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RESEARCH ARTICLE

Innovative Use of Pineapple Peel as a Coagulant: Insights from Factorial Analysis

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ABSTRACT - The increasing global population has led to heightened wastewater production, which creates environmental challenges due to its discharge into water sources. Pineapple peel has a high potential to be an environmentally friendly, natural-based coagulant that can substitute for conventional chemical coagulants. This study aims to optimise the preparation and application of pineapple peel coagulant to maximise turbidity reduction from simulated wastewater, with a focus on achieving higher viscosity to enhance turbidity effectiveness. Design Expert software designed the experimental setup and a two-level factorial design was used to analyse the data in accordance with that. The investigated factors include the drying time (0 and 24 h), settling period (0 and 24 h), coagulant dosage (1 and 2 ml), and agitation speed (10 and 50 rpm). The turbidity values were measured using the HACH Portable Turbidimeter and the viscosity values were obtained using the Brookfield Viscometer. Based on the analysis, the best condition to maximise turbidity reduction was suggested using 24 h dried pineapple peel and a settling period of 24 h. At this condition, the highest turbidity reduction of 71% was achieved, from 40 to 11.6 NTU. In contrast, undried pineapple peels with no settling period achieved a significant 61.69% turbidity reduction, demonstrating practical and time-efficient benefits. The *p*-value of 0.0003 shows that the chosen model is significant. The *R2* value of 0.8795 explains the fitted model for turbidity reduction. Therefore, investigating the production of coagulants from pineapple peel waste may be an alternative method to reduce turbidity while producing a natural coagulant.

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1. INTRODUCTION

Rising population levels are expected to lead to increased wastewater production, intensifying the demand for effective wastewater treatment solutions [1]. To treat the wastewater, coagulation treatment is required to remove the turbidity from wastewater. In current practice, chemical coagulants such as polyaluminium chloride (PAC) and aluminium sulphate (alum) are widely used by industries. However, these chemical coagulants pose adverse effects on human health, so mainly alum, is not a preferable option [2]. Therefore, pineapple peel-based coagulant is introduced. Pineapple-peel coagulant is an alternative organic coagulant for the existing chemical coagulant to reduce turbidity [3]. Pineapple peel consists of bioactive compounds such as vitamin C, carotenoids, phenolic compounds, and flavonoids, and it has a high adsorption capacity, making it a capable organic coagulant [4]. This organic coagulant is safer, cheaper, and more environmentally friendly than chemical coagulants.

Lots of pineapple peels are getting dumped in Malaysia every day [5]. It will cause environmental issues such as environmental pollution, microbial spoilage and water pollution if it is not treated properly [6]. Moreover, chemical coagulants such as PAC and alum used by industries have adverse effects on human health, endangering aquatic life and causing environmental damage [7]. Therefore, utilising the pineapple peel waste for coagulant leads to a sustainable application [8]. Pineapple peel coagulant serves as a natural coagulant that not only reduces turbidity but also mitigates adverse impacts on human health, aquatic life, and the environment. The objectives of the study are to screen the parameters in coagulant production from pineapple peel and to reduce the turbidity of simulated wastewater using the coagulant. The preparation of coagulant from pineapple peel involved the parameters of the drying process, settling period, coagulant dosage, and agitation, and the data were analysed using Design Expert software through two-level factorial design. This approach facilitates a structured and comprehensive assessment of the factors influencing the performance of the coagulant.

2. METHODS AND MATERIAL

2.1 Materials

Pineapple peels were obtained from TMG Express, Gambang, and Kaolin powder was provided by Kaolin (M) Sdn Bhd.

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2.2 Preparation of Coagulant

The pineapple peels were thoroughly washed with distilled water. They were then sliced into smaller pieces each 1-2 cm in width and length and dried in an oven for 24 h at 40°C. Another batch of washed and cut pineapple peels was stored in a zip-lock bag and kept in the refrigerator without being dried. The moisture content of the pineapple peel stored in the fridge will likely remain relatively stable as refrigeration slows down the evaporation process, preventing excessive moisture loss [9]. Both the dried and undried pineapple peels were ground into a fine powder using a household blender. The ground material was mixed with distilled water to prepare a 1% (w/v) coagulant solution. The mixture was stirred using a hot plate-magnetic stirrer for 30 min to ensure thorough mixing. The extract was filtered through a standard filter cloth to remove residue. The filtrate was refrigerated, and the clear liquid was used as a coagulant. Four sets of coagulants were prepared where two sets using dried and undried pineapple peels prepared 24 h earlier before the experiment and another two using dried and undried pineapple peels prepared immediately before use. The viscosity of the coagulant was measured using a Brookfield viscometer (model LV-DVII).

