Waterflooding Technique to the Kashkari Oilfield in the North Part of Afghanistan

Zabihullah Mahdi,*, Kazunori Abe, Khwaja Naweed Seddiqi, Hikari Fujii

Graduate School of International Resource Sciences, Akita University Department of Earth Resource Engineering and Environmental Science 1-1 Tegata gakuen-machi, Akita 010-8502, Japan
Corresponding author. Email: zabih.mahdi@gmail.com

ABSTRACT

Hydrocarbons represent an important natural resource for the rehabilitation and sustainable development of Afghanistan. In this paper, the use of waterflooding is demonstrated for the petroleum reservoirs of the Kashkari oilfield in northern Afghanistan. The technique stands on the Buckley–Leverett frontal-displacement theory, which enables computation of the progress of the waterfront in the reservoir. The oil and water relative permeabilities, the irreducible water saturation, and the residual oil saturation are obtained from a laboratory experiment. The technique is conducted to the Kashkari oilfield to predict the feasible quantity of the oil that could be produced from this reservoir. As a result, the Buckley–Leverett waterflooding technique recovered 67 MMBBL oil of Kashkari oilfield in 6200 days.

Keywords: Waterflooding, Buckley-Leverette, Petroleum Reservoir, Relative Permeability

1. INTRODUCTION

Afghanistan's petroleum resources have been known for a long time ago [1, 2], however, their exploitation has been limited. The energy demands of the country can be met by successfully developing its petroleum reserves [3]. In this paper, we propose the use of waterflooding to increase oil production from the Kashkari oilfield in northern Afghanistan. The displacement of oil by injected water into the petroleum reservoir is investigated based on the Buckley–Leverett (BL) theory [4, 5]. The Kashkari oilfield is now being explored and exploited by the China National Petroleum Corporation International (CNPCI) and the Watan Oil and Gas Company [6]. The oil recovery by waterflooding via a horizontal displacement method is demonstrated by a laboratory experiment, and the displacement progress is compared with the BL frontal-displacement theory. We then apply the theory to the Kashkari oilfield in the Amu Darya basin in the north part of Afghanistan, and we evaluate the oil production from this field by waterflooding.

1.1. Kashkari Oilfield

Figure 1 indicates the location of the Kashkari oilfield in the Amu Darya basin in the Sar-e-Pol district of Jowzjan province, northern Afghanistan [7, 8]. The oilfield is in the Kashkari block, which is connected to the Bazar-Kami block with an area of 1,103 km² and the Zamarudsay block with an area of 1,723 km². The sedimentary basin is a petroliferous area at the southeastern margin of the Amu Darya basin. It is situated 12 km from the southeast city of Sar-e-Pol, 10 km from the Angut oilfield, 5 km from the southwest Ak-Darya oilfield, and 27 km from the southeast Bazar-Kami oilfield. It is within the oil zone near the mountains to the east part of the Amu Darya basin. To the north of the block is the major gas zone of Afghanistan [9]. The Kashkari oilfield has a low degree of exploration and development, and no seismic prospecting has been done. The wells were drilled from the 1960s to 1980s, were positioned mainly according to gravity and magnetic data and the surface geological survey and deployment [10].

2. EXPERIMENTAL

2.1. Reservoir Characteristics

The Kashkari oilfield has considerable topographic irregularities and large differences in the exposed strata.
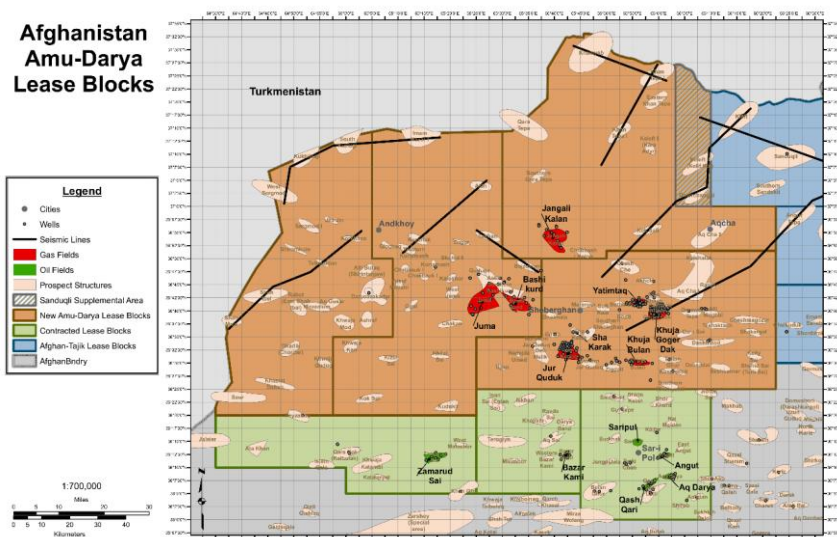
Figure 1. Kashkari oilfield in the north part of Afghanistan

