Chapter 10

EFFECT OF ENVIRONMENT CONDITION ON DRYING PERFORMANCE OF FLUIDIZED BED DRYER DURING KAOLIN CLAY DRYING: A NUMERICAL AND EXPERIMENTAL STUDY

10.1. Introduction

The main aim of this chapter is to present a numerical technique and develop a computer program for analysis of coupled heat and mass transfer phenomena of fluidized bed drying of a kaolin clay sample when subjected to different environmental conditions like hot, cold, and rainy seasons. The governing equations are cast in different forms and are solved iteratively in a sequential manner using implicit discretization of the differential equation for water diffusion inside the particle. Full drying performance of the dryer is investigated like in which ambient drying condition, moisture, and temperature gradient are less, which is a prime cause of the crack generation in the product.

. The computer program based on mathematical modeling allowed us to do a complete analysis and thus, compare the effect of different ambient conditions on drying rate, temperature, moisture content, and efficiency during drying. The numerical analysis shows that moisture gradient and temperature gradient in the cold ambient condition are less. Hence, that gives a good quality of dried product, but efficiency is higher in hotter ambient conditions.

10.2. Results and discussion

Input Parameters Used for Computation

Dryer geometry:

Length = 0.12m,   Width = 0.12m,

Distributor Plate thickness = 0.002m,

Hole size = 0.002m,   Number of holes = 387

Properties of kaolin :

D_p = 0.004m, ρ_m = 2630kg/m^3,   [Baumann & Keller, 1975]

$D_{wg} = 5.61e^{-10} * \left(7.5 + \exp\left[\frac{44X}{1.6+X}\right] \exp\left[\frac{-510}{T}\right]\right.$ m^2/sec   [I. Hammouda et.al. 2014]

Equilibrium equation for kaolin

The desorption isotherms of kaolin were studied by many researchers. The modelling of the desorption isotherms by GAB equation shows the best result among many isotherm. The GAB equation is shown in this form as below.

$$X_{eq} = \frac{CKW_m a_w}{(1-Ka_w)(1-Ka_w+CKa_w)}$$

where C, K, W_m are constants and a_w is water activity [Hammouda & Mihoubi, 2014a]

Table 10.0.1 value constants for GAB equation.

CONSTANTS	AT 30 deg C	At 50 deg C	At 70 deg C
K	0.876	0.929	0.954
C	160.3	41.19	9.212
W_m	0.0108	0.0071	0.0034

Water diffusivity in air [T. L. Norman et al., 2006] : $D_{wa} = 4.7931 * 10^{-5} * \left[\frac{T^{1.9}}{P}\right]$ m^2/sec,

where T is in K and P is in Pa

Design set of operating data :

Bed height = 0.1 m

X_{in} = 35 %(kg/kg;d.b),

dx = 0.001 (kg/kg; d.b.), dt = 0.1^0C,

U_{mf} = 2.18 m/s, $\epsilon = 0.4$

Range of operating variables:

T_{amb} = 16 – 40^0C, RH of ambient air = 50 –82%,

T_{Ain} = 50 –70^0C, X_{in} = 35 % (kg/kg; d.b.),

Conditions for different ambient is as follow,

Table 10.2value of atmospheric temperature and humidity in different climate

Ambient condition	Temperature (deg C)	Humidity (%)
Hot	38	52
Cold	16	64
Humid	29	82

Drying air inlet conditions reported in this work are such that falling rate drying prevails throughout for all combinations of input variables considered.

