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# Application of response surface methodology for optimization of green bricks drying process

**Berçem Kiran-Yildirim*, Ebru Mançuhan and Sibel Titiz-Sargut**

Chemical Engineering Department, Marmara University, Istanbul, Turkey

*E-mail:* bercem.kiran@marmara.edu.tr

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Drying operation may eventuate with occurring of shrinkage, which is an undesired process due to possibly causing cracks, deformation, etc., on the product. The reasons for shrinkage can be linked to drying process conditions and properties of dried samples, which should be under control. In this study, a laboratory-scale tunnel dryer was operated to examine the influence of drying air temperature and drying air velocity on the drying time of green brick samples with various clay contents (40–60%). The drying air temperature was varied between 323.15–343.15 K, while the velocity was between 1.0–3.0 m/s. The results indicated that the drying time became shorten with increasing the drying air temperature and drying air velocity. The contrariwise result was observed with increasing the clay content of green brick samples. Response surface methodology (RSM) using central composite design (CCD) was employed to analyze the influence of these three variables on the drying time of the samples.

Keywords: Experimental design, drying time, green brick, tunnel dryer.

## Introduction

Brick is an important building material by reason of having unique properties such as strength, durability, fire resistance, beauty, and satisfactory bond and performance with mortar[1,2]. Clay is one of the main ingredients of bricks besides clayey soils, soft slate, and shale[1]. The production process of clay bricks includes preparing clay soil paste with water, molding, drying, and firing. The drying process can be described as evaporation of the water and is of great influence on the quality of the brick product. Therefore, this process conditions should be under control due to possible occurring shrinkage, which can result in cracks, deformations, and so on. The brick body's properties, such as clay percentage, initial moisture content, etc., are of a great contribution to the shrinkage, like the drying air properties such as temperature, velocity, etc. In literature, there are lots of studies focused on the effect of various variables on the shrinkage behavior of clay[3,4]. These investigated parameters are also considered to optimize the brick drying time, which can lead to minimizing the process energy consumption. Kowalski and Pałowski examined the effect of changing temperature and humidity of the drying medium (air) on the quality of bricks, drying time, and the energy consumption during the drying process in a laboratory chamber. They revealed that non-stationary conditions more suitable than stationary in terms of the quality of the product, while slight differences were observed in drying time[5]. Moropoulou *et al.* were performed an experimental study and modeled the results for drying of stone materials, bricks, and plasters. They analyzed the influence of drying air properties such as temperature and velocity, and relative humidity on the drying air constant. The results suggested that the drying time decreased with increasing air velocity and decreasing relative humidity[6]. Chemkhi and Zagrouba studied with different drying air temperatures (40–60°C) and relative humidities (30–60%) at a constant drying air velocity of 2 m/s for drying of clay material. They revealed that the ambient temperature and the moisture content, and the physical structure of the product influenced the moisture diffusivity[7].

Even though the influence of various parameters was investigated in the literature, the combined impact of the clay content of brick samples, drying air velocity, and temperature on the drying time have not been examined in detail yet. Therefore, this study was focused on the interaction of these parameters in a laboratory-scale tunnel dryer. The green bricks were used as samples in this study. The complicated results of this study were evaluated by response surface methodology (RSM) based on central-composite design (CCD).

### Experimental method and design

A laboratory-scale tunnel dryer built in a previous study[8] was run for drying the green brick samples with clay contents of 40% to 60%. These samples were supplied from a brick factory. The drying air temperature was varied between 323.15 and 343.15 K while velocity was changed between 1.0 m/s and 3.0 m/s. Table 1 presents five different values of each variable used for performing the experimental study.

The tunnel dryer system consists of three main parts; the units of the air preparation and tunnel dryer and the control system. The drying air was prepared by a centrifugal fan and electrical heater. The drying air temperature was adjusted by a PID-controlled 500-W electric heater. The uniformity of the airflow in the dryer was provided by using a system of a wire meshes. After providing the steady-state conditions, a sample was laid on the wire mesh carrier. The change in sample weight was determined by the digital balance every 5 min. The sample surface temperature was measured by a Pt-100, connected to a computer, with an accuracy of ±0.1°C in every 20 s. The experiments were continued until obtaining the final moisture content of 0.06 kg $H_2O$/kg dry brick. The effects of the clay content of brick samples, drying air temperature, and drying air velocity on the drying time were measured, and each experiment was repeated three times.

