Optimization for Production Tert-Butyl Glycoside Nonionic Surfactant Using Response Surface Methodology

Harsa Pawignya¹,²*, T. D. Kusworo¹, and B. Pramudono¹

¹Department of Chemical Engineering, Diponegoro University, Jl. Prof. Soedarto, Kampus Undip Tembalang, Semarang 50239, Indonesia.
²Department of Chemical Engineering, University of Pembangunan Nasional “Veteran” Yogyakarta, Jl. SWK 104 Condongcatur Yogyakarta, 55283, Indonesia

email: harsa_paw@yahoo.co.id

Abstract. It is necessary to develop a surfactant production process using environmentally friendly raw materials and products. For raw materials such as surfactants are carbohydrate-based material utilization example, glucose, which is reacted with tert-butanol, to form tert-butyl glycoside (TBG). This study aims to obtain the optimum conditions TBG production process of acetalization reactions, glucose and tert-butanol, catalyst the para toluene sulfonic acid using response surface method to reach optimum yield TBG. The independent variable used is the mole ratio of glucose with tert-butanol, percent of the catalyst and a temperature. Optimization results obtained optimum conditions of mole ratios of 1: 5.06; 2.87 percent of the catalyst and the temperature of 71.21 °C with a TBG yield of 99.13%, with a TBG content of 61.2 %. The optimum process conditions are verified to strengthen the model equations obtained by the response surface method. Based on the Hydrophilic-Lipophilic Balance value of the surfactant TBG is 4.60, then these surfactants can be used as an emulsifier of water-in-oil.

1. Introduction

Surfactants from petroleum and natural gas derivatives can cause environmental pollution, because after use, it will be a difficult waste to degrade. In addition, petroleum is a source of non-renewable material. This problem has caused many parties to find alternative surfactants that are easily degraded and derived from renewable raw materials [1, 2]. Agricultural products containing carbohydrates can be used as raw materials in the environmentally friendly surfactant industry. Surfactants made from carbohydrate feedstocks can provide benefits that are easily degraded, environmentally friendly and non-toxic Nonionic surfactants can be used as detergents, solubilizing agents, emulsifying agents, dispersing agents, and potency biomaterials applications [3-7]. Surfactant alkyl polyglycoside (APG) is a non-ionic surfactant that made from renewable natural materials, namely carbohydrates and fatty alcohol [2, 8]. APG surfactant is a nonionic surfactant which has the properties as well as the ecological and toxicological properties of a good interface [9].

APG can be used as an additive in the formulation of some products such as herbicide formulations, personal care products, cosmetics and for bleaching fabrics/textiles [10]. The use of a surfactant may be selected based on the hydrophilic-lipophilic balance (HLB) value of the surfactant, for examples of HLB value of 1-3 for antifoaming, HLB 2-7 for emulsifier type W/O, HLB 7-9 for wetting, HLB 8-18 for emulsifier type O/W, HLB 13-15 for detergents and HLB 15-18 for a solvent
agent. HLB is a number that indicates the ratio between the hydrophilic and lipophilic groups in a surfactant [11]. The addition of the surfactant in the solution would cause a decrease in surface tension, once it reaches a certain concentration, surface tension will be constant even if the surfactant concentration increased, when a surfactant was added beyond this concentration, the surfactant aggregates to form molecules. At the concentration of molecule formation called the Critical Micelle Concentration (CMC) [12]. Various surfactant APG other types made from base ingredients carbohydrates such as surfactants ter-butyl glycoside (TBG), made from the reaction of acetalization of glucose with tert-butanol to produce TBG, TBG surfactants including APG surfactant group.

In this research, a new thing is synthesizing surfactant TBG, from the reaction of acetalization of glucose with tert-butanol to produce tert-butyl glycosides, using a para toluene sulfonic acid (p-TSA) catalyst and to use a solvent petroleum ether [13]. APG surfactant results of previous studies have a dark brown color that is not desirable because the temperature is too high above 80 °C, while this study using temperature below 80 °C to produce better color surfactant that is a clear. The purpose of this study was to optimize the conditions esterification process.

