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Analysis of Form Coefficient for Measuring Gross Tonnage of Wooden Ship Compared with Domestic Measurement Method of Indonesia

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Abstract

Most of the gross tonnage (GT) of the traditional wooden ship in Sinjai and Bone Regencies were measured using the domestic measurement method. By this measurement method, sometimes shipowners who belonged boats with sizes <30 GT think the disadvantaged matters in terms of policies, permits, landing fees, subsidized fuel rations, etc. The objectives of this study are to determine the characteristics of the main dimension and shape of traditional wooden ships affected on the GT calculation, to compare the GT of the traditional wooden ship between the real body calculation with the domestic measurement method, and to compile the formula in determining the value of the ship volume factor *f* based on the main dimensions for the calculation of the GT. The data were processed by using the Slovin technique with the sample number of the traditional wooden ship of 49 ship units. The results show that the traditional wooden ships in Sinjai and Bone Regencies have quite the same geometric characteristics. The GT between the real body and the domestic measurement method seems a difference wherein the GT of cargo ship using the real body is higher than the domestic measurement method, in contrast, for the fishing boat, the GT using the real body is smaller than the domestic measurement method. For small fishing boat <7 GT, the difference of the GT is approximately 40%. The correlation between the volume factor *f* with non-dimensional of volume $LBH^{1/3}$ expresses the high correlation. By an algorithmic equation, the volume factor *f* can be determined by using a function. Using the obtained formula, it can be a reference for a responsible person in charge of the GT measurement to obtain the proper GT.

Keywords: Form coefficient; gross tonnage; ship measurement; traditional wooden ship

1. Introduction

Geographically, Sinjai and Bone Regencies consist of coastal areas, lowlands, and highlands with an altitude between 0-2.871 meters above sea level (masl) of the groundwater level (GW). The two Regencies are contiguous and in the bay of Bone [1]. In general, the coastal communities of Sinjai and Bone Regencies work as fishermen and entrepreneurs. In their daily lives, they use the traditional wooden boat to carry out their activities [2].

Before operating a new ship, the ship has to obligated for being measured in order to obtain the physical identification of the ship such as main dimensions of length, breadth, and height, gross tonnage (GT), and net tonnage (NT). The purpose of the measurement is to fulfill the requirements for registration and issuance of a ship's nationality as well as safety requirements [3].

Most of the gross tonnage (GT) of the traditional wooden ships are measured using the domestic measurement method issued by the Regulation of the Minister of Transportation of the Republic of Indonesia Number PM 8 of 2013 concerning Ship Measurement. To calculate the GT of the traditional wooden ship using the domestic measurement method, it is obtained by multiplying the coefficient of 0.25 by the total volume of the space below the deck and the volume of all rooms above the closed deck [4].

There are several problems related to GT measurement results measured using the domestic measurement method wherein many ship GT do not match the physical themself. Usually, the ship's GT on the document is smaller than the GT of the physical ship wherein this problem is stated commonly as markdown [5], especially, the ships with initial size are less than 30 GT. The difference of GT measurement is the average of up to 111% between the new and old GT measurement result [3]. This happens on a fishing boat with an avoiding mode to obtain fishing permits (SIPI), fisheries business permits (SIUP), and fish transportation ship permits (SIKPI) issued by the head office of the Ministry of Marine Affairs and Fisheries [6], For this reason, many shipowners who belonged the

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traditional wooden boat with size <30 GT decline verification or re-measurement for their ships because the GT results by the verification or re-measurement have increased significantly from the previous GT [7]. Shipowners think the consequence of obtaining the disadvantaged matter in terms of policies, permits, landing fees, subsidized fuel rations, and etc.

By the problem mentioned above, it is very detrimental for the government wherein it can affect the inaccurate data and loss in terms of Non-Tax State Revenues (PNBP). The amount of PNBP is determined from the GT size stated in the ship's document. In addition, the shipowner also experiences loss in the form of assistance, insurance receipts when the shipowner makes a loan with a ship as collateral. As known, the assistance, insurance, and collateral depend on the amount of GT in the documents they have [8].

