Palacký University Olomouc
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Genesis of Heavy Oil and Production Challenges in the Kurdistan Region of Iraq

Bachelor Thesis

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Genesis of Heavy Oil and Production Challenges in the Kurdistan Region of Iraq

Anotace:

Tato práce se zabývá tématem těžké ropy v iráckém Kurdistánu prostřednictvím analýzy relevantních publikovaných článků a zpráv. Vznik těžké ropy v oblasti Kurdistánu je složitý proces, který trvá miliony let a zahrnuje hromadění a přeměnu organického materiálu. Region má významné zásoby těžké ropy díky své geologické historii, která zahrnuje tektonické síly, ukládání organicky bohatých sedimentů a tepelné zrání. Těžba a používání těžké ropy však naráží na různé výzvy, které je pro úspěšnou výrobu nutné řešit. Jednou z hlavních překážek je vysoká viskozita těžké ropy, která vytváří značný odpor proti proudění skrz ložiskové horniny a vrty. K překonání tohoto problému byly použity různé techniky, jako jsou tepelné metody, chemické přísady a procesy založené na rozpouštědlech. Ačkoli jsou tyto metody účinné, často vyžadují značné energetické vstupy, další infrastrukturu a zvýšené výrobní náklady. Kontaminanty a nečistoty jako síra, těžké kovy a asfaltény představují další výzvu, protože ovlivňují kvalitu a použitelnost těžké ropy. Správa těchto nečistot je klíčová během průzkumu, výroby a rafinačních procesů, aby se zajistily účinné operace a zabránilo korozi. Překážky související s infrastrukturou, jako jsou odlehlá místa, nedostatečná dopravní infrastruktura a nedostatečná skladovací a zpracovatelská zařízení, brání efektivní výrobě a přepravě těžké ropy. Kromě toho by měly být zváženy environmentální důsledky těžby těžké ropy. K dosažení udržitelného rozvoje a minimalizaci dopadu na životní prostředí by měla být zavedena zmírňující opatření, jako je zachycování a ukládání uhlíku, recyklace vody a programy monitorování životního prostředí. Stručně řečeno, problémy spojené s těžbou těžké ropy v iráckém Kurdistánu zahrnují nízkou globální tržní cenu těžké ropy, složitost a náklady na výrobu, stejně jako infrastrukturu a obavy o životní prostředí.

Klíčová slova: Těžká ropa, produkční výzvy, těžká ropa v KRG.

Počet stran: 44

Genesis of Heavy Oil and Production Challenges in the Kurdistan Region of Iraq

Anotation:

This thesis investigates the subject of heavy oil in Iraqi Kurdistan through an analysis of relevant published articles and reports. The formation of heavy oil in the Kurdistan Region is a complex process that takes millions of years and involves the accumulation and transformation of organic material. The region possesses significant reserves of heavy oil due to its geological history, which includes tectonic forces, the deposition of organic-rich sediments, and thermal maturation. However, extracting and using heavy oil encounter various challenges that must be addressed for successful production. One major obstacle is the high viscosity of heavy oil, which creates substantial resistance to flow through reservoir rocks and wells. To overcome this challenge, different techniques have been employed, such as thermal methods, chemical additives, and solvent-based processes. Although effective, these methods often require significant energy inputs, additional infrastructure, and increased production costs. Contaminants and impurities like sulfur, heavy metals, and asphaltenes present another challenge by affecting the quality and usability of heavy oil. Managing these impurities is crucial during exploration, production, and refining processes to ensure efficient operations and prevent corrosion. Infrastructure-related obstacles, such as remote locations, insufficient transportation infrastructure, and inadequate storage and processing facilities, hinder the efficient production and transportation of heavy oil. Additionally, the environmental consequences of heavy oil production should be considered. To achieve sustainable development and minimize environmental impact, mitigation measures such as carbon capture and storage, water recycling, and environmental monitoring programs should be implemented. In summary, the challenges of heavy oil production in Iraqi Kurdistan encompass the low global market price of heavy oil, the complexity, and cost of production, as well as infrastructure and environmental concerns.

Keywords: Heavy Oil, Production Challenges, Heavy Oil in KRG.

Number of pages: 38

I declare that I have prepared the bachelor's thesis myself and that I have stated all the used information resources in the thesis.

In Olomouc, July 27, 2023 ……………………………………………

Mohamed Ihsan Abdulaziz

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I would like to thank my family who supported me through this journey, my friends that accompanied me, and my supervisors that guided me.

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1 Introduction

The Kurdistan region of Iraq contains a good amount of heavy oils. However, the genesis and production of this oil is a bit of a challenge that is not yet to be resolved. In general, the production of any heavy oil in any area requires special and expensive means, and to be able to extract this oil, we need to know the chemical composition and physical behavior of the heavy oil, which makes it very important to understand the first cause and origin of heavy oils in the first place.

The region was estimated to have exceeded 15 billion barrels of crude oil, which put the region under the light for exploration and production (Mackertich and Samarrai, 2015). Although there are still obstacles to the foundation of this industry, it's still taken as a good potential for future production where the extraction of one barrel of heavy oil costs $10 (Abdula, 2018).

The production process is very sensitive, and the means of production depends highly on the reservoir mechanisms and the oil properties within the reservoir (Zhao et al., 2021). As expected for heavy oils with their high viscosity and high density, secondary or tertiary recovery is probably to be used (Xue, Liu, and Zhang, 2022), and in order to minimize the production challenges for heavy oil in this study, we aim to have a clear understanding of the origin of heavy oil and its production limitations.

The genesis of heavy oil in the Kurdistan Region of Iraq is intricately associated with geological phenomena, including sedimentation, burial, and thermal maturation mechanisms. The formation of the oil-rich reservoirs in the region occurred predominantly during the Mesozoic era, specifically in the Cretaceous and Jurassic eras (Perera et al., 2016). The primary origin of heavy oil in the area is frequently attributed to the organic-rich shale found within the middle Jurassic period's Sargelu Formation (Abdula, 2018). This particular formation has undergone substantial thermal maturation and subsequent hydrocarbon generation throughout its geological history (Perera et al., 2016).

The organic matter in the source rock underwent significant temperature and pressure conditions during burial and compaction, resulting in the formation of hydrocarbons (Pang et al., 2015). Nevertheless, heavy oil formation necessitates supplementary geological circumstances that facilitate the preservation of denser and more viscous hydrocarbon compounds (Pang et al., 2015). The retention of heavy oil within reservoirs is influenced by the presence of specific minerals and clay-rich formations, as well as the relatively low permeability of the reservoirs (Chen, 2019). These factors impede the complete maturation of heavy oils into lighter oils or natural gas (Pang et al., 2015). In addition, the movement of oil within reservoirs is of paramount importance in determining the concentration and spatial location of heavy oil accumulations (Chen and Yang, 2021). The presence of skeletal traps and faults within the region, in conjunction with the existence of cap rocks, impedes the migration of oil, resulting in the localized accumulation of heavy oil (Al-Qayim and Barzani, 2021). The geological processes and conditions present in the Kurdistan Region of Iraq have resulted in the formation of substantial reserves of heavy oil (Al-Qayim and Barzani, 2021).

The extraction and manufacturing of heavy oil in the Kurdistan Region of Iraq pose a range of challenges as a result of its unique properties (Hakimi et al., 2016). Heavy oil's elevated viscosity and weight lead to diminished flow rates and heightened resistance to fluid displacement within reservoir rocks (Hakimi et al., 2016). As a result, traditional extraction methods, including both primary and secondary recovery techniques, may be insufficient to achieve optimal heavy oil recovery efficiency (Tatar, 2018).

Enhanced oil recovery (EOR) techniques are frequently employed in the production of heavy oil in order to address the inherent difficulties associated with its extraction (Hasan and Rigby 2019). Thermal techniques, such as injecting steam or in-situ combustion, can potentially decrease oil viscosity and improve its flow characteristics (Arcelus-Arrillaga et al., 2017). In a similar vein, chemical techniques such as polymer flooding or the application of surfactants have the capacity to modify the oil-water interface, thereby enhancing the mobility of the oil (Ahmadi et al., 2022; Ali et al., 2019). Nevertheless, successfully implementing these techniques necessitates meticulous reservoir characterization, appropriate infrastructure, and substantial financial investments (Davoodi et al., 2022).

This study's purpose is to conduct a comprehensive review of heavy oil and its unique characteristics in the Kurdistan region of Iraq, focusing on the production challenges related to heavy oil extraction and potential solutions to these issues. The study will collect and evaluate existing literature and research articles pertaining to the region's production of heavy oil. This method enables a thorough synthesis of knowledge on the topic by facilitating a methodical and rigorous study of numerous sources of information. The study attempts to thoroughly understand the production issues particular to heavy oil in the Kurdistan region and offers practical solutions by examining and integrating the data from multiple studies. The extensive review will advance knowledge in the area of heavy oil extraction and be an invaluable tool for scholars and businesspeople in the Iraqi Kurdistan region.

1.1 Geological Setting and Study Area

The Kurdistan Region of Iraq (KRI) is located north and northeast of the Arabian plate. It is part of the Zagros fold and thrust belt, a zone of crustal rock formed by the collision of the Arabian and Eurasian plates during the late Cretaceous and Cenozoic (Karim et al., 2015). The hydrocarbon type and quality in Kurdistan exhibit a considerable range. Oil gravities reported in publications span from 12° API to over 57° API (English et al., 2015; Figure 2), indicating diverse characteristics. Additionally, substantial amounts of natural gas have been found in the region. The total oil reserves in Kurdistan region are estimated to be around 45 billion barrels with about 20 billion barrels being heavy oil located in some of the largest oil field that contain heavy oil reserves, Bai Hassan field, and the Avana field including the Kirkuk field (Saleh and Hamad, 2021; Figure 1).

Heavy oil in the Kurdistan region is predominantly sourced from the Sargelu, Chia Gara, Shiranish, and Kolosh Formations, which are organic-rich formations that have generated significant amounts of heavy oil over geologic time (Figure 1).

Since the late 1990s, the region has undergone exploration by international oil companies. However, creating a valid petroleum industry in the Iraqi Kurdistan region is difficult to move due to infrastructure, geopolitical constraints, legal and institutional concerns, and technological limits (Dargin, 2007).

