iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: VI Month of publication: June 2025

DOI: https://doi.org/10.22214/ijraset.2025.72837

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VI June 2025- Available at www.ijraset.com

Mathematical Modeling of Mass and Heat Transfer of Convective Air Drawing of Apple

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***Abstract:** The aim of the current research is to dry apples using a solar dryer with a desiccant cycle in two modes: direct radiation -convection and indirect radiation -convection. Two types of drying methods, direct and indirect with desiccant and without desiccant, moisture content, and drying in open air were used. Pre - prepared apple slices (flavored with cinnamon) were placed on a specific -sized mesh, the initial weight of the samples was measured, and they were placed inside the solar dryer with a desiccant cycle in two modes: direct radiation -convection and indirect radiation -convection. During the drying process, the evaporation rate, texture, wrinkling, water reabsorption, vitamin C retention, color changes, and sensory characteristics at different treatment levels (30% sucrose and without sucrose, 0.5%, 1%, and 2% cinnamon) were examined. Additionally, several samples were dried as controls without cinnamon flavoring using the solar dryer.*
***Keywords:** Drying; Mathematical modelling; Shrinkage; Simulation; Moisture diffusivity*

I. INTRODUCTION

Vegetable and fruits are seasonable agriculture products. Vitamins, minerals and fibers are the essential compounds of these products for human nutrition. Due to the presence of high moisture, vegetable and fruits are exposed to microbial spoilage sooner, and their shelf life is very short [1]. Apples (Malus domestica) are among the tree fruits that are grown and produced in most countries of the world. This fruit is rich in vitamins, minerals and fiber, and also it is consumed in various forms such as fresh juice, dried and compote. Apples are also used in the manufacturing industries of jams, vinegar, etc. [2,3]. Afghanistan's climate is also very suitable for growing apple seedlings and apple production. Eleven different types of apples such as Red Chief, Blushing Gold, Royal Gala, Double Red Delicious, Michgla, Modal Gala, Fuji, Galaxy and Saturn have the highest yield in Afghanistan and most of them are produced in the central provinces.

II. MATHEMATICAL MODELING

Various thin layer mathematical models were proposed in the literature. In this work the models were tested for drying of apple slice in solar dryer systems.In all models MR is moisture ratio, t is time, k is drying rate constant, a, b, c, g and n are model coefficients. Eq.1 is used for calculation of MR for apple drying.

$MR = Mt – Me/M0 - Me$ (1)

The initial and final moisture content of sliced apple has been funded with Eqs. 2,3.

$M0 = mi – md/md$ (2)

$Mf = mw – md/md$ (3)

In these equations, M0 Mf, Mt, and Me, represent initial moisture content (kg H2O/kg dry matter), final moisture content (kg H2O/kg dry matter), transient moisture content (kg H2O/kg dry matter) and equilibrium moisture content (kg H2O/kg dry matter); mi, md and mw represent initial mass (kg), dry material mass (kg) and mass of wet mater after drying process. For selecting of the best fitted mathematical models for apple slices drying, is necessary to calculate these three important statistical parameters: correlation coefficient (R 2) Eq. 4, chi-square (X 2) Eq. 5, and root mean square error (RMSE) Eq. 6. The model with the highest value of R 2 and lowest X 2 and RMSE indicate the best fit of the model.

$R\ 2 = 1 - \sum (MRpre, - MRexp,i)\ n\ 2\ i=1 / \sum (MRexp,i - MRexp,av)\ n\ 2\ i=1$ (4)

$X\ 2 = \sum (MRpre, - MRexp,i)\ n\ 2\ i=1/N - z$ (5)

RMSE= [1 $N \sum (MRpre,i - MRexp,i)\ ni=1$]½ (6)

In these equations, MRexp,i represents the ith experimentally observed normalized moisture ratio, MRpre,i represents the ith predicted value, MRex, av is average of normalized MR of experimental points, N is the number of observations and z is the number of constants in the model.

