Evaluation of electrical energy consumption in UV/H₂O₂ advanced oxidation process for simultaneous removal of NO and SO₂

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ABSTRACT

The electrical energy consumption (EEC) in removal of NO by a UV/H₂O₂ oxidation process was introduced and related to removal efficiency of this gas. The absorption-reaction of NO was conducted in a bubble column reactor in the presence of SO₂. The variation in NO removal efficiency was investigated for various process parameters including NO and SO₂ inlet concentrations, initial concentration of H₂O₂ solution and gas flow rate. EEC values were obtained in these different conditions. The removal efficiency was increased from about 22% to 54.7% when H₂O₂ concentration increased from 0.1 to 1.5 M, while EEC decreased by about 70%. However, further increase in H₂O₂ concentration, from 1.5 to 2, had no significant effect on NO absorption and EEC. An increase in NO inlet concentration, from 200 to 500 ppm, decreased its removal efficiency by about 10%. However, EEC increased from 2.9 x 10⁻² to 3.9 x 10⁻² kWh/m³. Results also revealed that the presence of SO₂ had negative effect on NO removal percentage and EEC values. Some experiments were conducted to investigate the effect of H₂O₂ solution pH. The changing of pH of oxidation-absorption medium in the ranges between 3 to 10, had positive and negative effects on removal efficiency depending on pH value.

Keywords: Electrical energy consumption, NO removal, UV/H₂O₂
ous for equipment especially in gas phase operations [16]. The majority of scientific works are based on using \( \text{H}_2\text{O}_2 \) as oxidation reagent because it is known as a lower cost and environmental friendly oxidant [17]. The major operating cost for the ozone oxidation process is the cost of electricity for ozone generation and expensive ozonizers [18]. The energy consumed for ozone synthesis, using air as a feed, ranges from 22 to 33 kWh/kg \( \text{O}_3 \), including air handling and ozone contacting with water. The energy requirement for ozone production from pure oxygen is also in the range from 12 to 18 kWh/kg \( \text{O}_3 \). The cost of oxygen should be added. However, the electrolytic process for producing \( \text{H}_2\text{O}_2 \) consumes approximately 7.7 kWh per 1 kg of \( \text{H}_2\text{O}_2 \) produced [19]. Some complex agents such as \( \text{Fe}^{\text{III}}\text{EDTA} \), \( \text{Fe}^{\text{III}}(\text{CYS})_2 \), and \( \text{Co}^{\text{III}}(\text{en})_3 \); and sono-chemical oxidation have been used to improve the absorption rate of NO in solutions [6, 7, 16, 19-21]. The use of these chemicals and methods often involves high costs and technical problems. Other oxidation agents such as \( \text{NaClO}_2 \), \( \text{KMnO}_4 \), \( \text{Na}_2\text{S}_2\text{O}_8 \) are also capable of converting NO into higher oxidation states. However, due to the formation of toxic by-products such as \( \text{ClO}_2 \) or insoluble products such as \( \text{MnO}_2 \) and the high cost of reagents, these oxidants may be not suitable for large-scale industrial applications. In the other word, \( \text{H}_2\text{O}_2 \) is the most suitable oxidant that can be used practically for simultaneous removal of \( \text{SO}_2 \) and NO in terms of cost and environmental impact [5].

Although advanced oxidation processes (AOPs) such as UV/\( \text{H}_2\text{O}_2 \) are widely applied in wastewater treatment [22, 23], recent findings show that such processes are also could be suitable alternative to conventional methods in gas purification field. UV light/\( \text{H}_2\text{O}_2 \) [24, 25], persulfate/heat/light/ultrasound [14, 26] and UV/Fenton-like reactions [10] are some examples of the most studied AOPs for gas purification, especially simultaneous removal of NO and \( \text{SO}_2 \). The application of UV or Vacuum Ultraviolet (VUV) combined with other chemical compounds such as Peroxymonosulfate (PMS) and \( \text{KHSO}_5 \) has been also studied by some researchers [27, 28]. AOPs are based on producing an active strong oxidant species such as hydroxyl radicals which can simultaneously oxidize and remove gaseous pollutants. UV/\( \text{H}_2\text{O}_2 \) process can be used for simultaneous oxidation of \( \text{SO}_2 \) and NO into sulfuric and nitric acid, respectively. This is usually a safe and simple process with no secondary pollution generation. UV light is applied to excite \( \text{H}_2\text{O}_2 \) and produce strong hydroxyl radicals [3, 4, 11, 12, 21, 25, 29-31].

