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Evaluation of the Hydrocarbon-Generation Potential of Pabdeh-Gurpi in one of the Fields in Southwest Iran

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Abstract: - The type of hydrocarbon potential of formations and their generation power can be investigated- regarding different aspects- by using and studying various features of the Pabdeh and Gurpi Formations. The source rock nature of Zagros Basin is the most important characteristic of these formations, playing the role of caprock for Bangestan reservoirs in some areas. The purpose of this study is to evaluate of hydrocarbon-generation potential of Pabdeh-Gurpi in one of the fields in Southwest Iran. In this research, the application of 44 palynological slides from 22 samples (2 slides from each sample) of drilling debris extracted from these formations in Mansouri Field led to the identification and determination of the amount of organic materials existing in each palynological slide. The selected samples for using Rock-Eval pyrolysis indicated that organic matters with marine sources are dominant, and the assessed Van Krevelen plot depicts the presence of kerogen type II in them. The generation potential of samples in which, parameters have had acceptable values includes oil and gas and is generally determined from almost good to very good. The trend of hydrogen index variations against the oxygen index of samples determined the B and BC facies, which implies anoxic to relatively anoxic environment with an average sedimentation rate that confirms palynological results. The plot of total organic carbon against the hydrogen index shows that when the hydrogen rate increases, the total organic carbon will increase, and the considered well with high amounts of total organic carbon and hydrogen index would specify anoxic (recovery) conditions and good durability of organic matter.

Keywords: Mansouri Field, Pabdeh-Gurpi Formation, Hydrocarbon-Generation Potential, Organic Carbon Plot

I. INTRODUCTION

Geology science has been developed to an extent that can be used to identify potential source rocks in sediments containing organic matter with good deposition and durability. Those hydrocarbons deposited from organic matter and sediments usually contain cost-effective accumulations [1]. The substances insoluble in organic solutions and found in sedimentary rocks are called kerogen, which have several categories each type expresses the type of generated hydrocarbon. The hydrogen content of organic matter would show the amount of generated hydrocarbon. In general, plant matter contains less hydrogen, woody and coal matter containing lignin are hydrogen-free, and algae that basically contain lipids are rich in hydrogen [1]. Therefore, the petroleum generation potential of each type of kerogen depends on the initial composition of organic matter. There is a high amount of hydrogen (500-800) in fresh waters to saline water in which amorph matter and algae are sedimented, which may be highly prone to oil generation [1]. The cases that are more prone to gas generation contain amorph matter with vascular plant sources. Plant components that contain less amounts of fungus and resin but more amounts of cuticles that are possibly deposited in fresh waters are prone to petroleum generation [1]. Palynomorphs containing hydrogen amounts (300-500) and phytoclasts with definite structures create almost equal petroleum products of liquids and gases [1]. There is a direct relationship between different types of kerogen and microscopic organic matter in terms of generation potential. Algae and amorph matter are abundant in dark brown to black shales, which indicate high oil-generation potential. In nonmarine environments with low petroleum-generation potential and more prone to gas production, black and brown woods are found [1].

On the other hand, kerogen type is an important factor for determining the potential rate of source rock and has a considerable effect on the nature of hydrocarbon. Each type of kerogen has a different potential for hydrocarbon generation. For instance, those samples containing high amounts of kerogen types I and II generate more petroleum [2]. In general, identification of kerogen type is highly necessary for studies on hydrocarbon products and organic matter; some kerogens have a clear structure and are observable as scattered organic crumbs, these organic crumbs have structure and are classified into several certain biological units called macerals. Three important categories of macerals include vitrinite, exinite, and inertinite [2]. Vitrinite is the most substantial factor for coal formation and is the most main maceral in the majority of kerogens, which indeed is composed of the

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woody tissue of plants. Exinite maceral is more made of cuticle waxes, algae, spores, and pollen that are usually found in shallow swamp environments [2]. Inertinite maceral is highly oxidated before being deposited, so can appear from various sources. Some constituent components of kerogen are amorphous, and their amorph fragments have had many mechanical changes, and chemical activity of fungi and bacteria has led to their decomposition so that their cellular structure and maceral type are destroyed, and they are not detectable [2 & 3]. Those kerogens that generate more petroleum have almost higher than 65% exinite and amorph fragments. Kerogens with lower percentages usually create wet gas and condensed oil. The matter rich in lipids is highly resistant to decomposition, while materials rich in protein and carbohydrates are not considerably resistant to decomposition [2 & 3]. Kerogen type II has a marine source and is also called liptinite. Their particles are amorphs, which are obtained from the decomposition of zooplankton and phytoplankton. Kerogen type II has a high potential for generating oil rich in aromatic materials; this kerogen generates more gas than kerogen type I. Kerogen type III, which is rich in vitrinite maceral has a very low petroleum generation and generally generates dry gas [3].