The experimental design optimization of the process conditions in production TBG, using Response Surface Methodology (RSM) and research using composite design centered. It is suitable for determining squared surfaces and helps to optimize effectiveness parameters with a minimum number of tests, and also to analyze the interaction between the parameters. By using RSM can be known functional relationship between response variables with a number of variables that have an effect. RSM can also be used to evaluate key experimental parameters simultaneously with time and cost efficiency [14]. Of the optimum processing conditions will yield maximum results obtained, so that the data can use as a condition of the data in the design of the reactor. Optimization is to determine the process parameters that are optimum mole ratio of reactants, percent p-TSA catalyst and process temperature, which produces the maximum yield TBG.

2. Experimental

2.1. Material

Glucose (Merck, 99 %), tert-butanol (Merck, 98 %), petroleum ether (Technical), p-TSA (Merck, 98.5 %), cupric sulfate (Merck, 99.28 %), natrium sulfate (Merck, 98 %).

2.2. Method

As much as 9 grams (0.05 moles) of glucose and tert-butanol (with mole ratio variation) was put into a 500 ml three-necked flask equipped with a mixer, a thermometer, a heater, and a chiller. It was then added to 50 ml of petroleum ether and p-TSA catalyst (the percent of the catalyst varied) and was then mixed and stirred for 2 hours in also varied temperatures. And then, it was refluxed until no water was left from the distillation. The water was contained in a separatory funnel after being tested using cupric sulfate. The result of the reaction was cooled down in a room temperature to be then added to 0.2 grams anhydrous natrium sulfate and stirred. After that, it was screened and the resulted filtrate was evaporated. The residue left was weighed and evaporated and weighed again until constant weight was obtained. The result left was the tert-butyl glycoside. Finally, the yield, CMC value, and HLB value were calculated. The yield is the weight of the product divided by the weight of the glucose reactant, CMC is the lowest surfactant concentration at the time of formation of micelles.

The values of HLB were calculated using the following formula:

\[
HLB = 7 - 0.36x \ln \frac{100 - CMC}{CMC}
\]

2.3. Design experiment.

Experimental design, TBG synthesis optimization using Response Surface Methods and research using a centralized composite design with software Statistics 6. Using the software can be determined
the model equation, to graph the 3-D contour of the response and to predict the interaction between the parameters [15]. In this experimental design, all the independent variables presented in Table 1.

### Table 1. The area level and the independent variable level code are used in the RSM design

| Independent variables | Coded Factor | Low (-1) | Center (0) | High (1) |
|-----------------------|--------------|----------|------------|----------|
| Mole Ratio (tert-butanol/glucose) | \(X_1\) | 4 | 5 | 6 |
| Temperature (°C) | \(X_2\) | 65 | 70 | 75 |
| Percent Catalyst (%) | \(X_3\) | 2 | 2.5 | 3 |

Responses were analyzed Yield (\(Y\)) on TBG generated. It is used to develop an empirical model linking the response to the independent variables by using the following polynomial Equation (2):

\[
Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2
\]  

(2)

Where \(Y\) is the response variable (Yield). \(\beta_0\) is the coefficient of the intercept, \(\beta_1\) to \(\beta_3\) is the coefficient of the tribe linear, \(\beta_{11}\), \(\beta_{22}\), \(\beta_{33}\) is the coefficient of the tribe quadratic, \(\beta_{12}\), \(\beta_{13}\), \(\beta_{23}\) is the coefficient of the variable interaction and \(X_1, X_2, X_3\) is the independent variable are encoded [16, 17].

### 3. Results and Discussion

#### 3.1. Use of models to predict TBG yields.

Response Surface Methodology is a statistical data processing method using a minimum set of experimental data to determine the coefficients of the mathematical model and the optimization of the conditions [18]. It is important to examine the suitability of the mathematical model, to predict the optimal variable and adequately represent the actual relationship between the selected parameters. [19, 20, 21]. An analysis of the variance of the experimental results is presented in Table 3. The designs of a centralized composite have been used to develop correlations between the variable mole ratio of tert-butanol/glucose, the percent of catalyst and process temperature to yield. From Table 3 indicates that the coefficient of determination, \(R^2\) of the model is 0.98 it shows that 98% of the amount of data can be adjusted to the predicted yield rate of the model and only 2% wrong data.