Correspondingly, the objectives of this study are to determine the characteristics of the main dimensions and shape of traditional wooden ships affected on the GT calculation, to compare the calculation results of the GT of the traditional wooden boat between the real body shape calculation with the domestic measurement methods, and to compile the equation in determining the value of the ship volume factor based on the main dimensions of the traditional boat for the calculation of the GT. The traditional wooden ship as the sample of this present study is in Sinjai and Bone Regencies.

2. Research Method

The locations of the traditional wooden ship are in two locations, namely the Cappa Ujung Port in Sinjai Regency and the Tuju-Tuju Port in Bone Regency, South Sulawesi Province. Both ports are under working area of the Class III Sinjai Port Administration Unit Office.

In this present study, the sample of the measurement documents of the traditional wooden ships are 49 ship units. The traditional wooden ship as a sample is the type of cargo and fishing boat operated at the Cappa Ujung Port and the Tuju-Tuju Port. For the first, the data were processed by using the Slovin technique to obtain a minimum number of sample.

Furthermore, the characteristics of hull and upperdeck on the traditional wooden ship were observed directly on site. Then, the geometry characteristics of the traditional wooden ships were defined by the ratios of L/B, B/H and L/H.

The GT was calculated based on the real body and domestic meaurement method. The real body means the body lines of a ship was directly measured and then it was described by dividing into 12 sections wherein each bow and stern parts are divided by four sections. Then, the real body is divided into five waterplanes wherein the bottom part is divided into two section because of extreme form. This method is used for obtaining the ship volume. For the GT based on the domestic measurement, the calculation of GT is followed Permenhub RI Number PM 8, 2013. Here, By using this domestic measurement method, the GT is applied for a ship with the length of less than 24 meters. The ship length used in the GT calculation is defined by 96% of the length of the length of waterline (LWL) at 85% of the ship height. By this definition of the ship length, it can be considered for using the domestic measurement method if the ship length meets less than 24 meters.

The total volume consists of the volume under the measuring deck (V_1) and the volume of the rooms above the closed deck (V_2). The volume under the measuring deck is defined by multiplying the main dimensions of the ship with a volume factor (*f*) regarding the ship form [4].

Finally, to determine the volume factor *f*, the correlation between the volume factor *f* with non-dimensional of volume defined by $LBH^{1/3}$ are expressed by using several equations such as linear equation, logarithmic equation, power expression equation, and exponential equation. The coefficient of determination (R Square) which gives the greatest influence is formulated in a mathematical equation [9]. Therefore, the equation with the highest determination coefficient becomes the equation of the volume factor used for the GT calculation.

3. Results and Discussion

3.1. Characteristics of traditional wooden ship buildings

3.1.1. General description

The traditional wooden ship is a transportation vehicle and supporting welfare for coastal communities. Generally, this kind of ship is constructed based on knowledge acquired from generation to generation based on tradition in the field and instincts in adapting to their environment [10]. The adaptation process is influenced by the local wisdom of the local area. The local wisdom of an area determines the various forms of traditional wooden ships, both in terms of variations in size and style [11]. The kinds of traditional wooden ship operating in the Regencies of Sinjai and Bone can be seen in Figs. 1 and 2.

Figure 1. Traditional wooden boat in Sinjai Regency

Figure 2. Traditional wooden boat in Bone Regency

3.1.2. Hull characteristics

Most of the traditional wooden ship operating in Sinjai and Bone Regencies are fishing boats and cargo ships. These ships are directly related to the livelihoods of the majority of the population living in coastal areas, who generally work as fishermen and entrepreneurs. There are differences in shape and size between traditional wooden ship operating near the coast and in offshore. However, most of the traditional wooden boat has the same shape characteristics only on the hull that is the bottom shape. The bottom shape is almost semicircular. The hull form of the traditional wooden ship operated in the Regencies of Sinjai and Bone [12,13] can be seen in Figs. 3 and 4.

