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Alpha Parameter Modeling of Nakayasu Synthetic Unit Hydrograph Based on the Watershed Shape Factor

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Abstract: The limitation of hydrograph data availability becomes an obstacle for the design of water resources. The obstacle makes the Synthetic Unit Hydrograph give the big enough benefit for the design of water resources. Ideally, every watershed has its unit hydrograph. The Nakayasu Synthetic Unit Hydrograph is one of the synthetic unit hydrographs frequently used in the analysis of design flood discharge in Indonesia. However, the Nakayasu Synthetic Unit Hydrograph concept has been widely used and evaluated in some areas in Indonesia, and there is bias in determining the watershed characteristic coefficient. This research intends to investigate the characteristic of the observed hydrograph in every watershed and the whole watershed in the South Sulawesi Province-Indonesia. The research aims to build the alpha formula using alpha modeling with the affected parameters of watershed area, river length, river bed slope, shape factor, and the time concentration. Based on the ArcGIS version 10.7, most of the watershed's shapes are elongated. The methodology consists of analyzing observed unit hydrograph by using the Collins method and Nakayasu Synthetic Unit Hydrograph. Then the model is built by using the statistical analysis of SPSS version 23 software for obtaining the affected level of each parameter that is determined. However, the modeling analysis uses the non-linear regression after there is carried out the descriptive test. The alpha formula for the elongate watershed in the Jeneberang River is proposed.

Keywords: alpha parameter, watershed area, river length, slope, shape factor.

基於流域形狀因子的中安合成單元水位線阿爾法參數建模

摘要：水文數據可用性的限製成為水資源設計的障礙。障礙使得綜合單元水文線為水資源設計提供了足夠大的收益。理想情況下，每個流域都有其單位水位線。中安合成單元水道線是印度尼西亞設計洩洪分析中常用的合成單元水道線之一。但是，中安合成單元水位線概念已在印度尼西亞部分地區得到廣泛應用和評估，在確定流域特徵係數時存在偏差。本研究旨在調查印度尼西亞南蘇拉威西省每個流域和整個流域的觀測水文特徵。本研究旨在利用流域面積、河流長度、河床坡度、形狀因子和時間濃度等影響參數，利用阿爾法模型建立阿爾法公式。基於航空偵察覆蓋地理信息系統 10.7 版，流域的大部分形狀都是拉長的。該方法包括使用柯林斯方法和中安合成單元水位線分析觀察到的單元水位線。然後利用社會科學統計軟件包 23 版軟件統計分析建立模型，得到確定的各參數的影響程度。但是，建模分析在進行描述性測試後使用非線性回歸。提出了傑尼貝朗 河中細長流域的α 公式。

关键词：α 參數、流域面積、河流長度、坡度、形狀因子。

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1. Introduction

The Synthetic Unit Hydrograph will become the important information source that is necessary for the reliability of hydraulic structures [1]. To well understand the run-off process is not easy [2]. However, ideally, every watershed has its particular hydrograph [3]. If the hydrological and physical conditions are generally very homogeneous, it would be possible to create a new Synthetic Unit Hydrograph model that resembles the ones made up by the previous researchers [4]. Realizing that the Synthetic Unit Hydrograph Models have been researched and developed in the areas where the watersheds are far different from the ones applied, it very often comes up with inaccurate results that influence the hydro structure design. Therefore, it was necessary to calibrate some parameters for the ideal cases [5]. The limiting physical parameters of the Synthetic Unit Hydrograph have been studied before [6-8]

The Nakayasu Synthetic Unit Hydrograph is one of the synthetic unit hydrographs frequently used in the analysis of design flood discharge in Indonesia. Nakayasu synthetic unit hydrograph was first developed on some rivers in Japan [9]. However, based on the Nakayasu synthetic unit hydrograph concept, widely used and evaluated in some areas of Indonesia [9], there is always an adjustment of the location characteristics parameters, mainly those related to the parameter α (alpha). The alpha (α) parameter has been determined with various values and ranges based on the results of studies conducted in Japan. The study by Dewi *et al.* [10] was conducted in the Lesti sub-watershed gave the result of α (alpha) value is about 2.777, and the relative error between the Nakayasu Synthetic Unit Hydrograph and the Collins Observed Hydrograph for the QP value is 0.33%. However, the mean absolute error (MAE) between the Nakayasu Synthetic Unit Hydrograph and the observed hydrograph is 0.782. Ramadani *et al.* [11] stated that α parameter depends on the watershed characteristic, namely the area and the length of the watershed, which the value of α alpha $604 \frac{A^{0,215}}{L^{0,528}}$ is. Priyantoro and Limantara [12] stated that α parameter is strongly affected by the river characteristic. Also, each watershed with a certain rainfall will produce certain α value. Therefore, research must be carried out to build the appropriate α parameters based on the watershed characteristic [13].