Also, the \(p\) and \(F\)-values of the respective models are 0.3013 and 62.24, indicating that the model predictions are significant. In consequence, the results show that the mathematical model is sufficient to predict the result, and according to the second-order polynomial equation formula can be seen in Equation (3):

\[
Y = 98.4444 + 1.3199 X_1 - 10.8941 X_2 + 4.1584 X_3 - 8.7251 X_1 X_2 + 4.0293 X_2 X_3 - 2.7076 X_3 - 0.1163 X_1^2 - 0.0737 X_2^2 + 0.0812 X_3^2.
\]  

(3)

By using centralizing composite design, so obtained Experimental design matrix presented in Table 2.
Table 2. Matrix of experimental design

| No | Mole Ratio (mole tertbutanol / mole glucose) | Temperature (°C) | Percent Catalyst (%) | Yield (%) Observed | Yield (%) Predicted |
|----|---------------------------------------------|-----------------|----------------------|-------------------|-------------------|
| 1  | 4.000                                       | 65.000          | 2.000                | 67.05             | 66.50             |
| 2  | 4.000                                       | 65.000          | 3.000                | 72.88             | 74.54             |
| 3  | 4.000                                       | 75.000          | 2.000                | 75.18             | 74.88             |
| 4  | 4.000                                       | 75.000          | 3.000                | 81.56             | 83.26             |
| 5  | 6.000                                       | 65.000          | 2.000                | 69.89             | 69.52             |
| 6  | 6.000                                       | 65.000          | 3.000                | 75.65             | 77.27             |
| 7  | 6.000                                       | 75.000          | 2.000                | 77.78             | 77.44             |
| 8  | 6.000                                       | 75.000          | 3.000                | 83.64             | 85.52             |
| 9  | 3.318                                       | 70.000          | 2.500                | 66.27             | 65.41             |
| 10 | 6.682                                       | 70.000          | 2.500                | 70.87             | 69.85             |
| 11 | 5.000                                       | 61.591          | 2.500                | 68.07             | 67.54             |
| 12 | 5.000                                       | 78.409          | 2.500                | 81.87             | 80.76             |
| 13 | 5.000                                       | 70.000          | 1.659                | 62.45             | 64.41             |
| 14 | 5.000                                       | 70.000          | 3.341                | 92.76             | 97.56             |
| 15 (C) | 5.000                                       | 70.000          | 2.500                | 98.42             | 98.44             |
| 16 (C) | 5.000                                       | 70.000          | 2.500                | 98.13             | 98.44             |
| 17 (C) | 5.000                                       | 70.000          | 2.500                | 98.43             | 98.44             |
| 18 (C) | 5.000                                       | 70.000          | 2.500                | 97.56             | 98.44             |
| 19 (C) | 5.000                                       | 70.000          | 2.500                | 98.36             | 98.44             |

Further supported by variance analysis model (ANOVA). The ANOVA results from the quadratic yield model can be seen in Table 3.

Table 3. Variance analysis of the regression model

| Source          | Sum of Squares | Df | Mean Square | F Value | P Value | Significance |
|-----------------|----------------|----|-------------|---------|---------|--------------|
| Model           | 23.749         | 9  | 23.749      | 62.2475 | 0.3013  |              |
| (A) Mole ratio  | 23.749         | 1  | 23.749      | 6.7903  | 0.028466| *            |
| (B) Percent catalyst (%) | 1620.039     | 1  | 1620.037   | 462.3292| 0.000000| **           |
| (C) Temperature (°C) | 236.154       | 1  | 236.154    | 67.3939 | 0.000018| **           |
| AB              | 1039.151       | 1  | 1039.151   | 296.5549| 0.000000| **           |
| AC              | 221.720        | 1  | 221.720    | 63.2749 | 0.000023| **           |
| BC              | 100.071        | 1  | 100.071    | 28.5586 | 0.000466| **           |
| A²              | 0.108          | 1  | 0.108      | 0.0309  | 0.86456 |              |
| B²              | 0.044          | 1  | 0.044      | 0.0124  | 0.91371 |              |
| C²              | 0.053          | 1  | 0.053      | 0.0151  | 0.904989|              |
| Residual        | 3.50407        | 9  | 3.504      |         |         |              |
| Pure Error      | 31.537         | 9  |            |         |         |              |
| Cor Total       | 2842.253       | 18 |            |         |         |              |
| R² = 0.98       |                |    |            |         | 0.9889  |              |

