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# THE INFLUENCE OF DRYING MODE ON THE DRYING TIME OF ANCHOVY FISH IN A HYBRID INFRARED-CONVECTIVE DRYER: DRYING TIME CORRELATION AND TAGUCHI ANALYSIS

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**Abstract:**
This work assesses the drying time correlation of anchovy fish in a hybrid infrared-convective dryer. The correlation of drying time was determined using the regression method. Moreover, the influence of drying mode on drying time was analyzed via the Taguchi approach. The effects of 0.4-0.8 kW infrared power, 0.5-1.5 m/s air velocity, and 50-70°C air temperature were considered. The maximum error of the value predicted using the drying time correlation and the experimental data was 2.7%. Analysis of the influence of input variables on drying time, performed according to the smaller-the-better criterion, showed an infrared power influence of 79.85%, air temperature influence of 19.30%, and air velocity influence of 0.85%. This result is a good orientation when setting up a drying mode in a hybrid dryer. Furthermore, the Taguchi approach fully visualizes the effects of the input variables on the drying time, which is an effective strategy for the present study.

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## 1. INTRODUCTION

Anchovy fish are small fish in the family Engraulidae. Found in most seas in the tropics, the large anchovy reserves bring many economic benefits to countries in Southeast Asia. Anchovy fish are often dried for medium- or long-term preservation. The technique of drying anchovy fish has been considered in many studies. Dongbang and Matthujak [1] experimentally studied the heat transfer characteristics of anchovy fish in a hybrid infrared-convective dryer. Research has developed the Nusselt number correlation for the anchovy drying process. Hamza et al. [2] studied the drying kinetics of anchovy fish in the solar dryer. They concluded that the Logarithmic model best describes the moisture reduction process and effective moisture diffusivity coefficient from 3.84 x $10^{-9}$ to 5.60 x $10^{-9}$ $m^2/s$. Kum et al. [3] studied the physicochemical properties of anchovy fish dried in a microwave dryer. They concluded that the microwave vacuum method produced fish of the highest quality among the six tested methods. Moraes and Pinto [4] investigated the drying kinetics of anchovy fish in a convective dryer. They reported that the Henderson–Pabis model best describes the moisture reduction process of fish. Delfiya et al. [5] examined anchovy drying in a convective-assisted infrared dryer. They concluded that the drying process was fast, with an efficiency reaching 38.8–46%. Abraha et al. [6] evaluated the quality of anchovies dried in solar tents and subjected to open-sun drying. They concluded that the quality of fish dried in solar tents was superior to those dried in the open sun. The drying time in a

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solar tent is reduced by 1.67 times compared to that in open sun. Cho et al. [7] studied the effect of drying mode on the lipid oxidation and fatty acid composition of anchovies. They reported low-temperature drying to be highly effective in preventing lipid oxidation. Al-Saadi et al. [8] evaluated the quality of dried anchovies in different solar dryers. They reported that the solar greenhouse tunnel dryer has advantages in reducing drying time and product color. Ragasudha et al. [9] analyzed the performance of a hybrid infrared-solar energy dryer to dry anchovy. They concluded that the maximum drying efficiency reached 41.11%.

Convective and infrared drying are two popular methods to dry agricultural and aquatic products in industrial procedures. Convective drying is simple in design and operation [10-12]. Meanwhile, infrared drying consumes limited energy and kills bacteria when drying aquatic products [13, 14]. Theoretically, combining infrared and convective strategies, a hybrid dryer accelerates the drying process due to moisture diffusion from inside the material to the outside due to the effect of temperature and infrared radiation. Furthermore, air velocity ensures a difference in vapor pressure between the surface of the material and the air, which facilitates moisture escape from the material's surface to the air environment, thereby creating motivation for moisture diffusion inside the material. Therefore, this hybrid dryer can be applied in actual production. This hybrid infrared-convective drying technology has been examined in several studies. Geng et al. [15] studied and optimized the potato-drying mode in a hybrid radiation convection dryer. They concluded that the mode with high air temperature and low infrared power generates high drying efficiency. Zadhossein et al. [16] analyzed the energy and exergy of a hybrid infrared-convection dryer for the goal of drying cantaloupe. The results indicate that high infrared energy and high air temperature can shorten drying time and increase energy efficiency. EL-Mesery [17] studied the influence of apple drying mode in a hybrid infrared-convective dryer. The results showed that the drying time decreased with rising temperature and infrared power. The lowest specific energy consumption was 4320 kJ/kg at 50°C air temperature and 0.30 W/cm$^2$ infrared intensity. Brandao et al. [18] studied bee pollen drying in a hybrid infrared-convective dryer with unheated airflow. They concluded that there was low energy consumption at mode with high infrared intensity and low air velocity. From studies on a hybrid infrared-convective dryer, it can be seen that this hybrid drying technology promotes a faster drying process. Hot air temperature, air velocity, and infrared power significantly influence the drying rate and drying efficiency of the dryer. This hybrid drying technology promises excellent efficiency and applicability in production.

