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Energy and Exergy Study of Microwave Assisted Thin-Layer Drying of Pomegranate Arils Using Artificial Neural Networks and Response Surface Methodology

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Introduction

Introduction

- Drying
- Modeling & Optimization
- ANN & RSM
- Energy & Exergy Analysis

Introduction

- Drying is known as the best method to preserve fruits and vegetables. Water removal during drying prevents the growth of microorganisms and harmful chemical reactions and this leads to longer shelf life.

- Thermodynamic analysis, including exergy analysis, plays an important role in system design, analysis and thermal system optimization.

Introduction

- ✓ Exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir.
- ✓ Exergy = Energy available to be used.
- ✓ Exergy analysis evaluates the accessible energy within several points and presents useful information for a favorable design methodology and part selection in a dryer.

Introduction

- Modeling and optimization to increase the efficiency of the process is one of the most important stages in a thermal process.
- However, many numerical methods have major drawbacks in finding constants and solving the complexities of non-linear behaviors.

Introduction

- Due to these disadvantages, researchers have looked for alternative methods. One of the popular approaches used in the last two decades is Response Surface Methodology (RSM).

- **RSM** is a combination of mathematical and statistical techniques that is useful for analyzing, developing, improving, and optimizing processes in which a response of interest is influenced by several variables and the objective is to optimize this response without the need for a predetermined relationship between the objective function and the variables.

RSM

- Although RSM has many advantages, it would be unwarranted to say that it is applicable to all optimization and modeling studies.

Artificial Neural Networks

- Artificial neural networks (ANN) have been successfully used to solve a wide variety of problems in science and engineering, particularly for some areas where the conventional modeling methods fail.

- A well-trained ANN can be used as a predictive model for a specific application, which is a data-processing system inspired by biological neural systems.

Literature Review

- Use of energy and exergy analyses has been reported in drying fruits and vegetables (pinar et al., 2004, Midilli and Kucuk, 2003, Ceylan et al., 2007, Corzo et al., 2008 and Motevali et al., 2011a).

- ANN methods are frequently reported in drying fruits and vegetables (Momenzadeh et al., 2010; Hernández, 2009; Aghbashlo et al., 2008; Movagharnejad and Nikzad, 2007; Shrivastav and Kumbhar 2011, Motevali et al. 2010, 2011 b).

Objective

- The objective of this paper is to develop ANN and RSM models for mapping input factors including temperature, air velocity, microwave pretreatment and time with the output energy performance of the thin-layer dryer for pomegranate arils.

Methods & Materials

Material and Methods

Independent variables

- Air velocity (0.5, 1, 1.5 m/s)
- Air Temperature (50, 60, 70 °C)
- Three treatments (control, microwave pretreatment 100 and 200W)
- Ambient relative humidity and temperature were 25–31% and 20-24 °C, respectively.

Material and Methods

Measurement Instruments

- Measurement of Temperature (Lutron, TM-925, Taiwan)
- Measurement of Air Velocity (Anemometer, Lutron-YK,80AM, Taiwan)
- Measurement of Pressure (PVR 0606A81,Italy)
- Measurement of Relative Humidity (Testo 650)
- Measurement of Sample Weight (Sarturius, TE214S, AG Germany)

Energy analysis

- Heater energy utilization can be calculated using the conservation energy law of thermodynamics.

$$EU = m_{da}(h_{dai} - h_{dao})$$

In which EU is energy utilization (kJ/s); m_{da}, mass flow rate of air (kg/s); h_{dai}, inlet dry air enthalpy and h_{dao}, outlet dry air enthalpy (kJ/kg)

Methods & Materials

- Values of the inlet and outlet air enthalpy are equal to the sum of dry air enthalpy and water vapor enthalpy.
- The following equation is frequently used to determine air enthalpy

$$h_{da} = C_{pda}(T - T_{\infty}) + h_{fg} w$$

which h_{da}, is the inlet or outlet dry air enthalpy (kJ/kg); C_{pda}, specific heat of inlet or outlet dry air (kJ/kg°C); T, inlet or outlet air temperature (°C); T_{∞}, the ambient temperature (°C); h_{fg}, the latent heat of vaporization of water (kJ/kg) and w the humidity ratio of air (kg water/kg dry air)