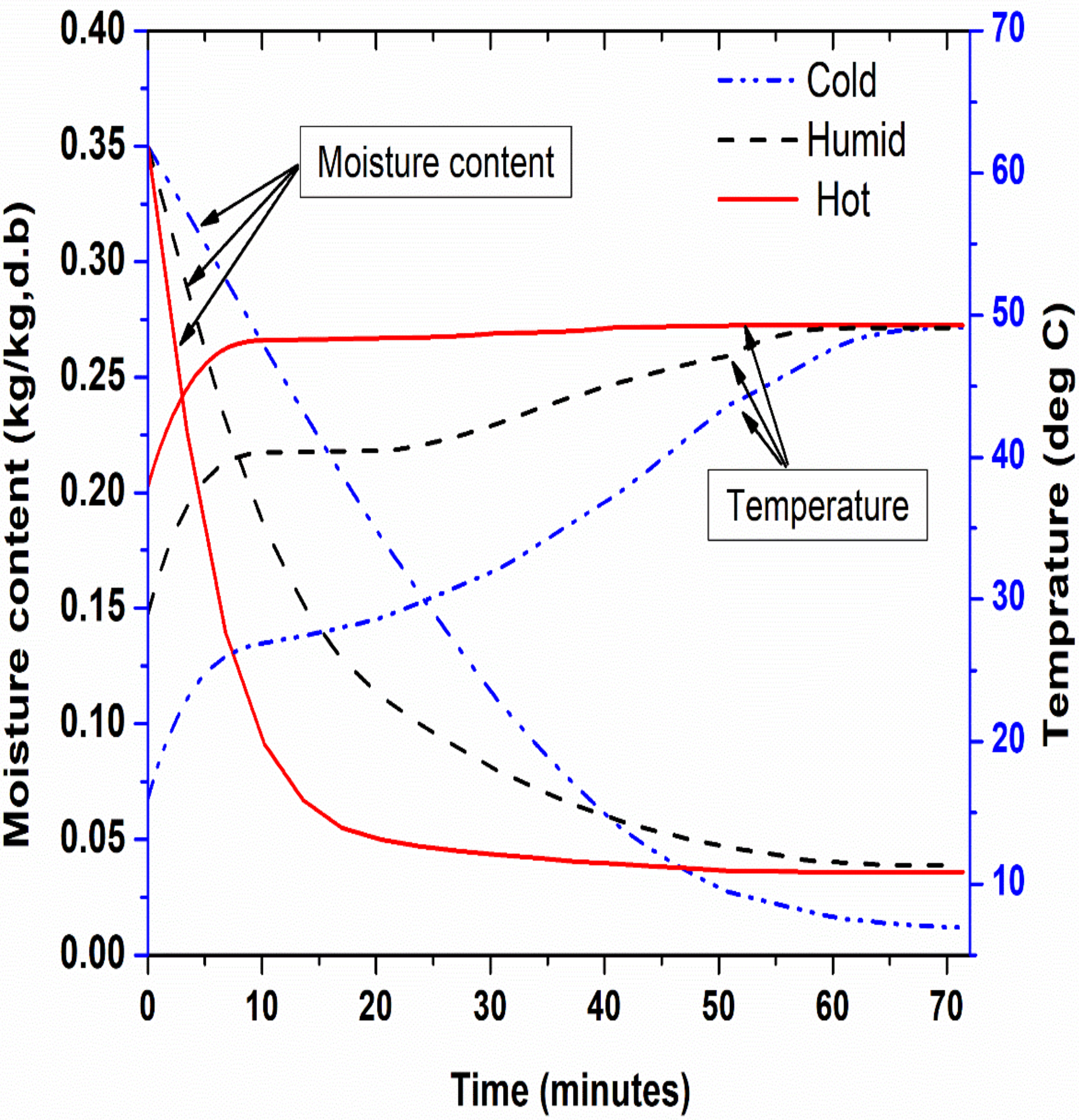

Figure 10.1. Variation of Moisture content of kaolin, X and material Temperature, Tm with time at Tain 50deg C in different drying conditions

