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Forecasting Air Pollution with Sulfur Dioxide Emitted from Burning Desulfurized Diesel Using Artificial Neural Network

Mohammad A. Hmadan[1], Eman Abdelhafez[2*], Reyad Shawabkeh[3]

[1] Department of Mechanical Engineering, School of Engineering, The University of Jordan, Amman, Jordan
[2] Al-Zaytoonah University of Jordan, Faculty of Engineering and Technology, Department of Alternative Energy Technology, Amman 11733, Jordan
[3] Department of Chemical Engineering, School of Engineering, The University of Jordan, Amman, Jordan
* Corresponding author's e-mail: eman.abdelhafez@zuj.edu.jo

ABSTRACT

Concentrations of emitted pollutants in the atmosphere are influenced by the emission sources and metrological data. In Jordan, diesel fuel is considered to be a main source of SO_2, which has a negative impact on the air quality. In this work, the SO_2 emitted during the burning of desulfurized diesel fuel using activated carbon is conducted using three types of Artificial Neural Network (Elman, NARX and Feedforward models). In order to accomplish this, the previous experimental work on desulfurization of diesel fuel using two types of activated carbon was adopted. The metrological data involved the average daily temperature (T), relative humidity (RH), wind speed (WS), pressure (P), concentration of Particulate Matter (PM10) and average daily solar radiation (SR) over the period from 2/1/2020 to 30/12/2020. It was found that NARX is the most accurate model in the forecasting process of SO_2, followed by Elman and feedforward, which was found to be the least capable model in predicting the SO_2 emitted concentration.

Keywords: desulfurized diesel, activated carbon, sulfur dioxide, air pollution.

INTRODUCTION

During the burning of sulfur containing fuels, sulfur oxides (SO_2) are produced, these oxides have severe negative impacts of the environment, as they lead to the formation of acid rain and cause corrosion, in addition they are considered as one of the main sources of air pollution (González-García et al., 2009; Rezvani et al., 2018). Consequently, desulfurization of such type of fuels is considered as an essential process in the oil refining industry (Zhao et al., 2017) to meet the new standards of sulfur content (10–15 ppm) (Chen et al., 2015).

During the last few years, studies conducted different desulfurization approaches focused on the establishment of energy efficient and reliable desulfurization technology to produce diesel fuel with desirable properties and sulfur concentration below the allowable limits (Aitani et al., 2000; More et al., 2019). A complete review on desulfurization processes of sulfur contained fuels were outlined by More and Gogate (More & Gogate, 2019).

Recently, Hamdan and Shawabkeh (Hamdan et al., 2021), conducted experimental work on the desulfurization of locally refined diesel fuel using three types of activated carbon, two of which were produced from olive cake (lignin activated carbon (LAC)) and from lube oil, while the third one is a commercial one (Norti). In order to investigate the desulfurization ability of each type of AC, they were added separately to diesel fuel sample before it was fed into a domestic boiler and burnt, then the concentration of Sox was measured and compared with that when pure diesel fuel was burned within the boiler. They concluded that the activated carbon type produced from olive cake (LAC) was the most efficient type to desulfurize diesel fuel, with a percentage reduction in the concentration of SO_2 equal to 11%,

followed by the commercial activated carbon with a percentage reduction equal to 7%.

Nowadays, it is well known that sulfur dioxide (SO_2) is considered to be one of the indicators of air quality. One of its main sources of formation is the combustion of sulfur contained fuel as a result of the reaction between sulfur contents of the fuel with oxygen. Its formation has a severe negative impact on the environment and quality of air. Hence, forecasting of the SO_2 formation caused by the sulfur containing fuel is essential for a better understanding and prevention of air pollution.

One the most promising approaches used in the prediction of its formation of SO_2 is based on artificial neural networks (ANN) (Boznar et al., 1993), which capture the link between the input data and the corresponding output data. In addition, it is widely used nowadays and covers a wide range of scientific research and applications. In addition, it has many benefits and advantages such as: it is easy to use, it takes less time, gives accurate results, as well as has many packages and methods that cover a wide range of different problems and fields. Boznar and Mlakar (Boznar et al., 1995) represented full details on the capabilities and disadvantages of neural networks for the cases of wind forecasting, reconstruction, and SO_2 pollution forecasting.

