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Determination of Biodegradation Zone in Central Sumatra Basin

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ABSTRACT - It is commonly known that heavy oil is mostly formed through biodegradation process within reservoir or on the surface both by aerobic and/or anaerobic bacteria that can live under specfic temperature level(s). In order to investigate heavy oil occurences in Central Sumatra Basin, efforts have been spent to determine the depths that represent the maximum temperature. By integrating the maximum viable temperature of typical bacteria and temperature gradient data, the depth of heavy oil zone is determined. The work is a combination of establishment of geothermal gradient map and laboratory analysis on field sampled oil for determining types and temperature characteristics of microorganism living in the samples. Heavy oil sampling is made on seepages in areas nearby Minas field. Subsequent laboratory analysis reveals *Burkholderia multivorans* ATCC BAA-247 as the predominant bacteria having maximum viabl temperature of 60° C. Based on the established geothermal gradient map, this maximum temperature correspond to average depth of 1818 ft (555.5 m). This average depth is used as the lower depth for the biodegradation zone over which investigation over presence of heavy oil bearing reservoirs/traps is made.

Keywords: Geothermal gradient, Bukholderia multivorans, biodegradation zone, Central Sumatra Basin

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INTRODUCTION

Heavy oil is formed as immature oil or as results of biodegradation and water washing processes. However, most heavy oil is generated from biodegradation process by microorganism (bacteria), either within reservoir or on the surface by both aerobic and anaerobic microorganism (Meyer, *et al.*, 2007, p. 3). Numerous studies have demonstrated that microorganisms play a crucial role in regulating biodegradation process of petroleum hydrocarbons (Sierra-Gracia &de-Olivera, 2013; Zhang, *et. al*., 2019). Those studies put that biodegradation process in subsurface usually takes place below temperature degree of less than 176°F (80°C).

All biological activities in oil and gas reservoirs requires free water, which means that water presence within reservoir may lead to biodegradation of crude oil (Head, *et al*, 2003). From studies upon correlation between degradation levels and oil composition in various oil fields (Figure 1), it has been acknowledged that most of biodegraded oil is located near oil water contact (OWC). This means that for an oil column in reservoir, the most biodegraded oil is usually at the lowest part of the column. The studies also suggest that biodegradation could take place during earlier phase of oil migration into trap, during which OWC is established.

Pannekens, *et al.* (2019) explained that microbiology degradation is limited to occurrence of electron acceptor since based on thermo-dynamic law, hydrocarbon cannot be fermented without hydrogen and acetate. Microbial actions could convert energy if they are in contact with electron donor from both crude and electron acceptor in water. This condition may best represent in the oil-water transition zone (OWTZ) below oil leg. Accordingly, this zone may be regarded as the hotspot for bacterial growth and its related oil/crude biodegradation (Figure 2).

Through the above understanding over heavy oil transformation from lighter weight oil, biodegradation zone in the Central Sumatra Basin is determined. This can be materialized if the micro-organism responsible for the biodegradation is known and subsurface temperature distribution in the sedimentary basin is made available. By knowing the microorganism (i.e bacteria) species and its viability under subsurface temperature, the established geothermal gradient map would serve as a guidance in determining the biodegradation - and the accompanying water washing mechanism - zone distribution in the Central Sumatra Basin. Maximum temperature that can be sustained by the microorganism determines the lower limit of the biodegradation zone hence heavy oil zone. The microorganism is obtained from heavy oil sampling in the field, and by isolating and identifying the specific bacteria distribution of heavy oil depth limits is determined.

METHODOLOGY

The work begins by collecting geothermal gradient data from several references and other sources in order to establish geothermal gradient map for the Central Sumatra Basin. The source of bacteria is the heavy oil itself. This is obtained from crude oil sampling on heavy oil seepage - or wells - over which any present microorganism is isolated and the resulting bacteria colony from the crude oil is further analysed to determine the most predominant typical bacteria. Once the bacteria type or species has been determined, any related information from references are used, which in turn leads to the bacteria's characteristics and maximum viable temperature. This maximum viable temperature determine the lower limit of the biodegradation zone. Figure 3 depicts the methodology used for the process.

