



INVESTIGATION OF THE HYDROCARBON-GENERATION POTENTIAL OF THE PABDEH FORMATION IN THE SOUTHWEST OF IRAN

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ABSTRACT

Nowadays, Rock-Eval pyrolysis and its results are commonly used to determine and interpret the characteristics of depositional basins. This study aims to investigate the hydrocarbon-generation potential of the Pabdeh Formation by using the Rock-Eval analysis method in the southwest zone. To do so, 226 data points of Pabdeh's source rock were extracted from Ahvaz, Zilaei, Mansuri, Gachsaran fields, Abadan Plain, and the northwest of Dezful Embayment based on the library method. According to variations in S_1+S_2 parameter versus TOC, this formation, serving as a source rock, provides a good hydrocarbon-generation potential. Despite the good potential and proper organic matters based on the diagram of Depth versus T-max, most samples of this formation have not passed the thermal maturity trajectory and have not entered the oil window. Also, the NT vs. T-max diagram indicates that the kerogen content of this formation is mainly made up of types II and III.

Keywords: Pabdeh Formation, Source Rock, Rock-Eval Pyrolysis, Kerogen.

INTRODUCTION

The oil system consists of three parts: source rock, caprock, and reservoir rock, where the hydrocarbon-generation process is done in source rock under appropriate conditions over millions of years, and the produced hydrocarbon accumulates in reservoir rock after primary immigration in the source rock and secondary immigration within the caprock. In the southwest of Iran, which is among the most important zones in terms of geochemical studies, Kazhdumi, Gurpi, Sargelu, Pabdeh, Siahoo, and Sarchahan provide some of the most important source rocks. As a source rock, the Pabdeh Formation plays a vital role in oil generation in various oilfields of southwest Iran. Thus, it is necessary to investigate its characteristics. Many studies

have been done on the Pabdeh Formation in different fields, including Ahvaz, Marun, Zilaei, Bibi Hakimeh, Gachsaran, Pars, Aghajari, etc., most of which have examined and evaluated oil generation and maturity of this formation by using the Rock-Eval pyrolysis method. These studies have provided useful information about the Pabdeh Formation. However, further studies must be done on this formation because it is one of the widest formations in the southwest of Iran. In this way, this formation can be identified better. The base of the source rock in the Zagros zone varies in depth between 35 km (coastal Fars) and 55km (Dinar-Zarkuh) based on the gravimetry measurements (Batten, 1996). By integrating the results, one can say that the source rock of Zagros has a thickness of about 25-50km (Motiee, 2003). Some believe that the thickness of the Zagros' depositional coating reaches 14km. Therefore, the average thickness of these sediments is estimated to be 5-10km in different areas of the Zagros (Hejr, 2007). Stoklin (1968) and Nabavi (1976) have classified the Zagros geology into three structural zones that have different tectonics, structural, and sedimentary backgrounds that each one is based on scientific reasons and evidence. Damman, Rus, and Umm er Rahduma are regional equivalents of the Pabdeh Formation (Lopatin, 1976). If finished wells in the Pabdeh Formation become hydrocarbon-generating regarding the porosity and water saturation rate, and a large area of this formation (particularly in Gachsaran, Bibi Hakimeh, Ahvaz, Aghajari, and Marun fields), there will be a considerable amount of oil in place in huge fields that this subject must receive great attention (Elhaei, 2016). Now, 9 wells have been completed in the southwest fields of Iran (National Iranian South Oilfields Company) in Pabdeh and Gurpi Formations, of which 5 wells have become oil-generating in Pabdeh Formation. Among them, those fields with more wells that are evaluated based on petrophysical assessment in Pabdeh formations, respectively, include Ahvaz, Gachsaran, Rag Sefid, Marun, Bibi Hakimeh, Kopal, Shadegan, Masjed Soleyman, Karun, Ghale Naz, Lali Aghajari, Golkhari, Siah Makan, Balarud, Naft Sefid, Kilvar Karim, Pranch, Tangu, and Zilaei (Elhaei, 2016). In most of the assessed wells, especially the wells located in the middle and southwest areas of Dezful Embayment, a petrological column of Pabdeh Formation consists of a clay-rich carbonate shale horizon. The upper boundary of this horizon is matched with the Late Eocene and tectonic phase of the Pyrenees. This horizon has been named "brown shale" to be a guide horizon (Alizadeh et al., 2012). Rock matrix of Pabdeh Formation in some oilfields such as Ahvaz, Shadegan, Rag Sefid, Marun, and Naft Sefid has a great porosity, which this porosity is even more than Asmari and Bangestan formations in some cases. In terms of permeability, generation potential is related to the fractures existing in this formation. Two viewpoints are available about this formation. A viewpoint suggests that the presence of a fracture in the Pabdeh Formation would expand the contact surface of the well with these layers that resulting in oil production by these two layers. Another viewpoint explains that these fractures are connected to the fracture network of Asmari and Bangestan and produce the oil of this formation. In some cases, such as Zagheh Field, production is not done due to the presence of heavy oil (with API=15), and production requires some methods such as hydraulic fracture or similar techniques (Elhaei, 2016).