*Notes: “*” represented p< 0.05, “**” represented p< 0.0001.
3.2. The effect of parameters on yield

The effect of the three parameters on the yield of the acetalization process being investigated. From Equation (3) indicates that the variable mole ratio \((X_1)\) and variable percent of catalyst \((X_3)\) at the same provide a positive effect. It is because the larger the mole ratio and temperature will accelerate the rate of reaction formation TBG, in which the effects, variable percent of catalyst \((X_3)\) is greater than the effect of mole ratio \((X_1)\). The variable temperature \((X_2)\) negative effect this is because the percent of the catalyst is too much would interfere with the reaction. The interaction between the mole ratio variable \((X_1)\) and the temperature \((X_2)\) as well as this is because the larger the mole ratio, then the reaction will be shifted to the right. A greater percent of the catalyst, the activation energy will be smaller, so the faster the reaction. The mole ratio \((X_1)\) and percent of catalyst \((X_3)\) give a negative effect this is due to the interaction with the mole ratio of temperature effect is approaching equilibrium reaction. The interaction variable temperature \((X_2)\) and percent of catalyst \((X_3)\) have a positive effect this is due to the interaction percent of the catalyst and the temperature, the faster the reaction result.

Table 3 as a p-value of 0.028466 for mole ratio, further confirming the significance of the mole ratio of the yield. This finding is consistent with previous findings of which states that the mole ratio provides a significant effect on yield [22]. It is because one of the reactants was provided excess so that the reaction would shift to the right and the yield obtained became greater.

Table 3 also shows that percent of the catalyst, further confirming significant to tbg yield \((p = 0.000000)\). It was because when the percent of catalyst became greater, it would reduce the activation energy, so the reaction speed became faster, and the yield increased. Nevertheless, after the catalyst reached 2 %, the yield decreased, for the catalyst was not able to lower the activation energy, and it could even disturb the reaction.

Table 3 also shows that temperature has a significant effect on yield \((p = 0.000018)\). This finding is consistent with previous findings of which states that the temperatures have a significant influence on yield [22]. When the temperature was getting higher, speed reaction was getting faster, and the yield became bigger. The relationship between the mole ratio, percent catalyst to the yield showed in Figure 1 [23].

The specific relationship between each parameter illustrated visually in the 3D profile shown in Figures 1, 2 and 3, obtained \(R^2\) of 0.98 (Table 3) shows that a total of 98% of the TBG yield variation can follow the model, while only 2 % of the variations can not be explained by the prediction profile. Finally obtained optimal conditions at mole ratio 1: 5.057, percent of catalyst 2.873 %, temperature 71.207 °C and the TBG yield 99.13 %, from the result of GCMS analysis obtained TBG 61.20 %.

From the optimization results then the optimum operating conditions are validated, the results can be seen in Table 4.

| Number | Mole ratio | Catalyst, % | Temperature | Experiment | Prediction | Error, % |
|--------|------------|-------------|-------------|------------|------------|----------|
| 1      | 5.057      | 2.873       | 71.207      | 97.76      | 99.13      | 1.38     |
| 2      | 5.057      | 2.873       | 71.207      | 96.20      | 99.13      | 2.96     |
| 3      | 5.057      | 2.873       | 71.207      | 96.58      | 99.13      | 2.57     |

Average error 2.30

3.2.1. Effect of mole ratio and percent of catalyst p-TSA on the yield

The effects of mole ratio and percent of catalyst p-TSA showed in Figure 1 respectively. Effects of mole ratio and percent catalyst is significant. Yield increases with the increasing mole ratio and percent of the catalyst. It is because the larger the mole ratio, the faster the reaction shifted to the right,
so that the yield increases, two percent greater catalyst activation, the power will be reduced so that the reaction rate increases. After the mole ratio of 5, the yield is nearly constant as the reaction approaches equilibrium. Nevertheless, after the catalyst reached 2.5%, the yield is nearly constant, for the catalyst was not able to lower the activation energy, and it could even disturb the reaction.