RESULTS AND DISCUSSIONS

Thermal Gradient Map

Several publication have discussed heat flow and temperature gradient (TG) in Central Sumatera Basin. They are Kenyon & Beddoes (1977); Carvalho, *et al*. (1980), Aadland & Phoa (1981); Eubank &

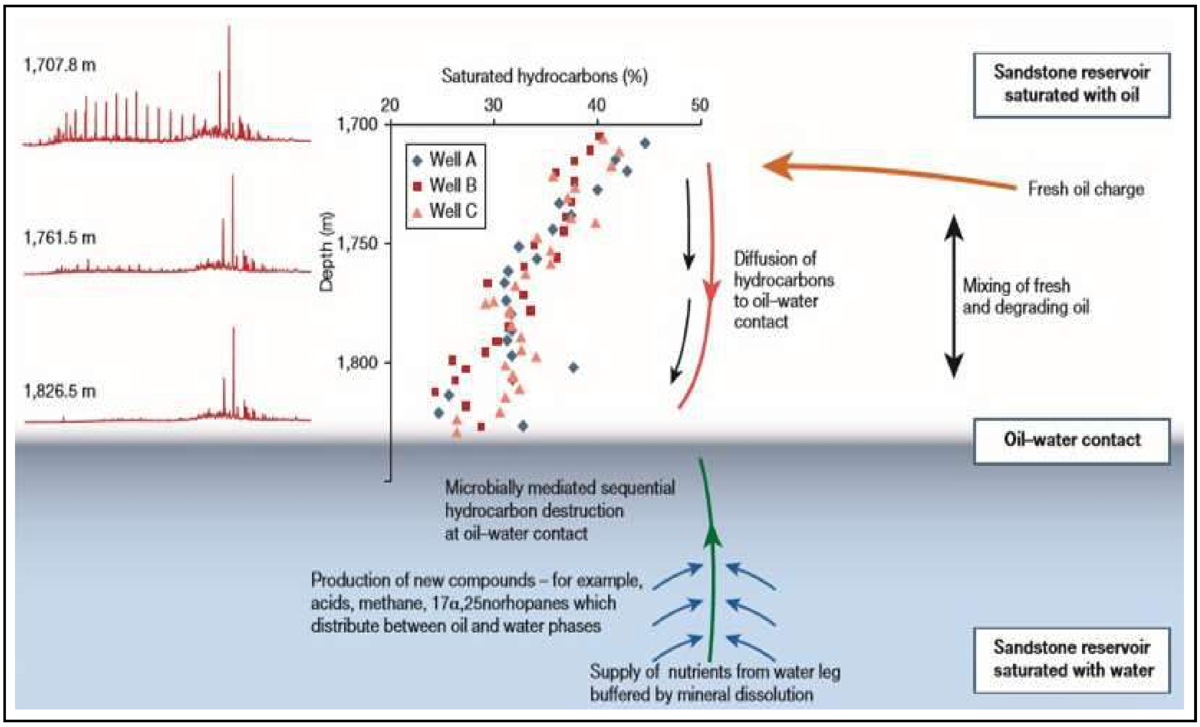

Figure 1
Hydrocarbon saturation and chromatograms of different depths in 3 (three) wells which represents higher level of biodegradation toward oil water contact in reservoir (Head, *et al.,* 2013).