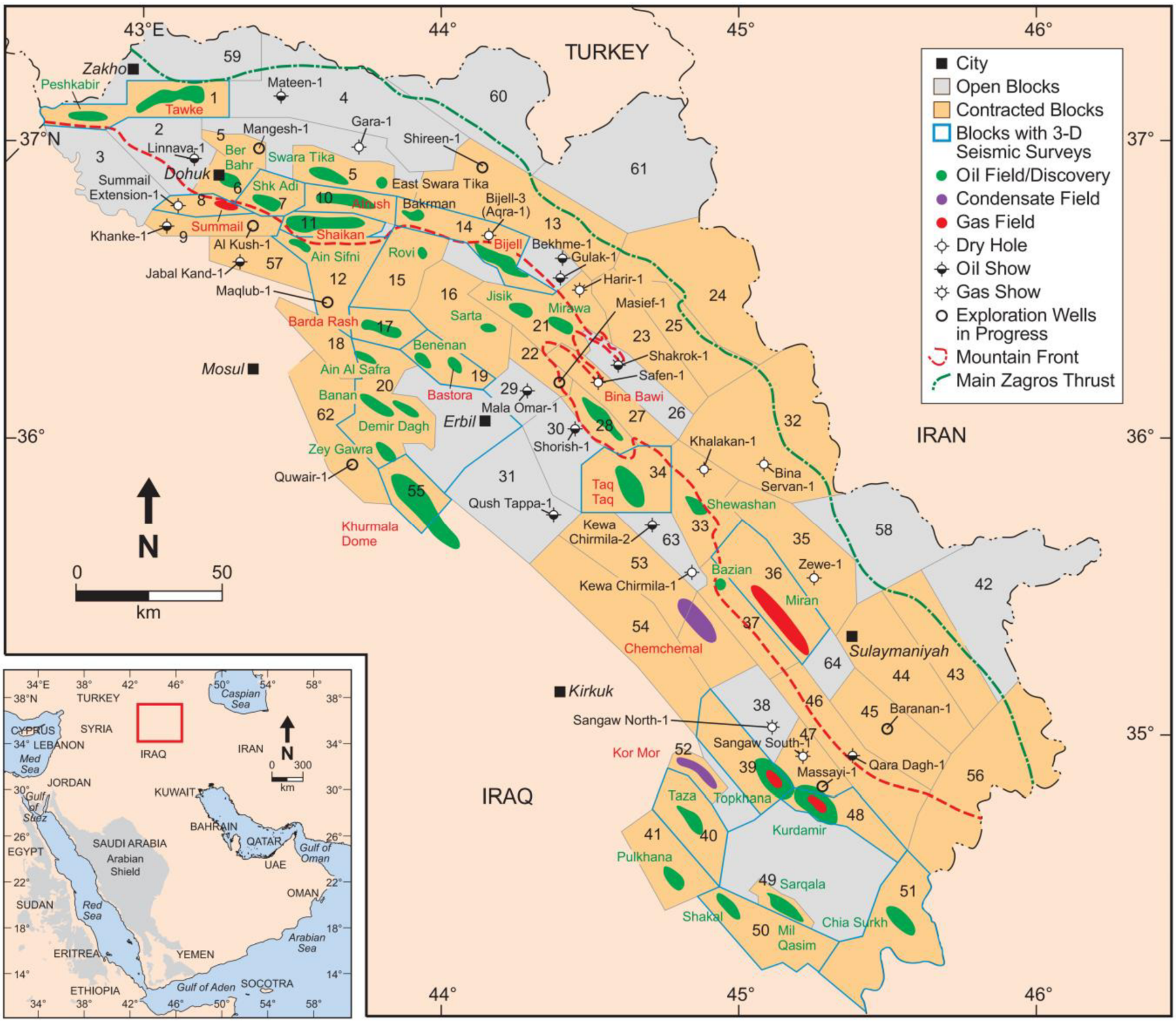


Figure 1. Block map and most important hydrocarbon fields in the Kurdistan region of Iraq (Mackertich and Samarrai, 2015)

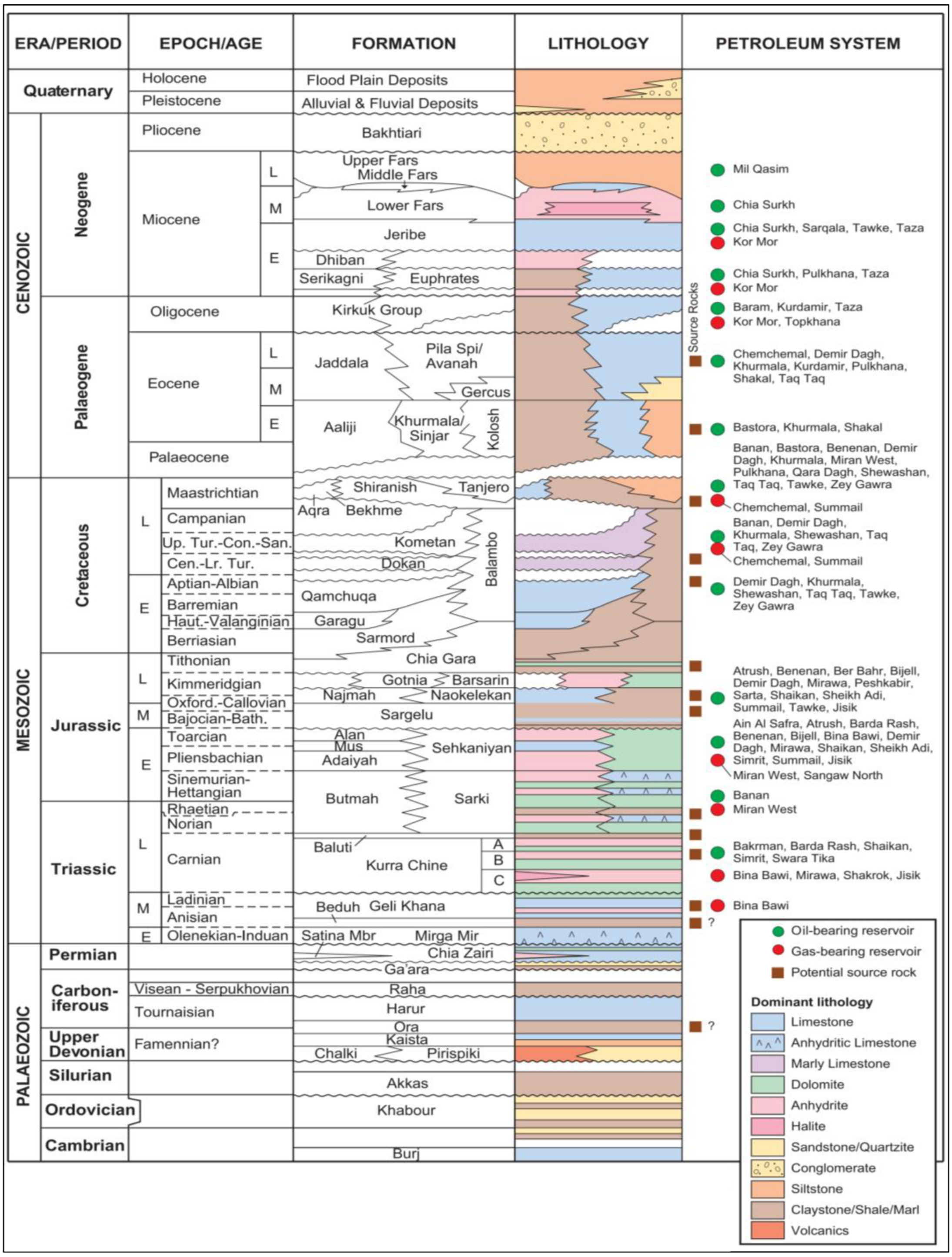


Figure 2. The stratigraphic column and the distribution of hydrocarbon occurrences in the Kurdistan Region of Iraq (English et al., 2015; Mackertich and Samarrai, 2015).

1.2 Classification of Crude Oil

Crude oil is mainly composed of hydrogen and carbon; it can also contain some nitrogen, oxygen and sulfide, which is referred to as the sulfur content of crude oil (Yakubov et al., 2020). In comparison to the other parts of crude, asphaltenes also have a larger concentration of heteroatoms, particularly sulfur and nitrogen (Hou et al., 2016; Table 1). Crude oil is, however, affected by the source rock's quality, type, and many other variables. There are several systems used to classify crude oil based on different criteria. Among the most important crude oil classification systems, the following can be mentioned:

1) API: The API gravity system measures the density of crude oil relative to water. It categorizes crude oil into light, medium, and heavy based on its API gravity value (Hou et al., 2016; Figure 3).

2) Sulfur Content: Crude oil can be classified based on its sulfur content, with low-sulfur crude oil considered more desirable due to lower environmental impact and reduced refining complexity (Yarranton, 2022).

3) Geographic Origins: Crude oil can also be classified based on its geographic sources, such as Brent crude, West Texas Intermediate (WTI), or Dubai crude, which reflect regional variations in composition and market pricing (Fakher et al., 2020).

4) SARA: SARA stands for Saturates, Aromatics, Resins, and Asphaltenes, which are the four main components used to classify and characterize crude oil based on their molecular structure and solubility (Karevan et al., 2022). SARA analysis is a commonly used method in the oil industry to understand the composition and properties of crude oil (Rezaee et al., 2020).

In this thesis, the main topic of discussion is heavy oil. For this reason, the most important features of heavy oil have been discussed in the following.

