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Research article

Selection of optimized air pollutant filtration technologies for petrochemical industries through multiple-attribute decision-making

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ABSTRACT

Selecting cost-effective and efficient air filtration technologies that ensure sustainable development is a challenge to national, regional and local policy makers. Various factors such as efficiency, maintainability, and design of the developed devices can affect the selection of optimized technologies. The present study aimed to select optimal technologies for air filtration devices in petrochemical industries through a multi-criteria decision-making (MADM) method based on a fuzzy model of Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). Five criteria (filtration efficiency, cost, maintainability, designability, and size) were used to rank air pollution control technologies designed to eliminate particulate matter (PM), volatile organic compounds (VOCs), and ammonia (NH_3). According to the results, the research criteria had different weights for different air pollutants. High-efficiency particulate air (HEPA + pre collector) filters, plasma chemistry, and chemical absorption were identified as the most appropriate filtration methods for PM, VOCs, and NH_3, respectively (coefficients = 0.923, 0.9586, and 0.867, respectively).

1. Introduction

Air pollution and its socioeconomic and environmental impacts are among the most important negative effects of petrochemical industries (Nath and Cholakov, 2009; Yang et al., 2002). Due to the adverse environmental and public health effects of air pollution in industrial and non-industrial areas all over the world (Aryal et al., 2013; Cakmak et al., 2014; Huang et al., 2014; Pellegrini et al., 2014; Vlachokostas et al., 2011), various air pollution modeling and control methods have been suggested over the past decades (Zannetti, 2013). Long-term, realistic, and feasible management strategies are required to eliminate, or at least reduce, the harmful effects of emissions from petrochemical industries. These emissions include particulate matter (PM), volatile organic compounds (VOCs), carbon monoxide (CO), ammonia (NH_3), sulfur oxides (SO_x), and carbon dioxide (CO_2) (Nath and Cholakov, 2009; Tassi et al., 2013; Vlachokostas et al., 2011). However, the high initial and operative costs of filtration methods and lack of return on investment have turned air pollution control into an unprofitable economic burden. Environmental researchers and policymakers have hence made numerous efforts to develop cost-effective methods (Seskin et al., 1983; Vanoye and Mendoza, 2014; Yarahmadi et al., 2010) and optimized techniques to manage air pollution based on all economic, environmental, and social considerations (Vlachokostas et al., 2011). Decision-making is a multi-criteria process whose application is essential in the assessment and selection of proper strategies (Karsak and Tolga, 2001; Mir et al., 2016). Therefore, multi-attribute decision-making (MADM) models have been proposed to prioritize and select technologies by seeking an option which provides maximum benefit based on all criteria (Mardani et al., 2015). MADM models clarify interrelationships between different indices and determine the priority of all options based on each criterion. Considering the specific limitations and characteristics of various methods used in MADM, selecting the best method is truly critical. Interactions between different indices, properties of each index (e.g. quantitative/qualitative and negative/positive), accessibility of relative weights of the indices, and the need for the decision-maker's opinion should all be taken into account when opting for a particular method (Pan et al.,

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2000). Due to the relationship between complexity and uncertainty, increased complexity will be associated with decreased confidence. Therefore, the application of fuzzy logic can solve the problems caused by uncertainty (Zadeh, 1996).

Decision-making and optimal use of resources will be complex tasks during activities such as identification, categorization, selection, and prioritization in which social, economic, operational, and industrial indices are involved. The inefficiency of one-dimensional approaches and the necessity of holistic methods in decision-making and management highlight the importance of multi-criteria methods of decision-making (Şengül et al., 2015). The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), presented by Hwang and Yoon (2012) is a famous method for issues related to MADM. It asserts that the selected alternative should have the shortest geometric distance from the positive ideal (the best possible state) and greatest geometric distance from the negative ideal (the worst possible state) (Yazdani et al., 2012). The TOPSIS is used to rank and compare different alternatives, to determine distances between the options, and to finally choose the best alternative (Chen et al., 2003).

Since the socioeconomic complexity in offshore oil and gas (OOG) activities turns decision-making into a complex process accompanied by uncertainty, fuzzy inference systems (FIS) and the analytic hierarchy process (AHP) have been suggested as powerful tools for prioritizing environmental issues under such conditions (Gholami et al., 2015; Yang et al., 2011). Moreover, fuzzy sets, introduced by Zadeh (1965), can properly describe vague, uncertain information during decision-making processes. The significance of air pollution control systems depends on not only the efficiency, design, expenses, and dimensions of the target organization, but also the regulations, geographical location, environmental considerations, and the characteristics of the pollutants (Mussatti et al., 2002).

