Operational assessment of biological wastewater treatment using advanced return-mass reactors based on principal component cluster analysis

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Abstract. In this study, field results data were conducted, implemented in 64 biofilm reactors to analyses extract organic matter nutrients from wastewater through a laboratory level nutrient removal process, biofilm layer moving process using anaerobic aerobic units. The kinetic layer biofilm reactors were continuously operating in Turbo 4BIO for BOD COD with nitrogen phosphorous. The Baraikia plant is designed to serve 200,000 resident works on biological treatment through merge two process (activated sludge process, moving bed bio reactor MBBR) with an average wastewater flow of 50,000 m3/day the data were collected annually from 2017-2020. The water samples were analysis in the central laboratory of the wastewater treatment plant in Baraikia region by the Directorate Sanitation in Najaf is influential, wastewater at the treatment plant for Al-Bio-shaft saw major water quality parameters. The data was analysis of using a principal component approach a cluster study of the return-mass reactors. The results showed that the biological oxygen dem (BOD5, 126 mg /L), chemical oxygen dem (COD, 222 mg /L), total solids, total suspended solids (TSS, 223 mg /L) a pH of 7.6 over a period of 4years, also the optimum removal rate was 89 %of the BOD, under optimum conditions, 78 % of the chemical oxygen occurred in the air reactor by nitrification with an average ammonium removal yield of 67 %. The cluster analysis results showed that the years (2018, 2017, and 2020) are a good level of treatment compared to 2020. The final effluent quality (an average value of three years) complies with the stringent regulations proposed by the Iraqi National Stards established by Regulation 25 of 1967 BOD / COD ratio were calculated Influence is 0.63 in total wastewater.

Key Word: Performance Evaluation, Biological Wastewater Treatment, Active Sludge, Principal Component Analysis, Clusters Analysis.

1. Introduction

Health public security is one of the main concerns nowadays, as half of the world's population is expected to face water shortages by 2030 [1]. Pollution of water resources, along with population
industrial growth, has increased the need for appropriate effective methods of water treatment [2]. Both organic inorganic wastewater pollutants are present in a suspended or dissolved state, while suspended pollutants are easily separated by sedimentation, dissolved compounds are difficult to remove, however, there is a large portion of degradable organic matter such as carbohydrates alcohols that are a food source for bacteria microalgae [3]. Many experiments studies have been conducted to improve develop wastewater reprocessing processes in a manner that meets the requirements of health [4]. Studies have focused on developing biological treatment units to increase efficiency, reduce energy consumption, reduce maintenance costs [5].

The activated sludge method (AS) It is one of the most frequently used biological treatment methods for wastewater treatment systems is Canada's conventional wastewater treatment method. Arden Locket [6] developed this method. The system includes an aeration tank for biological growth, a sedimentation tank to separate the produced biomass, recycling of biomass to the aeration basin (to maintain proper fractional biological concentration in the aeration tank) removal of excess biomass (sludge) to maintain stable system performance [7]. Liquid in the aeration basin, which eventually flows into the filter device, is called the mixed liquid. AS systems are mainly used for oxidation of carbonaceous matter removal of dissolved solids, it can also be designed for ammonia oxidation, denitrification (nitrification denitrification) phosphorous removal. The organisms present in the aeration tank remove target contaminants from the wastewater produce well-sediment biological masses that separate from the liquid in the sedimentation basin by gravity sedimentation [8]. The efficiency of the AS plant can be considered as the rate of decontamination issues, this is also known as factory performance. However, insufficient removals of suspended solids by the final preparation tank, is a critical factor in the performance of the AS plant [9]. In fact, the success of membrane bioreactors is partly due to their ability to reliably separate blocks from water. Its applications include extended aeration, advantage low installation cost, good quality sanitation minimal head loss. Free from flies odors with a high degree of treatment disadvantages very inflexible method (if a sudden increase in the volume of wastewater occurs or if there is It is a sudden change in the nature of wastewater, there are negative effects on the work of the process thus poor quality wastewater is obtained, the operating cost is high, the disposal of sludge is widely required, this process is sensitive to some industrial waste, skilled supervision is required to verify The returned sludge remains active. The quality of the AS system includes the variation of the influencing BOD, and SS concentration, environmental factors such as temperature, wind, biological operational parameters such as ratio of food to microorganism (F/M) backflow of sludge, stability characteristics (such as sludge volume index (SVI) solids solids). For tuning, filter design, process type human factors [10].

