Building and Environment 104 (2016) 68–75

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Selection of the most influential flow and thermal parameters for predicting the efficiency of activated carbon filters using neuro-fuzzy technique

Miomir Raos [a], Dalibor Petković [b,*], Milan Protić [a], Milena Jovanović [a], Dušan Marković [b]

[a] University of Niš, Faculty of Occupational Safety, Čarnojevića 10A, 18000 Niš, Serbia
[b] University of Niš, Faculty of Mechanical Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia

ARTICLE INFO

Article history:
Received 3 February 2016
Received in revised form
19 April 2016
Accepted 29 April 2016
Available online 30 April 2016

Keywords:
ANFIS
Prediction
Flow and thermal parameters
Activated carbon
Filter efficiency

ABSTRACT

This paper analyzes the influence of various flow and thermal variables on the performance of the activated carbon filter in the air-conditioning system. The ANFIS (adaptive neuro fuzzy inference system) method was applied to the data obtained from the experimental apparatus in order to select the most influential parameters for assessing the efficiency of the activated carbon filter. Acetone was selected as the target pollutant component. Experiments were performed for different temperature, humidity, and flow rate conditions, as well as for acetone concentrations. A set of four potential inputs was considered: velocities of gas mixture through ventilation duct (flow), temperature, humidity, and concentration of test chemical pollutants ahead of the filter module. The results show that the most influential parameter for predicting outlet concentrations of acetone is temperature.

1. Introduction

Indoor air purification is one of the main strategies to improve indoor air quality (IAQ) [1]. In the air filtration and purification applications, activated carbon or activated charcoal is widely used due to many potential advantages [2]. The applications of activated carbon can be found in a large number of industries, water filters, respirators, solvent recovery systems, etc. [3,4]. Activated carbon can be used for filtering most organic pollutants and solvents from air through the adsorption process [5].

The aim of this study was to analyze how different flow and thermal parameters of the air conditioning system (temperature, humidity, and air velocity) influence the efficiency of the activated carbon filter for different concentrations of the test pollutant. We used acetone, a volatile organic compound (VOC) frequently present in occupational and residential environments, as a test gas pollutant. Depending on its concentration in air, it can cause different symptoms, from irritations to headaches and dizziness [6–8], so effective elimination of this compound from air is mandatory.

Numerous studies regarding VOC adsorption were reported in open literature [9–15]. Benzene, toluene, MEK and acetone were used as prevailing challenge gases. Most of these studies were focused on activated carbon filters with concentrations ranging from a couple of ppm (residential indoor environments) to a few hundred ppm (industrial environments). Additionally, numerous studies were performed for theoretical modeling of fixed-bed adsorption filters. A comprehensive literature review of existing sorbent-based gas filter models used for predicting filter performance for nonindustrial buildings is provided in Ref. [16]. All of these studies were conducted for dry air, despite the fact that parameters of the two most important models for breakthrough curves, Wheeler–Jonas and Yoon–Nelson, are a function of humidity level. This inadequacy was reported in Ref. [17], where a framework was developed for predicting the breakthrough curve of activated carbon filters at low concentrations and different levels of relative humidity, applying accelerated test data. However, the influence of different temperature levels as well as of the simultaneous effect of temperature and humidity on the breakthrough and efficiency of filters has not been analyzed.

The aim of this study was to analyze the magnitude of the effect of different flow and thermal parameters (velocity of gas mixture through the ventilation duct (flow), temperature, humidity, and

* Corresponding author.
E-mail address: dalibortc@gmail.com (D. Petković).

http://dx.doi.org/10.1016/j.buildenv.2016.04.031
0360-1323/

upstream concentration of challenge gas (acetone)) on the efficiency of active carbon filters. We used a statistical learning approach, based on artificial neural networks, to develop suitable models, which were subsequently used to assess the importance of different flow and thermal parameters. We also used artificial neural networks (ANN) as a substitute for the analytical approach, as ANN offers advantages such as no required previous knowledge of internal system parameters [18]. In this study, we applied the adaptive neuro-fuzzy inference system (ANFIS), which is a specific type of the ANN family, to select the most influential parameters for predicting downstream concentration of acetone in the airstream [19].

2. Methodology

2.1. Experimental setup

Elements of a filter-ventilation system used in experiments under the different thermal and flow conditions are shown in Fig. 1. Supervisory control and data acquisition (SCADA) system was developed for examining the characteristics of the filter elements. The measurement system consists of sensors and transmitters of physical and nonelectrical quantities, a personal computer, and a source of direct current as a transmitter of power supply. The positions of measuring points on the examination line are also shown in Fig. 1.