In this work, the impact of using desulfurized diesel fuel on the formation of SO_2 during its burning was forecasted using artificial intelligence, the main results obtained by Hamdan and Shawabkeh (Hamdan et al., 2021) will be adopted in this work, such that the desulfurization of diesel fuel using LCM and CCA will cut down the emission of SO_2 by 11 and 7%, respectively. Hence, the actual amounts of SO_2 emitted during the burning of desulfurized diesel will be cut down by 11 and 7 % of those obtained when diesel fuel is burned. These actual data of emitted sulfur oxide, in addition to the metrological data (ambient temperature, humidity, wind speed) over the period from 2/1/2020 to 3/12/2020 were obtained from the World Air Quality Project website (https://aqicn.org/).

DATA ANALYSIS

Three types of Artificial Neural Network (Elman, NARX and Feedforward models) were designed and tested using MATLAB software with the total data used consisting of 355 samples as the inputs to the ANN network. The inputs to the ANN network are the average daily temperature (T), relative humidity (RH), wind speed (WS), pressure (P), concentration of Particulate Matter (PM10) and average daily solar radiation (SR). The outputs of the ANN network are the reduction of the emitted sulfur oxide (SO_2) when commercially activated carbon and that obtained from olive cake were used to desulfurize pure diesel.

RESULTS AND DISCUSSION

Elman, NARX and Feedforward models were designed and tested using the MATLAB software and they are used to correlate the weather variables with the emitted sulfur oxide during the desulfurization process of pure diesel fuel, which was refined locally. In turn, Levenberg-Marquardt (trainlm) was used as a training algorithm. The performance of the designed models has been conducted using the coefficient of correlation (R). The three models were presented and described thoroughly. More detailed description about the proposed three models of ANN are found in (Al-Naami et al., 2014).

ANN network with neuron numbers (6, 10, 2) were designed and tested within the MATLAB. A total data consists of 355 samples which were obtained from previously experimental results, all of which were used as the input of ANN network, a total of 70% of this data was used for training, 15% was used for validation and 15% was used for testing. Tangent sigmoid function was applied for the hidden layer, and linear transfer function was used in the output layer. Finally, and after many trails and errors, the number of the hidden layer is selected to be 10.

Artificial Neural Network (ANN)

Table 1 shows the coefficient of correlation (R) corresponds to each model. As it may be seen in the table, the maximum value of R is 0.93281 for NARX model, followed by 0.89778 for Elman model and finally the lowest value of R was 0.76384 for Feedforward model.

Table 1. Coefficient of correlation (R) for the proposed models

Specification	R
Feedforward	0.76384
Elman	0.89778
NARX	0.93281

Figure 1 represents the scatter plots of training, testing, and validation for the proposed three models. As indicated in this figure, the results of the scatter plot during training, validation, and testing of the reduction of the sulfur oxide emitted during the desulfurization process using the three different training models are quite close to each other. For the NARX model, it was found that it has the highest values of R in training, validation, and testing are, which are 0.93281, 0.89778, and 0.76384, respectively.

In Figures 2 and 3, a comparison between the measured and predicted values using the proposed models is shown. As indicated, the NARX model gave the best performance to predict reduction of the sulfur oxide emitted during the desulfurization process. Furthermore, and as shown in the table, the predictive capability of Feedforward and Elman models for the reduction of the sulfur oxide emitted during the desulfurization process is the least.