2.3 Preparation of Turbid Water

Three litres of tap water were mixed with 30 g of kaolin powder for 1 h. After mixing, the suspension was preserved as a stockpile suspension for 24 h in a dry place [10].

2.4 Viscosity Measurement

The viscosity of the pineapple peel coagulant was measured using a Brookfield viscometer (model LV-DVII). The measuring model was set as a multipoint configuration with a duration of 90 s to obtain an average reading. The speed of rotation was set at 200 rpm and the torque was set within the range of 60% – 80%.

2.5 Turbidity Measurement

The initial and final turbidity values were measured using the HACH Portable Turbidimeter (model 2100Q) in the Nephelometric Turbidity Unit (NTU).

2.6 Experimental Setup

This study used 2^4 fractional factorial designs (FFD) with sixteen experimental runs to examine the effect of four factors including drying time, settling period, coagulant dosage, and agitation speed on the viscosity value and turbidity reduction. Design Expert software designed the experimental setup, and a two-level factorial design was used to analyze the data. The actual lowest and highest factor ranges of the experimental setup are shown in Table 1. Analysis of variance (ANOVA) was performed on the responses, using a 95% confidence level based on the *p*-value.

Table 1. Factors and actual values of coded levels

Factors	Code	Unit	Type of Factors	Actual Value	
				-1	+1
Drying time	A	hour	Numeric	0	24
Settling period	B	hour	Numeric	0	24
Coagulant dosage	C	ml	Numeric	1	2
Agitation speed	D	rpm	Numeric	10	50

FFD was used to analyse the experimental data and fit the first-order polynomial equation shown in Eq. (1):

$$Y = \beta o + \sum^{n} \beta i \, Xi \quad {}_{i=1} \tag{1}$$

where, Y indicates the number of responses, β_0 represents the constant coefficient, n indicates the number of variables, I represent the linear parameters and Xi is the interaction parameters.

3. RESULTS AND DISCUSSION

3.1 Fractional factorial design experiments

Table 2 shows the result of the 2^4 fractional factorial experiments with the average response values. The value for the average turbidity response ranges between 11.6 and 29.5 NTU. The initial turbidity value was recorded as 40 NTU. From the experiment, Run 10 yielded the lowest average turbidity response (11.6 NTU) under the experimental conditions of 24 hours of drying time, 24 hours of settling period, 2 mL of coagulant dosage, and an agitation speed of 50 rpm. The turbidity reduction achieved is attributed to the coagulation mechanism of pineapple peel coagulants. These coagulants remove turbidity through charge neutralisation, interparticle bridging, and adsorption. The bioactive compounds in the peel neutralise negative charges on suspended particles, promoting floc formation and their eventual sedimentation. Optimal conditions such as sufficient drying and settling periods enhance these processes, leading to the significant reduction in turbidity observed in Run 10.

Table 2. The 2^4 fractional factorial design with responses

Runs	Factors				Turbidity			Average Turbidity NTU reading
	A Drying	B Settling period	C Coagulant	D Agitation	1	2	3	
1	0	24	2	10	29.6	29.5	29.5	29.5
2	24	0	1	10	26.9	26.8	26.9	26.8
3	24	24	2	10	12.9	12.8	12.9	12.9
4	24	0	2	10	18.2	18.1	18.1	18.1
5	24	0	1	50	16.5	16.6	16.5	16.5
6	0	24	1	10	29.6	29.5	29.5	29.5
7	0	0	1	50	14.1	14.9	14.2	14.4
8	0	24	1	50	25.1	25.2	25.1	25.1
9	0	0	2	10	13.9	14.2	13.9	14.0
10	24	24	2	50	11.6	11.5	11.7	11.6
11	0	0	2	50	15.2	16.0	15.2	15.5
12	0	24	2	50	24.0	24.1	24.1	24.1
13	24	24	1	10	12.0	12.5	12.0	12.2
14	0	0	1	10	17.3	17.7	17.3	17.4
15	24	0	2	50	16.5	16.6	16.6	16.6
16	24	24	1	50	15.2	15.1	15.1	15.1

