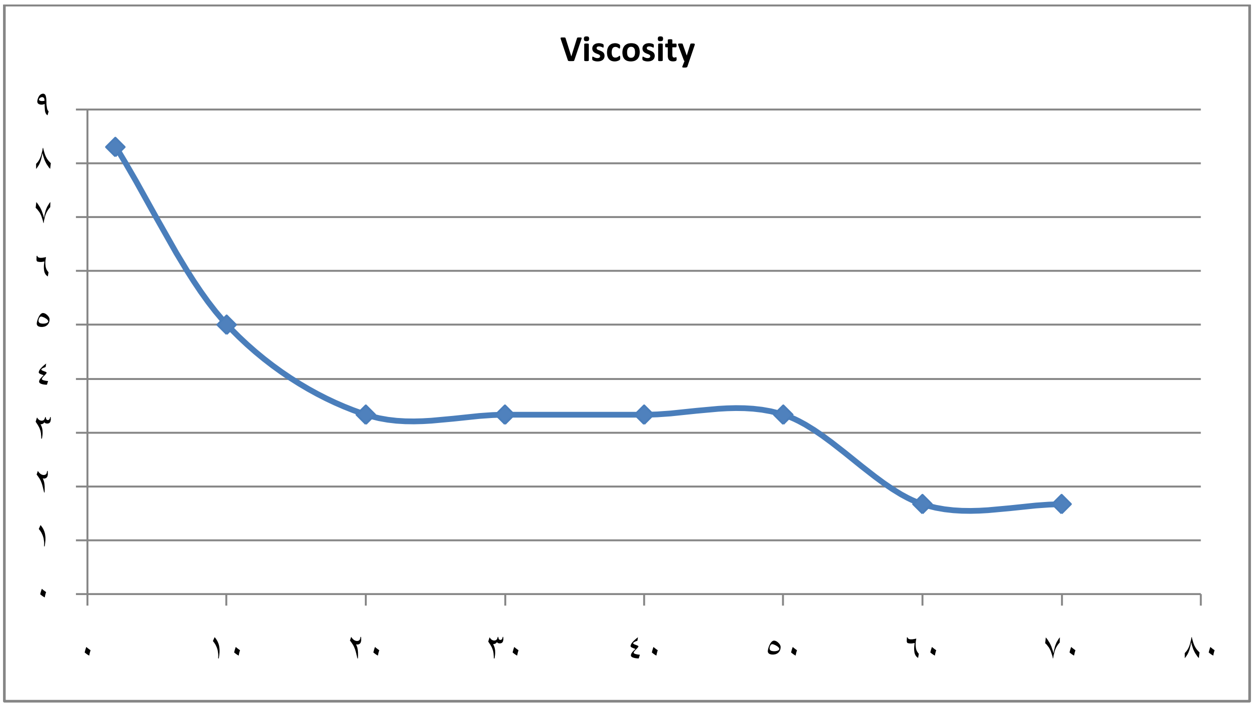


Figure (3. 66): Viscosity Vs Temperature of Safer crude oils

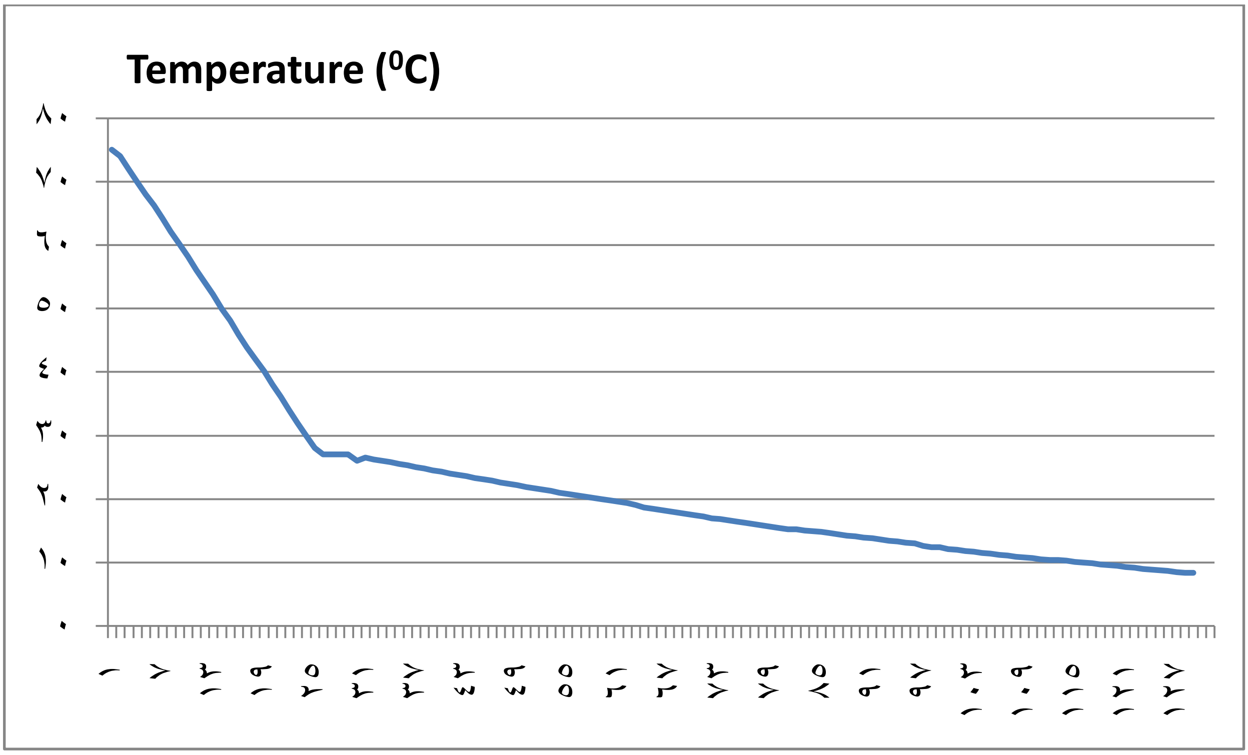


Figure (3. 67): Viscosity VS Temperature of Jannah crude oil.

Table (3.10) V/Ni and Ni/V in Yemeni and Sudanese crude oil

	Yemen			Sudan		
	Jannah	Almasyla	Safer	Dar blend	Nile blend	Moga
V/Ni	o.5516	0.44	0.29	0.01332	0.01310	0.02187
NI/V	1.92	2.82	3.49	75.06	32.24	45.71

From table (3-10) the range of V/ Ni ratio in Yemeni crude oil was found to be (0.29 – 0.5516), Ni/V (1.92- (0.009-3.15), the range of V/ Ni ratio in Sudanese crude oil was found to be (0.013 – 0.021), Ni/V (32.24- 75.06) show figure (3.68, 3.69) respectively.

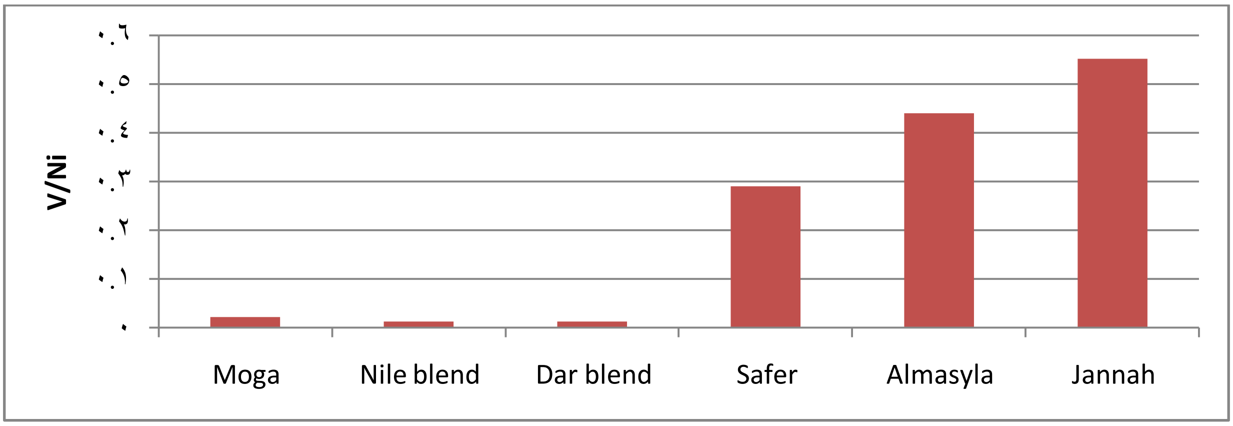


Figure (3. 68): Ratio V/Ni in Yemeni and Sudanese crude oil

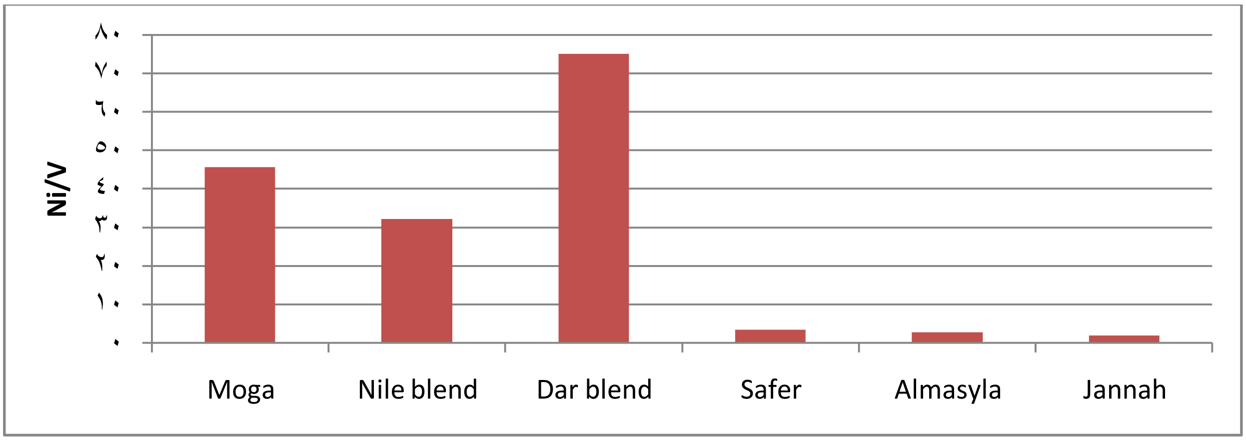


Figure (3. 69): Ratio V/Ni in Yemeni and Sudanese crude oil

Table (3.11): Compositional analysis using GC-FID of the Jannah crude oil sample

Component	Area	Area%	Component	Area	Area%
n-C3	671	0.1748	n-Butylbenzene	1435	0.3739
n-C4	1925	0.5015	n-C11	6908	1.7998
i-C5	1081	0.2816	1,2,4,5-Tetramethylbenzene	2742	0.7144
n-C5	648	0.1688	n-C12	4779	1.2451
2-MC5	1026	0.2673	n-C13	1985	0.5172
3-MC5	588	0.1532	n-C14	651	0.1696
n-C6	1022	0.2663	n-C15	1387	0.3614
2,2,4-DMC4	838	0.2183	n-C16	3172	0.8264
Benzene	1418	0.3694	n-C17	5873	1.5301
2,3-DMC5	546	0.1423	Pyristan	2439	0.6354
2-MC6	802	0.2089	n-C18	12748	3.3213
3-MC6	1104	0.2876	Phytane	6040	1.5736
n-C7	1196	0.3116	n-C19	18052	4.7031
2,2-DMC6	1973	0.5140	n-C20	22283	5.8055
Toluene	20350	5.3019	n-C21	27104	7.0615
4-MC7	870	0.2267	n-C22	28068	7.3127
n-C8	1852	0.4825	n-C23	24236	6.3143
2,5-MC7	715	0.1863	n-C24	11225	2.9245
Ethylbenzene	8902	2.3193	n-C25	7184	1.8717
(M+P)xylene	20488	5.3378	n-C26	14777	3.8499
2-MC8	640	0.1667	n-C27	17483	4.5549
o-xylene	9442	2.4600	n-C28	19879	5.1791
n-C9	1314	0.3423	n-C29	17232	4.4895
n-Propylbenzene	2777	0.7235	n-C30	548	0.1428

1,2,4-Trimethylbenzene	15232	3.9684	n-C31	14227	3.7066
n-C10	1031	0.2686	n-C32	12920	3.3361

3-11-GC Specroscopy analysis of Yemeni and Sudanese crude oils.