In Gachsaran Field, most cases in the Pabdeh Formation will not become generative, but wells 37, 43, and 152 in the Pabdeh Formation have produced 14, 29, and 17 million barrels of oil, respectively, until 2013. In well 415 of Marun Field in Pabdeh Formation, a Drill Stem Test (DST) was done, and no fluid was generated in it. There is a severe circulation loss in the Zilaei Oilfield in the Pabdeh Formation, and even gas flow to the surface has been reported in some cases. The wells 80 and 108 of the Paznan Field, Pabdeh Formation, have been tested, and no amount of hydrocarbon was observed in well 80, but oil was found in well 108, which was detected as dead crude oil without generation potential based on the geochemical assessment (Elhaei, 2016).

In Rag Sefid Field, wells 113, 120, and 126 of the Pabdeh Formation were tested, which had no generation. In DST of well 2 of this field in the Pabdeh Formation, heavy oil fluid was found. In well 5 of this field, the sample harvested from DST in the Pabdeh Formation indicated very high oil (bitumen-like). Well 9 was then drilled in this field to identify the Pabdeh

Formation, where oil fluid in the Pabdeh Formation was confirmed while flowing the well during drilling operations. However, pressure decline and the appearance of a barrier due to heavy reservoir fluid prevented the continuous production, and the well was finally completed in the Asmari Formation (Elhaei, 2016). The heavy oil (API=15) that was found in Rag Sefid Oilfield also exists in Zagheh Oilfield, which is geographically adjacent to Rag Sefid Oilfield in the Pabdeh Formation. Unlike Rag Sefid Oilfield, which has low pressure, the pressure in Zagheh Oilfield is very high, and heavy oil can be produced. In 1992, 10000 barrels of oil were produced in this oilfield, but the well was closed due to high sulfuric hydrogen (Elhaei, 2016). Pabdeh Formation (with shale lithology and shale limestones) is problematic in the drilling process of the Marun and Ahvaz oilfields. Illite is the major mineral in the studied formation, whose amount is vertically increased when depth is enhanced (Mohamadian & Ghaderi, 2012).

According to the mentioned points, this study aims to investigate the hydrocarbon-generation potential of the Pabdeh Formation in the southwest of Iran. This study provides other researchers with good information about the lithological characteristics of the Pabdeh Formation and the Zagros Zone, source rock assessment method, and evaluation of hydrocarbon generation of the Pabdeh Formation that comprises TOC, S1, S2, S3, HI, PI, and OI data. The purpose of this study is to evaluate the hydrocarbon-generation potential of the Pabdeh Formation.

Geology of the zone

The name of the Pabdeh Formation has been adopted from Pabdeh Tang in Gurpi Mountain (Alizadeh & Moradi, 2007). Pabdeh Formation is one of the oil source rocks in the depositional basins of the Zagros. In Fars and Khuzestan, the age of the Pabdeh Formation ranges from the Paleocene to the Oligocene. Expansion of this formation is especially in the southeast areas of Lorestan, Khuzestan, and the south areas of Fars Province (Aghanabati, 2006). This formation is composed of about 800m of marl, gray shales, and marine clay lime layers, which have two informal parts called purple shale and cherty lime.