The ANOVA R^2 was utilised to assess how similar the data is to the regression line. A model with an R^2 of more than 80% is considered well-fitting. The turbidity test achieved an acceptable R^2 value of 0.8795. In terms of actual factors, the resulting equation is shown in Eq. (2):

$$\text{Turbidity} = 18.71 - 2.48A + 1.29B - 0.9188C - 1.34D - 4.57AB \quad (2)$$

where the model term A is the drying time, B is the settling period, C is the coagulation dosage, D is the agitation speed, and AB is the interaction between drying time and settling period.

3.2 Analysis of Variance

The model's significance for the turbidity reduction value, as determined by an analysis of variance (ANOVA), is presented in Table 3. *F*-values were used to determine the regression equation's statistical significance, and *p*-values were used to determine the significance of each coefficient. From the model, the *F*-value is 14.60 and the *p*-value is 0.0003. The obtained *p*-value shows that the model is significant. The values of the turbidity reduction response are greatly influenced by the model term effects of A and AB. Meanwhile, model terms B, C, and D are insignificant as their *p*-values are larger than 0.05.

Table 3. Significance of regression coefficient for turbidity reduction

Source	Sum of squares	Degree of freedom	Mean square	*F*-value	*p*-value	
Model	501.66	5	100.33	14.60	0.0003	Significant
A-Drying time	98.51	1	98.51	14.33	0.0036	
B-Settling Period	26.78	1	26.78	3.90	0.0766	
C- Coagulant	13.51	1	13.51	1.96	0.1912	
D-Agitation	28.89	1	28.89	4.20	0.0675	
AB	333.98	1	333.98	48.59	<0.0001	
Residual	68.73	10	6.87			
Cor Total	570.39	15				

3.3 Effects of the Main and Interacting Factors

Figure 1 shows the Pareto chart to analyse the most significant factors. The *F*-value square root from the ANOVA was used to compute the *t*-value bars. Two limit lines, representing the *t*-value of the effects, are displayed: the 2.2281 *t*-value limit line and the 3.8273 Bonferroni limit line. The primary and interacting factors selected during the effect list selection are displayed by the hollow-coloured bars. The unselected factors are displayed by the solid-coloured bars because of their minimal process involvement. According to the chart, variables A and AB have a significant impact on the turbidity decrease and exceed the *t*-value line. A coefficient is probably significant if the *t*-value of the effect lies between the *t*- value limit line and the Bonferroni line.

