Identify the Oil Seepage in Plantungan Geothermal Manifestation, Kendal Using HVSR Method

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Abstract. The presence of oil seepage to the surface indicates that at least an active petroleum system is present subsurface. Oil seepage that occurred in Plantungan, Kendal, Central Java, has been known since 1971 and still produces seepage until today. On the research area, three oil seepages point were found. Plantungan region is located in East Serayu Zone underlain by volcanic area, and based on the Geology Map, the research area is located in Banjarnegara-Pekalongan Sheet. To understand the geology condition of the research area, a subsurface mapping is needed, even though the mapping does not provide the depth of bedrock and reservoir, data recording using HVSR (Horizontal to Vertical Spectrum Ratio) method that has been done in 18 points is able to provide V_p and density profile to understand the distribution of oil seepage. The oil seepage is most prominent close to SB09 location, however the result from crossplot found that the value of highest V_p×density is on SB12A with 4,306,197 kg/m^{2}s, and lowest V_p×density in on SB17A with 302,305.3 kg/m^{2}s.

Keywords: **Oil Seepage; Oil Seepage in Volcanic area; Oil Seeps in Geothermal Manifestation; Acoustic Impedance; HVSR Method; Spectra Ratio Method**

1 Introduction

Oil seepage is a presence of oil at the surface which migrated from the high pressure condition to low pressure through rocks fracture [1]. Seepage has various component variables, such as oil, gas, liquid bitumen, asphalt and tar [2]. According to Zheng et al. (2018), types of seepage are divided into two, which are macro-seepage; oil, gas, volcanic mud, and bitumen. While micro-seepage is the released emission.

Petroleum oil itself, both offshore and onshore, is predicted to have more than 1,150 seepage points in 84 countries in the world, including Indonesia [2]. In Java Island itself, oil and gas seepage is focused on three main area, which are Banten, Majalengka, and East Serayu. These three area are also located in volcanic area, however, based on the petroleum geology, all of them have a different petroleum system [3].

Administratively, the research area is located between two villages, which are Sangubanyu Village, Bawang District, Batang City and Tirtomulyo Village, Plantungan District, Kedal City. Geographically, the research area is located between 7°5'51.46"S – 7°6'4.55"S and 109°57'40.05"E – 109°57'55.43"E. If seen from the physiography of Central Java, the research area is included in the East Serayu Zone with many volcanic mountains surrounding the site (Fig 1)

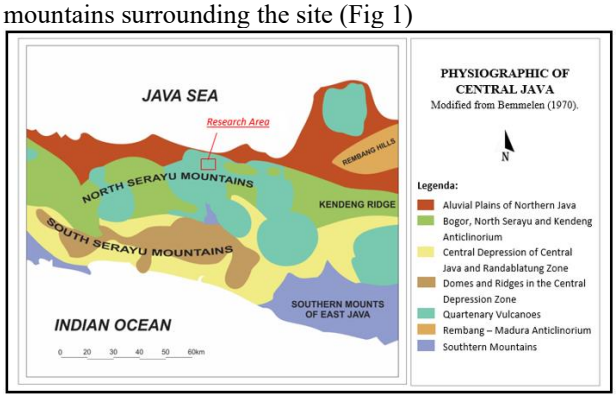

Fig. 1. Physiography Map of Central.

Oil seepage that happened in Plantungan District, Kendal, has been known before in a study done by Truesdell (1971). Other than oil seepage on the research area, there are also some hot pool point which is a characteristic of geothermal source manifestation, but will not discuss it in detail.

The conceptual model of a geothermal site is based on the geological information, both from the mapping of the surface to subsurface analysis, geophysics survey result, geochemical, to sampling of reservoir liquid from the

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well, temperature information and pressure condition based on well logging result [5]. Some of the results from that method can become a parameter that directly refer to geology activity [6]. There are various methods for geophysics that are usually done, such as geoelectricity, seismic, gravity, magnetic method. In this paper author used HVSR (Horizontal to Vertical Spectral Ratio) seismic method.

2 Horizontral to Vertical Spectral Ratio (HVSR) Method

The earth surface is always moving in seismic frequency even with or without earthquake movement. The constant vibration on the earth surface is called microseism or microtremors or generally termed as microtremor [7]. Microtremor is a vibration that has very small amplitude of approximately 0.1 to 1.0 μ and speed of vibration of approximately 0.001 cm/s to 0.01 cm/s [8].