The moving bed bioreactor (MBBR) originated in Norway grew up in a company known as Kaldnes Milj’teknologi or Anox Kaldnes within the Norwegian University of Science Technology. The first MBBR was established in 1989, albeit modern technology by contrast, but has been introduced in the United States since 1995. There are currently more than four hundred wastewater treatment plants around the world, each of which houses more than thirty-six municipal industrial plants. Departments in North America. [11]. America, however, the idea was to develop an MBBR system to enhance the reliability more effective features of the activated sludge method along with a bio-filter method that provides the opportunity benefits to be obtained from an effective wastewater treatment technology [10]. In addition, the MBBR approach takes advantage of this advantage due to the ability of this organism to bind to the surface to create stable polymer layers to protect itself from peeling [12] This function is utilized by the MBBR method extends to the growth of microorganisms above the media holder in the biofilms that move Freely inside the wastewater. Health [13] The Movable Bio-film Reactor (MBBR) has recently been used in the fields of wastewater treatment research is gaining greater interest in researching its applications to remove degradable organic matter. Degrees of adjustment growth. However, the MBBR for industrial waste material in terms of gas removal was the first use of this step [14]. Various applications were subsequently developed, including MBBR enhancer for skeletal removal, phosphorous removal, nitrification denitrification for the treatment of municipal industrial wastes [15]. Its applications include a distilled filter a rotating biological
conductive filter. The main advantages of this process are that it requires less surface area so that the purification result becomes less dependent on separating the biomass this biomass is more specialized. When sludge return is lost, the advantages of using mixed bed bioreactor technology in a wastewater treatment plant are as follows, the sludge retention time improves the increase in its effectiveness [13]. Fluctuating load does not cause operational problems, reduced sludge production, requires less space, toxic shock resistance. All the advantages that MBBR technology provides in the case of a wastewater treatment plant the disadvantages of mixed bed bioreactor technology in a wastewater treatment plant are as the main disadvantage is that it has to be done with MBBR technology, the wastewater treatment process becomes a biological process, so highly qualified personnel will be required [15]. The Turbo4bio system is the only system that has been developed to date, where related bacteria can exp form a homogeneous saturated biomass layer that acts as an enzyme plant in a traditional but more compact balance tank to digest the sludge, eliminating 98% of the suspended growth. The special design features of the system include the self-cleaning ability of the T4b-Turbo reactor against possible clogging make it maintenance-free. The MBBR / IFAS processes use the same validated biofilm holder technology used in the traditional activated sludge process in all MBBR systems. Known as Integrated Fixed Film Activated Sludge (IFAS) or Hybrid Activated Sludge (HYBAS), this blend preserves the suspended solids of the mixed liquid (MLSS). Higher than single-pass MBBR processes suitable for urban wastewater treatment facilities upgrading enhancement [5] The result is a hybrid activated sludge biofilm transfer technology process, achieving unprecedented biodegradation efficiency through similar-size traditional activated sludge systems. In MBBR, the MLSS equivalent is 6000 to 10,000 mg/L, so the MBBR impact of the process is one-third to one-half of the activated sludge process, IFAS/HYBAS MLSS will be higher Turbo 4bio will increase to 30,000 as more advanced Hybas! Turbo 4bio formulated its "Biomass Biomass Reactor" RBBR system as the only 100% related growth process that does not return sludge to the aeration tank, but biomass, resulting in no organic sludge. MBBR is not food/microorganisms ratio (F/M) sensitive about parameters. At organic loads several times greater than traditional systems, such as activated sludge, intermittent filters, erythrocytes, ABF, etc., it can completely preserve its stability [6] This is a very significant aspect of the process. With the old conventional processes, in order to minimize the organic load of wastewater to the optimal level, this method needs less HRT. This will decrease the aeration tank's size. MBBR can also be used to increase the capacity modernize wastewater treatment plants in order to enhance effluent efficiency. In addition, by integrating this method with anaerobic hypoxic systems (in the residual aeration tank), the resulting nutrient rate can be reduced to an appropriate level can therefore be upgraded. Adequate consideration should be paid to the selection of the necessary geographic area when transporting carriers to minimize the time needed for the curing process [16]. This was presented as a research paper to evaluate the performance functioning of the bio-shift station by collecting data for the last three years analyzing it within the analysis programs represented by SPSS 23, the principle of the main component the cluster analysis. One of the recent research that has been published on wastewater treatments are [17, 18].