This research intends to build the correction factor of α parameter of the Nakayasu Synthetic Unit Hydrograph. This alpha (α) parameter is predicted as the function of the watershed shape factor.

2. Materials and Methods

This research was conducted in the Jeneberang river area, which is the biggest river. The location is in the western of Makasar city (Ujung Pandang), the capital of Sulawesi Selatan Province. Geographically, the Jeneberang watershed is in the east longest of 119° 23' 50" - 119° 56' 10" and in the south longest of 05° 10' 00" - 05° 26' 00". The main river length is 78.75 km. The Jeneberang watershed is flowed by an effluent that is the Jenelata river. Map of location is presented as in Fig. 1.

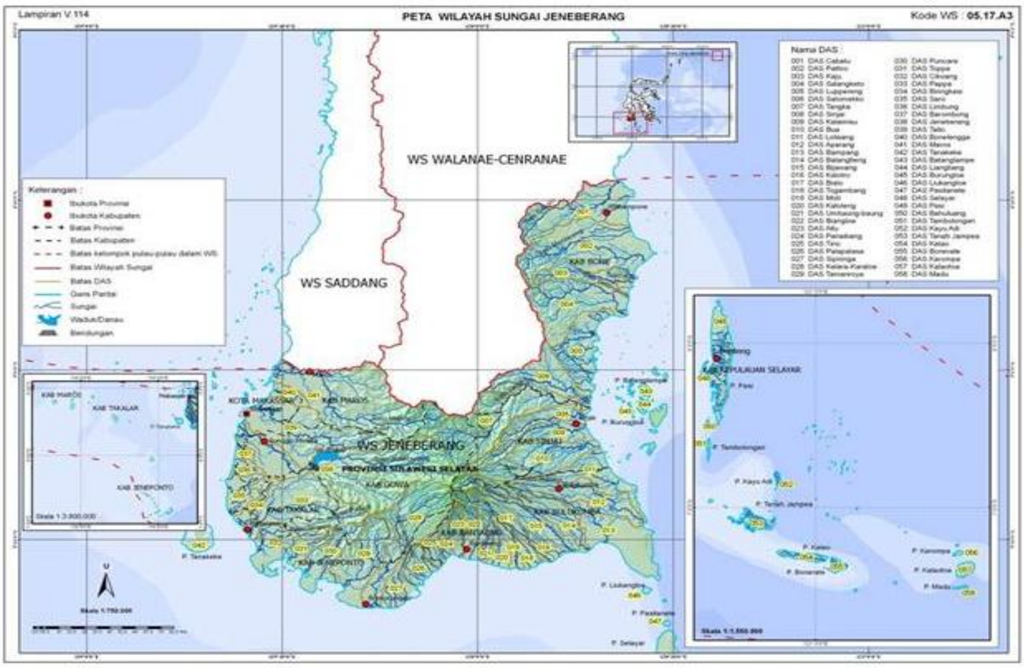

Fig. 1 Map of Jeneberang river area (Perpres Nomor 12 Tahun 2012)

The steps of this research are as follow:

2.1. Determination of Watershed Shape

The determination of watershed shape in the Jeneberang watershed is carried out by using the Software of Arc-GIS 10.7.

2.2. Collecting of Technical Data

The data collecting is carried out in detail as the data of ARR (Automatic Rainfall Recorder), AWLR (Automatic Water Level Recorder), DEM (Digital Equation Model), and topography.

2.3. Methodology

The methodology in this research is as follow:

a. To recap the maximum daily rainfall from 2008 until 2017 as the base of observed unit hydrograph analysis by using the Collins and Nakayasu Synthetic Unit Hydrograph methods.

b. To carry out the descriptive test using the Software of SPSS version 23.

c. To build the Alpha modeling by using the Software of SPSS version 23.

d. To carry out the model validity test of the Alpha formula.

e. To carry out the verification test of the Alpha formulation model.

