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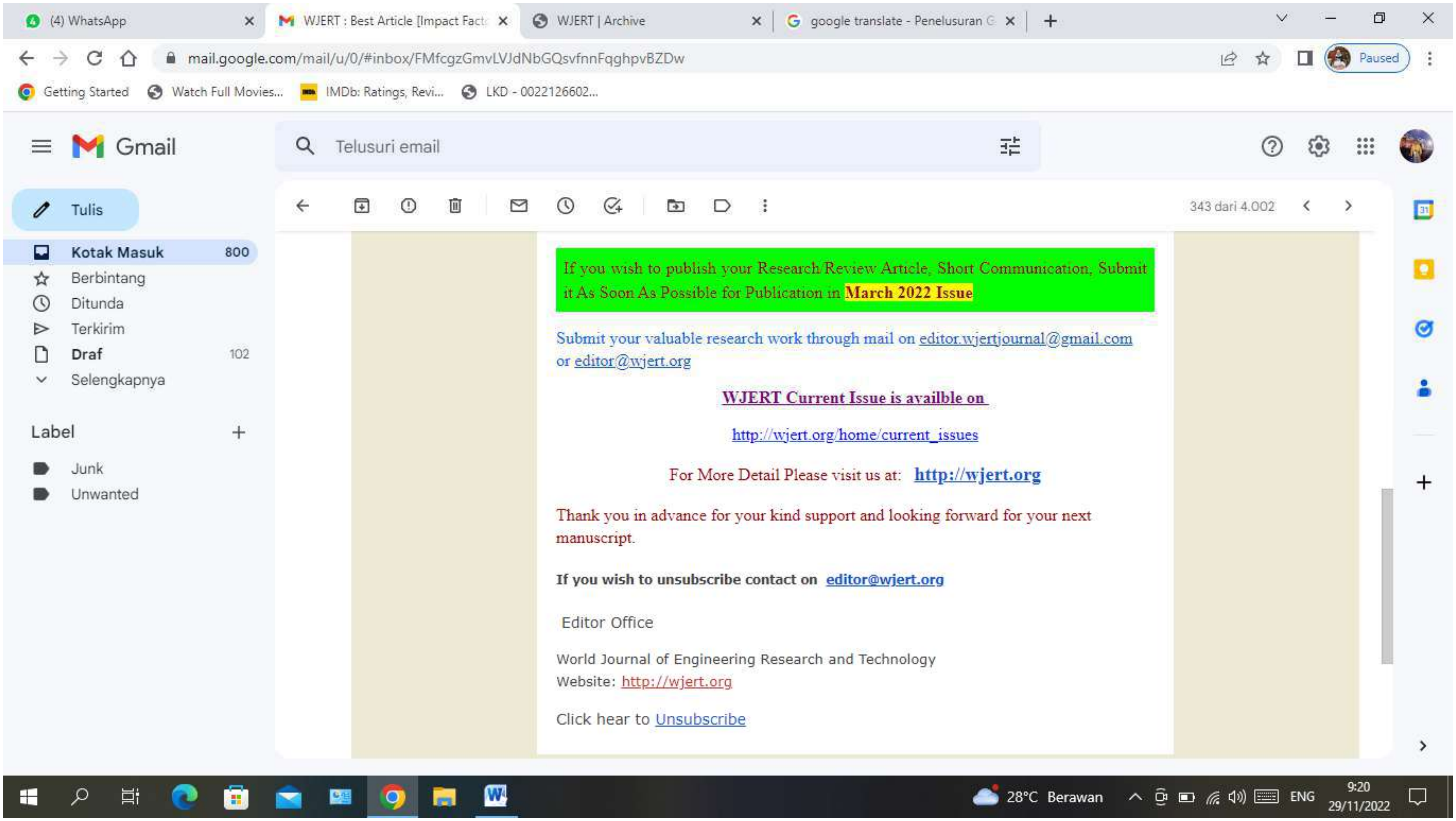
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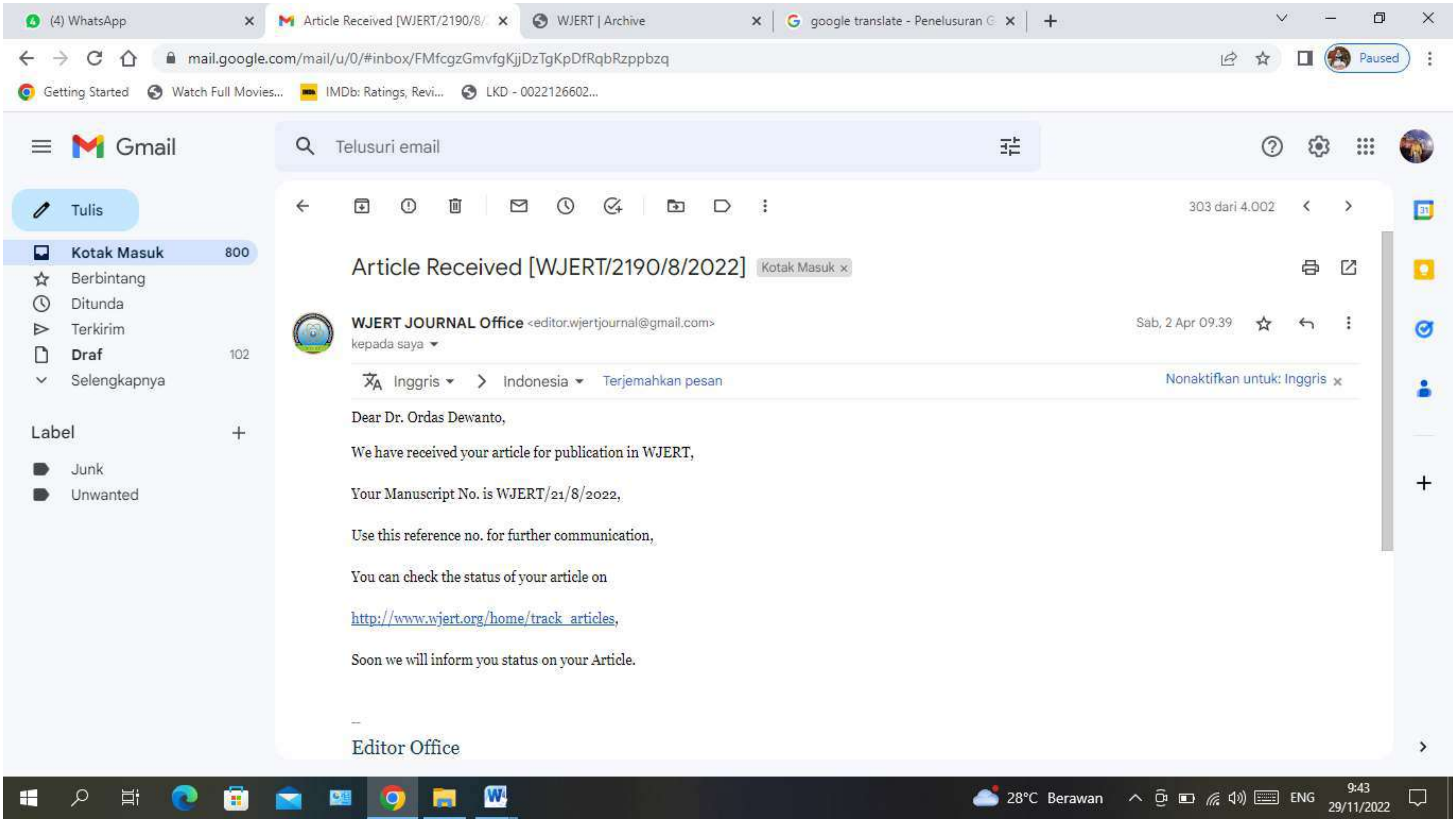
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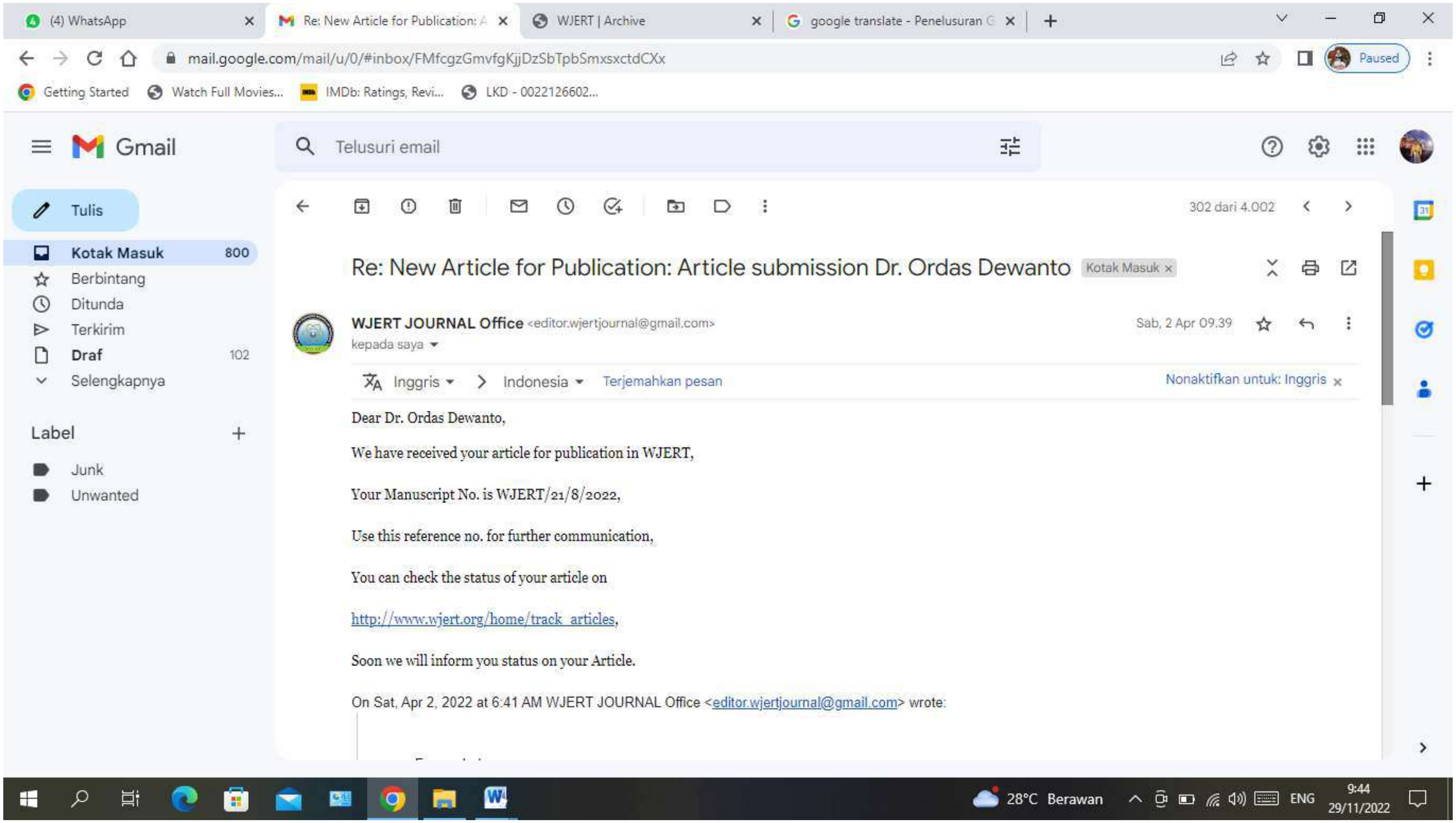

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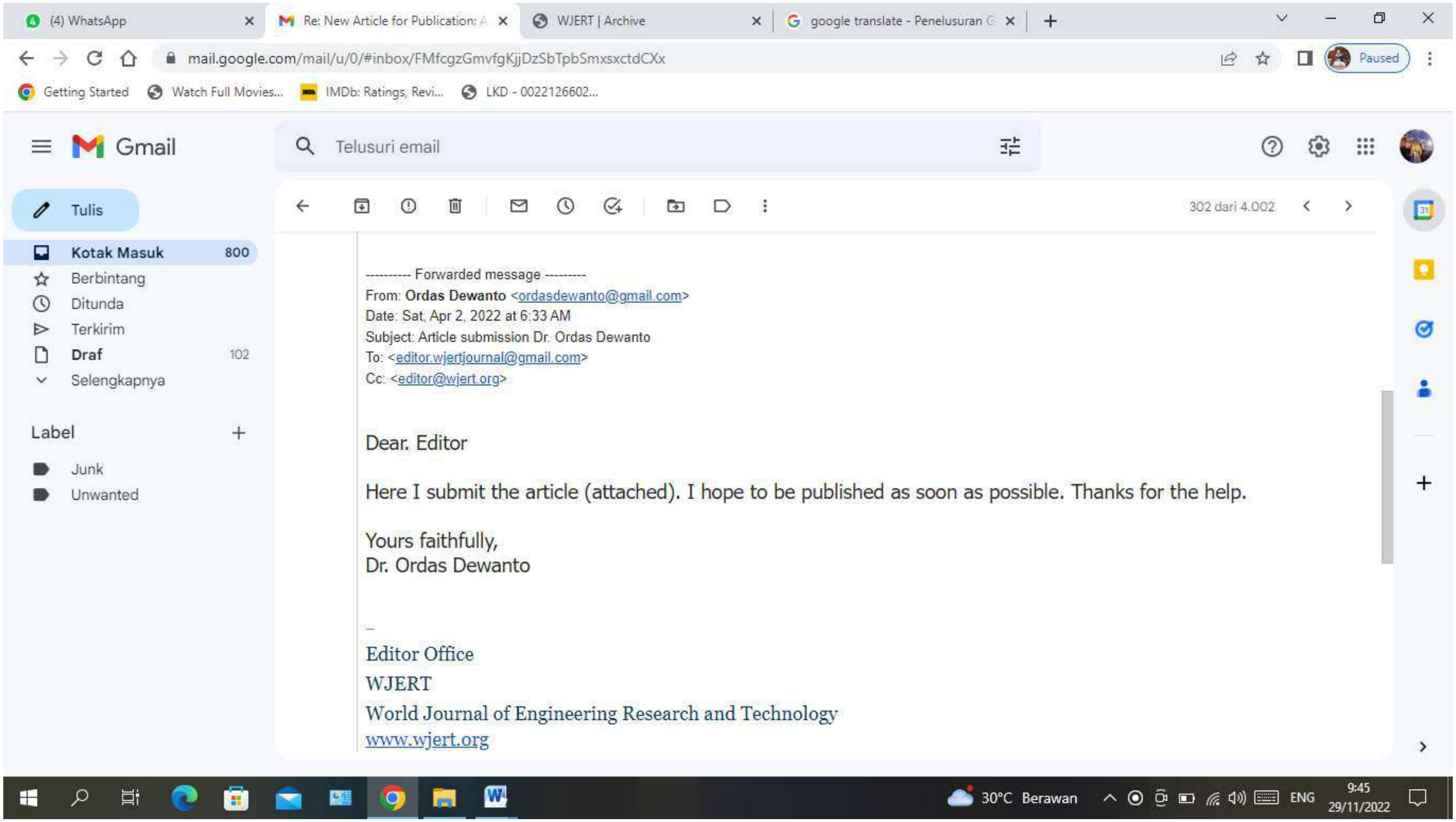