**Table 1.** Independent variables and their levels in CCD

| Independent variables | Range and levels | | | | |
|---|---|---|---|---|---|
| | –1.68179 | –1 | 0 | 1 | 1.68179 |
| A: Drying air temperature (K) | 323.15 | 328.15 | 333.15 | 338.15 | 343.15 |
| B: Drying air velocity (m/s) | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
| C: Clay content of green brick (%) | 40 | 45 | 50 | 55 | 60 |

**Table 2.** CCD and response results for the study of three independent variables in coded units

| Test number | Coded level of factors | | | Actual level of factors | | | Response |
|---|---|---|---|---|---|---|---|
| | $x_1$ | $x_2$ | $x_3$ | Drying air temperature (K) | Drying air velocity (m/s) | Clay content of green brick (%) | drying time (min) |
| 1 | 0 | 0 | 1.68179 | 333.15 | 2 | 60 | 265 |
| 2 | 1 | 1 | 1 | 338.15 | 2.5 | 55 | 220 |
| 3 | 1.68179 | 0 | 0 | 343.15 | 2 | 50 | 170 |
| 4 | 0 | 0 | 0 | 333.15 | 2 | 50 | 260 |
| 5 | 0 | 0 | 0 | 333.15 | 2 | 50 | 260 |
| 6 | –1 | –1 | 1 | 328.15 | 1.5 | 55 | 290 |
| 7 | 1 | –1 | –1 | 338.15 | 1.5 | 45 | 209 |
| 8 | 1 | –1 | 1 | 338.15 | 1.5 | 55 | 224 |
| 9 | –1 | 1 | 1 | 328.15 | 2.5 | 55 | 288 |
| 10 | 1 | 1 | –1 | 338.15 | 2.5 | 45 | 205 |
| 11 | 0 | 0 | 0 | 333.15 | 2 | 50 | 260 |
| 12 | 0 | 0 | 0 | 333.15 | 2 | 50 | 260 |
| 13 | 0 | 0 | 0 | 333.15 | 2 | 50 | 260 |
| 14 | –1 | –1 | –1 | 328.15 | 1.5 | 45 | 282 |
| 15 | –1.68179 | 0 | 0 | 323.15 | 2 | 50 | 314 |
| 16 | 0 | 0 | –1.68179 | 333.15 | 2 | 40 | 227 |
| 17 | –1 | 1 | –1 | 328.15 | 2.5 | 45 | 280 |
| 18 | 0 | –1.68179 | 0 | 333.15 | 1 | 50 | 261 |
| 19 | 0 | 1.68179 | 0 | 333.15 | 3 | 50 | 257 |
| 20 | 0 | 0 | 0 | 333.15 | 2 | 50 | 260 |

The combined effects of these variables on the drying time of green bricks were examined by CCD in RSM (Design Expert statistical software, version 10). CCD is one of the most popular experimental design techniques used to optimize the process parameters. The combined effect of two variables on the results is examined at a fixed level of the third variable. The significance of variables with different units might only be compared by coding them. Drying air temperature (K) and velocity (m/s) and clay content of green brick (%) were the independent variables, while the dependent variable was the drying time of green bricks (min). The effect of these independent variables was analyzed at three levels: high (–1), zero (0), and low (–1) levels[9,10]. The range and levels of independent variables are listed in Table 1. The actual design with the coded and actual levels of variables and experimental results as observed values are illustrated in Table 2. The results were examined by fitting the response variable to a second-order model in the form of quadratic polynomial equation. The model was tested statistically with the Analysis of Variance (ANOVA).

## Results and discussion

*Drying experiments:*

The effects of three variables, clay content of sample, drying air temperature, and drying air velocity, on the drying time of a green brick sample were examined in a laboratory-scale tunnel dryer. The results showed that the drying time highly depends on the drying air temperature. The less influence was observed with changing the drying air velocity and clay content of the sample. The results of drying air velocity effect on the drying time conform to those described by Chemkhi and Zagrouba[7]. The dependency of drying time on these variables can be summarized as the drying time of a green brick sample decreases with increasing the drying air temperature and velocity, while an increase in the green brick clay content results in increasing the drying air time. The experimental results are represented on the right side of Table 2 as the response, with the actual and coded level of variables.

