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Identifiction Of Oil-Gas Contact Using Radial Derivative Of 4D Gravity Anomaly

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Abstract: *Radial derivatives is horizontal derivatives of gravity anomaly along radial directions from a point wich selected as a centre of gravity anomaly. The second radial derivatives is derivatives of radial deriatives or the twice treatment of radial derivatives. The Time Lapse micro-gravity also known as 4D microgravity has long been developed and applied for various purposes related to the dynamics change beneath the earth's surface. The principle of this method is a repeated and periodic measurement to determine the change in gravity value at that time interval as a result of the dynamics changes in the density distribution of the subsurface. Time lapse microgravity or 4D microgravity can be used for monitoring and identify gas injections in oil reservoirs. Mass density changes due to gas injection provide changes in the response of gravity values over time. This respons change over time allows us to identify the dynamics of gas movement in the reservoir. In this research, a reservoir model has been made with gas injected in reservoir bulk. The time lapse gravity respons value is calculated numerically. Oil-gas contact is a boundary between gas injection front with oil wich move away from injection point. The first and second radial derivatives of the 4D gravity response can provide both the gas and oil as a front of the gas movement in the reservoir. Radial derivatives value of the model response have value range of 20 microGals/m while second radial derivatives has a range of values 0.05microGals/m^2. Curves of absolute value of radial derivatives and second radial derivatives of 4D gravity anomaly graphically correlated with the oil-gas contact of reservoir models. Radial derivatives and second radial derivatives has been proven as new method that can easily shows a boundary of a layer with vertical density contrast.*

Keywords*: Radial derivatives, reservoir, gas injection.*

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I. Introduction

Gravity method is a reliable method for exploration, and very cheap compared with Seismic methods. Gravity data is also used as a binder on data from seismic methods. Gravity methods are also used in mineral exploration to clarify the information already obtained from electromagnetic methods. The gravity method is also sometimes used for engineering and archaeological purposes [1]. Gravity method is the first geophysical method used for petroleum exploration [2]. Gravity Interpretation is an attempt to obtain the mass distribution of a gravity data present on a plane. Gravity Interpretation is actually an inverse procces of field theory, because the known value is its potential while the source is something to know [3].

The 4D micro-gravity method or also known as time lapse microgravity is the development of gravity method with the fourth dimension is time. This method is characterized by repeatable measurements either daily, weekly, monthly or yearly using very high-accuracy gravity measurements supported by positioning and height measurements with highly accuracy as well. The advantages of this method are relatively simple and environmentally friendly operations [4].

The world's oil demand is always increasing over time, while oil availability is running low. Efforts to meet the oil needs are done by exploring new oil resources and optimizing the oil reservoir that has been produced. One way to increase production is to inject fluids into the reservoir. This fluid will move away from the injection well and push the oil toward the production well.

In the fluid injection process, the density change of the bulk due to injection produce 4D micro gravity. The 4D anomaly is negative because the injection fluid is smaller than the initial fluid in pore.

Gas injection in the form of water vapor in the reservoir through oil wells can increase production in the surrounding wells, assuming the gas will push the oil toward the production well with radial and uniform direction. This drive will result in the accumulation of oil in the production well. The injection process should be monitored so that the injection fluid movement not directly towards the production well wich will result production cessation.

II. Basic Theory

The 4D gravity method has been widely used for the identification and monitoring of subsurface changes. Eiken et al, using inter-regional micro gravity, to monitor gas production in subsea reservoirs with gravimeter sensitivity up to 4 microgals. The confidence level of measurement results is at 80% [5]. Gettings et al. (2002), measured the value of 4D micro gravity around geothermal geysers sources to detect subsidence due to mass changes during production period with a 2 ± 2microGal and 4D anomaly rate of 10 ± 8 microGal [6]. Akasaka and Nakanishi (2000) separated the gravity anomaly of geothermal sources from the effect of groundwater change by correlating from drill data and rainfall data [7]. Rahman et al. (2007) succeeded in monitoring fluid injection in reservoirs in South Sumatra using the 4D gravity method [8]. Dafis et al. (2008), measured 4D gravity anomalies to monitor the rate of water injection in artificial aquifer storage and recovery (ASR) aquifers in Leyden Colorado. This method proved successful even to detect the movement of water in the aquiver [9]. Sarkowi (2008) examines the relationship between ground water changes with changes in the value of vertical gravity gradient in the city of Semarang and surrounding areas. The results of this study indicate that the decrease in ground water level will result in a decrease in the value of vertical gravity gradient [10]. Zuhdi and Sismanto have been made a reservoir model and its horizontal derivative treatment [11].