2. Materials and Methods

2.1. Study Area Description

The study was conducted at Albarrakiya WWTP (32° 0' 44” N, 44° 25' 20” E) in the province of Najaf, which lies south of Baghdad, about 175 km as Figuer1. The Bio-shaft is designed to accommodate treat wastewater of approximately 50,000 m3/day the station serves 200,000 residents as shown in Figure 1. The plant that contains two types of screens, coarse fine, are intended to protect other parts of the plant from floating particles large particles. These screens are cleaned manually automatically, There is a (19 * 6 * 4) m rectangular tank, which is a particle oil removal unit. The biological treatment unit in this plant is the aeration tank whose dimensions are (84.5 * 21.6 * 5.7) m includes a
blower to pump air into the tank to provide the oxygen that the microorganisms need to complete the treatment and provide the appropriate process. The mixing process inside the aeration tank comes after the second stage of biological treatment inside a turbo 4 Bio, which consists of 16 basins after one (5 * 5 * 7) m inside four cylindrical edges with a diameter of 2.4 m and a height of 6 m (Figure 2). Thus, the process of separating the sludge from the liquid in Secondary sedimentation of the tank, in which the filtration process is carried out using the principle of gravity, the rectangle, has dimensions of one (10.8 * 8 * 7.625) m. All sludge is returned to the aeration tank to increase processing efficiency.

Figure 1. Bio-Shaft station in Najaf.

Figure 2. Plan of turbo 4 bio plant.

2.2. Data collection analysis

The data used in this research was obtained from the field laboratory of the Sewerage Projects Administration in Najaf / Ministry of Municipalities Public Works in Iraq. The seven physical chemical pollutants approved in this study are: (BOD, 133 mg/L), (COD 185.7 mg/L), (TSS, 256.65 mg/L), (pH, 7.3 mg/L), (PO₄, 4.24 mg/L), (SO₄, 1898 mg/L), (NH₃, 15.7 mg/L) for a period of three years from 2017 to 2020. The plant's laboratory is examining raw sewage treated effluents using TURBO4 BIO. It should be noted that you do not exceed the local standards established by Single Contaminant Stacking [8].

2.3. The activated sludge process the biotechnology using advanced reflux sludge

From the literature, the information about the advantages of MBBR has been identified with some required points, which were mentioned by Lucidose Police [19]. According to these authors, the MBBR method was distinguished from others by the higher biomass concentrations with reduced sensitivity to toxic compounds the absence of long sludge sedimentation periods. This method is considered in one form another to be economical compared to other methods. In addition, Horan
colleagues [20] agree that both the organic ammonia removal processes are effective can be achieved in a phase standardized by the MBBR method where the transfer of the bio-film filter is small compared to the treatment. Activated sludge [21] In addition to that the temperature has a direct effect on the biological yield rate despite the operational costs being higher in MBBR because it has high efficiency for removing contaminants compared to which is the first biological treatment method followed mechanically prepared in Engl was in 1914 By ardent, there are several types of them, as the mixture is completely ventilated gradually, pure oxygen is ventilated to the lagoon, etc. The Bio station is considered a mixture of the two theories if it represents the elegant, economic, compact system that stimulates accelerates the natural process in rivers in terms of benefit from the attached growth of 100%, which gives a high concentration of the vital film to get rid of sludge odor as the bacteria grow work to form a sludge digestive enzyme in Nucleation balance reservoir, thus achieving 98% degradation of suspended growth [22].

2.4. Statistical analysis

correlations. Statistics is one of the branches of scientific methods that discuss data gathered by counting or measuring the characteristics of natural phenomenon groups in order to shed light on important decisions thus the ability to direct decisions [23].