Abbreviatons

A_{OUT} :Radiometric analog voltage output
A_{SAH} :Area of the solar dryer (m^2)
*Ad:*Area of the dryer (m^2)
C_d :Discharge coefficient ranges 0.6 to 0.9 for most orifices
*cDAQ:*Compact data acquisition
$C_{p.a.}$:Specific heat of air (kJ/kg.K)
*Dch:*Drying chamber
DR :Drying rate (kg/hr)
*Ex:*Exergy (kJ/kg)
E_{xi} :Exergy inflow (kJ/kg)
*Exo:*Exergy outflow(kJ/kg)
F_p :Fan power (Watt)
*g:*Gravitational acceleration, (m/s^2); gram
*gc:*Dimensional conversion constant
*hr:*Hour of drying (hr)
I_r :The amount of radiation striking the collector's plane (W/m^2)
$\dot{m}$:Mass flow rate, (kg/s)
M_f :Final mass of the sample at end of the time (wb)
M_d :Mass of the dried sample at time t (wb)
M_t :Instantaneous moisture content (wb)
M_w :Mass of the wet sample at time t (kg)
*Om:*Orifice meter
*P:*Power (W)
*RH:*Relative humidity (%)
*RTD:*Resistance temperature detector
*SAH:*Solar air heater
*T:*Temperature (°C)
T_{amb} :Ambient temperature (°C)
T_b :Temperature at which water boils under standard atmospheric pressure (°C)
*Tcr:*Critical temperature of water (377 °C)
*Tchi:*Temperature entering to the drying chamber (°C)
*Tcho:*Temperature leaving the drying chamber (°C)
T_{saho} :Temperature leaving the solar air heater (°C)
T_r :Tray
V_{DD} :Power supply voltage
*W:*Watt
*x:*Experimental (observed) data
*y:*Predicted (calculated) data
*a:*Air
*amb:*Ambient
*ch:*Drying chamber
*wb:*Wet basis

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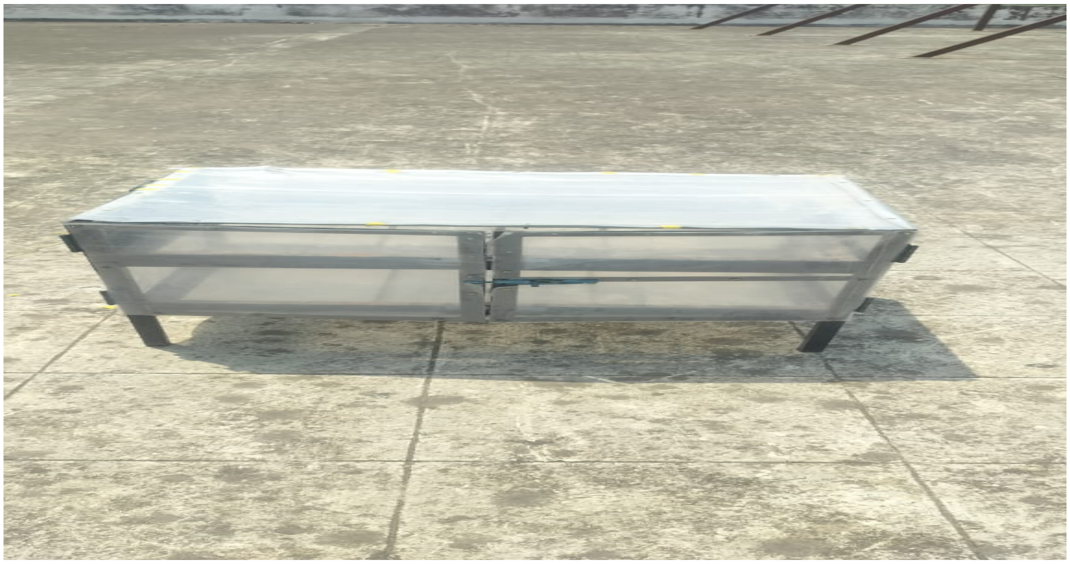


Fig. 1(Solar Dryer)

OBSERVATIONS

Specification:The150gmApple and(104)piecesindiameterofapple sampleis8mmandlength2.5cmincylindricalpieces.