**Figure 1.** The effect of mole ratio and percent of catalyst on the TBG yield shown by the surface and contour plot.

3.2.2. Effect of mole ratio and temperature on the yield

The effects of mole ratio and temperature on yield can be seen in Figure 2 respectively. Effects of mole ratio and temperature on yield is significant. Yield increases with the increasing mole ratio and temperature, it is because the larger the mole ratio, the faster the reaction shifted to the right, so that the yield increases, also the temperature the greater the reaction speed is accelerating. After the mole ratio of 5, the yield is reduced it is a reaction close to balance. However, after the temperature reached 70 °C, the yield is nearly constant, for after the temperature was above 70 °C, the reaction product started to break down.
3.2.3. Effect of percent of catalyst and temperature on the yield

The result of the percent of catalyst and temperature is shown in Figure 3 are respectively.

Figure 2. The effect of mole ratio and temperature on the TBG yield shown by the surface and contour plot.

Figure 3. The effect of percent catalyst and temperature on the TBG yield shown by the surface and contour plot.

Effects of percent catalyst and the temperature are significant. Yield increases with increasing percent catalyst and temperature. The greater the percent catalyst, the activation energy, reduced so that the
faster the reaction, also the temperature the greater the reaction speed is accelerating. Nevertheless, after the catalyst reached 2.5 %, the yield is nearly constant, for the catalyst was not able to lower the activation energy, and it could even disturb the reaction. However, after the temperature reached 70 °C, the yield is nearly constant, for after the temperature was above 70 °C, the reaction product started to break down.

3.3. Analysis of the nature of the TBG surfactant:

TBG surfactant obtained in optimum conditions hereinafter set its value HLB and CMC, by way of surfactant TBG dissolved in aquades at various concentration values were analyzed surface tension; the result showed in Figure 4.

Figure 4 shows that the surface tension reduced in line with the increase in the concentration of TBG solution and finally, it becomes constant although the percentage is increasing. It is because TBG solution is aggregated to form micelles, Figure 4 shows CMC about 0.014 %. That condition can reduce the surface tension up to 42.35 mN/m, while the water surface tension is 67.5 mN/m at 30 °C.

The HLB value obtained is 4.60. The decrease in the surface tension caused by the interaction of water molecules with tert-butyl glycosides containing hydrophilic groups (C-O-C, CH3, O-H) and lipophilic groups (hydrocarbon groups with a long chain of CH2, C-O to form micelles. The HLB obtained indicates that the TBG belongs to non-ionic surfactants that can function as water in oil (W/O) type of emulsifier [3, 13].

4. Conclusion

TBG surfactant in the production process, from materials glucose acetalization reaction with tert-butanol, the parameters that significantly influence is the percent of catalyst and mole ratio. Percent of catalyst and the mole ratio of positive impacts on yield, while the temperature has a bad impact on yield. The optimum conditions at a mole ratio of 1: 4.05; 2.88 percent of catalyst and temperature 71.21 °C and the TBG yield 99.13 %, clear color surfactant results. TBG surfactant obtained has the HLB value = 4.60. The HLB result indicates that the tert-butyl glycosides belong to non-ionic surfactants that can function as water in oil (W/O) type of emulsifier.
References

[1] M.M. El-Sukkary, N.A. Syed, L. Aiad, and W.I.M. El-Azab, 2008, Synthesis and Characterization of some Alkyl Polyglycosides Surfactants. Journal of Surfactants and Detergents, volume 11 no 2 p 129-137.

[2] A.M. Ware, J.T. Waghmare, and S.A. Momin, 2007, Alkylpolyglycoside: Carbohydrate Based Surfactant. Journal of Dispersion Science and Technology, volume 28 no 3 p 437-444

[3] A.A. Pavia, B. Pucci, J.G. Riess, and L. Zarif, (1992). New perfluoro alkylated telomeric nonionic surfactant synthesis physicochemical and biological properties. Macromolecular Chemistry, volume 193 no 9 p 2505-2517.

[4] Y. Sela, N. Garti, and S. Magdassi, 1993, Surface activity and emulsification properties of new polyethylene glycol based nonionic surfactants, Journal of Dispersion Science and Technology, volume 14 no 2 p 237-247

[5] H. Sagitani, 1988, Formation of O/W Emulsion by Surfactant phase Emulsification and Solution Behavior of Nonionic Surfactant system in the Emulsification Process, Journal of Dispersion Science Technology, volume 9 no 2 p 115-129

[6] M.J. Schick, 1967, Nonionic Surfactants, Dekker, New York.