2.4.1 Principal component analysis

(PCA) is a statistical technique that is useful for compression extracts useful information from multivariate data sets. The purpose is to reduce the dimensionality of a data set (sample) by finding a new set of variables (Uncorrelated), smaller than the original set of variables (Correlated), without much loss of information retains most of the sample's information [24]. The variance of each variable is the average squared deviation of its \( n \) values around the mean of that variable:

\[
V_i = \frac{1}{n-1} \sum_{m=1}^{n} (X_{im} - \bar{X}_i)^2
\]

(1)

The degree to which the variables are linearly correlated is represented by their covariance's

\[
C_{ij} = \frac{1}{n-1} \sum_{m=1}^{n} (X_{im} - \bar{X}_i)(X_{jm} - \bar{X}_j)
\]

(2)

\[
r_{ij} = \frac{C_{ij}}{\sqrt{V_i V_j}}
\]

(3)

where

\( C_{ij} \) = Covariance of variables \( j \)
\( m \) = Sum over All \( n \) objects
\( I, m \) = Value of variable \( i \) in object \( m \)
\( X \) = Mean of variable \( i \)
\( X_j \) = Value of variable in object \( m j \)
\( X_j \) = Mean of variable \( j \)

2.4.2 Analysis of clusters

It involves many distinct methods that group objects into groups according to their similarity. This exploratory approach is used to discover a data structure not only between observations but also
among variables, organized into dendrograms. The processes, algorithms similarity/dissimilarity measures used are listed elsewhere in the literature (e.g. Everitt et al., 2001) [25]. Ward's hierarchical method of clustering (Ward 1963) was used to cluster water samples in this common study.

$$\text{Distance}(X,Y)=\sqrt{\sum (X_i-Y_i)^2}$$  \hspace{1cm} (4)

2.4.3 Factor Analysis

Factor analysis is a statistical method that works in the variables (30) of the reserved sentence (factors), where each group of variables is linked to only one factor by a function that can set a set of tests with the achievement factor or ... First degrees, the function between the original variables their original factors are:

$$F_n= a_1X_1+a_2X_2+a_3X_3+...+a_nX_n \hspace{1cm} \text{m>n}$$  \hspace{1cm} (5)

The coefficients in the previous equations can be written in the form of a matrix known as the matrix of correlation can be rectangular or square (number of rows = number of columns). Where the elements of the matrix are the values of the coefficients of correlation between the variables, the value of the correlation coefficient is the intersection of the row with the column.

- The first factor is most closely connected to the factors.
- In any factor, there are zero coefficients.
- Ease of analysis through its links to original variables.

3. Results and Discussion

3.1. Evaluation of raw sewage

Evaluation of raw wastewater: the influencing characteristics of the raw sewage of the plant are the same as that of the one that is collected in the main pumping station, after entering the plant it is discharged at 50,000 m³ per day Table 1.

Table 1. Influent parameter variation during study period 2017-2020.

| Month    | BOD/COD | pH | NH₃ | SO₄ | PO₄ | TSS | COD | BOD |
|----------|---------|----|-----|-----|-----|-----|-----|-----|
| January  | 0.533   | 7.7| 11.7| 864 | 6   | 40  | 150 | 80  |
| March    | 0.666   | 7.8| 21.8| 1030| 6   | 168 | 150 | 100 |
| September| 0.75    | 7.8| 10.6| 918 | 4   | 119 | 120 | 90  |
| December | 0.487   | 6  | 11.7| 917 | 3   | 119 | 246 | 120 |
| January  | 0.75    | 7.8| 6   | 1035| 5   | 164 | 210 | 100 |
| March    | 0.505   | 7.7| 13.4| 1097| 9   | 225 | 198 | 100 |
| September| 0.710   | 7.8| 13.4| 1197| 3   | 210 | 228 | 130 |
| December | 0.489   | 6  | 12.8| 973 | 3   | 119 | 228 | 90  |
| January  | 0.756   | 7.7| 12.8| 950 | 3   | 180 | 228 | 90  |
| March    | 0.606   | 7.5| 12  | 1090| 3   | 119 | 228 | 90  |
| September| 0.666   | 7.6| 14.5| 1210| 5   | 350 | 320 | 100 |
| December | 0.710   | 7.4| 14.5| 1210| 3   | 192 | 180 | 130 |
| January  | 0.745   | 7.7| 14.5| 1210| 3   | 210 | 180 | 120 |
| March    | 0.489   | 6  | 12.8| 1090| 3   | 210 | 228 | 120 |
| September| 0.756   | 7.4| 12  | 1090| 3   | 210 | 228 | 120 |
| December | 0.710   | 7.4| 14.5| 1210| 3   | 210 | 180 | 120 |
| January  | 0.666   | 7.7| 14.5| 1210| 3   | 210 | 180 | 120 |
| March    | 0.692   | 7.4| 15  | 1026| 3   | 210 | 228 | 120 |
| September| 0.606   | 7.5| 12  | 1090| 3   | 210 | 228 | 120 |
| December | 0.930   | 7.4| 15  | 1362| 3   | 210 | 228 | 120 |
| January  | 0.692   | 7.4| 15  | 1026| 3   | 210 | 228 | 120 |
| May      | 0.666   | 7.7| 14.5| 1210| 3   | 210 | 180 | 120 |
| Mean     | 0.63    | 7.5| 12  | 1089.3| 4.4 | 112.3| 185.7| 4.4 |
Average monthly values of oxygen BOD, COD, TSS For the values of the concentrations entering the station, the mean annual values for each were 126 mg / L, 222 mg / L, 223, respectively, the maximum BOD was 201 mg / L November 2020 the limit was The minimum is 90 mg / L in August 2019. The maximum effective value of chemical oxygen was 352 mg / l in January / 2020, that is, in the year 2020, the month of April, the concentrations of TSS COD were the highest due to the presence of violations on the network the absence of government oversight due to the confusing conditions of the Corona pemic, so the treatment will be to limit abuses strive to exp Additional lines of treatment to avoid emergencies [10], [26], and [27].