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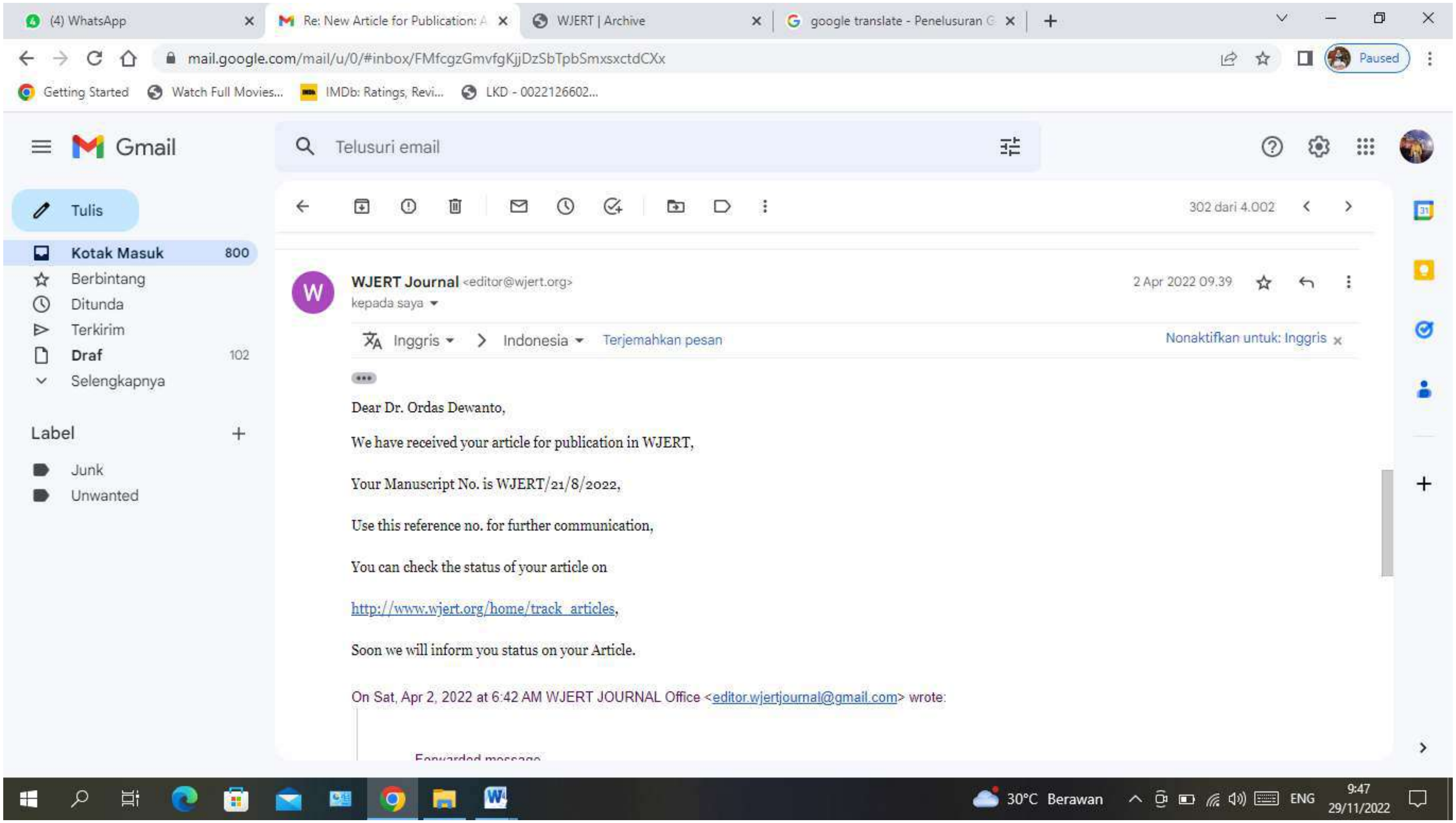

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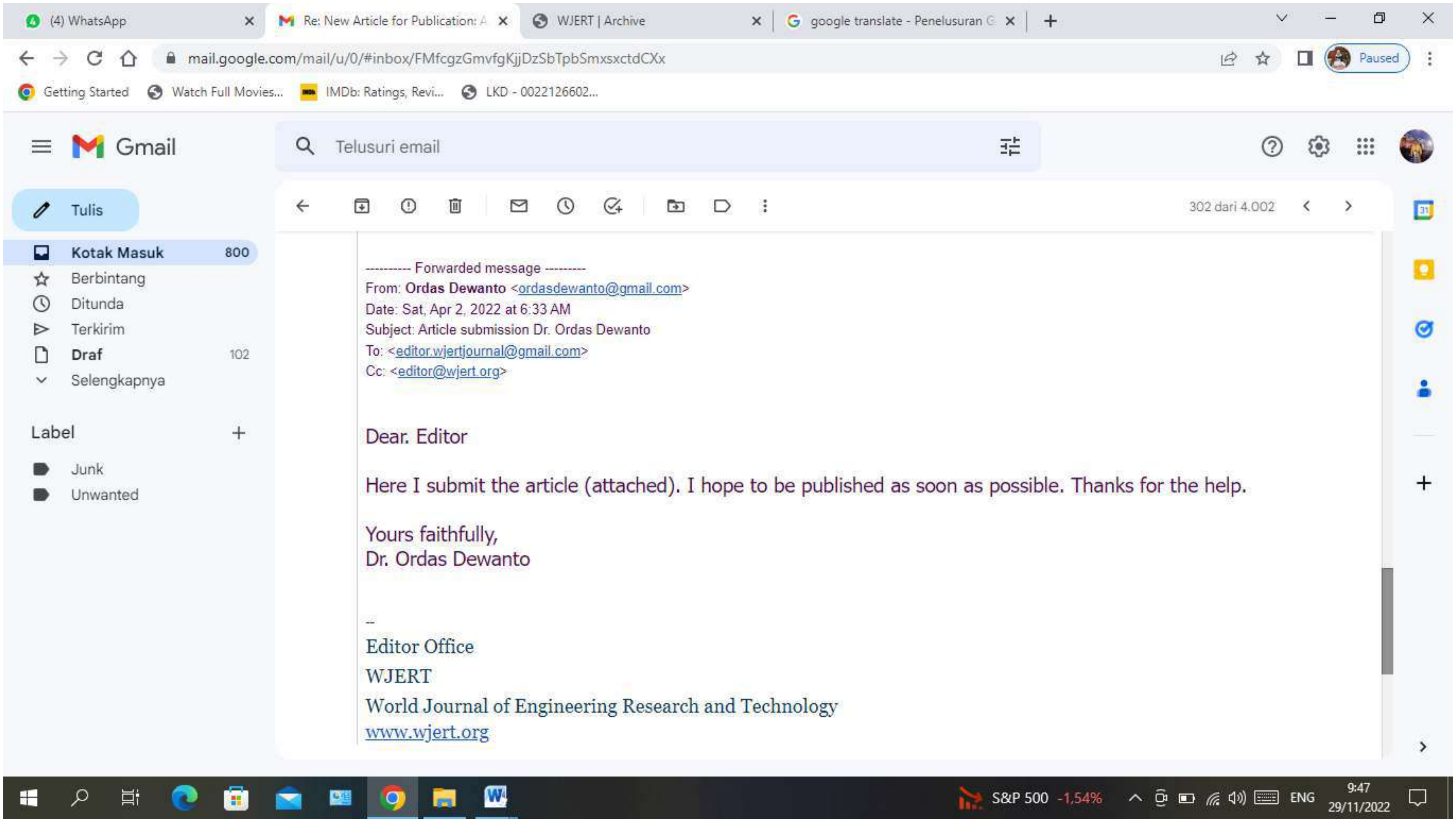

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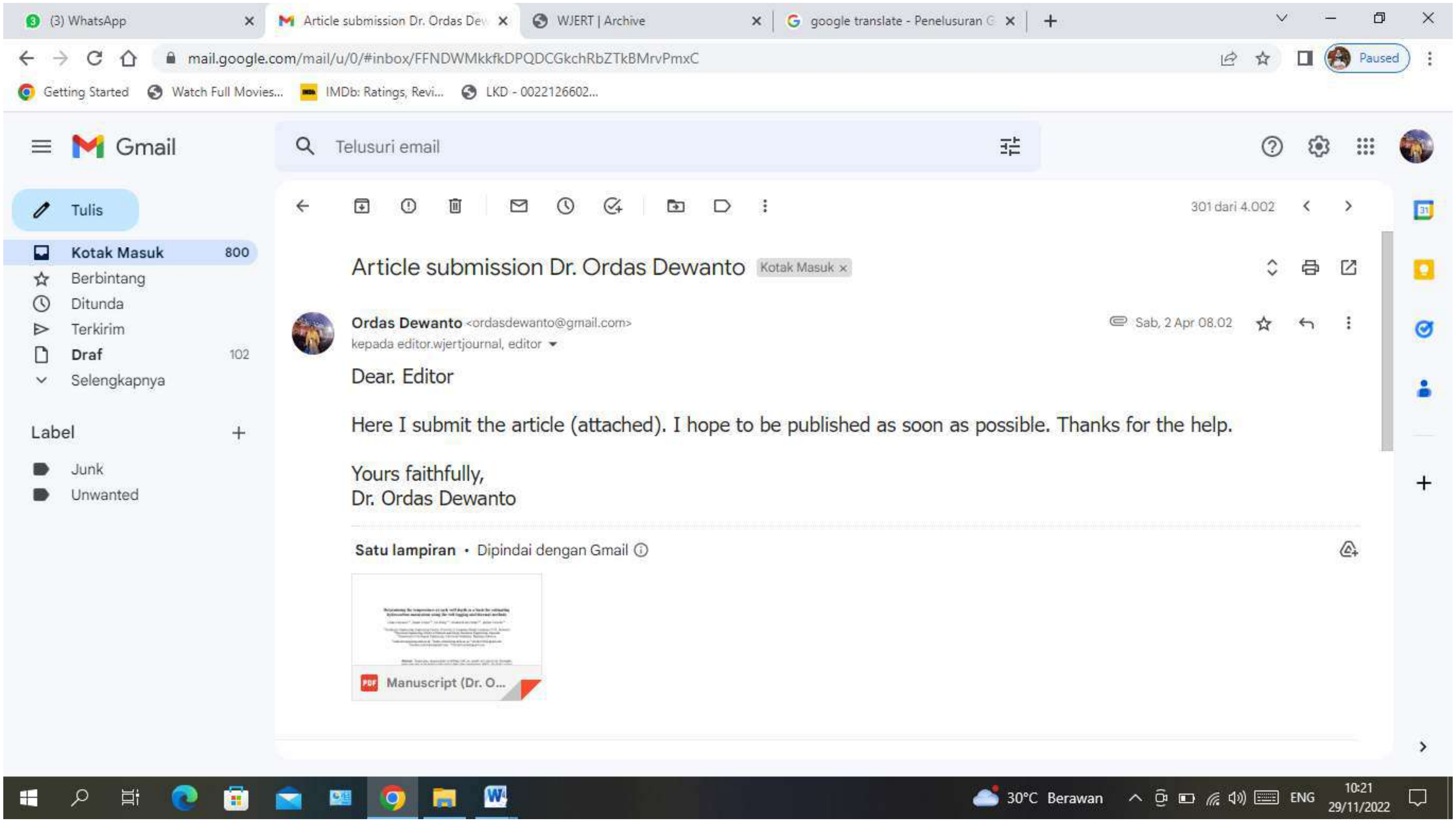
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Determining the temperature at each well depth as a basis for estimating hydrocarbon maturation using the well logging and thermal methods

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Abstract. Temperature measurements at drilling wells are usually not carried out thoroughly, some even only at the bottom of the well or Bore Hole Temperature (BHT). The Well Logging and thermal methods are used to determine the temperature at each depth, provided that the surface temperature and BHT of the well are available. The principle of the method is to determine the change in depth for each increase in temperature of $10^{O}C$ or $5^{O}C$. By developing the basic concept of geothermal flow it can be seen that changes in depth at each increase in temperature of $10^{O}C$, so that we can know the temperature value at each depth of the well. In well A, the temperature in the depth of 502-629m is $60^{O}C$-$70^{O}C$ with immature organic substances. The temperature in the depth of 1096-1276 m is $90^{O}C$-$100^{O}C$ with mature organic substances. The temperature in the depth of 1595-1699 m is $100^{O}C$-$120^{O}C$ with overmature organic substances. The temperature in the depth of 1780-1964 m is $120^{O}C$-$130^{O}C$ with gas organic substancesIn the process of hydrocarbon maturity, an increase in temperature will convert heavy petroleum into light oil, then become condensate and finally only gas. This is a function of depth and temperature gradient.

Keywords: bore hole temperature, well logging, immature, mature, gas, temperature gradient

INTRODUCTION

Research on the maturation of hydrocarbons in sedimentary basins in Indonesia has generally been successful, with the aim of estimating the level of maturity of organic material in the source rock of the basin. The research studies are very helpful to support the exploration of hydrocarbons (oil and gas). The basis for determining the maturation of hydrocarbons, generally based on the changes in their chemical properties, where analysis of changes in chemical properties is one indicator that is quite accurate. As technology develops and it becomes increasingly difficult to find new reserves of hydrocarbons, geoscience is increasingly developing to overcome these problems. Previous research that used the basic concept of terrestrial heat flow, which was supported by geological data related to geochemical technology, has obtained a fairly accurate result and more clearly understood the problems in exploration activities. This implies the importance of understanding the relationship between the thermal and physical properties of rocks to the level of hydrocarbon maturation (Hanun et al, 2016).

Based on these needs, this study presents research to improve the qualitative and quantitative analysis of log data (Dewanto et al, 2016) in supporting the initial estimates of the occurrence of petroleum and the formation of petroleum.

Core analysis data generated from measurements and analysis of reservoir rocks in the laboratory are much needed information to find out the very specific characteristics of rock physics, which will ultimately be used to predict the performance of reservoir rock.

The heat that flows from the bottom up spreads to the surface of the earth affecting the rock space, so that in each rock room has a different temperature. The temperature in each rock space is different, because of the different porosity and heat conductivity, as well as the difference in hydrostatic pressure from the rock.

Temperature can affect organic substances contained in sediments. An increase in temperature will change heavy petroleum into light petroleum, then condensate and finally only gas. Dewanto et al (2017) research results in the laboratory are that oil shale derived from clay-organic material occurs at a temperature of 300-400^{O}C and for carbonate-organic material occurs at a temperature of 400-500^{O}C. Whereas at temperatures of 900-1000^{O}C both materials produce gas. Temperature values can also be used to determine the depth of oil shale in wells (Mulyanto et al, 2018).

The duration of the formation of petroleum from the release of fat or lipids from kerogen is a temperature-related process, which is exponential and starts at temperatures around 93^{0}C (Klemme, 1972). The value of temperature in a rock pore is one of the important parameters in the process of determining the maturity of organic matter, to predict the maturity of hydrocarbons in sedimentary rocks. Temperature values can help estimate the maturity of organic material in CaCO3 (Dewanto et al, 2019). Moreover, it can also be used as a basis for research relating to geothermal reservoirs in regions containing geothermal energy. Estimated reservoir temperatures are very important to assess the potential for geothermal exploitation (Zhang et al, 2015).

Knowledge about downhole and around the temperature of the wellbore formation is an important factor during drilling operations. It is important to estimate the effect of pressure and temperature on the formation fluid density (Kutasov, 2015). This will enable a more accurate prediction of differential pressure in the lower hole and will help reduce fluid losses resulting from miscalculated pressure differences. Reservoir temperature modeling is carried out to estimate reservoir parameters (Siswoyo, 1995).

In terms of calculating water saturation (Sw) to determine the hydocarbon content in reservoir rocks, it needs the parameter of Rw (formation water). The formation water value (Rw) of each layer can be determined based on temperature. Therefore, determining the temperature at a certain layer depth is very important to calculate the value of Rw (Ushie, 2001). Determination of temperature in the log well is also very useful for determining the maturation level of oil shale in source rock (Mulyanto et al, 2018). Then also to determine the level of hydrocarbon (oil and gas) maturation in source rock (Nopiyanti, 2019 and Maulina, 2019).

In this study, the temperature at each layer will be determined to a certain depth. For example in a drilling well, logging is usually carried out to determine the temperature value at any given depth. This temperature measurement is not done thoroughly on the well. In fact, some are only measured at the bottom of the well (BHT). But with the development of technology, the temperature at each depth can be estimated, with the condition that the well is known for the surface temperature and Bore Hole Temperature (BHT).

One method for estimating the temperature is to determine the change in depth for each 10^{O}C or 5^{O}C rise in temperature. Subono et al (1995) and Dewanto et al (2001), developed the basic concept of geothermal flow to determine changes in depth at each 10^{O}C temperature rise, so that the value of temperature at each depth in the well can be known.

METHOD

The data required are BHT (bore hole temperature), porosity (ϕ), rock heat conductivity (K_B), heat flow (Q), temperature gradient, stratigraphy, rock age.

Data Processing Method

In this research several work stages are carried out, namely:

First Stage, Determination of Lithology, Age and Porosity

The first stage, determine the lithology in each formation of the well and determine the age and sedimentation time of the lithology. Then determine the value of porosity, as a reference base for doing work in the next stage.