[7] M.J. Schick, 1987, Nonionic Surfactants, Physical Chemistry, Dekker, New York.

[8] Th.F. Tadros, 2013, Emulsion Formation and Stability, Wiley-VCH Verlag GmbH &Co. KgaA, p 1-76.

[9] L. Zaijun, Y. Rui, L. Zhongyun, and Y. Fushan, 2005, Synthesis of a novel dialkylaryl disulfonate Gemini surfactant. Journal of Surfactants and Detergents, volume 8 no 4 p 337-340

[10] K. Hill, and O. Rhode, 1999, Sugar-based surfactants for consumer products and technical applications. Fett/Lipid., volume 101 no 1, p 25-33.

[11] M.J. Rosen, 2004, Surfactants and Interfacial Phenomena, 3 Ed, John Wiley & Sons, Inc, New Jersey.

[12] S.K. Hait, and S.P.J. Moulik, 2001, Determination of critical micelle concentration (CMC) of nonionic surfactants by donor-acceptor interaction with iodine and correlation of CMC with hydrophilic-lipophile balance and other parameters of the surfactants. Journal of Surfactants and Detergents, volume 4 no 3 p 303-309

[13] H.Br. Sembiring, 2007, Pembuatan surfaktan tert-butil galaktosida melalui reaksii galaktosa dengan tert-butanol, Jurnal Penelitian Mipa, volume 1 no 1 p 34-37.

[14] T. S. Ballard, P. Mallikarjunan, K. Zhou, S. f. O. Keefe, 2009, Optimizing the extraction of phenolic antioxidants from peanut skins using response surface methodology, Journal of agricultural and food chemistry, volume 57 p 3064-3072.

[15] H. Zhang, M. Liu, S. Han, and Y. Wei, 2013, Optimizing the Extraction of Catechin from Peanut Red Skin Using Response Surface Methodology and its Antioxidant Activity, IERI Procedia, volume 5 p 312-320

[16] O. Yemis, and G. Mazza, 2012, Optimization of furfural and 5-hydroxymethyl furfural production from wheat straw by a microwave-assisted process, Bioresource Technology, volume 109 no 39 p 215-223

[17] H. Le Man, S. K. Behera, H. S. Park, 2010, Optimization of operational parameters for ethanol production from Korean food waste leachate, International Journal of Environmental Science and Technology, volume 7 no 1 p 157-164

[18] Q.V. Vuong, J.B. Golding, C.E. Stathopoulos, M.H. Nguyen, and P.D. Roach, 2011, Optimizing conditions for the extraction of catechins from green tea using hot water, Journal of Separation Science, volume 34 no 21 p 3099-3106.
[19] H.M. Raymond, and M.A. Douglas, 2016, Response Surface Methodology: Process and Product Optimization Using Designed Experiments, 4 Ed, John Wiley & Sons, Canada.

[20] M.A. Bezerra, R.E. Santelli, E.P. Oliveira, L.S. Villar, L.A. Escaleira, 2008, Talanta, 76, 5

[21] N.A. Raji, and O.O. Oluwole, 2014, Phase Field Simulation for Recrystallization Kinetics of Cold-Drawn 0.12 wt % C Steel in Full Annealing, International Journal of Science and Engineering Research, volume 5 no 3 p 335-349

[22] D. Adisalamun, A. Mangunwidjaya, Suryani, T.C. Sunarti, and Y. Arkeman, 2012, Process Optimization for Production of Alkyl Polyglycosides Nonionic Surfactant Using Response Surface Methodology, Jurnal Teknologi Industri Pertanian, volume 22 no 1 p 51-57

[23] Q.V. Young, V.T. Nguyen, D.T. Thanh, D.J. Bhuyan, C.D. Goldsmith, E. Sadeqzadeh, C.J. Scarlett, and M.C. Bowyer, 2015, Optimization of ultrasound-assisted extraction conditions for euphol from the medicinal plant, Euphorbia tirucalli, using response surface methodology, Industrial Crops and Products, volume 63 p 197-202

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