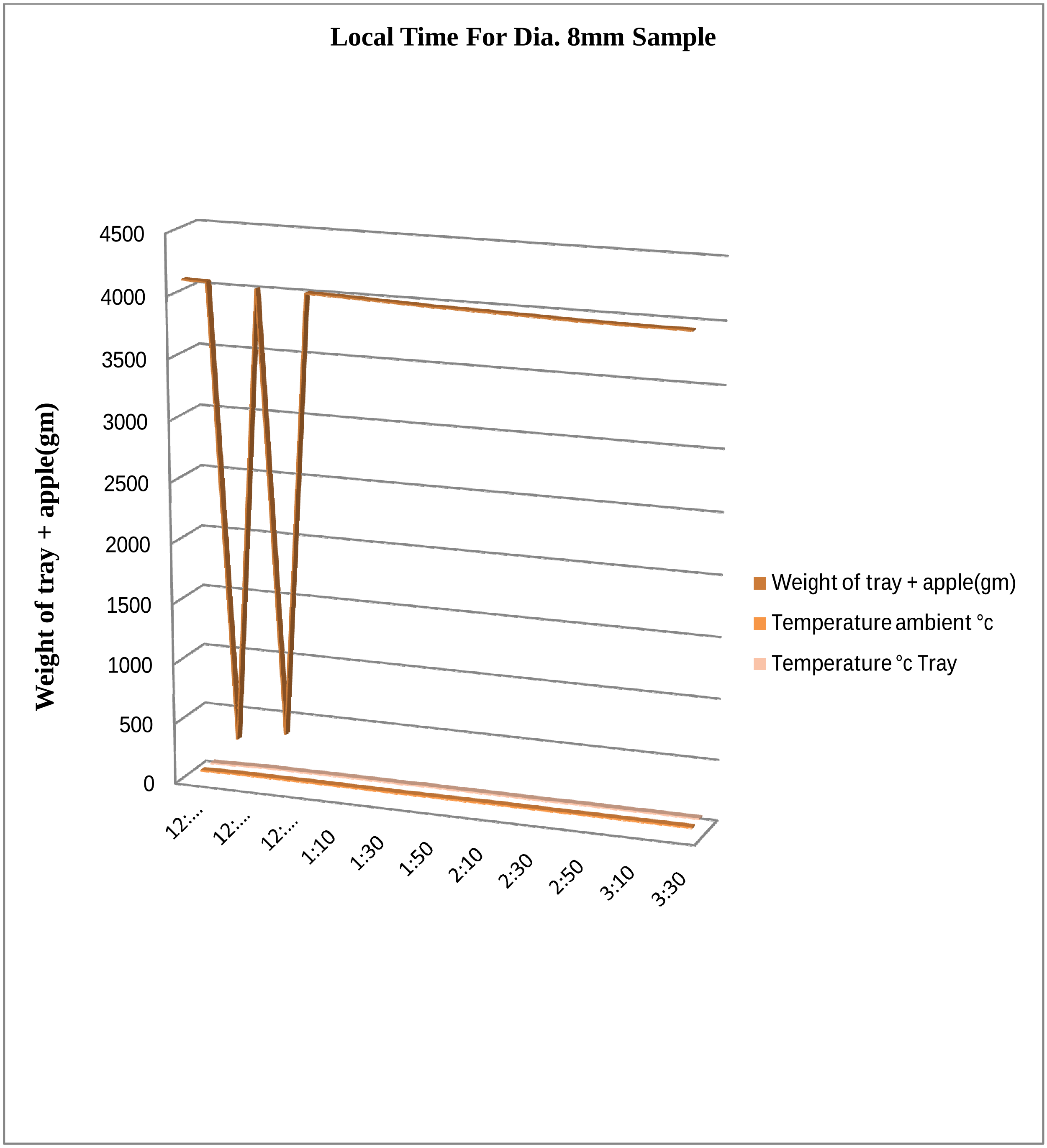
UppertrayWeight(empty)=3990gm.
UppertrayandpotatoWeight(Empty)=4130gm.

