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## DETERMINATION OF THE EFFICIENCY OF WASTE GAS WASHING EQUIPMENTS USED IN JEWELERY WORKSHOP

*Edip AVŞAR*<sup>\*</sup>  
*Asude HANEDAR*<sup>\*\*</sup>  
*Kadir ALP*<sup>\*\*\*</sup>  
*İsmail TORÖZ*<sup>\*\*\*</sup>

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**Abstract:** During the processes where acid and cyanide are used in jewelery workshops, waste gases originates that hazardous in terms of human and environmental health and material. It is necessary to control these originated gas flows with suitable methods and equipment in the workshop and convert them to non-hazardous forms. For this purpose, waste gas washing equipment which can be used by various producers in jewelery workshops are produced. In this study, waste gas stream hazardous emissions removal efficiency of a system produced for this purpose was examined and the measures to be taken for the continuous efficiency were mentioned. According to results; it has been determined that the nitric acid emissions and the sulfuric acid emissions originated from the iron / copper solvation process are reduced by 94.5% and 88.3%, respectively, by means of waste gas washing system. It has been determined that cyanide emissions are reduced by 98.7% by washing the waste gases from the bombing process by means of washing system. According to results, treated toxic gaseous emission concentrations were below the limit.

values of Turkish Industrial Air Pollution Control Regulation (TIAPCR) and Netherlands Emission Guidelines for Air (NER).

**Keywords:** Jewelery, Iron copper solvation, Bombing, Gas washing

### Kuyum Atölyelerinde Kullanılan Atıkgaz Yıkama Ekipmanlarının Verimliliklerinin Belirlenmesi

**Öz:** Kuyum atölyelerinde asit ve siyanür kullanılan işlemler esnasında, insan ve çevre sağlığı ile malzeme üzerinde zararlı olacak nitelikte atık gazlar ortaya çıkmaktadır. Oluşan bu atık gaz akımlarının, oluştuğu atölye içinde uygun yöntem ve ekipmanlarla kontrol edilmesi ve zararsız hale getirilmesi gerekmektedir. Bu amaçla çeşitli üreticiler tarafından kuyum atölyelerinde kullanılabilecek atık gaz yıkama ekipmanları üretilmektedir. Yapılan çalışmada bu amaçla üretilmiş bir sistemin atık gaz akımı içerisindeki zararlı emisyonları giderme verimi incelenmiş ve verimin sürekliliğinin sağlanması için alınması gereken önlemler belirtilmiştir. Elde edilen sonuçlar incelendiğinde; kullanılan atık gaz yıkama sistemi sayesinde demir/bakır indirme işleminden kaynaklanan nitrik asit emisyonlarının %94,5, sülfürik asit emisyonlarının ise %88,3 oranında giderildiği belirlenmiştir. Patlatma işleminden kaynaklanan atık gazların yıkama sisteminde yıkanması ile siyanür emisyonunun ise %98,7 oranında giderildiği tespit

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\* Bitlis Eren University, Engineering and Architecture Faculty, Environmental Engineering Department.13000. Center, Bitlis

\*\* Namık Kemal University, Çorlu Engineering Faculty, Environmental Engineering Department.59860, Tekirdağ

\*\*\* İstanbul Technical University, Civil Faculty, Environmental Engineering Department.34469. Maslak, İstanbul

CorrespondAuthor: Edip Avşar (edipavsar@hotmail.com)

edilmiştir. Elde edilen sonuçlara göre arıtılmış toksik gaz emisyonları; Sanayi Kaynaklı Hava Kirliliğinin Kontrolü Yönetmeliği ve Hollanda Hava Emisyon Klavuzu'nda verilen limit değerlerin altında kalmıştır.