3. Results and Discussion

3.1. Collins Method and Nakayasu Synthetic Unit Hydrograph Method

From the ten observation stations in the watersheds of Bonto Jai, Daraha, Jenelata, Jonggoa, Kampili, Maccini Sambala, KD-1, Malino, Limbunga, and Panaikang, there are obtained the data of ARR and AWLR from 2008 until 2017. Then there is the analysis of the Observed Unit Hydrograph (HSO) by using Collins's method and the Nakayasu synthetic unit hydrograph to obtain the Alpha value from the ten sub-watersheds. Table 1 presents the result of HSO analysis by using Collins's method and alpha value by using Nakayasu SUH.

Table 1 Analysis result of HSO (Collins's method) and alpha (α, Nakayasu SUH) (Own study)

Sub-watershed	Watershed area (A)	River length (L)	Tg			Shape factor	Watershed shape
	km²	km	Jam	S	α	FD	
Bonto Jai	312,010	33.00	2.314	0.018	0.60	3.83	Elongate
Daraha	15,780	9.33	1.003	0.016	1.10	0.69	Elongate
Janelata	187,998	29.00	2.082	0.028	1.20	2.86	Elongate
Jonggoa	119,047	20.00	1.560	0.082	1.40	2.35	Elongate
Kampili	646,651	55.00	3.590	0.040	0.56	4.99	Elongate
M.Sombala	737,000	73.00	4.634	0.007	1.04	4.42	Elongate
Malino	17,061	10.84	1.110	0.055	1.10	0.55	Elongate
KD-1	198,450	28.83	2.072	0.007	0.77	0.64	Elongate
Panaikang	437,780	69.00	4.410	0.052	0.70	0.49	Elongate
Limbunga	728,700	73.04	4.630	0.002	0.80	0.38	Elongate

Based on the statistical analysis between the observed unit hydrograph and Nakayasu Synthetic Unit Hydrograph, the factors that affect α value are: watershed area (A), river length (L), river slope (S), watershed shape factor (FD) with the correlation coefficient in the range of 0-5 and also the duration from a weighted point of rainfall until peak discharge (Tg).

3.2. Descriptive Analysis

This analysis is carried out to know the effect level of the variables of A (watershed area), L (river length), S (slope), and FD (shape factor) to α model. The results are presented in Fig. 2.

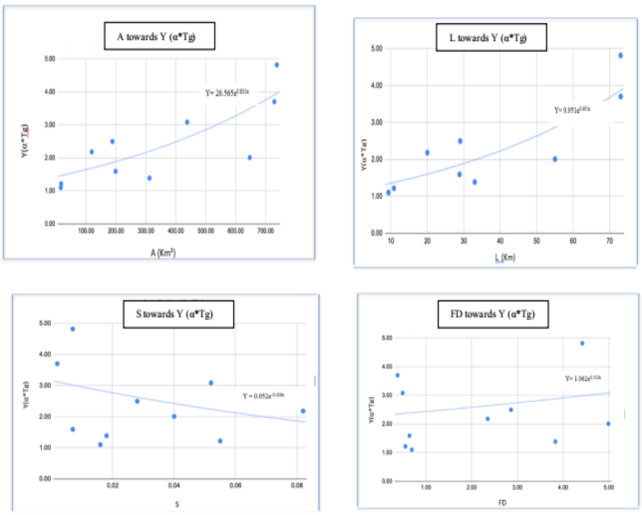

Fig. 2 The relation between A, L, S, and FD to the Y(α*Tg) exponentially

The parameter of A (watershed area), L (river length), and DF (shape factor) have a significant influence on the α parameter; however, the parameter of S (slope) is not significantly influenced by the α parameter as presented in Fig. 2.

3.3. Non-Linear Regression Analysis

The non-linear regression analysis is used to show the relation form or function in which the variable can function as the factor or the variable with a certain exponent and the exponential function. The value of α (alpha), A (watershed area), L (river length), FD (shape factor), Tg (duration from rainfall weight point until peak discharge), and S (river slope) are entered into the software of SPSS version 23. The result is the α formula modeling as follow:

$$\alpha = 0.129\ (A^{-0.727}\ L^{1.729}\ S^{-0.143}\ FD^{0.181})/Tg \qquad (1)$$

where α as the result of modeling is compared straight with L (river length) and FD (shape factor), however, α is versus inverse with A (watershed area), S (slope), and Tg (duration from rainfall weight point until peak discharge).

