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Effect of Magnetic Field on Convective Drying Of Ceramic Clay

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ABSTRACT

The concern about quality of dried products and the increasing energy costs during drying is motivating researchers to investigate and adopt innovative drying techniques capable of reducing both drying time and energy costs and at the same time improving dried product quality. Ceramic clay weighing 500 g was used for this study and the sample was dried in an experimental cabinet dryer under magnetic field range of 200 to 600 V/m and initial moisture content of 35%. The maximum temperature of 56.05 ºC was attained at magnetic field strength of 600 V/m, air velocity of 2.27 m/s and final moisture content of 16.5% after 150 minutes of drying. Energy consumption decreased with increasing magnetic field and air velocity. The final moisture content under normal convective drying without the influence of magnetic field was 20.6%, suggesting that lower moisture content and improved dried product quality can be achieved during convective drying of ceramic clay by use of magnetic field.

Keywords: *Innovative Drying Techniques, Magnetic Field, Ceramics, Product Quality*

1. INTRODUCTION

The most common challenge facing researchers involved in the study of the drying process is how to predict the appropriate average moisture content of dried product and the temperature at which it is attained in response to a given set of drying conditions capable of achieving overall dried product quality. Considering the physical mechanisms involved in the drying of ceramics and other industrial materials such as the effect of air temperature; air humidity, air velocity, moisture content of the sample material as well as the physical properties, it has been established that only the average temperature and moisture content constitute the drying quality indicators along with their distribution within the drying material (Nor Azni Shahari, 2012.Due to the changes in moisture and temperature gradients during drying, variations in moisture content as a function of both time and space exist within the drying materials. Various approaches have been deduced for the determination of the safe moisture on every location in the material being dried, including mathematical simulation involving simultaneous heat and moisture transfer under transient conditions.

The pioneer work on the development of simultaneous heat and mass transfer modeling was done by Darcy as far back as 1856. He proposed a direct relationship between flow rate and applied pressure difference. Luikov used thermodynamic theory of irreversible processes to describe the temperature, moisture and pressure distribution within porous media during drying using mass and energy conservation equations to describe water, vapor and heat fluxes within the porous media. Drying of ceramic products is a critical step in its processing due to the skill required to strike a balance between minimizing drying time and avoiding differential shrinkage, warping, and distortion. Relatively small number of research papers that describe the drying process of ceramics and especially clay materials are available in literature. The most commonly used method of drying ceramics is by convection, in which heated air is circulated around the material.

Wolny and Kaniuk (1995) carried out experiments on the convective drying of ceramic substance and water vaporization from surfaces in electric field in the presence of corona wind and the results of the research confirmed the importance of the influence of the corona wind on the heat and mass transfer at low air velocity. Zeden and Kerkhof, 1996 carried out extensive research on isothermal mass transport mechanisms during convective drying of clay products and presented a model which describes moisture transport inside a porous clay material during drying. Zagrouba et al., 2002 developed a mathematical model of transport phenomena involving heat, mass, and momentum transport during convective drying of clay tiles and presented a method for the determination of both the heat transfer coefficient and effective diffusion coefficient.

2. MATERIALS AND METHODS:.

Two sets of experiments were carried out, namely;

i. Experiment for the determination of rate of energy consumption and activation under the influence of varying magnetic field and their comparison with normal convection method.

ii. Determination of temperature and moisture content distribution during the convective and magnetic field assisted- convective drying of ceramics and their comparison.

The first category of the experiments involved convective drying using a cabinet dryer with an axial flow fan heater while the second category was by magnetic field-assisted convective drying using the same cabinet tray dryer but with additional copper wire coil round the tray and coupled to an electric variac to generate the magnetic field. The experiments were carried out at the Federal Institute of Industrial Research, Oshodi, Lagos.

Before the drying process, the samples were weighed with digital balance. The drying sample materials were artificially moistened up to 20%. From literature, the moisture content (wet basis) is determined using the formula;

$$MC_{db} = \frac{W_{wp} - W_{dp}}{W_{dp}} \qquad (1)$$

Where,

W_{dp} = weight of dry product (kg)

W_{wp} = Weight of wet product (kg)

Mc_{db} = Moisture content dry basis (%)

The initial and final temperature of each of the ceramics material was also determined using probe thermometer.
After the experimental dryer has reached steady state temperature conditions for operation, the measured weight of each sample was put on the tray of the dryer and dried in turn, first without the influence of magnetic field and second, with the influence of magnetic field of varying strengths of range 200 to 600 V/m. Drying was continued until the final moisture content of the samples reached approximately 0.06 g water / g dry matter. During the experiments, the ambient temperature and relative humidity, as well as the inlet and outlet temperatures of the drying air in the chamber were recorded at 30 minutes intervals.

