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Determination of emission factors for nitrogen oxides and volatile organic compounds emitted from jewelry making workshops

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ABSTRACT

Introduction: Air pollution is a major problem in Isfahan, one of the major cities of Iran. A large number of jewelry making workshops are located in Isfahan, yet there is insufficient information about their pollutants emission rates. The aim of this study is to determine the emission factors of nitrogen oxides and volatile organic compounds (VOCs) in Isfahan's jewelry making workshops.

Materials and methods: In the first step of this study, some jewelry making workshops were visited to find nitrogen oxides and VOCs emission sources. It was revealed that the only possible source of nitrogen oxides and VOCs in these workshops was use of the oxy fuel welding system used to melt gold. In the second step, a set of experiments was conducted to determine the emission factors of nitrogen oxides and VOCs while working with the oxy fuel welding system.

Results: The results of this study showed that the emission factor of nitrogen oxides in the oxy fuel welding system was 0.64 kg/kg consumed natural gas. It was also found that no VOCs were emitted while working with the oxy fuel welding system, since sufficient pure oxygen was produced in this system. Interview with managers of some jewelry making workshops showed that the average natural gas consumption in each workshop was 22 kg. Therefore, each jewelry making workshop in Isfahan emitted nearly 14.08 kg of nitrogen oxide per month.

Conclusion: It is revealed that in 2018, 81100.8 kg nitrogen oxides were emitted from jewelry making workshops into Isfahan's atmosphere.

Introduction

Air pollution has been become a major environmental issue in megacities worldwide [1, 2]. Technology expansion is a main reason for increasing the number of pollutant sources in both developed and developing countries [3-5]. Since the majority of air pollutants are harmful to human health, it is necessary to control their emission [6]. All air pollutant sources and their emission rates must be identified before planning for air pollution management [7]. There are many methods to determine the emission rates of pollutants [8]. Using emission factors is one of the most current methods to determine the emission rates of pollutants from different pollutant sources. An emission factor is a coefficient considered

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for a particular pollutant source [9]. The emission rates of pollutants from a specific pollutant source can be calculated by multiplying each activity by its emission factor. Using emission factors is a rapid and reliable method to determine the emission rates of pollutants [9]. Among thousands of air pollutants, only five compounds—carbon monoxide, nitrogen oxides, sulfur oxides, VOCs and particulate matter—have been selected as air pollution indicators [10]. Although several studies have been conducted on developing emission factors for various pollutant sources by the United State Environmental Protection Agency (US EPA) and the European Environmental Agency (EEA), each country should develop its own specific local emission factors.

Nitrogen oxides are one of the important air pollutants that are emitted from vehicles and some industries [11]. The health effects of nitrogen oxides can be attributed to increased methemoglobin, inhibitory activity of enzymes, effects on the human respiratory system and pathologic effects [12]. The amount of methemoglobin in the human blood is naturally between 0 and 8% [9]. When a person inhales air contaminated with nitrogen oxides, the concentration of methemoglobin in the blood reaches 10 to 15% [9]. In this range of nitrogen oxides concentration, some symptoms such as difficulty in breathing will appear that result in hypoxia. Exposure of animals to air contaminated with NO_2 at a concentration between 1200 and 1500 ppm leads to cyanosis and death. The concentration of 20 ppm of NO_2 has stopped the hydrogenase activity of Proteus bacteria. Changes in lung functioning were observed when humans were exposed to a concentration of up to 50 ppm for a short period of time. Similar problems were observed when humans were exposed to 0.8 ppm of NO_2 over a long period of time. VOCs are many organic compounds with low vapor pressure that can be evaporated in low temperatures. Many VOCs are toxic, carcinogenic and teratogenic [13]. Therefore, control of VOCs emissions in the atmosphere is important.

Isfahan is one of the major cities in Iran that is exposed to air pollution. The hundreds of thousands of cars in the city of Isfahan have led to the production of a large amount of pollutants in the city. Isfahan is also an industrial city with thousands of factories and workshops. These workshops and factories emit a large amount of pollutants into Isfahan's atmosphere. In order to control the air pollution of this city, it is essential to prepare an air pollutant emission inventory. Jewelry making workshops are one of the industries that have rapidly expanded in Isfahan. There are dozens of jewelry making workshops in Isfahan that are suspected of emitting air pollutants. Calculation of the emission rate of pollutants emitted by the jewelry making workshops is the first step in assessing the share of these workshops in Isfahan's air pollution. Unfortunately, to date no emission factor has been provided for the jewelry making workshops. The purpose of this study was to introduce the emission factors of nitrogen oxides and VOCs for jewelry making workshops in Isfahan. These emission factors were determined by designing and carrying out a set of experiments based upon technologies used in these workshops.