Materials and Methods

Energy Utilization Ratio

- The ratio of energy utilization to the provided energy in the dryer chamber is defined as energy utilization ratio:

$$EUR = \frac{m_{da}(h_{dai} - h_{dao})}{m_{da}(h_{dai} - h_{da\infty})}$$

$h_{da\infty}$ is the enthalpy of ambient dry air (kJ/kg)

Materials and Methods

Exergy

- The basic method for exergy analysis of dryer chamber is calculation under equilibrium conditions. For this purpose, the following equation is used:

$$Ex = \dot{m}_{da} C_{p\,da} \left[\left(T - T_{\infty}\right) - T_{\infty} \ln\left(\frac{T}{T_{\infty}}\right) \right]$$

Ex is the exergy of air (kJ/s); m, mass flow of inlet/outlet air (kg/s); C, specific heat of inlet/outlet air (kJ/kg °C); T, temperature of inlet/outlet air (°C); and T∞, ambient temperature (°C)

Materials and Methods

Exergy loss

- Exergy loss is determined as:

$$Ex_{loss} = Ex_{\inf low} - Ex_{outflow}$$

Exergy Efficiency

- Exergy efficiency can be calculated using:

$$Ex_{eff} = \frac{\sum Ex_i - \sum Ex_l}{\sum Ex_i} = \frac{\sum Ex_o}{\sum Ex_i}$$

Materials and Methods

RSM

- Design Expert 8.02 was used for developing RSM models. A second-order polynomial model was fitted to the measured data and regression coefficients were obtained. The generalized second-order polynomial model used in the response surface analysis was as follows:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{\substack{i=1 \\ i<j}}^{k-1} \sum_{j=2}^{k} \beta_{ji} X_i X_j$$

Where βo, βi, βii, and βij are the regression coefficients for intercept, linear, quadratic and interaction terms, respectively, and Xi, and Xj are the independent variables

Materials and Methods

Neural network design

- The back-propagation algorithm was utilized in training of all ANN models.

- This algorithm uses the supervised training technique where the network weights and biases are initialized randomly at the beginning of the training phase.

Materials and Methods

Neural network design

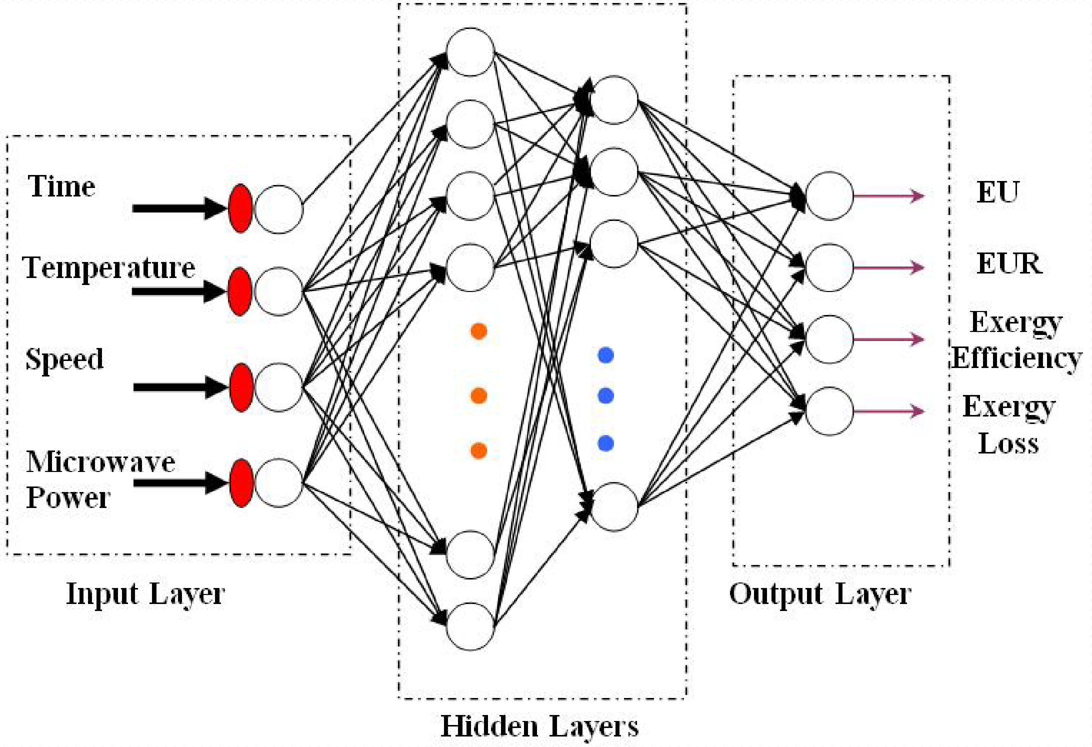
- The three input variables are time (in minutes) velocity (in m/s), temperature (in °C) and pretreatment (control, microwave 100 and 200 W). The four outputs for evaluating dryer performance Energy, EUR, Exergy and Exergy loss.