![Figure 3](image3.png)

**Figure 3.** Influent variation BOD, COD, and TSS

Through the Figure 3, it becomes clear to us that the differences as annual rates of each of BOD, COD, TSS are unequal. In 2020, there was the highest value of BOD while in 2020, it was the highest value in TSS the highest value of COD was in the year 2020.

![Figure 4](image4.png)

**Figure 4.** The annual significant difference BOD, COD, and TSS

The BOD/COD ratio of domestic wastewater BOD/interrelationships between BOD COD is as an indicator of biodegradability potential. Typical values for the untreated urban wastewater BOD/COD ratio vary from (0.3 to 0.8). If the untreated waste water BOD/COD ratio is 0.5 or more, the waste is deemed to be easy to hle (Figure 4). If the ratio is 0.3, it is either that there are no harmful components in the waste or that it can be contained by biological means. A BOD/COD ratio 2 is typically called the distinction point between degradable non-degradable waste. The ratio of BOD/COD to crude impact in this study was approximately 0.64, suggesting a significant amount of organic matter subject to biodegradation, where the average ratio over the three years was 0.63, which
indicates that solid decomposition is taken into consideration not. A nice toxicity biological process is Figure 5.

![Figure 5. Monthly variation of influent BOD/COD during study period](image)

3.2. Evaluation of BOD, COD, and TSS effluents

they were 20 mg/L, 58.229 mg /L 89.64 mg/L, respectively. Where it was the highest BOD, COD, TSS, in September of the year 2017, this indicates that there are operational problems of the system was addressed in subsequent years, where the values ranged from 10 to 15 mg/L to BOD. In addition, 20 to 85 mg /L to cod 16 to 150mg/L to TSS in Figure 6.

![Figure 6. Effluent variation BOD, COD, and TSS during study period](image)

3.3 Removal Efficiency

It is one of the most relevant metrics that can be used in wastewater treatment to measure the performance of selective bioreactors. To achieve efficiency, there are several types of ingredients: BOD, COD, N, TSS. Using Equation 1, RE is calculated. For BOD, COD, TSS, the four-year mean removal efficiency was (89, 78, 67)% respectively, which are good results in Figure 7.
The efficiency of removing BOD, COD, and TSS during study period.

3.4 PCA and FA

After collecting data for the tests confined between 2017 - 2020 conducting analysis about SPSS 23 of the principal component analysis, the results were according to the Table 2 the attached charts below: extraction common lists, where the results were greater than 75%, meaning that they have a good representation.

Figure 7 The efficiency of removing BOD, COD, and TSS during study period

| Table 2. Extraction method principal. |
|--------------------------------------|
| Communalities                        |
|                                      |
| Initial                              |
| COD                                  | .746 |
| CODout                               | .895 |
| TSS                                  | .86  |
| TSSout                               | .795 |
| PO4                                  | .79  |
| PO4our                               | .465 |
| NH3                                  | .84  |
| NH3out                               | .89  |
| BOD                                  | .752 |
| BODout                               | .847 |

Extraction Method: Principal Axis Factoring.