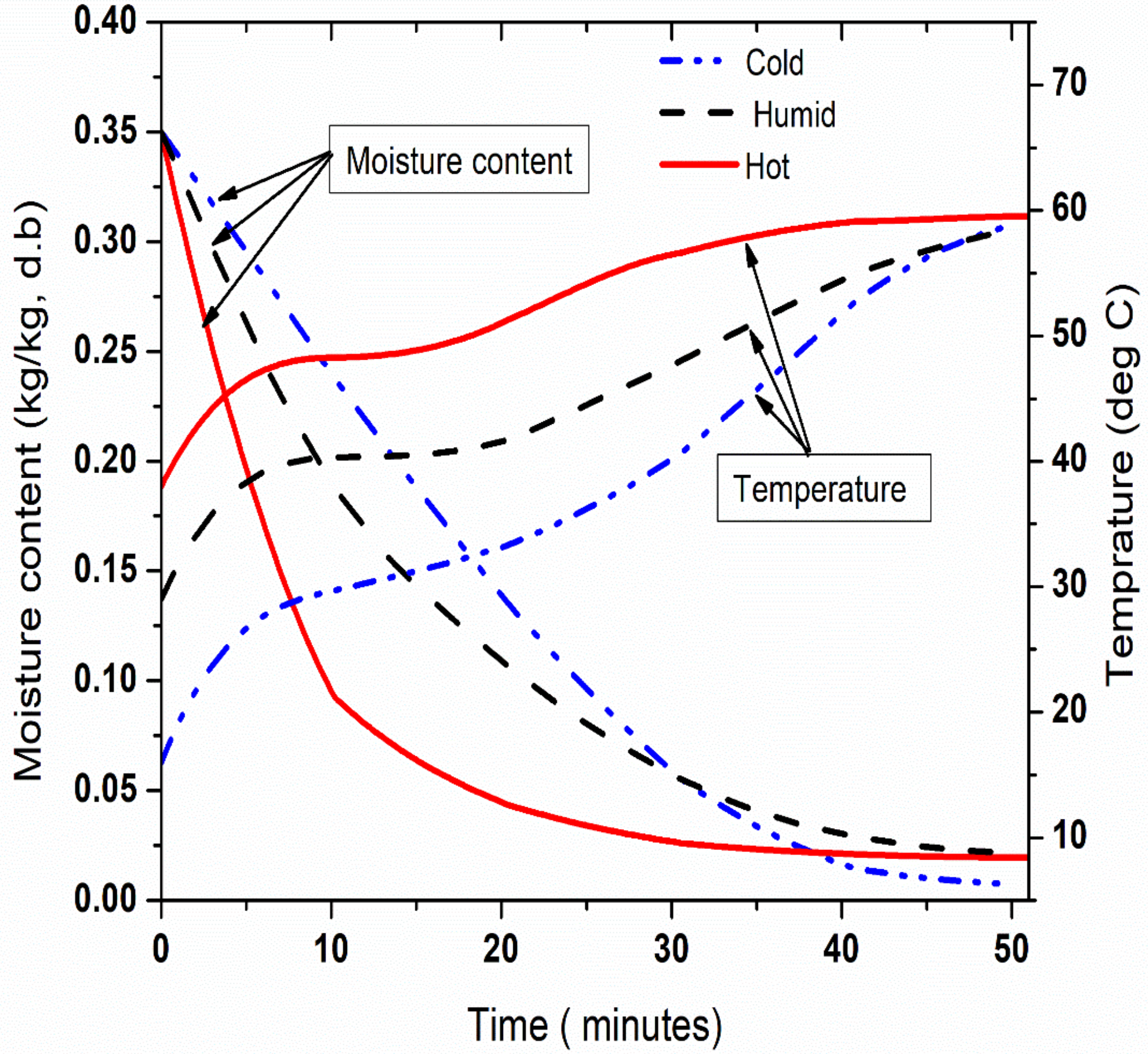

Figure 10.2. Variation of Moisture content of kaolin, X and material Temperature, Tm with time at Tain 60deg C in different drying conditions