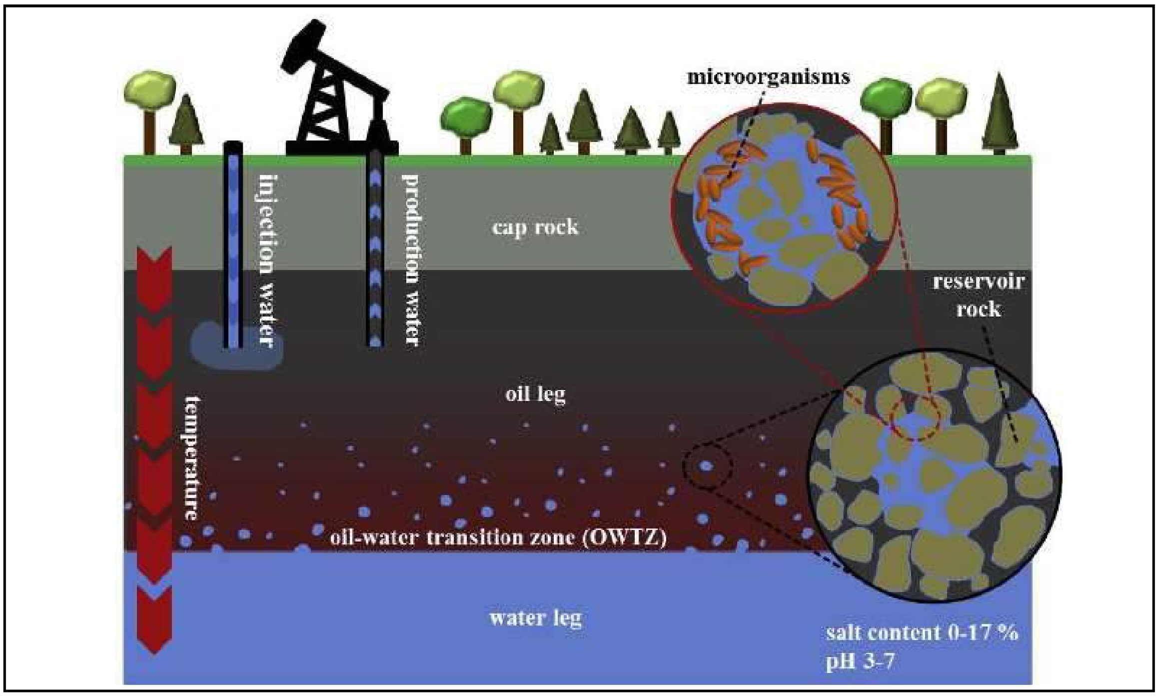

Figure 2
Illustration of oil biodegradation by microorganism (bacteria) within oil water transition zone (OWTG) of an oil reservoir (Pannekens, *et al.*, 2019).

Makki (1981); and (Grysen, *et. al.*, 2016). Based on compilation data from the references (see Appendix-A), it has been determined that average thermal gradient in Central Sumatera Basin is 3.30°F/100 feet or 6.0° C/100m. This average value represent all spatial geothermal gradient values within a range between the highest temperature gradient of 6.89°F/100 ft (12.57°C/100 m) and the lowest temperature gradient of 1.37°F/100 ft (2.5°C/100m) (Lemigas, 2020). The temperature gradient map, which was created based on the compilation data showing areas with higher temperature gradient in the Eastern-Northeastern and Western area of the basin is shown on Figure 4.

Typical Bacteria within Crude Oil Seepage in Ukai River, Minas Area

Crude oil from oil seepage located in Ukai River, Southeast from Minas field, Central Sumatera Basin, had been sampled for laboratory analysis on its isolated bacterial (micro-organisms) content. Figure 5 shows the sampling activities that took place in oil seepages in Ukai River area near Minas field. The near solid oil samples retained safely in sampling bottles were subsequently prepared for laboratory analyses. Laboratory analysis on the crude samples has revealed that the sampled oil is categorized as biodegraded heavy oil with API Gravity of 11.7° (Lemigas, 2020).

Apart from the measurements for physical properties, three (3) isolate samples from the crude had been analyzed at microbiology laboratory of the National Science Institute (Lembaga Ilmu Pengetahuan Indonesia, LIPI) with an aim of identifying typical bacteria in the isolate samples. Laboratory analysis results have managed to identify predominant presence of *Burkholderia multivorans ATCC BAA-247*; *Moraxella osloensis* strain NCTC 10465; and *Klepsiella quasipneumoniae strain KP18-31* (Lemigas, 2020).

The bacteria of *Burkholderia multivorans* (formally known as *Pseudomonas cepacia* and *Burkholderia cepacia genomovar II*) is an aerobic, glucose non-fermenting, gram-negative bacillus, and member of the *Burkholderia cepaciacomplex* (BCC) (Peralta, *et al*, 2018). According to Chaillan, *et al.* (2004), *Bukholderia multivorans* is considered as close relative to species of *Burkholderia thailandensis, B. pseudomallei, B. cepacia,* which are already known to be light/medium oil degraders. There is no specific references for *Burkholderia multivorans* ATCC BAA-247. However, according to Akita, *et al.* (2017) this bacteria has 99.6% similarities to *Burkholderia multivoran* CCA53