Applying AOPs in gas separation and purification is nearly a new subject. Photo-oxidation removal methods (e.g., AOP) have demonstrated good development prospects in the area of emission reduction of NOx and \( \text{SO}_2 \) from flue gas. However, more comprehensive research should be conducted to effective implementation of such processes as an alternative to conventional technologies in gas pollution control. Experimental and especially theoretical studies in this field are still in early stages of progress. The author's previous work is one the first researches on the theoretical aspects of UV/\( \text{H}_2\text{O}_2 \) AOP focusing on the mathematical modeling [32]. Liu et al. [3] also conducted a study on mass transfer-reaction kinetics of UV/\( \text{H}_2\text{O}_2/\text{NaOH} \) process for simultaneous removal of NO and \( \text{SO}_2 \). They developed a simple rate equation for NO absorption based on mass transfer-reaction parameters such as gas phase mass transfer coefficient.

There are very little researches focused on comparing the AOPs in terms of energy consumption or economic feasibility. Mahamuni et al. [33] studied different types of AOPs in the field of water/wastewater treatment from economic point of view with calculating operation, maintenance and capital cost and considering figure-of-merit (Electrical Energy per Order (EE/O)) as one of the operation cost components. In the field of gas purification AOPs the term of energy consumption should be described in different manner which is one the objects of this work. In the present study the influence of operation parameters on the nitric oxide absorption through a UV/\( \text{H}_2\text{O}_2 \) process in a bubble column reactor was investigated. The term of electrical energy consumption (EEC) in gas purification field was introduced for the first time. This term can be nearly equivalent to the term of figure-of-merit defined in water treatment processes. Calculation of the EEC, at least, is necessary to compare the AOP in the term of energy consumption cost. It also can provide the required information for scale-up and economic analysis for comparison with other technologies for gas purification. Therefore the introduction and definition of this term is valuable for the future research on AOP performance estimation in the field of gas separation.

2. Experimental Setup and Procedure

2.1. Experimental Setup

Fig. 1 shows experimental setup comprising a bubble column reactor, gas blending and gas analyzing system. The NO removal efficiency (or absorption rate) was investigated for various process parameters such as \( \text{H}_2\text{O}_2 \) initial concentration (0-2 molar), gas flow rate (450-750 mL/min), NO inlet concentration (200-500 ppm), \( \text{SO}_2 \) concentration (400-1,000 ppm) and solution pH (3-10).

![Fig. 1. Schematic of the experimental setup, 1-3: Gas cylinders, 4-6: Mass flow controllers, 7: Mixing manifold, 8: Bubble reactor, 9: Bubble maker, 10: UV lamp, 11: Liquid inlet, 12: Liquid discharge, 13-15: valves, 16: Gas analyzer.](image-url)
2.1.1. Gas blending system
To prepare simulated flue gas, three gas cylinders, three mass flow controllers (MFCs, Brooks Instrument), and a gas mixer were used. SO₂ (purity 99.5%) and NO gas cylinders (99.5%) supplied from FARAFAN Gas Company, Iran (Representative of Technical Gas, Dubai, United Arab Emirates) and N₂ gas cylinder purchased from DENA gas (Isfahan, Iran). The flow rates of SO₂ and NO were controlled by their MFCs and the desired concentrations were obtained by adding N₂ through the third flow controller. The maximum flow rates of MFCs were 2.5, 3, and 1,000 mL/min for SO₂, NO and N₂, respectively. Then the gases directed through pipelines into a mixing chamber to achieve complete mixing. All pipes, valves, regulators, and fittings were made up of SS-316 which was well compatible with the used gases.