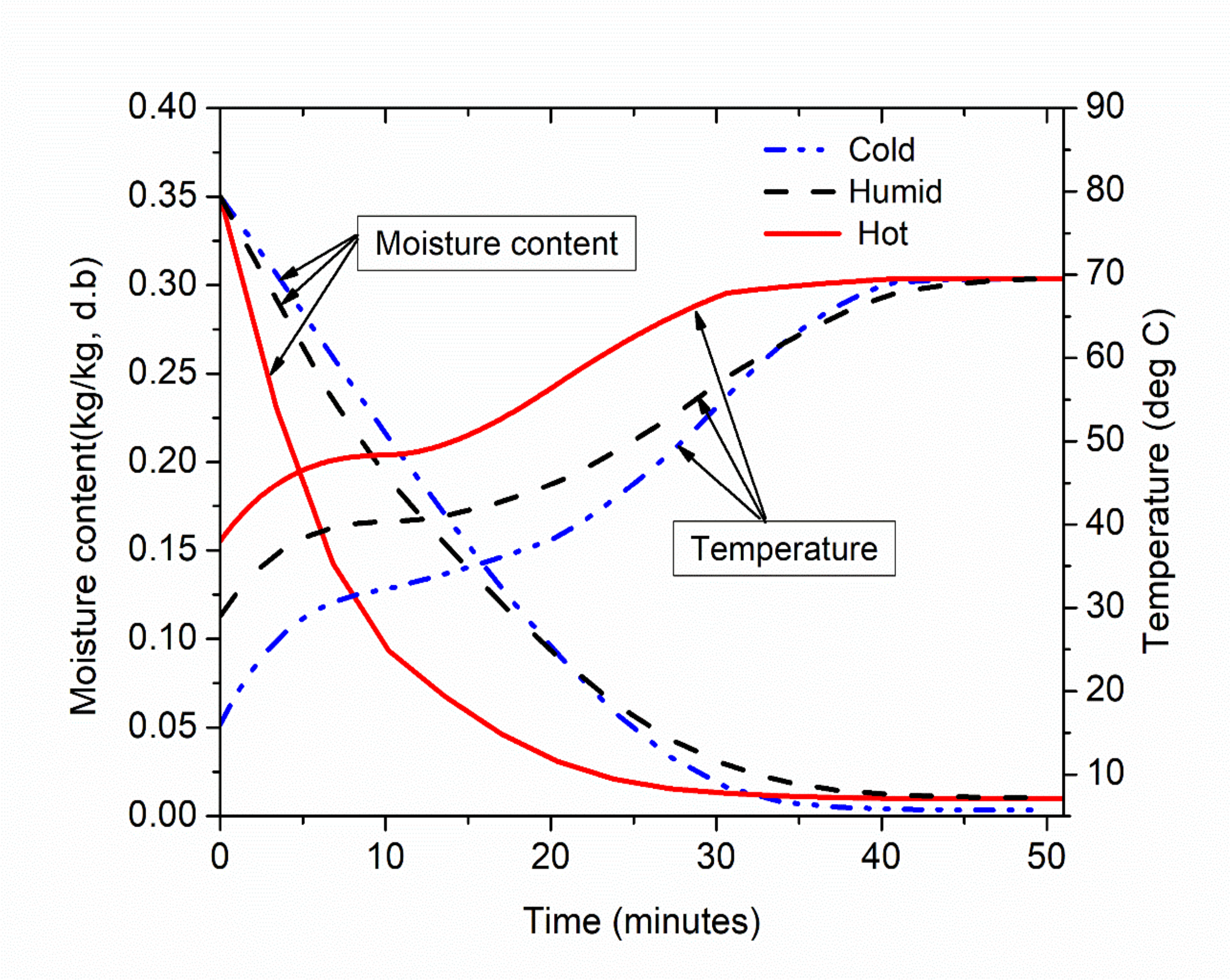

Figure 10.3. Variation of Moisture content of kaolin, X and material Temperature, Tm with time at Tain 70deg C in different drying conditions.

The varying air temperatures in all of the preceding simulations were 50 degrees Celsius, 60 degrees Celsius, and 70 degrees Celsius, respectively, at various climatic conditions as shown in table 10.1. Figures 10.1 to 10.3 show the fluctuations in average moisture content and temperature of the kaolin clay sample vs drying time for the three drying methods tested. The drying of viscoelastic material has two implications: moisture loss and shrinkage. The temperature has not yet reached the wet equilibrium temperature at the start of the drying process. That's why the drying rate is marginally higher at the starting of drying than after a few minutes. When equilibrium is attained, the drying loss proceeds in a linear manner, with liquid being carried to the surface product by capillary forces and then evaporating. The surface stays saturated with water during this continual drying phase, and drying is mostly regulated by external factors (temperature and humidity of the drying air flow). When the fluid phase does not redistribute to the upper surface at a rate equal to the evaporation rate, the shift from the constant rate stage to the falling rate stage happensThe liquid phase has receded within the porous body at this point, and the drying mechanism is regulated by water diffusion to the surface through the pores of the sample. During drying, the product shrinks in tandem with the loss of water. The volume fluctuation in the first stage corresponds to the volume of the evaporated liquid, ensuring that the liquid/gas boundary stays at the product's surface. The equilibrium between the capillary pressure created by the liquid in the pores and the elastic modulus of the material that resists shrinkage determines the volume of contraction during drying; when this last contribution dominates, the shrinkage ends. Since the evaporation of water is not counterbalanced by shrinkage, the end of shrinkage coincides to the appearance of porosity in the material sample. We can see that the drying duration is shorter in hotter climates and that the mass of evaporated water recorded during hot environment drying is bigger than that recorded during humid climate drying. The hot environment, which is a method of surface drying in this case, can cause significant moisture content gradients, which accelerates the drying rate and shortens the drying time of the process.