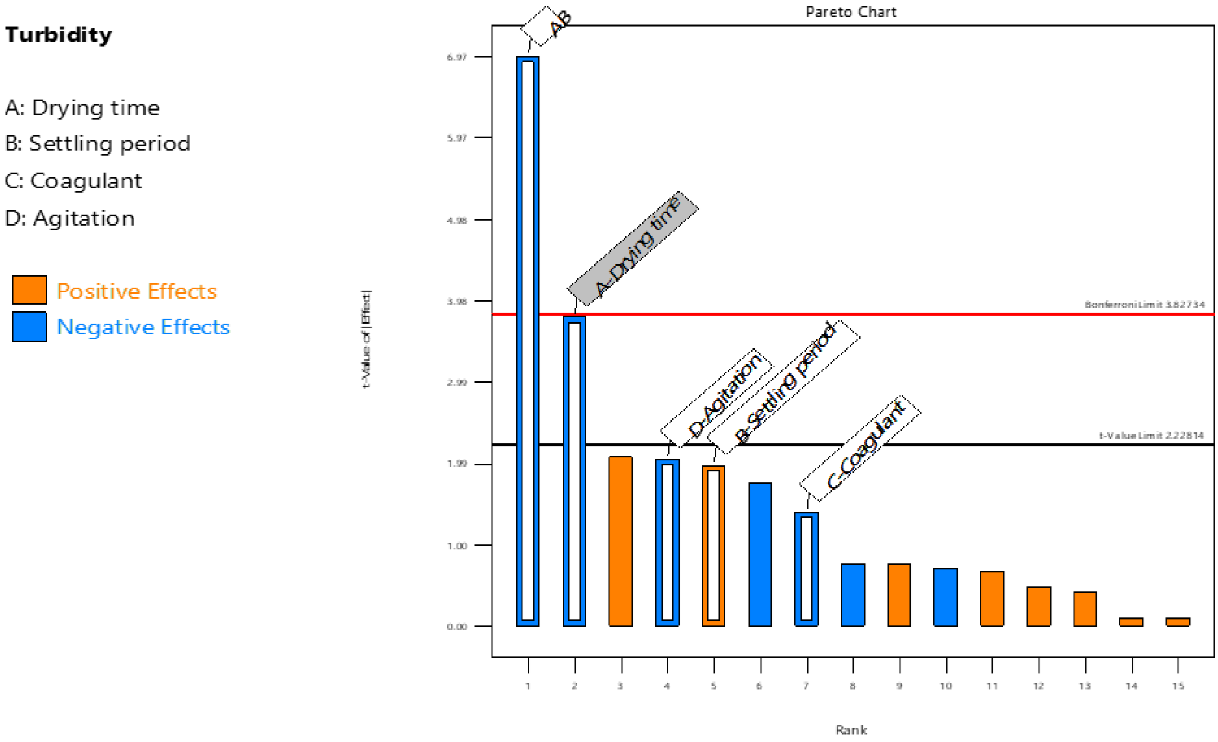

Figure 1. Effects of factors on turbidity reduction

3.4 Half-Normal Plot

Figure 2 shows the half-normal plot used to identify significant factors in a regression model. Factors with higher standardised effects and lower half-normal probabilities are more likely to be significant. From the figure, factors A and AB have higher standardised effects and lower half-normal probabilities, indicating they are significant.