Beyranvand, (2013) carried out a study on the biostratigraphy and paleoecology of Gurpi and Pabdeh formations in an area of the Izeh Zone and used them for basin analysis as a Ph.D. Thesis [4]. Tarjani Salehani (2014) studied Palynostratigraphy, palynofacies, and paleoecology of Sanganeh Formation in Toos Well 1 of Kopeh Dagh as a MA Thesis at Tehran University [5]. Hashemi Yazdi (2015) conducted a study on the Palynology and paleoecology of the Delichay Formation in the Central-Eastern Alborz Basin and Hajdak Formation in the East of Central Iran as Ph.D. Thesis in Tehran University [6]. Yousefi (2017) conducted a study on Palynostratigraphy, palynofacies, and paleoecology of Sarcheshmeh Formation in the section of Khemari Village in the east of Kopeh Dagh sedimentary basin [7]. Alizadeh, Alipour, and Kalani (2022), carried out some studies to examine the geochemical characteristics of source rock and shale oil potential of the Pabdeh Formation in the Dezful Embayment in southwest Iran [8].

Pyrolysis data can determine the source of the dominant organic matter of samples. In most studies and papers, hydrogen index values have been used to determine the type of kerogen. The presence of matter rich in lipids indeed indicates the high amount of kerogen and organic matter with terrestrial and continental sources depicting a low amount of hydrogen [9]. Variation in distances between coastal lines and sedimentation places occurs with changes in hydrogen amounts [9]. When pores and sediments are filled with inter-porous water and turbulent flows of organic matter with continental sources are simultaneously shaped, hydrogen amounts are decreased. In general, the study and interpretation of Rock-Eval data must be matched and confirmed based on other data, including fossilology and sedimentology. For instance, kerogen type II with marine sources may be converted to kerogen types II and III due to some processes such as chemical decomposition [9].

Zagros zone which has the largest area in Iran is one of the most important oil zones in the world, and the presence of source rocks has been confirmed based on the stratigraphy and organic geochemistry studies [10]. In southwest Iran, oil accumulation in the Cretaceous oil system as a result of oil migration from multiple layers of source rock occurs with different specific gravities that are based on the deposition time, including formations Govdan (Barmian), Kajdomi (Albian), Goro (Neocumian), Ahmadi (Lower Cenomanian), Pabdeh and Gurpi (Eosen, Campanian, Maastrichtian) [1 & 10]. To determine thermal maturity, organic matter rate oil and gas-generation potential, and geochemical analyses have been done on samples [1 & 10]. Thus, the purpose of this study is to evaluate the hydrocarbon-generation potential of Pabdeh-Gurpi in one of the fields in Southwest Iran.

II. METHOD

Among the obtained drilling debris, 22 samples from different depths in 4 wells of Mansouri Oilfield were used. In the Palynology lab of the Geological Survey and Mineral Exploration of Iran, 44 palynological slides were prepared using the Traverse method. In the Traverse technique, about 100gr of samples were isolated and washed through water and cleansed then Hydrochloric acid 30% was added to the samples. Samples were several times washed after 24 hours to become neutralized completely, and Hydrofluoric acid was added to samples. The obtained solution was boiled in distilled Hydrochloric acid 5% and centrifuged with the solution. The isolated phases were passed through considered filters, and organic matter on each filter was kept in the special capped sample containers [11]. Palynological slides were prepared from the isolated samples mentioned above. The prepared slides were tested with the magnificence of 10-100 under the microscope BH2 OLYMPUS in the microscopical lab of Mine Faculty of Industrial University of Isfahan, and the type of palynofacies and amounts of palynological elements in them were determined.

Three methods can be used for testing the source rock: chemical analysis, thermal assessment, and organic petrography. Pyrolysis is a thermal technique used to test and detect the source rock and its thermal maturity [9]. Regarding its numerous applications, pyrolysis device is widely used in the oil industry [9]. This device presents the obtained results as a log or geochemical plot, and analysis of samples is done automatically with this device. The objective and base of this method is equal heating for samples until the hydrocarbon is released completely [9]. The Rock-Eval indeed is the use of heat to create components with lower molecular weight and breaking molecules with larger dimensions [9]. This equal heat determines the overall hydrocarbon-generation potential of samples, which the process is done in oxygen absence (Figure 1).