2.1.2. Bubble column reactor with UV light source
The bubble column reactor was made of glass with a diameter of 5 cm and height of 25 cm equipped with a jacket heat exchanger to maintain the desired temperature (room temperature) through the experiments. An aquarium bubble maker served as bubble generator at the reactor bottom. The reactor was operated in semi-batch mode and the generated gas bubbles were continuously passed through a fixed-volume liquid bed. The radiation source was a mercury UV lamp (Philips, power 6 W, wavelength 254 nm) with quartz sleeve placed at the reactor center. This leads to a uniform light distribution within the small annular space.

2.1.3. Gas analyzing system
Before entering the reactor, to ensure the desired composition, the simulated flue gas was passed through a sampling line (valve 13) embedded to gas analyzing chamber and was analyzed by a gas analyzer. Then the valve 13 was closed. The concentrations of gaseous pollutants at the reactor outlet were also measured using the gas analyzer by opening the valve 14. This valve was opened during the experiment runs to continuously measure the outlet concentration of SO₂ and NO. The analyzer was a TESTO 350 XL gas analyzer (Germany) with the specifications summarized in Table S1 (See supplementary data).

2.2. Experimental Procedure
The absorption-reaction environment was a H₂O₂ solution. In each experiment, depending on the required H₂O₂ concentrations, 300 mL of solution were prepared with double-distilled water and a 30 wt % H₂O₂ solution (Merck). To investigate the effect of initial pH of reaction environment, in some experiment, the initial pH of solution was adjusted by adding a NaOH solution (0.5 M). In all experiments, the solution pH before and after the tests was measured by a pH meter (Model SL. 901, Sana, Iran, accuracy ± 0.01). Initial pH was held at 3.2 (2 molar H₂O₂ solution), except for experiments performed at different H₂O₂ concentrations. The flow rates for each gas were adjusted based on maximum allowable MFCs flow rates and desired gas concentrations. After solution temperature became stable, the simulated flue gas entered into the reactor by opening the valve 15 and the absorption process started with turning on the UV lamp. Each run lasted 1,800 s, the valve 14 also was opened and the outlet concentrations of gaseous pollutants were recorded and the outlet concentrations of NO, respectively. All concentrations are in ppm.

2.3. Results and Discussion
The results were presented based on the absorption rate or removal efficiency at different experimental conditions in the following sections. The SO₂ removal efficiency was nearly complete. Therefore, the results are not shown here.

3.1. Effect of H₂O₂ Initial Concentration on Removal Efficiency and EEC Values
The results shown in Fig. 2 and Table 1, reveal that this parameter has a significant impact on NO absorption-oxidation reaction during the UV/H₂O₂ AOP. The removal efficiency and absorption rate increase when H₂O₂ concentration increases from 0.1 to 1.5 mol/L. However, a further increase in H₂O₂ concentration, from 1.5 to 2 mol/L, has no considerable effect on NO removal efficiency and its absorption rate. H₂O₂ can directly react with NO based on Eq. (2) and oxidize this gas to HNO₃. Furthermore, according to Eq. (3), H₂O₂ is the key agent of photochemical reaction. Under constant UV light radiation, an increase in H₂O₂ concentration can enhance the photolysis reaction yield and also promote the rate of direct oxidation of NO with OH radicals based on Eq. (4). Therefore, NO absorption increases from 0.73 × 10⁻⁴ to 1.82 × 10⁻⁴ when H₂O₂ concentration increases from 0.1 to 1.5 M. According to Eq. (1), the removal percentage also increases because of a decrease in NO outlet concentration. However, further increases in H₂O₂ concentration may lead to some side reactions and producing OH scavengers (see Eq. (5) to (8)) finally reducing NO absorption and removal efficiency [4, 20, 29, 31, 34].