In the Table 3, in which the total influencing factors are Figure 8, which have a value greater than 1 this is also shown by the drawing below, which were measured as the key influencing components.
Table 3. Total Variance Explained

| Factor | Initial Eigenvalues | Total | % of Variance | Cumulative % |
|--------|---------------------|-------|---------------|--------------|
| 1      | 2.909               | 29.089| 29.089        |              |
| 2      | 2.190               | 21.899| 50.988        |              |
| 3      | 1.532               | 15.319| 66.308        |              |
| 4      | 1.050               | 10.499| 76.806        |              |
| 5      | .731                | 7.313 | 84.119        |              |
| 6      | .654                | 6.542 | 90.662        |              |
| 7      | .464                | 4.636 | 95.297        |              |
| 8      | .318                | 3.179 | 98.476        |              |
| 9      | .102                | 1.016 | 99.492        |              |
| 10     | .051                | .508  | 100.000       |              |

Extraction Method: Principal Axis Factoring.

Figure 8. Influencing factor

The correlation coefficient test was performed after studying the main variable, where the R value was high, 89%, the R square value was also high, 80%. This indicates that the parameters are strongly related the significant value means that the plant is operating well. The correlation coefficient, in which the results of the VF value is less than 3, is an indication of the elimination, treatment elimination of the linear multiplicity of its problems, as shown in the appendix below, that the regression is the optimal representation of the data presented in Table 4.
Table 4. Moral $R^2$.

| Model | $R$ Square | Adjusted $R^2$ | $R$ Square | $F$ | Change | $df_1$ | $df_2$ | Sig. $F$ |
|-------|------------|---------------|------------|-----|--------|--------|--------|----------|
| 1     | .897$^a$   | .805          | .741       | 3.119 | .805   | 12.422 | 4      | .000     |

a. Predictors: (Constant), REGR factor score 4 for analysis 1, REGR factor score 3 for analysis 1, REGR factor score 2 for analysis 1, REGR factor score 1 for analysis 1
b. Dependent Variable: BODout

BOD out was adopted in the operational evaluation of the filters, the figure (9) was as indicated, meaning that it has a clear relationship between the parameters.

3.5 CA

After conducting a cluster analysis of the data collected during the four years 2017-2020, his results that I indicated from the Excel analysis were that there were general problems that negatively affected the plant performance the output of the pollutants. It gave the highest pollutant values during the year 2020 during the months of December April.
The properties of the organic variables were analyzed in the extent of their influence on some of them, so the results were that BOD, COD, TSS had similar physical properties such as the arithmetic mean, the analysis of the standard deviation were as shown in the Figure 11.

Through the cluster diagram the relationship of clusters, we notice an explanation from the above, as each of the BOD is based on 1, COD, and TSS within Cluster 3 in the first stage 1 in the second stage, this indicates that there is a similarity in the characteristics features between them their effect. The second stage also settled in the same cluster No. 2 of this. We usually reach scientifically that both PO₄ and NH₃ are nutrients for the bacterium to bacteria (Figure 12).
4. Conclusions

Through the results, the obtained from the statistical analysis:

a) After data were collected analyzed by the SPSS 23 program, the annual rate of removal efficiency for BOD, COD, TSS was 89, 78, 60%, respectively, which are satisfactory results within the required standards ethnic specifications, the BOD / COD ratio was 0.63, average Organic analysis within good strong rates, hence the toxicity the possibility of putting the treated water in the river water.

b) After performing the analysis of the main component, the mass, we obtained the following results, where there were 6 influencing components, which after testing the correlation coefficient were $R = 0.89$ $R^2 = 0.79$ which are high indicators indicating a close significant correlation between the components.

c) During the cluster analysis, through which we were able to diagnose a year in which the plant was deteriorating the year was 2020, this may indicate operational problems as well as poor quality control standards or climate fluctuations changing consumption seasons.

d) Through the cluster diagram the relationship of groups, we note an explanation from the above, as each of the BOD depends on 1, COD TSS within group 3 in the first stage 1 in the second stage, this indicates that there is a similarity in the characteristics features between them their effect.

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