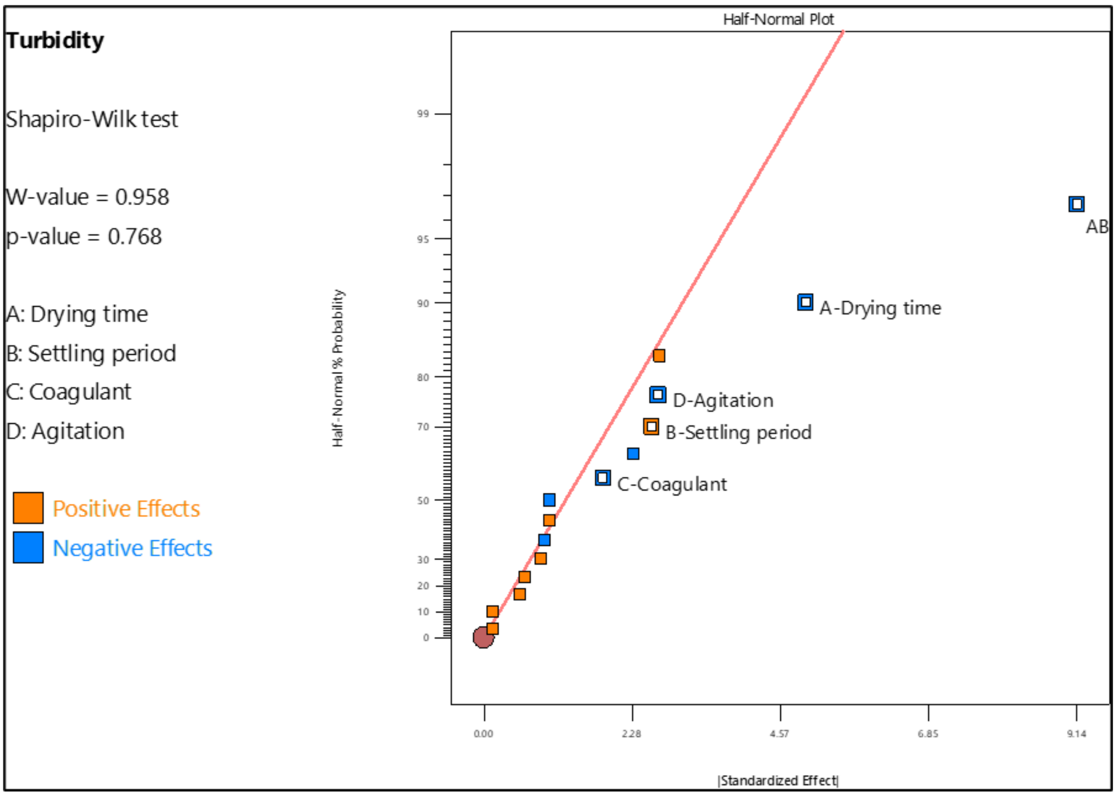

Figure 2. Half-normal plot

3.5 Interaction between Factors

Figure 3 shows the model graph for the interaction between factor A and factor B. The term AB is significant, indicating that the effect of one factor depends on the level of another factor. The factor A increases (moving from left to right along the x-axis) resulted in turbidity decreases. It might be due to the longer settling periods (factor B) generally allowing for more effective sedimentation, resulting in clearer water (lower turbidity). The interaction is minimal or non-significant, as seen by the consistent slope of the line across the levels of X1 since the lines do not intersect.