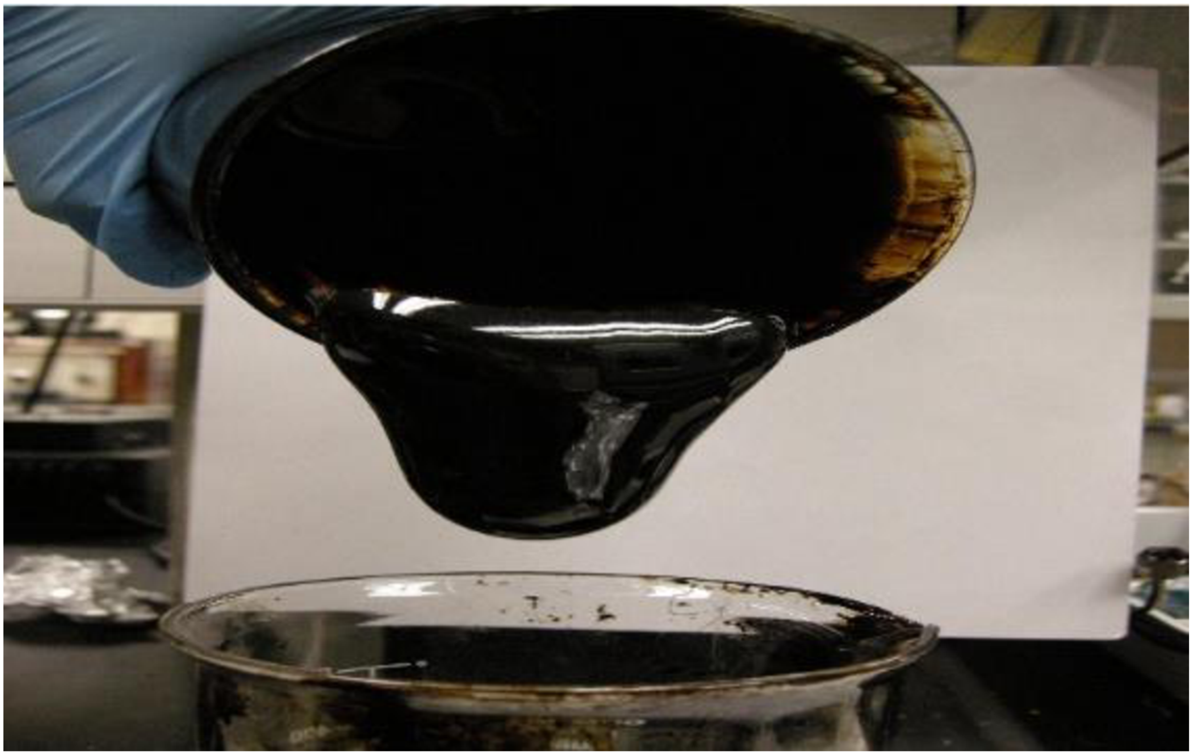


Figure 3. Heavy oil with API gravity lower than 20 (Alnoaimi, 2010).

Table 1. Composition of heavy oil (after Gateau et al., 2004).

Fraction	**Weight percentage (%)**	**Elementary Composition based on C20 + (%)**				
		C	**H**	**N**	**O**	**S**
Asphaltene	14.1	83.8	7.5	1.3	1.7	4.8
Resin	37.3	82.8	8.9	15	2.0	4.3
Aromatic	37.2	84.3	10.0	<03	1.1	4.0

Saturate	11.4	86.6	13.0	<0.3	<02	< 0.1

1.3 Formation of Heavy Oil

The most significant reason for the formation of heavy oil is the type of organic matter present in the source rocks and its subsequent thermal maturation (Xiong et al., 2022). Organic matter, such as kerogen, undergoes chemical transformations as it is subjected to increasing temperature and pressure over geological time (Hou et al., 2016). The type and composition of organic matter play a crucial role in determining the properties of the hydrocarbons generated (Hakimi et al., 2016; Malkin et al., 2016). The organic matter with higher molecular weight and a higher proportion of polar compounds tends to yield heavier hydrocarbons, including heavy oil (Yakubov et al., 2020).

During thermal maturation, the organic matter goes through processes such as cracking, polymerization, and condensation, resulting in the formation of heavier hydrocarbons (Chen, 2019). As the temperature and pressure increase, lighter hydrocarbons, such as methane and light oils, are expelled, leaving behind the heavier fractions (Malkin et al., 2016). The extent of thermal maturation, commonly characterized by parameters like vitrinite reflectance or maturity levels (e.g., measured in terms of the Rock-Eval Tmax parameter), determines the final composition and viscosity of the hydrocarbons, ranging from light crude oil to heavy oil or even bitumen (Malkin et al., 2016). Other factors, such as reservoir heterogeneity and trapping mechanisms, can influence the distribution and accumulation of heavy oil within reservoirs, but the primary reason for the formation of heavy oil lies in the organic matter type and the thermal maturation processes it undergoes (Malkin et al., 2016).

On the other hand, another factor that can cause heavy oil is bacteria (Shibulal et al., 2014). Bacteria can play a significant role in the creation of heavy oil through a process known as biodegradation. Biodegradation refers to the microbial alteration and degradation of hydrocarbon compounds in subsurface reservoirs (Shibulal et al., 2014). Bacteria have the ability to selectively consume lighter hydrocarbons, such as methane, ethane, and some light oils, as a source of energy and carbon. These lighter hydrocarbons are more readily biodegradable compared to the heavier components of the oil. As bacteria metabolize and degrade the lighter hydrocarbons, the heavier fractions, including heavy oil, become relatively enriched in the reservoir (Shibulal et al., 2014).

It is important to note that biodegradation can occur both before and after the hydrocarbons are trapped in the reservoir (Zadymova et al., 2016). In some cases, biodegradation can take place in the source rocks or during the migration process (Hakimi et al., 2016). The degree of biodegradation can vary, ranging from minor alterations to substantial changes in the composition and properties of the oil. (Zadymova et al., 2016). The presence of specific bacterial communities capable of metabolizing hydrocarbons and the environmental conditions within the reservoir, such as temperature, nutrient availability, and oxygen levels, can influence the extent and rate of biodegradation (Shibulal et al., 2014).

In addition, the presence of heavy metals can also influence the development of heavy oil. Heavy metal concentrations of nickel and vanadium can be particularly high in some types of source rocks, like shales (Zhao et al., 2021; Table 2). During the thermal maturation process, these metals may be absorbed into the hydrocarbons, which may lead to the creation of heavy oil (Chen, 2019).

Table 2. Classification of crude oil (after Zhao et al., 2021).

Classification	**Density 15 ° C (g / cm^3)**	**API Gravity**
Extra Light	p < 0.8017	39.0 < = p
Light	0.8017 ~ 0.829	38.9 ~ 34.0
Medium	0.830 ~ 0.903	33.9 30.0

Heavy	0.904 ~ 0.965	29.9 ~ 26.0
Extra Heavy	0.966 < = p	p < 26.0

2 Methodology

The method that was used to conduct a thorough to analyze heavy oil and its distinctive characteristics in the Kurdistan area of Iraq is presented in this chapter. This study aims to examine the production issues related to the extraction of heavy oil in the area and to suggest viable solutions to these problems. This study used a meta-analytical analysis as the research methodology, allowing for the methodical review and analysis of previously published literature and research publications. Gathering significant published references that are relevant to the research problem was the first step in the research procedure. A comprehensive search of databases, scholarly journals, conference proceedings, and other trustworthy sources was conducted to find studies that address the major components of the research topic. Relevant papers were identified using various search engines such as Google Scholar and ScienceDirect. The search terms used for the literature review included "heavy oil," "production challenges," "Kurdistan region," and "treatment methods." Additionally, the thesis advisors and supervisors provided research papers that were valuable resources for the study.

After collecting all the necessary references, the second step does a thorough and methodical investigation of each document to extract and highlight all the relevant facts and information. This required carefully assessing many different aspects of the studies, such as the method used, the variables explored, the reported results, and the characteristics of the sample. The analysis method involved more than just a cursory examination. It went deep into the study process, allowing for a more comprehensive understanding of the data collection and analysis methods in each article. By assessing the facts and conclusions offered in each study critically, a more thorough and in-depth understanding of the research issue was attained.

The next step was integrating and synthesizing the knowledge gathered from the examined publications in order to develop a full understanding of the characteristics of heavy oil, effect on reservoir behavior, and impact of heavy oil on production. Each study's data, findings, and conclusions were carefully analyzed in order to detect recurring facts, trends, and contradictions. The researcher acquired insights into the big picture by methodically comparing and contrasting the data and interpretations. This process enabled the development of a comprehensive understanding of the topic, summarizing the important findings, and offering a well-informed conclusion based on the overall data gathered from the examined papers.

Some of the most significant papers that were analyzed were Identity and hydrocarbon degradation activity of enriched microorganisms from natural oil and asphalt seeps in the Kurdistan Region of Iraq (KRI) by Shlimon et al. (2021), Microbial community composition in crude oils and asphalts from the Kurdistan Region of Iraq by Shlimon et al. (2021), Geology of Iraq (Kurdistan) by Abdula (2018), and An alternative anaerobic treatment process for treatment of heavy oil refinery wastewater containing polar organics by Wang et al. (2016).

The papers highlighted above among other resources used, highlighted the attributes of heavy oil and the methods of its production, its effect on reservoir behavior, the challenges heavy oil imposes on production, and treatment methods which are all presented in the next chapters.