Second stage, Calculation of Rock Thermal Conductivity

Rock heat conductivity can be determined by measurement and calculation. Calculation of rock heat conductivity, determined using the following equation:

$$K_B = K_f^{\phi} \times K_s^{(1-\phi)}$$

where, K_B = heat conductivity of the rock
K_f = heat conductivity of the liquid fraction
K_s = heat conductivity of solid fractions
ϕ = porosity

The value of the heat conductivity of the formation (K_F) is determined by calculation based on the value of heat conductivity of rocks and thickness in the formation.

$$K_F = \left[\left(\frac{d_{B1}}{K_{B1}} + \frac{d_{B2}}{K_{B2}} + ...\right) \times \frac{1}{d_{B1} + d_{B2} + ...}\right]^{-1}$$

Where, K_F = heat conductivity of the formation (10^{-3} cgs)
d_{B1} = the thicknessof lithology-1 (m) ;
d_{B2} = the thicknessof lithology-2 (m)
$d_{B1}+d_{B2}$ = formation thickness (m)
K_{B1} = heat conductivity of lithology-1 (10^{-3} cgs)
K_{B2} = heat conductivity of lithology-2 (10^{-3} cgs)

and so on adjusted to the type of lithology. Meanwhile, to calculate the value of heat conductivity wells are used the following formula:

$$K_{SM} = \left[\left(\frac{d_{FA}}{K_{FA}} + \frac{d_{FB}}{K_{FB}} + ... + \frac{d_{FN}}{K_{FN}}\right) \times \frac{1}{DA}\right]^{-1}$$

where, K_{SM} = heat conductivity calculated from the deepest well up to the surface (10^{-3} cgs)
d_{FA},d_{FB},d_{FN} = formation thickness A, B s/d N (m or cm)
DA = total depth

Third stage, Calculating Temperature Gradients

Temperature gradients are determined according to the equation: $GT = \frac{BHTc - Tp}{DA} \times 100$

where, GT = temperature gradient (^{O}C/100m)
BHTc = temperature corrected at DA (^{O}C)
Tp = average temperature on the surface
DA = total depth (m)

In this case the temperature gradient of each formation is also calculated, using the following equation:

$$GT_F = \frac{Q}{K_F}$$ (Subono, S. dan Siswoyo, 1995)

where, GT_F = formation temperature gradient (^{O}C/100m)
Q = geothermal flow, ($\times 10^{-6}$ cal cm^{-2}s^{-1})

K_F = heat conductivity of the formation ($\times 10^{-3}$ cal cm^{-1} det^{-1} $^{O}C^{-1}$)

Fourth stage, Determination of Heat Flow

After obtaining the value of heat conductivity and temperature gradient as mentioned above, then determine the value of heat flow (heat flow) at the well. Calculated using the formula according to the equation as follows:

$$Q = K\frac{dT}{dZ}$$

$$\Leftrightarrow \quad Q = (K_f^{\phi} \times K_s^{(1-\phi)}) \times GT \quad \Leftrightarrow \quad Q = K_F \times GT$$

$$\Leftrightarrow \quad Q = \left[\left(\frac{d_{FA}}{K_{FA}} + \frac{d_{FB}}{K_{FB}} + ... + \frac{d_{FN}}{K_{FN}}\right) \times \frac{1}{DA}\right]^{-1} \times GT$$

$$\Leftrightarrow \quad Q = K_{SM} \times GT$$

where, Q = geothermal flow, HFU or µcal/cm^{2}s, or *m*W/m^2
K_{SM} = heat conductivity, 10^{-3} cal cm^{-1} dt^{-1} $^{O}C^{-1}$ or W/m^{O}C
dT/dZ = temperature gradient, ^{O}C/100m (GT)
1 HFU = 10^{-6} kal cm^{-2} dt^{-1}

The method for estimating the temperature is to determine the change in depth for each 10^{O}C or 5^{O}C rise in temperature. Determination of temperature in well A, the temperature value will be determined by calculation. By knowing the change in depth at every 10^{O}C temperature rise, the value of the temperatur can be estimated. Basic formula used: $\Delta Z = \frac{10^{O}C}{GT_{KF}} \Rightarrow GT_{KF} = \frac{Q(t)}{K_{KF}}$

where, ΔZ : depth change (m)
Q : heat flow (HFU)
GT_{KF} : temperature gradient of the formation group (^{O}C/100m)
K_{KF} : heat conductivity of rock formation groups (mks)

By doing calculations to determine the change in depth of each 10^{O}C temperature rise, a model of the value of each depth will be obtained.

RESULTS AND DISCUSSION

In this study using the thermal method. Well A has a total depth of 6443.4 ft (1963.9 m) located in the Central Sumatra Basin. The data needed for data processing in this study are stratigraphic data and rock heat conductivity data (Table 1), temperature gradient data and BHT (Table 2), and porosity data (log data). Heat Flow is the flow of heat that comes from inside the earth to flow to the surface through a space / rock material. Because the nature and density or compactness of rocks differ, the value of heat flow (Q) for each well in an area also varies besides that there must be the same. The difference in the value of heat flow, in addition to the difference in temperature gradient is also influenced by the conductivity of rock heat (K_B) on the rock. Rock heat conductivity can be determined from measurements of rock samples (cores) directly in the laboratory. Moreover, it can also be determined by calculation based on the value of the porosity of the rock. Researchers determine the value of rock heat conductivity (K_B) by direct measurement.

Table 1. Stratigraphic Data and Heat Conductivity of Well Rocks A

FORMATION		AGE (million years)		LITOLOGY	DEPTH (m)	ROCK CONDUCTIVITY (cal/cm dt ^{O}C)
MINAS		*0*		sand	0 - 55	4.25
			1.6	shale	55 - 90	4.00
				sand	90 - 130	4.25
		1.6		shale	130 - 170	4.00
PETANI		*3*	11	shale	170 - 284	4.26
TELISA		*14*	3	shale	284 - 678	4.41
				sand	678 - 698	4.99
SIHAPAS	Upper	*17*	1	sand	698 - 738	5.32
				shale	738 - 778	4.64
	Lower	*18*		sand	778 - 803	5.52
				shale	803 - 828	4.87
				sand	828 - 853	5.52
			3	shale	853 - 883	4.87
				sand	883 - 908	5.52
				shale	908 - 933	4.87
		21		sand	933 - 969	5.52
PEMATANG GROUP	Pmt. SS	*22.5*		sand	969 - 1009	6.36
				shale	1009 - 1029	5.81
				sand	1029 -1069	6.38
				shale	1069 - 1089	5.81
				sand	1089 - 1131	6.63
				shale	1131 - 1151	5.81
			6.7	sand	1151 - 1211	6.65
				shale	1211 - 1231	6.00
				sand	1231 - 1291	7.55
				shale	1291 - 1311	6.00
				sand	1311 - 1391	7.97
				shale	1391 - 1411	6.00
				sand	1411 - 1457	8.40
	Pmt. MS	*29.2*	4.2	shale	1457 - 1719	6.81
	BRSH	*33.4*	1.3	coal	1719 - 1780	6.80
	LP	*34.7*		shale	1780 - 1815	6.81
			1.3	sand	1815 - 1840	8.83
				shale	1840 - 1880	7.17
BASEMENT		*36*		Quarzt	1880 - 1964	7.59

Table 2. Well BHT Data and Temperature Gradient A

A WELL	Depth (ft)	Depth (m)	Depth (cm)	Temperature (^{O}F)	(^{O}C)	Temperature Gradient (^{O}C/100cm)	(^{O}C/100m)
Total Depth	6443.4	1963.9	196385.2	-	-	0.0464	4.64
BHT	6456.0	1967.7	196769.3	244.00	117.78		
Surface Temperature	-	-	-	80.00	26.67		

After obtaining the value of KB then determine the value of heat conductivity (KF). To calculate the heat conductivity of the formation (KF), data on the thickness of the formation, the type and thickness of the rock in the formation are needed. From the calculation results, the heat conductivity value of the formation in well A is shown in Table 3. Furthermore, determining the value of the heat conductivity of the well (KSM), from the calculation results obtained the heat conductivity value of well A (KSM) is 5.4910^{-3} cgs.

Table 3. Results of Formation Heat Conduct Calculation, Well A

FORMATION	K-FORMATION (cal cm^{-1} dt^{-1} $^{O}C^{-1}$) K_B measurement in Well A
Minas	4.14 (0-170 m)
Petani	4.26 (170-284 m)
Telisa	4.43 (284-698 m)
Sihapas-Upper	4.96 (698-778 m)
Sihapas-Lower	5.23 (778-969 m)
Pematang SS	6.81 (969-1457 m)
Pematang MS	6.81 (1457-1719 m)
BRSH	6.80 (1719-1780 m)
LP	7.38 (1780-1880 m)
Basement	7.59 (1880-1964 m)

For the value of heat flow, can be obtained by looking at the value gradient temperature (GT) and K-*Well* determination of well temperature gradients, calculated using the equation:

$$\frac{dT}{dZ} = \frac{(Tf - Tm)}{D} \times 100$$ (Dresser Atlas, 1982)

The temperature gradient value for well A is 4.64 ^{O}C / 100m. While the value of geothermal flow (Q) can be determined using the equation:

$$Q = K_{SM} \frac{dT}{dZ}$$ (Gretener, 1982)

Table 4. Calculation Results of *K*-Well, *GT*-Well, Heat Flow in Wells A-1 and B-1 Based on KB measurements

Well	***K***-Well (cal cm^{-1} dt^{-1} $^{O}C^{-1}$)	***GT***-Well (^{O}C/100cm)	HEAT FLOW (HFU)	HEAT FLOW (*m*W/m^2)
A	5.491348×10^{-3}	0.046	2.75	110

The result of heat flow (Q) calculation for well A is 110 mW / m2. The values of *GT*-Well, *K*-Well, and Q of well A are shown in Table 4. After the value of heat flow in well A is obtained, the heat conductivity value of the formation group is calculated. Then determine the value gradient for the formation group temperature, using the equation:

$$GT_{KF} = \frac{Q}{K_{KF}}$$ (Subono dan Siswoyo, 1995)

Furthermore, determine the change in depth (ΔZ) for each temperature increase of 10^{O} C (10OC / Z). The results of the K_{KF}, GT_{KF} and ΔZ calculations are shown in Table 5. Next step is the determination of the depth change (ΔZ) for each temperature increase of 10^{O} C (10OC / Z). The results of the K_{KF}, GT_{KF} and ΔZ calculations are shown in Table 5

Table 5. Calculation results of K_{KF}, GT_{KF}, and depth change (dZ) in well A based on K_B measurements

Formation	Thickness of Formation Group (cm)	Heat Conductivity of Formation Group (cal/cm dt °C)	Temperature Gradient of Formation Group (°C/100m)	dT = 10 °C dZ = …. m
Minas Petani Telisa Sihapas Upper Sihapas Lower	96900	4.53	6.06	165
Pematang SS Pematang MS Pematang BRSH Pematang LP	91100	6.87	4.00	250
Basement	8400	7.59	3.62	276

temperature (°C)	depth change (cm)	Depth (cm)
30 - 40	16500	16500
40 - 50	16500	33000
50 - 60	16500	49500
60 - 70	16500	66000
70 - 80	16500	82500
80 - 90	25000	107500
90 - 100	25000	132500
100 - 110	25000	157500
110 - 120	25000	182500
120 - 130	27600	210100

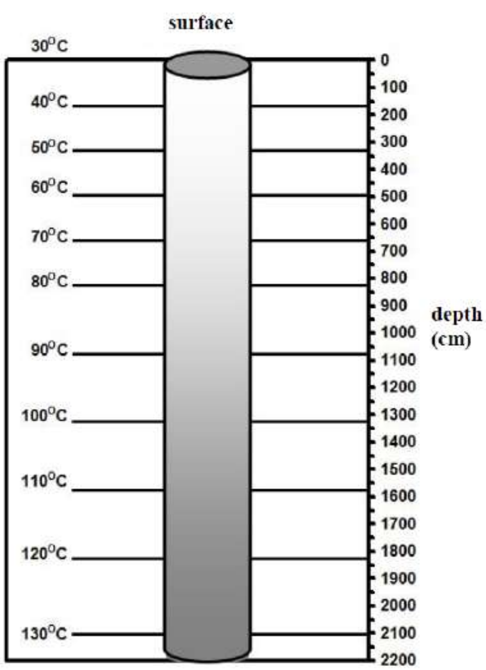

Figure 1. Changes in depth for each 10^{O}C temperature rise, in well A

The depth of well A is 1964 m, with a surface temperature of $30^{O}C$. From the data processing it is produced that 5x the same depth change every $10^{O}C$ temperature increase is 165 m. Then 4x the same depth change every $10^{O}C$ temperature increase is 250 m, and 1x the same depth change every $10^{O}C$ temperature increase is 276 m. Then a depth change model is made for every $10^{O}C$ temperature increase in well A, which is shown in Figure 1. Seen in Figure 1, the surface temperature is $30^{O}C$ and the temperature is $130^{O}C$ at a depth of 2100 m, while the Bore Hole Temperature (BHT) is $117.78^{O}C$ at a depth of 1967.7 m. So if we compare the results of the BHT measurement from the log method with the results of the calculation model of the depth change of each 10OC temperature rise, the results are close to similarity. BHT log measurement results (1967.7m = $117.78^{O}C$), the model changes depth every $10^{O}C$ (2100m = $130^{O}C$).

CONCLUSION

From the data processing it is produced that 5x the same depth change every $10^{O}C$ temperature increase is 165 m. Then 4x the same depth change every $10^{O}C$ temperature increase is 250 m, and 1x the same depth change every $10^{O}C$ temperature increase is 276 m. The depth of well A is 1964 m, with a surface temperature of $30^{O}C$. So the temperature value from a depth of 165 m to a depth of 2100 m is $40^{O}C$ to $130^{O}C$. Then a depth change model is made for every $10^{O}C$ temperature increase in well.

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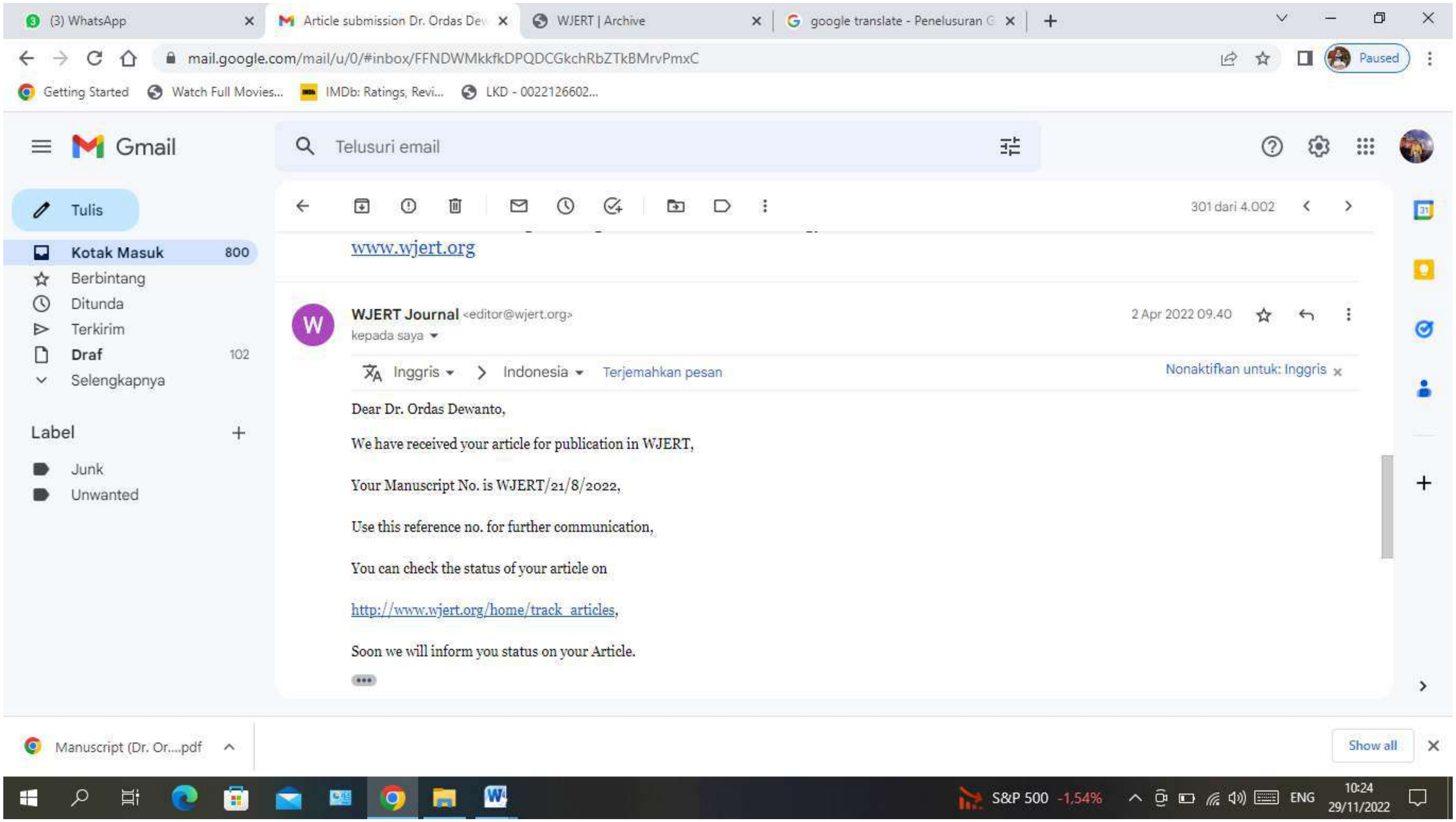