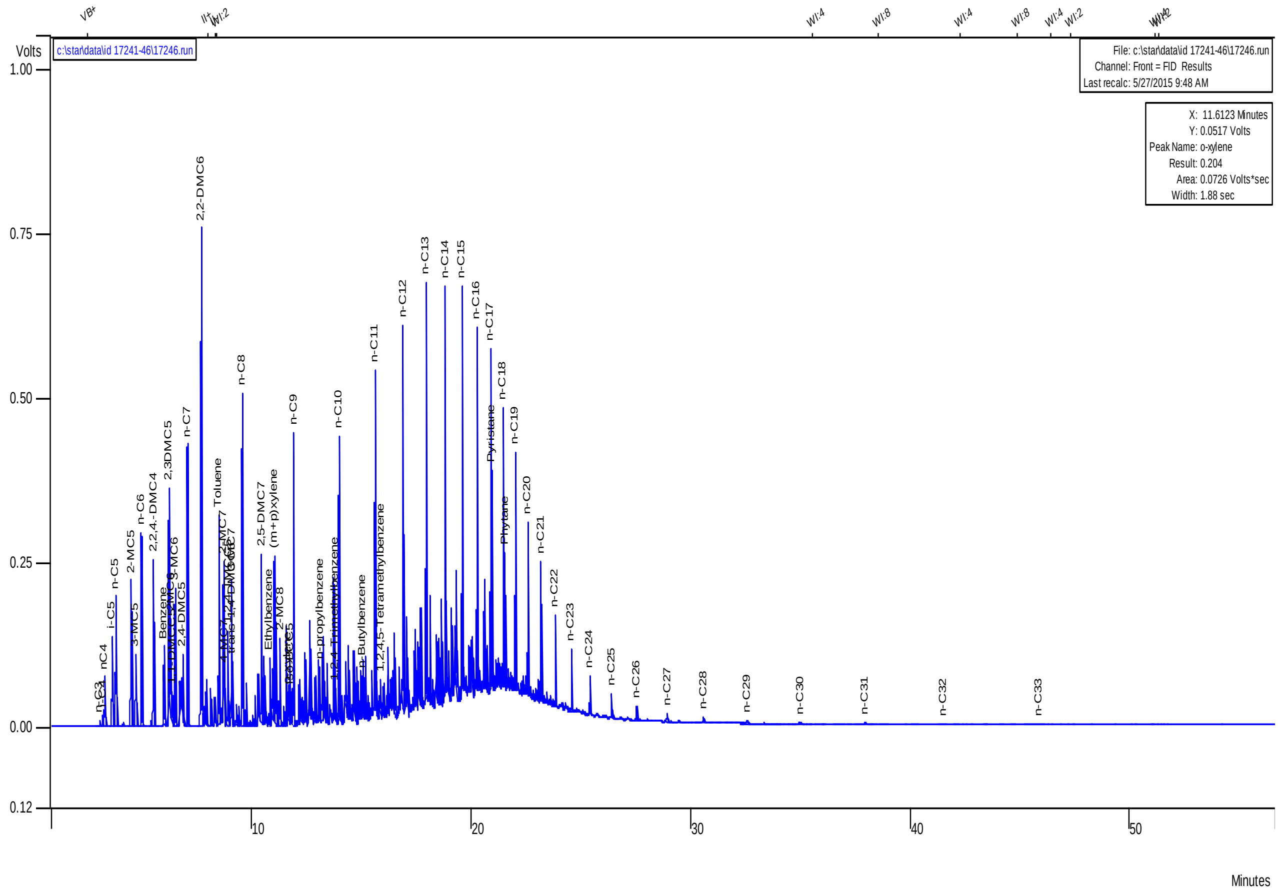


Figure (3.70): Representative whole oil using GC-FID fingerprint for Jannah crude oil sample.

Table (3.12): Compositional analysis using GC-FID of the Al-Masilah crude oil sample.

Component	Area	Area%	Component	Area	Area%
n-C3	23032	0.0959	n-Butylbenzene	99966	0.4162
i-C4	50607	0.2107	n-C11	802736	3.3423
n-C4	208750	0.8692	1,2,4,5-TMB	96415	0.4014
i-C5	399327	1.6627	n-C12	813528	3.3873
n-C5	567953	2.3648	n-C13	1043483	4.3447
2-MC5	748782	3.1177	n-C14	713737	2.9718
3-MC5	344055	1.4325	n-C15	714715	2.9758
n-C6	920056	3.3808	n-C16	635061	2.6442
2,2,4-DMC4	744223	3.0987	n-C17	590487	2.4586
Benzene	320976	1.3364	Pyristane	313474	1.3801
2,3-DMC5	874914	3.6428	n-C18	445697	1.8557
2MC6	294906	1.2279	Phytane	199851	0.8321
1,1DMCC5	98085	0.4084	n-C19	418842	1.7439
3-MC6	563018	2.3442	n-C20	297844	1.2401
2,4-DMC5	156412	0.6512	n-C21	250858	1.0445
n-C7	1049819	4.3711	n-C22	208078	0.8664
2,2-DMC6	2024721	8.4303	n-C23	156703	0.6525
Toluene	675928	2.8143	n-C24	104065	0.4333
2-MC7	378345	1.6128	n-C25	74717	0.3011
4-MC7	10944	0.0456	n-C26	59281.00	0.2468
1,2,4-TMCC5	337421	1.4049	n-C27	39996.00	0.1665
3-MC7	312604	1.3016	n-C28	27607.00	0.1149
Trans 1,4-DMCC6	75071	0.3126	n-C29	21478.00	0.0894
n-C8	1126704	4.6912	n-C30	13495.00	0.0562
2,5DMC7	524732	2.1848	n-C31	9876.00	0.0411
Ethylbenzene	182723	0.7608	n-C32	8518.00	0.0355
(M+P)xylene	571671	2.3802	n-C33	4703	0.0196
2-MC8	280032	1.1660			
o-xylene	72571	0.3022			
Iso-BCC5	65992	0.2748			

n-C9	850688	3.5420			
n-propylbenzene	133091	0.5541			
1,2,4-Trimethylbenzene	70162	0.2921			
n-C10	766780	3.1926			

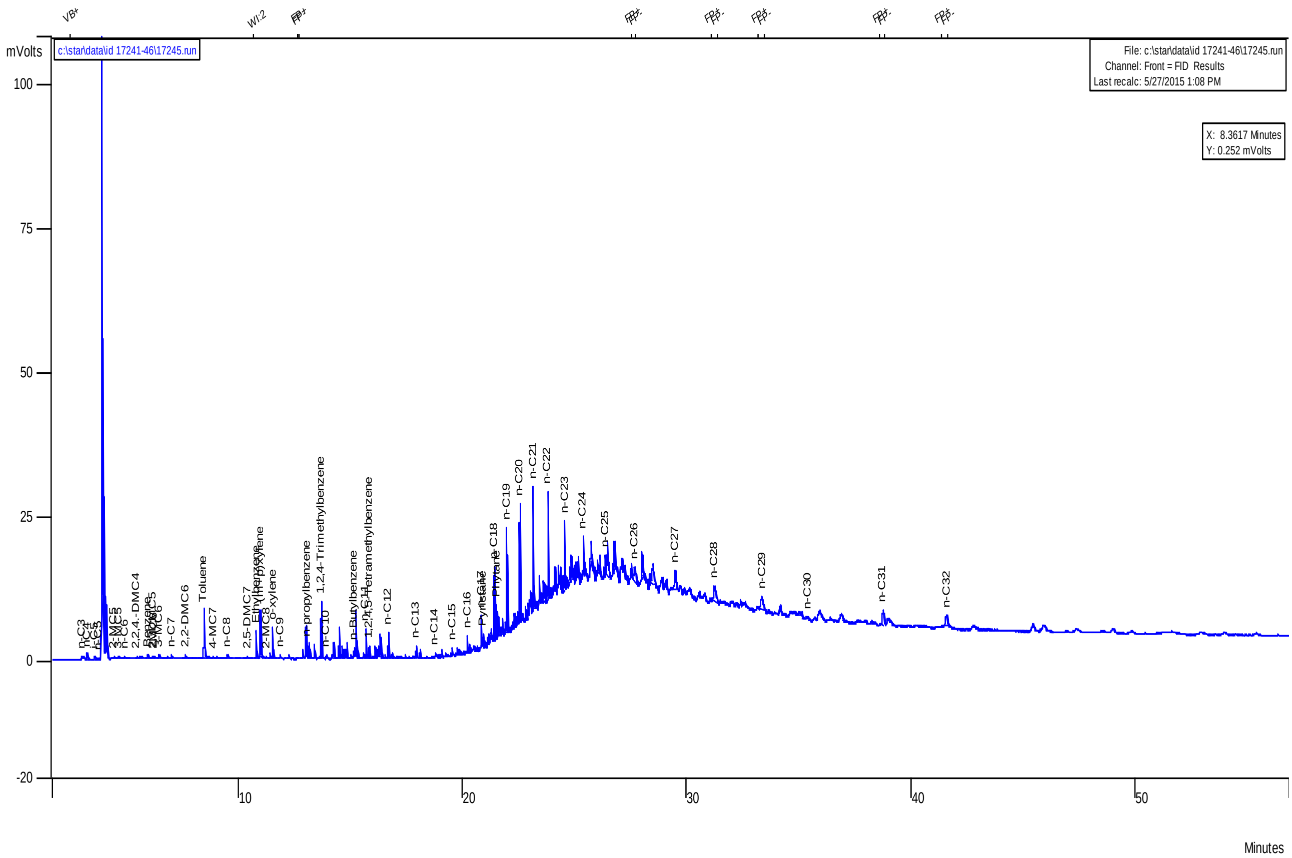


Figure (3.71): Representative whole oil using GC-FID fingerprint for AL-Masilah crude oil sample.