- Therefore, the input layer consisted of 4 neurons and the output layer had 4 neurons.

Materials and Methods

Neural network design

❖Therefore the input layer consisted of 4 neurons and the output layer had 4 neurons.



Materials and Methods

Neural network design

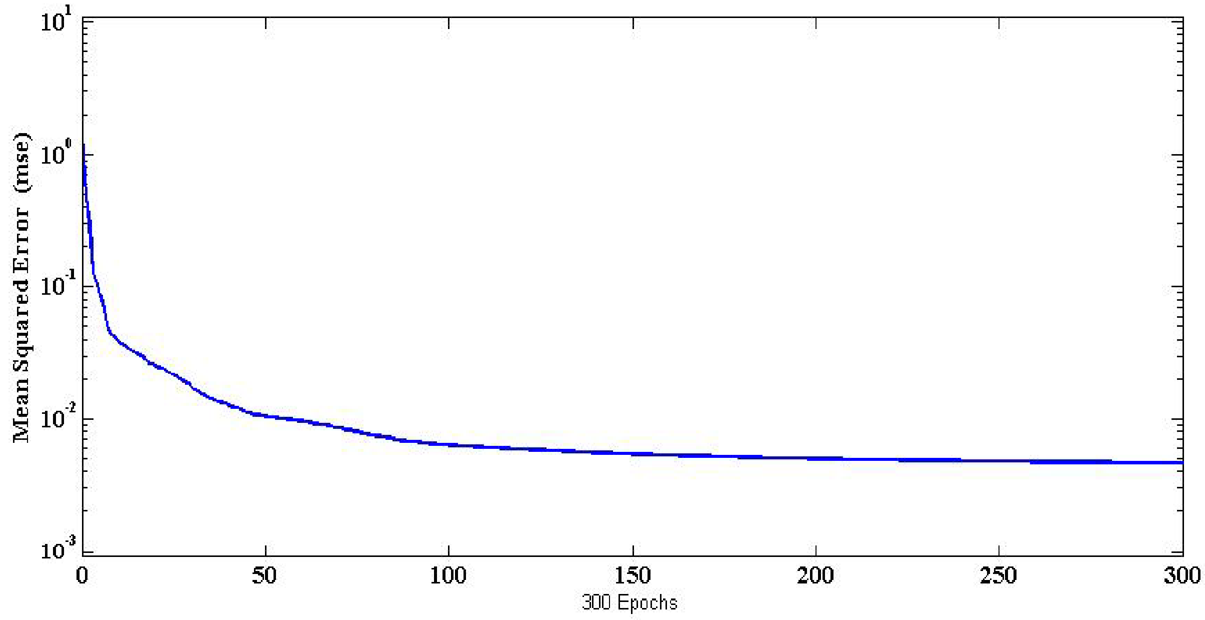
- The activation function for the hidden layers was selected to be log (logarithmic) and Tan (Tangent) function suited best for the output layer.

- This arrangement of functions in function approximation problems or modeling is common and yields better results.