\[
2NO + 3H₂O₂ → 2H^+ + 2NO₃⁻ + 2H₂O \tag{2}
\]

\[
H₂O₂ → \text{uv-light} → 2\cdot OH \tag{3}
\]

\[
\begin{align}
NO + \cdot OH & → NO₂⁺ + H^+ \quad k_1 = 5.5 \times 10^{14} \text{ M}^{-1} \text{s}^{-1} \tag{4}

\end{align}
\]

\[
\begin{align}
H₂O₂ + OH & → H₂O + HO₂ \quad k_3 = 2.7 \times 10^{7} \text{ M}^{-1} \text{s}^{-1} \tag{5}

\end{align}
\]

\[
\begin{align}
OH + HO₂ & → H₂O₂ \quad k_4 = 5.5 \times 10^{9} \text{ M}^{-1} \text{s}^{-1} \tag{6}

\end{align}
\]

\[
\begin{align}
OH + O₂ & → H₂O + O₂ \quad k_5 = 6.6 \times 10^{9} \text{ M}^{-1} \text{s}^{-1} \tag{7}

\end{align}
\]

\[
\begin{align}
HO₂ + HO₂ & → H₂O₂ + O₂ \quad k_6 = 8.3 \times 10^{8} \text{ M}^{-1} \text{s}^{-1} \tag{8}

\end{align}
\]

\[\eta = \frac{C_{NO,in} - C_{NO,out}}{C_{NO,in}} \tag{1}\]

where, \(\eta\) is final removal efficiency, \(C_{NO,in}\) and \(C_{NO,out}\) are inlet and final outlet concentrations of NO, respectively. All concentrations are in ppm.


Table 1. The Experimental Results for NO Absorption Rate at Different Conditions

| Parameter                           | NO absorption rate, \( R_{NO} \times 10^4 \) (mol/m³.s) |
|-------------------------------------|-----------------------------------------------------|
| \( \text{H}_2\text{O}_2 \) concentrations (mol/L) |                                                      |
| 0.1                                 | 0.73                                                |
| 0.5                                 | 0.78                                                |
| 1                                   | 1.07                                                |
| 1.5                                 | 1.82                                                |
| 2                                   | 2.1                                                 |
| \( \text{SO}_2 \) initial concentrations (ppm) |                                                      |
| 0                                   | 2.33                                                |
| 400                                 | 2.11                                                |
| 1,000                               | 1.48                                                |
| NO initial concentrations (ppm)      |                                                      |
| 200                                 | 1.44                                                |
| 250                                 | 1.75                                                |
| 500                                 | 2.84                                                |
| Gas flow rate (mL/min)              |                                                      |
| 450                                 | 1.56                                                |
| 550                                 | 1.84                                                |
| 750                                 | 2.2                                                 |
| Solution pH                         |                                                      |
| 6                                   | 1.14                                                |
| 7                                   | 1.32                                                |
| 10                                  | 3.03                                                |

\(^1\) It should be mentioned that experiments were conducted at \( \text{SO}_2 \) initial concentration = 800 ppm, NO initial concentration = 300 ppm, \( Q_g \) = 650 mL/min, and \( \text{H}_2\text{O}_2 \) = 2 M, except for cases where a parameter was changed based on first column.

\[
EEC = \frac{Pr_b}{v \log \left( \frac{C_0}{C} \right)} = \frac{Pr}{v \log \left( \frac{1}{1-\eta} \right)} \tag{9}
\]

where, \( EEC \) is electrical power consumption (kWh/m³), \( P \) is UV lamp power (W), and \( v \) is liquid volume (m³). \( C_0 \) and \( C \) are inlet and outlet concentration of NO (ppm), respectively. Average gas bubbles residence time can be calculated from gas hold-up \( (\varepsilon_g) \) and gas superficial velocity \( (u_g) \). Gas hold-up which is volume fraction of gas phase occupied by the gas bubbles can also be obtained from the increase in the height of the solution after gas injection. Therefore, Eq. (10) is used to calculate the gas hold-up [13, 35].