Within the Kashkari oilfield, the outcropped stratum is mainly Guri, with a few Quaternary strata in some parts.

According to the data from the drilled wells, the drilled stratum consists mainly of Cretaceous systematic strata. From top to bottom, the strata are Guri formation, Turonian, Cenomanian, Albian, Aptian, Barremian, Hauterivian, and Valanginian. Within the area, the strata have relatively stable thicknesses horizontally that are easy to track. Longitudinally, the lithological association and division of each stratum are clear on the logging curve. The Kashkari field is an asymmetrical and double-high layered edge-water oil reservoir with an anticline structure. The pay zones are Albian group XIa, Aptian groups XIIa and XIIb, and Hauterivian group XIV. The pay zone deep is located from surface 950 m to 1570 m. The lithology is mainly continental unsolid sandstone. The oil layers are characterized by thin interbeds. Reservoirs XIV and XIIa have good physical properties and are sandstone with medium porosity and medium-to-high permeability [10].

In the Hauterivian stratum (120-240 m), the lithology is mainly brown medium-to-small sandstone with siltstone and clay interbeds and some thin anhydrite interbeds. The lower part is a conglomerate. Reservoir XIV is in a stratum whose lithology is sandstone and siltstone. The lithology of the Aptian stratum (80-210 m) is mainly gray sandstone and medium-to-coarse sandstone with limestone and anhydrite interbeds. Reservoirs XIIa and XIIb are in a stratum whose lithology is mainly sandstone. The upper part of the Albian stratum

(290–400 m) is dominated by gray-black limestone and light-green sandstone, and the lower part is dominated by mudstone with sandstone and limestone in some parts. Reservoir XIa is in a stratum whose lithology is mainly sandstone.

According to temperature statistics of 7 wells and 19 test points in the Kashkari field, the temperature gradient of the oil reservoir is confirmed as 2.82ºC/100 m which is a normal temperature system. In the Kashkari field, the pressure gradient is around 1.13 psi/100 m [10].

Table 1. Pressure gradiant of Kashkari oilfield [10]

Formations	Original Stratum Pressure (psi)	Pressure Gradiant (psi/100 m)
XIa	1786	1.19
XIIa	1850	1.12
XIIb	1860	1.09
XIV	2348	1.12