The average moisture content attained 0.05 kg/kg d.b. after 1800 sec in hot climate, 0.025 kg/kg after 3000 sec in rainy season and 0.01 kg/kg in 3600 sec. in colder climate at 50 deg C , 0.025 kg/kg d.b. after 1800 sec in hot climate, 0.015 kg/kg after 2400 sec in rainy season and 0.001 kg/kg in 2700 sec. in colder climate at 60 deg C and average moisture content 0.01 kg/kg d.b. after 1800 sec in hot climate, 0.015 kg/kg after 2400 sec in rainy season and 0.001 kg/kg in 2100 sec. in colder climate at 70 deg C of convective drying. A notable reduction of drying time is also obtained in hot condition compared to others conditions. The average moisture content attained in hotter condition is less and hotter climate accelerates drying and reduces processing time. In addition for time gains, this method reduces energy costs. We note that the temperature of the sample is affected significantly by the drying climate. It is also seen that that in colder condition drying is more than hotter and humid climate, it's happen because value of Y_{in} which is combined effect of atmospheric temperature and humidity is lesser in cold climate, which allow atmosphere to take more moisture than others conditions at a given drying air temperature. But as we increase drying air temperature the difference will be less as reflected in Fig10.1 to Fig 10.3. One more feature which reflects in the above mention figures is as we increase drying air temperature the outlet air temperature of the dryer increases 1st with increasing rate then with decreasing rate then again increasing rate and at the end it becomes constant and becomes equal to inlet temperature. It happens because of diffusion coefficient of water inside kaolin material (D_{wg}) is exponentially proportion to temperature and moisture content mention in the expression of D_{wg} above in section 10.2.