Results and Discussion

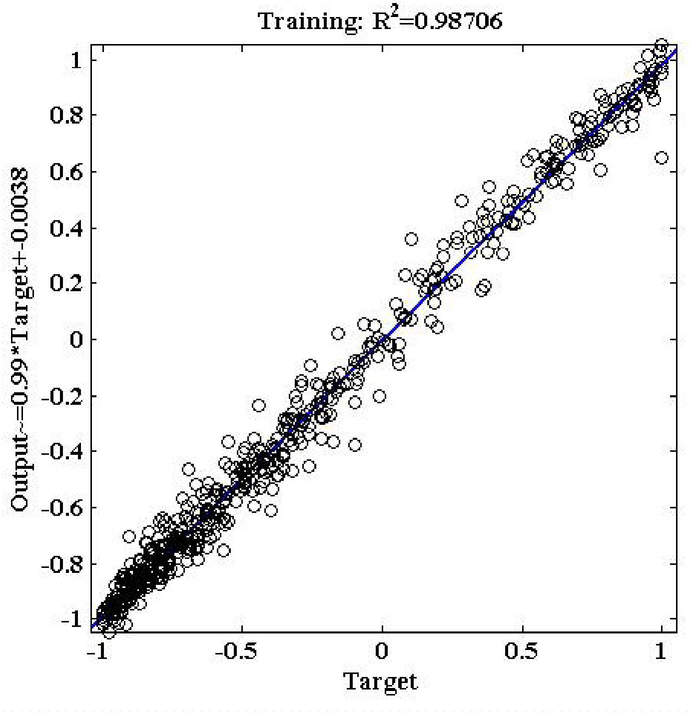
Results and Discussion

- A network with one hidden layer and 10 neurons proved to be an optimum ANN. In this model, 80% of the data set was randomly assigned as the training set, while the remaining 20% of data are put aside for prediction.



Results and Discussion

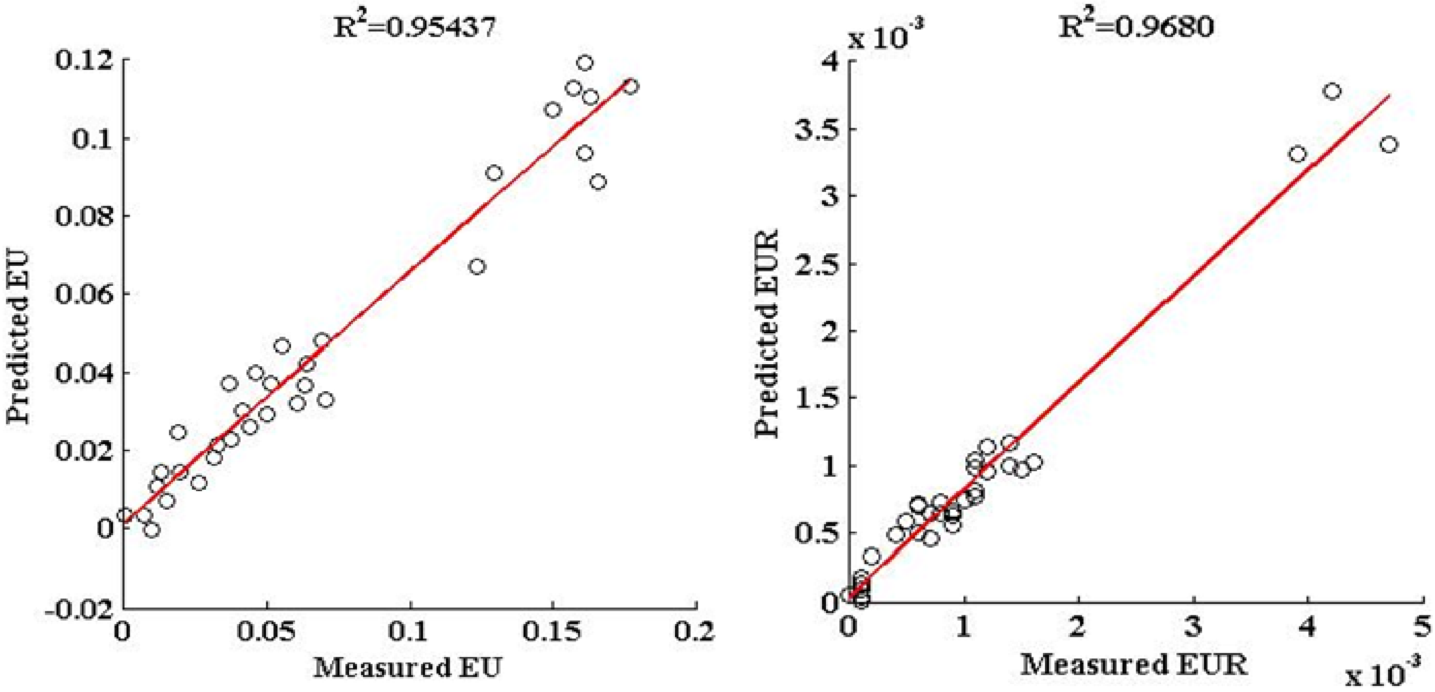
- Regression analysis of outputs and desired targets was performed which is a measure for checking the success of the training.