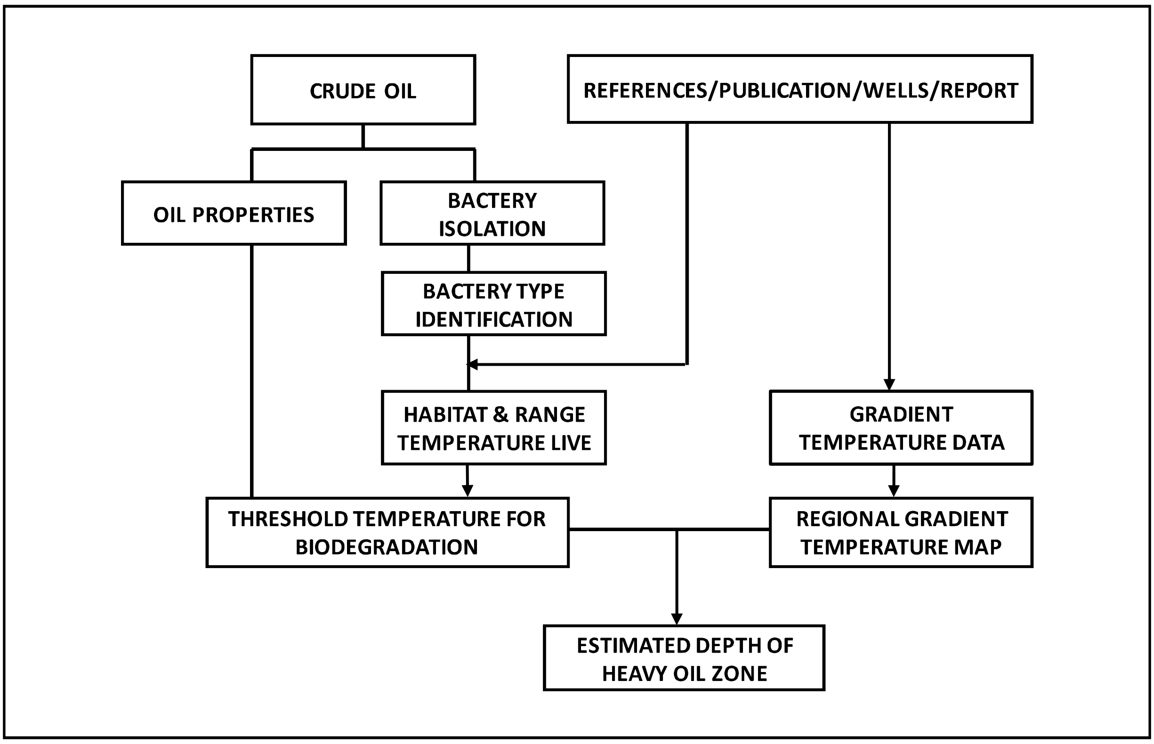

Figure 3
Workflow diagram that specifies works spent in the determination of biodegradation zone.

leading to an assumption that characteristics and habitat of *Burkholderia multivorans* ATCC BAA-247 are in strict similarity to *Burkholderia multivoran* CCA53.

Experiments on effect of temperature and pH for *Burkholderia multivoran* CCA53 growth reveals that this bacteria optimally grows at temperature of 20°C, and grows further within temperature range of 20 to 50°C, but its growth ceases at temperature levels higher than 60°C. Environmental characterictics of the microorganism species is marked by pH range that is needed for the growth of 4.0 to 9.0. At pH values of less than 3 and higher than 10 there is no growth is observed (Figure 6).

C. Depth Estimation of Heavy Oil Zone

Based on temperature range for the *Burkholderia multivorans* CCA53 (Figure 6), which is considered as an analogue to *Burkholderia multivorans* ATCC BAA-247, it is assumed that biodegradation process that has been taking place in the Central Sumatera Basin occurs within temperature of less than 60°C (140°F). The corresponding depths for the temperature of 60° C is naturally specific for each area, depending on the thermal gradient that prevails in the area/location or well within the basin (seeFigure 4). Through the use of the geothermal gradient distribution, depths are estimated using

Depth = (60° C –Tsurface)/TG*100 (1) with,

Depth = depth from surface (*ground surface*), meter,

Tsurface = surface temperature, ° C

TG = thermal gradient, ° C/100m

For example, for a well that has TG of 4.1° F/100ft (7.48 °C/100 m), Tsurface (ambient temperature) of 80° F (26.67° C), results in depth that correspond to 60°C is 445.58 m. Another example is for average TG of 3.30° F/100 ft. (6.0°C/100m) with calculated depth (@ 60°C) is 555.5 m. Through the use of this combined approach distribution of the lower depth of heavy oil zone (i.e biodegradation zone) in the Central Sumatra Basin is determined. In general, these lower depths are within the range of 1333.2 meter (calculated from the lowest TG) to 265.1 meter (calculated from the highest TG). Application of these bio-degradation zone in the Basement Highs in the basin has resulted in identification of more than 40 reservoirs/traps that contains or suspected to contain heavy oil (Lemigas, 2020).