**Anahtar Kelimeler:** Kuyum, Demir bakır indirme, Patlatma, Gaz yıkama

## 1. INTRODUCTION

Gold is an element present in the periodic table. The symbol is Au, which is the abbreviation of Aurum in Latin. Atom number of gold is 79. Gold does not react with most chemicals, but it interacts with chlorine, fluoride, royal water and cyanide and is soluble in mercury. In particular, nitric acid dissolves many metals but gold does not dissolve in nitric acid. Because of this property, nitric acid has been used for a long time to confirm the presence of gold in materials (Zhang et. al., 1995, Müezzinoğlu, 2003, Kaspın, 2013, Klotz, 2010).

The annual use of gold which is a valuable metal, is around 25,000 tons per year. Jewellery production is the most important use of gold with an 80% share. This is followed by industrial use with 12% and other uses with 8% (Corti, 2002, Corti, 2004, Yue et. al., 2017).

When the industrial use of gold is examined, it is seen that the most use is in the electronics sector, followed by dentistry and other industrial and decorative uses. Due to the chemical and physical properties of gold, such as corrosion resistance, industrial importance is increasing day by day (Corti, 2004).

When the processes applied and the chemicals used in processing the metals are considered from the environmental point of view, metal finishing processes are known as one of the most important causes of environmental pollution. Because of this feature, the sector is monitored worldwide and subject to legal regulations. Therefore, the commercial risks and operating costs of the industry are high. While this impacts on the reduction of environmental pollutants, firms also face a difficult problem of finding effective and cost-effective solutions (Giannetti et. al., 2008, Thammaraksa et. al. 2017).

Jewellery is one of the world's oldest manufacturing processes and contains many harmful operations. Today, harmful chemicals used in jewellery production are the most important problem in the industry. These chemicals are; cyanides, acids, solvents, compressed gases, powder of materials, polishing compounds and solders (Müezzinoğlu, 2003, [https://www.dtsc.ca.gov/.../Jewelry/.../HWM\\_FS\\_Jewelry\\_P2\\_Recommendations.pdf](https://www.dtsc.ca.gov/.../Jewelry/.../HWM_FS_Jewelry_P2_Recommendations.pdf)).

Free cyanide (HCN or CN<sup>-</sup>) emissions are important problem in terms of gold processing. It is a respiratory poison and has high acute toxicity. The dose-effect curve of the acute effects in humans is steep by step. 120–150 mg/m<sup>3</sup> is dangerous to life and may lead to death after 0.5–1 h, and 300 mg/m<sup>3</sup> is immediately fatal (<http://www.who.int/ipcs/publications/cicad/en/cicad61.pdf>).

Sulphuric acid and nitric acid mists are another problem originated from gold processing. Sulfuric acid is a highly corrosive and irritating. It cause direct local effects on the skin eyes, and respiratory and gastrointestinal tracts when there is direct exposure to sufficient concentrations. Breathing sulfuric acid mists can result in tooth erosion and respiratory tract irritation. US Occupational Safety and Health Administration (OSHA) limits the amount of sulfuric acid that can be present in workroom air to 1 mg/m<sup>3</sup>. The National Institute for Occupational Safety and Health (NIOSH) also recommends a time-weighted average limit of 1 mg/m<sup>3</sup> (<https://www.atsdr.cdc.gov/ToxProfiles/tp117-c1-b.pdf>).

The toxicity of HNO<sub>3</sub> is predominately associated with the extremely corrosive nature of this strong acid. In addition, it is an excellent oxidizing agent and reacts immediately with any tissue to cause such effects as skin burns, eye irritation, coughing, dyspnea, and pulmonary edema. inhalation exposure limits for HNO<sub>3</sub>. US Association Advancing Occupational and Environmental Health (ACGIH) set the Threshold Limit Value (TLV) time-weighted average (TWA) for HNO<sub>3</sub> at 2 ppm (5.16 mg/m<sup>3</sup> at 25 °C) The TLV-short-term exposure limit is twice the TLV-TWA value (<https://www.ncbi.nlm.nih.gov/books/NBK230439/>).