The parameters monitored during the experiments were; drying temperature, moisture content, air velocity, relative humidity at selected magnetic field strengths of 200, 300, 400, 500 and 600 V/m and the corresponding electric currents of 1.0, 1.5, 2.0, 2.5 and 3.0A respectively and between drying time duration of 30 to 150 minutes at intervals of 30 minutes. Readings were taken at five equidistant sampling points. Energy consumption at drying intervals for each product was monitored for the two drying methods. The optimum values obtained with respect to the drying period, energy consumption and moisture content for each sample product were also recorded. Drying temperature, drying time and magnetic field strength were the independent variables while, moisture content, air velocity, and energy consumption were the dependent variables.

2.2 Moisture Content Determination

The moisture content of the fresh as well as the dried samples of each product was determined according to the method recommended by the American Society of Agricultural Engineers Standard S410.1 Standard (ASAE, 1998). The moisture content was determined by placing the samples in an oven set at 102°C for 5 hours and the weight monitored every 1hour until three consecutive weights were the same, using the oven drying method. This involved removal of the samples from the oven and placing it in desiccators to allow for cooling before weighing. The percentage difference in weight of each sample before and after by oven drying was calculated as the moisture content dry basis. Having determined the values of the moisture content of the material before and after drying, the rate of moisture escape from the material being dried at a particular time was calculated using the equation of (Haghi, 2001).

$$EVAP = (H_i - H_f) \times SLD \qquad 2$$

Where

H_i = moisture content of material before drying (%)

H_f = moisture content of material after drying (%)

S = speed of drying air in the chamber (m/s)

L = material width (representative of lump size) (m)

D = superficial weight of dry material (kg/ m^3)

The moisture ratio (MR) of the samples during the drying experiments was calculated using the equation,

$$MR = \frac{M_t - M_e}{M_i - m_e} \qquad 3$$

Where

Mt = Moisture content at time, t

Mi = Initial moisture content

Me = Equilibrium moisture content

3. RESULTS AND DISCUSSION

The ranges for the drying parameters during convective drying of ceramic clay, namely temperature (30-70 °C), relative humidity (30-80%) and air velocity (1-3m/s) were set up as boundaries for the drying experiment. This is in line with Moropoulou et al., 2005 who investigated the influence of drying air temperature, relative humidity and air velocity of ceramic clay in order to develop a drying model which included in its structure the drying air parameters. Mancuhan 2009 also studied industrial drying of bricks in a tunnel dryer in order to find the optimal drying air parameters which are necessary for rationalization and optimization of the drying process. Two ceramic clay samples obtained from the Ceramic laboratory of the Federal Institute of Industrial Research Oshodi, Lagos were analyzed in the same laboratory.

3.1 Drying of ceramics under the influence of varying magnetic fields.

Under this drying regime, the maximum drying temperature recorded was 56.05 °C at magnetic field strength of 600 V/m. The drying air velocity was 3 m/s, a relative humidity of 34.63% and final moisture content of 16.5%. The relative humidity was lowest at 2hours duration and under magnetic field strengths of between 400 to 500 V/m.

Figures 1 and 2 show the temperature and moisture content distributions under combined convective and magnetic field assisted-convective drying of ceramic clay at different time duration. Tables 1 and 2 show the results of comparison of temperature and moisture content variation under combined convective and magnetic field assisted-convective drying of ceramic clay.

CD =Normal convective drying
MD = Magnetic field assisted drying at selected values

Temperature distribution under normal convective drying was uniform irrespective of the drying duration, maintaining a constant value of 40 ^{o}C. However, under magnetic field, there were variations with respect to drying time and magnetic field values. After a drying period of 60 minutes, a maximum temperature of 60 ^{o}C was attained under a magnetic field value of 600 V/m. This indicates that it is time and energy saving to dry ceramics under magnetic field value of 600 V/m.