In this research, 4D micro gravity method will be used to detect the movement of gas fluid in reservoir with new method i.e radial derivative and near zero anomaly. Oil-gas contact as a front of gas movement will be identified by radial derivatives and second radial derivatives.

Gas injection in the reservoir will decrease bulk density because oil and water replaced by a gas with a lower mass density, so that this density change gives a response of a negative gravity anomaly change. On the other hand, ground water change also has a great possitive value effect on the measured 4D gravity anomaly. This study was limited to identifying the contact between the injection fluid (gas) and the initial fluid in pore i.e oil.

The effort is to applicate radial derivatives which aims to obtain vertical boundary contrast density due to injection with near zero anomaly.

A three dimensional mass of any geometric shape with mass density distributed continuously, the gravity potential at the point P (x, y, z) above and outside the mass density distribution is given by:

$$U(x,y,z) = G\int\int\int \frac{\Delta\rho(\alpha,\beta,\gamma)}{\left[(x-\alpha)^2+(y-\beta)^2+(z-\gamma)^2\right]^{1/2}}\, d\alpha.d\beta.d\gamma \qquad 1$$

The vertical and horizontal force components due to the above mass density distribution are obtained by differentiating equation (1) to x, y, and z, whose results are:

$$\Delta g_x(x,y,z) = -G\int_0^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{\Delta\rho(\alpha,\beta,\gamma)(x-\alpha)}{\left[(x-\alpha)^2+(y-\beta)^2+(z-\gamma)^2\right]^{3/2}}\, d\alpha.d\beta.d\gamma \qquad 2$$

$$\Delta g_y(x,y,z) = -G\int_0^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{\Delta\rho(\alpha,\beta,\gamma)(y-\beta)}{\left[(x-\alpha)^2+(y-\beta)^2+(z-\gamma)^2\right]^{3/2}}\, d\alpha.d\beta.d\gamma \qquad 3$$

$$\Delta g_z(x,y,z) = -G\int_0^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{\Delta\rho(\alpha,\beta,\gamma)(z-\gamma)}{\left[(x-\alpha)^2+(y-\beta)^2+(z-\gamma)^2\right]^{3/2}}\, d\alpha.d\beta.d\gamma \qquad 4$$

From equation (4) it appears that the acceleration of gravity g on the surface of the earth varies and its values depends on the distribution of the mass below the surface which is controlled by the shape of geometry (structure) and the density.

The gravity field g is also called the acceleration of gravity, the unit in Gall (1 Gall = cm / s2). A 3-dimensional object with a mass density distribution Δρ = (α,β,γ), gives gravity effect at point P (x, y, z) on the surface within a certain time interval (Δt) given by Kadir (1996)[12]:

$$\Delta g(x,y,z,\Delta t) = -G\int_0^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{\Delta\rho(\alpha,\beta,\gamma,\Delta t)(z-\gamma)}{\left[(x-\alpha)^2+(y-\beta)^2+(z-\gamma)^2\right]^{3/2}}\, d\alpha.d\beta.d\gamma \qquad 5$$

From the equations above, the gravity change due to the change of mass density for the prism geometry, the anomaly is given by the equation:

$\Delta g(x,y,z,\Delta t) \cong \Delta\rho\,(\Delta t).K(x-\alpha,y-\beta,z-\gamma,a,b,c)$ 6

where K is a Green function of anomalies on the surface due to density changes $\Delta\rho$ with, whereas:

$\Delta g(x,y,z,\Delta t)=g(x,y,z,t')-g(x,y,z,t)$ 7

this gravity anomaly is directly related to mass density changes as a result of material changes due to sub-surface dynamics.