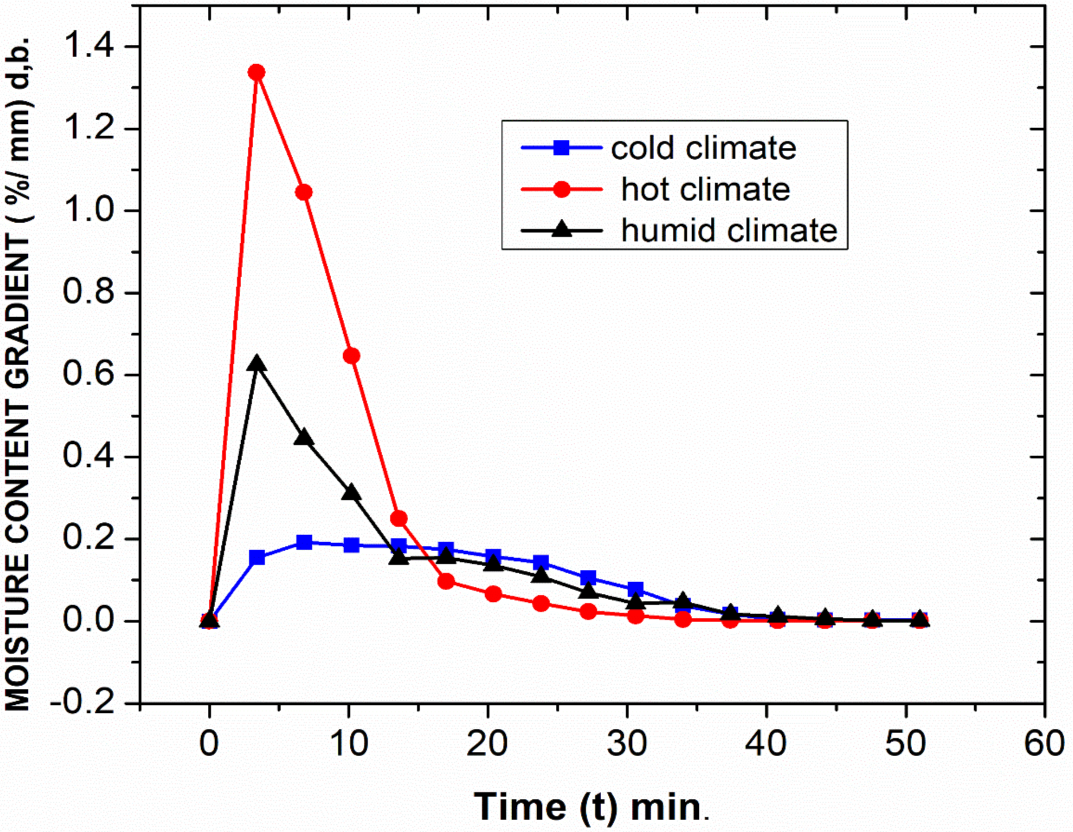

Figure 10.4. Moisture content gradient inside material in different drying condition with time

10.3. Stresses distribution inside material

Figure 10.4 depicts the development of normal stresses as a function of drying rate and moisture gradient. We can see that the sample is initially stress-free. As the drying process begins, the moisture distribution becomes non-uniform, resulting in stresses that reach a peak, then decreases gradually and eventually becomes close to zero. The viscoelastic nature of kaolin clay justifies the stress development inside kaolin. We can see that the most stress is created in hot climates, while the least is generated in cooler climates.