Results and Discussion

Artificial Neural Networks

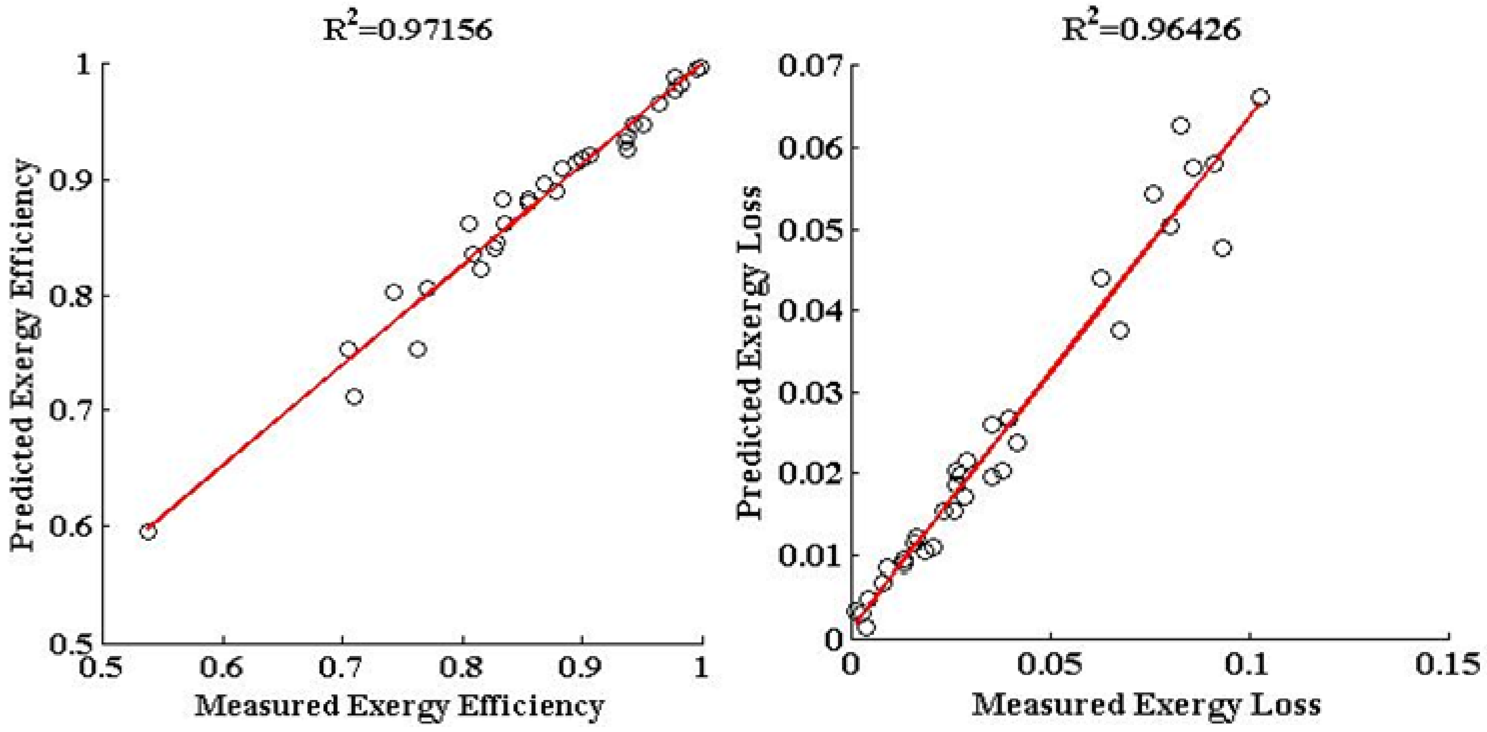
- There is a high correlation between the predicted values extracted by the ANN model and the measured values. Coefficients of determination (R^2) of 0.95 and 0.96 were obtained for predicting EU and EUR values.