The earth has elastic wave that propagates inside earth and on the surface, this is called seismic wave, this depends on the elasticity of the rocks. Body wave consists of P and S wave. P wave is a longitudinal wave that has the same direction with particles' movement to the propagated wave, while S wave is one of the wave propagations that has particles' movement perpendicular to the propagation. Surface wave is a complex wave with low frequency and high amplitude. This wave is divided into Love and Rayleigh wave. Love wave is a surface wave that the particles' are vibrating through the propagation direction. Rayleigh wave is a type of wave that has linear particles' movement direction to the direction of propagation and plane [9]. Moreover, P and S wave are used to determine the value of V_p and V_p/V_s [10].

HVSR method is one of the method that generally used for microtremor three components to identify the depth of bedrock. Moreover, this method can be used to determine the dominant resonance frequency (f0) and peak point of HVSR (A) which show the sediment's dynamic characteristic. If both values are known, then seismic susceptibility index in kg can be calculated. Parameters used in HVSR method are amplification and natural frequency, where these two factors are related to underground physical parameters to geologically understand the characteristics of research area [11]. This method was introduced by a researcher named Nakamura on 1989 with the principle of calculating the spectrum ration between total component of horizontal and vertical resultant [12].

In the beginning, this method is used to predict resonance frequency and amplification factor of local geology from microseisms data. However, in its development, this method is able to determine ground susceptibility index, rock susceptibility index, and to map sediment thickness qualitatively [13].

The equation of this HVSR method is as follows:

$$R(f) = \frac{\sqrt{Hew^2(\mathrm{f}) - Hns^2(\mathrm{f})}}{\mathrm{Vud\ (f)}} \quad (1)$$

Where:
R(f) = HVSR Rasio Spectrum
Hew (f) = Horizontal Component Spectrum E-W
Hns (f) = Horizontal Component Spectrum N-S.
Vud (f) = Vertical Component Spectrum.

Whereas to find the thickness of the sediment layer (H) the equation is used:

$$f0 = \frac{V_s}{4H} \quad (2)$$

Where f0 for Dominant frequency (Hz), V_s for Wave propagation in the sediment layer (m/s), and H for Thickness of sediment layer (m) [12].

Moreover, HVSR method can use to find $V_p \times \rho$ value, it is an acoustic impedance value. Acoustic impedance value is used to see rock compactness [14]. The equation of this can be described as bellow:

$$Z = V_p \times \rho \quad (3)$$

With Z = Acoustic Impedance (kg/m^{2}s), V_p = Propagation of wave P (m/s), ρ = Density of the formation (kg/m^2).

3 Methodology

Past observation was done by Truesdell in 1971, this is the basis of the continuation observation done in this research. The observation is done directly on site and three oil seepage point were found to be close to each other (Fig 5). The presence of oil to the surface that happens until now is an evidence that there is still an active petroleum system in subsurface [15]. Oil seepage that present to the surface of research area has the characteristics of yellowish black and has distinct smell of crude oil (Fig 2).

Equipment used for data acquisition are seismometer with three components, data logger DI 170, compass, and laptop to process data that has been collected on site. Data collection was done in an area of 560m x 400 m with 18 points at first and 4 additional points around the seepages they are SB09A, SB12A, SB13A, and SB17A (Fig 3 and 4). Components in seismometer consist of three parts, which are vertical data component (up and town) and two horizontal data component; South-North and East-West [9]. Data was processed with GEOPSY software to measure spectral ratio of HVSR and SURFER12 for contour mapping.

Fig. 2. One of Oil Seepage in Research Area.

Fig. 3. Map of Data Collection Planning in 18 Points without 4 additional points.

4 Result and Discussion

The collected data was then processed using GEOPSY software and dominant frequency value (f0) trough HVSR curve as Fig 4 and was obtained as shown in Table 1.