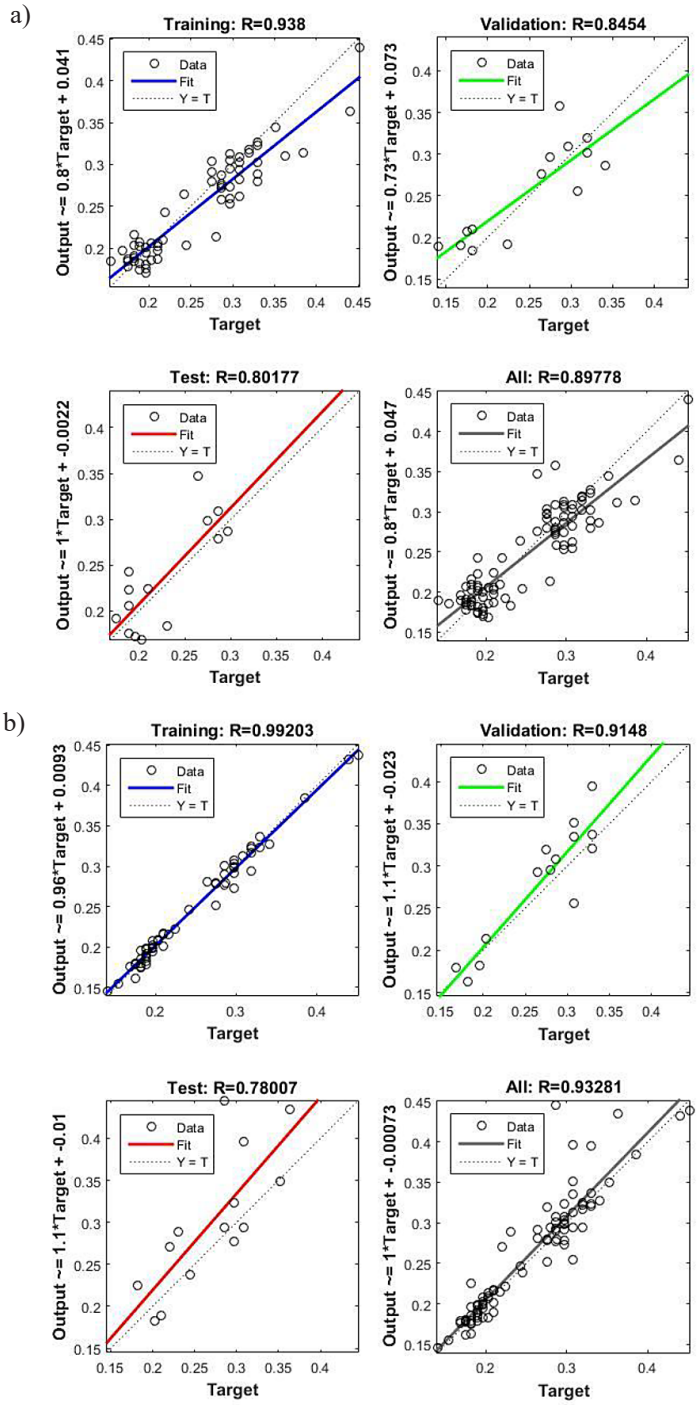

Figure 1. Comparison of scatter plots of the models used for the selected models (a) Elman, (b) NARX