Table (3.13) Compositional analysis using GC-FID of the safer crude oil sample

Component	Area	Area%	Component	Area	Area%
n-C2	4077	0.0099	n-Propylbenzene	157831	0.3841
n-C3	176597	0.4297	1,4 Trimethylebenzene	72966	0.1776
i-C4	270550	0.6584	n-C10	968546	2.3569
n-C4	1486419	3.6171	n-Butylebenzene	98324	0.2393
i-C5	2341347	5.6975	n-C11	874957	2.1291
n-C5	3293320	8.0141	1,2,4,5-Tetramethylbenzene	92882	0.2260
2-MC5	1925859	4.6864	n-C12	775646	1.8875
3-MC5	794882	1.9343	n-C13	868253	2.1128
n-C6	2271064	5.5265	n-C14	584118	1.4214
2,2,4-DMC4	1363335	3.3176	n-C15	619514	1.5075
Benzene	1344531	3.2718	n-C16	478524	1.1645
2,3-DMC5	1990282	4.8432	n-C17	451808	1.0994
2-MC6	642898	1.5644	Pyristane	263559	0.6414
1,1-DMCC5	184735	0.4495	n-C18	334042	0.8129
3-MC6	841834	2.0485	Phytane	164427	0.4001
2.4-DMC5	316098	0.7692	n-C19	322593	0.7850
n-C7	1839675	4.4702	n-C20	236637	005758
2.2-dmc6	2842430	6.9169	n-C21	207474	0.5049
Toluene	1678862	4.0854	n-C22	184119	0.4480
2-MC7	586107	1.4263	n-C23	152814	0.3719
4-mc7	76089	0.1852	n-C24	109935	0.2675
1.2,4TMCC5	333683	0.8120	n-C25	90056.00	0.2191
3-MC7	415136	1.0102	n-C26	68156.00	0.1659
Trans-1.4DMCC6	131209	0.3193	n-C27	59957.00	0.1459
n-C8	1654768	4.0268	n-C28	45410.00	0.1105
2.5-DMC7	640102	1.5576	n-C29	40743.00	0.0991
Ethylbenzene	294022	0.7155	n-C30	29042.00	0.0707

(M+P)xylene	959760	2.3355	n-C31	25226.00	0.0614
2-MC8	336362	0.8185	n-C32	22268.00	0.0542
o-xylene	3863363	0.9402	n-C33	16677.00	0.0406
Iso-BCC5	69883	0.1701	n-C34	7882.00	0.0192
n-C9	1180282	2.8721			

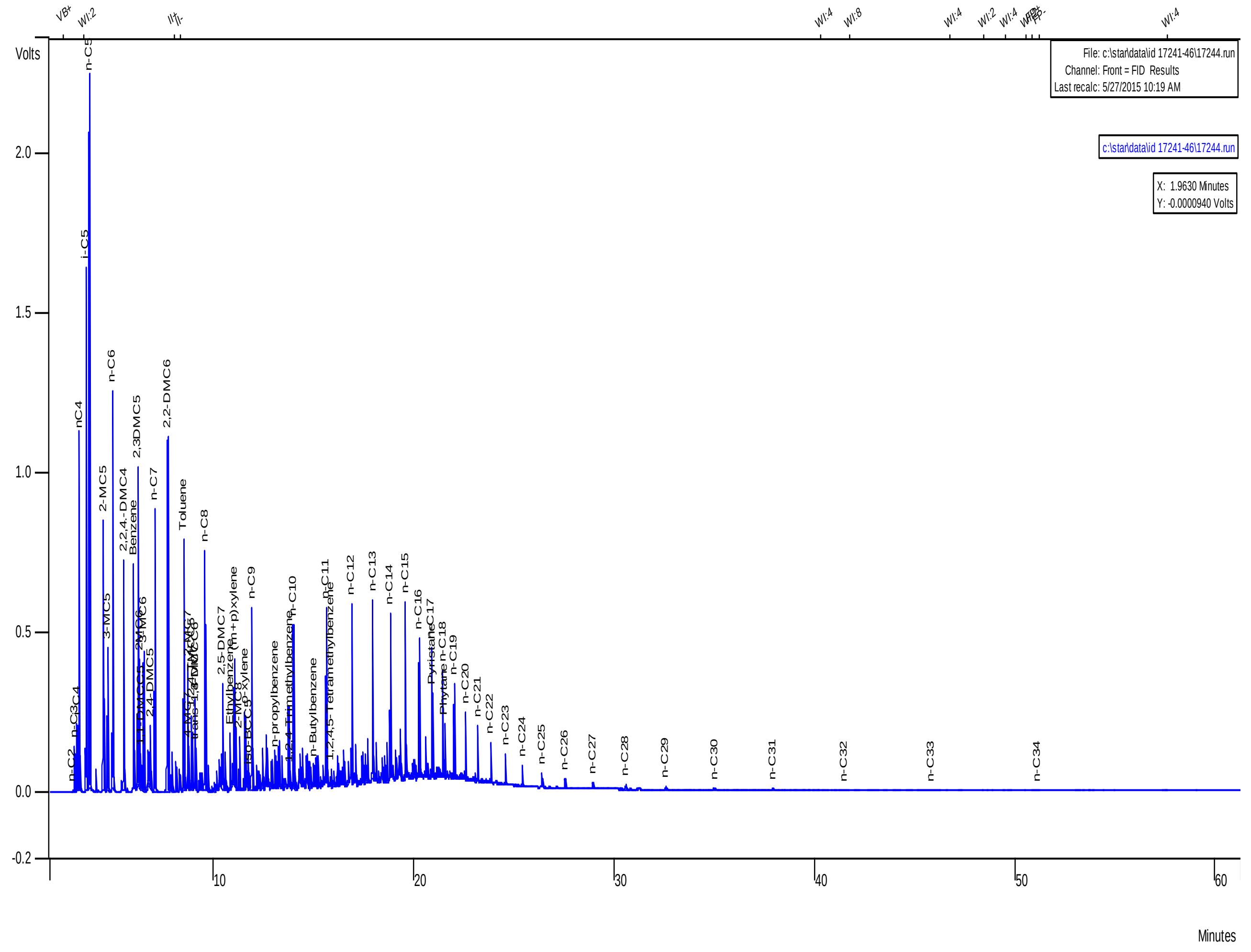


Fig 3.72: Representative whole oil using GC-FID fingerprint for safer crude oil sample.

Table (3.14): Compositional analysis using GC-FID of the Moga crude oil sample

Component	Area	Area%	Component	Area	Area%
2-MC5	848	0.0392	1,2,4,5-Tetramethylbenzene	11129	0.5139
n-C6	2506	0.1157	n-C12	49286	2.2757
2,2,4-DMC4	2562	0.1183	n-C13	47946	2.1723
2,3-DMC5	6234	0.2879	n-C14	54926	2.5362
2-MC6	1828	0.0844	n-C15	83989	3.8781
1,1-DMCC5	943	0.0435	n-C16	107048	4.9429
3-MC6	4509	0.2082	n-C17	119772	5.5304
2,4-DMC5	2866	0.1323	Pyristane	43146	1.9922
n-C7	14225	0.6568	n-C18	118430	4.4684
2,2-DMC6	37037	1.7102	Phytane	23345	0.0779
Toluene	4401	0.2032	n-C19	116338	5.3764
2-MC7	5043	0.2329	n-C20	84472	3.9004
1,2,4-TMCC5	3290	0.1519	n-C21	128456	5.9314
3-MC7	7516	0.3470	n-C22	110357	5.0956
Trans-1,4DMCC6	2892	0.1335	n-C23	84949	3.9225
n-C8	12070	0.5573	n-C24	76363	3.5260
2,5-DMC7	15851	0.7319	n-C25	87414	4.0363
Ethylbenzene	3229	0.1491	n-C26	93630	4.3233
(m+p)xylene	19955	0.9214	n-C27	95888	4.4276
2-MC8	8978	0.4146	n-C28	68752	3.1746
o-xylenen	3295	0.1521	n-C29	75076	3.4666
Iso-BCC5	2491	0.1150	n-C30	43542	2.0105
n-C9	30903	1.4269	n-C31	48548	2.2417
npropylbenzene	6700	0.3094	n-C32	70346	3.2482
1,2,4,5-TMB	4029	0.1860	n-C33	40675	1.8781
n-C1o	34527	1.5943			
n-Butylbenzene	1500	0.0693			

n-C11	42460	1.9606			

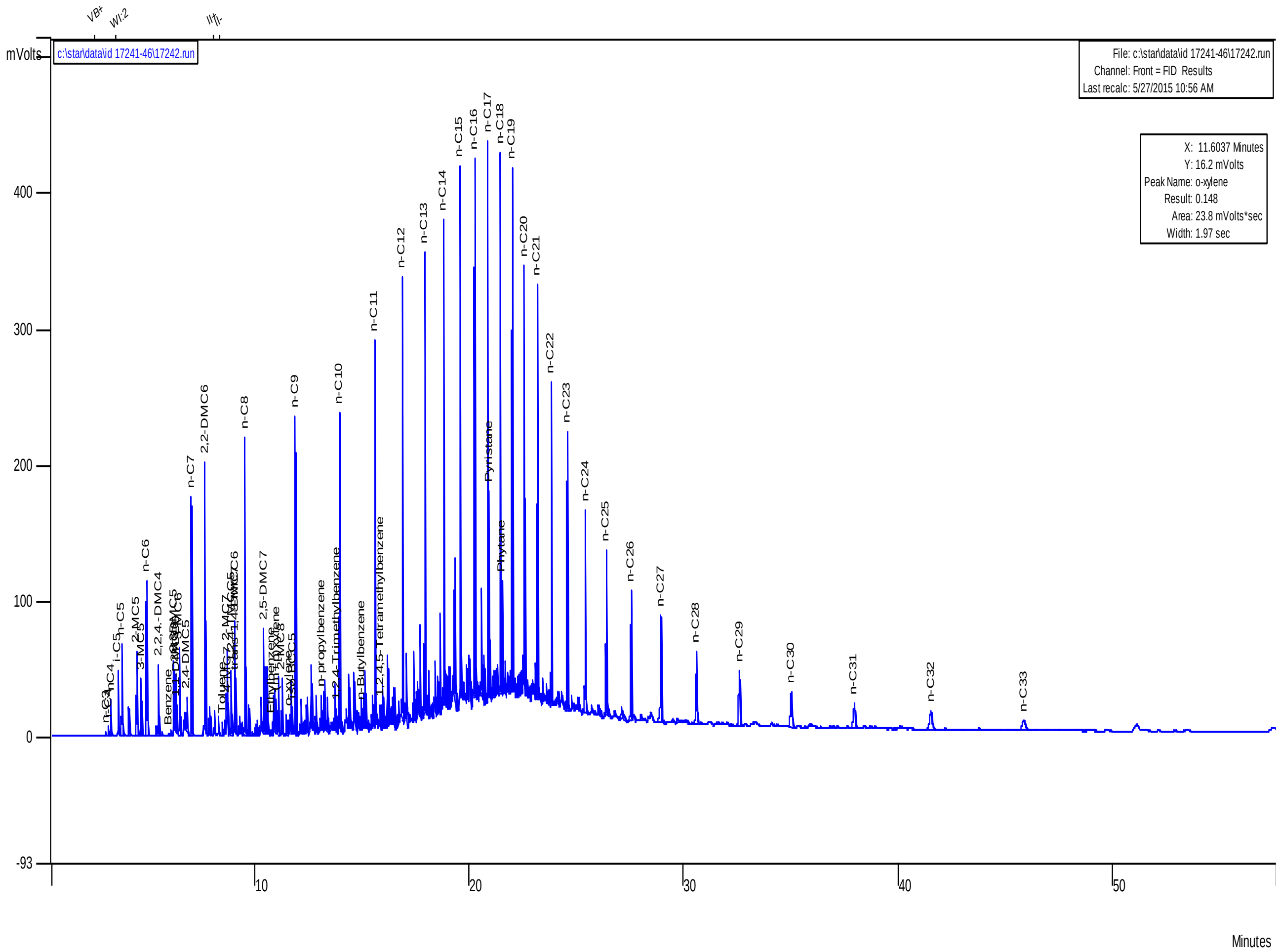


Figure (3.73): Representative whole oil using GC-FID fingerprint for Moga crude oil sample.