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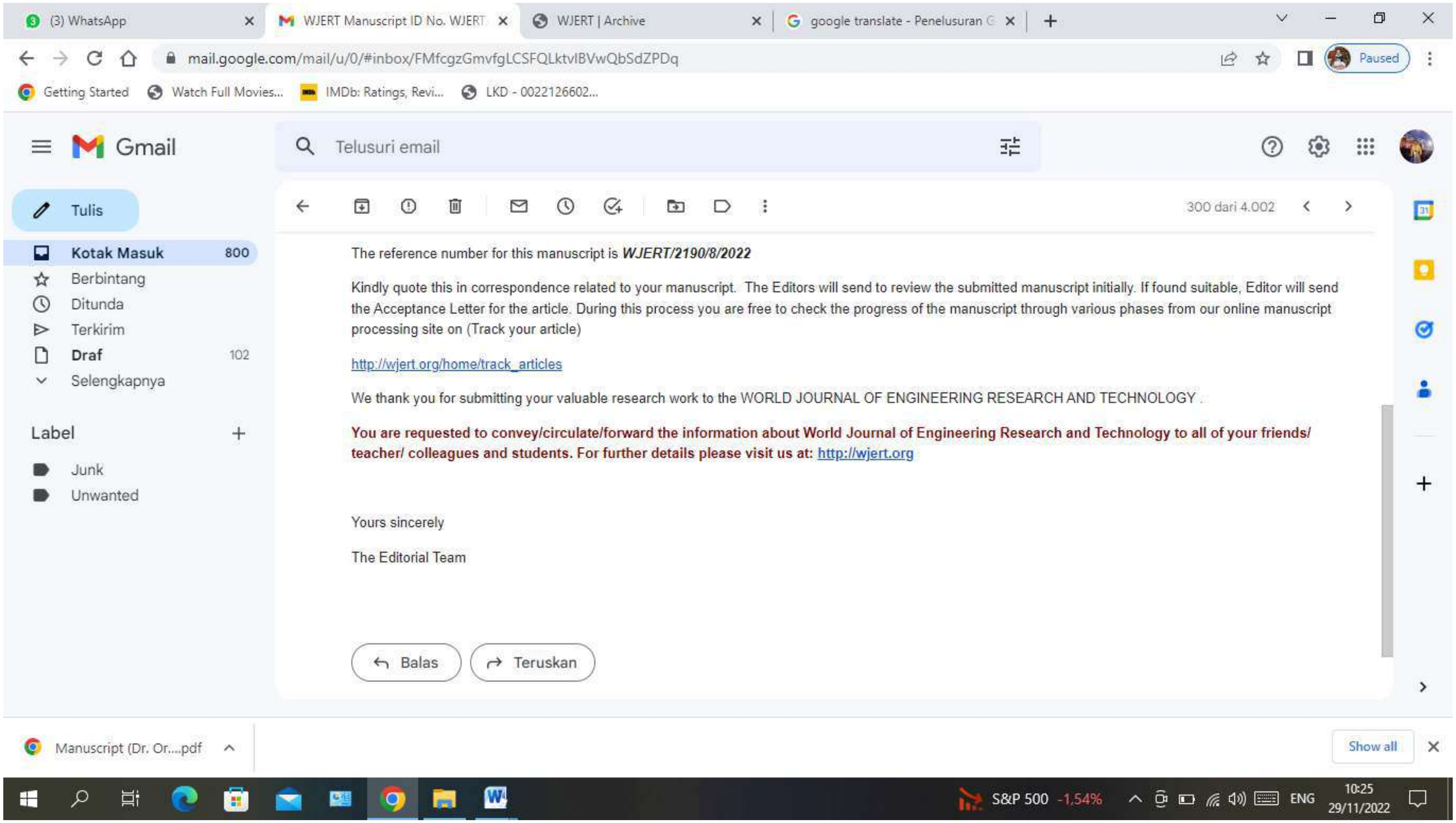

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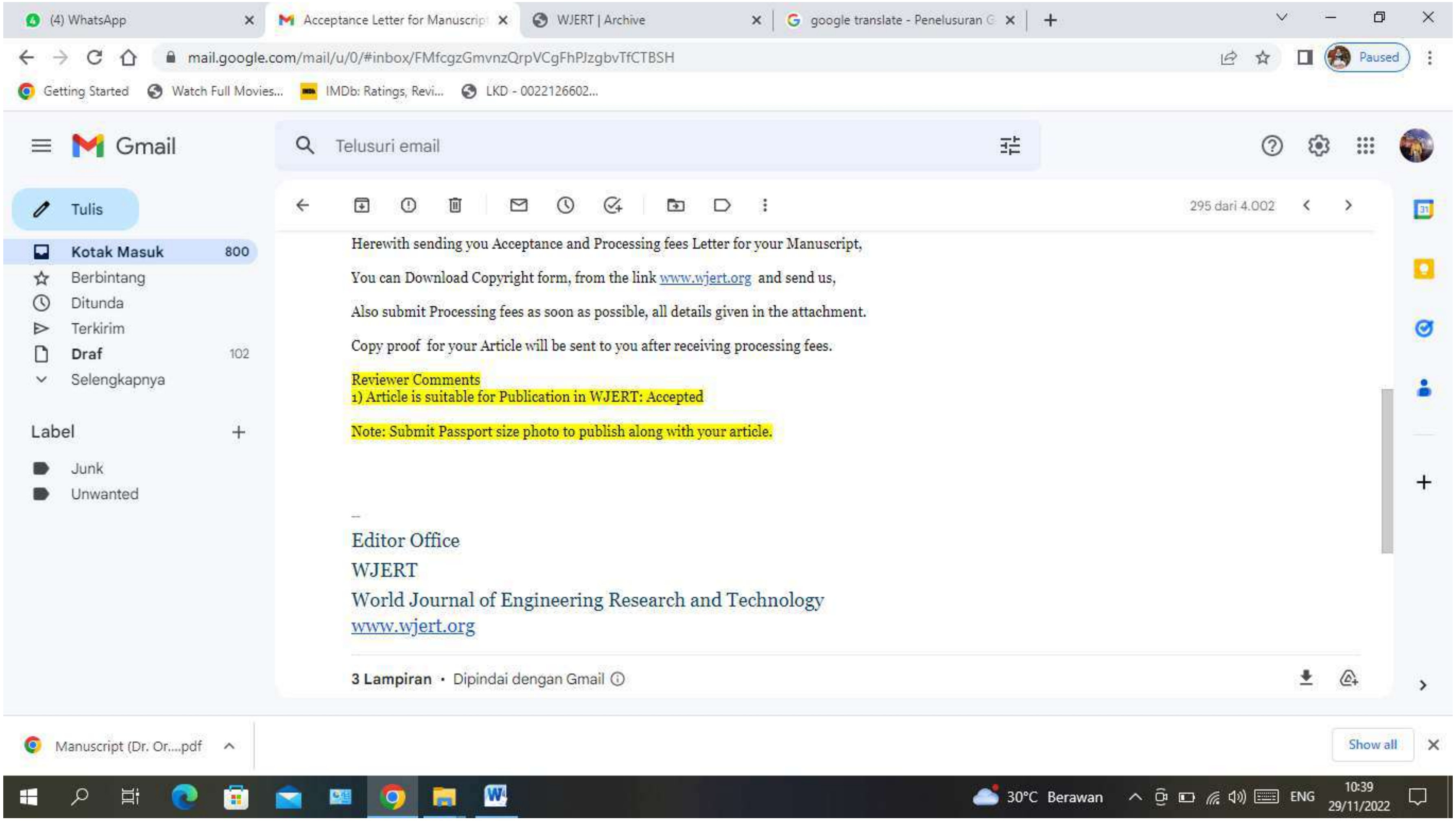
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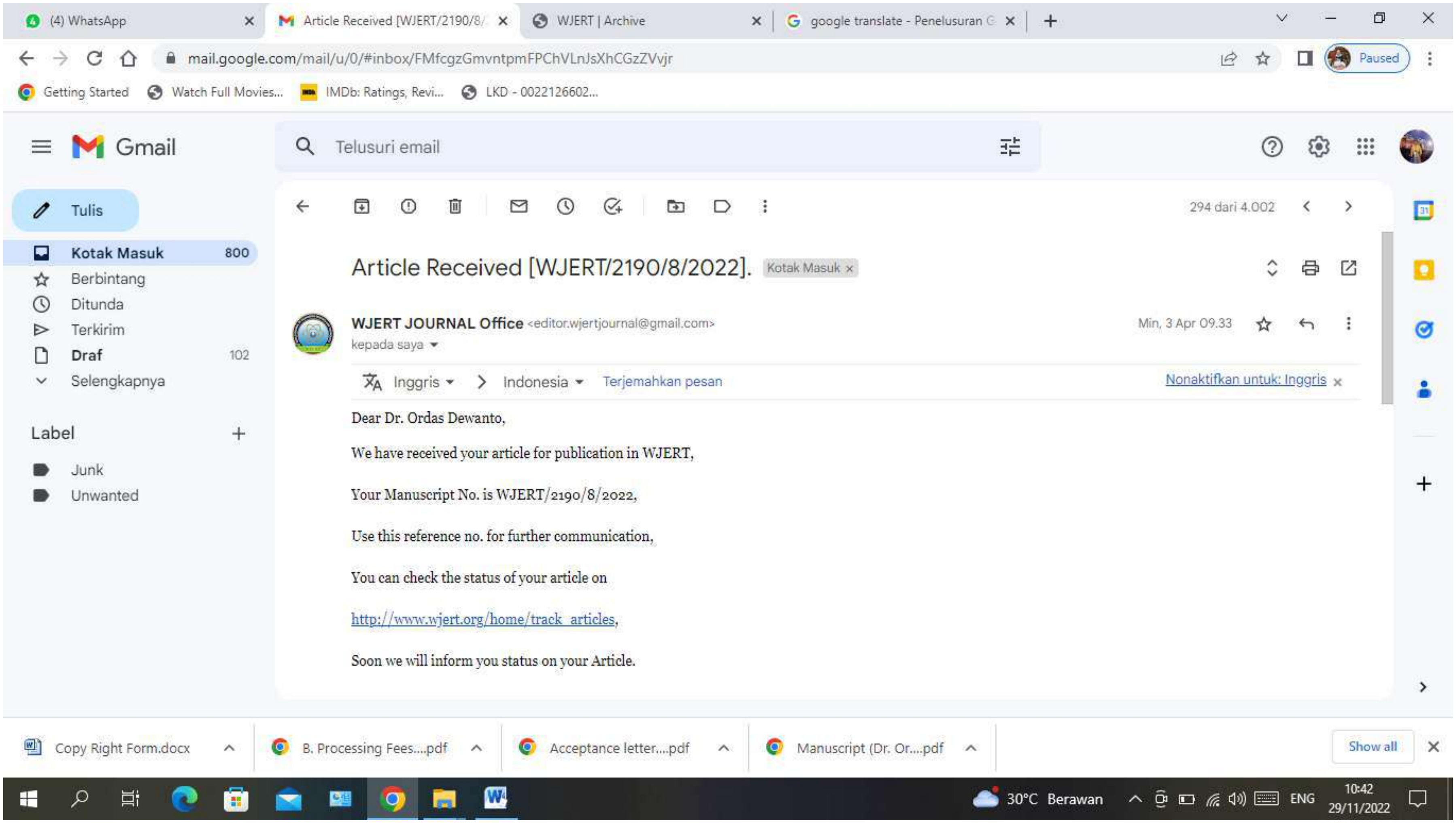

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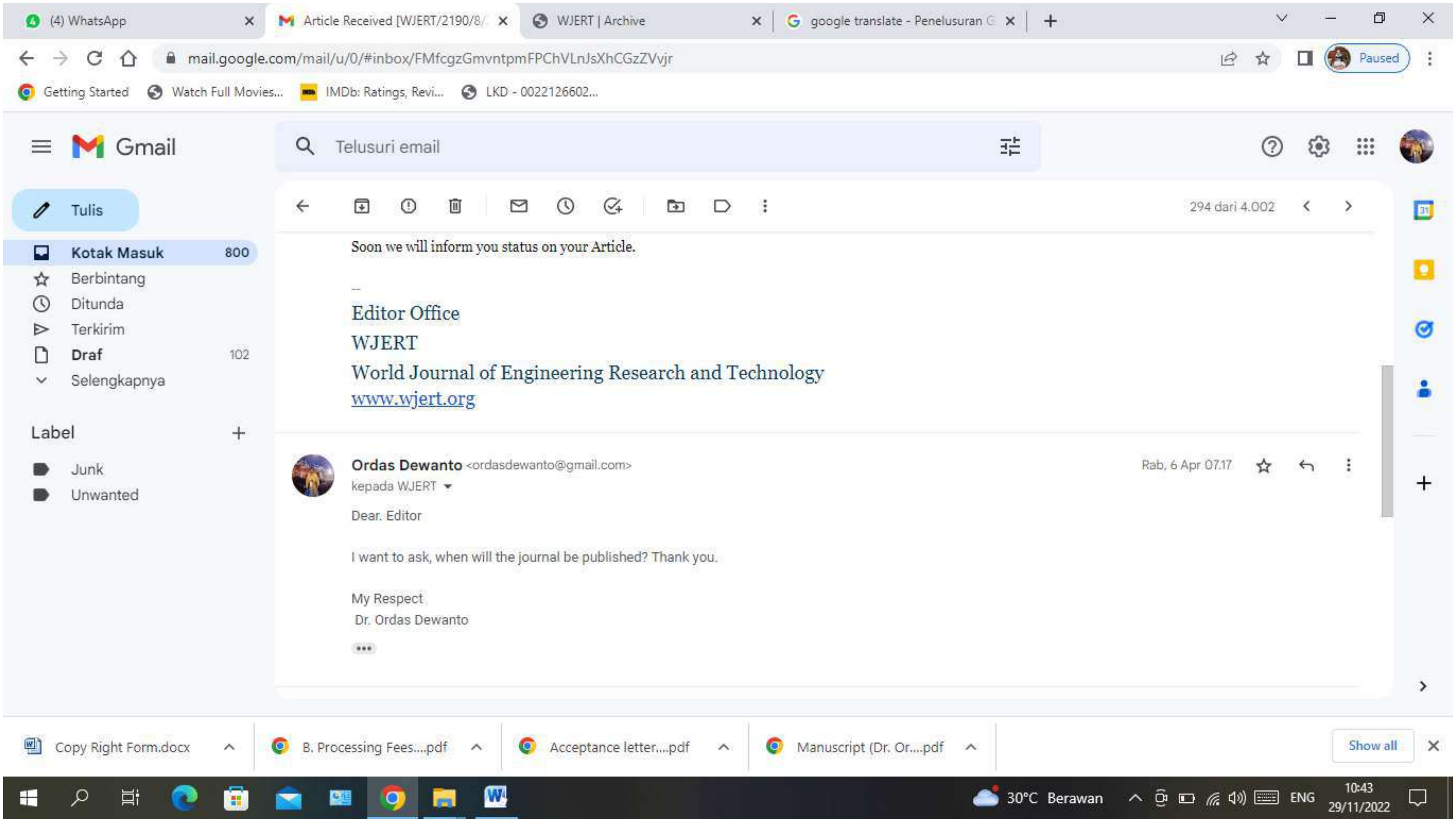