3 Results and Discussions

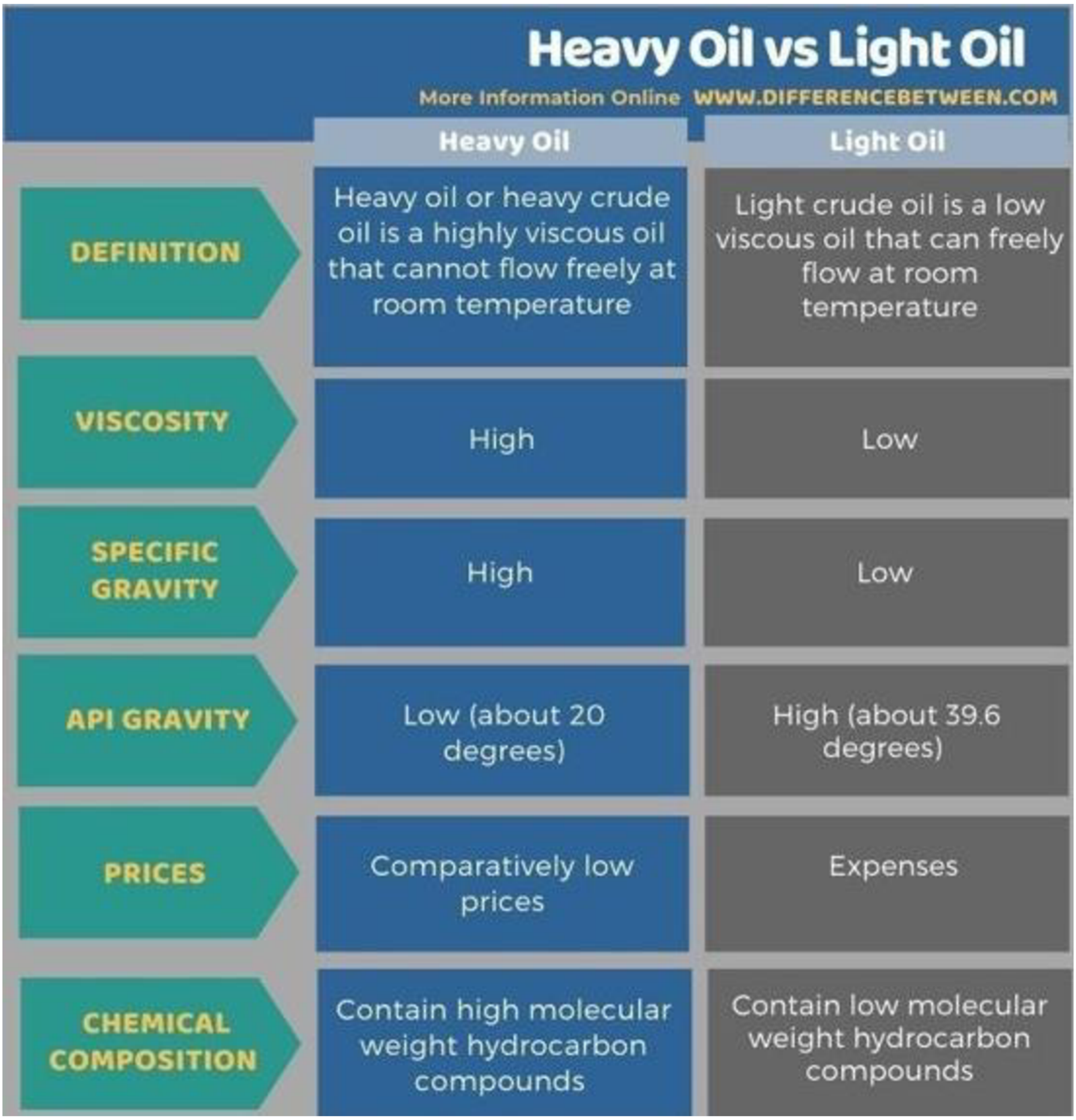
This chapter discusses the findings of the study in terms of heavy oil production methods, key characteristics of heavy oil, effects on reservoir behavior, the impact of heavy oil on production, and heavy oil production treatment methods.

3.1 Characteristics of Heavy Oil

Heavy oil is characterized by its high viscosity, which refers to its resistance to flow (Hakimi et al., 2016). The viscosity of heavy oil is significantly higher compared to lighter crude oils (El-Moniem, 2020). This high viscosity makes it more challenging to extract, transport, and refine heavy oil (Chen and Yang, 2021; El-Moniem, 2020). Also, heavy oil has a low API gravity, which is a measure of its density relative to water (Alnoaimi, 2010). API gravity is inversely related to density, so a lower API gravity indicates higher density. They typically have an API gravity below 20 degrees, indicating their denser nature (Alnoaimi, 2010). On another hand, they have a higher molecular weight compared to lighter crude oils (Hakimi et al., 2016). It contains larger hydrocarbon molecules, including an increased proportion of long-chain hydrocarbons, as well as more complex compounds such as asphaltenes and resins (Hou et al., 2016). Resins are polar compounds that can contribute to the adhesiveness and high viscosity of heavy oil (Arcelus-Arrillaga et al., 2017).

Heavy oil has a higher carbon content compared to lighter crude oils (Figure 4). This higher carbon content contributes to its heavier molecular structure and results in a higher carbon-to-hydrogen ratio. Moreover, they exhibit lower volatility, meaning it has a reduced tendency to vaporize at normal reservoir and ambient conditions (Arcelus-Arrillaga et al., 2017). Due to its heavy molecular composition, heavy oil requires higher temperatures to achieve vaporization and has a lower vapor pressure compared to lighter crude oils (Stratiev et al., 2019). Heavy oil typically contains higher concentrations of sulfur and metals, such as nickel and vanadium (Stratiev et al., 2019). These impurities can pose challenges during refining processes and may require additional treatment to meet environmental regulations (Stratiev et al., 2019).

Another feature of heavy oil, apart from its special compounds and other unique features, is its low price in the market (Heshmati and Auzer, 2018; Mills, 2016). Normally, the price of heavy oil is cheaper than light oil in world markets (Heshmati and Auzer, 2018).


Heavy Oil vs Light Oil

More Information Online WWW.DIFFERENCEBETWEEN.COM

	Heavy Oil	Light Oil
DEFINITION	Heavy oil or heavy crude oil is a highly viscous oil that cannot flow freely at room temperature	Light crude oil is a low viscous oil that can freely flow at room temperature
VISCOSITY	High	Low
SPECIFIC GRAVITY	High	Low
API GRAVITY	Low (about 20 degrees)	High (about 39.6 degrees)
PRICES	Comparatively low prices	Expenses
CHEMICAL COMPOSITION	Contain high molecular weight hydrocarbon compounds	Contain low molecular weight hydrocarbon compounds

Figure 4. Differences between heavy oil and light oil (differencebetween.com, 2023).

3.1.1 Characteristics of Heavy Oil in Kurdistan

In the Kurdistan Region of Iraq, several important oil discoveries have been made which provide evidence containing heavy oil, which refers to oil with a gravity below 22.3° API. In the Shaikan Field, the majority of estimated hydrocarbon resources, around 80%, are believed to be located in Jurassic reservoirs that hold heavy oil ranging from 12° to 22° API (Gulf Keystone, 2013; Mackertich and Samarrai, 2015; Table 3). Similarly, the Barda Rash Field is estimated to have over 10 billion barrels of total stock tank oil initially in place (STOIIP), with slightly more than half of it found in Cretaceous reservoirs that also contain heavy oil (Afren, 2011; Mackertich and Samarrai, 2015).

The reason for the heavy nature of the oil in the Kurdish discoveries is attributed to the maturity of the source rock. Lower-maturity oils are found over the Mosul High, while higher maturity oils have been encountered elsewhere (English et al., 2015). In some cases, heavy oil may result from near-surface water influx and associated biodegradation. Although one might expect heavier oils at greater depths within a reservoir due to gravity segregation, this doesn't appear to be the case in certain fields (Mackertich and Samarrai, 2015). In the Atrush Field, the discovered oil becomes progressively heavier with depth, ranging from 27° API to 14° API. The flow rates achieved during well testing depend on reservoir quality, API gravity, viscosity, and the specific lifting mechanism used (Shamaran Petroleum Corporation, 2015; Mackertich and Samarrai, 2015).

Regarding the Shaikan Field, the latest Competent Person Report (CPR) suggests that there is movable oil in fractures down to a depth of approximately 1,350 to 1,400 meters' true vertical depth subsea (TVDSS). This depth is nearly 1,000 meters below the highest point of the Jurassic structure (Mackertich and Samarrai, 2015). Below this level is a zone with semi-mobile oil, known as the "high viscosity zone," extending a further 50 to 100 meters. Beyond that, the fractures are believed to contain water. However, the matrix (rock) is interpreted to hold oil down to 1,950 meters TVDSS. Within the interval of 1,450 to 1,950 meters TVDSS, water is present in fractures surrounding oil-saturated matrix blocks (Law et al., 2014;

Mackertich and Samarrai, 2015). This situation is likely caused by potential oil leakage from the structure in recent geological time, resulting in drainage of the fractures and water influx from the aquifer. The influx of freshwater may have caused the oil to degrade, forming a zone of high viscosity, semi-mobile oil, or tar within the fractures (Mackertich and Samarrai, 2015).

Table 3. Reported Reservoir Age and Oil Gravity for Significant Hydrocarbon Findings in Kurdistan (after English et al., 2015; Mackertich and Samarrai, 2015).

Discovery (bold = approved field development plan)	**Year**	**Reservoir Age**	**Formation**	**Oil Gravity (API)**
Ain Al Safra	2013	Jurassic	Alan Mus	20-29
Atrush	2011	Jurassic	Barsarin-Naokelekan-Sargelu-Alan-Mu	22-27
Bakrman	2013	Triassic	Kurra Chine	31-38
		Cenozoic	Pila Spi	Heavy oil
Banan	2014	Cretaceous	Shiranish-Kometan	21
		Jurassic	Butmah	29
Baram	2014	Cenozoic	Kirkuk	42
		Cretaceous	Shiranish-Qamchuga	Heavy oil
Barda Rash	2009	Jurassic	Mus-Adaiyah	28-30
		Triassic	Kurra Chine	38-40
Bastora		Cenozoic	Sinjar	10
	2011	Cretaceous	Bekhme	17
Bijell	2010	Jurassic	Barsarin-Naokelekan-Sargelu- Sehkaniyan	14-23
Benenan	2008	Cretaceous	Bekhme	10
		Jurassic	Najmah / Mus	8-12 30
Ber Bahr	2013	Jurassic	Sargelu	12-15
Bina Bawi	2007	Jurassic	Mus-Adaiyah	44-47
		Triassic	Kurra Chine-Geli Khana	Gas (10-14 bbl/MMcf)
Chemchemal	1929	Cenozoic	Pila Spi	43 & Gas
		Cretaceous	Shiranish-Kometan	Gas
Chia Surkh	1901	Cenozoic	Lower Fars / Jeribe-Dhiban-Euphrates	38 & Gas / 38-50
		Cenozoic	Pila Spi	15
Demir Dagh	1960	Cretaceous	Shiranish-Kometan-Qamchuqa	23
		Jurassic	Najmah/Sargelu/Mus-Adaiyah	10 29-32/37-4
Jisik	2014	Jurassic	Sargelu-Mus-Adaiyah ?	39-45 ?
		Triassic	Kurra Chine	Gas
Khurmala Dome	1935	Cenozoic	Avanah-Khurmala	34
		Cretaceous	Shiranish-Kometan-Qamchuqa	28-41