In the cyanide/peroxide bombing process, a significant amount of gold is often lost as a valuable end product because of the dissolution of gold in the bombing chemical. In this context, electrostripping systems with potassium or sodium can be preferred due to the fact that it is environmentally safer than the cyanide system. However, if the operator cannot provide good control of this process, there may be intense corrosion on the surface of the jewel ([https://www.dtsc.ca.gov/.../Jewelry/.../HWM\\_FS\\_Jewelry\\_P2\\_Recommendations.pdf](https://www.dtsc.ca.gov/.../Jewelry/.../HWM_FS_Jewelry_P2_Recommendations.pdf)).

For safety in bombing with cyanide, the use of water-diluted 4% cyanide solution is recommended. It is important that the acids do not interfere with cyanide in the process, and if the acids mistakenly mix with cyanide, cyanide gas, which causes sudden deaths, appears. In the closed bombing system with cyanide, jewel fragments can be cleaned with minimal human interaction, the cyanide solution can be rendered harmless, and dissolved precious metals can be recovered from the waste (Yannopoulos, 1991, [https://www.dtsc.ca.gov/.../Jewelry/.../HWM\\_FS\\_Jewelry\\_P2\\_Recommendations.pdf](https://www.dtsc.ca.gov/.../Jewelry/.../HWM_FS_Jewelry_P2_Recommendations.pdf)).

Nitrogen dioxide (NO<sub>2</sub>) from the recovery process of gold also causes significant air pollution. This key problem is related to the quality control process of all recovery methods performed in small scale enterprises (Kaspın, 2013).

Significant use of acid and cyanide are present in the processes applied in jewelry and ramming shops. The acidic and cyanide wastes generated from these processes cause damage to the material as well as human health and environment. These cyanide and sulphuric acid mists are defined as inorganic vapors and gaseous substances Class II and nitrogen oxides (NO<sub>x</sub>) and sulphure oxides (SO<sub>x</sub>) are defined as inorganic gaseous substances Class IV according to Turkish Industrial Air Pollution Control Regulation (TIAPCR) Annex 7 ([http://sgb.csb.gov.tr/mevzuat/dosyalar/r\\_20130929233746779\\_7ef68822-c2b0-41fc-b125-916a43b480a2.pdf](http://sgb.csb.gov.tr/mevzuat/dosyalar/r_20130929233746779_7ef68822-c2b0-41fc-b125-916a43b480a2.pdf)). Emission levels and limitations can be significant depending on the operation size ([http://eippcb.jrc.ec.europa.eu/reference/BREF/stm\\_bref\\_0806.pdf](http://eippcb.jrc.ec.europa.eu/reference/BREF/stm_bref_0806.pdf)). Limit values of emissions are tabulated in Table 1 below. In terms of European Union same limitations with the TIAPCR can be seen in the Netherlands Emission Guidelines for Air (NER), Section 3.2.4. Emission standards for inorganic substances ([www.infomil.nl/publish/pages/63235/lvoc-annexviii.pdf](http://www.infomil.nl/publish/pages/63235/lvoc-annexviii.pdf)).

**Table 1. inorganic vapors and gaseous substances and their limit values <  
[http://sgb.csb.gov.tr/mevzuat/dosyalar/r\\_20130929233746779\\_7ef68822-c2b0-41fc-b125-916a43b480a2.pdf](http://sgb.csb.gov.tr/mevzuat/dosyalar/r_20130929233746779_7ef68822-c2b0-41fc-b125-916a43b480a2.pdf) , [www.infomil.nl/publish/pages/63235/lvoc-annexviii.pdf](http://www.infomil.nl/publish/pages/63235/lvoc-annexviii.pdf) >**

| Contaminant                                      | Class | Limit Value   |
|--|-------|---|
| Sulphuric acid (H <sub>2</sub> SO <sub>4</sub> ) | II    | 5 mg/Nm <sup>3</sup> (for emission flows higher than 50 g/hour)   |
| Hydrogen cyanide (HCN)                           |       |   |
| NO <sub>x</sub> (calculated as NO <sub>2</sub> ) | IV    | 200 mg/Nm <sup>3</sup> (for emission flows higher than 5 kg/hour) |
| SO <sub>x</sub> (calculated as SO <sub>2</sub> ) |       |   |

In places such as industrial sites, it is inevitable that these gas flows will be adversely affected if they are given to the ventilation systems which are open to the use of other businesses. For this reason, these waste gas flows must be controlled and rendered harmless in the workshop with suitable treatment methods and equipment. For this purpose, waste gas washing equipment which can be used by various producers in jewelry workshops are produced.