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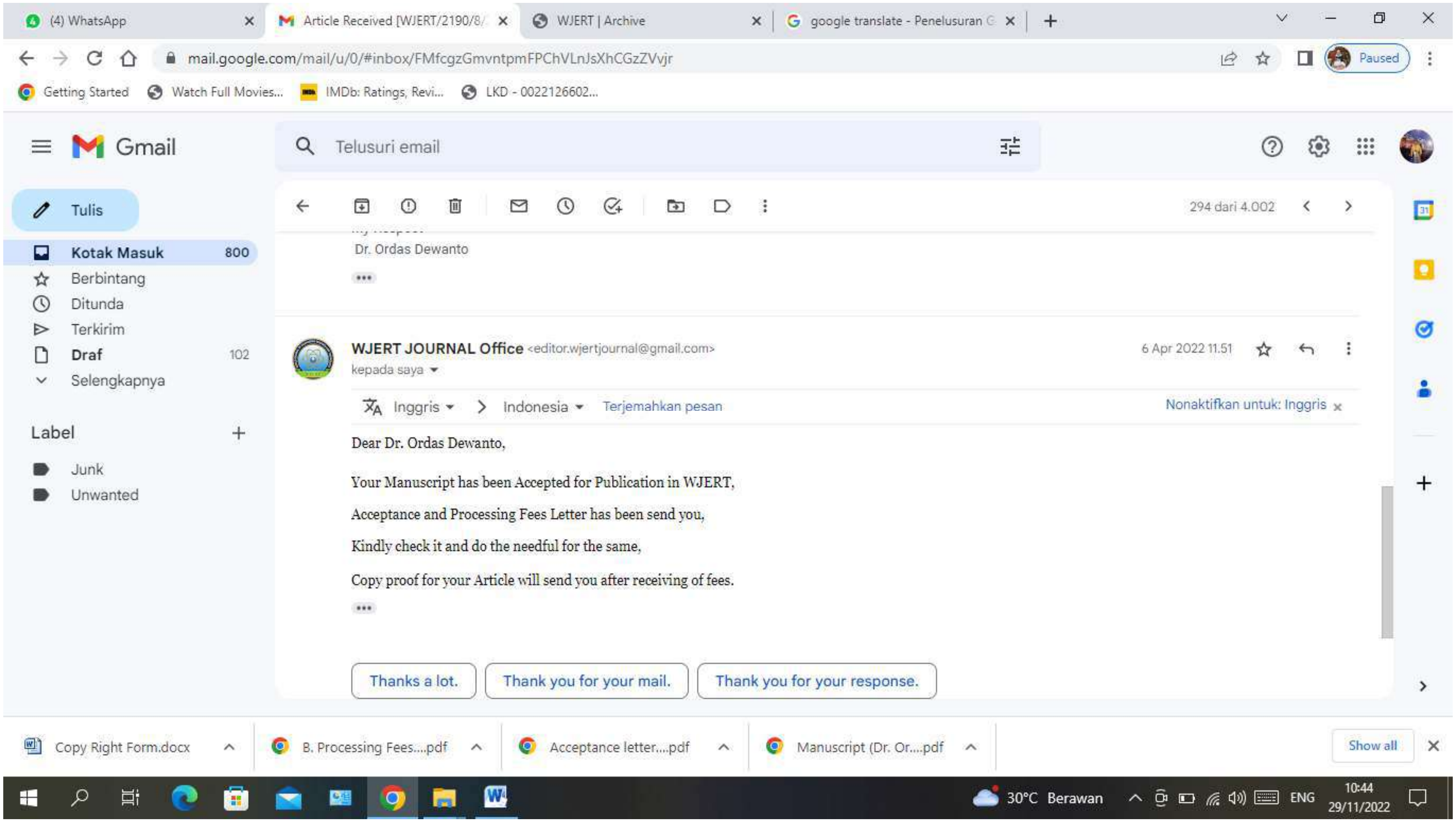

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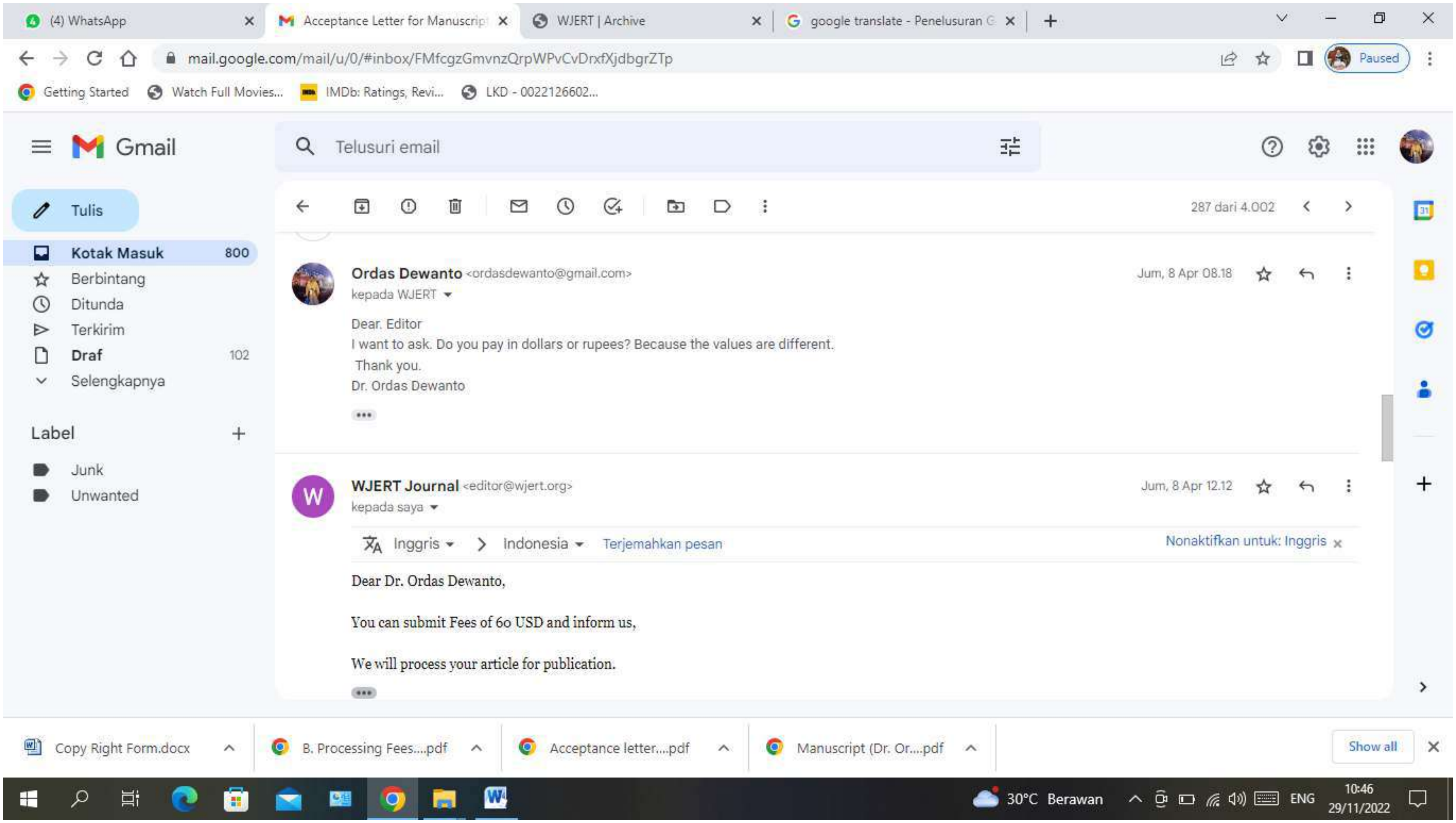
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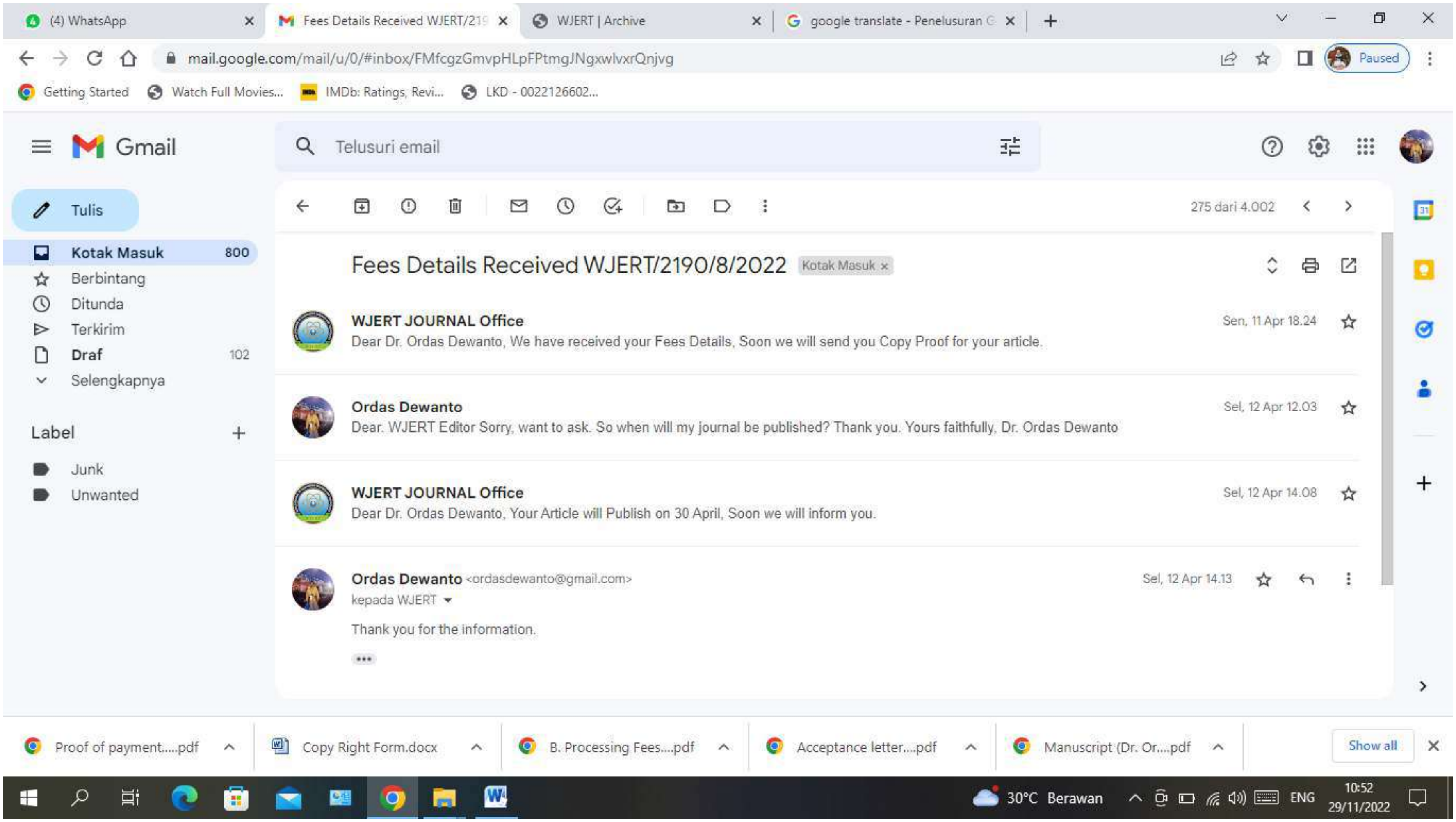
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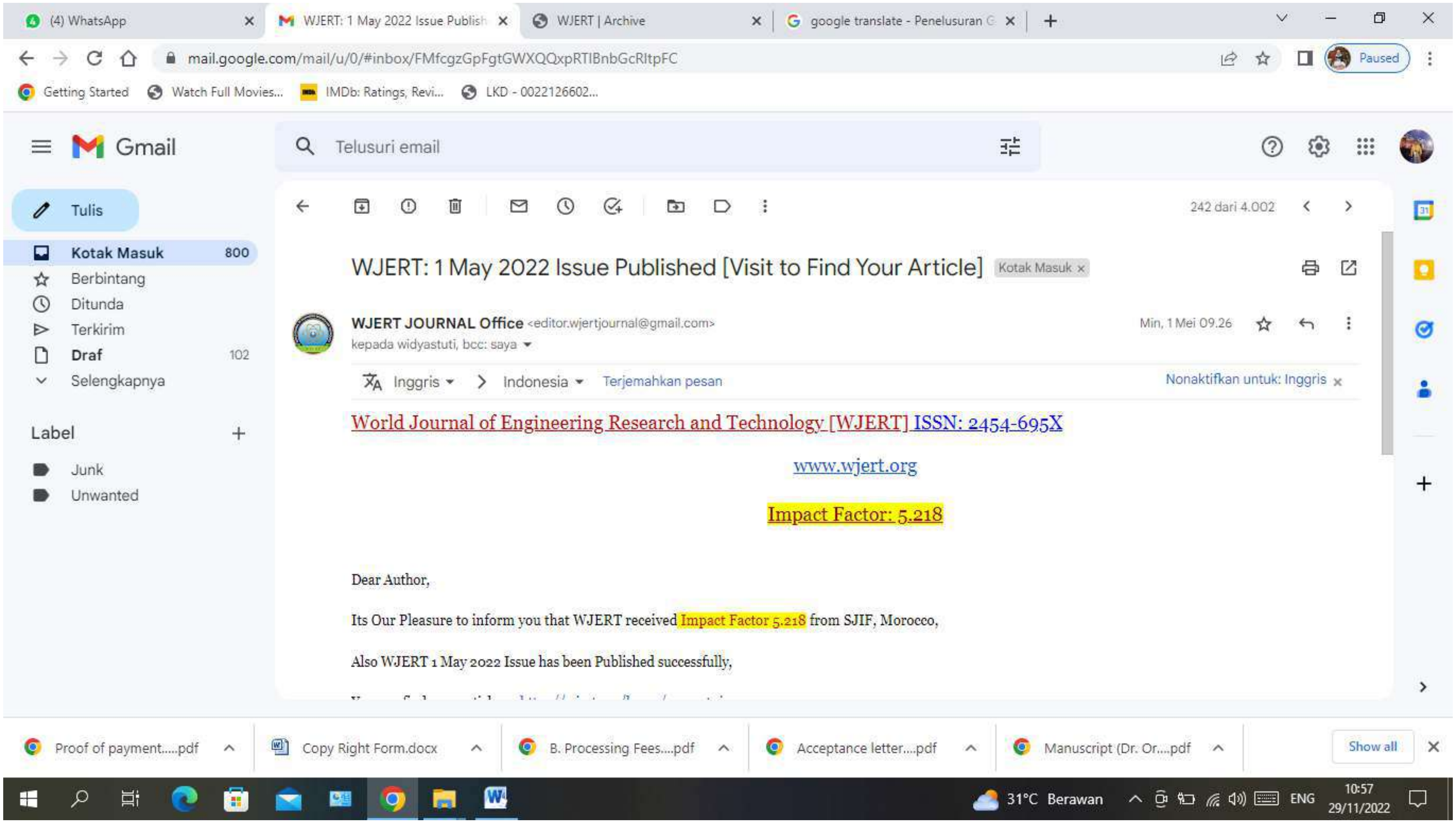