Table (3.15) Compositional analysis using GC-FID of the Dar blend crude oil sample.

Component	Area	Area%	Component	Area	Area%
n-C3	719	0.006	n-propylbenzene	8365	0.0764
i-C4	1803	0.0165	1,2,4-TMB	7949	0.0726
n-C4	4989	0.0455	n-C10	303398	2.7692
i-C5	10391	0.0948	n-Butylbenzene	9037	0.0825
n-C5	16840	0.1537	n-C11	337658	3.0818
2-MC5	26064	0.2379	1,2,4,5-TMB	6429	0.0578
3-MC5	13524	0.1234	n-C12	384042	3.5053
n-C6	62239	0.5681	n-C13	411178	3.7530
2,2,4-DMC4	16726	0.1527	n-C14	410123	3.7433
Benzene	2148	0.0196	n-C15	444186	4.0543
2,3-DMC5	21758	0.1986	n-C16	464269	4.2376
2-MC6	19459	0.1776	n-C17	460670	4.2047
1,1-DMCC5	5674	0.0518	Prystane	91035	0.8309
3-MC6	29005	0.2647	n-C18	425502	3.8837
2.4-DMC5	10534	0.0961	Phytane	45395	0.4143
n-C7	132213	1.2068	n-C19	434188	3.9630
2,2-DMC6	87200	0.7959	n-C20	416000	3.7970
Tolune	4328	0.0395	n-C21	432373	3.9464
2- MC7	31850	0.2907	n-C22	457387	401747
4-MC7	1670	0.0152	n-C23	478646	4.3688
1,2,4-TMCC5	27417	0.2502	n-C24	463148	4.2273
3-MC7	34603	0.3158	n-C25	464585	4.2404
Trans1,4-DMCC6	9738	0.0889	n-C26	482687.00	4.4057
n-C8	221231	2.0193	n-C27	499484.00	4.5590
2,5-DMC7	41370	0.3776	n-C28	411279.00	3.7539
Ethylebenzene	5393	0.0492	n-C29	379414.00	3.4631
(m+p)xylene	10164	0.0.0928	n-C30	303065	2.7662
2-MC8	27423	0.2503	n-31	252206.00	2.3020
o-xylene	7623	0.0696	n-C32	252638.00	2.3059
so-BCC5	7680	0.0701	n-C33	165028.00	1.5063

n-C9	258292	2.3575	n-C34	104620.00	0.9549

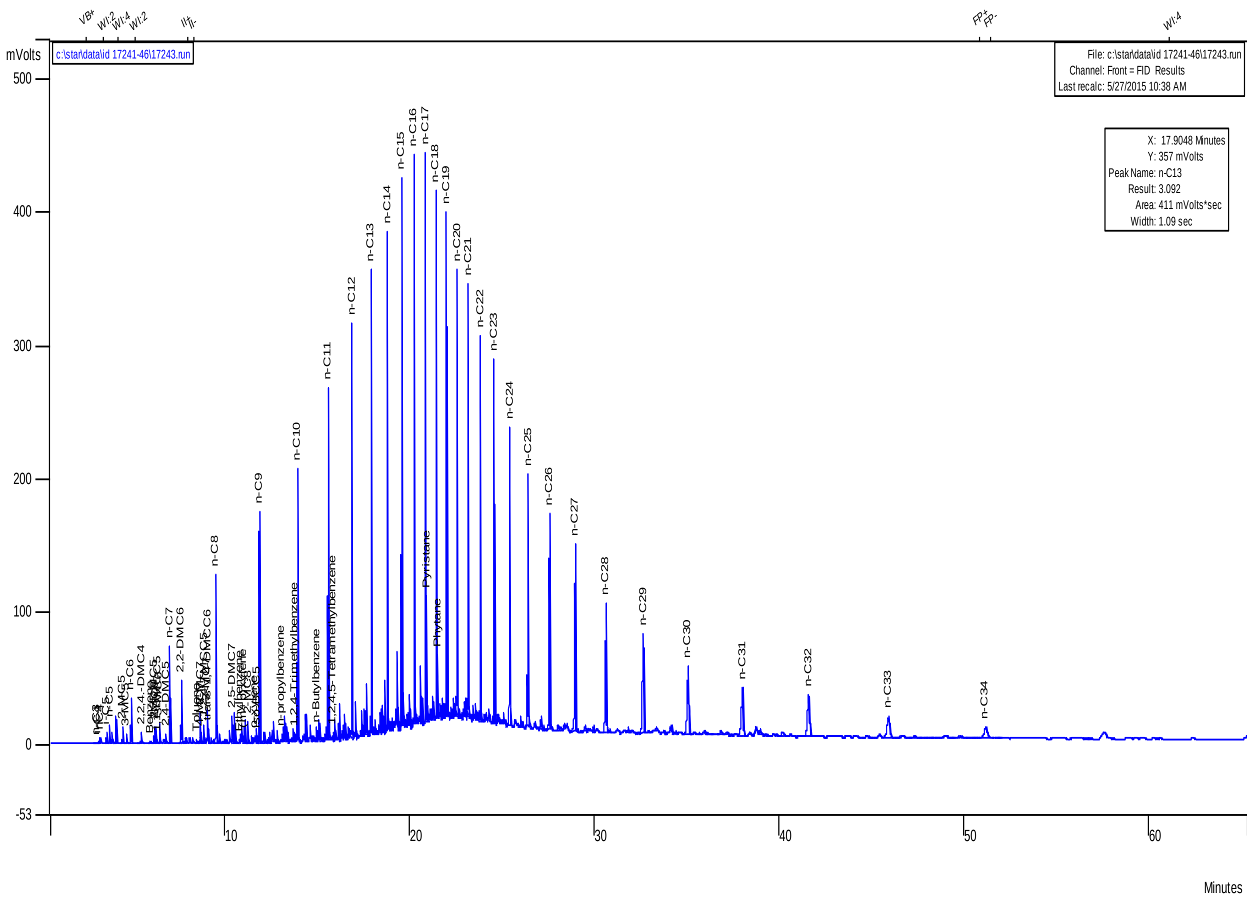


Figure (3.74): Representative whole oil using GC-FID fingerprint for Dar blend crude oil sample.

Table 3.16: Compositional analysis using GC-FID of the Nile blend crude oil sample

Component	Area	Area%	Component	Area	Area%
n-C3	5586	0.0489	n-C9	363546	3.1825
i-C4	11461	0.1003	n-propyibenzen	39503	0.3458
n-C4	44865	0.3927	1,2,4-TM B	24114	0.2111
i-C5	64825	0.5675	n-C10	360373	3.1547
n-C5	122661	1.0738	n-Butybenzene	20476	0.1792
2-MC5	154896	1.3560	n-C11	368658	3.2272
3-MC5	86469	0.7569	1,2,4,5-TMB	34712	0.3069
n-C6	239738	2..0987	n-C12	400007	3.5017
2,2,MC44.-D	111401	0.9752	n-C13	433970	3.7990
Benzene	3026	0.0265	n-C14	378596	3.3142
2,3DMC5	96894	0.8482	n-C15	419994	3.6766
2MC6	765540	0.6700	n-C16	422710	3.7004
1,1-DMC5	37361	0.3271	n-C17	451498	3.9524
3-MC6	138149	1.2094	Pyristane	148034	1.2959
2,4-DMC6	44111	0.3861	n-C18	424436	3.7155
n-C7	350580	3.0960	Phytane	78534	0.6875
2,2-DMC6	404096	3.5375	n-C19	442905	3.8772
Toluene	20826	0.1823	n-C20	365685	3.2012
2-MC7	79685	0.6976	n-C21	390941	3.4223
4-MC7	7716	0.0675	n-C22	368506	3. 2259
1,2,4-TMCC5	109642	0.9598	n-C23	352759	3.0880
3-MC7	114300	1.0006	n-C24	296046	2.5916
Trans-1,4DMCC6	37339	0.3269	n-C25	270360	2.3667
n-C8	439137	3.8442	n-C26	260369.00	2.2793
2,5-DMC7	169808	1.84650	n-C27	265883.00	2.3275
Ethylbenzen	17618	0.1542	n-C28	203912.00	1.7850
(m+p)xylene	515040	0.4818	n-C29	196767.00	1.7225
2-MC8	83577	0.7316	n-C30	148130.00	1.2967
o-xylene	23497	0.2083	n-C31	122764	1.0747

Iso-BCC5	28407	0.2487	n-C32	112276	0.9829
			n-C33	77352.00	0.6771

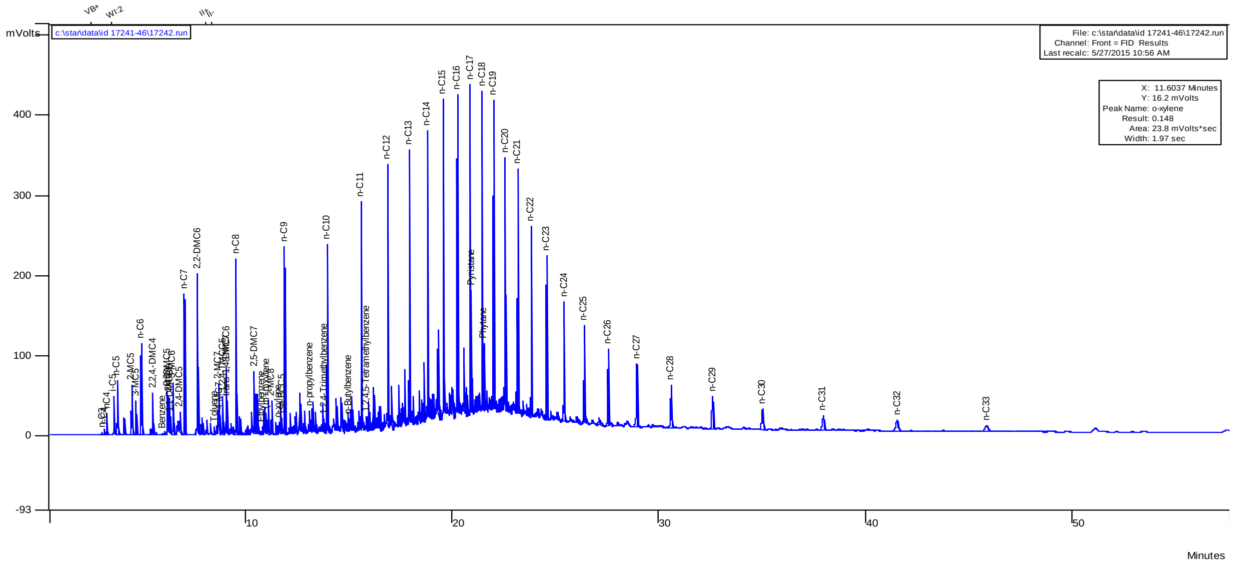


Figure (4.75): Representative whole oil using GC-FID fingerprint for Nile blend crude oil sample

Table (3.17) Corresponding between IR test to Marib crude as standard and Jannah, Almasilah, Nile blend, Dar blend and Moga.