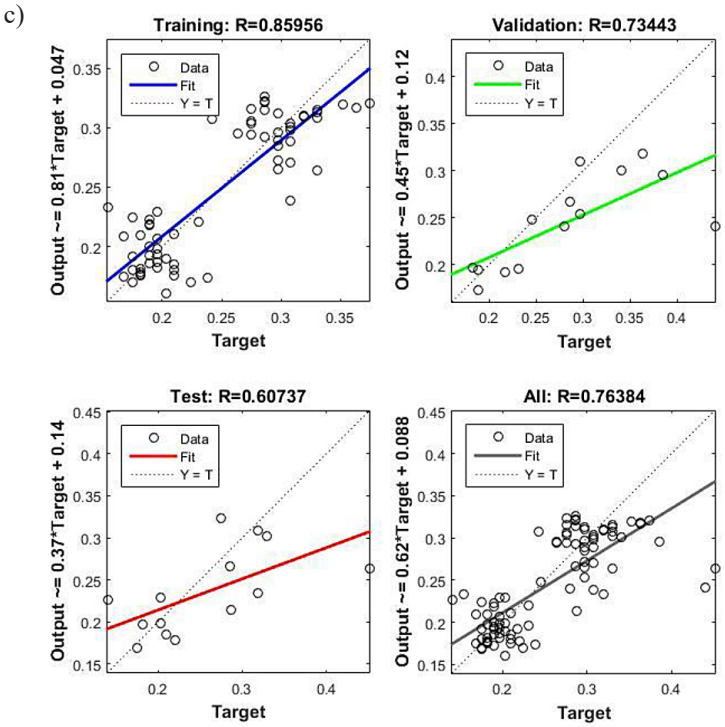

Figure 1. Cont. Comparison of scatter plots of the models used for the selected models: (c) Feedforward

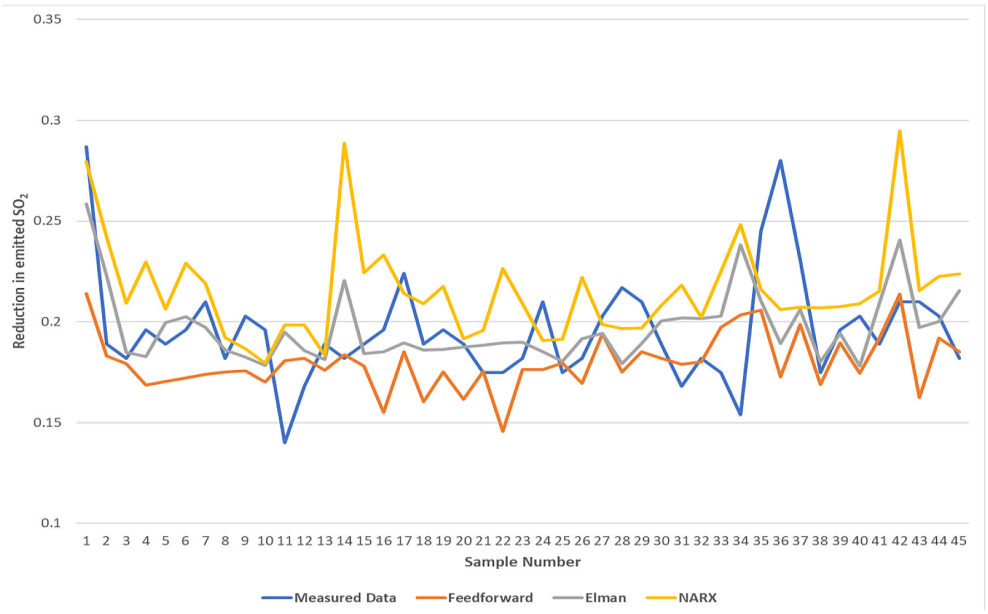

Figure 2. Comparison between experimental and estimated reduction of emitted sulfur oxide when diesel was desulfurized using olive cake activated carbon

Sensitivity Test

Multilayer perceptron (MLP) is considered to be a popular feed-forward neural network architecture, it consists of three layers, namely input, output, and hidden layers (Ahmadi et al., 2019). Independent variable importance, which was conducted using MLP represents the measuring of how much the network's model-predicted value changes for different values of the independent variable (Abdelhafez et al., 2021).

Using trial and error method, MLP technique, with 10 hidden neurons and using 70% of the data for training, 15% testing and 15% for validation, was performed to obtain the best model that predicts with highest accuracy the reduction of the emitted sulfur oxide during desulfurized process.