Kor Mor	1928	Cenozoic	Jeribe-Euphrates-Kirkuk	57 & Gas
Kurdamir	2010	Cenozoic	Kirkuk-Jaddala	38-47 & Gas (30-40 bbl/MMcf)
Mil Qasim	2011	Cenozoic	Upper Fars	43-44
Miran West	2009	Cretaceous	Shiranish	15
		Jurassic	Adaiyah-Butmah	Gas (2-20 bbl/MMcf)
Mirawa	2013	Jurassic	Sargelu-Mus-Adaiyah	39-45
		Triassic	Kurra Chine	Gas
Peshkabin	2012	Jurassic	Sargelu	32
Pulkhana	1927	Cenozoic	Euphrates-Serikagni-Jaddala	31-34
		Cretaceous	Shiranish-Balambo	28-32
Qara Dagh	2011	Cretaceous	Tanjero-Shiranish	43-46
Sarqala	2011	Cenozoic	Jeribe-Dhiban	40
Sarta	2010	Jurassic	Sargelu	20
Sangaw North	2011	Jurassic	Mus	Dry Gas
		Cretaceous	Sarmord-Garagu-Chia Gara	Heavy / bituminous oil
Shaikan	2009	Jurassic	Naokelekan-Sargelu-Mus	14-20
		Triassic	Kurra Chine	37-43 & Gas (120 bbl/MMcf)
Shakal	2009	Cenozoic	Jaddala-Aaliji	35
		Cretaceous	Sarmord-Garagu-Chia Gara	Heavy oil
Sheikh Adi	2012	Jurassic	Naokelekan-Sargelu-Mus	16-19
Shewashan	2014	Cretaceous	Shiranish-Kometan-Qamchuqa	45
Simrit		Jurassic	Mus-Adaiyah	14-21
	2012	Triassic	Kurra Chine	36-39
	2011	Cretaceous	Shiranish-Agra-Kometan	Gas
Summail		Jurassic	Sargelu-Mus	14
Swara Tika	2011	Triassic	Kurra Chine	36-38
	1958	Cenozoic	Pila Spi	24
Taq Taq		Cretaceous	Shiranish-Kometan-Qamchuqa	48
		Cenozoic	Jeribe	24
Tawke	2006	Cretaceous	Bekhme-Qamchuqa	26-27
		Jurassic	Sargelu	32
Taza	2013	Cenozoic	Jeribe-Dhiban-Euphrates-Kirkuk	36
Topkhana	2011	Cenozoic	Kirkuk	Gas (30-40 bbl/MMcf)
Zey Gawra	2013	Cretaceous	Shiranish-Kometan-Qamchuqa	35

3.2 Heavy oil effect on Reservoir Behavior

Due to its special characteristics, heavy oil has different effects on reservoirs. In general, it can be said that these effects are negative and cause various challenges in oil reservoirs (Karim et al., 2015; Fernandes, 2014). For instance, heavy oil reserves typically exhibit lower permeability compared to lighter crude oils (Fernandes, 2014). Heavy oil's high viscosity and density can restrict fluid flow through the reservoir rock, resulting in reduced permeability. This reduced permeability affects the rate at which the oil can be produced from the reservoir (Fernandes, 2014).

On the other hand, the high viscosity of heavy oil can lead to a phenomenon called viscous fingering (Mohamad-Hussein et al., 2022). When heavy oil is produced, it can channel preferentially through high-permeability pathways within the reservoir, creating fingers or channels while leaving behind unproduced oil (Tahir et al., 2022). This uneven production profile can result in poor sweep efficiency and leave significant volumes of oil unrecovered (Figure 5).

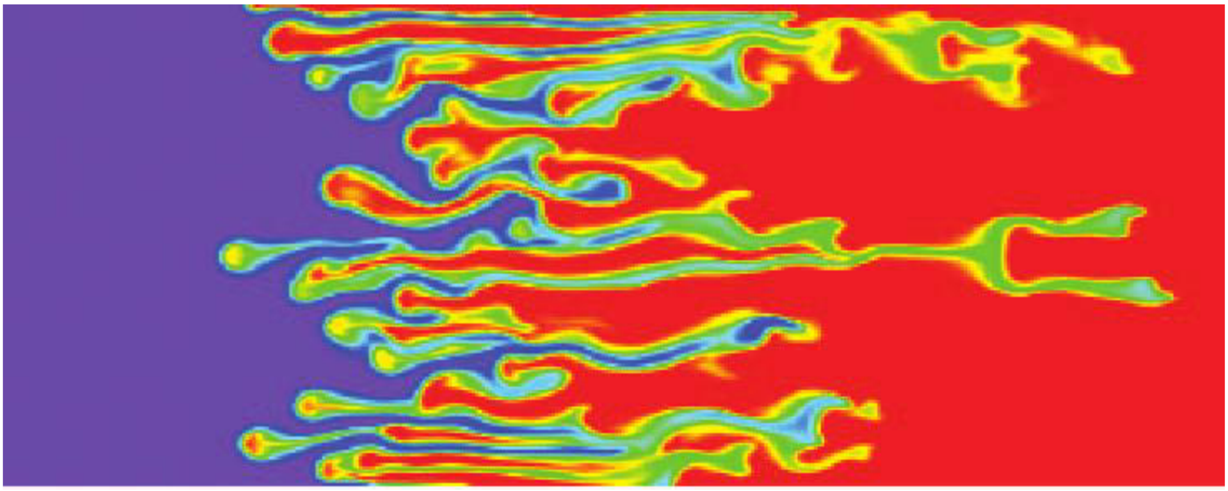


Figure 5. The phenomenon of viscous fingering in heavy oil reservoirs (Christie et al., 2005).

Due to the density difference between heavy oil and reservoir fluids, heavy oil has a tendency to sink and segregate in the lower portions of the reservoir. This can result in a vertical variation in oil saturation and can lead to vertical compartmentalization of the reservoir. It poses challenges for efficient fluid displacement during production (Christie et al., 2005).

In addition, the presence of capillary forces in the reservoir can result in the trapping of heavy oil in small pore spaces and rock matrix (Karim et al., 2015). Capillary trapping can reduce the effective oil saturation and affect the recovery factor of the reservoir. The high viscosity of heavy oil exacerbates the capillary trapping effect (Mohamad-Hussein et al., 2022). Moreover, heavy oil has a higher residual oil saturation compared to lighter crude oils. Residual oil saturation refers to the portion of oil that remains trapped in the reservoir after primary production methods (Tahir et al., 2022). The higher residual oil saturation of heavy oil reduces the recovery factor and requires enhanced recovery techniques for efficient production.

The higher viscosity of heavy oil can lead to more severe formation damage during production. The oil may cause plugging or clogging of the pore spaces, reducing permeability further and hindering fluid flow within the reservoir (Fernandes, 2014). Also, heavy oil often contains higher concentrations of impurities, such as calcium, magnesium, and other minerals (Fernandes, 2014). During production, these impurities can precipitate and form scale deposits, leading to reduced permeability and wellbore blockages (Figure 6). Additionally, heavy oil's high paraffin content can result in wax deposition, which can restrict fluid flow and hinder production (Mohamad-Hussein et al., 2022).

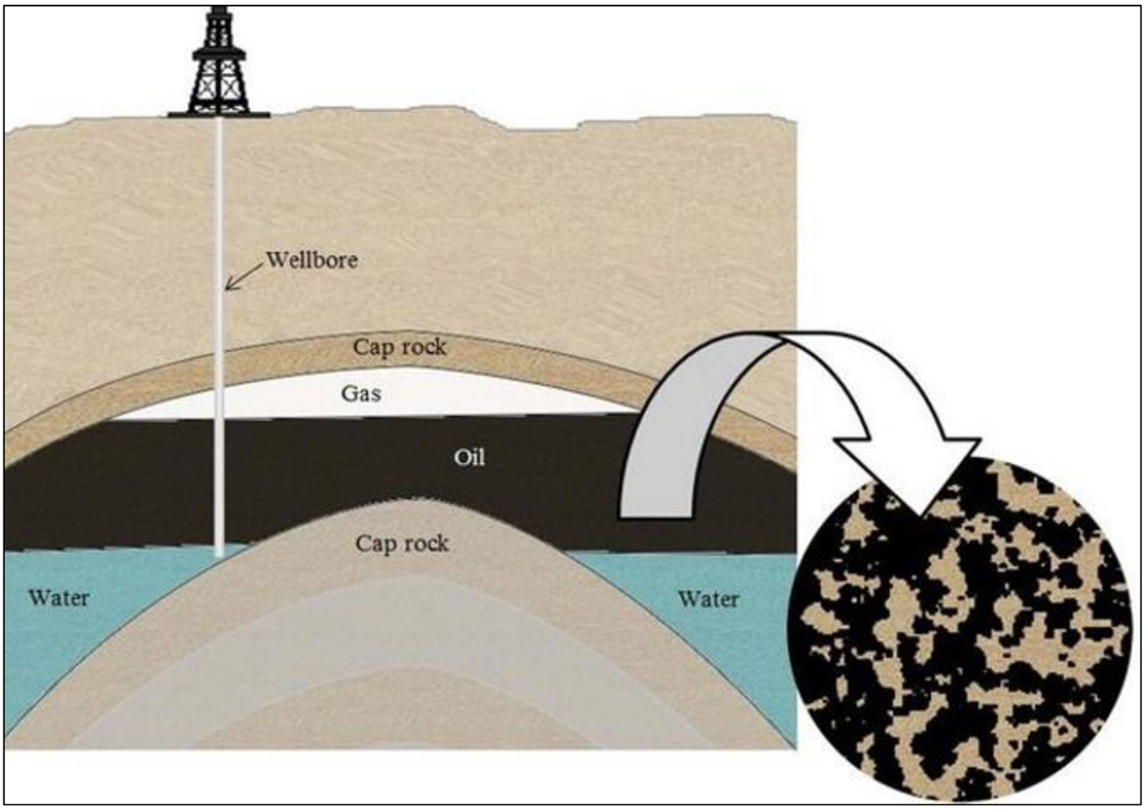


Figure 6. Blockage in the porosity and permeability of the reservoir rock due to heavy oil (Fernandes, 2014).