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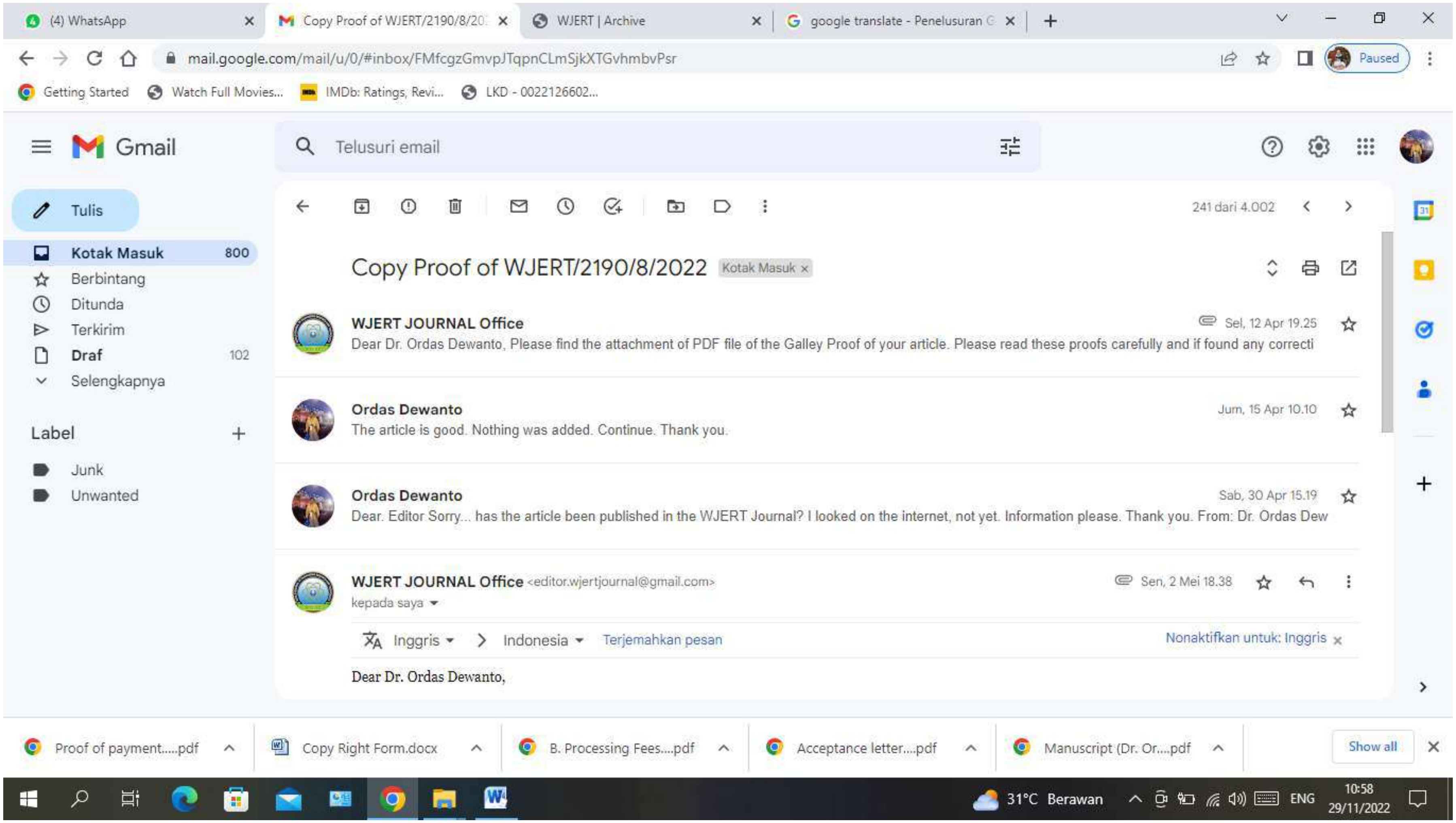
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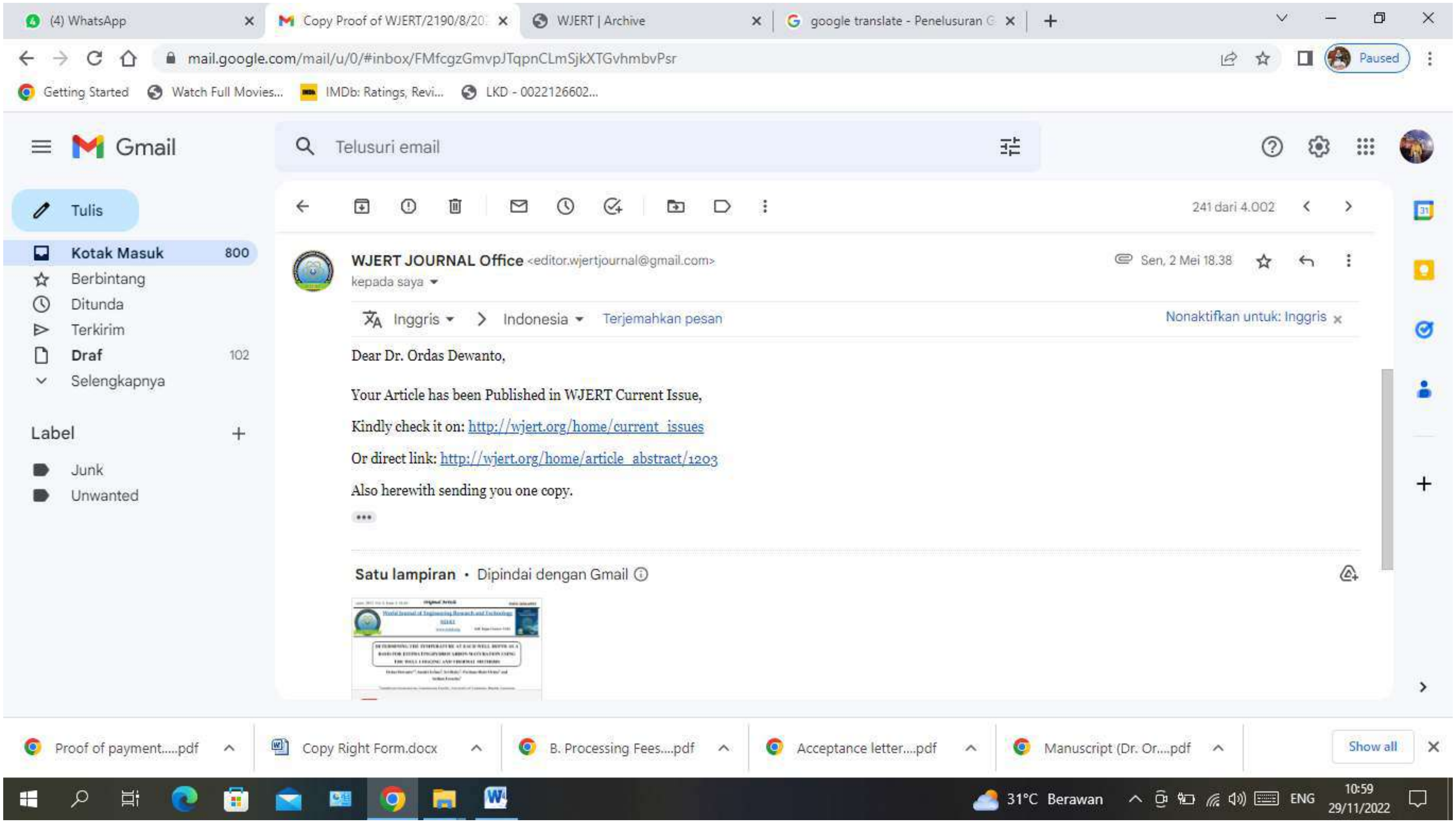
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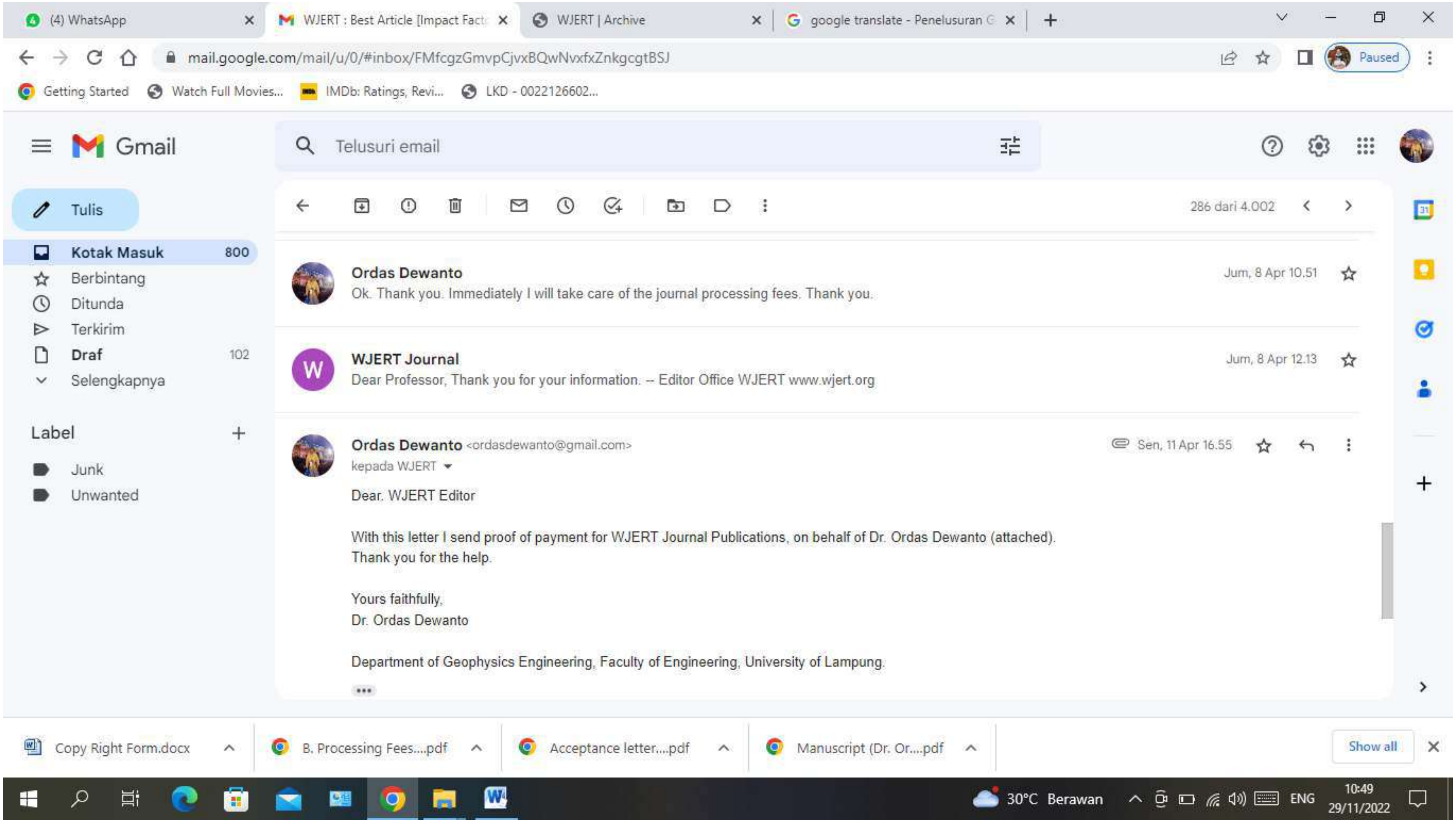
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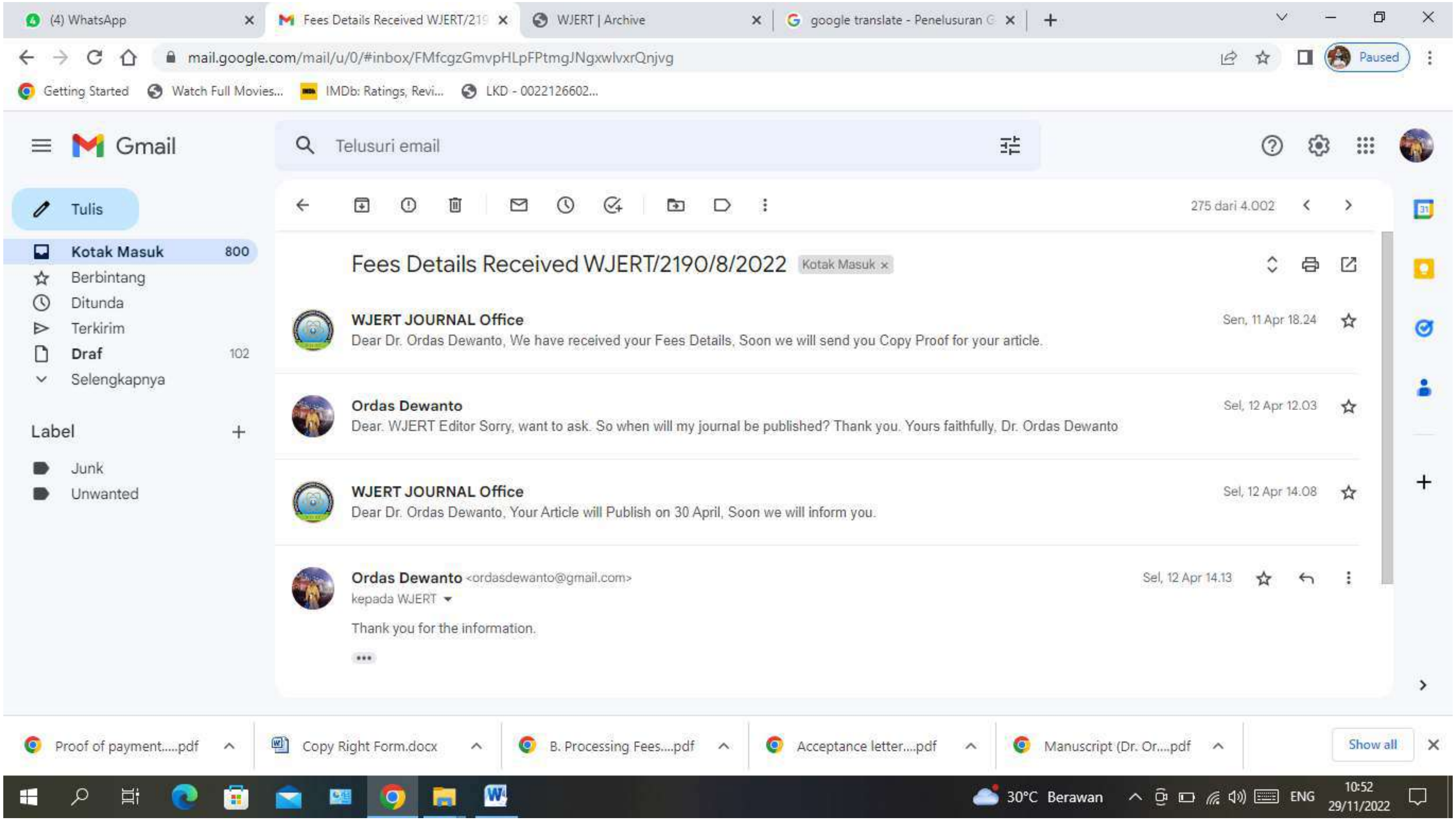

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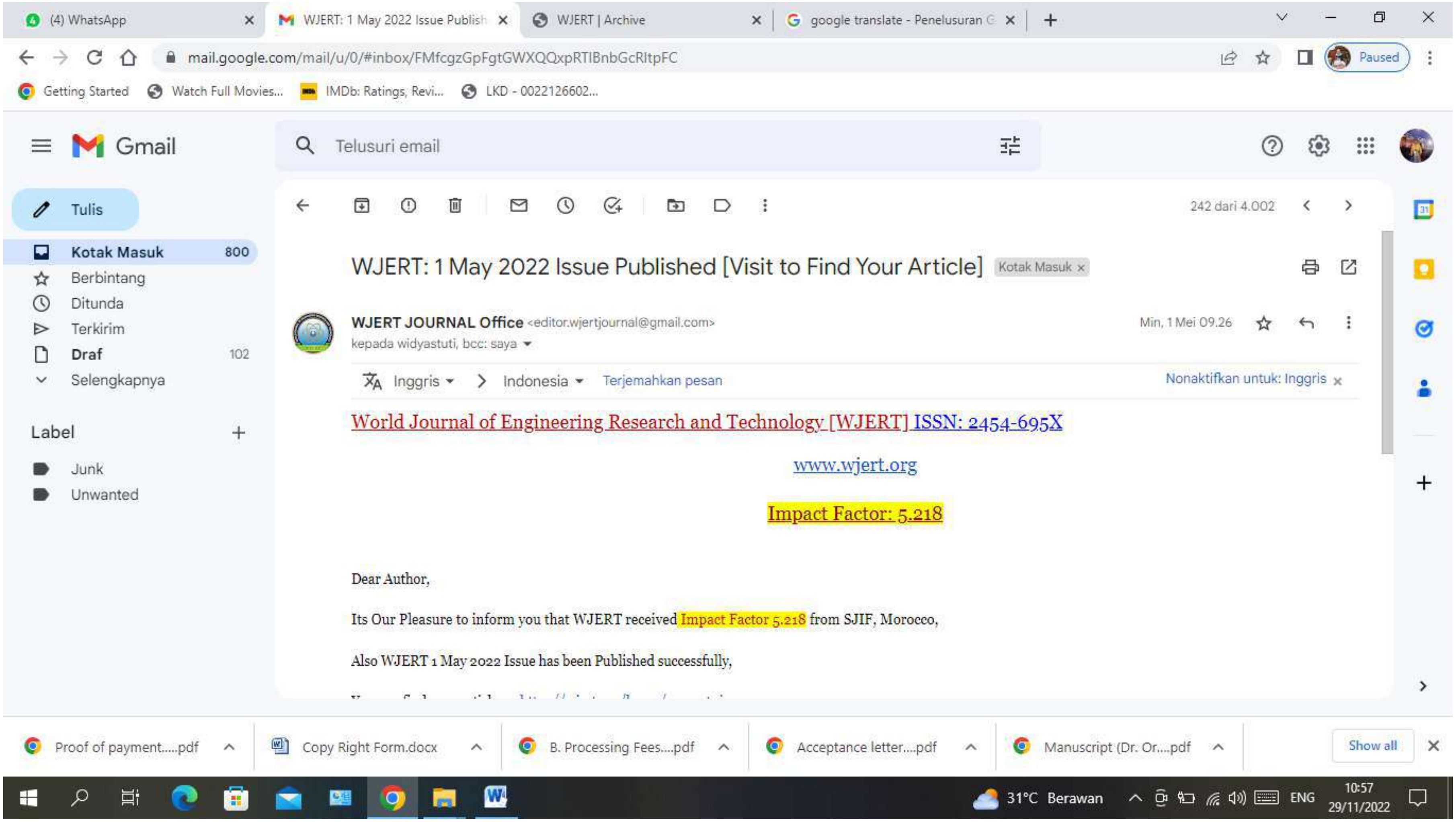