3.1.3. Characteristics of upper deck

The building of traditional wooden ship operated in Sinjai and Bone Regencies have the characteristics of the upper deck divided into two characteristics of the deckhouse based on the type of ship. A cargo ship generally only has a maximum of two deck houses arranged at the rear wherein the deckhouse is usually used for the crew room, wheelhouse, map room, and radio communication room. The cargo hold is located in the middle part. On the other hand, the fishing boat generally has one deckhouse located in the rear or middle and used for the navigation room, and several fish cargo hatches. The characteristics of the upper deck of the traditional wooden ship operated in the Regencies of Sinjai and Bone are shown in Figs. 5 and 6.

Figure 3. Characteristics of ship hulls in Sinjai Regency

Figure 4. Characteristics of ship hulls in Bone Regency

Figure 5. Characteristics of upper deck of the traditional wooden boat in Sinjai Regency

Figure 6. Characteristics of upper deck of the traditional wooden boat in Bone Regency

3.2. Analysis of geometry characteristics of traditional wooden ships

The number of ship samples operated at the Ports of Cappa Ujung and Tuju-Tuju is 49 units. The data were processed using the Slovin technique with the error of 15%. After the data processing, the minimum number of ship samples was considered 23 units. By the 23 ship units, eight ships are the cargo type and 15 ships are the fishing type.

Moreover, the minimum number of ship sample was further used to analyze the geometric characteristics of traditional wooden ships by using the ratio of main dimensions as follows:

$$\frac{L}{B} = \frac{Length}{Breadth} \tag{1}$$

$$\frac{B}{H} = \frac{Breadth}{Length} \tag{2}$$

$$\frac{L}{H} = \frac{Length}{Height} \tag{3}$$

As the results, the ratio of main dimensions is shown in Table 1 and then the tendency of the main dimension ratio of cargo ship and fishing boat is shown in Figs. 7 and 8 respectively. In those figures, the *x*-axis is defined by *n* ship where *n* is ordered from the small to large ship dimension.

Table 1. The ratio of the main sizes of traditional wooden ship

Type of Ship	L/B	B/H	L/H
Cargo	3.56 – 5.93	2.03 – 3.24	7.77 – 13.43
Fishing Boat	4/42 – 7.25	1.86 – 3.25	9.97 – 20.50

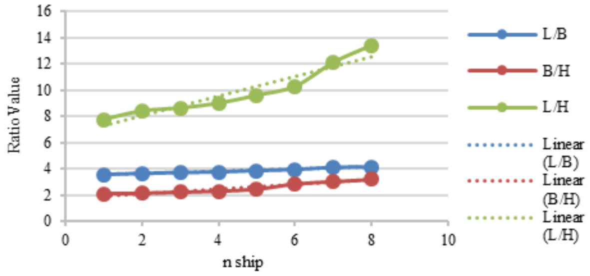

Figure 7. The tendency of the ratio of main dimensions of cargo ship

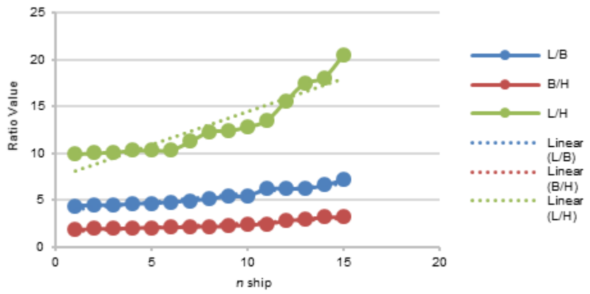

Figure 8. The tendency of the main dimension ratio of the fishing boat

Based on Fig. 7, for the cargo ship, the ratio of L/B is the range of 3.56 to 5.93 and it is obtained in the range of ship length from 20.19 to 27.0 m and ship breadth in the range of 4.75-6.90 m. The overall ratio L/B is an average of 3.86. The ratio of B/H is in the range of 2.03 to 3.24 for the height range 1.55-3.09 m. The overall ratio B/H is an average of 2.56. Moreover, the ratio of L/H is the range of 7.77-13.43. Then, the overall ratio L/H is an average of 9.91.