Maarib-Janna%	Marib-Almasilah%	Marib-Nile blend%	Marib-Dar blend%	Marib-Moga%
60.22	98.90	85.16	79.06	86.97

3-12-Corresponding between IR test to Marib crude as standard and Jannah, Almasilah, Nile blend, Dar blend and Moga.

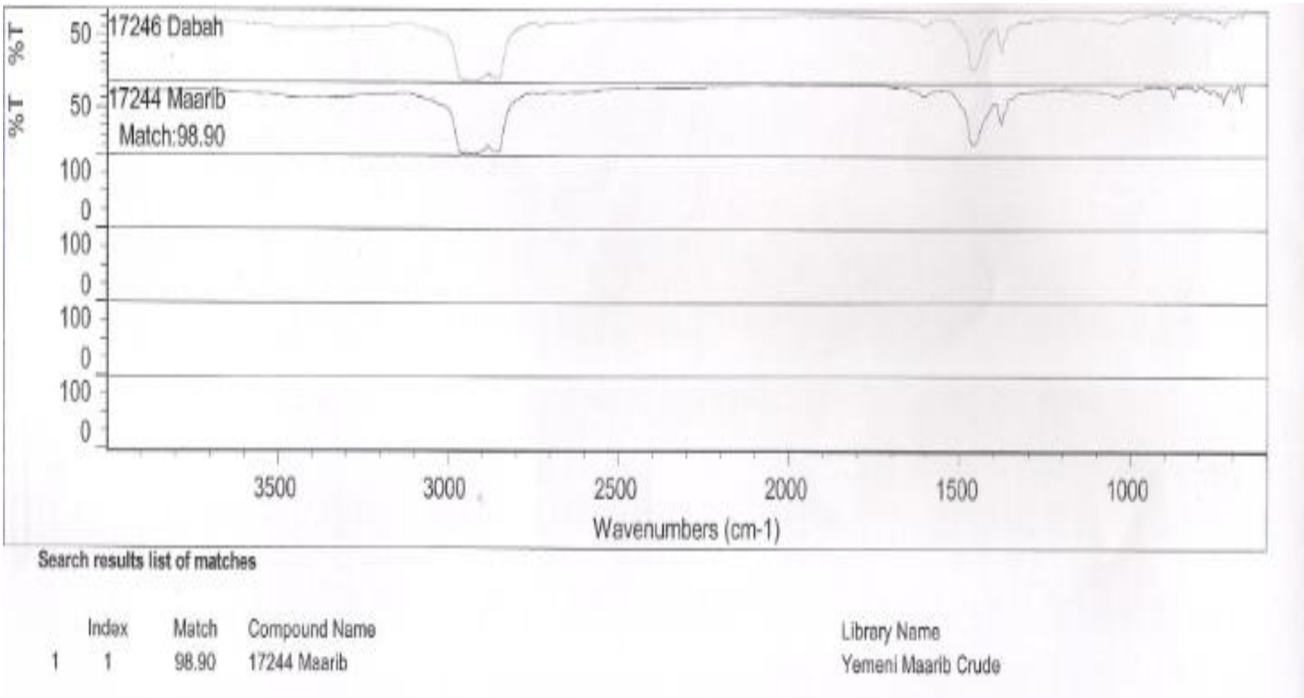


Figure (4.76): corresponding IR between marib and Dabah

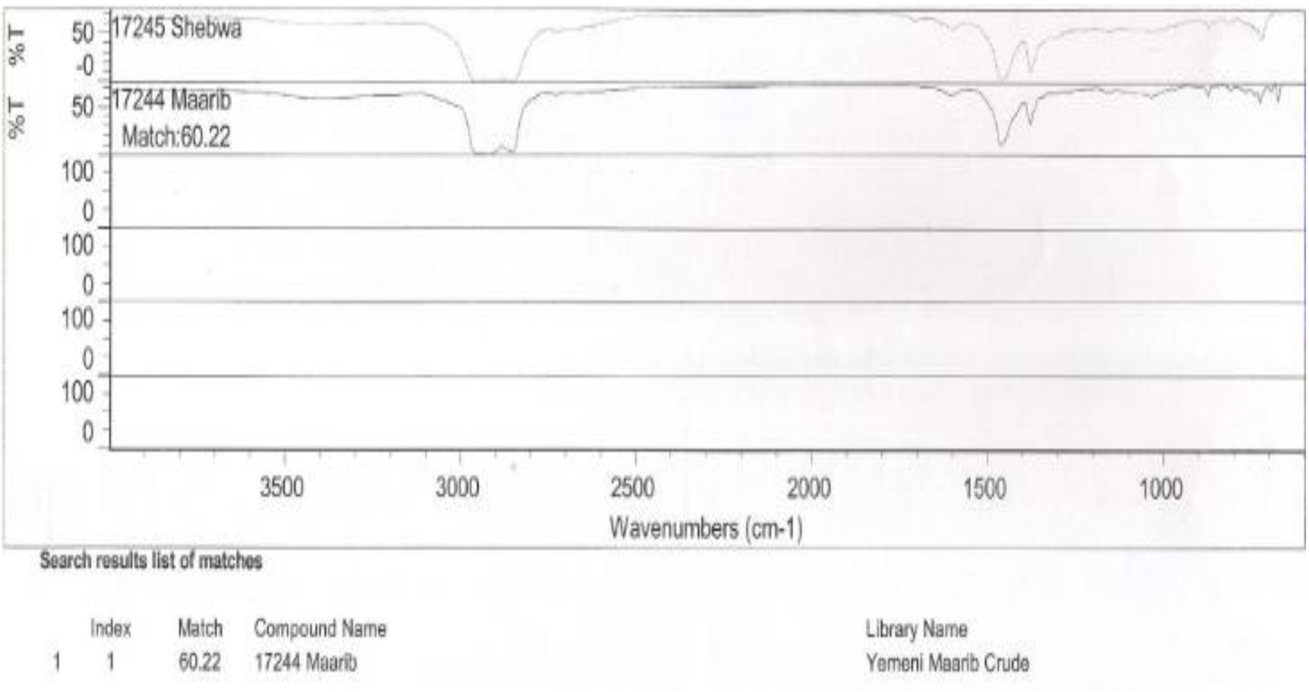


Figure (3.77) corresponding IR between marib and Jannah

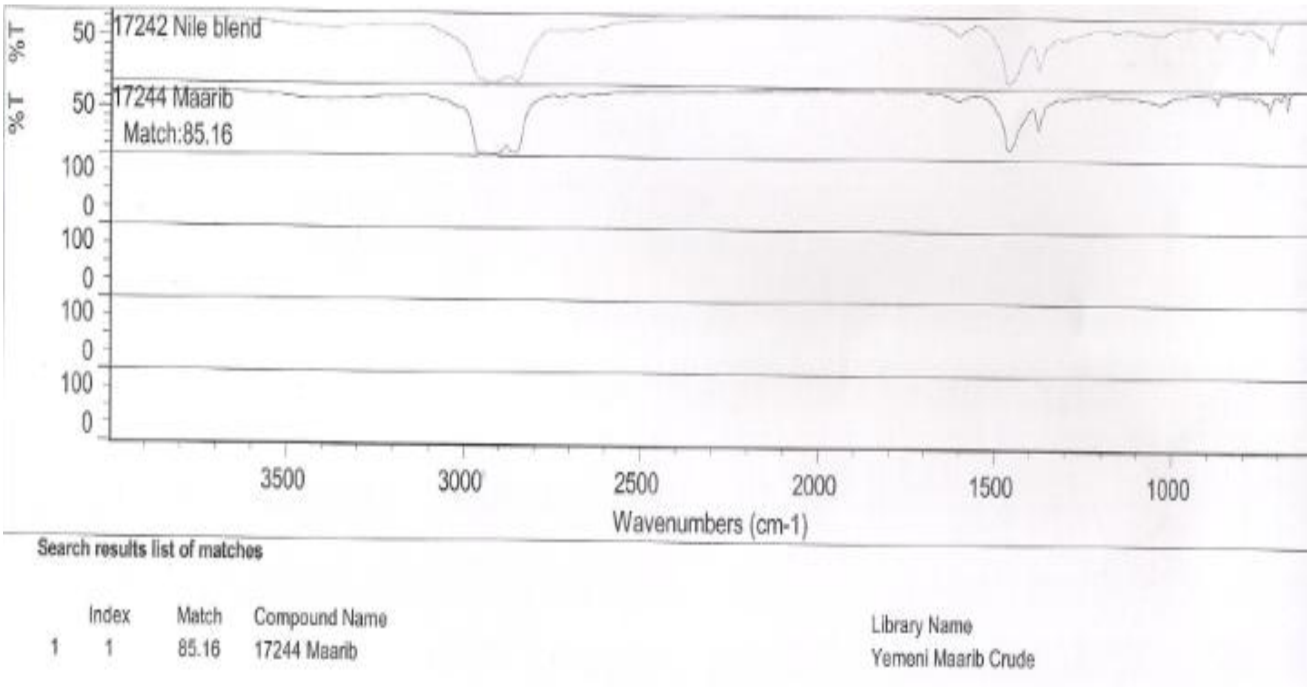


Figure (3.78): corresponding IR between marib and Nile blend

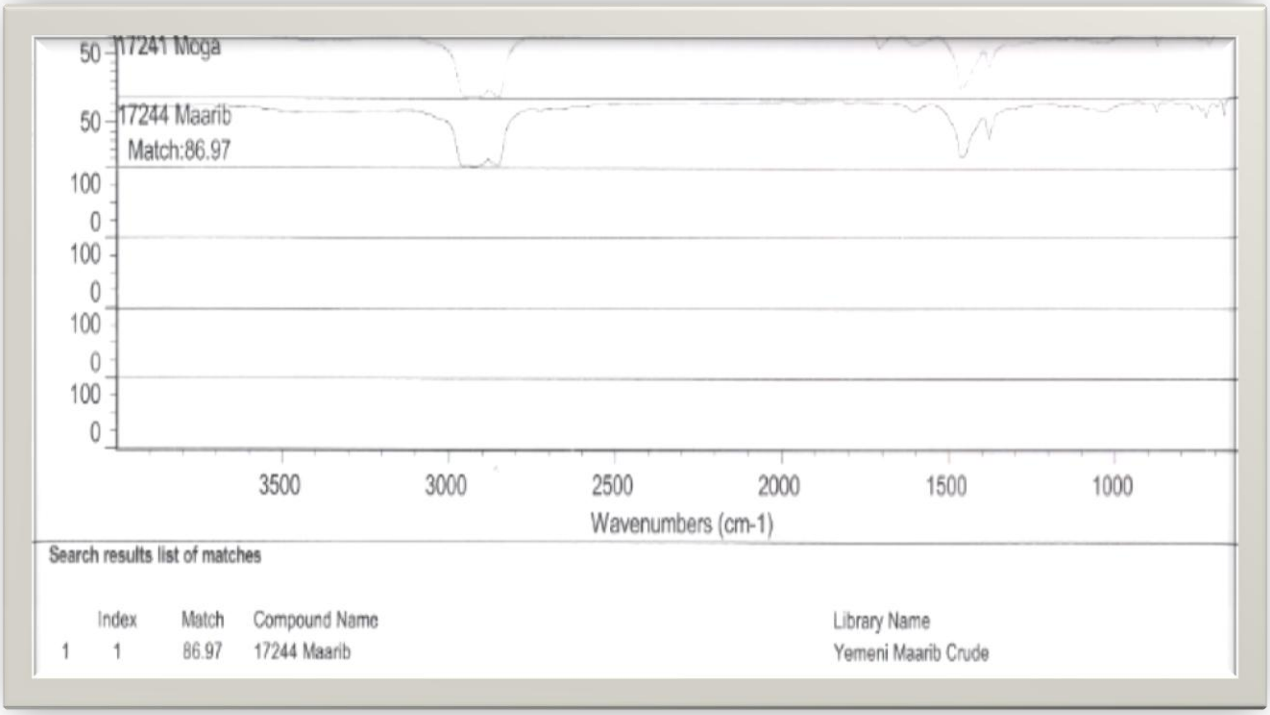


Figure (3.79): corresponding IR between marib and Moga

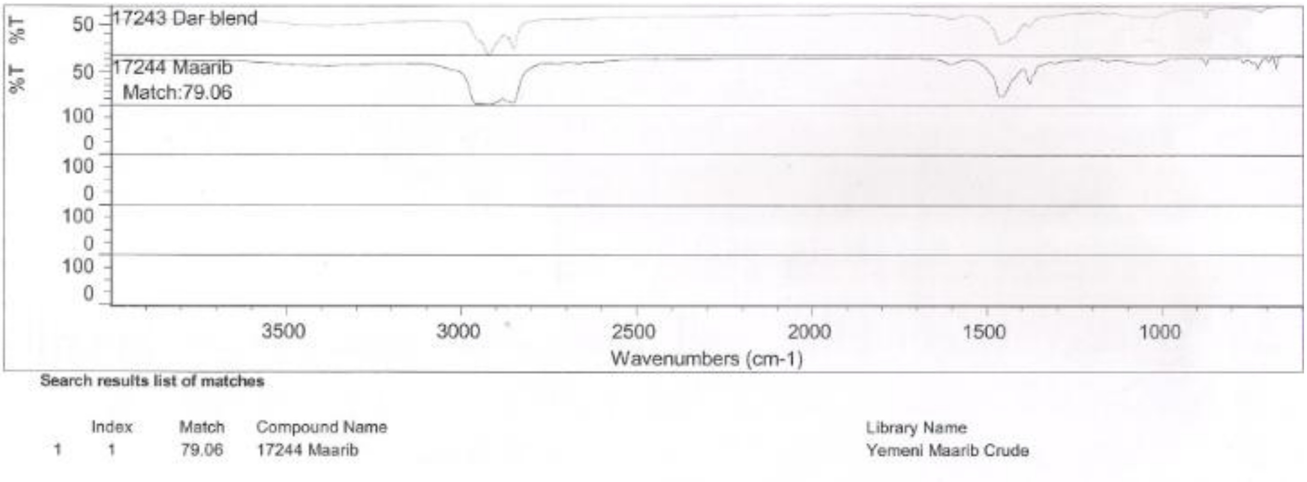


Figure (3.80): corresponding IR between marib and Dar blend

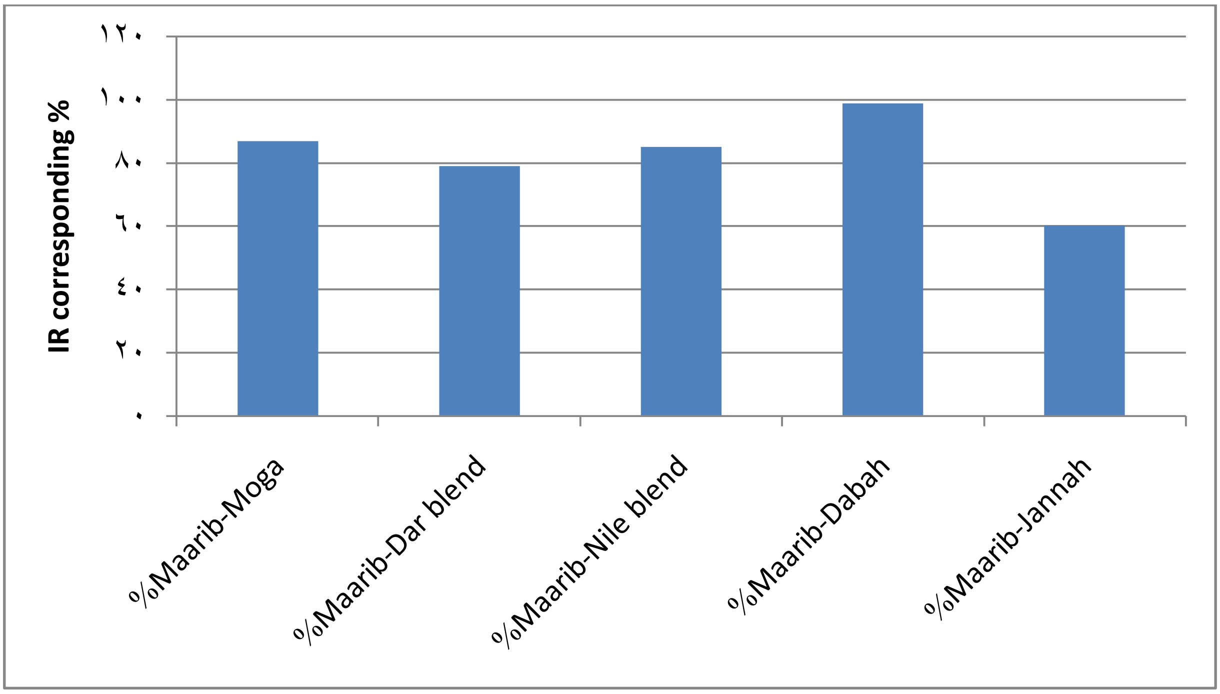


Figure (3. 81): Corresponding between IR test to Marib crude as standard and Jannah, Almasilah, Nile blend, Dar blend and Moga.

3.2 .Statistical analysis

Table (3.18): Mean an standard deviation of Properties of Yemeni crude oil

Properties	Mean	Standard deviation	CV
Density at 15^{o}C	0.85	0.04	0.04
API	34.17	6.75	0.20
S.G	0.86	0.04	0.04
TAN	0.06	0.16	2.75
Pour point	-0.14	12.49	-0.89
Water content by distillation	0.53	1.40	2.63
Wax content	43.30	11.17	0.26
Sulfur content	0.36	0.29	0.81
R.V.P	22.14	9.80	44. 0
Asphalten content	0.17	0.29	1.75
Kinamatic viscos at 50^{0}C	23.88	40.09	1.68

Table (3.19): Mean an standard deviation of heavy metals of Yemeni crude oils

Properties	Mean	Standard deviation	CV
Ag	03484.	1.2238	0.0614
Ca	27.3442	0.8560	1876.000
Cd	34980.	1.2272	0.0195
Co	00083.	2.3875	0.1615
Cr	6.4986	1.6214	1.7760
Fe	3.0091	1.7985	94.3000
K	19.2976	1.2951	4.1690
Na	33.9723	2.6766	19.6700
Ni	11.7285	1.2240	0.3915
Pb	0.01354	2.7469	0.3915
V	2.0366	0.8103	0.2073

Table (3.20.1): statistical analysis between heavy metal of Yemeni and Sudanese crude oils.

Test Name	Country	Mean	Std. Deviation	P-value
	Sudan	252.3733	413.3826	
Cd	Yemen	0.0656	0.11206	0.405
	Sudan	0.0054	0.00394	
Co	Yemen	0.0773	0.08020	0.002