3. RESULT AND DISCUSSION

3.1. Core Sample Analysis

Electron-probe micro-analyzer (EPMA-1610, Shimadzu) analysis of a core sample from well no. 3 from a depth of 1100 - 1110 m in the Kashkari oilfield showed that the elemental composition of reservoir rocks in the Kashkari oilfield is 47% O, 22% Si, 15% Al, 9.5% C, 2% K, and 1% Ca, as shown in Figure 2. The core sample was taken from the Sheberghan province branch of the Afghanistan Petroleum Authority during a research trip to the Kashkari oilfield.
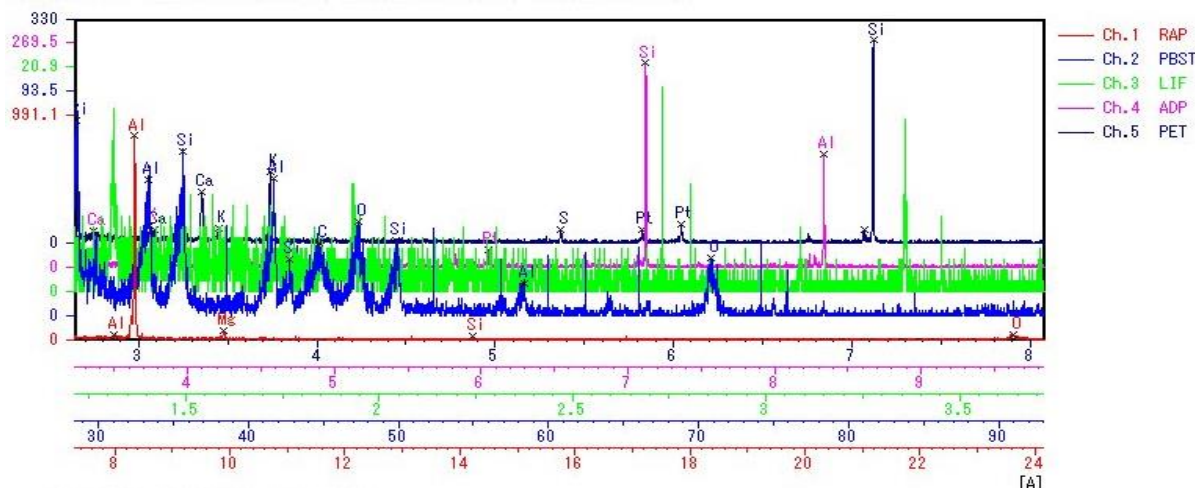
Figure 2. Elemental composition of a reservoir rock (Well 3, 1100-1110 m)

Eight wells were cored in the Kash-1 to Kash-9 reservoirs by China National Petroleum Corporation (CNPC). The results of the core analysis revealed that the reservoirs with varying levels of permeability were identified as the XIa, XIIa, or XIV groups. The highest porosity range was found in the XIIb group, which has a permeability average of 352.6 mD. Thus, the reservoirs are characterized by medium-porosity and medium-to-high permeability.

Comparison of the top structures of the Albian, Aptian, and Hauterivian stages as shown in Figure 3 indicates clearly that the structures of these three formations are similar in shape, and that the structural development and evolution of the oilfield are partly inherited. Figure 3 also shows the stratigraphic sequence column of the Kashkari oilfield [11, 12].

The Kashkari oilfield is a long and narrow NE–SW trending asymmetric anticline with a relatively complete structure. There are two structural highs that are connected through a saddle 32-35° in the northeast direction, 26.5° in the east direction, and 12° in the northwest direction. The oil column height of the Hauterivian stage is 150 m. No previous seismic exploration has been carried out; the current underground contour maps were compiled based on data from drilling, so the correctness of the structural structures in regions with fewer wells is low. The stratum groups XIa, XIIa, XIIb, and XIV were identified in vertical drilling of the Kashkari field. Different oil layers have different oil/water contact, so four independent oil reservoirs formed vertically [7].

The Kashkari oilfield is a black oil reservoir under normal temperature and pressure; the crude oil contains sulfur and wax and has a density of 0.81–0.87 g/cm^3 and a viscosity of 2.64–5.38 cp. The properties of the crude oil from the Kashkari oilfield
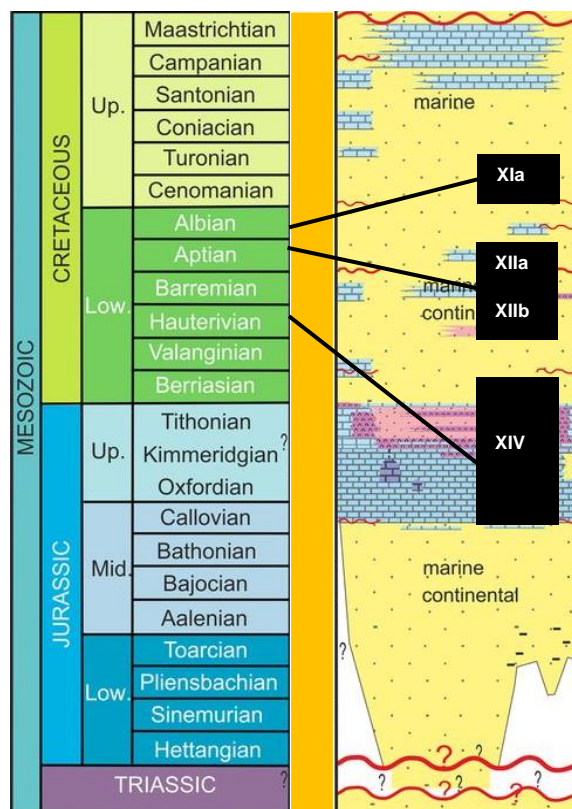