*Central composite design (CCD):*

As indicated, the evaluation of three variables' effects is more complicated, and the RSM was used to optimize the conditions. An equation was developed for the drying time to correlate the clay contents of green brick samples, drying air temperature, and velocity variables. The polynomial model equation as a function of variables in coded units obtained for the drying time of green bricks is presented in eq. (1).

$$Y_{\text{Drying time}} = 259.95 - 38.38A - 1.37B + 8.05C - 0.50AB + 1.75AC - 6.06A^2 - 0.054B^2 - 4.65C^2 \quad (1)$$

As can be understood from eq. (1), the increase in positive value, clay content of green brick ($C$), causes an increase in the drying time of green bricks, while it decreases with increasing negative values (drying air temperature ($A$), and

**Table 3.** ANOVA for the quadratic model for drying time of green bricks with different clay content

ANOVA for response surface quadratic model

| Source | Sum of squares | *df* | Mean square | *F*-value | *p*-value Prob > *F* | |
|---|---|---|---|---|---|---|
| Model | 21836.62 | 9 | 2426.29 | 81.37 | < 0.0001 | Significant |
| A: Drying air temperature | 20119.04 | 1 | 20119.04 | 674.74 | < 0.0001 | |
| B: Drying air velocity | 25.68 | 1 | 25.68 | 0.86 | 0.3753 | |
| C: Clay content of green brick | 884.52 | 1 | 884.52 | 29.66 | 0.0003 | |
| AB | 2.00 | 1 | 2.00 | 0.067 | 0.8009 | |
| AC | 24.50 | 1 | 24.50 | 0.82 | 0.3860 | |
| BC | 0.000 | 1 | 0.000 | 0.000 | 1.0000 | |
| $A^2$ | 530.09 | 1 | 530.09 | 17.78 | 0.0018 | |
| $B^2$ | 0.043 | 1 | 0.043 | 0.001434 | 0.9705 | |
| $C^2$ | 311.70 | 1 | 311.70 | 10.45 | 0.0090 | |
| Residual | 298.18 | 10 | 29.82 | | | |
| Lack of Fit | 298.18 | 5 | 59.64 | | | |
| $R^2$ | 0.9865 | | | | | |

drying air velocity (*B*)). The model was tested statistically by ANOVA technique, and the results are illustrated in Table 3.

The probability value (*p*-value) determined as < 0.0001, smaller than 0.05 (*p*-value < 0.05), refers to the model is significant statistically. The determination coefficient ($R^2$) value obtained as 0.9865 points out that the model equation