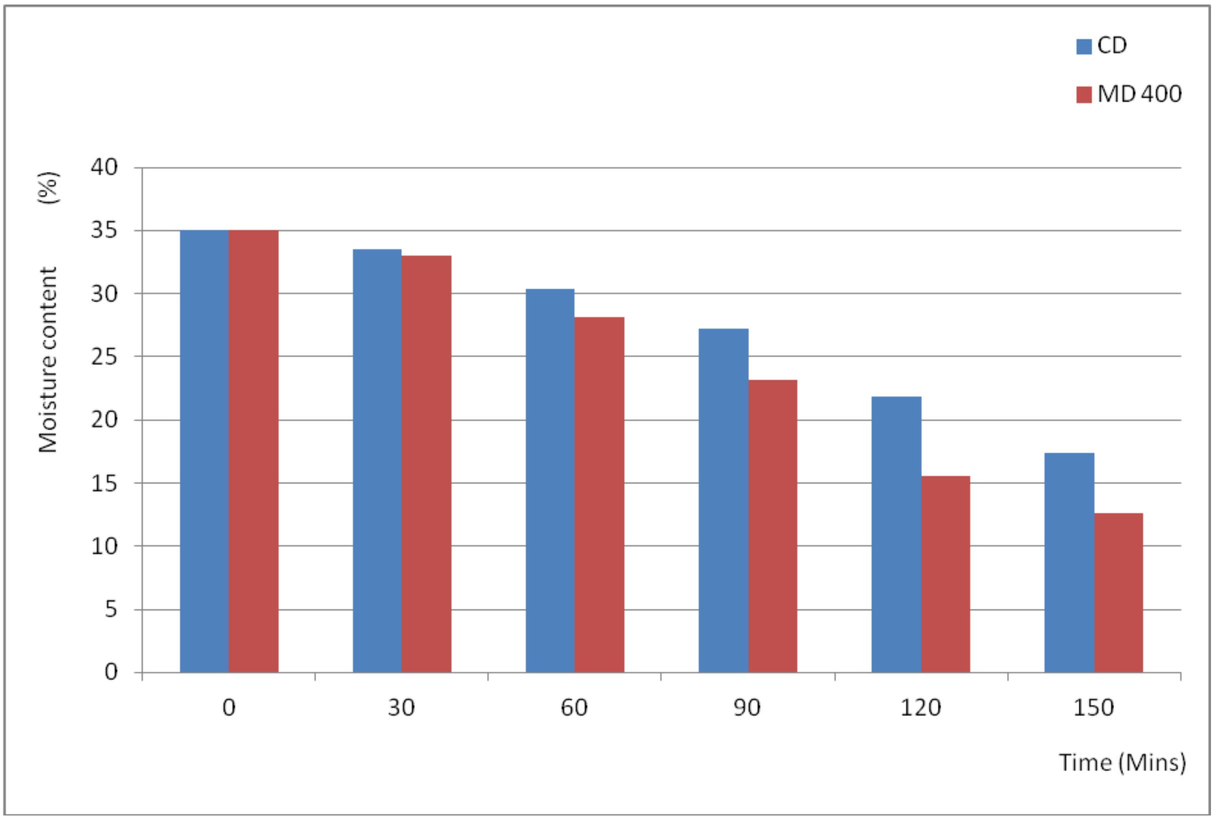

Figure 1 Comparison of temperature distribution pattern of ceramics under convective and magnetic field-assisted convective drying

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Figure 2 Comparison of moisture content distribution pattern of ceramics under convective and magnetic field-assisted convective drying.

Lowest moisture content value of 13% was attained at 400 V/m after 150 minutes drying time as against 17.5% obtained under convective method. The moisture content distribution was uniform for both convective and magnetic field-assisted convective drying up to 30 minutes drying duration. From 60 minutes of drying to 150 minutes, the decrease in moisture content removal became steadily faster under magnetic field value than under the convective drying method. Thus, magnetic field enhances the rate of moisture removal during drying of ceramics.