Figure 3. Stratigraphic sequence column of Kashkari oilfield

were obtained mostly from the oil used for experimental and graphical studies. The four reservoirs have different oil/water contacts and the oil-bearing area is 2.41–8.57 km^2. According to the reserve estimation, the original oil in place (OOIP) is 133.994 MMbbl. In the plane, the OOIP was estimated previously by the Soviet Union as 137.403 MMbbl with reserves of 6.381 MM ton (=46.773 MMbbl) [10].

Table 2. Effective thickness, porosity, and oil saturation of reservoirs in the Kashkari oilfield [10]

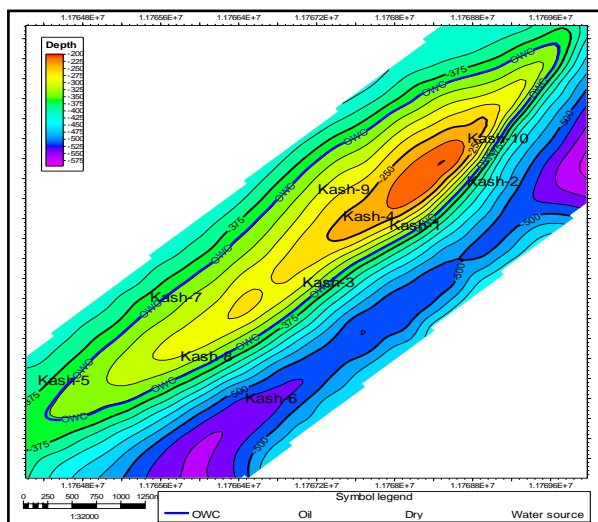| Formation	Reservoir	Effective Thickness (m)	Porosity (%)	Oil saturation (%)
Albian	XIa	5.0	17.0	62
Aptian	XIIa	11.2	22.0	70
	XIIb	4.5	18.5	67
Hauterivian	XIV	14.1	20.1	71

Figure 4. Underground contour maps of the Kashkari oilfield [10]

The relative permeability of oil and water used in this study is from reference [13, 14], published by Seddiqi *et al*. The relative permeability curves with different residual oil and water saturations used for the design of waterflooding techniques to evaluate the amount of oil recovery by artificially injecting water into the reservoir.
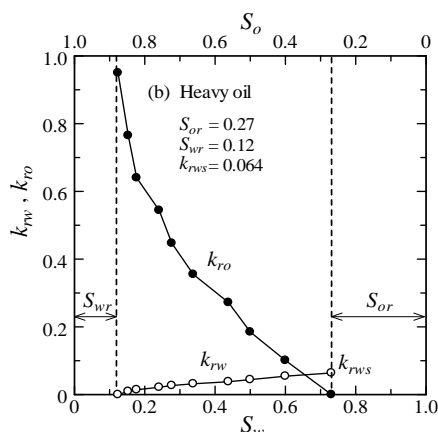

Figure 5. Relative permeability curves obtained from column test [14]

The rate of advancement of the waterfront can be calculated by BL frontal displacement theory using fractional flow curves that are evaluated from the relative permeability curves [13-15]. The BL frontal displacement theory is explored in reference [16] and reference [17] experimental analyses and the application of the theory to the experimental model is discussed in reference [18].

3.2. Application of Waterflooding to the Kashkari Oilfield

As explained, the Kashkari oilfield is made of stratum groups XIa, XIIa, XIIb, and XIV. A rate of $qT=1000$ m³/d of water injection is assumed through the reservoir.

To apply waterflooding to these reservoirs, the flow direction is approximated as a horizontal linear flow, and a cubic geometrical configuration is assumed. Table 3 shows reservoir properties used in the calculation of waterflooding technique. The water injection wells are assumed to be located close to the oil/water contact in the western part of the reservoir.