Results and Discussion

Artificial Neural Networks

- Exergy loss and exergy efficiency values (important factors for dryer evaluation) were predicted with R^2 of 0.96 and 0.97, respectively.



Results and Discussion

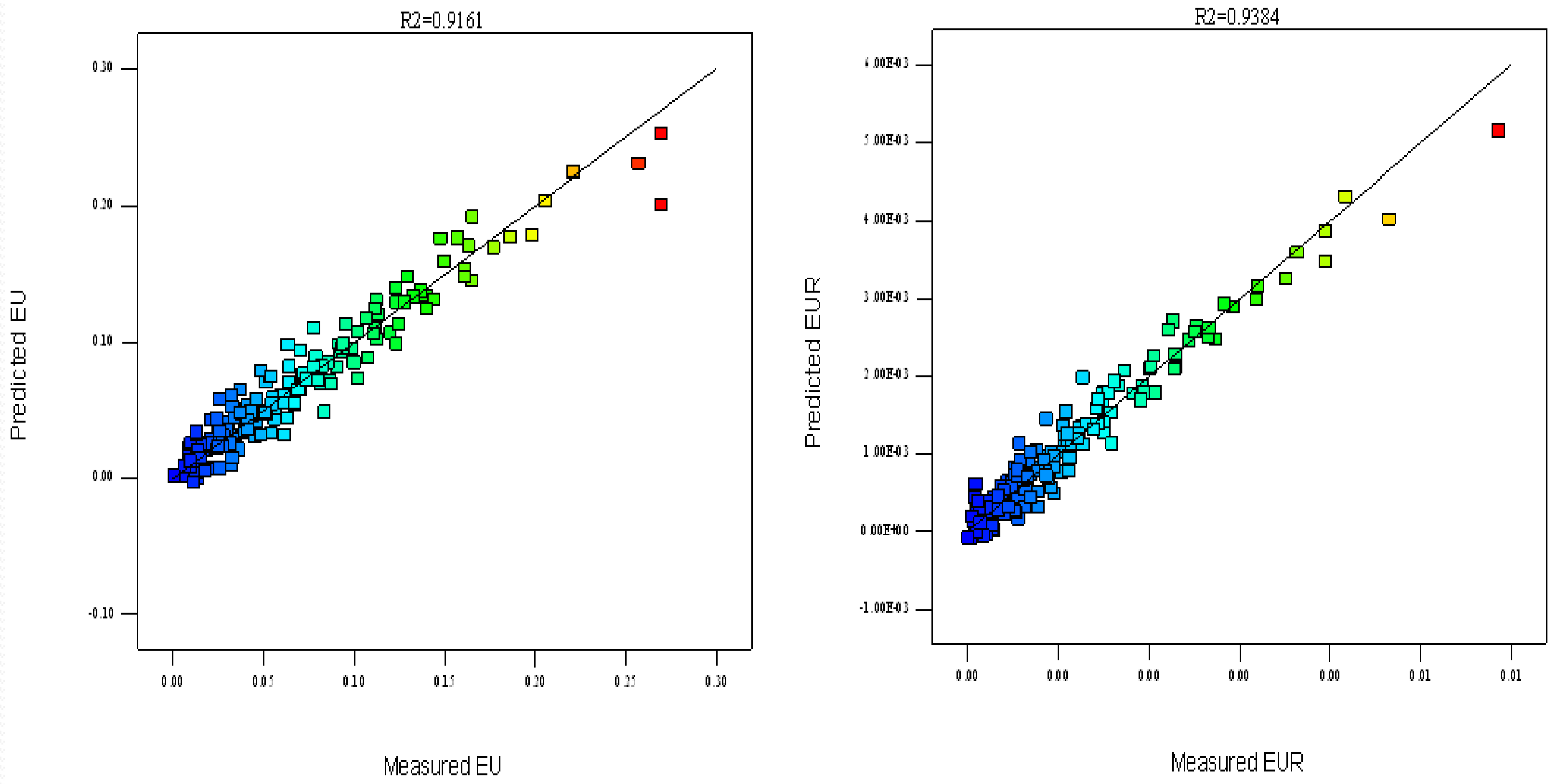
Response Surface Methodology (RSM)

The following figures show the coefficients of determination, R^2 (a measure of how well the regression model can be made to fit the raw data).