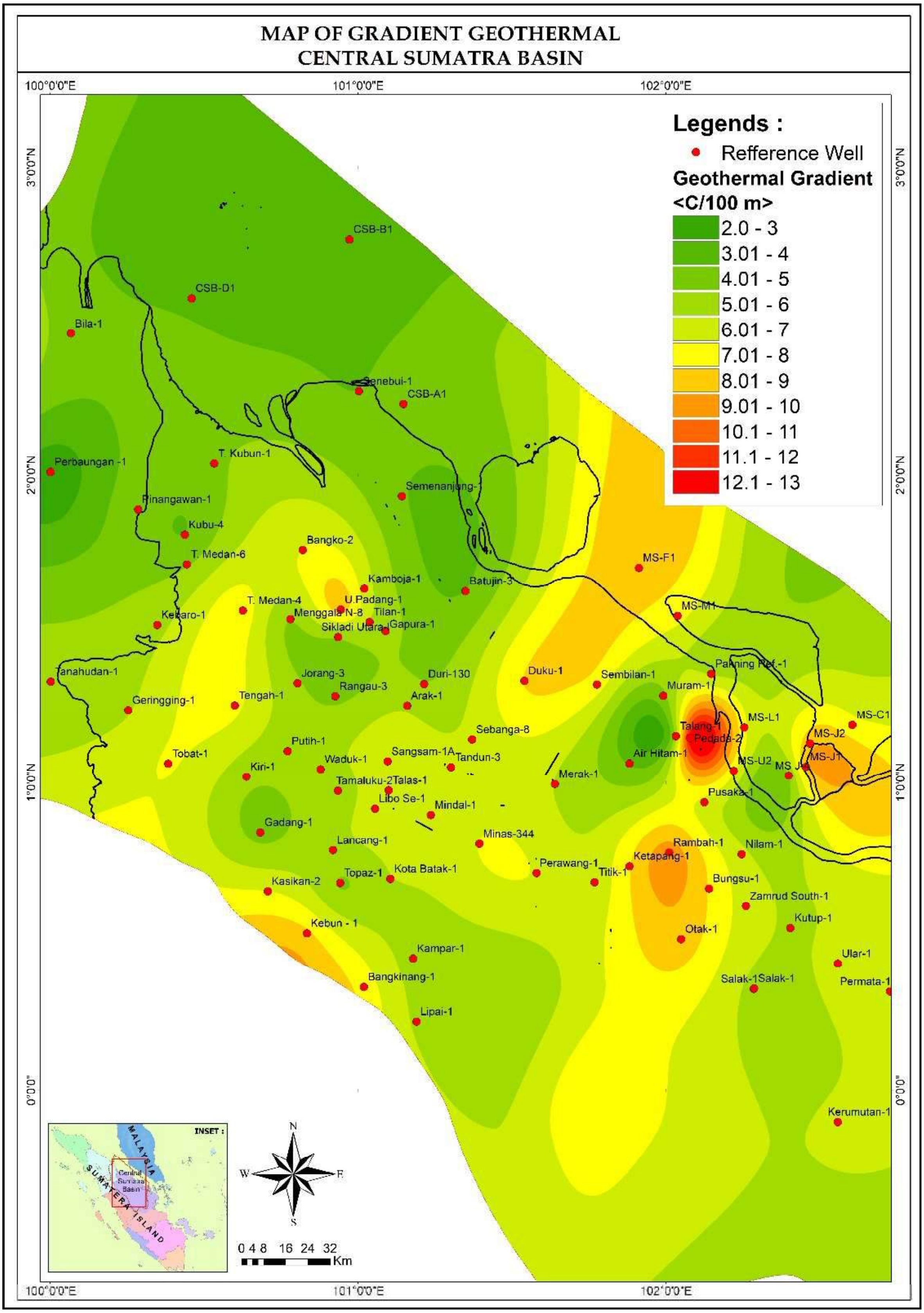

Figure 4
Gradient geothermal map of Central Sumatera Basin.
This map is created based on compilation data (Appendix-A) obtained from
Kenyon & Beddoes (1977); Aadland & Phoa (1981); and Eubank & Makki (1981) (source: Lemigas, 2020).

Figure 5
Oil seep/oil spill? In Ukai River, in Minas Area, Central Sumatera Basin (Lemigas, 2020).