In addition to product quality, drying time and energy consumption are worthy of consideration. Drying mode, drying time, and energy consumption are closely related. Therefore, analysis of the influence of input factors on drying time gives a reference for the design and setting of drying mode with the lowest energy cost and reasonable drying time. Among many analytical methods, the Taguchi method emerges as the best choice when considering the influence of input variables on response variables with a minimum number of experiments [19, 20]. This method has been applied to perform impact analysis and optimization in many research fields [21-23]

The previously published literature shows that drying anchovy fish has been considered in many studies. Drying anchovy fish in a hybrid infrared-convective dryer is a process that can be applied in actual production. This solution can reduce drying time, improve the quality of dried fish, and reduce energy consumption. The data on drying time, heat transfer characteristics, and drying efficiency of anchovy fish in a hybrid infrared-convective dryer have been provided by previous studies [1, 5]. However, no study has analyzed the effect of drying mode on the drying time of anchovies in a hybrid infrared-convective dryer. As mentioned, the influence of input parameters on drying time is the basis for considering and choosing an appropriate drying mode with adequately low energy costs. Therefore, in the present work, we applied the Taguchi method to evaluate the influence of input variables on the drying time of anchovy fish using experimental data in the literature [1]. The Taguchi analysis fully visualizes the influence of input variables on drying time, which was an effective strategy for the present study. Moreover, a correlation of drying time according to air temperature, air velocity, and infrared power was developed. This correlation can be used as a reference in design and operation. The results of the present work are expected to provide helpful data for using a hybrid infrared-convective dryer to dry anchovy fish in actual production.

## 2. MATERIALS AND METHODS

Fig. 1 describes the hybrid infrared-convective dryer model used to dry anchovy. The influence of 50-70°C air temperature, 0.5-1.5 m/s air velocity, and 0.4-0.8 kW infrared power on drying was considered. Specific details of the experimental description can be found in [1]. Some information about drying materials: Anchovy fish samples with an average diameter of 6±2 mm and length of 5±1 cm are used. The fish drying process is experimented with from an initial moisture content of 78±1% until the final moisture content of 20±1%.

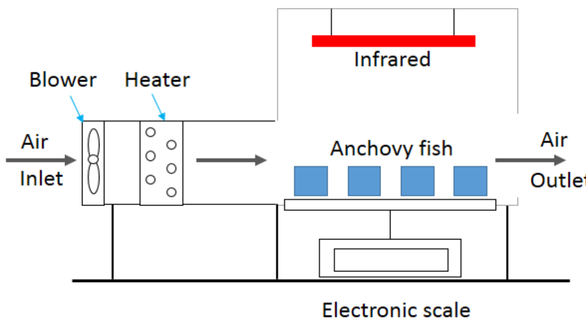



**Fig. 1.** The hybrid infrared-convective dryer

The experiments are strategically designed to determine the correlation between input and response parameters. There are many varients of experimental design, among which the Taguchi method has emerged as a valuable option with the advantages of visualization and a minimum number of experiments. The Taguchi method is a type of orthogonal array design. The orthogonal array table is determined based on the total degrees of freedom of a factor [24]. In the present work, three input variables are used to consider the effect on drying time, including air temperature (*T*), air velocity (*V*), and infrared power (*P*). Each input variable is taken into three levels of consideration. Thus, the total Degrees of Freedom (DOF) is shown in Table 1.