In gold processing, possible waste management routes include new production methods like selective ion exchange with subsequent refining of gold. But classical methods described above and precipitation of the air contaminants via waste gas washing equipment is more common in the industry. Also gas washing systems are preferred in terms of easy and low cost operation ([http://eippcb.jrc.ec.europa.eu/reference/BREF/stm\\_bref\\_0806.pdf](http://eippcb.jrc.ec.europa.eu/reference/BREF/stm_bref_0806.pdf)).

In this study, the efficiency of removing the harmful emissions in the waste gas stream of two different systems manufactured by Permaksan Machine / İstanbul firm have been investigated. In the first phase of the study, removal efficiency of the acid mists originated from nitric and sulfuric acid used in the iron copper solvation process were investigated by means of PRM001 Iron / copper solvation and waste gas washing equipment. In the second phase of the study, removal efficiency of the cyanide emissions in the waste gas resulting from the treatment of gold with cyanide was investigated by means of PRM002 bombing and waste gas washing equipment. In this context, pollutant parameters were measured in waste gas inlet and washed gas outlet streams of both devices and the removal efficiencies of the devices were determined and compared with literature and limit values given by Turkish Industrial Air Pollution Control Regulation Annex 7. Also the measures to be taken for the continuity of the removing efficiency of devices are given as conclusion.

## **2. MATERIALS AND METHODS**

### **2.1. Processes Applied in Researched Workshop and Environmental Precautions in Processes**

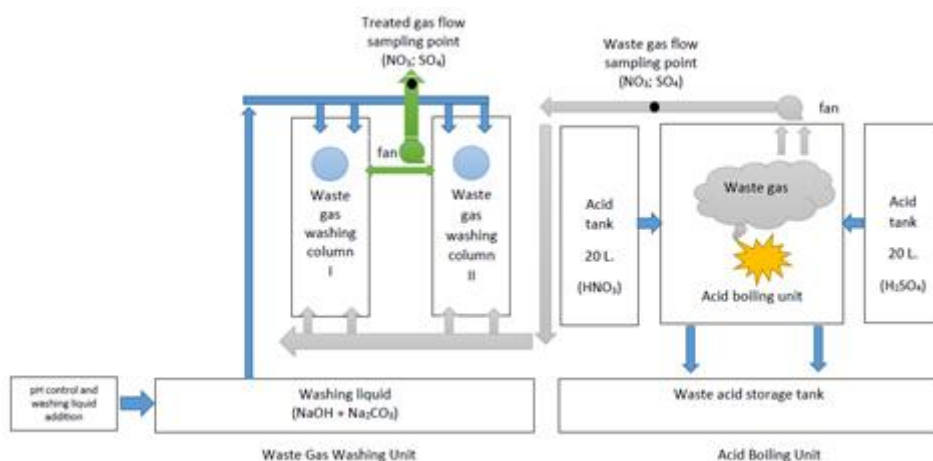
#### **2.1.1. Iron / Copper Solvation And Waste Gas Washing Equipment**

The process of iron and/or copper solvation in jewellery workshops is based on heating the materials which are covered with gold in different setting and contains iron or copper inside as well in the acid environment. Thus, iron or copper is absorbed into the solution, so that only the outer gold part of the materials are obtained and used to form ornamental products. In this process, nitric acid ( $\text{HNO}_3$ ) is used as an acid for solving copper, and sulfuric acid ( $\text{H}_2\text{SO}_4$ ) is used for iron solvation. In practice, 150 mL technical grade nitric acid is added to 1 liter of water for copper solvation, and an acid solution is prepared by using technical grade sulfuric acid at the same rate in iron solvation. In this way, the acid prepared in the desired volume with iron/copper solvation material in it is heated with electrical resistors to 80-90 °C without boiling ([https://www.dtsc.ca.gov/.../Jewelry/.../HWM\\_FS\\_Jewelry\\_P2\\_Recommendations.pdf](https://www.dtsc.ca.gov/.../Jewelry/.../HWM_FS_Jewelry_P2_Recommendations.pdf), <http://www.who.int/ipcs/publications/cicad/en/cicad61.pdf>, Alp et. al., 2007).