Based on Fig. 8, for the fishing boat, the ratio of L/B is the range of 4.42-7.25 and it is obtained in the range of ship length from 11.60-21.70 m and ship breadth in the range of 1.85-4.85 m. The overall ratio L/B is an average of 5.42. The ratio of B/H is in the range of 1.86-3.25 for the height range 0.60-1.97 m. The overall ratio B/H is an average of 2.41. Moreover, the ratio of L/H is the range of 9.97-20.50. Then, the overall ratio L/H is an average of 13.05.

As known, the ratios of L/B and B/H characterize the ship stability and resistance. Meanwhile, the ratio of L/H characterize the longitudinal ship strength. In future work, the influence of the main dimension ratios should be analyzed on ship hydrodynamics and strength because the geometry of the traditional wooden ship is quite different with the modern ship.

3.3. Calculation and comparison of gross tonnage (GT)

3.3.1. Direct measurement of the ship main dimensions of the ship

The main dimensions of the wooden ships were measured directly in Sinjai and Bone Regencies and the main dimensions are shown in Table 2. The direct measurement was carried out to the conformity of the main dimensions of the wooden ship stated in the ship document. In fact, the direct measurement of the main dimensions for five traditional wooden ships is larger than stated in ship document. These direct measurement results are used for the GT calculation followings.

Table 2. Main dimensions of traditional wooden ship

Ship Name	Type of Ship	Main Dimensions (m) Ldeck	B	H	LOA	LWL	LBP
Ship A	Cargo	26.00	6.90	3.05	27.18	23.93	21.44
Ship B	Cargo	25.85	5.02	2.12	26.78	22.58	21.07
Ship C	Fishing Boat	19.00	4.06	1.68	19.00	17.05	15.60
Ship D	Fishing Boat	14.70	2.44	1.29	14.70	13.23	12.36
Ship E	Fishing Boat	13.60	2.06	1.10	13.60	12.25	11.44

Table 3. The GT of real ship body

Ship Name	Type of Ship	V under deck (V_1)	V upper deck (V_2)	V ($V_1 + V_2$)	GT
Ship A	Cargo	298.68	68.46	367.14	92
Ship B	Cargo	155.20	45.44	200.64	49
Ship C	Fishing Boat	7.63	17.03	88.66	21
Ship D	Fishing Boat	25.74	0	25.74	5
Ship E	Fishing Boat	16.61	0	16.61	3

3.3.2. GT calculation of the actual main dimensions and shape (real body)

The GT calculations of the actual main dimensions as result of the direct measurement mentioned previously were conducted. Here, the ship body were divided by the large number of sections to obtain the real body of the traditional wooden ship because the body form of the traditional is generally different and almost parallel bodies are less [14]. The calculation method using the real body is almost same method with the international measurement method. By the difference of body form, the real body is considered to be divided into 12 sections wherein each bow and stern parts are divided by four sections. Then, the real body is divided into five waterplanes wherein the bottom part is divided into two section because of extreme form. This method is used for obtaining the ship volume. As the results, the GT for the five traditional wooden ships is shown in Table 3.

3.4. GT calculation based on domestic measurement method

Here, the GT calculation is referred to the Regulation of Transportation Ministry of Republic of Indonesia Number PM 8, 2013. By using this domestic measurement method, the GT is applied for a ship with the length of less than 24 meters. The ship length used in the GT calculation is defined by 96% of the length of the length of waterline (LWL) at 85% of the ship height. By this definition of the ship length, it can be considered for using the domestic measurement method if ship length meets less than 24 m.

The total volume consists of the volume under the measuring deck (V_1) and the volume of the rooms above the closed deck (V_2). The volume under the measuring deck is defined by multiplying the main dimensions of the ship with a volume factor (*f*) regarding the ship form [4]. The volume factor *f* is here used that are 0.50 and 0.70 mentioned in the measurement documents. Correspondingly, the GT of a ship is obtained by multiplying a coefficient K_1 of 0.25 with the total volume (V). Therefore, the GT are obtained for the five sample vessels as shown in Table 4.