	Sudan	0.7699	0.93284	
Cr	Yemen	0.5952	1.02258	0.000
	Sudan	0.0407	0.05273	
Fe	Yemen	33.0613	53.03966	0.000
	Sudan	17.9250	23.29562	
K	Yemen	1.8736	2.02893	0.545
	Sudan	1.0096	1.01084	
Na	Yemen	16.4920	15.11960	0.931
	Sudan	15.4927	11.08943	
Ni	Yemen	0.7191	0.77208	0.000
	Sudan	29.2967	33.88428	
Pb	Yemen	136.5094	235.20512	0.000
	Sudan	0.0151	0.00023	

Table (3.20.2): statistical analysis between properties of Yemeni and Sudanese crude oils.

Test Name	Country	Mean	Std. Deviation	P-value
Density at 15 C^0	Yemen	0.8455	0.04973	0.126
	Sudan	0.9089	0.02754	
API	Yemen	36.0600	9.71207	0.129
	Sudan	24.1400	4.75785	
S.G	Yemen	0.8461	0.05007	0.129
	Sudan	0.9097	0.02755	
TAN	Yemen	0.1867	0.30616	0.124
	Sudan	2.4000	1.94741	
Wax content	Yemen	23.5400	20.84726	0.901
	Sudan	25.1867	5.15529	
WAT	Yemen	21.6333	19.21598	0.170
	Sudan	48.4767	20.08439	
Dynamic viscosity at 75 ^oC	Yemen	16.6633	24.54565	0.007
	Sudan	116.3133	86.47776	
Kinematic viscosity at 75 ^oC	Yemen	18.6967	27.15209	0.000
	Sudan	126.1033	92.36959	

Table (3.21): Comparison between V/Ni and Ni/V in Yemeni and Sudanese crude oil

Test Name	Country	Mean	Std. Deviation	P-value
V/Ni	Yemen	0.4272	0.13127	0.006
	Sudan	0.0161	0.00500	
Ni/V	Yemen	2.7433	0.78780	0.019
	Sudan	51.0033	21.89527	

- From above table, it shown the P-value of t-test (0.006) is less than significant level (0.05) that mean there is statistical difference between Yemen and Sudan in V/Ni for Yemen.

From above table, it shown the P-value of t-test (0.019) is less than significant level (0.05) that mean there is statistical difference between Yemen and Sudan in Ni/V for Sudan.

Table (3.22): Comparison between Normal alkanes/isoprenoid ratios In Yemeni and Sudanese crude oil

Country	Mean	Std. Deviation	P-value
Yemen	0.8107	0.52705	0.000
Sudan	2.2921	5.84743	

From above table, it shown the P-value of t-test (0.000) is less than significant level (0.05) that mean there is statistical difference between Yemen and Sudan in normalalkanes/isoprenoid ratios.