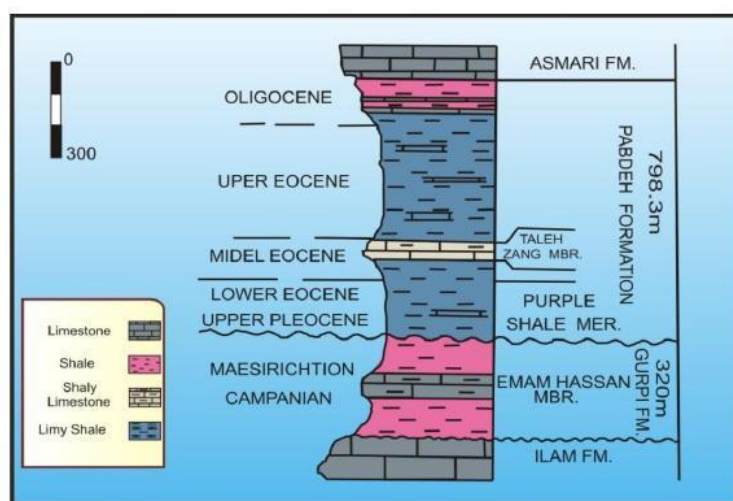


Figure 1. Stratigraphy of Pabdeh Formation (James and Wynd, 1965)

The lower area of the Pabdeh Formation (140m) is made of blue and purple marl and shale, which is formally called purple shale (Elhaei, 2016). The middle part of the Pabdeh Formation of Ahvaz and Marun Oilfields contains a large amount of clay minerals, including active clay minerals of Montmorillonite, which causes numerous problems in drilling operations. The pipes are clogged more in this area, which increases the cost of drilling operations (Mohammadian & Ghaderi, 2012).

METHODOLOGY

The data of this study comprises 226 samples located in Mansuri, Ahvaz, Zilaei, and Gachsaran fields, and Abadan Plain and Dezful Embayment areas.¹ That was analyzed through Rock-Eval pyrolysis. The required data and information, including parameters obtained from Rock-Eval pyrolysis such as TOC, S₁, S₂, S₃, HI, PI, and OI, have been collected. Appropriate evaluation of source rock requires its assessment in terms of three cases: quantity, quality, and maturity of organic matter. To do so, the library method and previous studies conducted by Alizadeh et al. (2012), Alizadeh et al. (2013), Kobraei et al. (2016), Alizadeh and Moradi (2007), Orak et al. (2018), and Safaei Farooji et al. (2019) were used. Most fields and zones are located in Khuzestan Province, and their locations are shown in Figure 2.

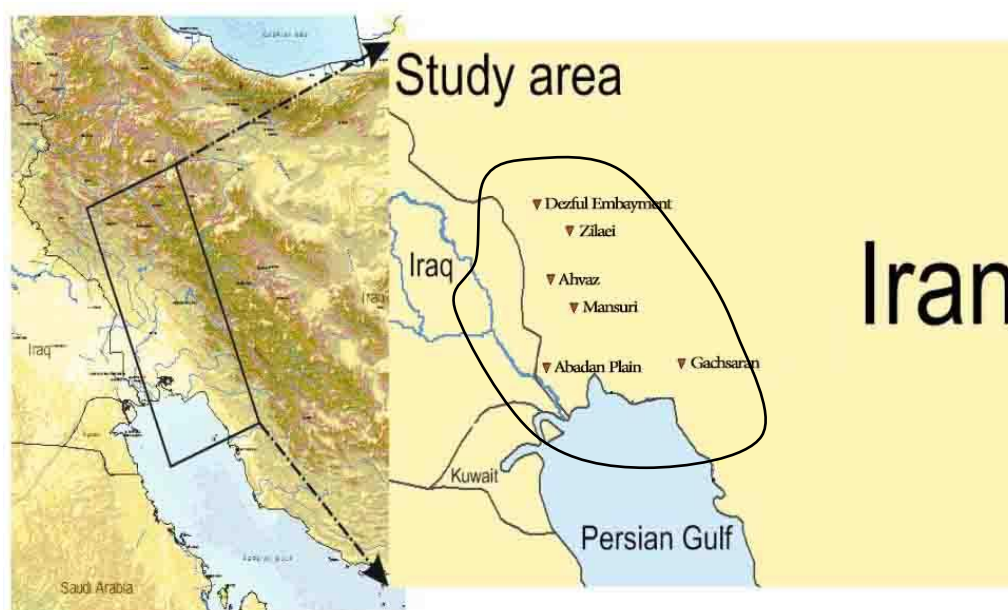


Figure 2. Study area (derived from Hosseini et al., 2020)

This process has been done through Excel Software in such a way that the considered graphs were plotted precisely and the data were placed on them. These graphs provide specific applications and interpretations, and significant results can be acquired by using them.