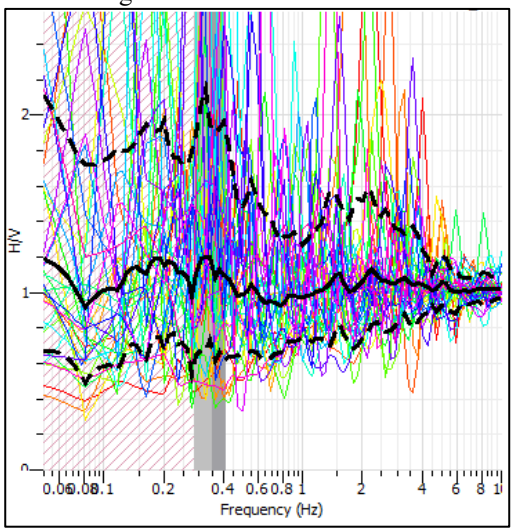

Fig. 4. HVSR curve at Point SB13 with highest dominant frequency value (f0).

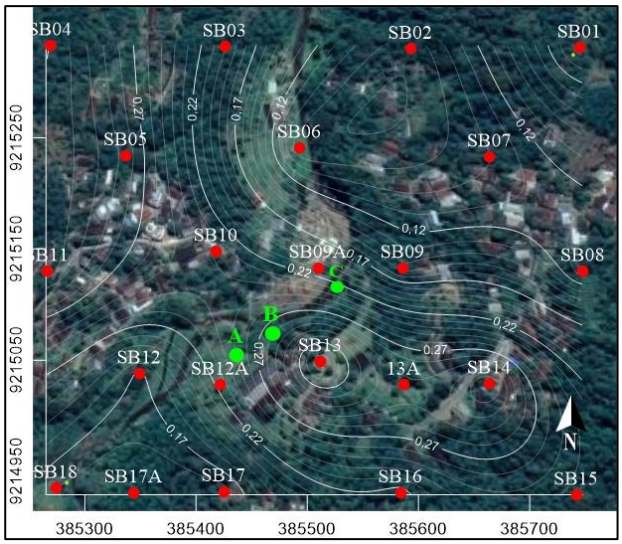

Fig. 5. Point A, B and C are the points where oil seepage to the surface is found. The most visible seepage is at point C.

Table 1. Result of f0 Value Analysis.

Point Name	Coordinate		Dominant Frequency (Hz)	Sediment Thickness (m)
	Easting	Northing		
SB01	385745	9215331	0.195216	514.46
SB02	385593	9215330	0.080938	1,240.82
SB03	385426	9215332	0.201886	497.46
SB04	385269	9215333	0.319821	314.02
SB05	385337	9215234	0.286295	350.79
SB06	385493	9215241	0.080614	1,245.81
SB07	385664	9215233	0.099419	1,010.17
SB08	385748	9215130	0.103424	971.05
SB09	385586	9215133	0.143077	701.93
SB09A	385510	9215133	0.274879	365.36
SB10	385418	9215148	0.23836	421.34
SB11	385266	9215130	0.316759	317.05
SB12	385349	9215038	0.167293	600.32
SB12A	385418	9215148	0.23836	461.66
SB13	385512	9215049	0.350805	286.28
SB13A	385357	9215137	0.22065	289.43
SB14	385664	9215029	0.322214	311.69
SB15	385742	9214929	0.235971	425.60
SB16	385584	9214931	0.214435	468.35
SB17	385425	9214932	0.15492	648.27
SB17A	385266	9215130	0.316759	524.13
SB18	385274	9214935	0.159994	627.71

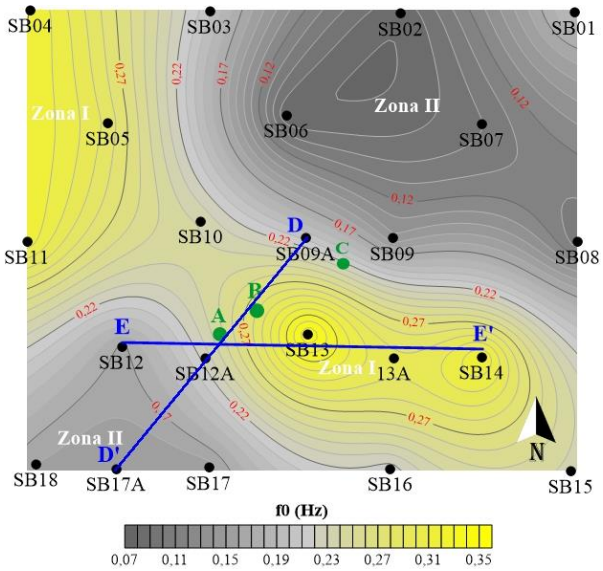

Fig. 6. Contour Map of Dominant Frequency (f0).