ExperimentStartDate:15/04/2025

Time	Weight of tray + apple(gm)	Temperature ambient °c	Temperature °c Tray
12:10	4130	34.9	34.2
12:20	4123	38.6	37.9
12:30	411	40.6	45.6
12:40	4099	39.5	46.8
12:50	497	39.8	45.7
1:00	4091	40.4	47.1
1:10	4086	39.6	46.7
1:20	4079	39.5	46.6
1:30	4072	38.3	45.1
1:40	4065	39.1	48.7
1:50	4058	39.2	46.6
2:00	4055	39.1	47.1
2:10	4050	40.6	46.8
2:20	4045	39.7	45.3
2:30	4041	39.5	43.9

2:40	4035	39.3	46.1
2:50	4031	40.6	45.5
3:00	4030	39.3	44.5
3:10	4027	39.5	46.8
3:10	4027	39.6	45.6
3:30	4027	38.7	44.3

Observation Table Chart 1 (8mm diagram)



No. 1(8mm line chart diagram)

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OBSERVATIONS

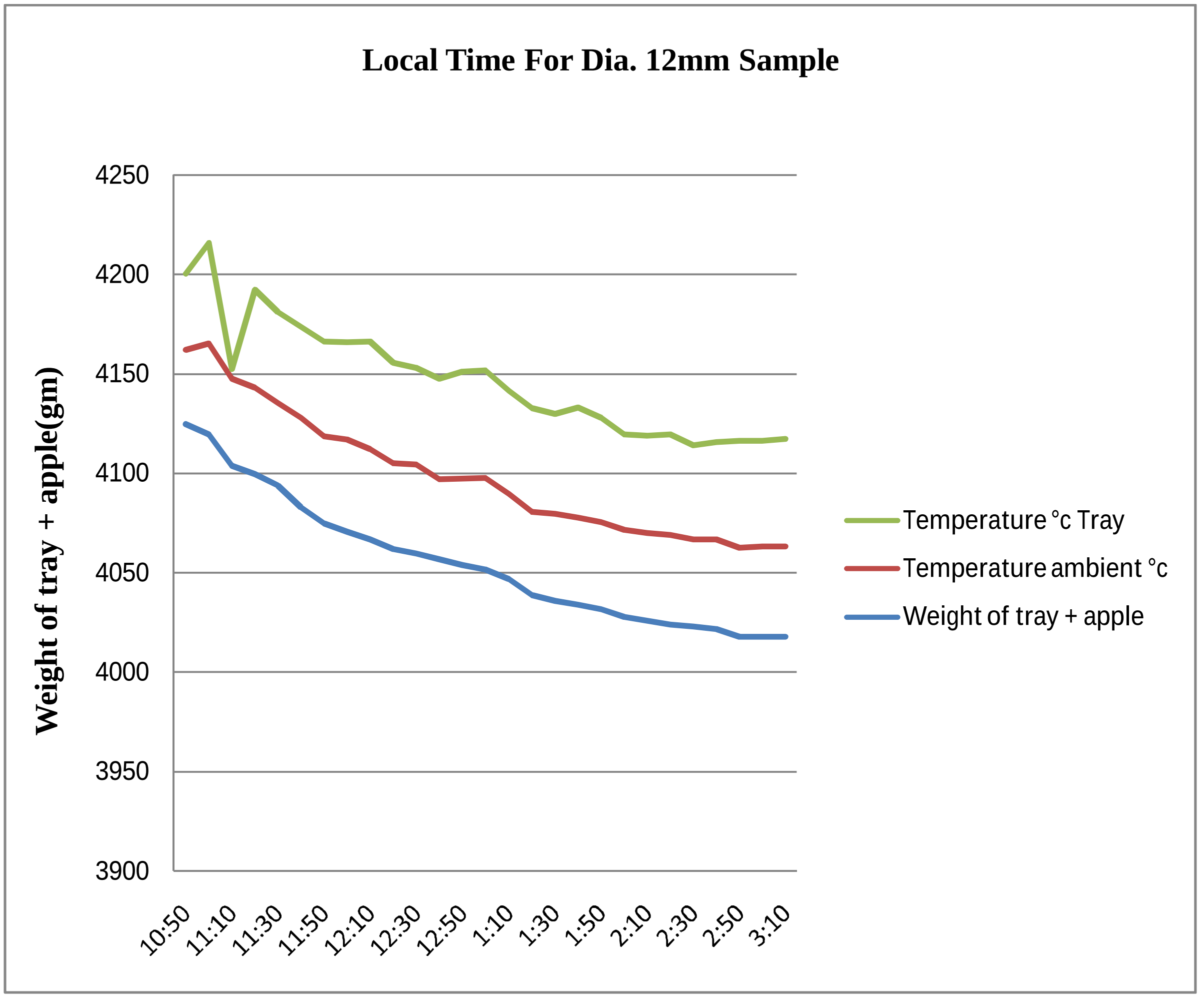
Specification:The 150gm Apple and (75)piecesindiameterof apple sampleis 12mmandlength 2.5cmincylindricalpieces.