RESULTS

In source rock assessments, the samples must first be examined in terms of being in situ (uncontaminated) and ex-situ (contaminated) to prevent any error in data analysis. Thus, the S₁-to-TOC ratio graph was used because this diagram helps to detect and remove the contaminated data easily. As seen in Figure 3, almost all analyzed samples are uncontaminated, except for two samples in Dezful Embayment and one sample in Mansuri 2, which are removed in the following interpretations.

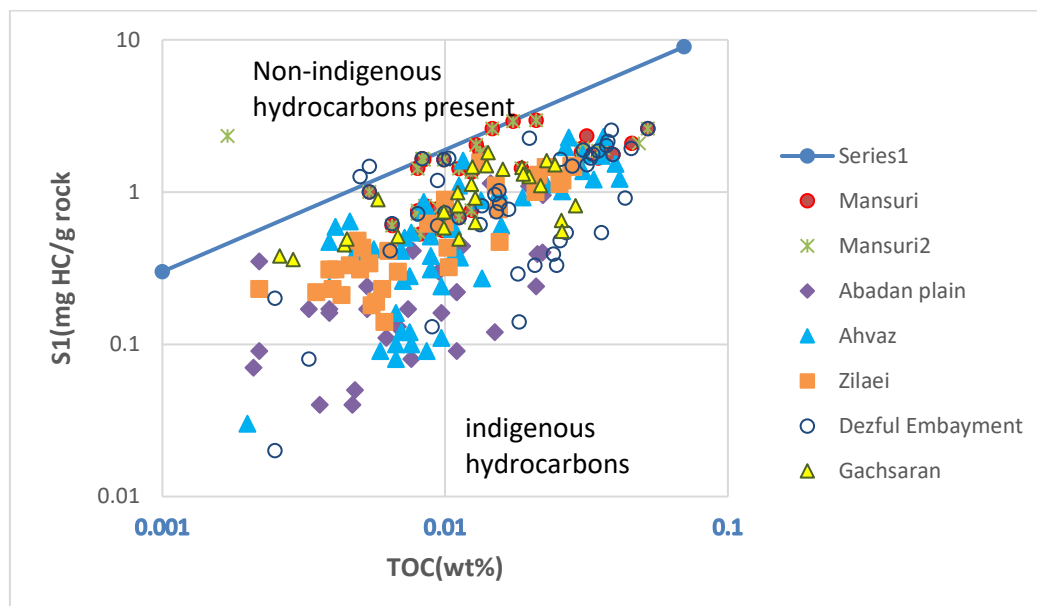


Figure 3. Graph of S_1 to TOC variations to determine in-situ (uncontaminated) and ex-situ (contaminated) oil (adopted from Hunt, 1996)

Carbon is the most basic element in all organic compounds. Measurement of organic carbon rate is one of the ways to evaluate source rock. Organic carbon measurement helps to measure the quantity of organic matter. The total amount of organic carbon in the studied samples varies between 0.17 and 5.21 weight percent (wt%) and mean value of 1.54 wt%. As shown in Figure 4, division of samples has been done within the following intervals: 0-0.5, 0.5-1, 1-2, 2-4, >4, which respectively represent poor, fair, good, very good, and excellent quantities of organic matter.

It is worth noting that this method must not be used as the only method for evaluating the total amount of organic matter. The other methods include S_2 -to-TOC and $S_1 + S_2$ -to-TOC ratios.