The variability of dominant frequency (f0) will impact directly to the thickness of sediment layer. If f0 value decreasing then sediment thickness will increasing, and conversely [12]. At Fig 6, Zone I, the zone with yellow dominated tends to have f0 higher compared to Zone II that dominated with grey. On SB13 which has the highest dominant frequency, the sediment thickness was found to be 286.28 m by using equation (2) with V_s value is 401.72 m/s according to USGS data.

Table 2. Result of Acoustic Impedance (Z) Value Analysis.

Point Name	Elevation (m)	V_p (m/s)	ρ (kg/m^3)	Z (kg/m^{2}s)
SB09A	662	477.6382	1400.044	668,714.7
SB12A	674	3593.513	1198.325	4,306,197
SB17A	680	249.1254	1213.466	302,305.3
SB12	653	2368.91	1148.08	2,719,697
SB13	672	1024.32	1221.881	1,251,598
SB13A	684	2450.635	1401.914	3,435,580
SB14	690	2155.278	1206.352	2,600,023

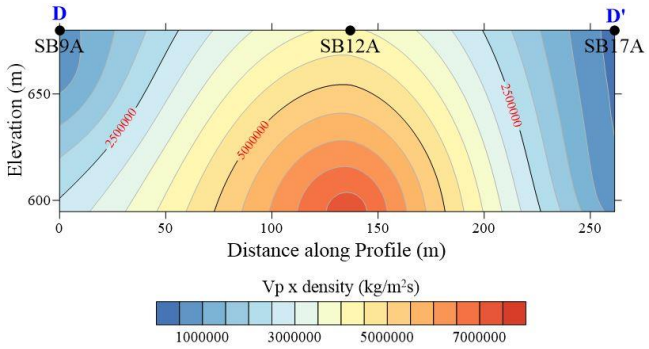

Fig. 7. Crossplot Acoustic Impedance (Z) from D-D'

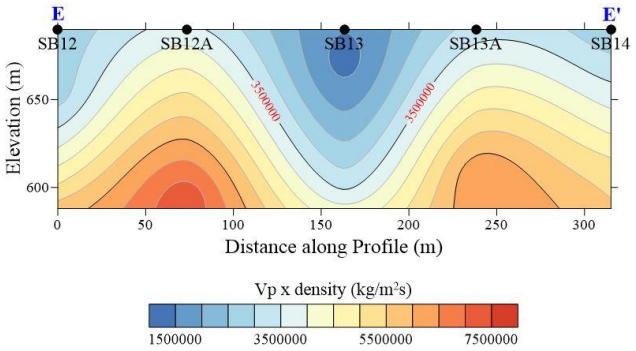

Fig. 8. Crossplot Acoustic Impedance (Z) from E-E'

After crossplot was done for $V_p \times \rho$ from SB09A to SB17A by drawing a line from D to D' and crossing three seepages points (Fig 6.), the highest Z value was found on point SB12A. SB09A is a measurement point that very close to the seepages and also has Z value lower than SB12A (Fig 7.).

If seen by forward, the crossplot at fifth point (SB12, SB12A, SB13, SB13A, and SB14) by drawing a line E–E', the lowest Z value was found and it is located to SB13. According to Horsfall (2018), compactions of the rock depends on Acoustic Impedance (Z). If compactions of the rock has a high value, then porosity will be opposite. According to this law, SB13 has a low compactions but porosity is higher than SB12A and 13A.

5 Conclusion

According to HVSR curve analysis, at research site crossplot has been did around oil seepage points by crossing Zone I which showed dominant frequency with range of 0.20-0.35 Hz and Zone II has low dominant frequency in range of 0.08-0.19 Hz.

SB13 separates a correlation between SB12A and SB13A against acoustic impedance (Z) value. This separation gives a hypothesis, there is fractures in subsurface caused Z value is low and impact to porosity. This fractures predicted to be a migration of oil seepage with starts from SB09A which has lower Z value and closer to point C with oil seepage really showed, and it is predicted towards to SB13.

The highest $V_p \times \rho$ is showed in SB12A with 4,306,197 kg/m^{2}s and SB09A has acoustic impedance value 668,714.7 kg/m^{2}s, although SB17A has the lowest acoustic impedance however it has a great distance from seepage and not convince to be a migration path.

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