**Table 1.** Total Degrees of Freedom

| Factor | Degrees of Freedom |
|---|---|
| Overall mean | 1 |
| T, V, P | (3-1) x 3 |
| Interaction | 0 |
| Total DOF | 7 |

The total DOF of all factors is 7, so the number of experiments should be greater than 7. Therefore, the L9 orthogonal array is chosen in the present work. Details of the arrangement are shown in Table 2.

**Table 2.** Orthogonal array L9 according to Taguchi design

| No. | Factor | | |
|---|---|---|---|
| | T (°C) | V (m/s) | P (kW) |
| 1 | 50 | 0.5 | 0.4 |
| 2 | 50 | 1.0 | 0.6 |
| 3 | 50 | 1.5 | 0.8 |
| 4 | 60 | 0.5 | 0.6 |
| 5 | 60 | 1.0 | 0.8 |
| 6 | 60 | 1.5 | 0.4 |
| 7 | 70 | 0.5 | 0.8 |
| 8 | 70 | 1.0 | 0.4 |
| 9 | 70 | 1.5 | 0.6 |

In the Taguchi method, the signal-to-noise ratio (SN) is a typical quantity used to consider the effect of the input variable on the response variable. Depending on the target of the response variable, this value has a corresponding calculation formula [20, 25]:

For larger-the-better criterion:

$$SN = -10 \log \sum_{i=1}^{n} \frac{1}{n}\left(\frac{1}{y_i^2}\right) \quad (1)$$

For smaller-the-better criterion:

$$SN = -10 \log \sum_{i=1}^{n} \frac{1}{n}\left(y_i^2\right) \quad (2)$$

where *n* and *y* are the number of observation and the observed data, respectively.

Table 3 shows the computed method of ranking about the influence of input variables on the response variable. The larger the delta value, the higher the rank.

Analysis of the input variable contribution to the response variable is performed through analysis of variance of SN data, then calculated according to the following formula [20]:

$$CF = \frac{SS_i}{SS_T} \cdot 100\% \quad (3)$$

where $SS_i$ and $SS_T$ are the sequential sum of squares and the total sequential sum of squares, respectively, they were determined by analysis of the variance of SN data on Minitab software [26].

**Table 3.** Computed the ranking of the influence of input variables on the response variable

| Level | T (°C) | V (m/s) | P (kW) |
|---|---|---|---|
| 1 | $x_1 = \frac{1}{n}\sum_{i=1}^{n=3} SN_{1,T}$ | $y_1 = \frac{1}{n}\sum_{i=1}^{n=3} SN_{1,V}$ | $z_1 = \frac{1}{n}\sum_{i=1}^{n=3} SN_{1,P}$ |
| 2 | $x_2 = \frac{1}{n}\sum_{i=1}^{n=3} SN_{2,T}$ | $y_2 = \frac{1}{n}\sum_{i=1}^{n=3} SN_{2,V}$ | $z_2 = \frac{1}{n}\sum_{i=1}^{n=3} SN_{2,P}$ |
| 3 | $x_3 = \frac{1}{n}\sum_{i=1}^{n=3} SN_{3,T}$ | $y_3 = \frac{1}{n}\sum_{i=1}^{n=3} SN_{3,V}$ | $z_3 = \frac{1}{n}\sum_{i=1}^{n=3} SN_{3,P}$ |
| Delta | Max ($x_1$, $x_2$, $x_3$) - Min ($x_1$, $x_2$, $x_3$) | Max ($y_1$, $y_2$, $y_3$) - Min ($y_1$, $y_2$, $y_3$) | Max ($z_1$, $z_2$, $z_3$) - Min($z_1$, $z_2$, $z_3$) |

*Note: $SN_{j,A}$ is *SN* of variable *A* at level *j*.

## 3. RESULTS AND DISCUSSION

The values shown in Table 4 are taken according to the L9 orthogonal array, and they are the drying time values extracted from [1]. This study used these data to analyze the influence of infrared power, air temperature, and air velocity on drying time.