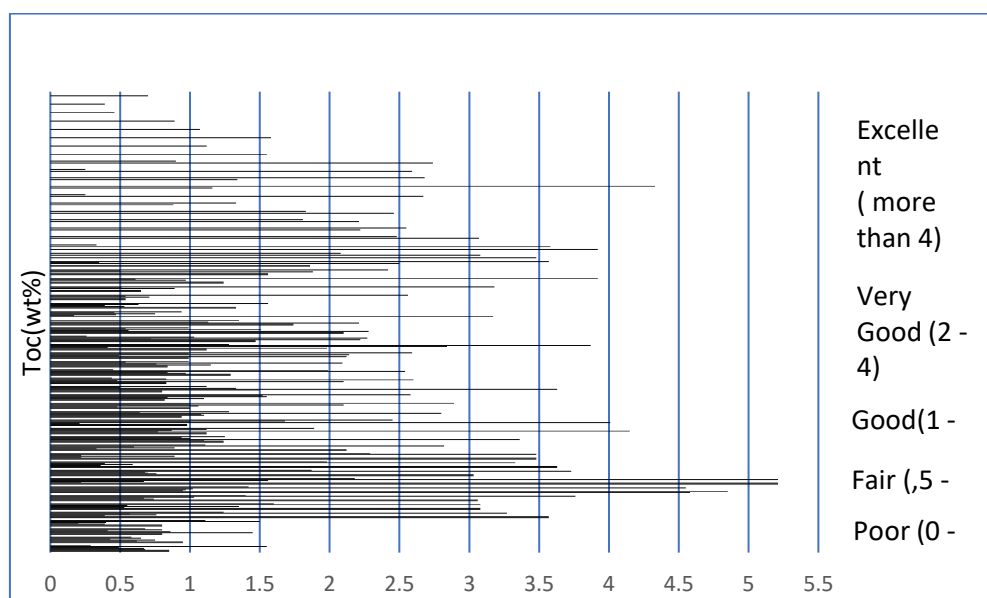


Figure 4. Frequency of TOC values in Pabdeh Formation samples in the study area to determine the generation potential

As seen in Figure 4, the total amount of organic carbon in samples is in poor to good areas. Few samples provide very good results, and very few samples are in the excellent area.

If TOC amounts of Pabdeh Formation's samples are studied more precisely, it will be found

that about 12.8% of data are in poor area, 34.45% of data in fair area, 26.04% in good area, 25.28% of data in very good area, and 3.4% of data in excellent area. According to TOC (total organic carbon) amounts of Pabdeh Formation's samples in Zilaei, Gachsaran, Ahvaz, and Mansuri oilfield, Abadan Plain, and Dezful Embayment, it is confirmed that the TOC amount of the samples is the least in Zilaei Oilfield and Abadan Plain. The average TOC amounts of samples will increase by moving from Zilaei Oilfield and Abadan Plain towards Ahvaz and Mansuri oilfields, and this amount averagely increase when moving from Abadan Plain towards Gachsaran Oilfield. The TOC number of samples averagely, reaches the highest rate among the studied data when moving from Zilaei Oilfield towards Dezful Embayment. In summary, the TOC number of samples increases when moving from the southeast to the northwest zone of the study area. In general, the considered area provides a great potential based on the TOC graph.



Figure 5. Graph of S_1+S_2 to TOC variations to determine generation potential (adopted from Yalçın et al., 2004)

In Figure 5, S_1 expresses free hydrocarbons existing in the rock, and S_2 represents the present potential available in the rock, whose sum (S_1+S_2) is shown based on mg NC/g rock. TOC indicates the total organic carbon of samples based on the wt%. As shown in Figure 5, samples of the Abadan Plain area provide the lowest potential among the analyzed samples. A higher potential is observed when moving from the Abadan Plain towards Gachsaran. Also, the potential will increase by moving from Abadan Plain towards Ahvaz Oilfield and Mansuri Oilfield, showing better amounts rather Abadan Plain and Gachsaran Oilfield. Interestingly, the potential will decrease when moving from Ahvaz Oilfield and Mansuri Oilfield towards Zilaei Oilfield, but the potential of Zilaei Oilfield indicates better amounts than Gachsaran Oilfield and Abadan Plain. Finally, the highest potential is seen when moving from the Zilaei Oilfield towards Dezful Embayment. In general, the northwest zone of the studied area provides higher potential.

The quality of organic matter must be examined after measuring the quantity. The kerogen type of organic matter can be measured by using parameters obtained from Rock-Eval pyrolysis. To do so, the graphs obtained from S_2 -to-TOC and HI-to-T-max ratios can be used. Kerogen type indicates where (gas-prone, oil-prone, and oil/ga-prone areas) the source rock exists.