\[
\varepsilon_g = \frac{Z_b - Z_0}{Z_b} \tag{10}
\]

where, \( Z_0 \) and \( Z_b \) are liquid height in the reactor before gas injection and after expansion, respectively. Then, the average gas bubbles residence time is calculated by Eq. (11) [13, 35].

\[
t_b = \frac{\varepsilon_g Z_b}{u_g Q_g} \tag{11}
\]

where, \( u_g \) is superficial gas velocity (cm/s) calculated from total gas flow rate and reactor surface area. \( V_g \) (cm³) and \( Q_g \) (cm³/s) are the gas hold-up volume and gas flow rate, respectively. The values of the parameters used to calculate EEC are presented in Table 2.

As can be seen from Fig. 2, when \( \text{H}_2\text{O}_2 \) concentration increases from 0.1 to 1.5 M, the EEC decreases from 12.2 × 10⁻² to 3.8 × 10⁻² kWh/m³. As mentioned, \( \text{H}_2\text{O}_2 \) concentration directly affects photolysis reaction and amount of OH radical produced. Therefore, at a constant UV lamp power, an increase in \( \text{H}_2\text{O}_2 \) concentration means higher removal efficiency and consequently the lower EEC. However, further increase in \( \text{H}_2\text{O}_2 \) concentration has no considerable effect on NO removal percentage and EEC value as explained before. In other words, there is a maximum amount of \( \text{H}_2\text{O}_2 \) where the removal efficiency not affected by \( \text{H}_2\text{O}_2 \) concentration. Therefore the energy consumption term is not improved with an increase in \( \text{H}_2\text{O}_2 \) concentration.
3.2. Effect of Gas Flow Rate on NO Removal Efficiency and EEC Values

As can be seen from Fig. 3, NO removal efficiency is decreased from 67% to about 52% when gas flow rate increases from 450 to 750 mL/min. The results are consistent with those of obtained by other research which their finding confirm the decreasing trend for NO removal efficiency [11, 12, 24]. Fig. 3 also reveals that, the values of EEC are higher at higher flow rates and EEC increases by about 20% when gas flow rate increases from 450 mL/min to 750 mL/min. According to data from Table 2, as gas flow rate increases the gas-liquid contact time decreases which leads to higher NO outlet concentrations and consequently lower removal efficiencies. However, it should be mention that the NO absorption rate increases from $1.56 \times 10^{-4}$ to $2.2 \times 10^{-4}$ (see Table 1) because the gas phase mass transfer coefficient increases with gas flow rate as shown in Table 2. The volumetric gas phase mass transfer coefficients are calculated from experimental data of SO2 absorption (inlet concentration = 700 ppm) in NaOH solution (0.1 M) at different flow rates and then converted to mass transfer coefficient for NO gas, according to Wang et al. [36]. However, because of the effect of flow rate on removal efficiency which is appeared in Eq. (9), the energy consumption increases. Therefore, increasing the gas flow rate is not desirable from economic point of view and process efficiency.

3.3. Competitive Absorption of NO in Presence of SO2: The Effect on Removal Efficiency and EEC Values

SO2 solubility in aqueous solutions is larger than that of NO and can more quickly reach reaction zone and competes with NO in consuming OH radicals or H2O2 according to Eq. (12)-(13) [3, 4, 20, 29, 37]. As data in Fig. 4 and Table 2 show, the NO removal efficiency and absorption rate decrease when SO2 concentration increases from 0 to 1,000 ppm. In addition to SO2 high solubility, according to the Liu et al. [37] the hydrolysis reactions of SO2, based on Eq. (14) and (15), can lead to an increase in its absorption compared with that of NO. Also, according to the Eq. (16)-(19) the hydrolysis products of SO2, including HSO3− and SO32−, can also be further oxidized and reacted by OH free radicals and H2O2, leading to a further increase in the SO2 absorption rate compared to that of NO [3, 4, 20, 29, 37].