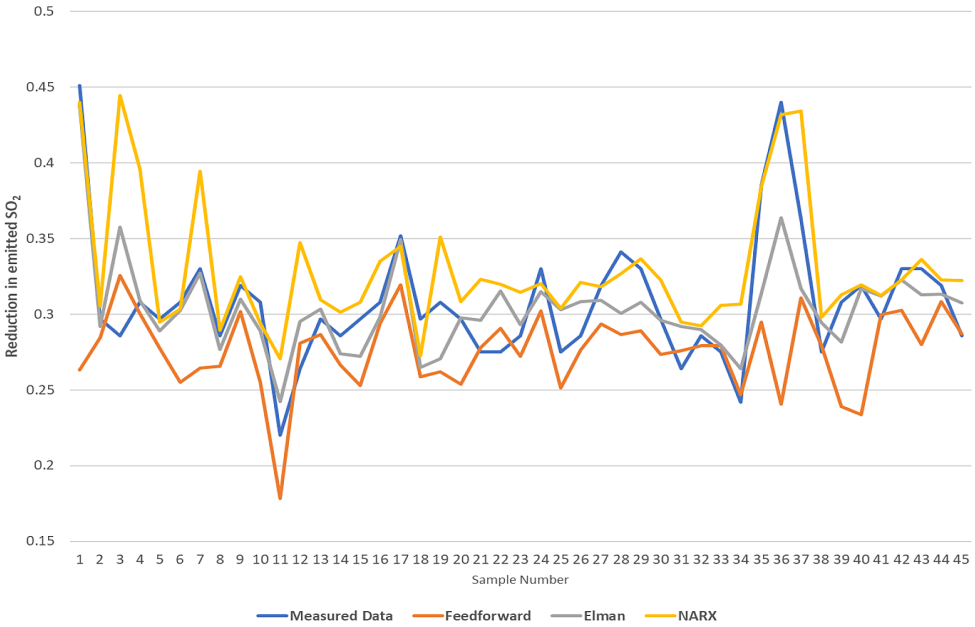

Figure 3. Comparison between experimental and estimated reduction of emitted sulfur oxide when commercially activated carbon was used for diesel desulfurization

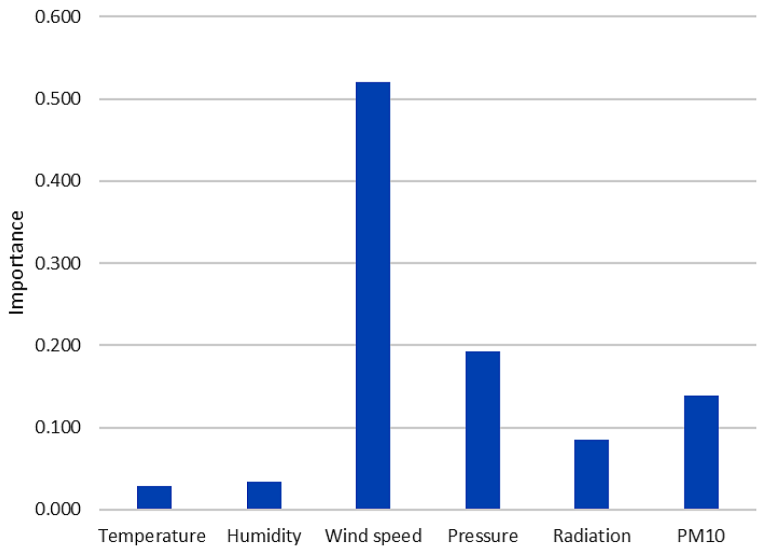

Figure 4. Independent Variable Importance for the reduction of the sulfur oxide emitted during the desulfurization process when diesel was desulfurized using olive cake activated carbon

Figure (4) shows independent variable importance for the reduction of the sulfur oxide emitted during the desulfurization process when diesel was desulfurized using olive cake activated carbon. As indicated, wind speed is the most effective variable on the reduction of the sulfur oxide emitted during the desulfurization process when diesel was desulfurized using olive cake activated carbon and commercially activated carbon.

CONCLUSIONS

In this study, the emission of sulfur dioxides from desulfurized locally refined diesel fuel using activated carbons was successfully forecasted. This was achieved using three types of Artificial Neural Network (Elman, NARX and Feedforward models). It may be concluded that NARX was the most accurate model in the forecasting process of SO_2, followed by Elman and feedforward which was found to be the least capable model in predicting the emitted SO_2 concentration.

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