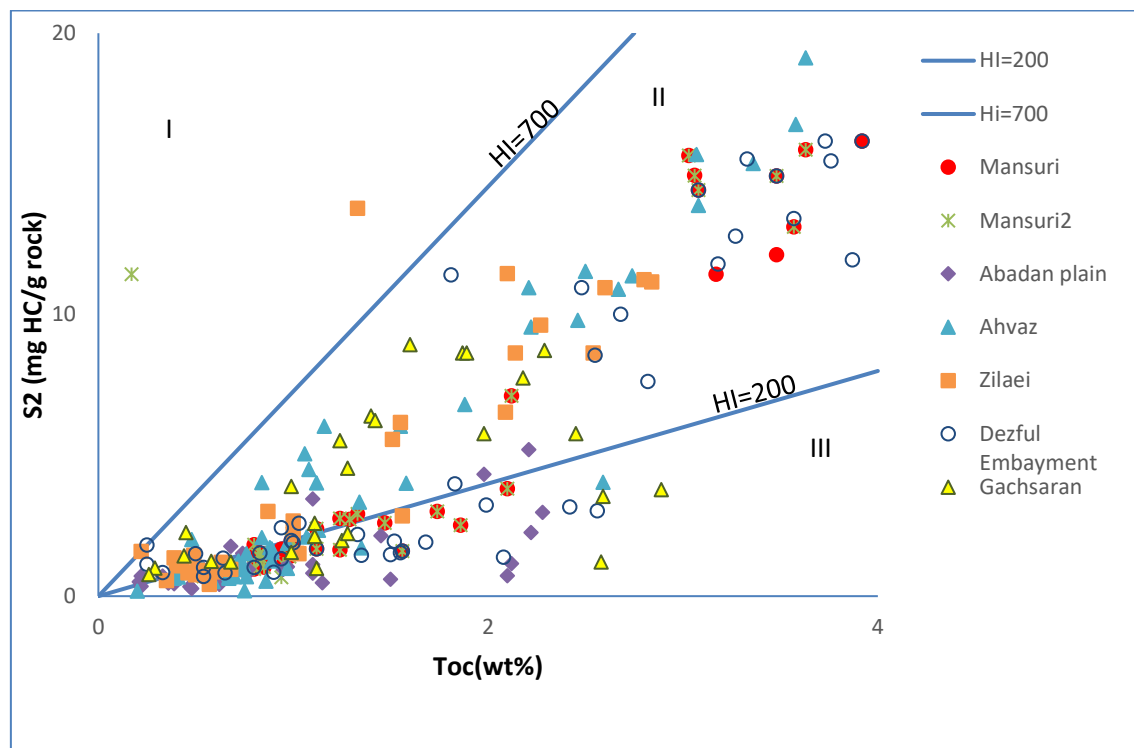


Figure 6. Graph of S₂ to TOC values to determine Kerogen type (adopted from Tissot, 1984)

In the TOC-S₂ ratio graph, (HI=700 mg HC/gr TOC) (i.e., organic matter with 70wt% hydrocarbon) is considered as the center of kerogen type I and II and HI=200 mg HC/gr TOC as the center of kerogen type II and III (Langford and Blanc-Valleron, 1990).

As shown in Figure 6, most data for kerogen types II and III, the Abadan Plain has kerogen types II and III. In this case, the plain has kerogen type III, and its kerogen type II is close to the division line and has not entered the type II area. Gachsaran Oilfield has kerogen types II and III, with kerogen type II being more common than kerogen type III. Ahvaz Oilfield has kerogen types II and III; thus, the data related to this oilfield have been distributed equally in the area of kerogen types II and III. Mansuri Oilfield also contains kerogen types II and III, with its kerogen III being greater. Zilaei Oilfield has kerogen types III, II, and I, with its most kerogen being of type II.

Dezful Embayment also consists of kerogen types II and III, which are equally distributed in the area of kerogen types II and III. It is seen that the kerogen amount in the study area is of types II and III. In general, the quality of kerogen will increase by moving from the Abadan Plain towards the Gachsaran Oilfield. On the other hand, the quality of kerogen is improved when moving from the Ahvaz Oilfield towards the Mansuri Oilfield. By moving from the Mansuri Oilfield and Ahvaz Oilfield towards the Zilaei Oilfield, the best type of kerogen is seen in the studied area. The quality of kerogen will decrease by moving from the Zilaei Oilfield towards the Dezful Embayment.