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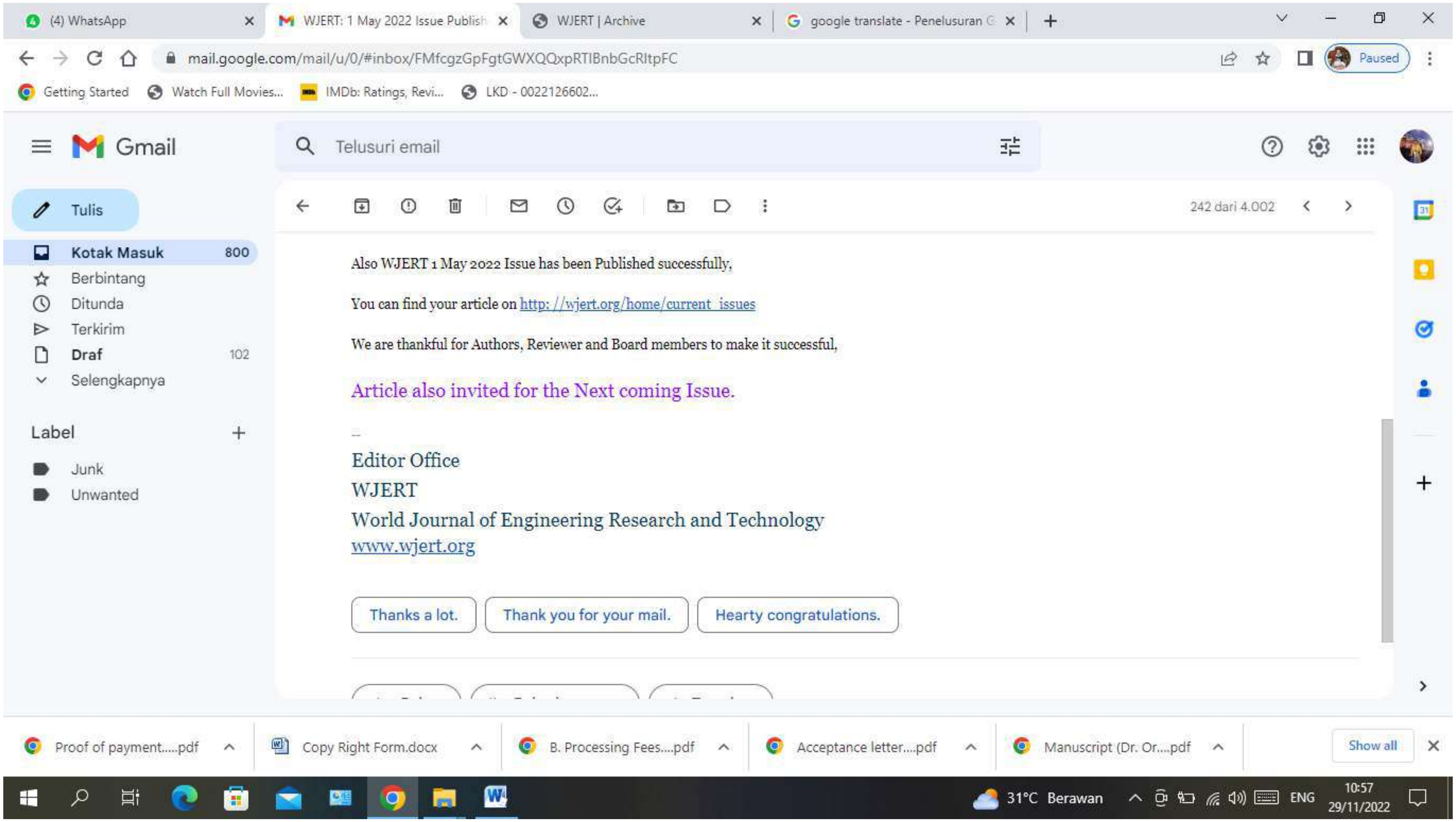
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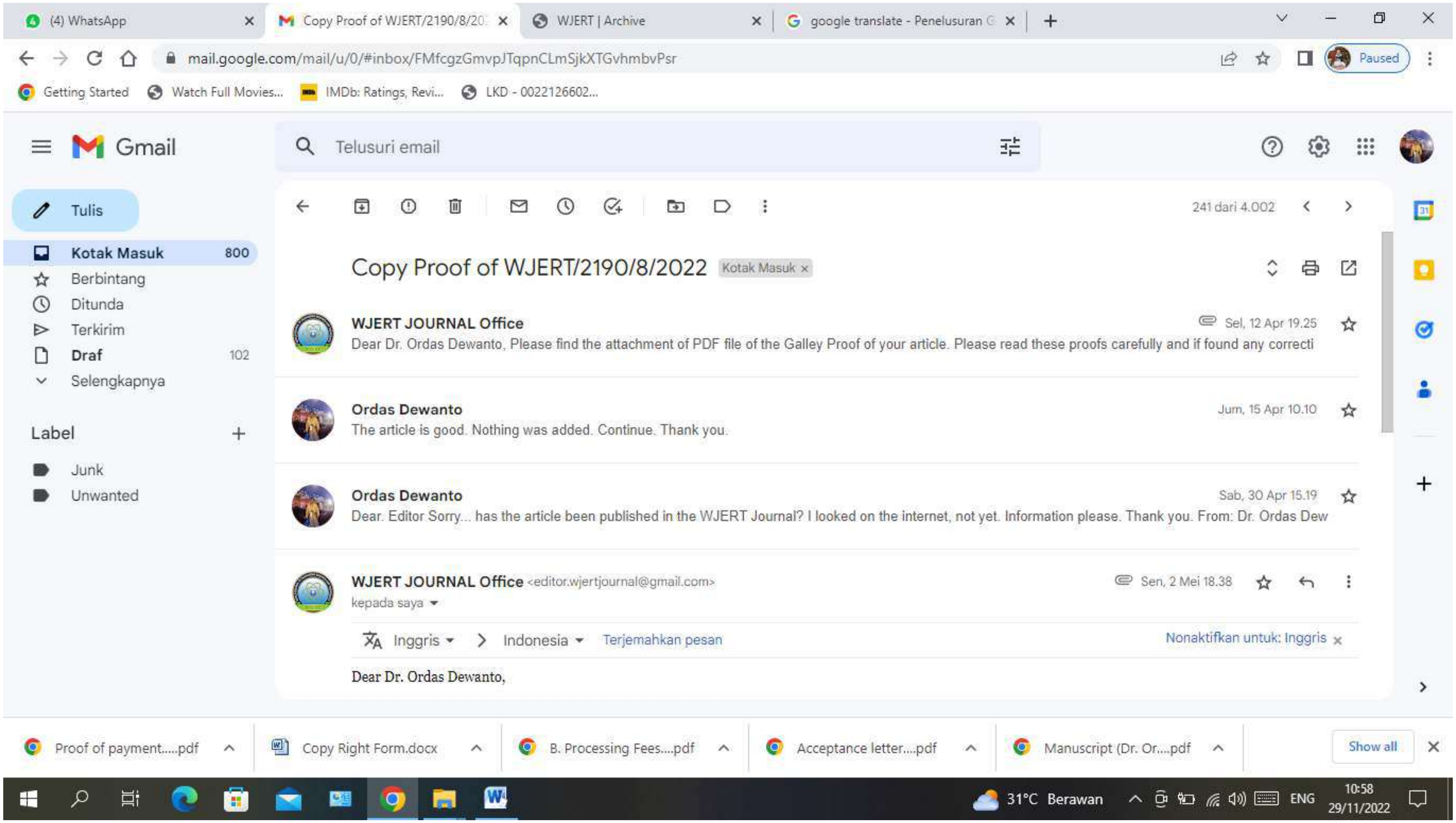
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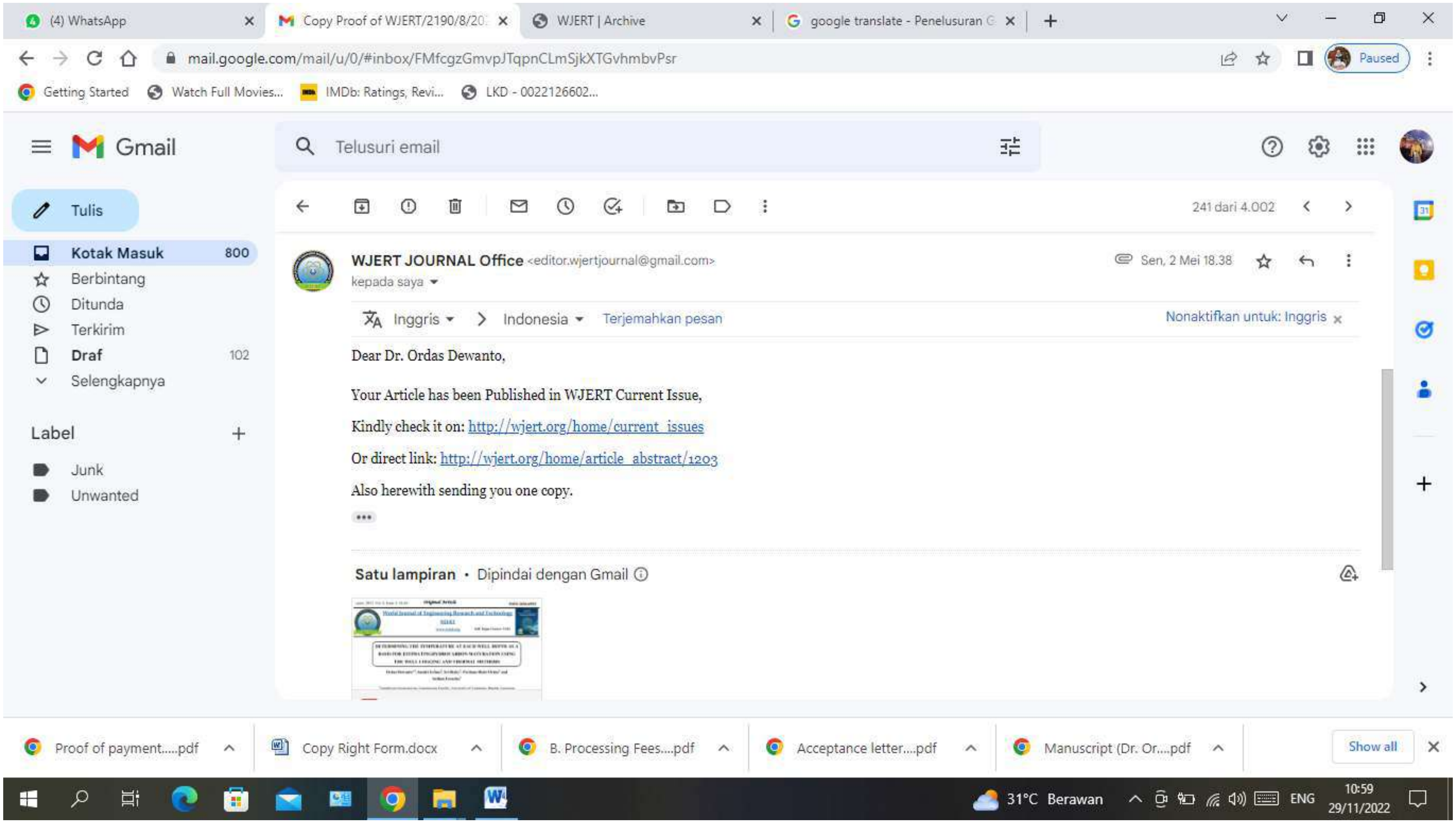

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DETERMINING THE TEMPERATURE AT EACH WELL DEPTH AS A BASIS FOR ESTIMATINGHYDROCARBON MATURATION USING THE WELL LOGGING AND THERMAL METHODS

Ordas Dewanto*[1], Sandri Erfani[1], Sri Rizky[2], Perdana Rizki Ordas[3] and Istifani Ferucha[1]

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Article Received on 01/03/2022 **Article Revised on 20/03/2022** **Article Accepted on 10/04/2022**

***Corresponding Author**
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ABSTRACT

Temperature measurements at drilling wells are usually not carried out thoroughly, some even only at the bottom of the well or Bore Hole Temperature (BHT). The Well Logging and thermal methods are used to determine the temperature at each depth, provided that the surface temperature and BHT of the well are available. The principle of the method is to determine the change in depth for each increase in temperature of 10^{O}C or 5^{O}C. By developing the basic concept of geothermal flow it can be seen that changes in depth at each increase in temperature of 10^{O}C, so that we can know the temperature value at each depth of the well. In well A, the temperature in the depth of 502-629m is 60^{O}C-70^{O}C with immature organic substances. The temperature in the depth of 1096-1276 m is 90^{O}C-100^{O}C with mature organic substances. The temperature in the depth of 1595-1699 m is 100^{O}C-120^{O}C with overmature organic substances. The temperature in the depth of 1780-1964 m is 120^{O}C-130^{O}C with gas organic substancesIn the process of hydrocarbon maturity, an increase in temperature will convert heavy petroleum into light oil, then become condensate and finally only gas. This is a function of depth and temperature gradient.

KEYWORDS: Bore hole temperature, well logging, immature, mature, gas, temperature gradient.

INTRODUCTION

Research on the maturation of hydrocarbons in sedimentary basins in Indonesia has generally been successful, with the aim of estimating the level of maturity of organic material in the source rock of the basin. The research studies are very helpful to support the exploration of hydrocarbons (oil and gas). The basis for determining the maturation of hydrocarbons, generally based on the changes in their chemical properties, where analysis of changes in chemical properties is one indicator that is quite accurate. As technology develops and it becomes increasingly difficult to find new reserves of hydrocarbons, geoscience is increasingly developing to overcome these problems. Previous research that used the basic concept of terrestrial heat flow, which was supported by geological data related to geochemical technology, has obtained a fairly accurate result and more clearly understood the problems in exploration activities. This implies the importance of understanding the relationship between the thermal and physical properties of rocks to the level of hydrocarbon maturation (Hanun et al, 2016).

Based on these needs, this study presents research to improve the qualitative and quantitative analysis of log data (Dewanto et al, 2016) in supporting the initial estimates of the occurrence of petroleum and the formation of petroleum.

Core analysis data generated from measurements and analysis of reservoir rocks in the laboratory are much needed information to find out the very specific characteristics of rock physics, which will ultimately be used to predict the performance of reservoir rock.

The heat that flows from the bottom up spreads to the surface of the earth affecting the rock space, so that in each rock room has a different temperature. The temperature in each rock space is different, because of the different porosity and heat conductivity, as well as the difference in hydrostatic pressure from the rock.

Temperature can affect organic substances contained in sediments. An increase in temperature will change heavy petroleum into light petroleum, then condensate and finally only gas. Dewanto et al (2017) research results in the laboratory are that oil shale derived from clay-organic material occurs at a temperature of 300-400^{O}C and for carbonate-organic material occurs at a temperature of 400-500^{O}C. Whereas at temperatures of 900-1000^{O}C both materials produce gas. Temperature values can also be used to determine the depth of oil shale in wells (Mulyanto et al, 2018).