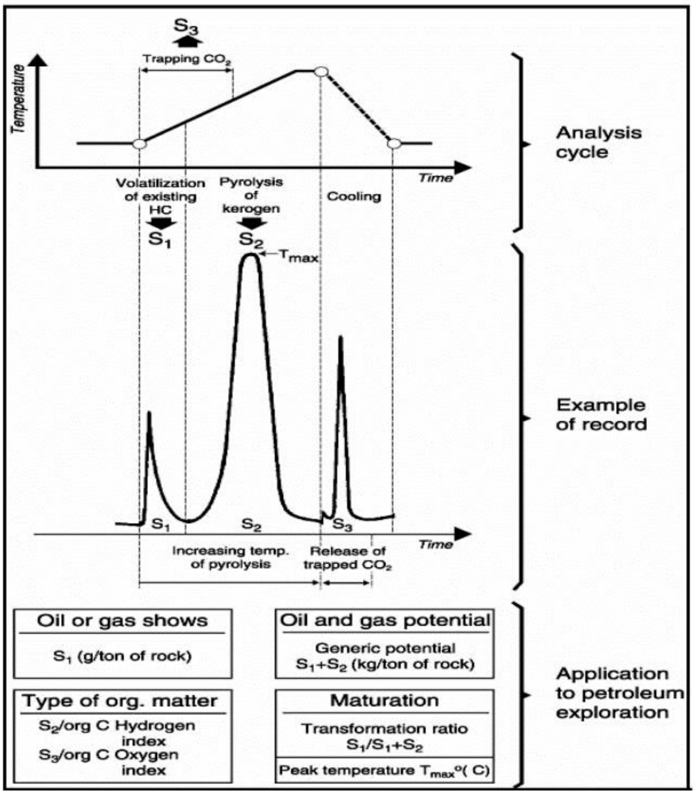

Figure 1. Different steps of Rock-Avel analysis of a sample rock [9]

The parameters recorded in the computer by pyrolysis include S3, S2, S1, HI, OI, Tmax, TOC, and S2/S3. These parameters represent the amount and type of organic matter, amount of generated hydrocarbon, and maturity level of organic matter (Table 1) [9].

Table 1. Parameters obtained for Rock-Avel pyrolysis [9]

	Detector/Oven	Unit	Name
S1	FID/Pyrolysis at 300°c	mgHC/g Sample	Free Hydrocarbons
S2	FID/Pyrolysis at 300-650°C	mgHC/g Sample	Oil Potential
Tmax	Pyrolysis thermocouple	°C	Temprature for maximum of curve S2

	Unit	Formula	Name
TOC	wt%	PC+RC	Total organic carbon
HI	-	100S2/TOC	Hydrogen index
OI	-	100S3/TOC	Oxygen index

Tmax: temperature under which the highest amount of generated hydrocarbon is produced through kerogen decomposition. This parameter represents the level of thermal maturity, which does not determine the actual temperature under which the rock is buried. If the organic matter of rock has the lowest decomposition and generates very low hydrocarbon with the least heat, the rock would not be prone to oil generation. On the contrary, when the maturity of organic matter is greater, the same level of heat is required for hydrocarbon generation. This parameter depends on the type of kerogen for sample-specific oil generation and expresses the maturity step of each sample [9].

S1: mg weighted percentage of hydrocarbon released from 1gr rock due to heat. S1 peak appears in the first pyrolysis step of Rock-Avel, and its measurement temperature is up to 300 degrees. In general, those samples with a high rate of S1 have higher maturity [9].

S2: this is the weighted percentage of hydrocarbon generated from 1gr rock through kerogen decomposition. This peak appears in the second pyrolysis step of Rock-Avel with a heat measurement degree of 300-600 [9]. The maximum peak of S2 is indeed Tmax, which depends on the lithology of the source rock and its kerogen type. If there is low organic matter in the sample rock, it naturally generates highly limited hydrocarbon; thus, S1 and S2 peaks become low and their curves become short and wide in the plot [42].

S3: mg weighted percentage up to 390° heat that generated CO_2 while doing pyrolysis at the same time [9].