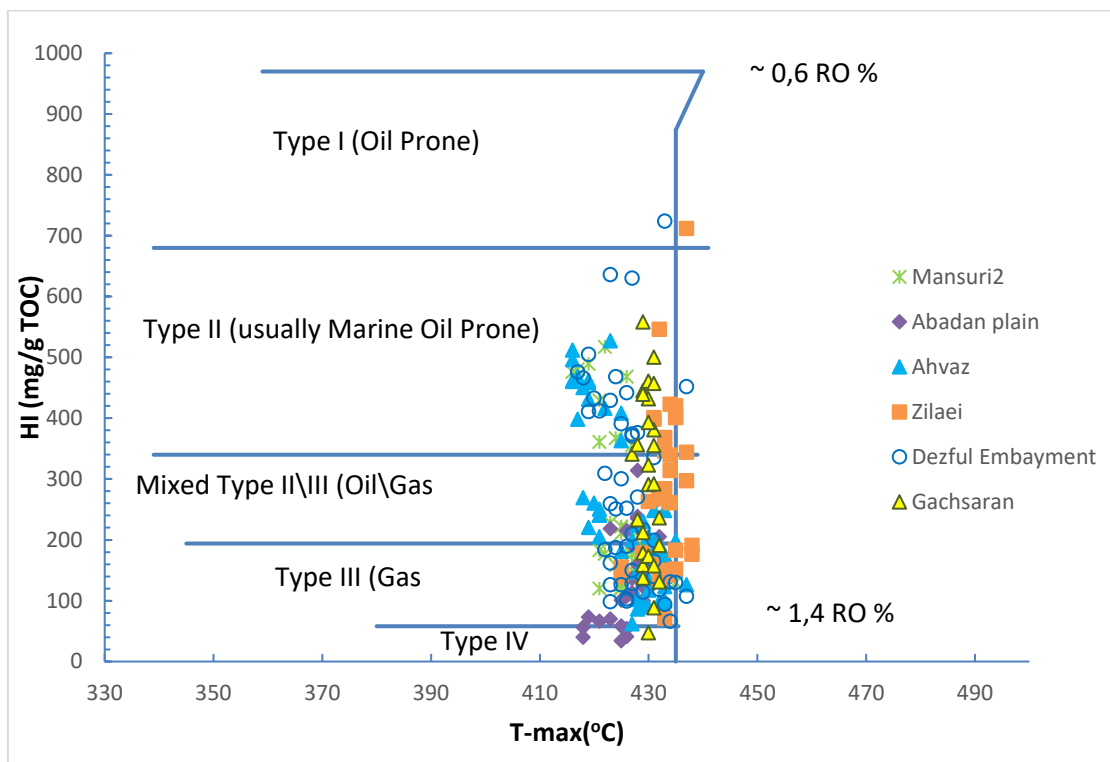


Figure 7. Graph of HI to T-max values to determine Kerogen type (adopted from Hosseini et al., 2020)

As shown in Figure 7, kerogen type is determined by using the ratio of NT(mg/gTOC) to T-max (°C), so that kerogen type IV is determined from 0-60 HI, which is called dead kerogen and does not provide generation.

The 60-200 HI area outlines the kerogen type III, which can be gas-prone, and the 200-320 NI area sets a mixture of kerogen types II and III that can be an oil-gas mixture. The 320-680 NI outlines the kerogen type II, which can be oil-prone. The 680-960 NI outlines the area of kerogen type I, which can be oil-prone. The oil of this area provides a better quality than the oil of kerogen type II. It can be confirmed that Abadan Oilfield provides kerogen type IV, kerogen type III, and kerogen type II/III that its kerogen is more of type III and close to kerogen type IV. Gachsaran Oilfield provides kerogen type IV, kerogen type III, kerogen type II/III, and kerogen type II, with its most abundant kerogen being of type II. Ahvaz Oilfield provides kerogen types III, kerogen type II/III, and kerogen type II, with its kerogen type III having an abundance. Mansuri Oilfield has kerogen types III, II/III, and II, with its kerogen type III having the highest abundance. Zilaei Oilfield has kerogen type III, kerogen II/III, kerogen type II, and kerogen type I, with its most abundant kerogen is of types being II and II/III. Dezful Embayment has kerogen type III, kerogen type II/III, kerogen type II, and kerogen type I, with kerogen type III being more abundant. In general, kerogen types II and III provide the most abundance. Finally, it is seen that Zilaei Oilfield has the best kerogen type, and the quality of kerogen is reduced when moving from this oilfield towards Dezful Embayment. Also, the quality of kerogen is increased when moving from the Abadan Plain towards the Gachsaran Oilfield. It can be generally expressed that the quality of kerogen is decreased when moving from northwest towards southwest, and vice versa.

According to the graphs and comparison between them, the Pabdeh Formation in the southwest of Iran can generate oil and gas if it has thermal maturity. This formation is oil-prone and oil-prone and gas-prone in Dezful Embayment and has oil- and gas-generation potential. Zilaei, Mansuri, Ahvaz, and Gachsaran oilfields are oil-prone-gas-prone and gas-prone, and provide less oil and gas generation potential, and Abadan Plain is hardly gas-prone.