Solvation and waste gas washing process at the workshop where the test is performed have been done by the equipment named PRM 001 manufactured by Permaksan Machine/Istanbul. This equipment is made from polypropylene material and consists of two basic parts which are acid boiling unit and waste gas treatment unit. Acid boiling unit is a closed system that can be opened at the front, with a transparent cover, two 20 liters capacity acid tanks in the side and one washing tank in the middle. Diluted  $\text{HNO}_3$  and  $\text{H}_2\text{SO}_4$  solutions are obtained by adding 15 liters of water to 1.5 liters of acid in accordance with the above rates. In the process of iron solvation, about 5 kg of ferrous gold material can be processed with the acid mixture in the tank and 2.5 kg gold can be obtained. In other words, 2.5 kg of iron are dissolved. As a result of this operation, the acid solution in the tank is changed because of its strength loss. Off duty acids and washing waters are collected in a waste acid storage tank to which this unit is connected. The flow chart of the system is given in Figure 1. PRM 001 does not carry gold recovery from dross, which is carried out with acid mixture of HCl which is known as goldwater or royal water and  $\text{HNO}_3$  (Alp et. al., 2007).

Sulfur dioxide ( $\text{SO}_2$ ) gas and sulphate mists, which can be formed from sulfuric acid during the process; nitrogen monoxide (NO), nitrogen dioxide ( $\text{NO}_2$ ) gases, nitric acid vapor, and mists that can come from nitric acid are transferred to the waste gas treatment unit which is the second unit, through the fan. This unit consists of a 150 liters capacity tank with acidic gas washing solution (Caustic soda (NaOH)/ Sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) solution with pH = 13.8) at the bottom and two washing columns on it. Raschig rings are located inside the columns to increase the interaction of acid emissions with the washing solution by expanding the surface. With a

pump located between the two columns, the absorbing solution is sprayed from the tops of both columns and absorbed by acidic gases in the opposite direction, thereby removing the acidic components. Caustic soda solution, which completes the washing process in the columns, returns to the storage tank again. The pH of the washing solution can be continuously controlled by means of a pH meter located inside the tank. Accordingly, necessary alkali additions can be made. Acidic gases are brought to the washing columns which is in connected in series to the first acid boiling section through a polypropylene fan and washed. After this process, the gases are treated and emitted to the air through the waste gas stack (Alp et. al., 2007).



**Figure 1:**  
PRM001 system flow chart

### 2.1.2. PRM 002 Bombing and Waste Gas Washing Equipment

Bombing is the process of removing impurities on silver or gold material using potassium cyanide (KCN) and hydrogen peroxide ( $H_2O_2$ ). At this stage 30-60 g of potassium cyanide is dissolved in 30 liters of water to obtain cyanide solution. Hydrogen peroxide solution is prepared to 30-50 mL in 30 liters of water. Proper volumes are processed from cyanide and hydrogen peroxide solutions proportional to the amount of substance to be bombed. These quantities are related to the gold setting and surface size of the material to be bombed. Generally, 0.1 liter of hydrogen peroxide solution with 1 liter of cyanide solution is used for 0.5 kg of material with large surface. Reaction is stated below and is finished in a few minutes.