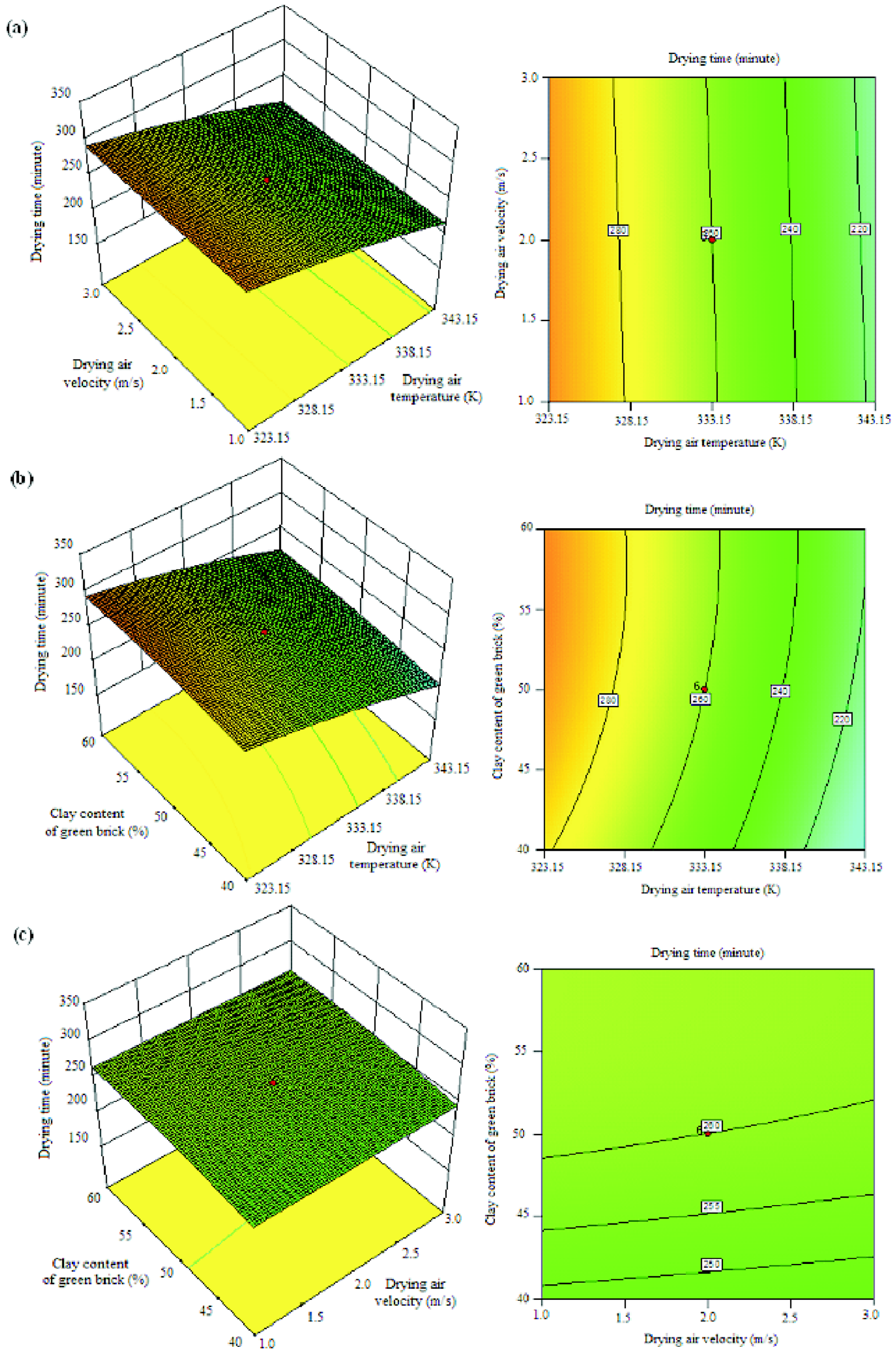


**Fig. 1.** Response surface and contour plots with respect to the impact of (a) drying air velocity and drying air temperature, (b) clay content of green brick and drying air temperature and (c) clay content of green brick and drying air velocity on the drying time of green bricks.

fits with the experimental results. The sample variation of 98.65% is linked to the independent variables, and only 1.35% of the total variance are not be explained by the model. The relation of the drying time with the combined impact of two variables (drying air temperature-drying air velocity or drying air temperature-clay content of green brick or drying air velocity-clay content of green brick) at a constant level of the third variable are presented in Fig. 1.

Each plot shown in Fig. 1 reveals the effects of two variables on the drying time when the third variable fixed to the zero level. The response surface can be evaluated for examining the tendency of each factor affecting the drying time of green bricks. As for the contour plots, the shape of them can be analyzed for the nature and extent of the interactions between factors. A prominent interaction is represented with an elliptical contour plot while a circular contour plot indicates a negligible effect[11]. Based on the figures, the drying air temperature and clay content of the green brick sample had a greater effect than the drying air velocity on the drying time.

## Conclusions

CCD in RSM was used to elucidate the impact of drying air temperature, drying air velocity, and clay content of green brick on the drying time of green bricks. The second-order polynomial equation was established to reveal the relationship between the drying time of green bricks and three parameters. Following conclusions have been withdrawn from this study:

(i) The drying time highly depends on drying air temperature while there is a little interaction of drying air velocity and clay content of green brick samples with drying time.

(ii) The proposed model is statistically significant, and there is a good correlation between the experimental data and predicted values.

(iii) According to all evaluations, the drying time could be under control with drying air temperature.

The optimization of the drying time and thus, energy consumption may be attained by these experimental results and theoretical evaluations.

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