**Table 4.** The L9 orthogonal array with the response variable values

| No. | T (°C) | V (m/s) | P (kW) | t (minutes) |
|---|---|---|---|---|
| 1 | 50 | 0.5 | 0.4 | 687 |
| 2 | 50 | 1.0 | 0.6 | 568 |
| 3 | 50 | 1.5 | 0.8 | 319 |
| 4 | 60 | 0.5 | 0.6 | 478 |
| 5 | 60 | 1.0 | 0.8 | 260 |
| 6 | 60 | 1.5 | 0.4 | 508 |
| 7 | 70 | 0.5 | 0.8 | 240 |
| 8 | 70 | 1.0 | 0.4 | 456 |
| 9 | 70 | 1.5 | 0.6 | 390 |

Fig. 2 shows the influence of the input variables on the SN value for the drying time criterion smaller-the-better. The results show that drying time decreases with the rise in infrared power, air temperature, and air velocity. Anchovy fish receive more heat when there is a rise in infrared power and air temperature, leading to increased moisture diffusion from inside the fish to the exterior. Furthermore, the high air velocity ensures the high vapor pressure gradient between the fish surface and the air, facilitating moisture diffusion inside fish. Thus, drying time decreases with increasing values of input variables. The influence curve of air velocity is almost horizontal, which shows that the air velocity does not significantly affect drying time. The influence curve of air temperature has a higher slope than that of air velocity. So, the influence of air temperature on drying time is more significant. Drying time is inversely proportional to air temperature. The influence curve of infrared power has the highest slope, demonstrating that this factor significantly influences the drying time. Details of the impact ranking can be seen in Table 5. Infrared power has the highest influence with a delta of 6.02, and air velocity has the lowest influence with a delta value of 0.64.

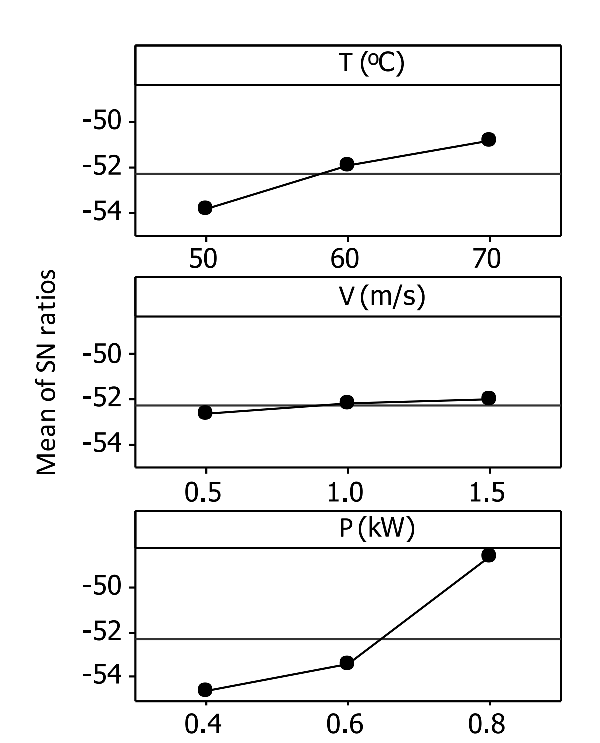



**Fig. 2.** The influence of input variables on the signal-to-noise ratio (SN)

**Table 5.** Ranking influence of input factors on drying time

| Level | T (°C) | V (m/s) | P (kW) |
|---|---|---|---|
| 1 | -53.97 | -52.64 | -54.68 |
| 2 | -52.00 | -52.19 | -53.50 |
| 3 | -50.87 | -52.00 | -48.66 |
| Delta | 3.10 | 0.64 | 6.02 |
| Rank | **2** | **3** | **1** |

The above analysis shows trends and ranks of the influence of infrared power, air temperature, and air velocity on drying time. However, the value of the contribution is not provided. This issue can be performed through an analysis of the variance of SN data and calculated according to Eq.3. The results show an infrared power contribution of 79.85%, an air temperature contribution of 19.30%, and an air velocity contribution of 0.85%, with a confidence level of approximately 100% (see Table 6). This is valuable information when establishing the drying mode on a hybrid infrared-convective dryer to dry anchovy fish. When considering the effect of air velocity on drying time—0.85%—it is clear that drying at high air velocity is unnecessary. The air velocity should only be sufficient to remove moisture from the surface of the fish to the air. The results on the effects of infrared power, air temperature, and air velocity in this study are highly consistent with the conclusions reached in the previous studies [16-18].