The duration of the formation of petroleum from the release of fat or lipids from kerogen is a temperature-related process, which is exponential and starts at temperatures around 93^{0}C (Klemme, 1972). The value of temperature in a rock pore is one of the important parameters in the process of determining the maturity of organic matter, to predict the maturity of hydrocarbons in sedimentary rocks. Temperature values can help estimate the maturity of organic material in CaCO3 (Dewanto et al, 2019). Moreover, it can also be used as a basis for research relating to geothermal reservoirs in regions containing geothermal energy. Estimated reservoir temperatures are very important to assess the potential for geothermal exploitation (Zhang et al, 2015).

Knowledge about downhole and around the temperature of the wellbore formation is an important factor during drilling operations. It is important to estimate the effect of pressure and temperature on the formation fluid density (Kutasov, 2015). This will enable a more accurate prediction of differential pressure in the lower hole and will help reduce fluid losses resulting from miscalculated pressure differences. Reservoir temperature modeling is carried out to estimate reservoirparameters (Siswoyo, 1995).

In terms of calculating water saturation (Sw) to determine the hydocarbon content in reservoir rocks, it needs the parameter of Rw (formation water). The formation water value (Rw) of each layer can be determined based on temperature. Therefore, determining the temperature at a certain layer depth is very important to calculate the value of Rw (Ushie, 2001). Determination of temperature in the log well is also very useful for determining the maturation level of oil shale in source rock (Mulyanto et al, 2018). Then also to determine the level of hydrocarbon (oil and gas) maturation in source rock (Nopiyanti, 2019 and Maulina, 2019).

In this study, the temperature at each layer will be determined to a certain depth. For example in a drilling well, logging is usually carried out to determine the temperature value at any given depth. This temperature measurement is not done thoroughly on the well. In fact, some are only measured at the bottom of the well (BHT). But with the development of technology, the temperature at each depth can be estimated, with the condition that the well is known for the surface temperature and Bore Hole Temperature (BHT).

One method for estimating the temperature is to determine the change in depth for each $10^{O}C$ or $5^{O}C$ rise in temperature. Subono et al (1995) and Dewanto et al (2001), developed the basic concept of geothermal flow to determine changes in depth at each $10^{O}C$ temperature rise, so that the value of temperature at each depth in the well can be known.

METHOD

The data required are BHT (bore hole temperature), porosity, rock heat conductivity (K_B), heat flow (Q), temperature gradient, stratigraphy, rock age.

Data Processing Method

In this research several work stages are carried out, namely.

First Stage, Determination of Lithology, Age and Porosity

The first stage, determine the lithology in each formation of the well and determine the age and sedimentation time of the lithology. Then determine the value of porosity, as a reference base for doing work in the next stage.

Second stage, Calculation of Rock Thermal Conductivity

Rock heat conductivity can be determined by measurement and calculation. Calculation of rockheat conductivity, determined using the following equation:

$$K_B = K_f^{\phi} \times K_s^{(1-\phi)}$$

Where, K_B = heat conductivity of the rock

K_f = heat conductivity of the liquid fraction

K_s = heat conductivity of solid fractions porosity

The value of the heat conductivity of the formation (K_F) is determined by calculation based on thevalue of heat conductivity of rocks and thickness in the formation.

$$K_F = \left[\left(\frac{d_{B1}}{K_{B1}} + \frac{d_{B2}}{K_{B2}} + \ldots\right) \times \frac{1}{d_{B1} + d_{B2} + \ldots}\right]^{-1}$$

Where, K_F = heat conductivity of the formation (10^{-3} cgs)d_{B1} = the thicknessof lithology-1 (m); d_{B2} = the thicknessof lithology-2 (m)d_{B1}+d_{B2} = formation thickness (m)

K_{B1} = heat conductivity of lithology-1 (10^{-3} cgs)K_{B2} = heat conductivity of lithology-2

(10^{-3} cgs) and so on adjusted to the type of lithology. Meanwhile, to calculate the value of heat conductivitywells are used the following formula:

$$K_{SM} = \left[\left(\frac{d_{FA}}{K_{FA}} + \frac{d_{FB}}{K_{FB}} + \ldots + \frac{d_{FN}}{K_{FN}}\right) \times \frac{1}{DA}\right]^{-1}$$

Where, K_{SM} = heat conductivity calculated from the deepest well up to the surface (10^{-3} cgs)d_{FA},d_{FB},d_{FN} = formation thickness A, B s/d N (m or cm)

DA = total depth

Third stage, Calculating Temperature Gradients

Temperature gradients are determined according to the equation: $GT = \frac{BHTc - Tp}{DA} \times 100$

Where, GT = temperature gradient (^{O}C/100m) BHTc = temperature corrected at DA (^{O}C) Tp = average temperature on the surface DA = total depth (m)

In this case the temperature gradient of each formation is also calculated, using the followingequation:

$$GT_F = \frac{Q}{K_F}$$

(Subono, S. dan Siswoyo, 1995)

Where, GT_F = formation temperature gradient (^{O}C/100m)Q = geothermal flow, (□10^{-6} cal $cm^{-2}s^{-1}$)

K_F = heat conductivity of the formation (10^{-3} cal cm^{-1} det^{-1} $^{O}C^{-1}$)

Fourth stage, Determination of Heat Flow

After obtaining the value of heat conductivity and temperature gradient as mentioned above, then determine the value of heat flow (heat flow) at the well. Calculated using the formula according to the equation as follows:

$$Q = K\frac{dT}{dZ}$$

$$\Leftrightarrow \quad Q = (K_f^{\phi} \times K_s^{(1-\phi)}) \times GT \quad \Leftrightarrow \quad Q = K_F \times GT$$

$$\Leftrightarrow \quad Q = \left[\left(\frac{d_{FA}}{K_{FA}} + \frac{d_{FB}}{K_{FB}} + \ldots + \frac{d_{FN}}{K_{FN}}\right) \times \frac{1}{DA}\right]^{-1} \times GT$$

$$\Leftrightarrow \quad Q = K_{SM} \times GT$$

where, Q = geothermal flow, HFU or µcal/cm^{2}s, or mW/m^2
K_{SM} = heat conductivity, 10^{-3} cal cm^{-1} dt^{-1} ^{O}C^{-1} or W/m^{O}C
dT/dZ = temperature gradient, ^{O}C/100m (GT)
1 HFU = 10^{-6} kal cm^{-2} dt^{-1}

The method for estimating the temperature is to determine the change in depth for each 10^{O}C or 5^{O}C rise in temperature. Determination of temperature in well A, the temperature value will be determined by calculation. By knowing the change in depth at every 10^{O}C temperature rise, the value of the temperatur can be estimated. Basic formula used: where, Z : depth change (m)

$$\Delta Z = \frac{10^{O}C}{GT_{KF}} \Rightarrow GT_{KF} = \frac{Q(t)}{K_{KF}}$$

GT_{KF}: temperature gradient of the formation group (^{O}C/100m) K_{KF} : heat conductivity of rock formation groups (mks)

By doing calculations to determine the change in depth of each 10^{O}C temperature rise, a model of the value of each depth will be obtained.

RESULTS AND DISCUSSION

In this study using the thermal method. Well A has a total depth of 6443.4 ft (1963.9 m) located in the Central Sumatra Basin. The data needed for data processing in this study are stratigraphic data and rock heat conductivity data (Table 1), temperature gradient data and BHT (Table 2), and porosity data (log data). Heat Flow is the flow of heat that comes from inside the earth to flow to the surface through a space / rock material. Because the nature and density or compactness of rocks differ, the value of heat flow (Q) for each well in an area also varies besides that there must be the same. The difference in the value of heat flow, in addition to the difference in temperature gradient is also influenced by the conductivity of rock heat (K_B) on the rock. Rock heat conductivity can be determined from measurements of rock samples (cores) directly in the laboratory. Moreover, it can also be determined by calculation based on the value of the porosity of the rock. Researchers determine the value of rock heat conductivity (K_B) by direct measurement.

Table 1: Stratigraphic Data and Heat Conductivity of Well Rocks A.

FORMATION		AGE (million years)	LITOLOGY	DEPTH (m)	ROCK CONDUCTIVITY (cal/cm dt ^{O}C)
MINAS		*0* 1.6 *1.6*	sand shale sand shale	0 - 55 55 - 90 90 - 130 130 - 170	4.25 4.00 4.25 4.00
PETANI		*3* 11	shale	170 - 284	4.26
TELISA		*14* 3	shale sand	284 - 678 678 - 698	4.41 4.99
SIHAPAS	Upper	*17* 1	sand shale	698 - 738 738 - 778	5.32 4.64
	Lower	*18* 3	sandshale sand shale sand shale sand	778 - 803 803 - 828 828 - 853 853 - 883 883 - 908 908 - 933 933 - 969	5.52 4.87 5.52 4.87 5.52 4.87 5.52
PEMATAN GGROUP	Pmt. SS	*21* *22.5* 6.7	sandshale sandshale sandshale sandshale sandshale sand shalesand	969 - 1009 1009 - 1029 1029 -1069 1069 - 1089 1089 - 1131 1131 - 1151 1151 - 1211 1211 - 1231 1231 - 1291 1291 - 1311 1311 - 1391 1391 - 1411 1411 - 1457	6.36 5.81 6.38 5.81 6.63 5.81 6.65 6.00 7.55 6.00 7.97 6.00 8.40
	Pmt. MS	*29.2* 4.2	shale	1457 - 1719	6.81
	BRSH	*33.4* 1.3	coal	1719 - 1780	6.80
	LP	*34.7* 1.3	shalesand shale	1780 - 1815 1815 - 1840 1840 - 1880	6.81 8.83 7.17
BASEMENT		*36*	Quarzt	1880 - 1964	7.59

Table 2: Well BHT Data and Temperature Gradient A.

A WELL	Depth (ft)	Depth (m)	Depth (cm)	Temperature		Temperature Gradient	
				(^{O}F)	(^{O}C)	(^{O}C/100cm)	(^{O}C/100m)
Total Depth	6443.4	1963.9	196385.2	-	-	0.0464	4.64
BHT	6456.0	1967.7	196769.3	244.00	117.78		
Surface Temperature	-	-	-	80.00	26.67		

After obtaining the value of KB then determine the value of heat conductivity (KF). To calculate the heat conductivity of the formation (KF), data on the thickness of the formation, the type and thickness of the rock in the formation are needed. From the calculation results, the heat conductivity value of the formation in well A is shown in Table 3. Furthermore, determining the value of the heat conductivity of the well (KSM), from the calculation results obtained the heat conductivity value of well A (KSM) is 5.4910^{-3} cgs.

Table 3: Results of Formation Heat Conduct Calculation, Well A.

FORMATION	K-FORMATION (cal cm^{-1} dt^{-1} ^{O}C^{-1}) K_B measurement in Well A
Minas	4.14 (0-170 m)
Petani	4.26 (170-284 m)
Telisa	4.43 (284-698 m)
Sihapas-Upper	4.96 (698-778 m)
Sihapas-Lower	5.23 (778-969 m)
Pematang SS	6.81 (969-1457 m)
Pematang MS	6.81 (1457-1719 m)
BRSH	6.80 (1719-1780 m)
LP	7.38 (1780-1880 m)
Basement	7.59 (1880-1964 m)

For the value of heat flow, can be obtained by looking at the value gradient temperature (GT) and K-*Well* determination of well temperature gradients, calculated using the equation:

$$\frac{dT}{dZ} = \frac{(Tf - Tm)}{D} \times 100 \quad \text{(Dresser Atlas, 1982)}$$

The temperature gradient value for well A is 4.64 ^{O}C / 100m. While the value of geothermal flow (Q)can be determined using the equation:

$$Q = K_{SM} \frac{dT}{dZ} \quad \text{(Gretener, 1982)}$$

Table 4: Calculation Results of *K*-Well, *GT*-Well, Heat Flow in Wells A-1 and B-1 Based on KBmeasurements.

Well	*K*-Well (cal cm^{-1} dt^{-1} ^{O}C^{-1})	*GT*-Well (^{O}C/100cm)	HEAT FLOW (HFU)	HEAT FLOW (*m*W/m^2)
A	5.491348□10^{-3}	0.046	2.75	110

The result of heat flow (Q) calculation for well A is 110 mW / m2. The values of *GT*-Well, *K*- Well, and Q of well A are shown in Table 4. After the value of heat flow in well A is obtained, the heat conductivity value of the formation group is calculated. Then determine the value gradient for theformation group temperature, using the equation:

$$GT_{KF} = \frac{Q}{K_{KF}}$$ (Subono dan Siswoyo, 1995)

Furthermore, determine the change in depth (□Z) for each temperature increase of 10^{O} C (10OC / Z). The results of the K_{KF}, GT_{KF} and □Z calculations are shown in Table 5. Next step is the determination of the depth change (□Z) for each temperature increase of 10^{O} C (10OC / Z). The resultsof the K_{KF}, GT_{KF} and □Z calculations are shown in Table 5

Table 5: Calculation results of K_{KF}, GT_{KF}, and depth change (dZ) in well A based on K_B measurements.

Formation	Thickness of Formation Group (cm)	Heat Conductivity ofFormation Group (cal/cm dt ^{o}C)	Temperature Gradient of Formation Group (^{o}C/100m)	dT = 10 ^{o}C dZ = …. m
MinasPetani Telisa Sihapas Upper Sihapas Lower	96900	4.53	6.06	165
Pematang SS Pematang MS Pematang BRSH Pematang LP	91100	6.87	4.00	250
Basement	8400	7.59	3.62	276

temperature (^{o}C)	depth change (cm)	Depth (cm)
30 - 40	16500	16500
40 - 50	16500	33000
50 - 60	16500	49500
60 - 70	16500	66000
70 - 80	16500	82500
80 - 90	25000	107500
90 - 100	25000	132500
100 - 110	25000	157500
110 - 120	25000	182500
120 - 130	27600	210100

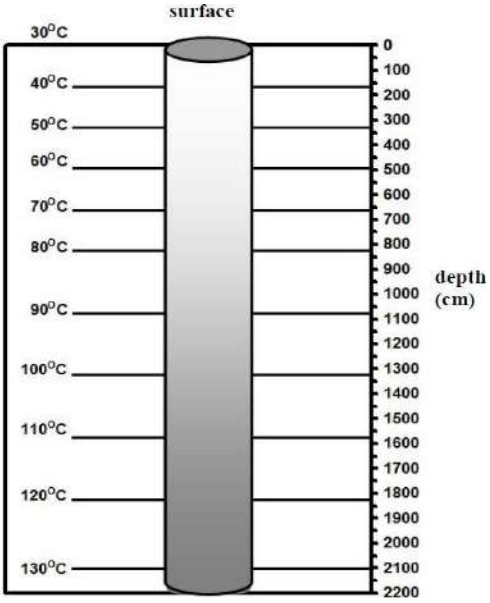

Figure 1: Changes in depth for each 10^{O}C temperature rise, in well A.

The depth of well A is 1964 m, with a surface temperature of 30^{O}C. From the data processing itis produced that 5x the same depth change every 10^{O}C temperature increase is 165 m. Then 4x the same depth change every 10^{O}C temperature increase is 250 m, and 1x the same depth change every 10^{O}C temperature increase is 276 m. Then a depth change model is made for every 10^{O}C temperature increase in well A, which is shown in Figure 1. Seen in Figure 1, the surface temperature is 30^{O}C andthe temperature is 130^{O}C at a depth of 2100 m, while the Bore Hole Temperature (BHT) is 117.78^{O}C at a depth of 1967.7 m. So if we compare the results of the BHT measurement from the log method with the results of the calculation model of the depth change of each 10OC temperature rise, the results are close to similarity. BHT log measurement results (1967.7m = 117.78^{O}C), the model changes depth every 10^{O}C (2100m = 130^{O}C).

CONCLUSION

From the data processing it is produced that 5x the same depth change every 10^{O}C temperature increase is 165 m. Then 4x the same depth change every 10^{O}C temperature increase is 250 m, and 1xthe same depth change every 10^{O}C temperature increase is 276 m. The depth of well A is 1964 m, with a surface temperature of 30^{O}C. So the temperature value from a depth of 165 m to a depth of 2100 m is 40^{O}C to 130^{O}C. Then a depth change model is made for every 10^{O}C temperature increase in well.

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