Table 4. The GT using the domestic measurement method

Ship Name	Type of Ship	Length (L)	Breadth (B)	Height (H)	85% H (T)	LOA	LWL	96% LWL	LBP	*f*	V_1	V_2	V (V_1+V_2)	GT
Ship A	Cargo	26.00	6.90	3.05	2.59	27.18	23.93	22.97	21.44	0.50	273.59	68.46	342.05	85
Ship B	Cargo	25.85	5.02	2.12	1.80	26.78	22.58	21.68	21.07	0.50	137.55	45.44	182.99	45
Ship C	Fishing Boat	19.00	4.06	1.68	1.43	19.00	17.05	16.37	15.60	0.70	90.72	17.03	107.75	26
Ship D	Fishing Boat	14.70	2.44	1.29	1.10	14.70	13.23	12.70	12.36	0.70	32.39	0.00	32.39	8
Ship E	Fishing Boat	13.60	2.06	1.10	0.94	13.60	12.25	11.76	11.44	0.70	21.57	0.00	21.57	5

Table 5. The GT using the real body and the domestic measurement method

Comparison of GT Real Body (RB) vs Domestic	Ship A		Ship B		Ship C		Ship D		Ship E	
	Cargo		Cargo		Fishing Boat		Fishing Boat		Fishing Boat	
	RB	Domestic	RB	Domestic	RB	Domestic	RB	Domestic	RB	Domestic
Length (L)	26.00	26.00	25.85	25.85	19.00	19.00	14.7	14.7	13.6	13.6
Breadth (B)	6.90	6.90	5.02	5.02	4.06	4.06	2.44	2.44	2.06	2.06
Height (H)	3.05	3.05	2.12	2.12	1.68	1.68	1.29	1.29	1.1	1.1
85% H (T)	2.59	2.59	1.80	1.80	1.43	1.43	1.1	1.1	0.94	0.94
LWL	23.93	23.93	22.58	22.58	17.05	17.05	13.23	13.23	12.25	12.25
96% LWL	22.97	22.97	21.68	21.68	16.37	16.37	12.7	12.7	11.76	11.76
LBP	21.44	21.44	21.07	21.07	15.60	15.60	12.36	12.36	11.44	11.44
V_1	298.68	273.59	155.20	137.55	71.63	90.72	25.74	32.39	16.61	21.57
V_2	68.46	68.46	45.44	45.44	17.03	17.03	0	0	0	0
V $(V_1 + V_2)$	367.14	342.05	200.64	182.99	88.66	107.75	25.74	32.39	16.61	21.57
GT	**92**	**85**	**49**	**45**	**21**	**26**	**5**	**8**	**3**	**5**
f	**0.55**	**0.50**	**0.56**	**0.50**	**0.55**	**0.70**	**0.56**	**0.7**	**0.54**	**0.7**

Table 6. The difference in GT using the real body and the domestic measurement method

Ship Name	Type	GT	GT	Difference (%)	Description
		RB	Domestic		
Ship A	Cargo	92	85	7.61	RB > Domestic
Ship B	Cargo	49	45	8.16	RB > Domestic
Ship C	Fishing Boat	21	26	19.23	RB < Domestic
Ship D	Fishing Boat	5	8	37.50	RB < Domestic
Ship E	Fishing Boat	3	5	40.00	RB < Domestic

Table 7. The GT using the same *f* for the real body and domestic measurement method