PI index: it is determined based on the ratio of S1/S1 + S2 and represents the maturity level of rocks' organic matter. Migration is the factor that has a direct effect on this index and increases it apparently. Kerogens have different percentages based on their types, so that type I has almost 80%, type II has 50%, and type III has 10-30% [9]. After the pyrolysis steps are finished, samples are heated in oxidants up to 600 degrees in the absence of oxygen and after passing through some catalysts, the CO2 released from remaining organic matter is measured. The rate of this carbon is added to S1 and S2 values to find the overall organic matter based on the weighted percentage [9].

OI: rate of oxygen in kerogen and degree of organic matter oxidations in the source rock [9].

HI: the higher this value, the greater the oil-generation potential of the source rock. This rate indeed specifies the oil-generation potential of source rock and is measured based on the S2/TOC ratio [9].

After the palynofacies of considered samples were identified and separated in this research, 10 samples were isolated from all wells observing variation in the type of palynofacies and distance then were analyzed in a Rock-Avel pyrolysis device (Table 2).

Table 2. The general profile of samples used for the Rock-Avel test

Formation		Depth of sample (m)	Well No.	Sample No.
⬬	Gurpi	3048	62	1
▲	Pabdeh	2700	70	2
⬬	Gurpi	3030	70	3
▲	Pabdeh	2846	26	4
▲	Pabdeh	2950	26	5
▲	Pabdeh	2758	50	6
▲	Pabdeh	2819	50	7
▲	Pabdeh	2880	50	8

	Gurpi	2972	50	9
	Gurpi	3018	50	10

Samples 2 and 6 were selected from well 70 in 2700m depth and well 50 in 2900 depth, respectively representing the palynofacies IX; samples 1, 3, 7, 8, 9, 10 were selected from well 62 in 3048m depth, well 70 in 3030m depth, well 50 in 2819m depth, well 50 in 3100m depth, well 50 in 2972m depth, and well 50 in 3300m depth, respectively representing the palynofacies VI; finally, samples 4 and 5 were selected from well 26 in 2846m and 2950m depth, respectively representing palynofacies VI and II. Also, parameter values obtained from Rock-Avel pyrolysis in selected samples are reported in the table below (Table 3).

Table 3. Parameter values obtained from Rock-Avel pyrolysis

SAMPLE	Oil Well	Formation	Depth	S1	S2	S3	S1+S2	S2/S3	Tmax	HI	OI	TOC
1	62	Gurpi	3048	5.13	9.41	0.85	14.54	11.07	435	509	46	1.85
2	70	Pabdeh	2700	15.7	26.15	1.72	41.85	15.20	423	546	36	4.79
3	70	Gurpi	3030	14.63	14.53	1.93	29.14	7.52	428	486	65	2.99
4	26	Pabdeh	2846	2.6	3.78	1.19	6.38	3.17	427	256	80	1.48
5	26	Pabdeh	2950	2.09	1.32	1.23	3.41	1.07	429	245	227	0.54
6	50	Pabdeh	2758	13.92	32.11	2.46	46.03	13.05	421	500	36	6.43
7	50	Pabdeh	2819	8.28	6.11	0.85	14.39	7.18	430	402	56	1.52
8	50	Pabdeh	2880	12.77	13.36	2.04	26.13	6.54	428	501	76	2.67
9	50	Gurpi	2972	6.61	6.24	1.21	12.85	5.15	433	434	84	1.44
10	50	Gurpi	3018	8.67	7.94	0.8	16.61	9.92	433	469	47	1.69

Geographical location of Mansouri Oilfield

The Mansouri Oilfield is one of the oilfields of Iran that is located in Khuzestan Province. This field is neighboring Ahvaz Oilfield from the northwest to Ab Teimour Field from the west, and next to Shadegan Oilfield from the northeast (Figure 2) [12].

Figure 2. Geographical location of Mansouri Field [12]

In this research, experiments were done based on the sample of drilling debris harvested from wells 26, 62, 70, and 50 in Mansouri Oilfield to evaluate the hydrocarbon generation potential in these four wells (Figure 2). Pabdeh Formation is located in Tang Pabdeh and the anticline of Gurpi Mountain at a 34 km distance from the north of Lali County (northeast of Kuzestan Province). Pabdeh Formation contains bluish-gray marls with thin clay lime stratum and thin to medium-layered marls and shale between these layers. The row of this formation is not resistant to erosion and creates a gentle topography. In general, the Gurpi Formation consists of two lime areas of Emam Hasan and Simreh [13].

III. RESULTS

Determining the type of kerogen in considered samples

By drawing hydrogen index values against Tmax and doing microscopical studies, one can detect the amounts and types of kerogen (Figure 3).