**Table 6.** Analysis of the influence of input variables on drying time

| Source | DOF | Seq SS | F test | P - value | CF, % |
|---|---|---|---|---|---|
| T (°C) | 2 | 14.7522 | 32013.21 | 0.000 | 19.30 |
| V (m/s) | 2 | 0.6497 | 1409.92 | 0.001 | 0.85 |
| P (kW) | 2 | 61.0336 | 132447.1 | 0.000 | 79.85 |
| Error | 2 | 0.0005 | | | 0.00 |
| Total | 8 | 76.4359 | | | 100 |

[*] *Note:* DOF: degrees of freedom, Seq SS: sequential sum of squares; S = 0.01518, R-Sq = 100%.

Fig. 3 visualizes the influence of infrared power and air temperature on the drying time of anchovies with air velocity ranging from 0.5 m/s to 1.5 m/s. Drying time is sharply reduced when air temperature and infrared power are increased.

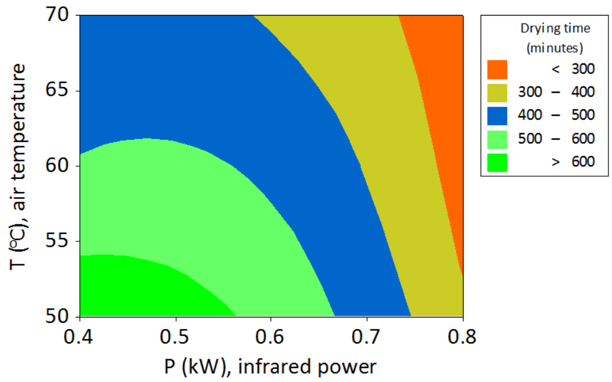



**Fig. 3.** Variation of drying time with infrared power and air temperature

As mentioned, developing correlations of drying time with input variables is a significant task in contemporary research. Scholars have developed a mathematical model for predicting drying time using three parameters (air temperature, air velocity, and infrared power) based on experimental data from [1]. The mathematical model is determined via the regression method using EES (Engineering Equation Solver) software [27].

The proposed drying time correlation has the form:

$$t = f(P, T, V) \tag{4}$$

where *t* (hour), *P* (kW), *T* (°C), and *V* (m/s) are drying time, infrared power, air temperature, and air velocity, respectively.

Fig. 4a shows the relationship between drying time and air temperature. The proposed regression form is as follows:

$$t = A_o \cdot T^n \tag{5}$$

where $A_o$ and $n$ are model constants.

The influence of air velocity on $t/T^n$ is plotted as shown in Fig. 4b. The proposed regression form is as follows:

$$t/T^n = B_o \cdot V^m \tag{6}$$

where $B_o$ and $m$ are model constants.

Fig. 4c shows the effect of infrared power on $t/(T^n.V^m)$. Due to the complex influence of infrared power on drying time, the proposed regression model gives the form:

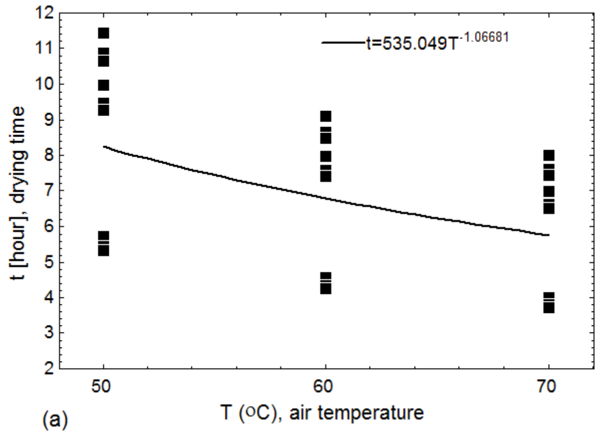
$$t/(T^n \cdot V^m) = A_1 + A_2 \cdot P + A_3 \cdot P^2 \tag{7}$$