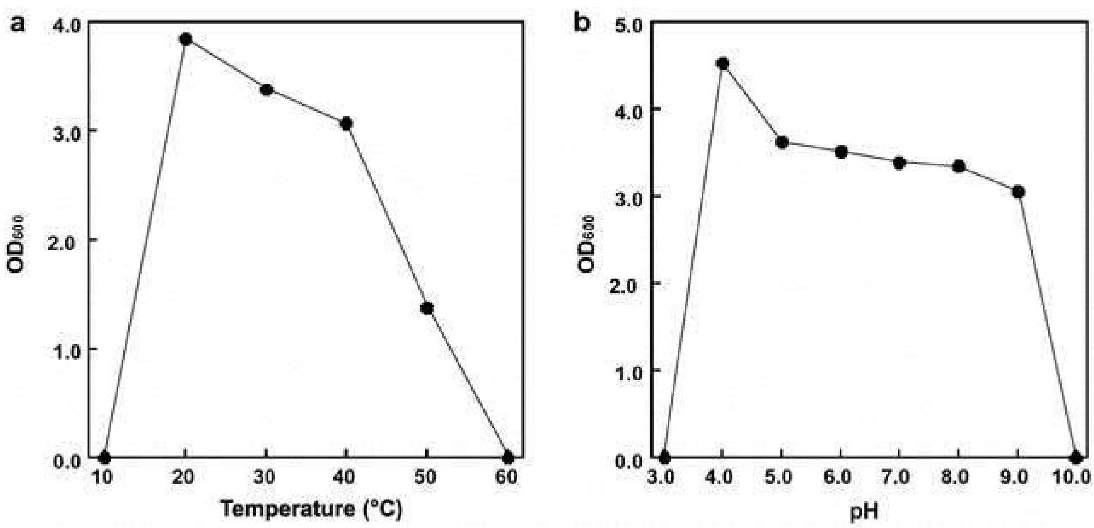

Figure 6
Effect of temperature (a) and pH (b) for *Burkholderia multivorans* CCA53 growth (Akita, *et al.*, 2017).
Optimum temperature growth is 20°C, whilst maximum temperature for bacteria live is about 60°C.

CONCLUSION

From all observations and analyses related to the determination of heavy oil vertical zone (biodegradation zone), there are several main points that can be concluded:

Isolation and determination of bacteria from oil seepage/oil spill In Ukai River, near Minas field in Central Sumatera Basin has resulted in *Burkholderia multivorans ATCC BAA-247*, which based on available reference has maximum viable temperature of 60°C (140°F).

Biodegradation of crude oil within reservoir Has been taking place when micro-organism (bacteria) and encroaching water are in contact with crude oil. This original crude oil was usually light or medium in weight. Hotspot area for biodegradation in reservoir occurs around oil water transition zone (OWTZ) that separates water and oil legs. The biodegradation process also occurs within ranges of temperature of less than maximum temperature under which bacteria can live. In accordance with characteristics of *Burkholderia multivorans* CCA53, the maximum temperature for biodegradation process the Central Sumatra Basin is 60°C.

Based on compiled data, average thermal gradient in Central Sumatra is 3.33°F/100 ft. (5.93°C/100m), with highest temperature gradient of 1.37°F/100 ft. (2.5°C/100m) and lowest temperature gradient of 6.89°F/100 ft. (12.57°C/100m).

With regard to average temperature gradient (3.30° F/100ft.or 6.0°C/100m) in Central S u matra Basin, temperature of 60° C occurs at 1818.2ft, or 555.5 m. This depth is regarded as a threshold depth (limiting lower depth) for further analysis such as petrophysical and seismic analyses aimed at investigating potentials of heavy oil bearing zones at depths shalower than 555.5 m.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
Bacteria	small single-celled organisms. Bacteria are found almost everywhere on Earth and are vital to the planet's ecosystems. Some species can live under extreme conditions of temperature and pressure.	
Biodegradation	the breakdown of organic matter by microorganisms, such as bacteria and fungi	
Geothermal gradient	the increase in temperature with increasing depth beneath the Earth's surface. This gradient is due to outward heat flow from a hot interior. The magnitude of the geothermal gradient depends on the rate of heat production at depth, the dynamics of the system, and the conductivity of rocks	
Heavy Oil	a crude oil that has a viscosity typically greater than 0.01 Pa. s [10 cP] and a high specific gravity. The World Petroleum Congress classifies heavy oils as crude oils that have a gravity below 22.3 degree API	

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APPENDIX-A

GRADIENT GEOTHERMAL OF WELLS from CENTRAL SUMATERA BASIN

Source data : Kenyon & Beddoes (1977); Aadland & Phoa (1981); Eubank & Makki (1981)