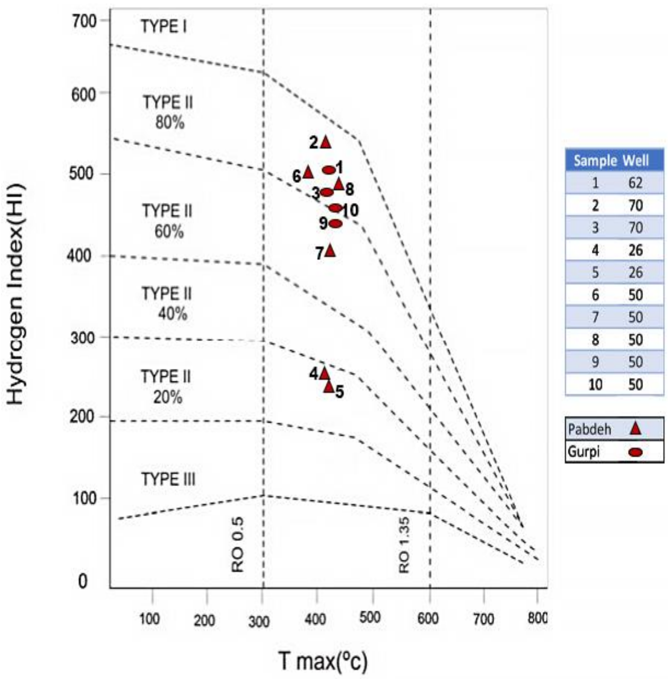

Figure 3. Tmax variations against hydrogen index to detect the type of organic matter in samples [14]

Different types of kerogen can be separated by assessing the hydrogen index against the oxygen index (Figure 4) [14]. In this method, S2 and S3 performance is considered during the pyrolysis process. This plot indicated that most kerogens in the considered samples are of type II, which confirms the obtained palynofacies results.

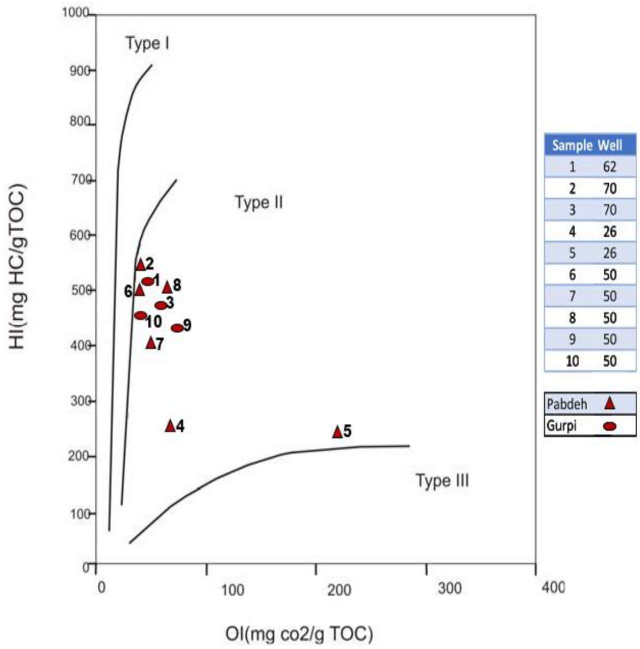

Figure 4. OI variations against HI on the plot to find the type of kerogen in samples [14]

Evaluation of hydrocarbon-generation potential and type of hydrocarbon generated by samples

According to assessments on kerogen types and their petroleum potential, organic matter with a hydrogen index less than 200 is prone to gas generation, those with HI between 200-300 are prone to a mixture of oil and gas generation, and those with HI 350-1000 are prone to oil generation [14]. The rocks prone to gas generation have a hydrogen index of less than 150, those with 150-300 produce a mixture of oil and gas, and those with a hydrogen index greater than 300 are oil-prone (Figure 5) [14].