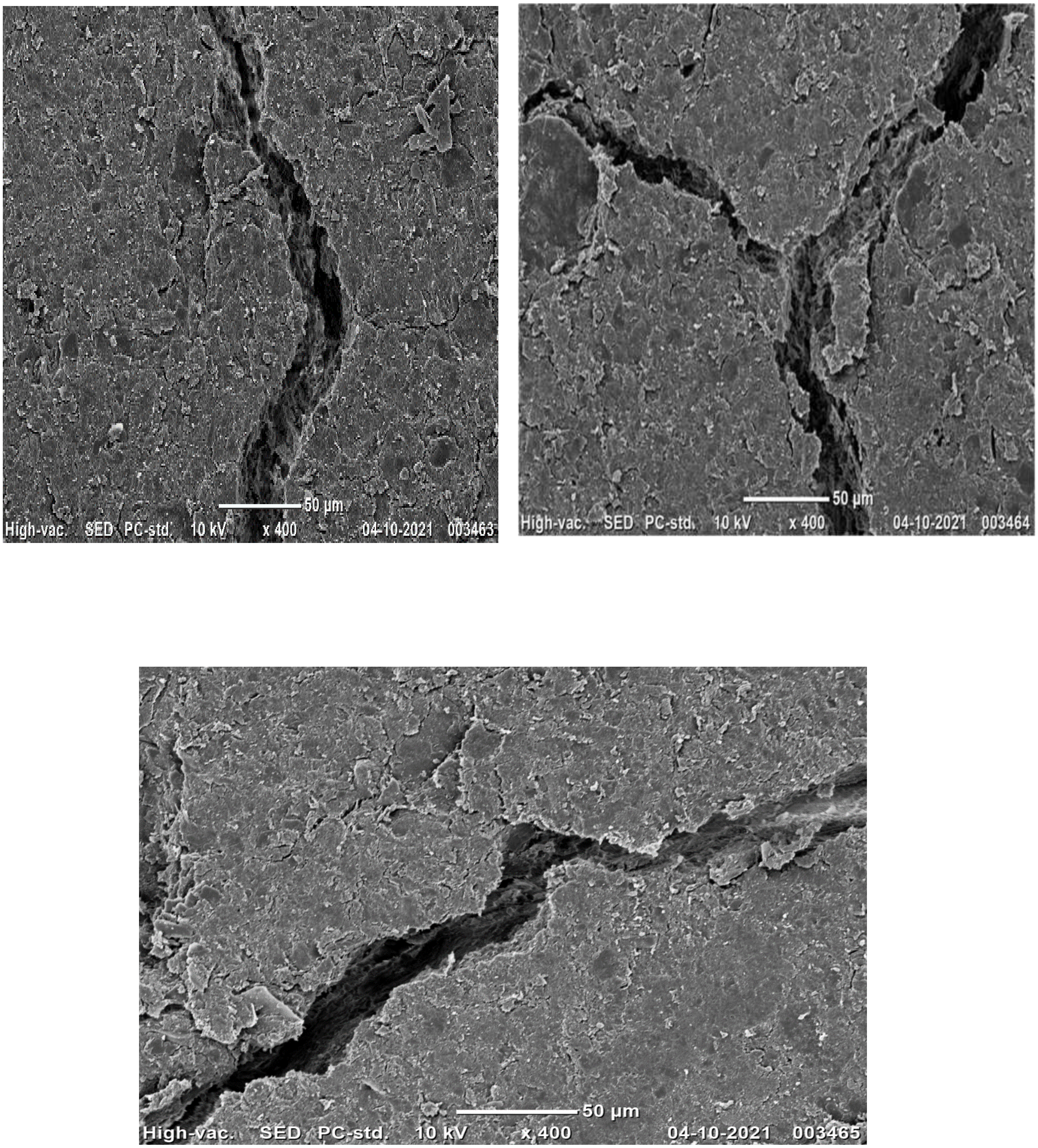

Figure 10.5. SEM image of different cracked kaolin ball with high moisture content gradient (improper drying)

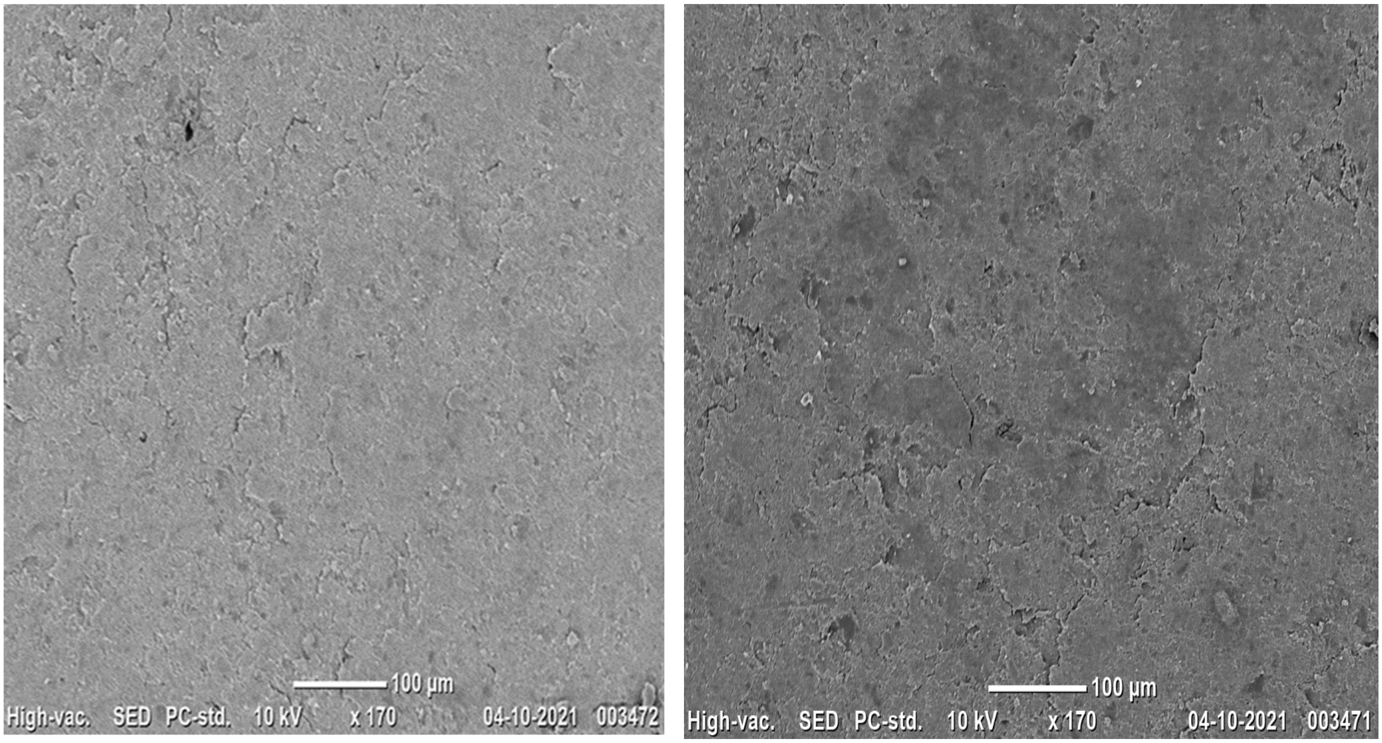

Figure 10.6. SEM image of different kaolin ball with no crack having low moisture content gradient (controlled drying)

Moisture gradients are lower in colder and humid climates than in hotter climates, and as a result, the produced stresses are highly essential in determining fracture development inside the material. A cold temperature is a favorable drying environment because it reduces stress values, which are responsible for product deformation and cracking. However, the stress produced under three different drying conditions may be compared.