3.4. Validation of Model

To validate the model to the observed one is carried out using Root Mean Square Errors (RMSE). RMSE intends to present the mean square error between the model and the measuring value or target. The Root Mean Square Errors (RMSE) require close to zero. The formula of RMSE is as follow:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \overline{y_i}\right)^2}{n}} \qquad (2)$$

Table 2 presents the result of model validation.

Table 2 Result of model validation (Own study)

Sub-watershed	Watershed area, A, km^2	River length, L, km	New Alpha	Old Alpha	New Alpha-Old Alpha
Bontojai	312.010	33.000	0.816	0.600	0.050
Daraha	15.780	9.330	1.386	1.100	0.080
Janelata	187.998	29.000	0.934	1.200	0.070
Jonggoa	119.047	20.000	0.756	1.400	0.410
Kampili	646.651	55.000	0.700	0.560	0.020
M. Sombala	737.000	73.000	1.011	1.040	0.000
Malino	17.061	10.840	1.233	1.100	0.020
KD-1	198.450	28.830	0.831	0.770	0.000
Panaikang	437.780	69.000	0.709	0.700	0.000
Limbuga	728.700	73.040	0.784	0.800	0.000
				Total	0.66
				RMSE	0.26

The results show that the RMSE is 0.26, which means that the value is close to zero. There is a good correlation between the alpha of the model and AWLR or in the field. The validation result shows that the area under the hydrograph curve limited by the x-axis and y-axis from the new-alpha and old alpha is close to the existing condition, as presented in Fig 3. As the model result, the alpha is the suitable approach with the river characteristic regarding the watershed area. That happens because the effect of the new alpha value gives the impact to the whole parameters that affect it. Table 3 presents the area under the alpha modeling curve.

Table 3 Area under alpha modeling curve (Own study)

Sub-watershed	Existing data		Modeling data	
	Watershed area (A)	Old Alpha	Area under curve (A)	Alpha Model
Bonto Jai	312.010	0.600	350,010	0.816
Daraha	15.780	1.100	18,400	1.386
Janelata	187.998	1.200	160,153	0.934
Jonggoa	119.047	1.400	85,047	0.756
Kampili	646.651	0.560	628,651	0.700
M.Sombala	737.000	1.040	725,000	1.011
Malino	17.061	1.100	19,060	1.233
KD-1	198.450	0.770	209,580	0.831
Panaikang	437.780	0.700	439,980	0.709
Limbunga	728.700	0.800	720,700	0.784