Comparison of GT Real Body (RB) vs Domestic	Ship A		Ship B		Ship C		Ship D		Ship E	
	Cargo		Cargo		Fishing Boat		Fishing Boat		Fishing Boat	
	RB	Domestic	RB	Domestic	RB	Domestic	RB	Domestic	RB	Domestic
Length (L)	26.00	26.00	25.85	25.85	19.00	19.00	14.7	14.7	13.6	13.6
Breadth (B)	6.90	6.90	5.02	5.02	4.06	4.06	2.44	2.44	2.06	2.06
Height (H)	3.05	3.05	2.12	2.12	1.68	1.68	1.29	1.29	1.1	1.1
85% H (T)	2.59	2.59	1.80	1.80	1.43	1.43	1.1	1.1	0.94	0.94
LWL	23.93	23.93	22.58	22.58	17.05	17.05	13.23	13.23	12.25	12.25
96% LWL	22.97	22.97	21.68	21.68	16.37	16.37	12.7	12.7	11.76	11.76
LBP	21.44	21.44	21.07	21.07	15.60	15.60	12.36	12.36	11.44	11.44
V_1 (LxBxHx *f*)	300.94	273.59	154.06	137.55	71.28	90.72	25.91	32.39	16.64	21.57
V_2	68.46	68.46	45.44	45.44	17.03	17.03	0	0	0	0
V $(V_1 + V_2)$	369.40	342.05	199.50	183.00	88.30	107.74	25.91	32.39	16.64	21.57
GT	**92**	**85**	**49**	**45**	**22**	**26**	**6**	**8**	**4**	**5**
f	**0.55**	**0.50**	**0.56**	**0.50**	**0.55**	**0.70**	**0.56**	**0.70**	**0.54**	**0.70**

Table 8. The difference in GT using the same *f* between the real body and the domestic measurement method

Ship Name	Type	GT		Difference (%)	Description
		RB	Domestic		
Ship A	Cargo	92	85	7.61	RB > Domestic
Ship B	Cargo	49	45	8.16	RB > Domestic
Ship C	Fishing Boat	22	26	15.38	RB < Domestic
Ship D	Fishing Boat	6	8	25	RB < Domestic
Ship E	Fishing Boat	4	5	20	RB < Domestic

3.4.1. Comparison of the calculation results of Gross Tonnage (GT)

The GT using the real body calculation and the domestic measurement method is shown in Tables in Table 5 and the weight of the difference between real body calculation and the domestic measurement method is shown in Table 6. As the results, the GT between the real body and the domestic measurement method seems a difference wherein the GT of cargo ship using the real body is higher than the domestic measurement method, in contrast, for the fishing boat, the GT using the real body is smaller than the domestic measurement method. For small fishing boat <7 GT, the difference of the GT is approximately 40% and this is higher value. This matter should be an attention for Government because it relates directly to the fishermen.

On the other hand, by using the volume factor *f* as obtained from the real body, it is further used in the GT calculation of the domestic measurement method as shown in Table 7. Then, the weight of the difference between real body calculation and the domestic measurement method in using the same volume factor *f* obtained from the real body is shown in Table 8. As the comparison result between Table 6 and 8, the GT of the ship cargo is the same difference, however, the difference of the GT for the fishing boat is an average of 12.12%.

3.5. Mathematical equations for determination of volume factor

To determine the volume factor *f*, the correlation between the volume factor *f* with non-dimensional of volume defined by $LBH^{1/3}$ are expressed by using several equations such as linear equation, logarithmic equation, power expression equation, and exponential equation as shown in Figs. 9-12. On the other hand, the coefficient block is used to replace *f* in calculating the GT [15].

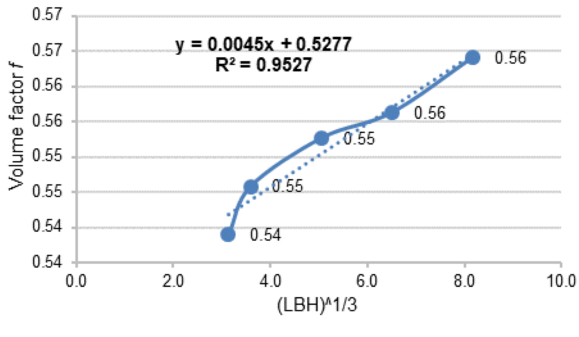

Figure 9. The correlation of the volume factor *f* and $(LBH)^{1/3}$ using linear equation