Materials and methods

In the first step of this study, a few of Isfahan's jewelry making workshops were visited. It was found that the only source of nitrogen oxide emission in jewelry making workshops was their use of oxy fuel welding for melting gold. In oxy fuel welding, natural gas is burned with pure oxygen, which produces a large amount of heat that causes gold to melt. Since in oxy fuel welding enough oxygen exists for burning natural gas, lower amounts of air pollutants are emitted compared with other combustion methods. A set of experiments was designed to determine the emission factors of nitrogen oxides and VOCs generated while working with oxy fuel welding for gold melting. As shown in Figure 1, in these experiments the flame of oxy fuel welding was located in a chimney with a diameter of 30 cm. Then the concentration of nitrogen oxides and VOCs were determined using a QROTECH gas analyzer model QRO-401. The speed of gas in the chimney was measured by PROVA digital gas speed meter model AVM-07. Next, the flow of oxygen in the oxy fuel welding was cut to measure the natural gas flow rate. After that, the emission factor was calculated using Eqs. 1 and 2. The average amount of natural gas used in jewelry making workshops in 2018 was determined by interviewing some managers of the jewelry making workshops. Finally, the emission rates of nitrogen oxide and VOCs for each jewelry making workshop were determined using Eq. 3.

$$ER = \left[V \times \frac{\pi D^2}{4}\right] \times C \quad (1)$$

where ER is the emission rate of pollutants in mg/s, V is the velocity of gases in the chimney, D is the diameter of chimney in mm and C is the concentration of pollutants in chimney in mg/m^3.

$$EF = \frac{ER}{Q_{Natural\ gas}} \quad (2)$$

where EF is the emission factor of pollutants in kg/kg consumed natural gas and is the mass flow rate of natural gas in kg/s.

$$E_{pollutant} = AR \times EF \quad (3)$$

where is the rate of pollutant emission in kg/year and AR is consumed natural gas in kg/year.

Results and discussion

In the gold-smelting workshop, the mixture of oxygen gas is about 70% and the gas cylinder

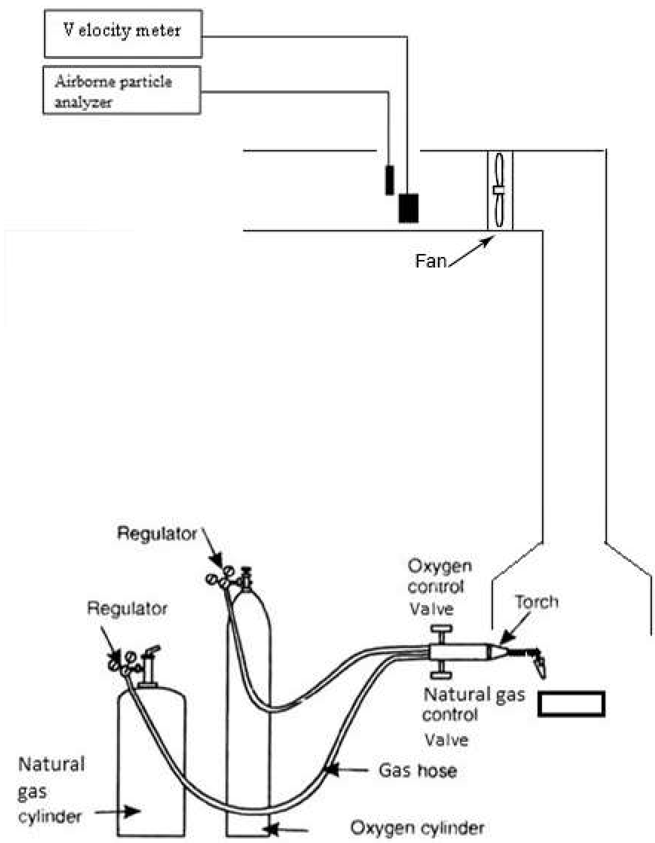

Fig. 1. Schematic of an experimental pilot to determine the emission factors of nitrogen oxide and VOCs in oxy fuel welding