Table 3. Reservoir properties used in calculation of the waterflooding technique

Formation	Reservoir	Cross-Sectional Area, m²	Reservoir Length, m	Porosity, %
Albian	XIa	3428	3500	17.0
Aptian	XIIa	10440	3750	22.0
	XIIb	4790	3500	18.5
Hauterivian	XIV	15504	4750	20.1

Figure 6 shows the displacement of oil by water calculated by BL frontal-displacement theory. It shows a constant speed of front progresses of saturation toward the production wells, and breakthrough occurs at different times for different reservoirs. Figure 6 (a) shows the displacement of oil by water in the Albian group XIa reservoir toward the production wells, then breakthrough occurred at time $t=900$ days. The recovery factor was calculated to be recovery factory is 0.40, from the amount of oil produced up to breakthrough is 5.39 MMbbl. The OOIP is estimated by CNPCI/Watan to be 9.10 MMbbl.

Based on the BL frontal-displacement calculation shown in Figure 6 (b), the oil displaced by water in the Aptian group XIIa reservoir moved toward the outlet and breakthrough occurred at $t=3200$ days. The

oil produced up to breakthrough was 19.5 MMbbl. In this reservoir, the OOIP was estimated by CNPCI/Watan to be 42.6 MMbbl. Breakthrough for the Aptian XIIb occurred at t =1200 days and total oil production was calculated to be 7.1 MMbbl. The OOIP for this reservoir was estimated by CNPCI/Watan to be 12.2 MMbbl.

The Hauterivian group XIV is the biggest reservoir in the Kashkari oilfield. Figure 6 (d) shows the frontal saturation profile calculated by BL theory. Based on the graphical calculation, the breakthrough

occurred at t=6200 days. The total oil produced from the Hauterivian reservoir was calculated to be QT = 36.8 MMbbl. The OOIP estimated in 2013 by CNPCI/Watan was 70.28 MMbbl. There should still be residual oil in the reservoirs that could be discharged with water.

CNPCI/Watan estimated the geological reserves of the Kashkari oilfield in 2013 to be 133.99 MMbbl. Table 4 lists the calculation results of the oil reserves for each zone.
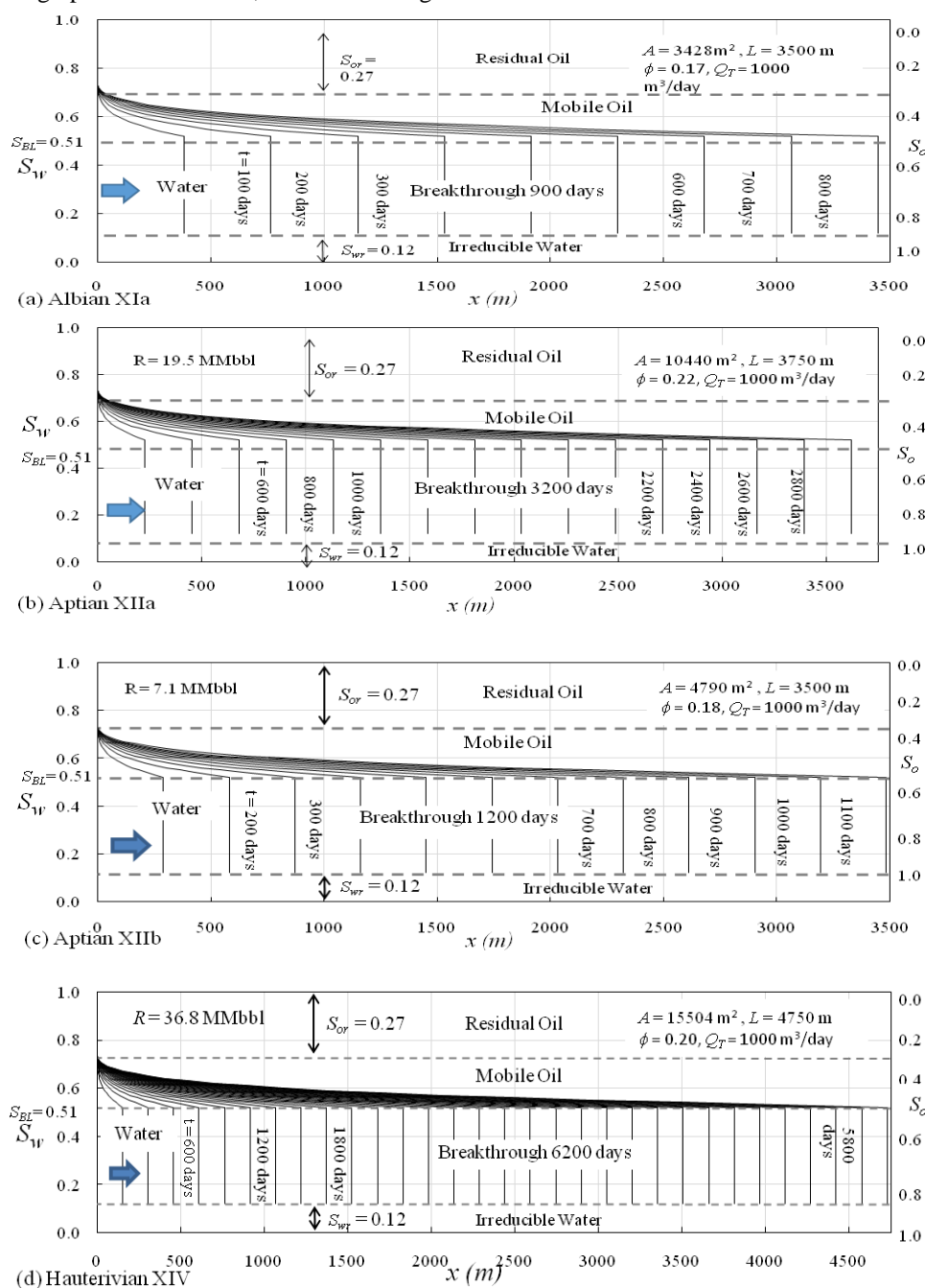