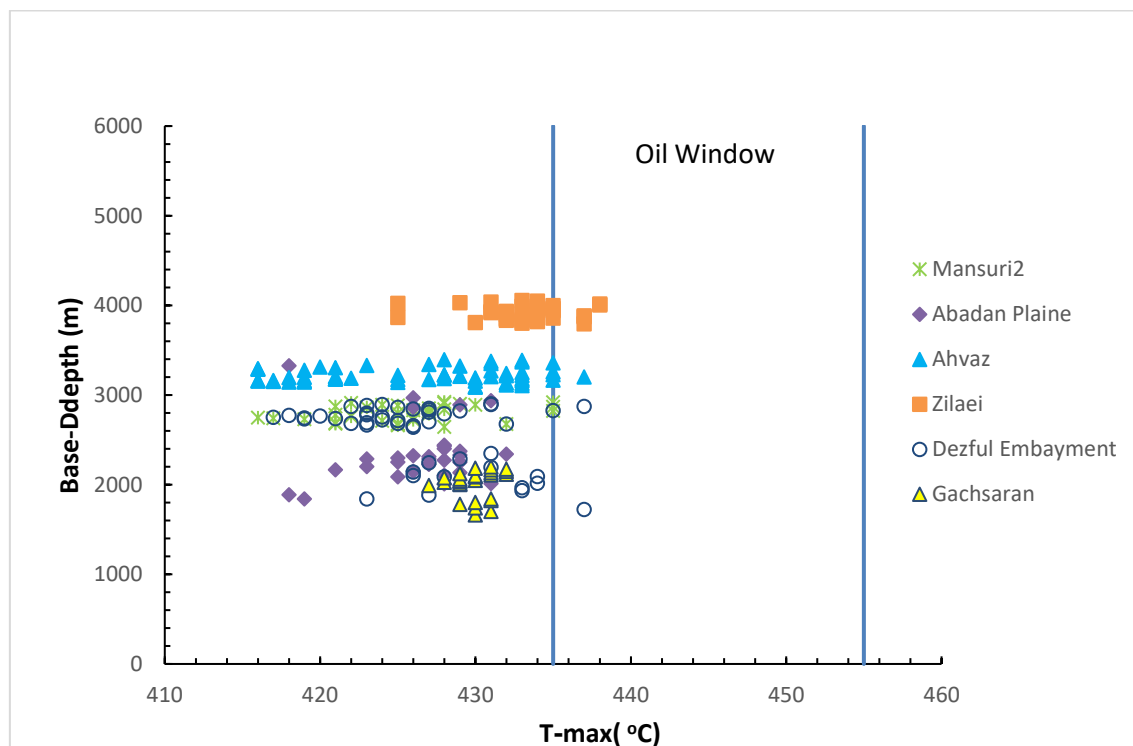


Figure 8. Graph of Depth to T-max values (adopted from Hosseini et al., 2020)

As seen in Figure 8, one can determine thermal maturity based on the Depth to T-max ratio. The oil window starts from 435 degrees and ends at 455 degrees. According to Figure 8, most samples have not reached the oil window except for some samples in Zilaei and Ahvaz oilfields and Dezful Embayment, so Zilaei Oilfield has the most points in the oil window interval, and its samples are near the oil window with less dispersion. On the other hand, samples in Abadan Plain and Gachsaran are far from the oil window and are not mature. Therefore, the Pabdeh Formation is immature in the study area.

CONCLUSION

Pabdeh Formation in the study area has a poor to good total organic carbon amount, and most areas are in the good zone when moving from south to north and northwest of Khuzestan province, and reaching Ahvaz and Mansuri oilfields. The very good and excellent samples are also seen in the Dezful embayment. In terms of organic matter's quality, this formation contains kerogen types II, III, and a mixture of both types, implying the potential of this formation for generating oil, gas, and an oil-gas mixture. In most of the studied oilfields and zones, the Pabdeh Formation has not entered the hydrocarbon-generation window, so it is not expected to be generative. Thus, quality and quantity are increased in Ahvaz, Mansuri field, and Dezful Embayment when moving from the Abadan Plain-that is hardly gas-prone and is semi-dead, towards the north and northwest of Khuzestan Province. However, these cases are not expected to provide hydrocarbon-generation potential because they have not reached the oil window. Among the mentioned cases, Zilaei Oilfield has barely entered the oil window, but its low quality and quantity prevent any generation. It can be stated that Gachsaran Oilfield, located in the southwest of Khuzestan, provides a relatively good quality but is not expected to be generative since it has low quantity and no access to the oil window. Finally, it cannot be stated that the Pabdeh Formation in the study area is generative now.

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