3.3 Impact of Heavy Oil on Production

Considering the characteristics of heavy oil and its negative effects on the reservoir, there is definitely no expectation of easy production. There is no doubt that its production is full of various and difficult challenges, for example, high viscosity and density pose flow assurance challenges during production (Yakubov et al., 2020). The high viscosity makes it more difficult for the oil to flow through the reservoir, wellbore, and production facilities (Collitt et al., 2023). Specialized production techniques and infrastructure, such as artificial lift systems and heating methods, may be required to overcome these challenges and ensure continuous production (Figure 7). Also, the low permeability and high viscosity of heavy oil restrict fluid flow, resulting in lower production rates per well (Mohamad-Hussein et al., 2022).

In addition, the deposition of heavy oil components, such as asphaltenes and solids, can cause wellbore plugging (Mohamad-Hussein et al., 2022). This can lead to reduced production rates and the need for frequent well interventions and maintenance to mitigate the plugging issues (Yakubov et al., 2020). Careful well design and effective wellbore management practices are crucial to prevent and address plugging challenges, likewise, the higher energy requirements for heavy oil production and processing impact the overall economics and operational costs (Yakubov et al., 2020). The energy-intensive methods employed for heavy oil recovery necessitate additional energy inputs. These energy demands can affect the profitability of heavy oil production projects (Collitt et al., 2023).

On the other hand, one of the most important and challenging issues in heavy oil production they have environmental impacts due to the higher carbon content, impurities (such as sulfur and heavy metals), and energy-intensive processes involved (Ahmadi et al., 2022). For this reason, proper management and mitigation measures, such as effective waste management, emissions control, and adherence to environmental regulations, are essential to minimize the environmental footprint of heavy oil production (Alshammari et al., 2018). Understanding and addressing these production-related challenges are vital for maximizing the recovery and economic potential of heavy oil resources (Abdula, 2018).

The things mentioned above are the most important challenges of heavy oil production in the world, but there is no doubt that all these challenges also exist for the Kurdistan region of Iraq (Abdula, 2018). Most importantly, Iraqi Kurdistan is facing major problems due to political-economic problems and issues in recent years and the lack of sufficient equipment and knowledge to produce this particular type of crude oil.

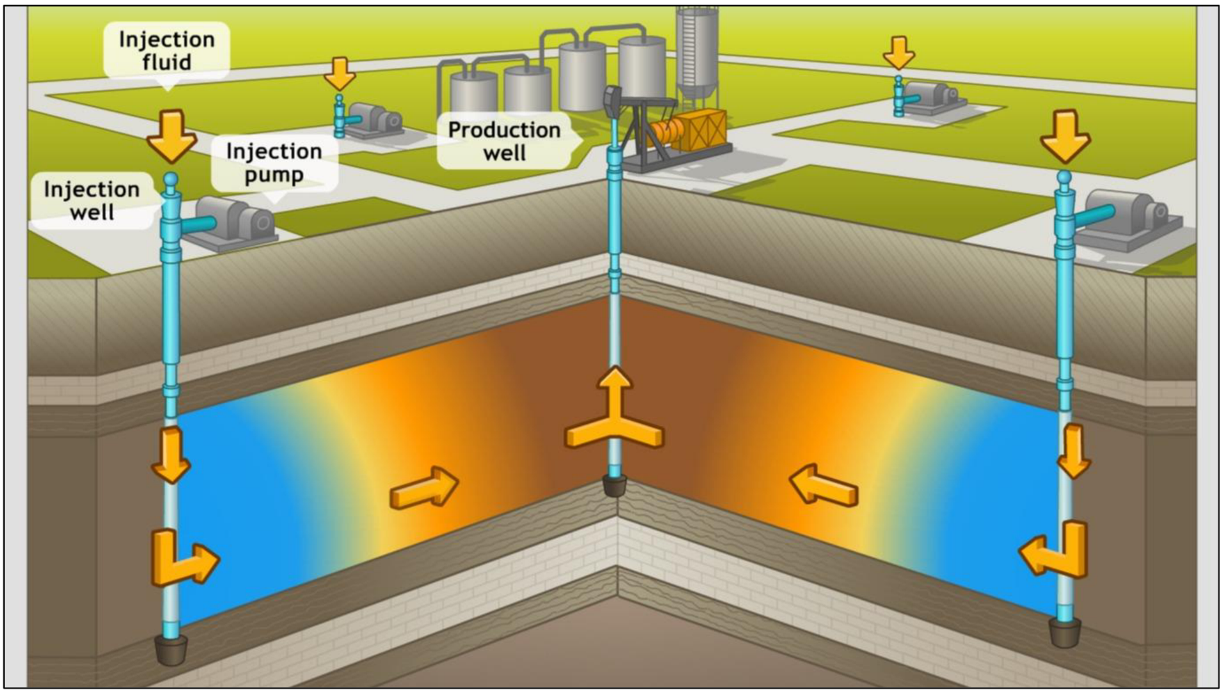


Figure 7. Heavy Oil production well model (Britannica, 2023).

3.4 Treatment Methods in the Production of Heavy Oil

Heavy oil production is a complicated operation that calls for methods and technology to extract oil from the reservoir (Babalola and Susu, 2019). As referred to previously in this study, heavy oil has a high viscosity, density, and low mobility, making it difficult to extract using typical production methods such as primary recovery procedures. Therefore, better recovery strategies have been discussed and proved to enhance heavy oil recovery rates by lowering viscosity, raising mobility, and enhancing reservoir sweep efficiency (Xue, et al., 2022; Babalola and Susu, 2019). The primary recovery methods, enhanced recovery methods, and the possible procedure that need to be taken to enhance recovery on heavy oil production in the Kurdistan Region of Iraq.

3.4.1 Primary Recovery Techniques

The early procedures for extracting oil from reservoirs are known as primary recovery techniques. These approaches are employed when the reservoir's natural pressure can force the oil toward the surface (Ahmadi et al., 2022). Primary recovery procedures are typically the most straightforward and economical ways to extract oil from the reservoir.

The natural flow approach, where oil rises to the surface due to inherent pressure in the reservoir, is the most popular primary recovery technique (Babalola and Susu, 2019; Mai et al., 2009). This technique is frequently employed when the shallow reservoir has a high porosity and good effective permeability, which makes it easier for the oil to flow throughout the formation (Babalola and Susu, 2019).

Using a sucker rod pump, which includes inserting a rod into the wellbore and using a pump to extract the oil, is another common recovery technique (Ahmadi et al., 2022). This method is frequently employed when the reservoir's natural pressure is insufficient to push the oil to the surface. The sucker rod pump is a straightforward, dependable, and affordable oil extraction technique, but it is constrained by the depth and viscosity of the oil in the formation (Ahmadi et al., 2022).

Waterflooding is another important oil recovery method (Hayatolgheibi et al., 2022). Water is injected into the reservoir to move the oil toward the production well. According to Hayatolgheibi et al. (2022), this method forces oil toward the production well by raising reservoir pressure. Of course, oil production rates can be increased, and that is by combining water flooding with other primary recovery methods. However, it must be noted that to apply this method, the reservoir must have sufficient permeability and an appropriate water supply (Wang et al., 2016).

Another important method of oil recovery is gas injection (Ahmadi et al., 2022). It is basically pumping gas into the reservoir, such as nitrogen or natural gas, to raise pressure and force the oil toward the production well (Malkin et al., 2016). The production rate can also be raised here by combining gas injection with various primary recovery methods. However, this method is restricted to specific reservoir types; therefore, it might not be appropriate for all kinds of heavy oil production (Babalola and Susu, 2019).

According to Hayatolgheibi et al. (2022) and Mai et al. (2009), primary recovery techniques must be carefully studied, and all physical characterization of the reservoir must be considered before making the final decision. In addition to this, they are generally ineffective at successfully extracting heavy oil, especially in regions with low natural pressure. As a result, increased recovery procedures are frequently required to increase the amount of recoverable oil (Tahir et al., 2022).

3.4.2 Enhanced Recovery Techniques

Heavy oil that is now difficult to generate using primary recovery methods is extracted using enhanced or tertiary recovery techniques. Thermal recovery and chemical recovery are the two most popular enhanced recovery methods (Collitt et al., 2023).

1. Thermal Recovery Techniques

By raising the temperature of heavy oil, thermal recovery techniques reduce its viscosity and make it easier for the oil to move in the formation. Steam injection, cyclic steam stimulation, and steam-assisted gravity drainage are the most often used thermal recovery methods.

Steam is injected into the reservoir by heating the oil, improving flow, and reducing viscosity, as shown in figure 8. In shallow reservoirs with high permeability, this approach works well (El-Moniem, 2020). On the other hand, in deeper reservoirs with low permeability, cyclic steam stimulation (CSS) is preferred to be employed (Kalita et al., 2022). With this method, the reservoir is filled with steam for a number of weeks, after which the oil is generated during soaking. After that, the procedure is repeated many times, as shown in figure 8 (Phukan et al., 2022).