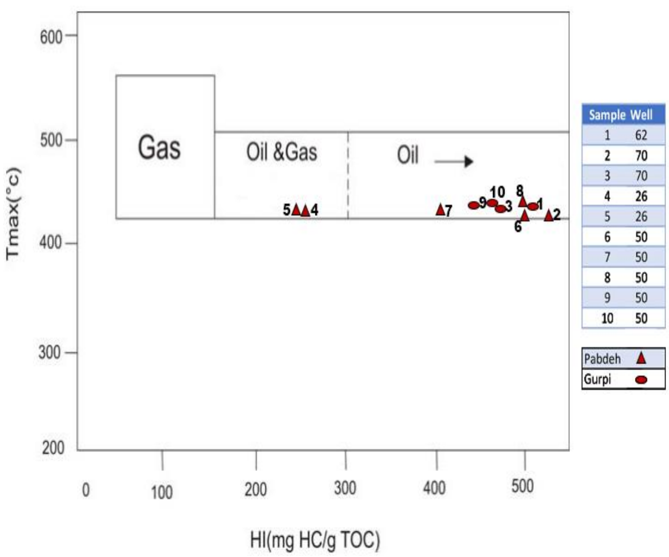

Figure 5. Tmax variations compared to HI to detect the type of generated hydrocarbon [14]. Samples 4 and 5 are in the area of oil and gas the rest are in the area of the oil window.

The S2/S3 ratio shows what kind of hydrocarbon is generated, and these results are obtained based on the findings of the Palynological Tyson Plot. According to the tables, samples with values greater than 5 and hydrogen index greater than 300 are oil-generation prone and samples with values between 3 and 5 and hydrogen index of 150-

300 are prone to oil and gas generation (Table 4) [14]. According to values of samples 2 and 6 from palynofacies group IX, these equal 15.20 and 13.05, respectively with hydrogen indices of 546 and 500. There is a high percentage of amorph organic matter in these two samples so were classified as palynofacies type, and their kerogen was type II prone to oil generation. Samples 1, 3, 7, 8, 9, and 10 have S2/S3 values of 11.07, 7.52, 7.18, 6.54, 5.15, and 9.92, respectively with hydrogen indexes of 509, 486, 402, 501, 434, and 469. Therefore, these samples are of palynofacies type IV and kerogen type II that have oil-generation potential. Samples 4 and 5 are both extracted from well 26 and have S2.S3 values of 3.17 and 1.07 with hydrogen indices of 256 and 245, respectively. These samples are placed in Kerogen type II that have the potential to generate less oil and gas.

Table 4. Detection of hydrocarbon type based on the hydrogen index and S2/S3 ratio (Peters & Cassa, 1994) [14]

Type of hydrocarbon	HI	S2/S3
Gas	0-150	0-3
Oil and gas	150-300	3-5
Oil	>300	>5

Another way for the detection of hydrocarbon generation potential is the use of TOC values and S1, S2, and S1+S2 parameters (Table 5) [14]. Hydrocarbon-generation potential of considered samples is shown in Table 6 based on these parameters.

Table 5. Evaluation of hydrocarbon-generation potential using S2, S1, and S1+S2 parameters [14]

Hydrocarbon-generation potential	S1	S2	S1+S2
Poor	0-0.5	0-2.5	0-3
Fair	0.5-1	2.5-5	3-6
Good	1-2	5-10	6-12
Very good	>2	>10	>12

Table 6. Classification of hydrocarbon source rocks based on the TOC content [14]

Hydrocarbon-generation potential	TOC in shale (weighted percentage)	TOC in carbonate (weighted percentage)
Poor	0-0.5	0-0.2
Fair	0.5-1	0.2-0.5
Good	1-2	0.5-1
Very good	2-5	1-2
Perfect	>5	>1

According to the S1+S2 parameter of samples 2 and 6 from Palynofacies, group IX equals 4.185 and 46.03, respectively, S1 values of 15.7 and 13.92 and S2 values of 26.15 and 32.11 are in the category of kerogen II that provide a very high potential for hydrocarbon generation. Samples 1, 3, 7, 8, 9 and 10 have S1+S2 values of 14.54, 29.14, 14.39, 26.13, 12.85, 16.61, respectively, S1 values of 5.13, 14.63, 8.28, 12.77, 6.61, and 8.67, and S2 values of 9.41, 14.53, 6.11, 13.36, 6.24, and 7.94, respectively, so they are under category of palynofacies VI with kerogen type II, showing a good to very good hydrocarbon-generation potential. These samples provide less hydrocarbon-generation potential than samples 2 and 6. Ultimately, samples 4 and 5 have S1+S2 values of 6.38 and 3.41, respectively with S1 values of 2.6 and 2.09 and S2 values of 3.78 and 1.32, respectively, so these samples are in the category of kerogen type II with low percentage and poor to fair hydrocarbon-generation potential.