Table (3.23): Comparison between Ratio Saturated to Aromatic between Yemeni and Sudanese crude oil sample.

Country	Country	Mean	Std. Deviation	P-value
Saturated %	Yemen	13.5800	5.03496	0.015
	Sudan	1.5180	0.84291	
Aromatic%	Yemen	86.4194	5.03474	0.007
	Sudan	95.7173	4.94595	

From above table, it shown the P-value of t-test (0.015) is less than significant level (0.05) that mean there is statistical difference between Yemen and Sudan in Saturated % for Yemeni.

From above table, it shown the P-value of t-test (0.015) is less than significant level (0.05) that mean there is statistical difference between Yemeni and Sudanese in Aromatic% for Sudanese.

Table (3. 24): Comparison between wax Appearance Temperature of Yemeni and Sudanese crude oil

Test name		Mean	Std. Deviation	P-value
WAT ^{0}C	Yemen	21.6333	19.21598	0.000
	Sudan	48.4900	20.06146	

From above table, it shown the P-value of t-test (0.000) is less than significant level (0.05) that mean there is statistical difference between Yemeni and Sudanese in WAT ^{0}C for Sudanese.

3-3-Dewaxing

Table (3.25): Properties of Safer light blend

Properties	Unit	Test Method	Value
Density at 15^0C	Gm/ml	ASTM D5002	0.8010
API		ASTM D5002	44.99
S.G		ASTM D5002	0.8010
TAN	Mg KOH/gm	ASTM D664	0 .02
Pour point	^0C	ASTM D5853	-33
Water content by distillation	%V	ASTM D4006	0.00
Wax content	Wt%	UOP46	39.67
Sulfur content	%m	ASTM D4294	0.127
Asphalten content	Wt%	IP 143	0.00
Kinamatic viscosity at75^0C	cSt	ASTM D445	2.08
Dynamic viscosity at $75C^0$	cP		1.67
WAT	^0C		14.48

From table above, all properties of safer blend assure that light crude oil.

Table (3.26): Properties of MEK and toluene

Properties	MEK	Toluene
Molecular Formula	C_4H_8O	C_7H_8
Molecular Weight	72.11	92.14
Boiling Point ^{0}C	79-80	109-112
Melting Point ^{0}C	-86	95
Flash point ^{0}C	-6	4
Vapor Pressure at 20 ^{0}C (mmHg)	77.5	22
Solubility in Water at 20 ^{o}C	27.5%	Nearly Insoluble
Density at20 ^{0}C	0.804gm	0.864gm
Purity w%	99%	99%
Manufacturer	Central drug house (P) Ltd Ind	Central drug house (P) LtdInd

Table (4.27) GC Analysis for Produced Wax

Component	Area	Area%	Component	Area	Area%
n-C9	31915	0.1817	n-C23	690942	3.9342
n-C10	251890	1.4343	n-C24	623985	3.5530
n-C11	614059	3.4965	n-C25	551817	3.1421
n-C12	914229	5.2056	n-C26	491204	2.7969
n-C13	1365517	7.7753	n-C27	493109	2.8078
n-C14	1084923	6.1776	n-C28	419554	2.3890
n-C15	1350576	7.6902	n-C29	407191	2.3186
n-C16	1032542	5.8793	n-C30	328507	1.8705
n-C17	1035514	5.8962	n-C31	290191	1.6524
n-C18	817345	4.6540	n-C32	254652	1.4500
n-C19	825618	4.7011	n-C33	204640	1.1652
n-C20	667889	3.8030	n-C34	134947	.7684
n-C21	679170	3.8672	n-C35	116173	.6615
n-C22	692121	3.9410	n-C36+		6.6057

3-4- Disscution

3-4-1- Properties of Yemeni crude oils.

From tables (3.1) and figures (3.1- 3.11): The results indicate that the crude oils belong to the light crude oil type with API gravity of about 44.99 (sp.gr. 0.8010) to safer, 41.15(sp.gr. 08188) to **34**, 38.90 (sp. gr. 0.8296) AL-masilah, 37.47 (sp.gr. 0.8364) Dabah, 37.45 (sp.gr. 0.8368) **51**, 36.32 (sp.gr.0.8432) **10**, 36.29 (sp.gr. 0.8324) S2, 31.55 (sp.gr. 0.8671) **43**, 31.48 (sp.gr.0.8674) **32**. While 25.72 (sp.gr. 0.8992) Jannah, 25.72 (sp.gr. 0.8992) AL naser, 22.79 (sp.gr. 0.9152) Malik, are medium crude oil. The low values of pour point of all samples are not compatible with the high wax content but they are agreed with GC-FID analysis. The high values of wax content and low values of asphaltene content for samples characterize Yemeni crude oils are paraffinic type. Sulfur content is low < o.5 in most crude samples these indicate sweet type and light crude oil exception Jannah, AL naser and Malik higher than 0.5% and less than <1% these indicate three samples are medium crude oils.TAN low value (0.00-0.54) in all samples, these indicate no corrosion tendency of Yemeni crude oil.

Water content (0.00-0.90) exception AL masilah (4.9) so that enhance Ca, K, Na in this sample. Kinamatic viscosity at 50^{0}C is very low so therefore, the low viscosity obtained for the crude oil indicates that the crude can easily flow when transported through pipes.The implication however is that crude oil easy flow until very low temperatures at transportation; the properties assure quality of Yemeni crude oil. From table (3.18) it shown CV of t-test is more than significant level (0.05) that mean there is no difference exception density, S.G (0.04) in some properties.

3-4-2- Heavy metals of Yemeni crude oils .

Heavy metals are often found to be part of crude oil samples. Possible sources of trace metals in crude oil are: through incorporation and diagenesis of metal complexes of the original biological materials; through incorporation into the organic matrix during diagenesis of the biological materials in the source rocks either from clay minerals or interstitial aqueous solution through an aqueous phase during primary and secondary migration and from formation waters or reservoirs' rock minerals

(Fausnaugh, 2002). From table (3.2), figure (3.12-3.22) show the levels of most of the trace elements obtained in this study was generally low. This agrees with reports that light crude oil samples usually contain relatively low trace metal contents compared to the heavy crudes (Robert *et al*, 1995). The relatively higher levels of Ni in Malik, **32**, **43** (3.942, 4.058, 4.005) and V (4.919, 3.582, 3.633) respectively, Fe (Jannah, Al naser, Malik), (94.3, 92.7, 33.45) respectively. Ni, V and Fe observed in results should be expected because these are metals commonly associated with crude oil samples (Madu, et al, 2011). From table (3.19) it shown CV of t-test is more than significant level (0.05) that mean there is no statistical difference in trace metals in Yemen crude oil exception Ag, Cd (0.0614, 0.0195).

3-4-3- Properties and heavy metals of Yemeni and Sudanese crude oils.

The elemental compositions of the studied oil samples using ICP.The studied crude oil sample is heavy, because its API-gravity is very low (16.32) and this like for heavy crude oil (Hunt, 1996). Flash and pour points are high indicates the absence of light hydrocarbons (Abdulkareem, 2006). Although similar crude oil samples with low API unit have high percentage of sulfur (Mello, 1988). Specific gravity, API gravity and sulfur content these are important parameters commonly used for the classification of crude oil sample (Odebunmi and Adeniyi, 2007). Generally API gravity of crude oil is known to increase as specific gravity decreases (Riegel, et al 2007). API gravity has also been reported to have an inverse relationship with % sulphur contents of crude oil blends (Ekwere, 1991). While light crude oil samples are found mostly in areas with low deposits of sulfur rocks. Furthermore, Sulfur is relatively a heavy element Thus, its presence will therefore add to the specific gravity of oil samples. This also explains why crude oil samples with low sulfur content have low specific gravity and vice versa. Studies such as the study of (Odebunmi and Adeniyi, 2007), had already shown that, API gravity varies inversely with specific gravity and also the % sulfur contents other studies such as (Joel, *etal,* 2009). In this study API is as expected determines the grade or quality of crude oils.

Generally, crude oil samples with API gravity greater than 31 are classified as light crude oils; those with API gravity of between (22-31) are classified as medium crude oils while those with API gravity of 20 and less are referred to as heavy crude oil (AP1, 2011). In this study with that of API shows that, most of the crude oils obtained from some fields of Yemeni is light crude oils. Exceptions is sample of Jannah which is medium. While crude oil samples obtained from Sudanese is medium crude oils, in Nile blend API (29.28), Dar blend API (23.25) but Moga crude oil is heavy API (19.89). Light crude oil samples are in high demand and are of high market value because heavy crude is harder to handle, too thick to pump easily through pipelines unless diluted with light crude and is more expensive to refine to produce the most valuable petroleum products such as petrol, diesel and aviation fuel. In the process of refining crude oil into useful products, it is generally observed that, the heavier the oil, the more difficult its refining process (American Petroleum Institute, 2011). Sulfur content determines whether particular crude is sweet or sour. Crude oil samples are classified as sweet if it sulfurs content is less than 0.5%. Anything greater than 0.5% is termed sour. With respect to their sulfur contents, all the crude oil used in this study was found to be of low sulfur with reference to API standards Yemeni crude oil samples can thus be classified as sweet (0.0846- 0.488). The Sudanese crude samples are sweet. Viscosity, Water Content, Pour Point, Salt Content and Acid Number. Viscosity is a measure of internal friction of a liquid which is the reluctance of a liquid to flow. It therefore indicates the flowing ability of crude oil from one point to another (Kurt, 2005). The results of this study shows that the crude oils from Yemeni is relatively of low viscosity this implies that, they have the ability to flow rapidly during spillage but the viscosity of Sudanese crude oils is high exception Nile blend (22.74), table (3.4). Viscosity of petroleum is important in studying the energy loss during production. Any engineering activities including piping and pipeline construction require the knowledge of the viscosity of the crude oil to enhance transportation. Viscosity also plays an important role in reservoir simulations as well as in determining the structure of liquids (Abdulkareem and Kovo, 2006). Therefore, the low viscosity obtained form the crude oil indicates that the crude can easily flow when transported through pipes thus making for easy transportation. The implication, however that, the crude oil samples for some fields in Yemeni have the ability to readily flow into the environment in events of oils pillage to cause pollution. The negative correlation observed between viscosity and temperature show figures (3.62 and 3.67) and table (3.9.1). The pour point values of the crude oil are low and indicate that the oils can easily be utilized under low temperature conditions. Salt content and acid number are important index for refining operations. High values of any of these parameters indicate high corrosion tendency of crude oil (Ganji *et al*, 2010). The values of these parameters obtained in some fields of Yemeni crude oil. Table show (3.4) water content (0.00-0.90) is very low except AL-masilah crude oil (4.9), (that these crude possess very low corrosion potentials). The pour point values of the Yemeni crude are low and indicate that the oils can easily be utilized under low temperature conditions, TAN is not seen in all samples except Jannah (0.54) these indicate no corrosion tendency of Yemeni crude oil but some Sudanese crude oil properties such as pour point is medium (19.89-29.28) this indicate oils cannot easily be utilized under low temperature conditions TAN is seen high in some Sudanese samples, exception the Nile blend these indicate corrosion tendency of some Sudanese crude oils. The V/Ni ratio increased with the age of the host rock. Similar inclusions were used by (A bu- Elgheit *et al*, 1979), to suggest that a V/Ni ratio of less than 1 indicates that oil is of a younger age, while, a ratio of more than 1 indicates that oil is of an older age. More recently, (Abu-Elgheit *et al*, 1979), studied the total V and Ni contents of petroleum residues from different oil fields in Egypt and concluded that the V/Ni decreases with the age of oil,Yemeni and Sudanese crude oils are young age and mature because V/Ni less than 1 as shown in table (3.10).