Nine measurement points were realized (Fig. 1): M1 – inlet velocity of air flow in the intake air duct was measured with a velocity transmitter type TN 00398935, JUMO GmbH; M2 –temperature and relative humidity in the intake air duct was measured with a transmitter type 90702, JUMO GmbH; M3 –pressure difference of the first filter element was measured with a differential pressure transmitter type 4304, JUMO GmbH; M4 – temperature and relative humidity of air in the secondary air duct; M5 – concentration of the gaseous chemical test pollutants (conditional measurement point) in the secondary air duct, realized using a mobile concentration measuring unit Thermo, model 580S; M6 – differential pressure of the secondary filter element; M7 – concentration of the gaseous chemical test pollutants in the tertiary air duct; M8– temperature and relative humidity of the air in the outlet duct; M9 – room temperature (enclosed space), realized by using a resistant temperature transmitter with a current output type 90.2523/12, JUMO GmbH.

In order to regulate air velocity, we coupled the electric motor with a frequency regulator Sinamics G110, Siemens AG. The electric motor synchronic speed, or the impeller of the fan, was changed with the frequency of the electric current, which affected the gas mixture flow velocity in the ducts. The fan was made of a combination of thermo-plastic and steel materials for all parts coming in contact with aggressive gases. The impeller of the fan was directly connected to the shaft of the electric motor to provide proper and long-lasting operation of the device. The suction and delivery duct of the fan was connected by a flexible connection to other parts of the installation in order to reduce vibration. The centrifugal fan was driven by a three-phase asynchronous motor with a squirrel-cage rotor (0.75 kW).

We constructed a 1270-mm charcoal filter module for removing gaseous pollutants as an integrated input-output line segment of the filter-ventilation line. The module was made of PVC by means of the vacuum processing method. Connection of diffusers with the body of the module was made by flanges, bolts, and nuts with a suitable sealing element in the flange. Fig. 2 shows the filter module for chemical pollutants with measuring and data acquisition equipment.

The cartridges, filled with activated carbon, were stored in the filter module in order to provide adequate housing and ensure adequate flow characteristics of the gas mixture when it passes through the adsorption filling [20]. The size of the perforation was smaller than the grain size of the activated carbon so as to avoid grains falling through the holes of cartridge layers. The cartridge housing was made by perforation of 1.4-mm thick acid-resistant plastic film (variable number and size of perforations per square centimeter) reducing the weight and price of the filters. The cartridges were arranged in a chessboard layout forming a cluster group placed inside the adsorption filter module. The filter module was filled with pellets of activated carbon with different granularity (3 mm, 4 mm), Envirocarb™ series AP4-60.

This type of activated carbon has a very high density, which contributes to a fairly good volume activity. In addition, activated carbon pellets in this series are characterized by good mechanical strength, easy and inexpensive recycling, low ash content, resistance to thermal loads, and low pressure drop of activated carbon in a layer. This results in the reduction of fan strain (less power).

During the experiments we conducted a number of test runs with controlled dosage of gaseous test chemical pollutant – acetone. This module contained the source reservoir of acetone, proper measuring and regulating apparatus, as well as elements for insertion into the air duct.

We used the data acquisition system to obtain a picture of the behavior of the adsorption filter prototype compared to simulated parameters of the gas mixture [21].

2.2. Input and output variables for ANFIS model

We selected the following four parameters as the inputs: humidity, temperature, and velocity of air stream with pollutants, as well as upstream acetone concentration. Table 1 shows these four inputs and the output – downstream acetone concentration–-which were used in this study. All the parameters were determined by measurements.

2.3. ANFIS methodology

2.3.1. Neuro-fuzzy computing

Soft computing is an innovative approach in the construction of systems that are computationally intelligent and possess human-like expertise within a specific domain. These systems are supposed to adapt in changing environments, learn to do better, and explain their decision-making process. It is usually more beneficial to employ several computing methods in a synergistic way rather than build a system based exclusively on a single technique. This is useful when confronting real-world computing problems. The result of such synergistic use of computing techniques is the construction of complementary hybrid intelligent systems. The epitome of designing and constructing intelligent systems of this kind is neuro-fuzzy computing: firstly, neural networks recognizing patterns and adapting to cope with evolving environments; and secondly, fuzzy inference systems that include human knowledge and implement decision making and differentiation. The combination and integration of these two complementary methodologies produces a novel discipline called neuro-fuzzy computing.

2.3.2. Adaptive neuro-fuzzy inference system

The ANFIS (adaptive neuro-fuzzy inference system) is a class of adaptive networks functionally equivalent to the fuzzy inference systems. In this study, the fuzzy inference system used has two inputs, x and m y, and one output z. In this study, we used the first-order Sugeno fuzzy model, with two fuzzy if-then rules as follows: