Study of Oil and Gas Prospecting Techniques: A Review

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Consumption of petroleum products continues to grow steadily. In 2020, oil consumption numbers surpassed exploration's, indicating a possible market imbalance. That said, the demand for new oil reserves becomes essential. Prospecting techniques for these commodities are used to have greater accuracy before drilling a well. Different Geological, Geophysical, and Geochemical methods are applied with different principles in their search, with Seismic being the most widely used technique. Sniffers have gained ground among geochemical methods, and new technologies are emerging. Despite many methods, none is conclusive and should be used in conjunction with others, whether in the prospecting area or for leak monitoring.
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Introduction

The search for oil and gas continues to grow yearly, and it is not without reason. According to data from the statistical yearbook of ANP (National Agency of Petroleum, Natural Gas, and Biofuels of Brazil) for 2022, the volume of oil production increased by 1.6% from 2020 to 2021, totaling an average of 89.9 million barrels per day. As for the consumption of this commodity, it rose by 6% during the same period, reaching 94.1 million barrels per day. Regarding Natural Gas, the production and consumption equaled absolute numbers of 4 trillion cubic meters in 2021, but in percentage terms, the growth was 4.5% and 5%, respectively [1].

In other words, the pursuit of acquiring oil and gas has been greater than the quest for exploration. Despite significant reserves being exploited, paying attention to studies searching for new deposits is essential to maintaining a balanced market.

The prospecting of oil and gas areas and the involved techniques are paramount and constitute the first and most crucial part of their exploration. Through prospecting, it becomes possible to determine qualitatively and even quantitatively the presence or absence of hydrocarbon chains, thereby eliminating high drilling costs in unpromising areas. Numerous methods are used, and many have emerged or been refined over the years to increase reliability, reduce environmental impact, and mitigate exploration failures, as the absolute certainty of the amount of oil present in a well is only obtained when it is drilled. This paper aims to mention the methods and techniques already used and consolidated in the prospecting of oil and gas areas while providing a brief overview of some new strategies and methodologies under study that are being developed for the subject at hand.

Materials and Methods

Three main methods are used for oil and gas prospecting, namely Geological, Geophysical, and Geochemical [2]. Each method involves specialized techniques to obtain specific information when searching for hydrocarbon chains. Each technique alone cannot predict the occurrence of oil in the region. However, combining the results obtained from each method makes it possible to achieve a more accurate prediction. Generally, Geological and Geophysical methods are the first to be performed, followed by Geochemical methods to complement and validate the entire study [2].

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We used the "Web of Science" database based on two systematic reviews to identify the most established techniques and those being tested in recent years in the field of oil and gas exploration,

In the first and most comprehensive review, the Boolean operator "and" was used with the keywords "prospecting techniques," "oil and gas," and "methods of prospect" for the last 10 years. After gaining a broader understanding of the subject, the second review aimed to delve deeper into the techniques, and the following keywords were used with the "and" operator: "methods of prospecting of oil and gas", "exploration of oil and gas" and "hydrocarbon anomaly."

Geological Methods

The first step in prospecting a new region is to study its geology, aiming to understand all the conditions of hydrocarbon formation and accumulation. Geologists' main tools in this stage are called surface geology maps and data [2]. The construction of the surface geology map is carried out by explorations using techniques such as aerial photogrammetry and photogeology to indicate potential areas. By analyzing the rocks that emerge on the surface, it is possible to understand the sedimentary basins in the region comprehensively and search for hydrocarbon accumulations [2].

In summary, the techniques employed in geological methods involve studying samples of collected rocks and the presence of fossils within them. Based on this, geologists can identify the most favorable structures for oil and gas accumulation and collect data on the permeability and porosity of the basin, as these parameters can pose challenges in the exploration process [2].

Geophysical Methods

After applying geological methods, indirect or geophysical methods are employed to enrich the analysis and enhance the prospecting process. Geophysics involves studying the composition of rocks and their structures [2].

Seismic reflection is still the most widely used method for oil and gas prospecting in the industry. Due to its relatively low cost compared to other techniques and its ability to provide high-quality subsurface descriptions, this geophysical method is extensively employed as an initial study to locate hydrocarbon accumulations [2].

Its methodology involves generating elastic waves within the Earth that, as they propagate and reflect off petrophysical rock layers, return to surface sensors, providing images of the local geology and its layers, allowing for the analysis of the presence or absence of oil reserves [4]. Figure 1 demonstrates this phenomenon.

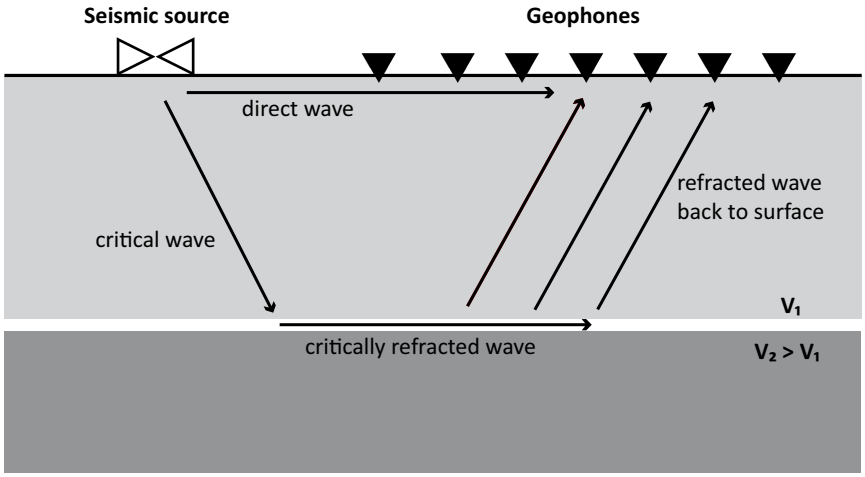
Explosives and vibratory equipment are commonly used in land prospecting to generate these elastic waves, while compressed air guns are utilized in marine prospecting. The pulses generated by these disturbances propagate in all directions and are then captured by electromagnetic receivers onshore and pressure receivers offshore, known as geophones and hydrophones, respectively. After processing the acquired data, images are generated, and location analysis can be conducted [2].

However, every prospecting methodology has limitations, so professionals must combine other methods for a higher success rate and reliability. Other techniques can also complement seismic studies, such as magnetometry, which is based on detecting magnetic anomalies that may be present on the seafloor.

Rocks that can provide information about hydrocarbons commonly contain magnetic minerals in their composition. In the offshore industry, this detection can be performed using a remotely operated underwater vehicle (ROV) or an autonomous underwater vehicle (AUV). However, the downside of magnetometry is that anomalies may not be detected for various reasons, such as sediment accumulation in the area, or it could mistakenly detect a magnetic field generated by any other source [5].

Electromagnetic methods function similarly to magnetometry, where transmitters are placed

Figure 1. Seismic data survey scheme [4].



on the seafloor and send electrical currents into the rocks. Analyzing the difference between the transmitted and received electrical currents makes it possible to assess the presence or absence of petroleum, as the layers may exhibit different electrical resistivity compared to the rocks. One advantage of this method is its ability to be used in profound layers. However, its disadvantages include the influence of salt presence on the seafloor readings and higher costs and complexity of the equipment involved [5].

Geochemical methods serve as complementary approaches to the geophysical methods already employed. As locating oil reserves becomes increasingly challenging, geochemical methods gain more and more significance due to their accuracy in directly indicating the presence of petroleum. Prospecting for oil via the geochemical method involves searching for chemical activity to detect the accumulation of hydrocarbons at the surface. It is possible because oil reserves are not completely impermeable, causing volatile components in the reservoirs to escape through diffusion to the atmosphere and oceans' surface [3].

Gas chromatography techniques are commonly used to analyze the presence of hydrocarbons, both in onshore and offshore situations [3].Methane is not a suitable parameter for indicating the presence of oil, as it is produced in large quantities by other natural processes. The hydrocarbons most used as indicators are Ethane, Propane, N-butane, and iso-butane [3].

One of the earliest methods used was the analysis of pore gas, where at the site to be analyzed, a hole is drilled to a depth of 1 to 2 meters, sealed, and then a sample of air is extracted for analysis. The technique involves reducing the pressure in the hole and collecting the geo-gas. If the ratio between the concentration of light to heavy hydrocarbons is high, it indicates the presence of a gas reservoir, while a low ratio indicates an oil deposit. However, this method is not always conclusive as it heavily depends on the geological characteristics of the area, such as faults and fractures. Therefore, this method has been improved over time to enhance its accuracy [3].

One of these improvements was using gas chromatographic analysis of adsorbed gas. A soil sample is collected at 5 to 10 meters deep and then treated with acid and heat to release the hydrocarbons. Subsequently, a gas chromatographic analysis is conducted [6]. These methods are more commonly used in the onshore industry and, in comparison, to offshore operations. In marine environments, the influence of fluid zones is much less impactful than on land, and the temperature and pressure at the ocean

floor are more constant, facilitating the analysis of hydrocarbon anomalies in the area [3,6] (Table 1).

The geochemical methods for oil and gas prospecting in oceans have similarities, with the main differences in the way samples are collected and where and when they are analyzed. Older and less efficient techniques, such as collecting gas bubbles, may be used to store these gases in glass vessels for subsequent analysis of carbon compound concentrations and isotopes. Another method involves phase equilibrium analysis of water samples along with a sample of equal volume of Helium [3], which, being an inert gas, does not react with hydrocarbon compounds and can be inserted into a chromatograph to measure the concentrations of molecules.

Newer and more efficient methods are being studied and continuously improved, utilizing devices that conduct remote analysis, referred to by some researchers as "sniffers," which collect samples of dissolved gases and perform the analysis. This method shows a strong tendency to evolve and become increasingly influential, as accurate on-site analysis saves significant time and enhances productivity in the process [6].