Radial Derivatives

Radial derivatives is horizontal derivatives of gravity anomaly along radial directions from a point wich selected as a centre of gravity anomaly. Radial derivatives is a better way than usual horizontal derivatives because its allow us to get maximum value for circle body source anomaly. The second radial derivatives is derivatives of radial deriatives or the twice treatment of radial derivatives.

Radial derivatives can be approached by subtracting each point of measurement towards a particular direction. From figure 1, the derivative toward the *X* axis is obtained by subtracting the gravity value of the measurement at point *X2* to the gravity value at *X1* and then dividing by the distance *X2* to *X1*. To derive the value of the derivative toward the *Y* axis is obtained by subtracting the gravity value of the measurement at point *Y2* to the gravity value at point *Y1* then in the same way divided by the distance *Y2* to *Y1*.

In many cases, it takes a derivative not only on the x or y axis but in a particular direction, often called directional derivatives.

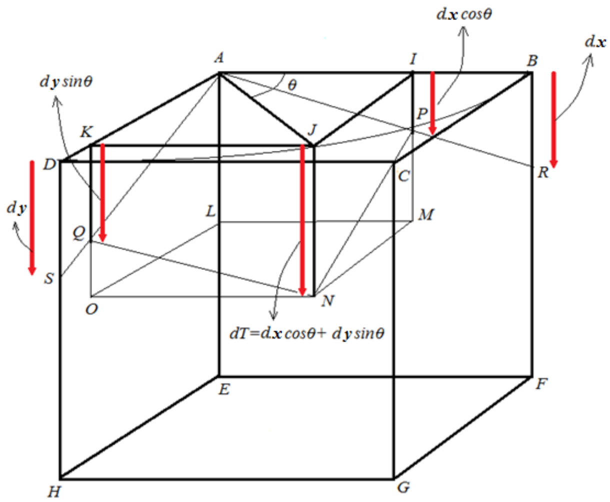


Figure 1. Aproaching of radial derivative.

Figure 1. shows the field diagram used to calculate the radial derivative. *ABCD*, *EFGH* is a cube with length of *AB* which is also the same as length of *AJ*. Points *A*, *B*, *C* and *D* are stations of gravity measurement. *A* to *B* is the line towards the x-axis while *A* to *D* is towards the y-axis.

If the value difference of gravity at point *B* and *A* is *dx* whose vector length is proportional to *BR*, whereas the value difference of point *A* with *D* is the length of the vector along the *DS*, the *APNQ* plane become a plane with the same gravity value. If *dT* is the value of the directional derivative, then:

$dT = JN= IP +KQ$ 8

with *dT* having a vector length equal to JN whose value is equal to the number of *IP* and *KQ*.

IP length can be described as follows:

$$\frac{IP}{BR}=\frac{AI}{AB}=\frac{AB\cos\theta}{AB}=\cos\theta$$

with *BR* = *dx*, so:

$IP = dx\cos\theta$

With the same way, length of *KQ* is:

$$\frac{KQ}{DS}=\frac{DA}{KA}=\frac{KA\sin\theta}{KA}=\sin\theta$$

when *KQ* = *dy*, so:

$KQ = dy\sin\theta$

Substituting in the equation 8 then we find:

$dT = dx\cos\theta + dy\sin\theta$ 9

III. Research Method

This research is application of laboratory scale model with model parameter adjusted to real field possible value. This study aims to determine the gravity anomaly response between time from gas injection to the reservoir and changes in water table changes.

The model is made with model variables based on real value in the field: reservoir depth, water table depth, rock porosity around water table, oil saturation, reservoir rock porosity, gas density, oil density and injection gas density.

The area used in this model is 680 hectares with a square shape with the length of its sides of 2.6 km. The grid interval used is 10m, so the model response is a 261 x 261 square matrix.

The model response is formed by the gravitational convolution with numerical program with a 3-dimensional view. In the response then selected cross section representing the area through which the most important anomaly. In the cross section is then performed radial derivatives and second radial derivatives. The results of this derivative will be used for more in reservoir injection analysis.