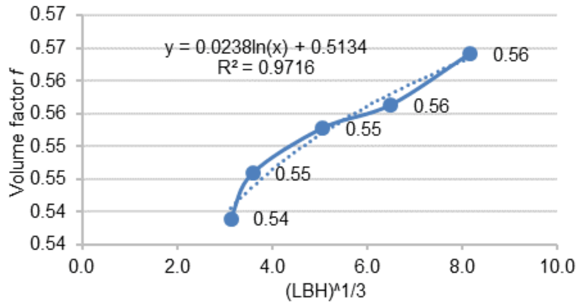

Figure 10. The correlation of the volume factor *f* and $(LBH)^{1/3}$ using logarithmic equation

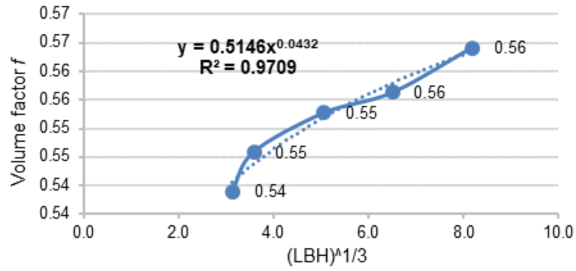

Figure 11. The correlation of the volume factor *f* and $(LBH)^{1/3}$ using power expression equation

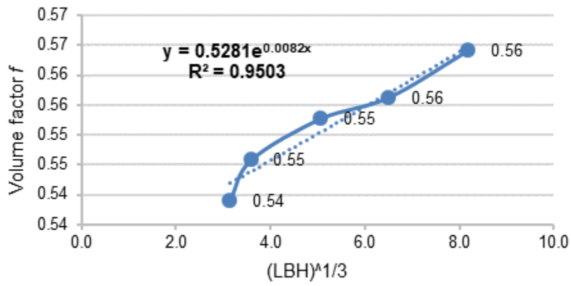

Figure 12. The correlation of the volume factor *f* and $(LBH)^{1/3}$ using exponential equation

Based on Figs. 9-12, the logarithmic equation is the highest correlation between volume factor *f* with $LBH^{1/3}$ due to the determination (R Square) result given the value of 0.9176. By the algorithmic equation, the volume factor *f* can be determined by using the function of y = 0.238 log (x) + 0.5134 or f = 0.238 log $(LBH)^{1/3}$ + 0.5134.

4. Conclusion

This present study was successfully conducted in order to obtain the characteristics of the main dimensions of the traditional wooden ships affected on the GT calculation, the difference of the GT of the traditional wooden boat between the real body and the domestic measurement methods, last but not least the equation in determining the value of the ship volume factor based on the main dimensions of the traditional boat for the calculation of the GT followings.

- The overall ratio of L/B, B/H, and L/H for ship cargo is an average of 3.86, 2.56, and 9.91 respectively. For the fishing boat, the overall ratio of L/B, B/H, and L/H is an average of 5.42, 2.41, and 13.05 respectively. Also, these ratios indicate that traditional wooden ships operated in the Sinjai and Bone Regencies have the quite same of geometry characteristics.
- The GT between the real body and the domestic measurement method seems a difference wherein the GT of cargo ship using the real body is higher than the domestic measurement method, in contrast, for the fishing boat, the GT using the real body is smaller than the domestic measurement method. For small fishing boat <7 GT, the difference of the GT is approximately 40% and this is higher value. This matter should be an attention for Government because it relates directly to the fishermen. This matter should be an attention for Government because it relates directly to the fishermen. Moreover, by using the volume factor *f* as obtained from the real body, the weight of the difference between real body calculation and the

domestic measurement method, the GT of the ship cargo is the same difference, however, the difference of the GT for the fishing boat is an average of 12.12%.

- The correlation between the volume factor f with non-dimensional of volume defined by $LBH^{1/3}$ expresses the high correlation. For highest correlation, the logarithmic equation is given the determination (R Square) of 0.9176. By the algorithmic equation, the volume factor f can be determined by using the function of $y = 0.238 \log(x) + 0.5134$ or $f = 0.238 \log (LBH)^{1/3} + 0.5134$.

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