No	Well Name	Company	Coordinate	Total Depth	Ambient Temperature (assumed)	Geothermal Gradient	
			LatLong	Feet	°F	°F/100 Ft.	°C/100 m
1	CSB-B1	Mobil	02°45'57" N; 100°58'21" E	5721	80	1.86	3.39
2	CSB-D1	Mobil	02°34'28" N; 100°27'33" E	6039	80	2.12	3.87
3	CSB-A1	Mobil	02°13'53" N; 101°08'51" E	2487	80	2.44	4.45
4	MS-F1	Hudbay	01°41'54" N; 101°54'47" E	3212	80	4.73	8.63
5	MS-M1	Arco	01°32'30" N; 102°02'18" E	4015	80	4	7.3
6	MS-U2	Hudbay	01°02119" N; 102°13'14" E	5000	80	3.94	7.19
7	MS-J2	Arco	01°07139" N; 102°28'06" E	3269	80	4.74	8.65
8	MS-J1	Arco	01°03'07" N; 102°27'19" E	2101	80	4.71	8.59
9	MS-C1	Hudbay	01°11'16" N; 102°36'23" E	3485	80	4.03	7.35
10	MS A-1	Arco	00°14'51" N; 103°55'28" E	3397	80	2.29	4.18
11	Lupak-1	Total	00°59'38" N; 103°51'56" E	5682	80	2.61	4.76
12	Lupak-3	Total	00°59'12" N; 103°58'30" E	2805	80	2.88	5.25
13	Berhala-IX	Gulf oil	01°01'19" N; 104°28'38" E	4619	80	1.78	3.25
14	Ledung-1	Union	02°40'30" N; 99°52'25" E	3310	80	3.16	5.76
15	Kualu-1	Union	02°42'17" N; 99°56'13" E	4324	80	2.72	4.97
16	Bila-1	Union	02°27'36" N; 100°04'03" E	7135	80	2.53	4.61
17	Merbau-1	Union	02°15'42" N; 99°47'17" E	1873	80	3.22	5.87
18	Perbaungan -1	Caltex	02°00'34" N; 100°00'04" E	5891	80	1.37	2.5
19	T. Kubun-1	Caltex	02°02'15" N; 100°31'58" E	6078	80	2.65	4.83
20	Pinangawan-1	Caltex	01°53'19" N; 100°17'08" E	3154	80	2.5	4.56
21	Kubu-4	Caltex	01°48'19" N; 100°26'14" E	3212	80	2.2	4.01
22	Bangko-2	Caltex	01°45'22" N; 100°49'14" E	3932	80	3.85	7.02
23	T. Medan-6	Caltex	01°42'33" N; 100°26'40" E	2773	80	2.7	4.92
24	Batujin-3	Caltex	01°37'19" N; 101°20'57" E	2592	80	2.2	4.01
25	T. Medan-4	Caltex	01°33'32" N; 100°37'34" E	2356	80	4.1	7.48
26	Kamboja-1	Caltex	01°37'48" N; 101°01'15" E	3778	80	3.6	6.57
27	Semenanjung-1	Caltex	01°55'53" N; 101°08'33" E	2111	80	2.54	4.1
28	Gapura-1	Caltex	01°29'35" N; 101°05'21" E	4375	80	2.95	5.38
29	U.Padang-1	Caltex	01°33'43" N; 100°56'38" E	1812	80	4.6	8.39
30	Menggala N-8	Caltex	01°31'53" N; 100°46'48" E	3865	80	2.77	5.05
31	Sikladi Utara-I	Caltex	01°28'24" N; 100°56'09" E	4847	80	2.8	5.11
32	Kebaro-1	Caltex	01°30'44" N; 100°20'53" E	4092	80	3.13	5.71
33	Tilan-1	Caltex	01°31'19" N; 101°02'16" E	5220	80	3.24	5.91
34	Tanahudan-1	Caltex	01°19'41" N; 100°00'05" E	4157	80	2.94	5.36
35	Geringging-1	Caltex	01°14'08" N; 100°15'12" E	4491	80	3.25	5.93
36	Tengah-1	Caltex	01°15'04" N; 100°35'59" E	5296	80	3.96	7.22
37	Jorang-3	Caltex	01°19'23" N; 100°48'12' E	7484	80	2.85	5.14
38	Rangau-3	Caltex	01°16'51' N; 100°55'34' E	8520	80	2.62	4.78
39	Duri-130	Caltex	01°19'14" N; 101°12'54" E	2782	80	2.77	5.05
40	Arak-1	Caltex	01°15'01" N; 101°09'34" E	5000	80	3.2	5.84
41	Duku-1	Caltex	01°19'51" N; 101°32'26" E	2250	80	4.4	8.03
42	Sembilan-1	Caltex	01°19'08" N; 101°46'36" E	1288	80	4.1	7.48
43	Muram-1	Caltex	01°16'59" N; 101°59'31" E	5539	80	2.6	4.74