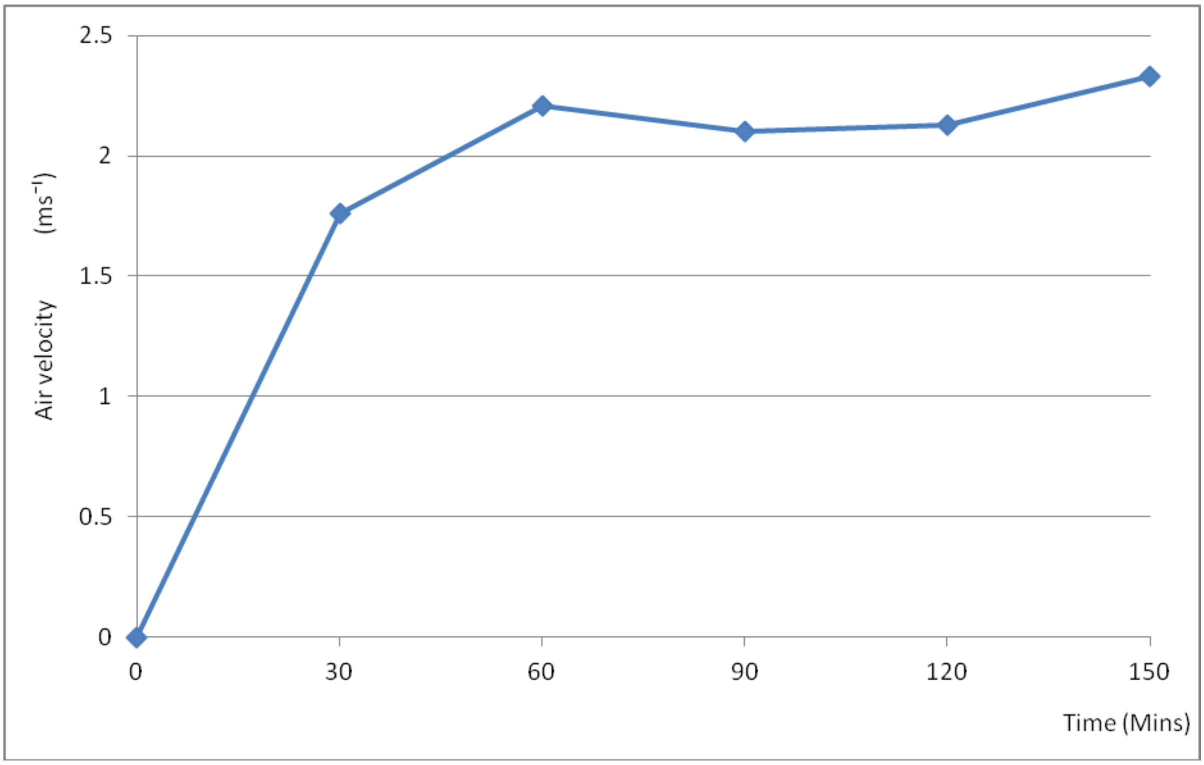

Figure 3 Drying rate curve of ceramics under convective drying without magnetic field effect.

The drying rate curve of ceramics without the influence of magnetic field shows a steep rise from zero 1.75 m/s within the first 30 minutes of drying and a gradual increase to 2.2 m/s after 60 minutes. There was a slight decrease from 2.2 to 2.1 m/s between 60 minutes to 120 minutes duration before another gradual increase up to 2.3 m/s at the end of the drying period. The reason for this is attributable to a decrease in solid moisture content and the fall in surface area moisture layer during the falling rate period.