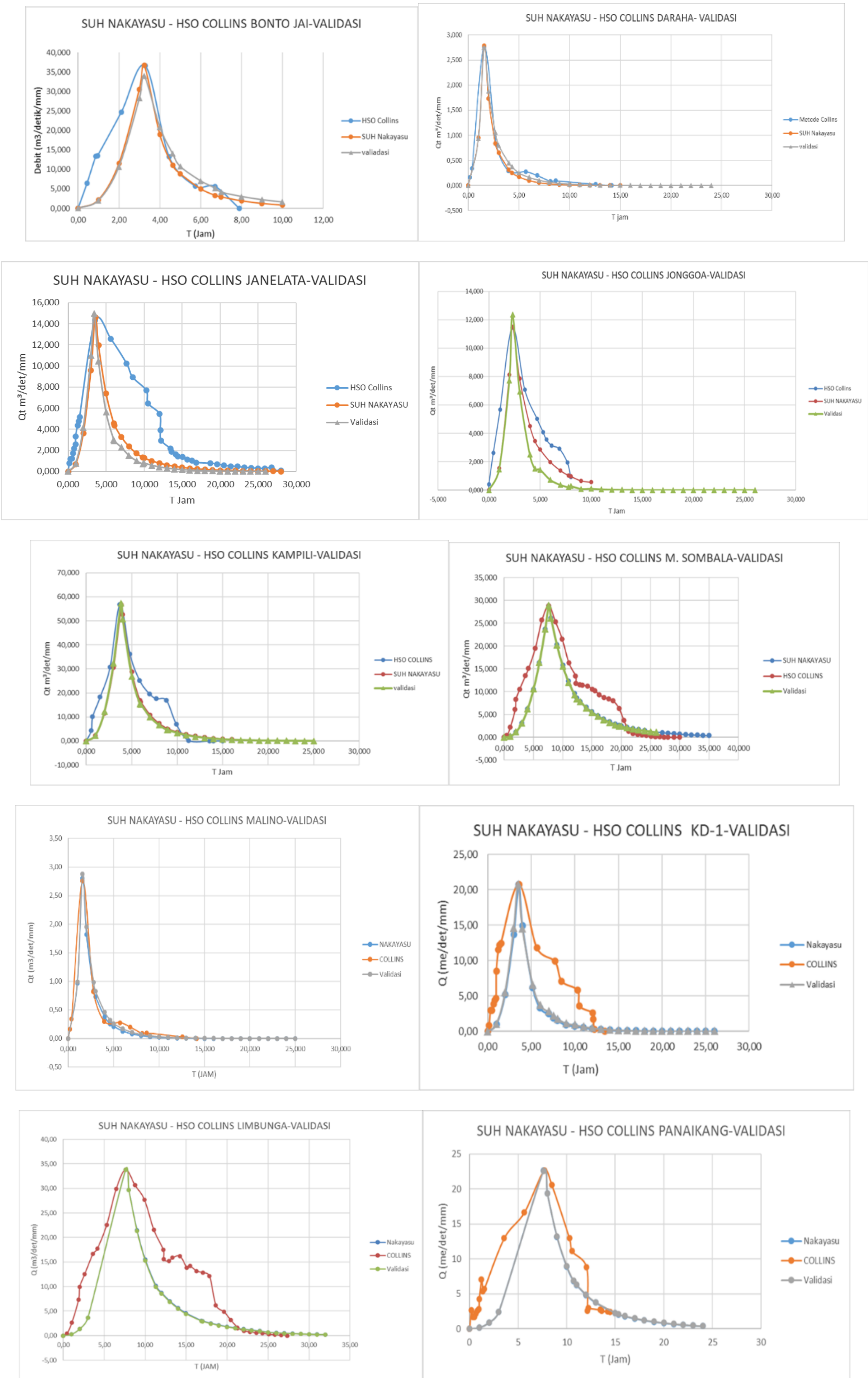

Fig. 3 Validation of area under the hydrograph curve in the 10 Sub-watersheds in the Jeneberang river area

3.5. Model Verification

The model is verified in other sub-watershed using α model; the result is presented in Table 4.

Table 4 Result of model verification (Own study)

Sub-watershed	New Alpha	Old Alpha
Megempang	1.87	1.59
Bili-Bili	1.05	1.55

4. Conclusion

Based on the analysis and discussion above, it can be concluded as follow:

1. Based on the data analysis by using ArcGIS 10.7 software for 58 watersheds and the criteria of watershed shape, it is obtained that most sub-watersheds in the Jeneberang river area have the elongate shape. The criterion of the watershed that is used is that the watershed has to have the data of ARR and AWLR as the base for analyzing by using the Collins and Nakayasu SUH method. Ten sub-watersheds have the data of ARR and AWLR from 2008 until 2017. According to the criteria for using the researched watershed, this research uses the ten sub-watersheds.
2. Based on the approach result (statistical analysis) between the observed unit hydrograph and Nakayasu Synthetic Unit Hydrograph, the factors that affect the α value are watershed area (A), river length (L), river slope (S), watershed shape factor (FD) with the correlation coefficient in the range of 0-5 and also the duration from a weighted point of rainfall until peak discharge (Tg). The result of the descriptive analysis shows that the factor A (watershed area), L (river length), and FD (shape factor) have a positive effect on the alpha (α) in the meaning of having a significant effect on α parameter. However, S (slope) has a negative effect on α parameter in the meaning of the effect is not significant. The modeling result shows that α is compared straight with L (river length) and FD (shape factor); however, α is versus inverse with A (watershed area), S (slope), and Tg (duration from rainfall weight point until peak discharge).

Alpha modeling is obtained due to the limitation as follow: $15\ km^2 \leq A \leq 750\ km^2$; $9\ km \leq L \leq 75\ km$; $0 \leq FD \leq 5$; $0 \leq S \leq 0.04$; and $1\ hour \leq Tg \leq 5$ hours. Alpha model for the elongate shape by using non-linear regression analysis produces the formula as follow:

$$\alpha = 0{,}129\ (A^{-0.727}\ L^{1.729}\ S^{-0{,}143}\ FD^{0.181})/Tg$$

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