UppertrayWeight(empty)= 3990gm.
UppertrayandAppleWeight(Empty)= 4125gm.

ExperimentStartDate: 24/04/2025

Time	Weight of tray + apple(gm)	Temperature ambient °c	Temperature °c Tray
10:50	4125	37.2	38.3
11:00	4120	45.3	50.6
11:10	4104	43.7	4.8
11:20	4100	43.1	49.2
11:30	4094	41.3	45.8
11:40	4083	45.1	45.7
11:50	4075	43.6	47.6
12:00	4071	46.1	48.8
12:10	4067	45.1	54.3
12:20	4062	43.1	50.6
12:30	4060	44.5	48.5
12:40	4057	40.2	50.6
12:50	4054	43.5	53.6
1:00	4052	45.8	53.9
1:10	4047	42.6	51.9
1:20	4039	41.6	52.3
1:30	4036	43.6	50.3
1:40	4034	43.7	55.4
1:50	4032	43.5	52.6
2:00	4028	43.6	48.1
2:10	4026	44.1	48.9
2:20	4024	44.9	50.8
2:30	4023	43.9	47.3
2:40	4022	44.8	48.9
2:50	4018	44.6	53.8
3:00	4018	45.3	53.1
3:10	4018	45.1	54.3

Observation Table Chart 2. (12mm diagram)



No. 2 (12mm line chart diagram)