Samples 2 and 6 with palynofacies IX and high total organic carbon values of 4.79 and 6.43, respectively indicate very high potential for hydrocarbon generation. This parameter is matched with palynological data of these two samples that have kerogen type II and many amorph organic matter. Samples 3 and 8 with total organic carbon contents of 2.99 and 2.67, respectively are at a good level, and samples 1, 4, 7, 9, and 10 with total organic carbon contents of 1.85, 1.48, 1.52, 1.44, and 1.69, respectively show almost fair hydrocarbon-generation potential and sample 5 with a total organic carbon content of 0.54 and TOC value of 3.41 provide poorer hydrocarbon-generation potential rather than other samples (Figure 6). Possible hydrocarbon in this sample is gas and a little oil; therefore, hydrocarbon is not trapped in the source rock, and migration has occurred very fast [15].

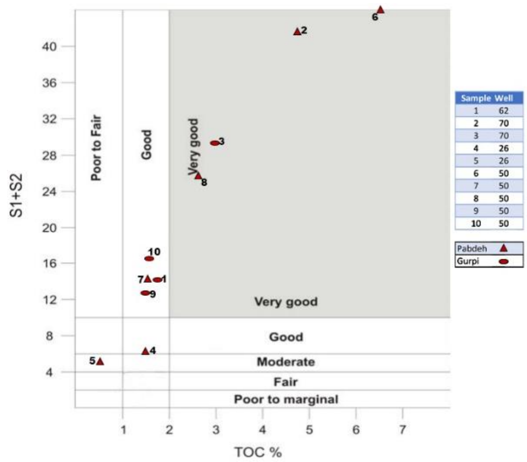

Figure 6. The plot of S1+S2/TOC variations to evaluate the genetic potential of samples [15]

Organic facies and determining sedimentation environment

The oxygen index plot helps to identify the type of sedimentation environment of organic matter [16]. According to these indexes, environments are either anoxic or oxic [16]. An anoxic environment is classified into settings with high hydrogen index and low oxygen index, and an oxic environment is divided into settings with low hydrogen and high oxygen indexes. Illustration and interpretation of plot of oxygen against hydrogen for the studied samples indicate a marine anoxic to almost anoxic environment with relatively average sedimentation speed (Figure 7) [16]. Results of geochemical analyses are matched with results obtained from palynological studies.

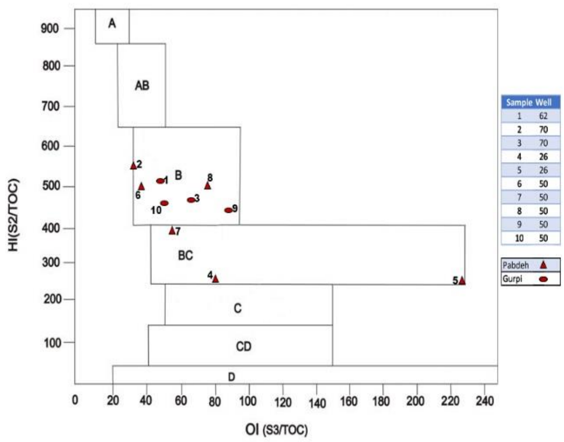

Figure 7. Depiction of organic facies using OI/HI variations [17]

(samples 1, 2, 3, 6, 8, 9, and 10 are in zone B, and sample 4, 5, and 7 are in the zone BC)

A: extremely anoxic marine environment (Distal Suboxic-Anoxic basin)

AB: progressive marine anoxic environments (Distal Anoxic shelf)

B: relatively anoxic marine or lake environments (Proximal suboxic-anoxic shelf)

BC: environments containing marine or continental organic matters and rapid sedimentation under relatively oxidant conditions (Marginal dysoxic)

C: environments with average sedimentation speed under anoxic conditions (Distal anoxic shelf)

CD: deep environments next to orogenesis areas (Distal dysoxic shelf)

D: Extremely anoxic continental environments (Highly proximal shelf) [17].

Thermal maturity

Heat quality and the nature of organic matter have a direct effect on the type and amount of generated hydrocarbon. Tmax is the parameter used as the thermal maturity index of organic matter, which increases in thermal maturity rate leads to an increase in kerogen [15 & 16]. During Rock-Eval pyrolysis, results of this parameter indicate 420-540˚C for oil generation of kerogen type II and 470-600˚C for kerogen type III. In this case, this temperature range equals 470-540˚ for the production of wet gas and condensed oil and greater than 540˚ for the production of dry gas [15 & 16]. According to the plot of considered samples, most of them are in the early maturity stage, so when kerogen type III increases more heat is required for the maturity of the source rock (Figure 8) [15 & 16]. The color of these samples mainly varies from orange to brown, which indicates the early phases of the maturity process through which, heavy oil, oil, and gas are generated [15 & 16].