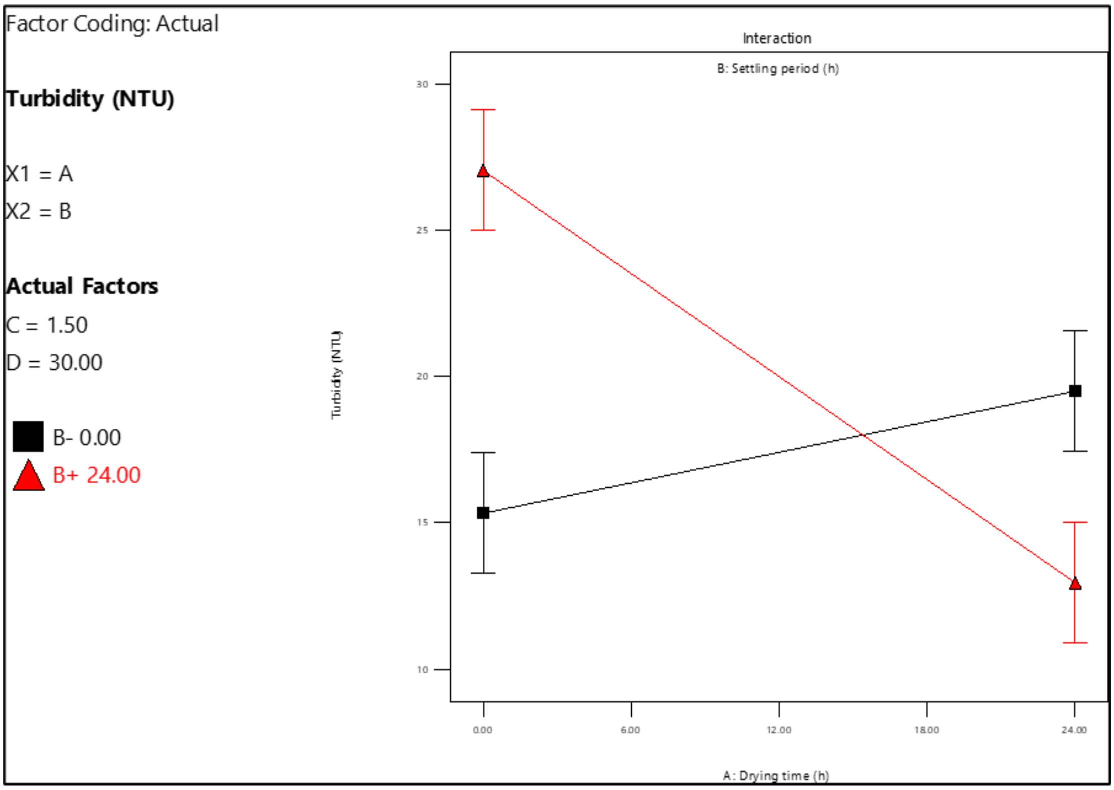

Figure 3. Model graph interaction between factor A and factor B

3.6 Viscosity

Table 4 shows the viscosities of the coagulants. The dried pineapple peel coagulant with immediate use without a settling period shows the highest viscosity of 2.097, followed by the dried pineapple peel coagulant with a 24-hour settling period of 2.088, then 2.075 for the undried pineapple peel at 0 hours settling period, and lastly 2.028 for undried pineapple peel with 24-hours settling period. According to Ampai et al. [11], the highest viscosity leads to the highest turbidity removal because greater viscosity in coagulants enables improved interparticle bridging between the coagulant and suspended particles. This bridging process facilitates the formation of bigger aggregates that settle more quickly and effectively, removing more turbidity. Coagulants having a higher viscosity can interact with suspended particles more effectively because they can penetrate the water more effectively. Better turbidity reduction results from this enhanced penetration, which also improves the coagulation process [12].

Table 4. Viscosities of coagulants

Sample	Speed (rpm)	Torque (%)	Viscosity (cP)
Dried PP 24h	200	70	2.088
Undried PP 0h	200	69	2.075
Undried PP 24h	200	67	2.028
Dried PP 0h	200	72	2.097

In this study, run 10 reduced the turbidity the most to 11.6 NTU. However, the coagulant used in run 10 was dried pineapple peel coagulant that was stored for 24 h, which contrasts with the previous study for the viscosity [11]. This is because the method of coagulant preparation in the previous study differs from this method for the drying temperature and the parameters as well. Alternatively, the turbidity reduction using 24-h dried pineapple peels and a settling period of 24 h and the undried pineapple peels and a settling period of 0 h. The initial average turbidity of the turbid water was 40. Table 5 shows the comparison of drying time and settling period for coagulant.

Table 5. Comparison of data between type 1 and type 2

Type	Factor AB	Std	Run	Average NTU Reading	Turbidity Reduction %
1	Drying Time – 24 H	1	3	12.9	67.75
	Settling Period – 24 H	2	10	11.6	71.00
		3	13	12.2	69.50
		4	16	15.1	62.25
2	Drying Time – 0 H	5	7	14.4	64.00
	Settling Period – 0 H	6	9	14.0	65.00
		7	11	15.5	61.25
		8	14	17.4	56.5

The average turbidity reduction (%) for Type 1 coagulants is 67.63%, while for Type 2 coagulants is 61.69%, with a 5.94% difference between coagulants type 1 and type 2. Considering the turbidity reduction, drying time, and settling period, Type 2 is the better coagulant. Furthermore, the drying time and the settling period required for Type 1 are time-consuming. The Type 2 coagulants had a slightly higher average turbidity reduction, with no drying time and a settling period compared to those for Type 1. These advantages make Type 2 coagulants more efficient and effective for turbidity reduction.

This study has achieved a 71% turbidity reduction (from 40 NTU to 11.6 NTU) using a 24 h dried pineapple peel coagulant with a 24 h settling period. Similar to this, findings by Syafiqah et al. [5], reported a 75% turbidity reduction using a pineapple leaf coagulant at higher dosages. However, this study highlights the advantage of time efficiency with undried peel coagulants, achieving a 61.69% turbidity reduction without any drying or settling time, as opposed to the longer preparation process reported by Denzil et al. [7]. These findings highlight the importance of process conditions and preparation techniques in maximizing performance while confirming the efficiency of pineapple-based coagulants.

4. CONCLUSIONS

The results indicate that the best performance was achieved with dried pineapple peel coagulants that had a settling period of 24 h, resulting in a turbidity reduction from 40 to 11.6 NTU, a 71% decrease. In contrast, undried pineapple peels with no settling period achieved a turbidity reduction of 61.69%. Despite the slight advantage in turbidity reduction using the dried peels, the undried peels offered a significant advantage in terms of time efficiency as they required no drying or settling period.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHORS CONTRIBUTION

N. Ragu (Writing; Data curation; Formal analysis; Visualisation; Methodology)

S.A. Rahman (Funding acquisition; Project administration; Supervision)

R.A. samah (Formal analysis; Visualisation; Methodology)

N. Zainol (Formal analysis; Methodology)

Z. Helwani (Project administration; Supervision)

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