$$SO_2 + * OH \rightarrow SO_3 + H$$  

$$SO_3 + H_2O_2 \rightarrow H_2SO_4$$  

$$SO_2 + H_2O \leftrightarrow HSO_3 + H^+$$  

$$HSO_3 \leftrightarrow SO_3^- + H^+$$  

$$HSO_3^- + NH \rightarrow SO_3^- + H_2O$$  

$$SO_3^- + * OH \rightarrow SO_3^- + OH^+$$  

$$HSO_3^- + H_2O_2 \rightarrow SO_3^- + H^+ + H_2O$$  

$$SO_3^- + H_2O_2 \rightarrow SO_3^- + H_2O$$

Fig. 4 also confirms the competing effect of the presence of SO2 on NO. With increasing SO2 inlet concentration and decreasing the removal percentage, the EEC significantly increases. As SO2 inlet concentration increases, the removal efficiency and absorption rate of NO decreases because of the competing role of...
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3.4. Effect of NO Inlet Concentration on Its Removal Efficiency and EEC Values

According to the data shown in Table 1, the NO absorption rate increases from $1.44 \times 10^{-4}$ to $2.84 \times 10^{-4}$ when NO concentration increases from 200 to 500 ppm. The absorption rate enhances because NO partial pressure in gas phase increases. This leads to an increase in NO mass transfer driving force and promotes the absorption rate of this gas. However, as can be seen from Fig. 5, the removal efficiency decreases from 65% to approximately 51%. Fig. 5 also depicts that the electrical energy increases with NO inlet concentration and reach $4 \times 10^{-2}$ kWh/m³. Because of the low solubility of NO in aqueous H₂O₂ solution, its absorption is affected by its solubility in liquid phase. The NO solubility parameter is nearly $1.82 \times 10^{-8}$ mol/L Pa in water [3]. The NO outlet concentration becomes higher when its inlet concentration increases. Similar results were reported by other researchers such as Liu et al. [11] and Liu et al. [24]. This has negative effect on removal efficiency and EEC.

3.5. Effect of Solution pH on NO Removal Efficiency

To investigate the effect of pH of oxidation medium on NO removal efficiency, some experiments were performed by preparing H₂O₂ solutions with different pH by adding NaOH solution (0.5 M). As Fig. 6(a) shows, an increase in solution pH from 3.2 (2 molar H₂O₂) to about 6, leads to a significant decrease in removal efficiency. However, with an increase in pH from 7 to 10, removal efficiency reaches to 91%. The effect of oxidation solution pH can be explained from two perspectives. First, an increase in solution pH intensify H₂O₂ hydrolysis reaction and produce the •OH free radical scavenger species such as HO₂⁻ consuming OH free radicals and H₂O₂ and therefore reducing NO removal efficiency [20, 22, 23]. The related reactions are as follows. Furthermore, according to Eq. (23), under this condition H₂O₂ may decompose to water and oxygen rather than hydroxyl radical. Therefore, the lower removal percentage in this pH range is due to reduction of hydroxyl radical concentration [23].

$$H_2O_2 \leftrightarrow HO_2^- + H^+ \tag{20}$$

$$\cdot OH + HO_2^- \rightarrow OH^- + \cdot HO_2 \tag{21}$$

$$H_2O_2 + HO_2^- \rightarrow O_2 + H_2O + OH^- \tag{22}$$

$$2H_2O_2 \rightarrow 2H_2O + O_2 \tag{23}$$

Fig. 4. Effect of SO₂ inlet concentration on NO final removal efficiency and EEC value, NO inlet concentration: 300 ppm, H₂O₂ initial concentration = 2 mol/L, total gas flow rate = 650 mL/min.