A major challenge faced by factory and industry managers is thus to identify the most suitable technologies based on both their own priorities and the ranking of air filtration technologies in the country. Since the absence of relevant studies can lead to economic, social, and environmental losses, the present research was the first to prioritize and select the most appropriate air filtration technologies in petrochemical industries. In 2012, Kalbar applied multiple-criteria decision-making (MCDM) to select an optimized technology for sewage filtration. While numerous indices can be used in the selection of proper controlling equipment (Kalbar et al., 2012), multiple criteria decision analysis (MCDA) facilitates the identification and prioritization of suitable technologies based on key elements determined by Multiple Criteria Decision Support Systems (MCDSS).

In an attempt to quantitatively assess the performance of control systems, the current research applied MCDA based on fuzzy TOPSIS to weight all factors involved in the selection of efficient technologies. In order to determine indices affecting the identification and assessment of optimized air pollution control systems (OAPCS), a list of all technical, economic, and operational indices involved in air pollution control equipment was prepared based on the set of indices provided by previous research and the U.S. Department of Environment, Iran's Department of Environment, the UK Health and Safety Executive, the Organization for Sustainable Development, and Iran's Ministry of Petroleum and Port Authority. While the performance of optimized air purification systems can be accessed through numerous indices, limited indices are available for performance evaluation in OAPCS. The aim of the present research was prioritization of the air pollution control technologies for PM, VOCs, and NH_3 pollutants in the petrochemical complex field by using TOPSIS method.

2. Methods

In this research, fuzzy TOPSIS technique was used to rank the key performance indicators of the OAPCS according to the mentioned criteria. In the absence of a specific standard questionnaire to rank optimized air purification technologies in petrochemical industries, such technologies were first identified and coded based on literature review and opinions of the experts.

2.1. Selection the criteria and alternatives

First, a list containing an extensive range of air pollution control technologies (for PM, VOCs, and NH3) and an initial list of criteria for Selection of Optimized Air Pollutant Filtration Technologies for Petrochemical Industries were prepared. Then, semi-structured interviews were conducted with fifteen experts (six air pollution experts, six managers from the department of environment, two industrial hygienist, and one air filtration designers) to gain a deeper understanding of their objectives and to refine the list of criteria and control technologies (alternatives). Experts were identified using the Hydra technique (Sanò and Medina, 2012). Suitable criteria and alternatives were selected considering the air pollution control effective parameters or air pollution equipment, previous studies, experts' practical experience, and the characteristics of the study area. Five criteria, including cost, size of the system, filtration efficiency, maintainability, and designability, due to the incorporation of all social, technical, environmental, economic, and operational arrangements were considered as the objectives of the present research (Bradley, 2005; Brauer and Varma, 2012; Spiegel and Maystre, 1998; Yi, 2007). Finally, the initial questionnaires were prepared based on the selected criteria and alternatives.

2.2. Screening the criteria and alternatives

Experts were assessed the initial survey list containing criteria and alternatives. They were also asked to respond to the question "Which criteria are essential for selection of optimized air pollutant filtration technologies for petrochemical industries?" Content Validity Ratio (CVR) was computed to choose the criteria and alternatives for Selection of Optimized Air Pollutant Filtration Technologies (Lawshe, 1975). Equation (1) was devised for CVR:

$$\mathrm{CVR} = \frac{\mathrm{n_e} - \mathrm{N}/2}{\mathrm{N}/2} \tag{1}$$

where, n_e is the number of respondents indicating "essential" and N is the total number of respondents. The value of CVR has been computed for each alternative and criterion. After identification and inclusion of all criteria and alternatives in the final list, the content validity index (CVI) was computed for all alternatives and criteria as Eq. (2). The CVI is the mean of the CVR values of the remaining criteria and alternatives. Then the remaining alternatives based on criteria were organized in the questionnaire form to determine the priority of each criterion for selection of optimized air pollutant filtration technologies in petrochemical industries.

$$\mathrm{CVI} = \frac{\sum_1^n \mathrm{CVR}}{\mathrm{n}} \tag{2}$$

The influence priority was assessed on a scale of 1–7, while 1 representing "no influence" and 7 representing "extreme influence". Firstly, the questionnaire's internal consistency was confirmed with a Cronbach's alpha equal to 0.995. Item analysis was considered satisfactory if the Cronbach's alpha value was 0.7 or