In the gravity anomaly respons then selected cross section representing the area through which the most important anomaly. In the cross section is then performed radial derivatives and second radial derivatives. The results of this derivatives will be used for further analysis of gas injection in the reservoir.

IV. Result And Discusson

For aviability and reasonability, the model is made with model variables based on real value in the field i.e: reservoir depth, water table depth, rock porosity around water table, oil saturation, reservoir rock porosity, gas density, oil density and density of injected gas.

The reasonable reservoir depth is chosen at 300 meters, the initial water table depth is 15 meters, reservoir rock porosity 30%, rock porosity around water table is 20%, oil saturation is 50%, density water filling the pore is 1 g/cc, density of oil in the reservoir bulk is 0.8 g/cc and the gas density is injected in the bulk is 0 g / cc. The area of the model is chosen so that in gravity value at the edges of the model is less than 10 percent of maximum gravity value in the centre of model. The area used in this model is 680 hectares with a rectangular shape with a length of each sides is 2.61 km. This area is reasonable for gravity anomaly depth to about 1km. The grid interval used is 10 m, the first grid at 0 m and the last grid at 2610 m. From the grid sizes mentioned above, the model response is in the form of square matrix with 261 raws and 261 columns.

Respons of Model

The model of water table change is a 3 meter high increasing of water table in form of two circles with a diameter of 150 meters each with distance of each center of the 6.5 km circle. The gas injection in the reservoir at a depth of 300 meters with a gas injection volume of 3,600,000 m3.