Normal stresses cause cracks to propagate in drying materials, which is referred to as an opening mode (a tensile stress normal to the plane of the crack). As a result, we suggest that in terms of quality, cold climatic conditions are the optimum mode for minimizing cracking and may be employed especially when stiffness and surface state for the dried material are critical.

10.4. Validation of numerical model.

The objective of this analysis is to compare the drying curves generated by numerical simulations to experimental data. The kaolin powder was combined with water to make an uniform paste, which was then shaped into a sphere. Under a convective fluidized bed, a kaolin sample with a moisture content of 0.35 kg/kg d.b. was processed at a constant drying temperature of 70 deg C in various climatic conditions throughout the year. The average moisture content development in time is shown in Fig.10.7, both empirically and numerically. When comparing the different curves, the empirically obtained moisture content and the theoretically expected moisture content can be seen. The difference between simulated and experimental data is mostly attributable to computation errors and the two-dimensional issue hypothesis. As a result, the model's capacity to replicate the drying kinetics of a kaolin sample was proven.

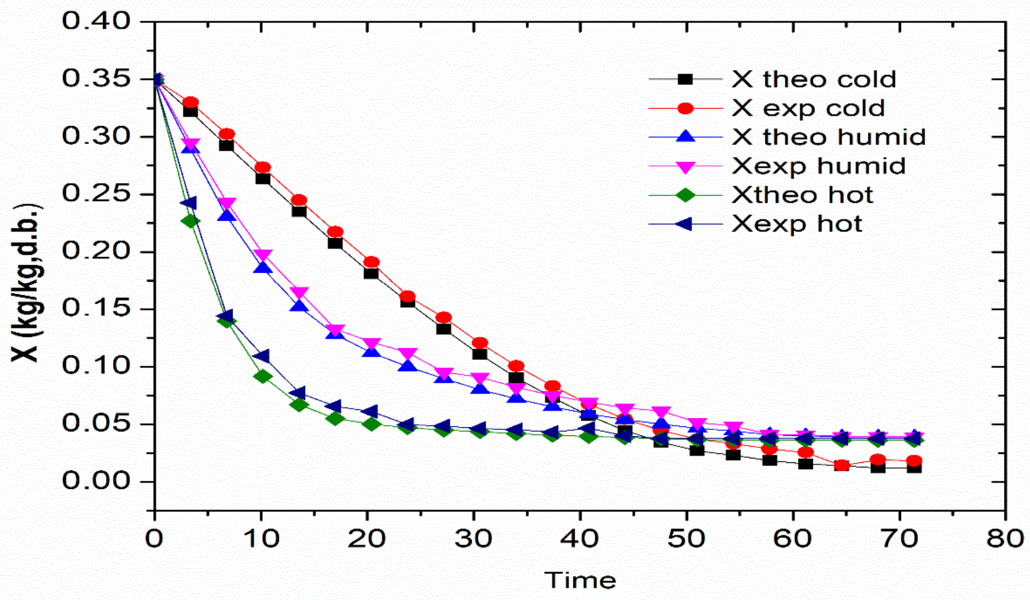

Figure 10.7. experimental and theoritical value of moisture content in different ambient condition at 70 deg C

10.5. Conclusion

This report offers numerical findings of kaolin clay drying under various drying conditions. The topic under investigation includes coupling equations that take into account heat, mass, and mechanical characteristics. This model was solved numerically, and simulations for the three drying regimes resulted in the development of material moisture content, temperature, drying rate, and moisture gradient inside the clay sample. The numerical study shows that moisture gradient and temperature gradient are less in cold ambient conditions, resulting in superior dried product quality, while efficiency is higher in hotter ambient conditions.