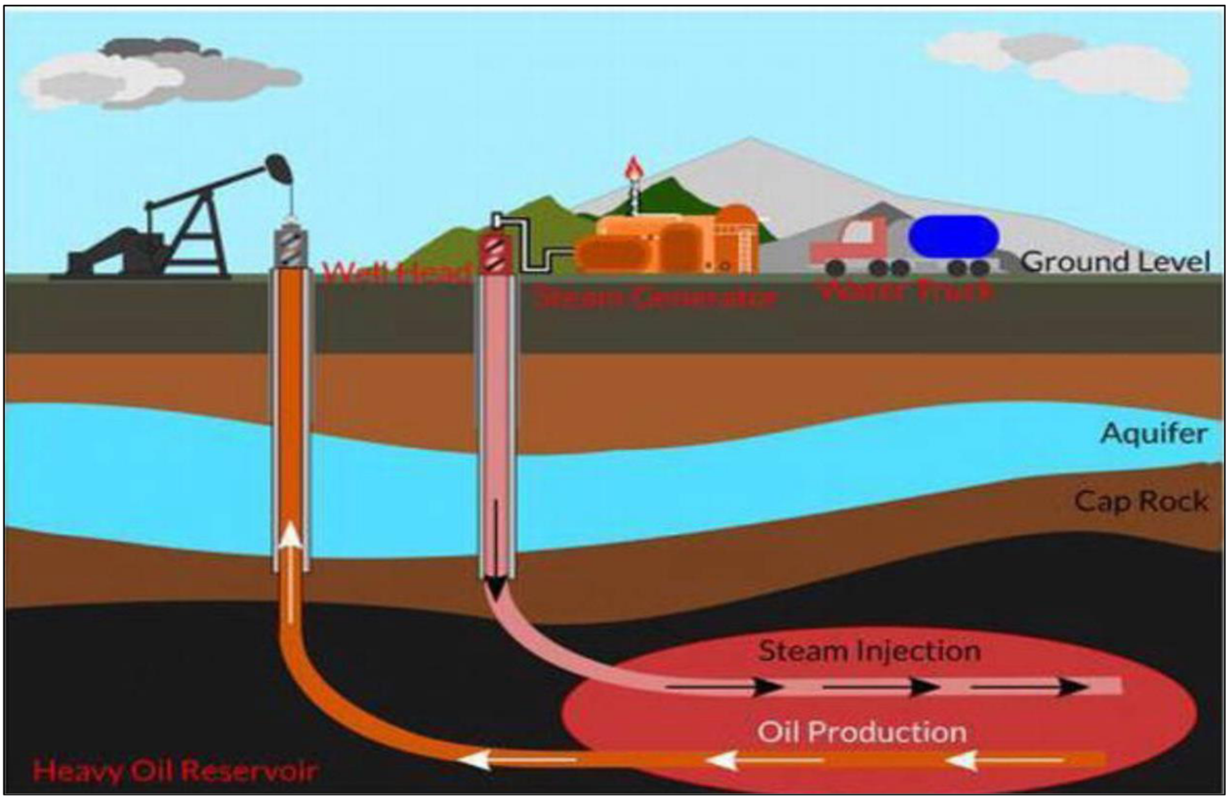


Figure 8. Heavy oil treatment with steam (El-Moniem, 2020).

To extract heavy oil from deep reservoirs with low permeability, steam-assisted gravity drainage (SAGD) is the technique we will aim to use (Collitt et al., 2023; Tahir et al., 2022). It entails drilling two horizontal wells into the reservoir, one on top of the other (Figure 9). Oil production will occur in the lower well after steam injection into the upper well warms the oil and reduces its viscosity (Phukan et al., 2022).

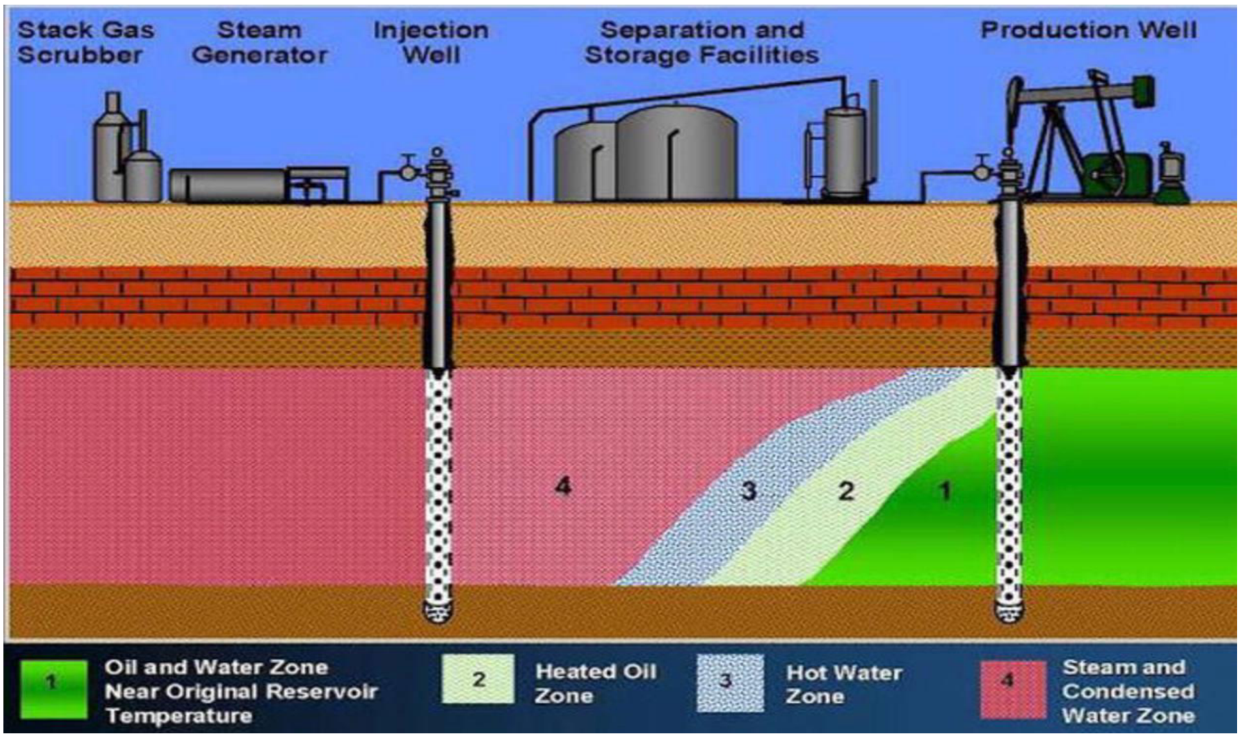


Figure 9. Surface and subsurface explanation of steam treatment (El-Moniem, 2020).

2. Chemical Recovery Techniques

For this recovery technique, chemicals are injected into the reservoir as part of chemical recovery strategies to increase the flow of heavy oil. The most popular chemical recovery methods include flooding with polymers and surfactants (Tatar, 2018; Shibulal et al., 2014). A polymer solution is injected into the reservoir during polymer flooding (Ali et al., 2019). The polymer solution thickens the reservoir's water, decreasing its flow and enhancing its capacity to remove oil (Ali et al., 2019; Tatar, 2018). A surfactant solution is injected into the reservoir during surfactant flooding. Oil can flow freely because the surfactant solution lowers the surface tension between the oil and the rock (Hasan and Rigby, 2019).

3.4.3 Other Enhanced Recovery Techniques

For heavy oil extraction, numerous other enhanced recovery strategies have been developed in addition to thermal and chemical recovery methods (Speight and El-Gendy, 2018; Shibulal et al., 2014). These include electromagnetic heating, gas injection, and microbiological injection.

The gas injection method injects natural gas or other gases into the reservoir, such as nitrogen or carbon dioxide (Collitt et al., 2023). The heavy oil is pushed toward the production well by gas injection, as opposed to microbial infusion, which includes injecting microorganisms into the reservoir to aid in the breakdown of heavy oil and lower viscosity (Tatar, 2018). According to Kalita et al. (2022) and Phukan et al. (2022), electromagnetic heating entails heating the oil and reducing viscosity to make it easier to extract (Figure 10).

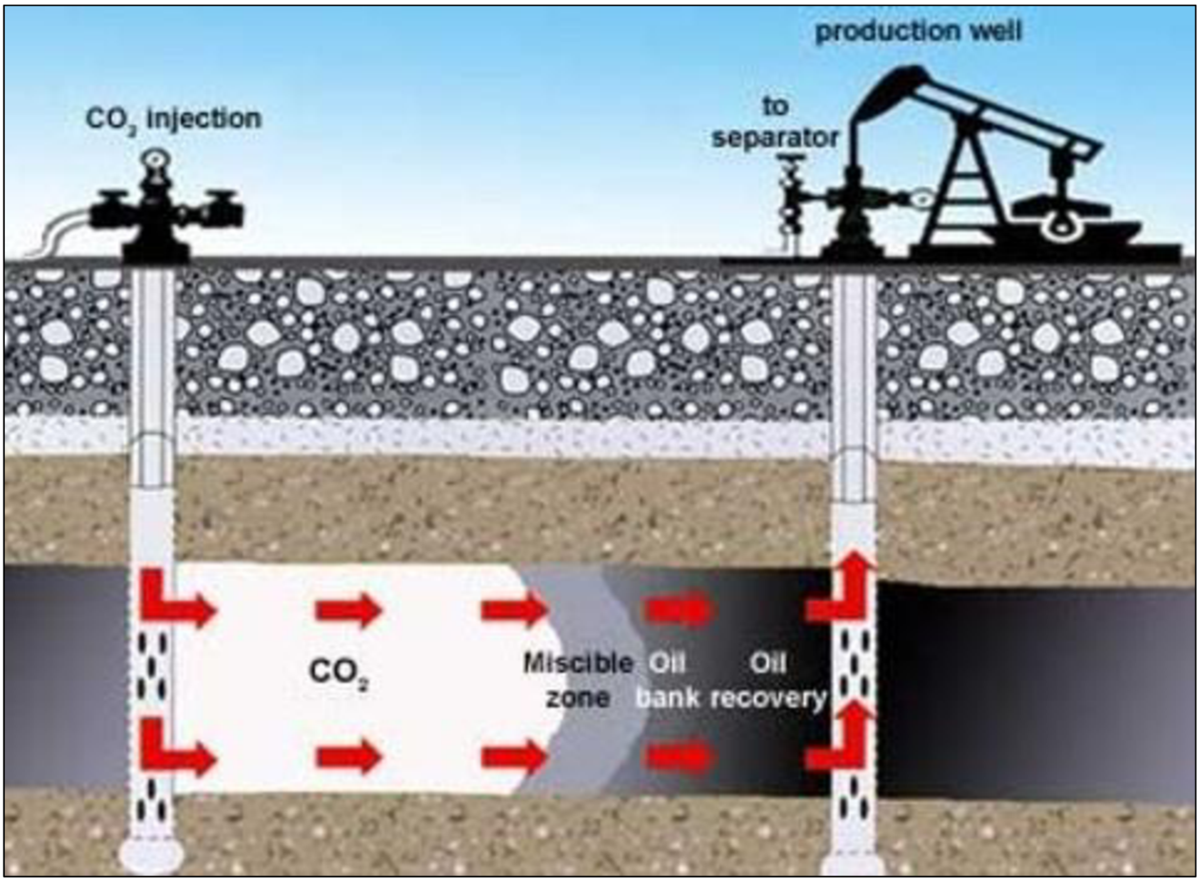


Figure 10. Production treatment method (after Andrei et al., 2010)

3.5 Current Economic Challenges of Heavy Oil Production

Heavy oil production in the Kurdistan region currently faces multiple economic challenges such as the low price of oil in the world market in general and the low price of heavy oil specifically, high production costs, energy requirements, and infrastructural and logistical challenges (Qadir et al., 2021; Zebaria, 2020; Mills, 2016). This section explores these challenges based on the papers reviewed.