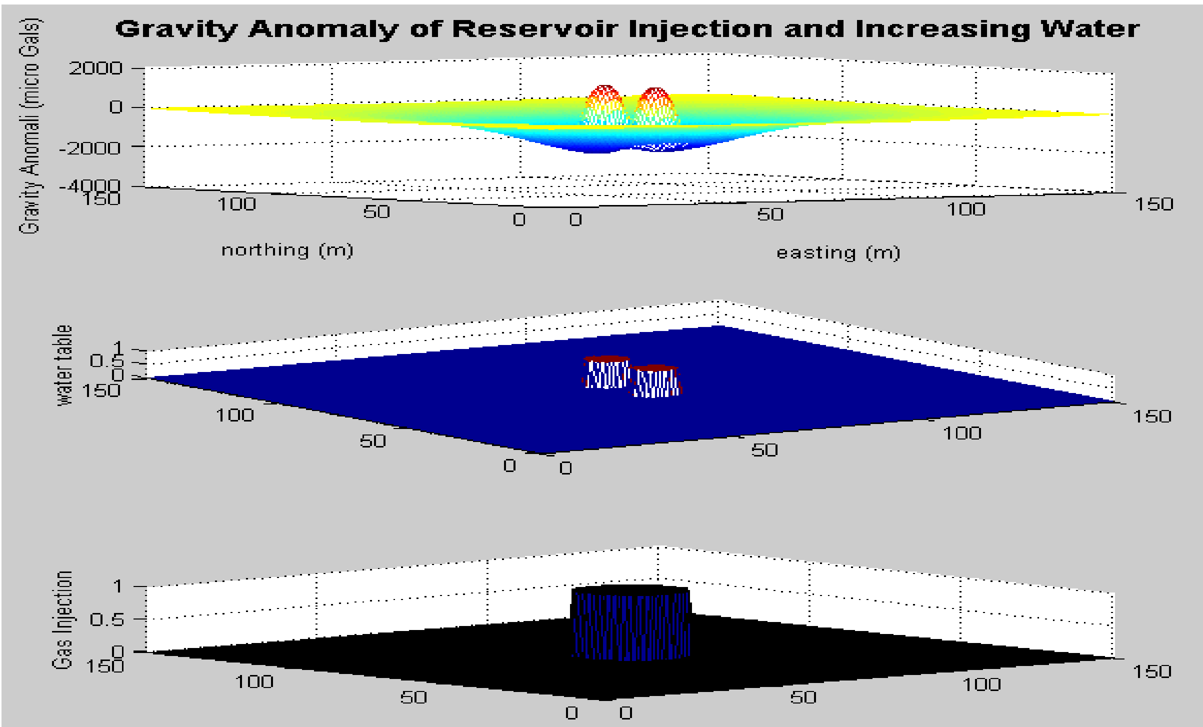


Figure 2. Water table increasement, gas injection and its gravity response

The model of water table change is based on the assumption that the previous fluid filling rock around the water table is air with a density of 0 g / cc then be replaced by water with a density of 1 g / cc. The porosity of the rock around the water table is 0.3. Mass change in the reservoir is due to fluid replacement (oil and water) with a density of 0.9 g / cc to a gas with a density of 0 g / cc. The maximum 4D gravity anomaly around the centre of the model response has values up to 55 micro Gal and at least -77 micro Gal.Anomali gravity 4D from response model 3 has a range of -770 micro Gals to 570 micro Gals. The largest anomaly on this model is right in the middle of the water table circle reaching maximum value 570 micro Gals. The anomaly response at the edge of the matrix is only 2 micro Gals. Figure 2 shows the gas injection in model reservoir and total 4D gravity anomaly response due to the gas injection and water table increasement.

Line AB is cross section of the model wich is made to show the gravity anomaly response in 2 dimension. On the line of AB, horizontal derivative treatment is made to assist two dimension analysis.

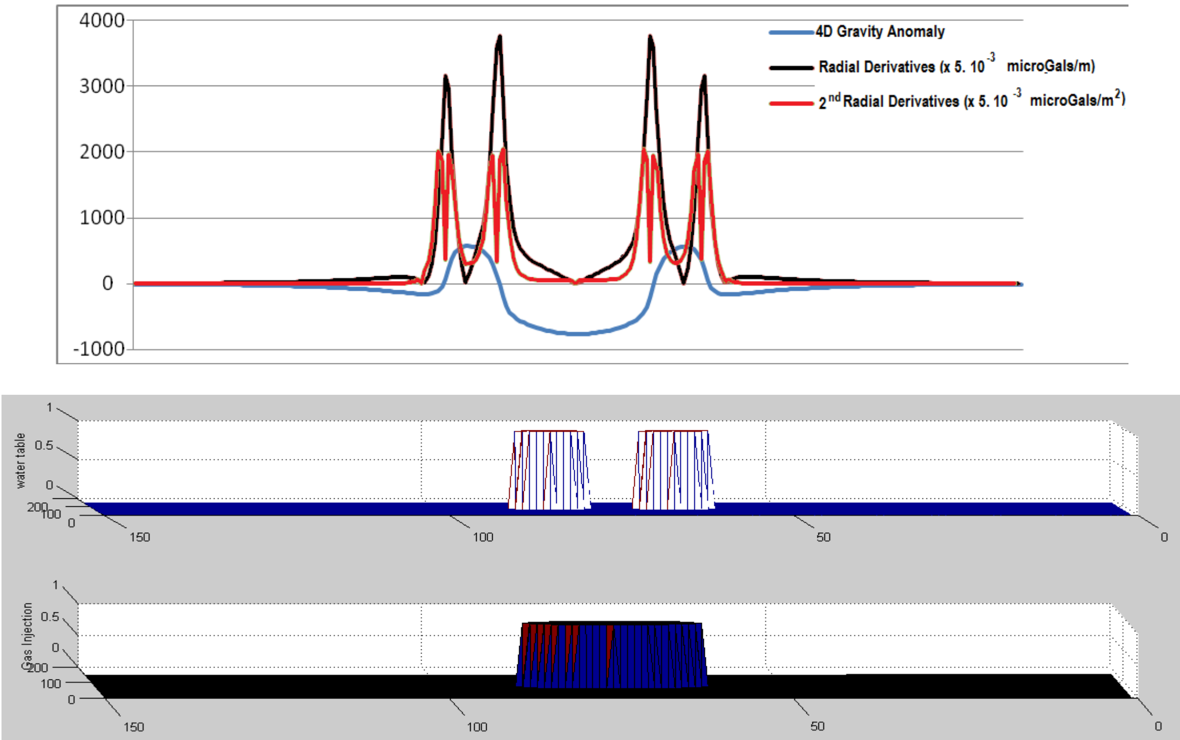
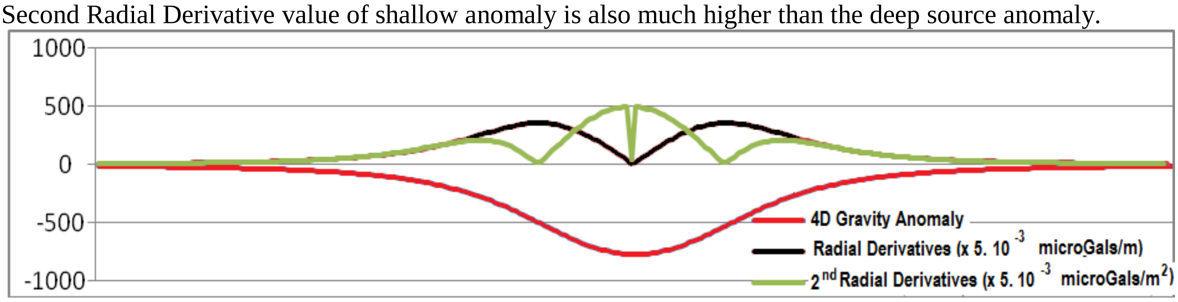