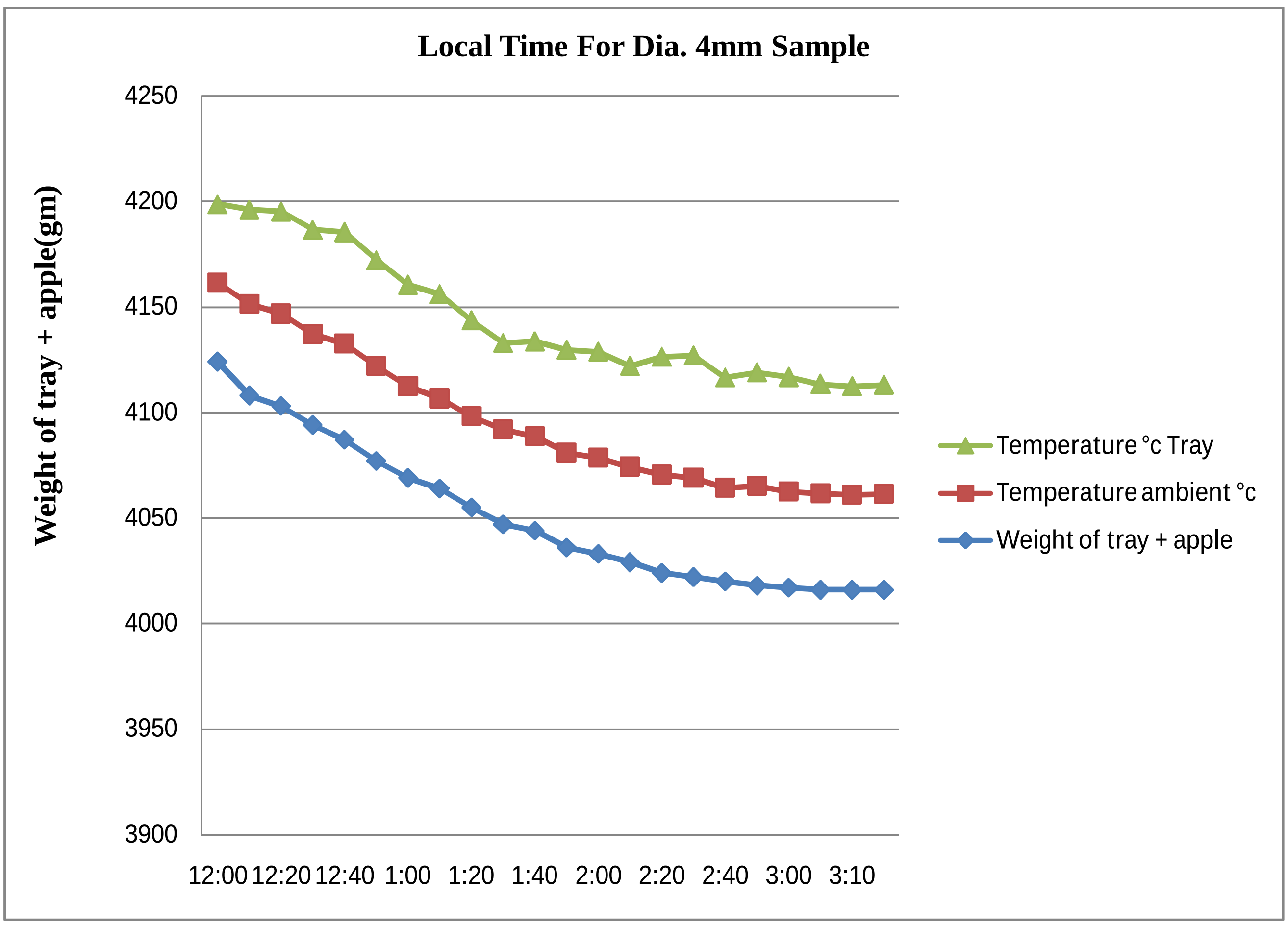
OBSERVATIONS
Specification:The 150gm Apple and (352)piecesindiameterof apple sampleis 4mmandlength 2.5cmincylindricalpieces.

UppertrayWeight(empty)= 3990gm.
Uppertrayand AppleWeight(Empty)= 4124gm
ExperimentStartDate: 26/04/2025

Time	Weight of tray + apple(gm)	Temperature ambient °c	Temperature °c Tray
12:00	4124	37.5	37.2
12:10	4108	43.5	44.5
12:20	4103	43.8	48.4
12:30	4094	43.1	49.5
12:40	4087	45.7	52.8
12:50	4077	45.1	50.1
1:00	4069	43.4	48.1
1:10	4064	42.7	49.4

1:20	4055	43.1	45.6
1:30	4047	45.1	40.9
1:40	4044	44.6	45.1
1:50	4036	44.9	48.8
2:00	4033	45.7	50.2
2:10	4029	45.3	47.8
2:20	4024	46.6	55.8
2:30	4022	47.2	57.9
2:40	4020	44.3	52.4
2:50	4018	47.3	53.7
3:00	4017	45.6	54.2
3:10	4016	45.7	51.8
3:10	4016	45.1	51.4
3:30	4016	45.3	51.9

Observation Table Chart 3. (4mm diagram)



No. 3(12mm line chart diagram)

III. CONCLUSIONS

The drying process of the apple slices were experimentally analyzed by means of the industrial solar dryer. During the drying tests, the drying curves of the apple slices were obtained as a function of temperature. The diffusion approximation model was employed to fit the experimental drying curves obtained for constant temperatures. A novel model was proposed based on diffusion approximation model to predict the evaluation of the moisture ratio during the drying process.