SO₂ in consuming produced OH radicals or the direct oxidation with H₂O₂. This effect becomes more intense at higher SO₂ concentrations. In fact, at the presence of SO₂ the more electrical power is required to produce enough OH radicals and limit the competitive effect as much as possible.

Fig. 5. Effect of NO initial concentration on NO removal efficiency and EEC value, H₂O₂ initial concentration = 2 mol/L, total gas flow rate = 650 mL/min, SO₂ inlet concentration = 800 ppm.

Fig. 6. (a) Effect of solution pH on NO removal efficiency, (b) Comparison between different reaction medium in NO removal efficiency.
On the other hand, further increase in pH from 7 to 10, leads to production of more hydroxyl ions consuming H+ ions and promotes NO absorption by the reaction with •OH free radicals or direct oxidation with H2O2 as described by Eq. [2] and [4] [4, 20, 29].

3.6. Comparison between Different Oxidation-reaction Mediums

In order to compare the effect of oxidation solution on removal efficiency, some experiments were conducted by adding NaOH (0.5 M solution) into the H2O2 solution. The experimental results shown as a histogram in Fig. 6(b), are related to different oxidation mediums. The removal efficiency of NO in pure water solution is about 2% (not shown in Fig. 6) due to the very low solubility of NO in water. However, the removal efficiency reached about 10%, in reaction medium including H2O and UV light, which can contribute to the effect of UV source. Although, using H2O2 or H2O2/NaOH (pH = 10) without UV light can enhance NO removal efficiency in comparison with H2O, but the presence of UV source significantly promotes NO absorption process. The NO removal efficiency is approximately 90% for UV/H2O2/NaOH (0.5 M) reaction system at pH = 10.

A cooperative factor between UV light and oxidant solution is defined as Eq. (24) and (25) [37]:

\[
\varepsilon_1 = \frac{\eta_{UV-H_2O_2}}{\eta_{UV-H_2O} + \eta_{H_2O}} = 1.2
\]

\[
\varepsilon_2 = \frac{\eta_{UV-H_2O_2-NaOH}}{\eta_{UV-H_2O} + \eta_{H_2O_2-NaOH}} = 1.8
\]

The results presented in Fig. 6(b) are used to calculate the values of ε1 and ε2. The values of 1.2 and 1.8 are obtained for H2O2/UV and H2O2/NaOH (0.5 M)/UV (pH = 10), respectively. The additive factors are lower than that of obtained by Liu et al. [37] because the lower power of UV lamp used in this study. However, these values confirm the positive effect of applying UV light source in enhancing the performance of oxidant solutions in an AOP process for simultaneous removal of NO and SO2. The H2O2 photolysis under UV irradiation and producing OH radicals with strong oxidation ability in comparison with H2O2 results in more NO absorption capacity for H2O2 solution. Because of the positive effect of NaOH (at pH = 10) on NO absorption, the cooperative factor between UV lamp and H2O2 solution enhances in the presence of NaOH. The result is in consistency with that of obtained in section 3.5 for pH of oxidation medium. By adding NaOH into H2O2 solution and adjusting pH of solution into 10, the NO removal efficiency improved.

4. Conclusions

The performance of a UV/H2O2 AOP in removing gases pollutant, including NO and SO2, was experimentally investigated to relate EEC values to NO removal efficiency. The variations in NO removal efficiencies in different NO, SO2 and H2O2 inlet concentrations are analyzed and EEC term was obtained. The results indicated that the presence of SO2 has negative effect on NO removal efficiency and EEC values. An increase in NO inlet concentration and gas flow rate decreased NO removal percentage. However, EEC values increased. The result of experiments which performed to investigate the effect of oxidation medium pH, also revealed that pH had different positive and negative effects depending on its value. Adding NaOH into oxidation medium caused an increase in removal efficiency.

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