Using these figures it is inferred that RSM has been efficient enough to provide reasonable regression models for the dataset.

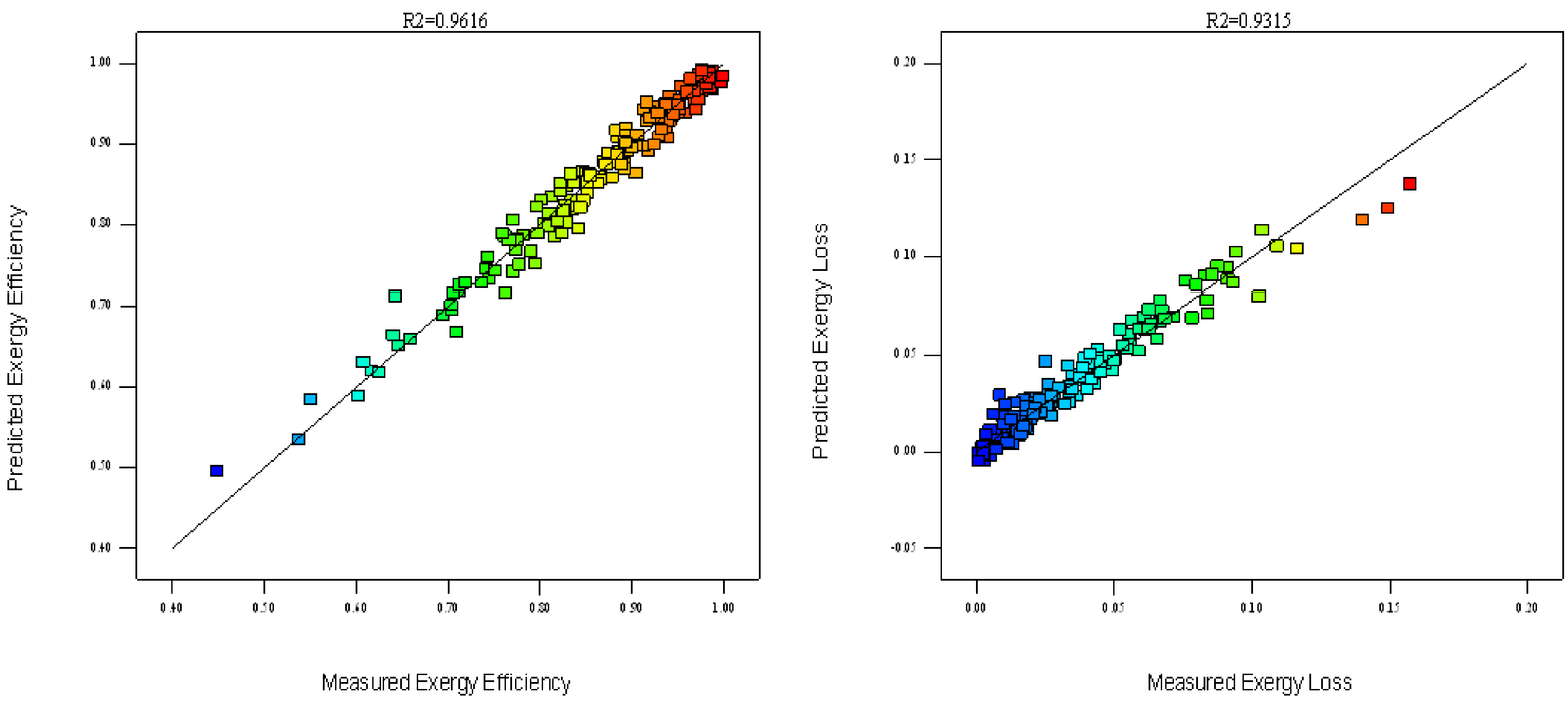
Results and Discussion

Measured vs. predicted values for EU and EUR obtained using the response surface method



Results and Discussion

Measured vs. predicted values for Exergy and Exergy loss obtained using the response surface method



Conclusions

- Microwave pretreatment improved the thermodynamic efficiency of the drying process.

- ANN and RSM models demonstrated reasonable performance in predicting dryer energy and exergy characteristics.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Attention