(which is the greater volume of butane) is about 30%. Also, given that the volumetric flow rate of gas was1.1 × m^3/s, the required density of the sum two gases were obtained which were calculated in 1.67 kg/m^3. It should be noted that in order to calculate the mass of gas, the volume of discharge gas was multiplied by a total density of 1,837 kg/s and the velocity of gases in the chimney was around 5/8 m/s during the experiments. The results showed that while working with the oxy-fuel device, the nitrogen oxides concentration was 2.88 mg/m^3. The results illustrated that the emission rate of nitrogen oxides in the presence of pure oxygen in oxy fuel welding was 1.18013 mg/s. It was found that the emission factor of nitrogen oxides in the jewelry making workshops was 0.64 kg/kg consumed natural gas. Since pure oxygen is used for natural gas burning, the concentration of VOCs during experiments was zero. This meant that almost all natural gas was burned in oxy fuel welding. Therefore, there was no significant VOCs emission in jewelry making workshops. The European Environmental Agency (EEA) introduced some emission factors to estimate the emission rate of pollutants during natural gas combustion. Based on EEA, the emission factors for nitrogen oxides and VOCs during natural gas combustion are 0.1 and 2.96 g/kg consumed natural gas, respectively [7]. It is clear that the introduced emission factor for nitrogen oxide by the EEA is much lower than that described in this study. Nitrogen oxides are generally produced from the reaction between oxygen and nitrogen during fuels combustion in air [14]. The rate of produced nitrogen oxides increased at high temperatures, such as occurs in oxy fuel welding [15]. Since in oxy fuel welding a very high temperature is produced by using pure oxygen to combust natural gas, the amount of produced nitrogen oxides is three times higher than from the combustion of natural gas in the presence of air. Also, in the presence of pure oxygen almost all natural gas is combusted; therefore, the amount of emitted VOCs is insignificant. The interviews with managers of some of the workshops revealed that the average of consumed natural gas in each month is approximately 22 kg. The calculations showed that each jewelry making workshop emits nearly 14.08 kg nitrogen oxide per year. Since approximately 480 active jewelry workshops were operating in Isfahan in 2018, This means that the amount of the nitrogen oxide monthly and annually produced by these workshops in the city of Isfahan is approximately 6758.4 kilograms and 81100.8 kilograms respectively which are emitted in the atmosphere.

It was reported that the monthly averages of nitrogen oxides concentration between 2008 and 2009 in Isfahan were 67.6 to 202 ppb [16]. The US EPA has set a one-hour NO_2 standard of 100 ppb for ambient air. US EPA has also retained the annual average NO_2 standard of 53 ppb [17]. The first step to control nitrogen oxide emission is legislation of stringent nitrogen oxide emissions regulations [18]. Then, an emission inventory of nitrogen oxides should be prepared to find the major sources of this pollutant in cities. Next, new technologies should be implemented to reduce the nitrogen oxides emissions from the recognized major sources [18]. At the present time, there is no comprehensive information to support a nitrogen oxides emission inventory in Isfahan. It was reported that the amount of nitrogen oxides emitted from 9868 Isfahan taxies is approximately 25700 kg/year [19]. This report showed that the nitrogen oxides emitted by taxis is 2.4 times less than that from Isfahan's jewelry making workshops. Therefore, the jewelry making workshops may be introduced as one of the major nitrogen oxides sources for this city.

Conclusion

In this study, emission factors of nitrogen oxide and VOCs for jewelry making workshops are introduced. The emission factor of nitrogen oxides for jewelry making workshops is determined to be equivalent to 0.64 kg/kg consumed natural gas. It is revealed that in 2018, 81100.8 kg nitrogen oxides were emitted from Isfahan's jewelry making workshops into the atmosphere. It is also revealed that jewelry making workshops do not have VOCs emission. It is recommended that the exact location of each jewelry making workshop in Isfahan be found in order to model the distribution of nitrogen oxide in Isfahan's atmosphere.

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Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Author contributions

It is certified that all of the authors have made the same contribution in the experiments and manuscript writing.

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In this study, the number of active units from the Gold Union and Jewelers in Isfahan was quoted and their written response was received by the study team via the letter No. 97.4082 dated 27 January 2019. This information was used for this study.

Ethical considerations

Authors are aware of, and have complied with, best practices in ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. The authors have adhered to the publication requirements that the submitted work is original and has not been published elsewhere in any language.

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