44	Pakning Ref.-1	Caltex	01°21'13" N; 102°08'52" E	5196	80	3.23	5.89
45	Pedada-2	Caltex	01°08'45" N; 102°04'43" E	1684	80	6.89	12.57
46	Talang-1	Caltex	01°09'04" N; 102°01'59" E	2532	80	3	5.47
47	Air Hitam-1	Caltex	01°03'46" N; 101°52'56" E	4606	80	2.15	3.92
48	Merak-1	Caltex	00°59'43" N; 101°38'23" E	4693	80	3.28	5.98
49	Sebanga-8	Caltex	01°08'25" N; 101°22'15" E	1908	80	3.4	6.2
50	Sangsam-1A	Caltex	01°04'10" N; 101°05'46" E	6564	80	3.7	6.75
51	Waduk-1	Caltex	01°02'37" N; 100°52'42" E	6610	80	3.23	5.89
52	Talas-1	Caltex	00°58'28" N; 101°05'59" E	6369	80	3.45	6.29
53	Putih-1	Caltex	01°06'09" N; 100°46'17" E	8700	80	3.01	5.49
54	Kiri-1	Caltex	01°01'10" N; 100°38'13" E	5688	80	2.92	5.33
55	Tobat-1	Caltex	01°03'44" N; 100°23101" E	1940	80	3.87	7.06
56	Tandun-3	Caltex	01°03'02" N; 101°18'07" E	3719	80	3.41	6.22
57	Tamaluku-2	Caltex	00°58'23" N; 100°56'06" E	6044	80	2.99	5.45
58	Libo Se-1	Caltex	00°54'53" N; 101°03'19" E	6073	80	3.55	6.48
59	Gadang-1	Caltex	00°50'17" N; 100°40'58" E	5663	80	2.58	4.71
60	Mindal-1	Caltex	00°53140" N; 101°14'10" E	3825	80	3.3	6.02
61	Minas-344	Caltex	00°48'03" N; 101°23'39" E	2881	80	3.85	7.02
62	Lancang-1	Caltex	00°46'49" N; 100°55'06" E	7071	80	3.17	5.78
63	Kota Batak-1	Caltex	00°41'14" N; 101°06'18" E	5542	80	3.27	5.96
64	Topaz-1	Caltex	00°40'27" N; 100°56'31" E	5139	80	2.7	4.92
65	Kasikan-2	Caltex	00°38'49" N; 100°42124" E	2015	80	3.85	7.02
66	Kebun - 1	Caltex	00°30'37" N; 100°50'03" E	1743	80	4.5	8.21
67	Bangkinang-1	Caltex	00°20'10" N; 101°01109" E	1841	80	4.16	7.59
68	Pusaka-1	Caltex	00°56108" N; 102°07131" E	5628	80	3.68	6.71
69	Rambah-1	Caltex	00°46'21" N; 102°00140" E	2510	80	5.2	9.48
70	Ketapang-1	Caltex	00°43'41" N; 101°52155" E	2623	80	4.35	7.93
71	Perawang-1	Caltex	00°42'21" N; 101°34'49" E	3249	80	3.8	6.93
72	Bungsu-1	Caltex	00°39'21" N; 102°08'26" E	2228	80	4.35	7.93
73	Otak-1	Caltex	00°29'29" N; 102°03'00" E	2856	80	4.69	8.55
74	Zamrud South-1	Caltex	00°35'55" N; 102°15'37" E	3722	80	3.6	6.57
75	Kutup-1	Caltex	00°31'39" N; 102°24'18" E		80	3.25	5.93
76	Ular-1	Caltex	00°24'44" N; 102°33'33" E	3565	80	3.4	6.2
77	Permata-1	Caltex	00°19'16" N; 102°43'43" E	2730	80	3.37	6.15
78	Salak-1	Caltex	00°19'46" N; 102°17'10" E	5900	80	3.15	5.75
79	Kuantan Strat.-1	Caltex	00°02'15" S; 102°56'34" E	1885	80	2.88	5.25
80	Titik-1	Caltex	00°40'35" N; 101°46'07" E	3717	80	3.47	6.33
81	Senebui-1	Caltex	02°16'23" N; 101°00'11" E	1922	80	2.25	4.01
82	Kerumutan-1	Caltex	00°06'12" S; 102°33'32" E	5350	80	3.32	6.06
83	CSB-C1	Mobil		4254	80	2.32	4.24
84	Kanopan	Union		4715	80	2.88	5.25
85	Salak-1	Caltex		5900	80	3.15	5.75
86	MS-L1	Arco		4789	80	3.97	7.24
87	MS J-4	Arco		5754	80	2.7	4.92
88	Peranap	Total		3206	80	3.33	6.07
89	Lipai-1	Stanvac		3164	80	3.19	5.82
90	Kampar-1	Stanvac		4694	80	3.07	5.6
91	Nilam-1		00°46'00" N; 102°14'46" E	4824	80	3.45	6.29