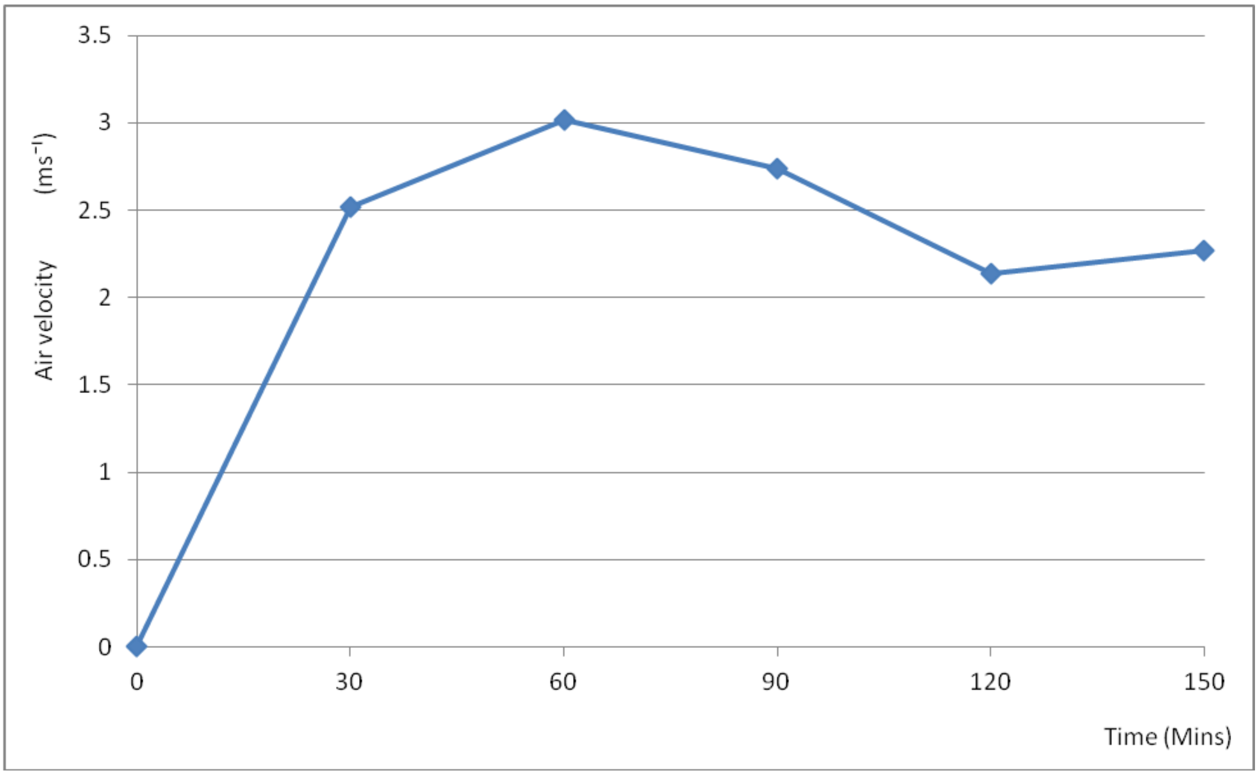

Figure 4 Drying rate curve of ceramics under the influence of magnetic field.

The drying rate curve rose sharply to 2.5 m/s within 30 minutes and gradually to a maximum value of 3 m/s after 60 minutes. There was a sharp decrease from 3 to 2.75 m/s and further decrease to 2.2 m/s at 120 minutes drying. After this period, it rose gradually to a maximum value of 2.3 m/s at 150 minutes drying duration. The explanation of this behavior lies in the falling rate drying theory, though this behavior tends to be more rapid under the influence of magnetic field.

Table 1 Comparison of Moisture Content Variation with Drying Time and Temperature Under Convective And Magnetic Field Assisted-Convective Drying Of Ceramics.

		Moisture content values (%)	
Drying time (min)	Drying temp.(ºC)	Conv.method	Magnetic assisted method
0	0	45.5	45.5
30	39	40.5	38.6
60	46	34.7	32.5
90	51	29.6	25.5
120	57	24.5	20.3
150	65	20.6	16.5

Table 2 Energy consumption variation with drying parameters for ceramics under the influence of magnetic field.

Magnetic Field	Temp	Duration	Air velocity	Moisture content	Energy consumption
Tesla	ºC	Minutes	m/s	%	kWh
200	45.68	30	2.52	33.0	2.8
300	60.0	60	3.02	28.1	2.5
400	58.56	90	2.74	23.2	2.2
500	55.66	120	2.14	15.6	1.8
600	56.05	150	2.27	16.5	1.3

The energy consumption decreased with increasing magnetic strength and increasing temperature. Optimum values for the drying characteristics were obtained at magnetic field strength of 600 V/m, drying temperature of 56.05 ºC, at 150 minutes of drying with the final moisture content of 16.5% and energy consumption of 1.3 kWh.

CONCLUSION

The results indicate that temperature and moisture distribution pattern of ceramics can be enhanced under the influence of magnetic field assisted-convective drying. There was increase in drying temperature compared with drying under convective method. The rate of moisture removal was equally faster under magnetic field, thus leading to decrease in drying time and energy usage. Total energy requirement decreased with increase in temperature and magnetic field but increased with increase in air velocity. The drying rate values were significantly higher under magnetic field than the values obtained under normal convective drying.

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