Low price of oil in the world market:

The global oil market experiences fluctuations in oil prices, which can have a significant impact on the profitability of heavy oil production (Mills, 2016). In the preceding decade, there have been intermittent instances of reduced oil prices, wherein heavy oil has consistently been valued at a lower rate relative to light crude oil (Heshmati and Auzer, 2018; Mills, 2016). This discrepancy can be attributed to the inferior quality of heavy oil and the elevated expenses associated with its extraction (Heshmati and Auzer, 2018). When the price of oil experiences a decline, producers of heavy oil encounter diminished profit margins or potential losses, rendering the economic viability of heavy oil production unappealing (Heshmati and Auzer, 2018; Mills, 2016). Price volatility and uncertainty within the oil market can discourage investment in heavy oil projects and impede their economic feasibility (Mills, 2016; Figures 11 and 12).

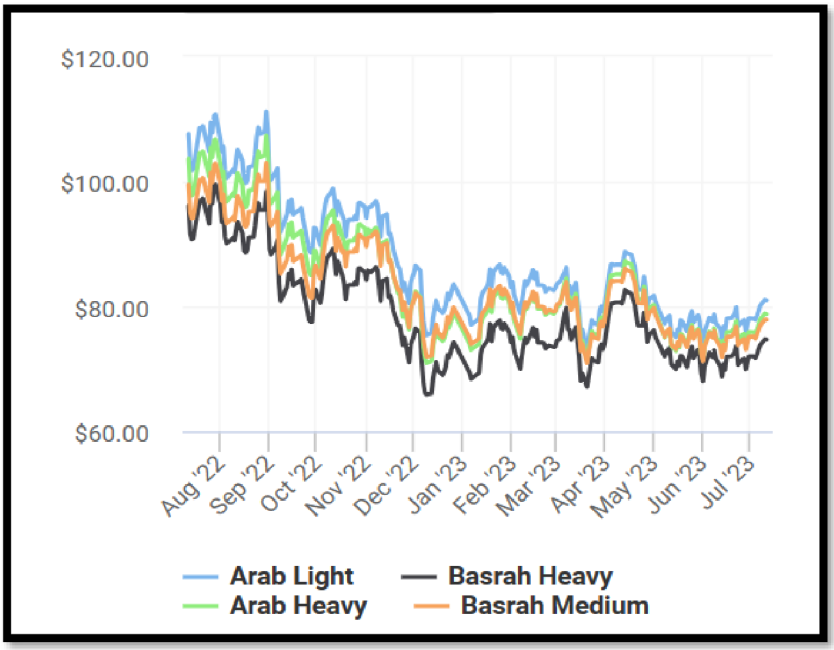


Figure 11. Chart comparing the prices of different oils (light, medium and heavy) in the global oil market in the last year (Oilprice.com)

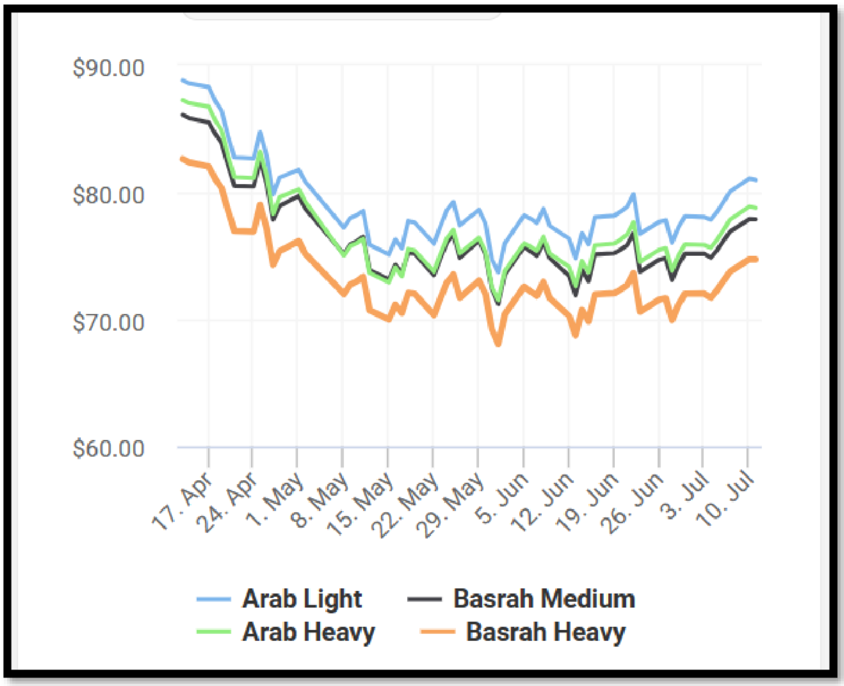


Figure 12. Chart comparing the prices of different oils (light, medium and heavy) in the global oil market in the last three months (Oilprice.com).

3.5.1 Low Price of Heavy Oil

Heavy oil's price is generally lower in the market when compared to light crude oil, primarily because of its inferior quality and higher levels of impurities (Mills, 2016). The reduced profitability of heavy oil is primarily attributed to its lower price, particularly in regions characterized by elevated production costs (Hassan, 2017). In the Kurdistan Region, heavy oil producers face a potential challenge in terms of cost recovery and revenue generation, which could impact the economic viability of heavy oil projects (Hassan, 2017). The financial viability of heavy oil production is constrained by the prevailing low prices, thereby impeding the progress of heavy oil resource development within the region (Hassan, 2017; Mills, 2016).

3.5.2 High Production Costs

Heavy oil production incurs higher costs compared to conventional oil due to its distinctive attributes, such as its elevated viscosity, impurities, and the demanding conditions of its reservoir (Collitt et al., 2023). Reducing viscosity, separating impurities, and improving recovery rates are necessary for heavy oil by implementing supplementary processes and technologies (Qadir et al., 2021; Zebaria, 2020). Implementing various processes, such as thermal methods (e.g., steam injection), upgrading facilities, and advanced separation techniques, results in significant financial investments and ongoing expenses (Qadir et al., 2021). Furthermore, extracting heavy oil from tight reservoirs frequently requires implementing intricate drilling techniques, well-stimulation procedures, and enhanced oil recovery methods, thereby contributing to the overall expenses associated with production (Qadir et al., 2021). The economic viability of heavy oil production is significantly hindered by the substantial costs involved, particularly during periods of low oil prices (Zebaria, 2020).

3.5.3 Energy Requirements

The production and processing of heavy oil necessitate substantial energy inputs in order to meet the required energy demands. Thermal techniques, such as the use of steam injection, are frequently utilized in order to decrease the viscosity of heavy oil and augment its fluidity (Zhao et al., 2021). The mentioned thermal processes necessitate significant quantities of steam, thereby requiring the consumption of substantial amounts of natural gas or alternative energy sources (Qadir et al., 2021). The substantial energy demands associated with the extraction of heavy oil play a significant role in total production expenses and can potentially result in unfavorable economic consequences, especially during periods of elevated or fluctuating energy prices (Zebaria, 2020; Heshmati and Auzer, 2018). Hence, the accessibility and cost-effectiveness of energy resources are pivotal factors in determining the economic feasibility of heavy oil extraction (Heshmati and Auzer, 2018).

3.5.4 Infrastructure and Logistical Challenges

Heavy oil production's economic viability is contingent upon the infrastructure's presence and sufficiency, encompassing pipelines, storage facilities, and transportation networks, which pose logistical and operational obstacles (Qadir et al., 2021). The Kurdistan Region is likely to encounter difficulties with its current infrastructure in managing the extraction and processing of heavy oil, particularly in remote or underdeveloped regions (Qadir et al., 2021; Hassan, 2017). Insufficient transportation alternatives, limited storage capacity, and inadequate processing facilities can amplify logistical expenses and impede the commercialization of heavy oil resources (Heshmati and Auzer, 2018). The enhancement of economic feasibility in heavy oil production necessitates the prioritization of infrastructure development as a crucial measure to address these obstacles (Hassan, 2017).

4 Conclusion

Heavy oil formation in the Kurdistan Region of Iraq is a complex process that spans millions of years and involves the accumulation and transformation of organic material. The region has extensive heavy oil reserves due to its geological history, including tectonic forces, sediment deposition rich in organic matter, and thermal maturation. However, the extraction and utilization of heavy oil face multiple challenges that need to be addressed for successful production.

The high viscosity of heavy oil is a primary obstacle in production, causing significant resistance to flow through reservoir rocks and wells. To address this, various techniques have been used, including thermal methods, chemical additives, and solvent-based processes. While effective, these methods often require substantial energy inputs, additional infrastructure, and increased production costs.

Another challenge is the presence of contaminants and impurities, such as sulfur, heavy metals, and asphaltenes, which significantly impact the quality and usability of heavy oil. Managing these impurities is crucial during exploration, production, and refining processes to maintain operational efficiency and prevent corrosion. Corrosion is a concern as it can degrade equipment integrity and lead to leaks and safety hazards. To address impurities and ensure high-quality heavy oil production, advanced separation and upgrading technologies are necessary. These technologies mitigate the adverse effects of impurities and enhance the overall quality of heavy oil, meeting market standards.

However, another important factor infrastructure-related obstacles, including remote locations, insufficient transportation infrastructure, and inadequate storage and processing facilities, impede the efficient production and transportation of heavy oil. Investing in infrastructure development, including pipelines, storage tanks, and facility enhancements, is crucial to address these obstacles and expedite commercialization.

In addition, theenvironmental consequences of heavy oil production must also be considered. Heavy oil extraction and processing result in elevated greenhouse gas emissions, increased water consumption, and greater land disturbance compared to conventional methods. To achieve sustainable development and minimize environmental impact, mitigation measures like carbon capture and storage, water recycling, and environmental monitoring programs should be implemented.

In general, it can be said that the low price of heavy oil in the world market and the complexity and cost of its production in Iraqi Kurdistan are one of the challenges of heavy oil production in this region.

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