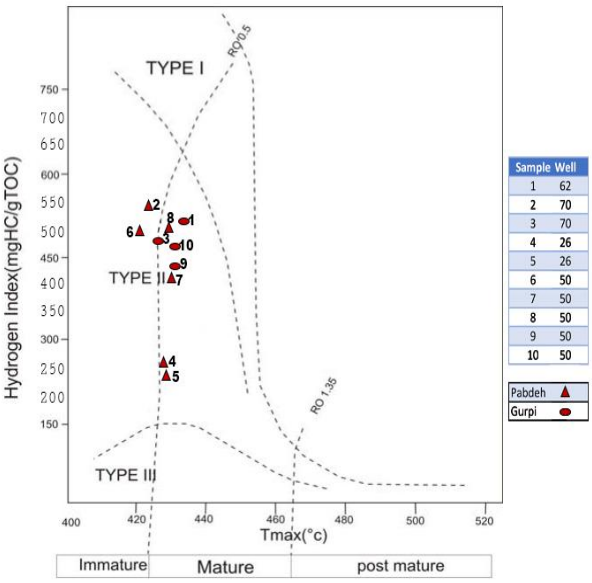

Figure 8. Thermal maturity of studied samples [16]

Quantity of organic matter

Total organic carbon percentage is used to enrich the organic matter and determine generation potential [16]. If the percentage of total organic carbon varies between 0 and 0.5w%, the rock will be poor and if it is in the range of 0.5-1w%, the rock is a fair sample in terms of generation potential. According to the TOC plot, sample 5 is in this range and the rest exist in the very good and good zones based on their determined percentages in the plot in terms of quantity and generation potential (Figure 9) [16].

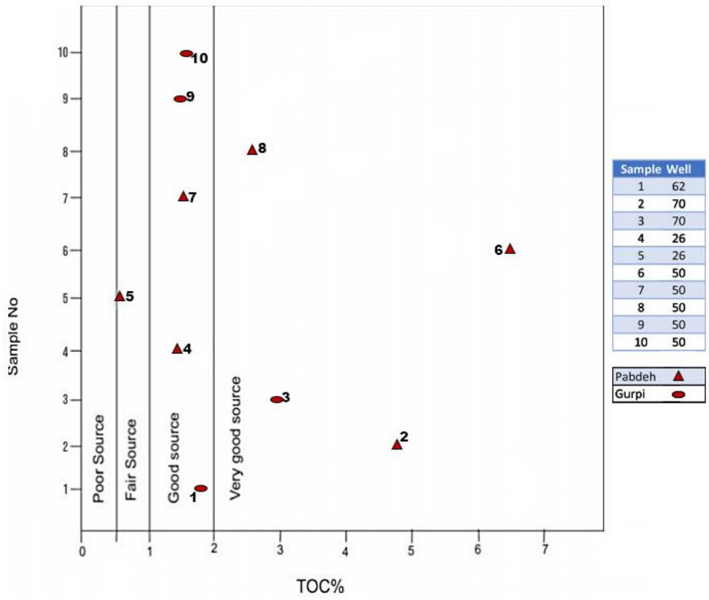

Figure 9. Total organic carbon rate in studied samples [14]

IV. CONCLUSION

The hydrogen index has less effect rather than the durability of amorph organic matter; hence, the durability rate of amorph organic matter must reach 80% so that the hydrogen index can reach 600 and above. When a part of the hydrogen index is low, it may be related to the high percentage of phytoclasts or high maturity. The selected samples for application of Rock-Ovel pyrolysis indicate that organic matter with marine sources is dominant, and the examined Van Krevelen plot indicates the presence of kerogen type II in them. The generation potential of samples with acceptable parameters include oil and gas and are generally determined from almost fair to very good. Variation trends of hydrogen index compared to oxygen index of samples confirmed facies B and BC, which represent the anoxic to relatively anoxic environment with an average sedimentation rate that confirms the palynological results. The plot of total organic carbon against hydrogen index indicates that an increase in hydrogen rate leads to an increase in total organic carbon, which the studied wells provide good anoxic and matter durability conditions due to their high amounts of total organic carbon and hydrogen index. The thermal index indicates the maturity of samples, which is also confirmed by the color of palynomorphs.

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