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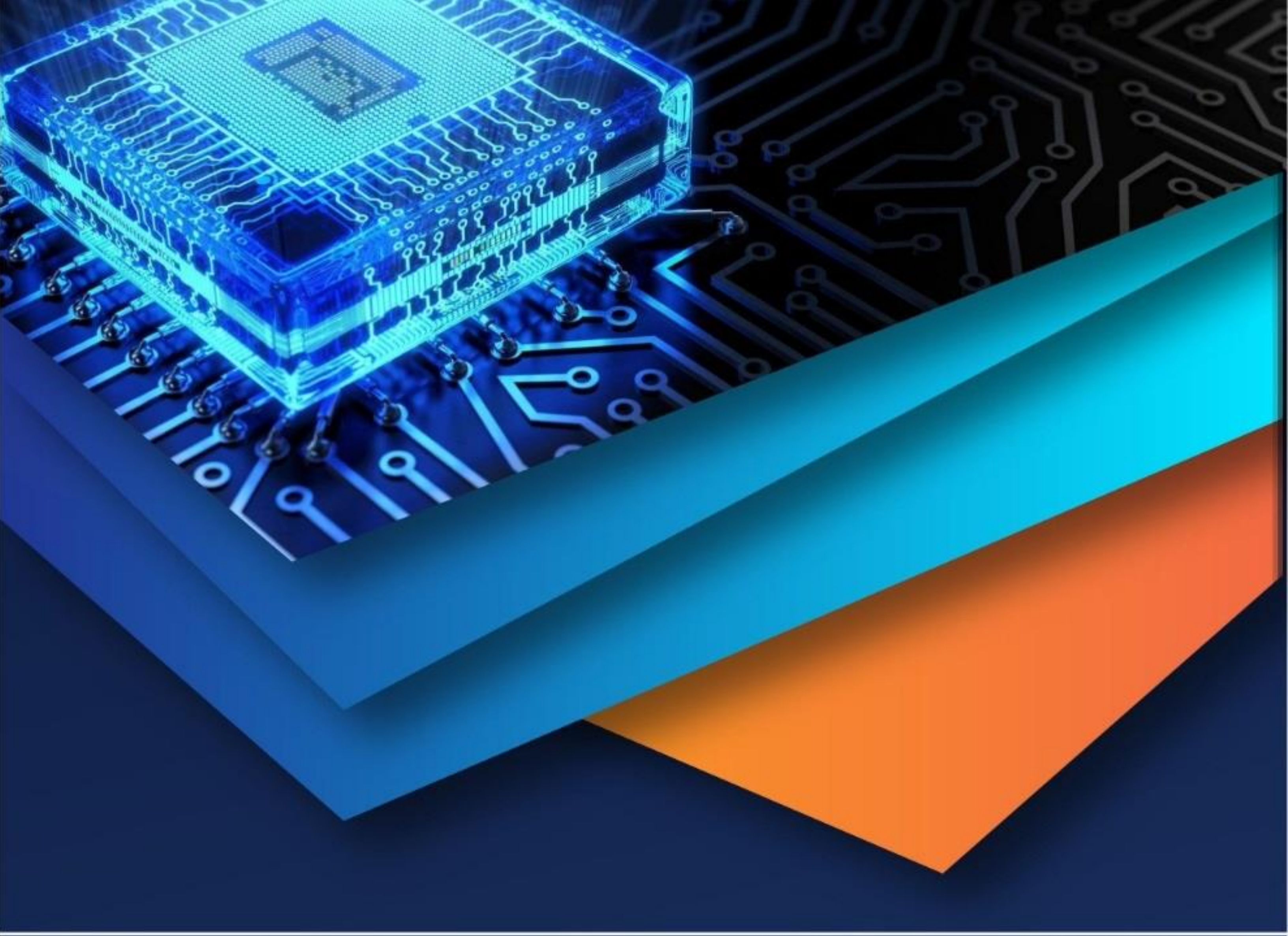

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