Figure 6. Saturation profiles calculated by BL analysis of the Kashkari oilfield (a, b, c, d)

Table 4. Calculation of Kashkari oilfield reserves by CNPCI/Watan [10]

Reservoir	Oil-bearing area (km²)	h (m)	P_{or}	S_o	ρ_o (g/cm³)	B_{oi}	OOIP (MMbbl)
XIa	8.57	2.14	0.183	0.478	0.851	1.05	9.10
XIIa	5.28	11.6	0.203	0.586	0.852	1.02	42.60
XIIb	2.41	9.58	0.174	0.542	0.86	1.09	12.02
XIV	5.17	19.38	0.206	0.568	0.89	1.04	70.28
Total	8.57	42.7					133.99

From 1978 to 2012, seven organizations evaluated the reserves in the Kashkari field, and the estimates have been revised from 99.48 to 137.40 MMbbl (Table 4). More data are available from the reserve calculations by the Research Institute of the former Soviet Union, the Academy of Sciences of the Ministry of Geology of the former Soviet Union, and Sofregaz, and there are only small differences among the results of calculations.

Table 5. Comparison of estimated reserves [10]

Parties	Categories of reserves (MMbbl)	
	OOIP	Recoverable
Gustavson	99.48	26.12
Russian Reserves Estimates	-	41.86
Soviet Union (1978)	122.99	47.60
Research Institute of Soviet Union (1980)	137.40	44.67
Geological Institute of Soviet (1987)	137.40	44.67
Sofregaz (2004)	137.31	44.57
CNPCI/Watan (2013/01)	133.99	43.58
Buckley–Leverett Theory	-	68.79

4. CONCLUSION

In this paper, the oil displacement by water has been evaluated by the well-known BL frontal-displacement theory. A graphical calculation of oil displacement by water was applied. In addition, the breakthrough time with the recovery factor of each reservoir has been evaluated. Based on the BL theory, the water fractional flow rate (i.e., the fraction of pore-water flow through displacement) is given as a function of the ratios in the viscosities of the two liquids and the relative permeability's in the reservoir, assuming that capillary pressure and gravity can be neglected. The BL equation implies that the rate of advance of a plane of fixed saturation S_w is proportional to the rate of change of the stream composition for saturation. By integrating the BL equation, the position of a particular saturation value is given as a function of time. The advance of the constant saturation front, S_{wf}, can be calculated by using the derivative of the fractional flow function for water saturation. The average saturation behind the front is obtained by the derivative and the irreducible water saturation.