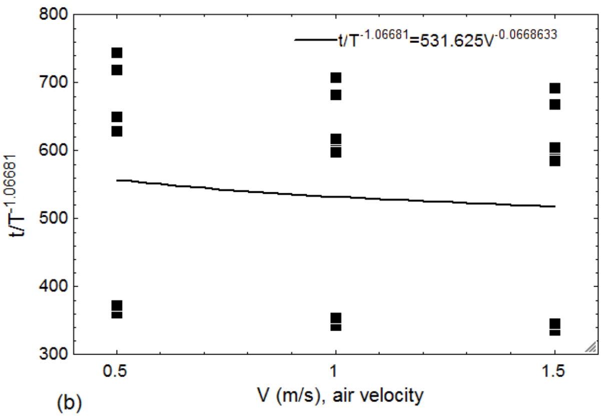
where $A_1$, $A_2$, and $A_3$ are model constants.

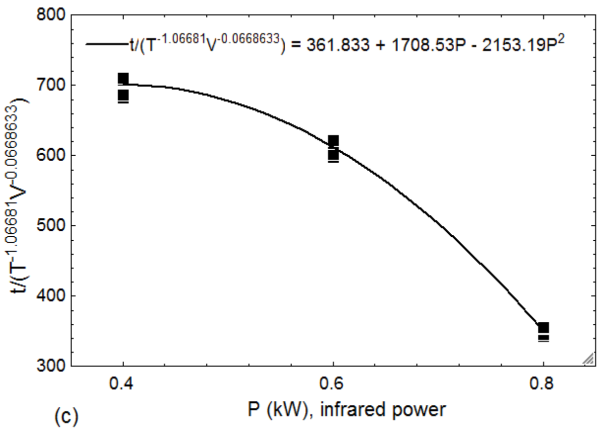
The drying time model is obtained as follows:

$$t = T^n \cdot V^m \cdot (A_1 + A_2 \cdot P + A_3 \cdot P^2) \quad (8)$$

The model coefficients *m, n, $A_1$, $A_2$,* and *$A_3$* are shown in Table 7. The maximum deviation between the predicted value obtained by correlation and the experimental value is shown in Fig. 4d, with an error of approximately ±2.7%. The correlation coefficient of the Eq.8 with the experimental data was $R^2$ = 0.9974.



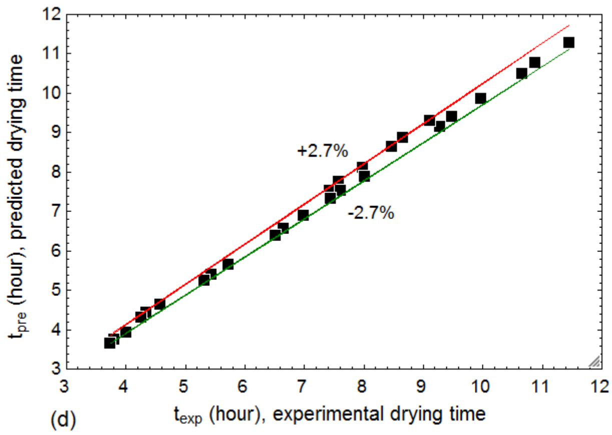




**Fig. 4.** Development of the drying time correlation

**Table 7.** The constants in the correlation model

| | |
|---|---|
| n | -1.06681 |
| m | -0.0668633 |
| $A_1$ | 361.833 |
| $A_2$ | 1708.53 |
| $A_3$ | -2153.19 |

## 4. CONCLUSION

In the present work, the drying time correlation of anchovy fish in a hybrid infrared-convective dryer was developed from experimental data. The influence of input factors on drying time was performed using the Taguchi analysis. The main findings are given as follows:

The correlation equation of drying time with air temperature, air velocity, and infrared power is highly reliable. The maximum error between the predicted value obtained via correlation and the experimental value is about 2.7%. This correlation can predict drying times for design and operational purposes.

The influence of the infrared power, air temperature, and air velocity on drying time was 79.85%, 19.30%, and 0.85%, respectively, with a confidence level prediction of about 100%. Infrared power exerts the most significant influence on drying time, and air velocity has the least significant effect.

The influence of input parameters, drying time, and equipment power is the basis for establishing a drying mode with an appropriate duration and reasonable energy costs in actual production. Future research will further assess drying efficiency and the quality of anchovies under a hybrid infrared-convective dryer. This will provide additional data for anchovy drying for actual production.

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