However, these sniffers have specific sensors for predetermined compounds, usually light hydrocarbons, which means they can still not capture all present hydrocarbon chains. Similar studies are being conducted in the mining prospecting industry, where a robot known as "PMGRA - Portable Multicomponent Gas Rapid Analyzer" [7] is used to analyze hard-to-reach areas and provide solutions to overcome limitations in terms of sample transportation, analysis, and the number of human resources required. These areas' geological and physical characteristics favor the diffusion and vertical migration of gases, which can carry information about deep mineralization in the region based on their composition. In other words, by analyzing geo gases (gases in the soil) that reach the surface, conducting both mineral and oil prospecting in those areas is possible. In other words, the main objective of geochemical techniques is to determine the presence of hydrocarbons in a particular location, not only

Table 1. Prospecting techniques and their place of application.

Method	Technique	Application
Geological	Aerophotogrammetry	On-shore/Off-shore
	Photogeology	On-shore/Off-shore
Geophysical	Seismic	On-shore/Off-shore
	Seismic 3D	On-shore/Off-shore
	Seismic 4D	On-shore/Off-shore
	Magnetometry	On-shore/Off-shore
	Electromagnetism	On-shore/Off-shore
	Gravimetry	On-shore/Off-shore
Geochemical	Pore gas analysis	On-shore
	Adsorbed gas analysis	On-shore
	Dissolved gas analysis	On-shore/Off-shore
	Phase equilibrium (Helium)	Off-shore
	Microbiological analysis	Off-shore
	Sniffers	On-shore/Off-shore
	Isotope analysis	Off-shore

qualitatively but also quantitatively, assessing their distribution in space. The choice of technique will depend on each specific case and the research objectives. However, operating with more than one methodology is crucial to ensure excellent reliability in the final results. Combining multiple methods provides a more comprehensive and accurate investigation.

New Prospecting Methods

Due to the most methodologies has pros and cons, new techniques are being studied and tested in relevant environments to complement these studies. This article will briefly mention some new methods that go beyond the traditional approaches, bringing innovation and fresh perspectives to oil and gas prospecting.

One of the techniques that is gaining space and relevance and yielding highly positive results is the use of suggested gamma-ray spectrometric data. Although this method was developed in the late 20th century, it is currently being utilized on a larger scale due to advancements in surface and aerial spectrometry prospecting technologies [8]. The methodology involves the normalization of Thorium to reduce the influence of lithological and environmental factors, where Potassium and Uranium values are regulated based on Thorium [8]. Experiments and tests show that low measurements of these two normalized components can indicate the presence of nearby hydrocarbon deposits [9].

A study conducted in the Egyptian desert by Nigm and colleagues (2018) exemplifies this method well, where airborne gamma-ray spectrometry was employed, and several maps of the region with radioelement compositions were generated and analyzed. The result identified nine large, well-defined areas with high confidence in the presence of hydrocarbons.

Another technique targeted for studies in the last decade to prospect oil areas involves the quantitative and qualitative analysis of hydrocarbon-degrading bacteria in the soil. Lighter gases such as methane, ethanol, propane, and butane migrate from petroleum reservoirs to the soil through diffusion [10], and various microorganisms, including these bacteria, take advantage of these components for metabolic activities. The soil collection is performed, and the sample is stored in sterilized backpacks, then rapidly cooled to temperatures between 2 – 4°C until they arrive at the laboratories to analyze the bacterial colonies. The results are plotted as a function of the population density of these microorganisms [10]. Like other prospecting methods, this technique is used with other techniques. Its significant advantage is that it can be applied in any area where soil samples can be collected, including those where the seismic method (initial information) cannot be used due to the geography of particular locations.

Another technique refined over the past 20 years is the indirect analysis of hydrocarbon presence based on heavy metal ion measurements in regions close to oil basins. Metals as Cu, Pb, Ni, Ti, V, Co, Mg, and so on are expected to be observed. Nickel, lead, and mercury are present in heavier oil fractions, such as asphaltenes [11]. Therefore, using selective electrodes capable of detecting the presence of heavy metals in potential areas is necessary, especially in the offshore sector, where water near oil basins becomes enriched with heavy metals. Studies conducted in Russia in 2020 [11] used an apparatus that performed seismic measurements, geo-electrical mapping of heavy metal ions, and sonar for methane detection. In other words, it was a hardware device that incorporated at least three different prospecting methods, complementing each other to provide more significant reliability in the final results. Lead and copper were the heavy metals measured using a potentiometer, and the device could be used at distances between 200-400m below the watercraft's level [11].

Conclusion

Many methods and techniques concerning oil and gas prospecting can be observed. Some of them are already well-established, like the seismic

method, while others, such as Sniffers, show high prospects for improvements and applicability. However, more recent methodologies are proving to be increasingly refined and innovative, gaining prominence in research and development. It is worth noting that no technique is 100% effective and will not provide reliability if used alone. Combinations of techniques are necessary to ensure the investment in drilling the well. In addition to this, these technologies can not only be used for oil prospecting but also for monitoring hydrocarbon leaks in platforms.

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