3-4-4- Compositional analysis using GC-FID.

From table (3.11) The gas chromatograms of six Yemeni and Sudanese crude oil samples as shown in Figures (3.70 to 3.75) showed close similarity between Dar blend, Nile blend, Moga, Jannah and Safer crude oil sample (Figure 3.74, 3.75, 3.73, 3.70, 3.72) (rich hydrocarbons), but Safer crude oil sample is light (Figure 3.72) and Al-Masilah crude oil sample (Figure 3.71) (poor hydrocarbons), the results as shown in Tables (3.11 to 3.16). The distribution pattern of the all chromatograms which are shown in Figures (3.70 to 3.75) is a single distribution but figure (3.70) bimodal disribution. Normal alkanes and isoprenoids distribution which are shown in Tables (3.11 to 3.16) were used in crude oil correlation, the ratios of isoprenoids to n-paraffin are often used for oil source correlation, maturation and biodegradation studies (Didyk, *et al;* 1978). Various ratios of isoprenoids to n-alkanes were computed such as the Pr/Ph, Pr/n-C17, and Ph/n-C18, nC25/nC18 and (Pr+C17)/ (Ph+C18) which are shown in Table (3.5). Normal alkanes/isoprenoid ratios the distribution of n-alkanes in crude oils can be used to indicate the organic matter source (Udeme, *et al*, 2012). For example, the increase in the n-C_{15} to n-C_{20} suggests marine organic matters with a contribution to the biomass from algae and plankton (Peters, *et al*, 2005). In this study n-C_{15} to C_{20} increases, so Yemeni crude oil marine organic matters. Oil samples characterized by uniformity in n-alkenes distribution patterns suggest that they are related and have undergone similar histories with no signs of biodegradation. Carbon preference index (CPI) is affected by both source and maturity of crude oils (Maioli, *et al;* 2011). CPI of petroleum oils ranging about 1.00 generally shows no even or odd carbon preference indicates mature samples. Also, it can be used in source identification; petroleum origin contaminants characteristically have CPI values close to one (Bray, 1961). CPI of Yemeni and Sudanese crude oils ranging about 1.00 (1.04-1.16), (1.02–1.12) these mean maturity of Yemeni and Sudanese crude oils. Table (3.5) show. The relative amounts of C_{27}-C_{29} and steranes can be used to give an indication of source differences (Hunt, 1996). For example, the predominance of C_{28}, C_{29} and C_{30} steranes indicate an origin of the oils derived mainly from mixed terrestrial and marine organic sources, while oils showing a slightly low abundance of C_{28} and C_{29} and relatively higher concentrations of C_{27} sterans indicate more input of marine organic source. In this study showing a slightly low abundance of C_{28} and C_{29} and relatively higher concentrations of C_{27} sterans indicate more input of marine organic source. Pr/Ph believed to be sensitive to diagenetic conditions; Pr/Ph ratios substantially below unity could be taken as an indicator of petroleum origin and/or highly reducing depositional environments. Very high Pr/Ph ratios more than 3 are associated with terrestrial sediments. Pr/Ph ratios ranging between 1 and 3 reflect oxidizing depositional environments (Lijmbach, 1975). Low Pr/Ph values < 2 indicate aquatic depositional environments including marine, fresh and brackish water (reducing conditions), intermediate values 2-4 indicate mixed organic source matter terrestrial environments, whereas high values up to 10 are related to peat swamp depositional environments (oxidizing conditions) (Lijmbach, 1975). pr/ph in this study < 2 (0.4037-1.6585) these indicate Yemeni crude oils including marine, with increasing maturity but Sudanese crude oils Pr/Ph (2.005–2.32) describe mixed organic source matter terrestrial environments while Moga is terrestrial sediments crude oil Pr/Ph (25.57). N-alkanes are generated faster than iosprenoids in contrast to biodegradation. Accordingly, isopreniods/n-alkanes (Pr/n-C_{17} and Ph/n-C_{18}) ratios provide valuable information on biodegradation, maturation and diagenetic conditions. The early effect of microbial degradation can be monitored by the ratios of biodegradable to the less degradable compounds. Isoprenoid hydrocarbons are generally more resistant to biodegradation than normal alkanes. Thus, the ratio of the pristane to its neighboring n-alkane C_{17} is provided as a rough indication to the relative state of biodegradation. This ratio decreases as weathering proceeds (Waples, D, 1985). The Ph/n-C_{18} values less than 1.0 are indicative of non-biodegraded oils. Both Pr/n-C_{17} and Ph/n-C_{18} decrease with maturation due to increased prevalence of the n-paraffin. From table (3.5), ph/n-C18 of Yemeni crude oils (0.4484-0.4921), and Sudanese crude oils (0.0174 – 0.1066) values less than 1.0 are indicative of non-biodegraded Yemeni and Sudanese crude oils but. Both Pr/n-C_{17} and Ph/n-C_{18} decrease it is indicator on Yemen and Sudan crude oils maturation.

From table (3.6) and figures (3.70-3.75) all crude oils are paraffinic because the ratio of saturated compound varies from (88.89%–99.43%) but from table (3.7) wax appearance temperature (WAT^{0}C) and figure (3.50-3.55) Jannah (-7.02), Almasilah

(43.40), Marib (14.48), Dar blend (62.38), Nile blend (57.60), Moga (25.49) and the result degree of wax to Moga, Nile blend, Dar blend, Safer blend, Dabah and Jannah samples as following (1.65, 1.006, 1.74, 0.0419, 0.3113 and 2.449) respectively, this mean Jannah, Dar blend, Moga need treatment. From table (3.17), figures (3.76-3.81) All samples show(OH) Pike except Jannah. From tables (3.18, 3.19) no difference between all properties except in viscosity, while trace metals Statistical analysis difference at (Co, Cr, Fe, Ni, Pb, V). From table (3.20, 3.21), it is shown the P-value of t-test (0.006) is less than significant level (0.05) that mean there is a statistical difference between Yemeni and Sudanese crude in V/Ni, too, it is shown the P-value of t-test (0.019) is less than significant level (0.05) that mean there is a statistical difference between Yemeni and Sudanese in Ni/V. From table (3.22) it is shown the P-value of t-test (0.000) is less than significant level (0.05) that mean there is a statistical difference between Yemeni and Sudanese crude oil in normalalkanes/isoprenoid ratios, From table (3.23), it is shown the P-value of t-test (0.015) is less than significant level (0.05) that mean there is a statistical difference between Yemeni and Sudanese crude in Saturated %.Too it is shown the P-value of t-test (0.015) is less than significant level (0.05) that mean there is a statistical difference between Yemen and Sudan in aromatic%. From table (23), it is shown the P-value of t-test (0.000) is less than significant level (0.05) that means there is a statistical difference between Yemen and Sudan in WAT ^{0}C.

3-4-5- Wax Characteristics.

The wax produced at the operational conditions of 75% MEK solvent composition, 20:1 solvent to oil ratio, 50 ^{0}C mixing temperature, and 20 minute residence time at -22 0C filtration temperatures is inspected and found to be slightly greasy to the touch. It is also found to be soluble in naphtha, toluene, xylene, kerosene, benzene, ethyl alcohol, hot Acetone, and carbon tetra chloride. Table (4.25) shows the result of GC. The light hydrocarbon (n-C10–n-C16) constitutes about 37.8405% and C36+ is 6.6057 %. The light n-paraffins may originate from the oil entrapped within the wax. This study more corresponding with (Amel A Nimer, et al, 2010), the result showed that 92% of the wax in the crude can be extracted with a mixture of 75v% MEK at a maxing temperature of 50 ^{o}C, residence time of 20 minutes, and solvent to oil ratio of 20:1 at a filtration temperature of -17 ^{o}C. The wax produced is characterized by a slightly greasy feel and is soluble in naphtha, toluene, xylene, kerosene, benzene, Ethyl alcohol, acetone, and carbon tetra chloride. The gas chromography analysis showed that the light products (C10 -C16) constitute 6% of the produced wax and C 45+ is 10%. And study of (As'ad, *et al,* 2015) this study has successfully established the effect s o f parametric variations on wax extraction from an Australian heavy crude oil usinga pure Methyl Ethyl Ketone solvent. It was observed that the wax yield increases with increasing mixing temperature and solvent to oil ratio, as well as a decrease in chilling temperature. Based on the experimental results it was concluded that the optimum wax yield of 27.9 wt% was obtained using a 15:1 solvent to crude oil ratio, at a mixing temperature of 50°C, and a chilling temperature of -20°C.

Conclusion.

The result of this study has shown that the crude oils obtained from some Yemeni fields contain low levels of sulphur. Most crude oils obtained from some Yemeni fields can thus be classified as light-sweet crude oils, while some Sudanese field's crude oils can be classified as medium–sweet and sour. Lower values of viscosity obtained for the Yemeni crude oils, these oil samples can flow easily. On the whole, the low levels % pour point observed for the oil samples coupled with other physiochemical parameters show that: Yemeni crude oil has characteristics which enhance their preferences in the oil market and refinery operations, but Sudanese crude oils cannot flow easily so the necessary of addition of diluents, exception was the Nile blend. The levels of most of the trace elements obtained in this study were generally low. CPI of Yemeni and Sudanese crude oils ranging about 1.00 these mean maturity of Yemeni and Sudanese crude oil. pr/ph in this study <2 (0.4037 - 1.6585), these indicate Yemeni crude oil including marine organic matters, with increasing maturity, but Sudanese crude oils Pr/Ph (2.005– 2.32) describe mixed organic source matter terrestrial environments while Moga is terrestrial sediment crude oil Pr/Ph (25.57), with increasing maturity, The V/Ni index decreases with the age of oil So Yemeni and Sudanese crude oils are young and maturate because V/Ni less than one. All crude oils are paraffinic because the ratio of saturated compound varies from (88.89%–99.43%) and high waxes.

This study provides experimental data on dewaxing of Safer Blend, The operational conditions for wax production from Safer Blend are 75% MEK, 20 minute retention time, and 20:1 solvent to oil ratio at -22 ^{0}C cooling and a one hour cooling time. Under these conditions, the wax contains 37.8405% of light n-paraffins (n-C10–n-C16) and 6.5057% of C 36+.

3-6- Recommendations

1-Processing crude oil fields Jannah and Al Nasser of elemental calcium, chromium, lead and sulfur content.

2 - Improve the viscosity of the crude oil fields Jannah, Alnasser and Malik.

3- Improve the viscosity of Sudanese crude oil fields Moga, Dar blend and Nile blend.

4- The removal TAN and wax of crude oils of Moga and Dar blend.

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