Figure 3. Time lapse gravity respon, its absolute radial derivatives and the second radial derivatives of AB cross section due to gas injection and water water table increasement.

At the cross section AB, it appears that the maximum time lapse gravity value is 57 micro Gals. This value is indicated by the blue line on the graph. The radial derivative of the response indicates the slope of the model response, the first radial derivative value shown by the black line while the second radial derivative value is represented by the red line. The maximum value of the first derivative is 19 micro gal / meter while the maximum value of the second derivative is 100 micro gal / meter^2.

Absolute Horizontal Derivative

The radial derivative of the 4D microgravity anomaly is the slope of the gravity anomaly. For the shallow source the radial derivative value is much greater than the radial derivative value for the deep source, although the anomaly value of both represents almost the same value. As the radial derivative value, the Second Radial Derivative value of shallow anomaly is also much higher than the deep source anomaly.



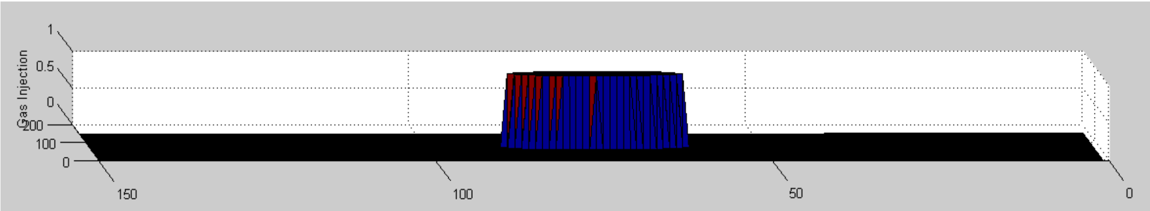


Figure 4. Time lapse gravity respon, absolute value of radial derivative and second radial derivative due to gas injection in reservoir.

Graphically the absolute radial derivative curve and the absolute second radial derivative curve is available to find the vertical boundary anomaly. This is because of the symmetry of the curve. There are very good correlation between anomaly sources with curves.

The near zero values of absolute radial derivative curve on the graph is very clear indicating the anomaly source center while the peak corresponds to the anomaly source boundaries. The absolute second radial derivative curve clearly shows the symmetry center directly related to the anomaly source center whereas the vertical boundaries of the anomaly source are represented by the zero value (sharp change) of the curve.

Radial derivative generally can be a new method for interpretate either timelapse or conventional gravity anomaly, without any other additional field data. This method is available for identification of any single layer anomaly source with lateral difference density. So the radial derivative is not merely for timelapse microgravity, but also availabe to conventional gravity anomaly analysis.

V. Conclusion

The 4D gravity anomaly response of model due to gas injection and increase of water table has the same order range as hundreds of micro Gals. The values of radial derivative and second radial derivative for both models are very much different. This indicates that the FHD and SHD values can display the source depth characteristics.

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