Based on Buckley and Leverett, BL frontal displacement theory the oil recovery factor in the Kashkari oilfield was calculated as RF=0.40. The total recoverable oil for the aforementioned oilfield is calculated to be 68.79 MMbbl.

REFERENCES

[1] Mehrad A. T., Zvolinski V. P., Kapralova D. O., Niazmand M.A., (2020) Assessment of oil and gas resources of northern Afghanistan and their impact on energy security in the country, IOP Conference Series: Materials Science and Engineering, Vol. 976 (1). 012038. DOI: 10.1088/1757-899X/976/1/012038

[2] Frotan M. S., Nakaza E., Carolyn S., (2019) Afghanistan's natural resources proceedings of gsrd international conference, Tokyo, Japan, 29-33.

[3] Daly T., Singh S., (2021.08.19.) What are Afghanistan's untapped minerals and resources? Asia Pacific, Reuters, https://www.reuters.com/world/asia-pacific/what-are-afghanistans-untapped-minerals-resources-2021-08-19/

[4] Craft B.C., Hawkins M., Revised by Terry R.E., (1991) Applied Petroleum Reservoir Engineering, Prentice-Hall chemical engineering series, 1-35.

[5] Dullien F.A.L., (1979) Porous Media: Fluid Transport and Pore Structure, Academic Press, 303-309.

[6] Petzet A., (2012.01.16) CNPC gets three Afghanistan Amu Darya blocks, Oil and Gas Journal, HOUSTON http://www.ogj.com/articles/2012/01/cnpc-gets-three-afghanistan-amu-darya-blocks

[7] Promotion of Oil and Gas Production Areas to the Private Sector Grant Agreement, No. H007-AF, Gustavson Associates report, Jul-2005.

[8] Ministry of Mines and petroleum of Afghanistan "Oil and Gas Resources in Afghanistan", https://momp.gov.af/en

[9] Afghanistan, CNPC International Reach Agreement for Amu Darya Oil Tender. https://momp.gov.af/en/announcement/10780

[10] Ministry of Mines and Petroleum of Afghanistan, CNPC-W report to Afghanistan Petroleum Authority (APA) 2018.

[11] Kingston J., (1990) The Undiscovered Oil and Gas of Afghanistan, Department of the interior US. Geological Survey, USGS. Open-File Report, 90-401, DOI: 10.3133/ofr90401

[12] Klett T.R., Amirzada A., Selab A., Muty S. A., *et al.* (2006) Assessment of Undiscovered Petroleum Resources of Northern Afghanistan, Fact Sheet 2006-3031, Department of the interior U.S. Geological Survey, USGS.

[13] Nazari J., Nasiry F., Seddiqi N., Honma S., (2015) Influence of Relative Permeability and Viscosity Ratio on Oil Displacement by Water in Petroleum Reservoir, School of Engineering. Tokai University, Vol. 40, 15-20.

[14] Seddiqi K.N., Mahdi Z., Honma S., (2016) Laboratory Measurement of Relative Permeability of Oil and Water in Sand, Proc. School of Engineering. Tokai University, Vol. 41, 47-51.

[15] Buckley S.E., Leverett M.C., (1942) Mechanism of Fluid Displacement in Sands, Transactions AIME, Vol. 146, 107-116.

[16] Seddiqi K.N., Mahdi Z., Honma S., (2017) Experimental and Graphical Investigation on Oil Recovery by Buckley-Leveret Theory, World Academy of Science, Engineering and Technology, International Journal of Geological and Environmental Engineering, Vol. 11(1), 64-73.

[17] Arabzai A., Honma S., (2013) Numerical Simulation of the Buckley-Leverett Problem, Proceedings of School of Engineering of Tokai University, Vol. 38, 9-14.

[18] Seddiqi K.N, Mahdi Z., (2017) Application of Waterflooding Technique to the Angut Oilfield in the Northern Part of Afghanistan, Journal of Petroleum Exploration and Production Technology, DOI:10.1007/s13202-017-0392-5