Accordingly, the concentrations are close to the stoichiometric ratios. Cyanide (HCN) gases which may be formed during the process are treated by being washed with an alkali solution ([https://www.dtsc.ca.gov/.../Jewelry/.../HWM\\_FS\\_Jewelry\\_P2\\_Recommendations.pdf](https://www.dtsc.ca.gov/.../Jewelry/.../HWM_FS_Jewelry_P2_Recommendations.pdf), <http://www.who.int/ipcs/publications/cicad/en/cicad61.pdf>, Alp et. al., 2007).

PRM 002 bombing and wastewater treatment equipment consists of two parts. In the bombing unit made of polypropylene material, there are cyanide and hydrogen peroxide solution storage tanks in the side; and in the middle, there is a bombing part covered with a transparent cover that opens and closes on the front side. Solution can be taken from the tanks in the desired volume and delivered to the bombing tank. The wastewater resulting from the bombing reaction is gathered in a collection tank located under this unit. At the top of the bombing tank there is a stack like connection for transporting the generated waste gas.

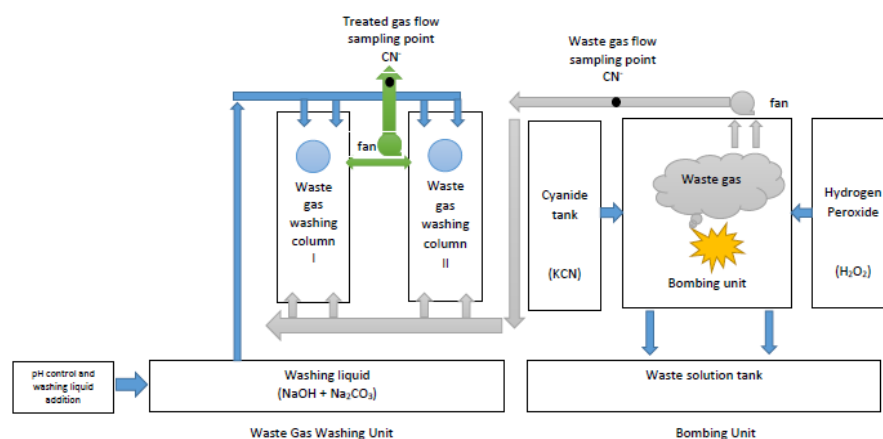
The second unit is the part where cyanide wastes are washed away. This part is also made from polypropylene material and is as described in PRM 001. Caustic or sodium carbonate solutions are also used in the washings in columns with raschig rings to increase the liquid / gas contact surface. The flow chart of the system is given in Figure 2 (Alp et. al., 2007).

## 2.2. Analysis/Measurement Methods Utilized in This Research

### 2.2.1. Process of Iron/Copper Solvation

At the jewellery workshop, the iron solvation waste gases mainly contain nitrogen compounds as well as sulphate mists. Nitrogen compounds include  $\text{NO}_x$  gases ( $\text{NO} + \text{NO}_2$ ) and nitric acid mists. Two different methods have been used to determine the refining efficiency of PRM 001 equipment:

- Firstly,  $\text{NO}_x$  gases were measured using the electrochemical cell method in the gas stream before and after treatment process.
- Secondly, gas is removed by means of an appropriate pump from the air stream containing acid gases before and after the treatment stage. Contaminants in the gas phase were absorbed by two interconnected gas absorbing bottles filled with 0.1 N sodium hydroxide solution. Then samples were analysed in the laboratory using standard analysis methods.



**Figure 2:**  
PRM002 system flow chart

### 2.2.2. Bombing Process

In order to determine the efficiency of the PRM 002 unit, cyanide gas resulting from the bombing process was sampled from the gas stream at two points. First point was the inlet to the treatment system and second point was the outlet of the treated gas. For this purpose; the gas stream drawn by the pump means was passed through two interconnected washing flasks with 0.1 N sodium hydroxide absorption solution and analysed in the laboratory using standard analytical methods (colorimetric method). Descriptions of the methods used in the measurements are given in Table 2 below.

**Table 2. Measurement methods used in waste gas washing equipment**

| Contaminant   | Measurement Methods   | Measurement Equipment                   | Measurement Range <sup>1</sup> or Detection Limit <sup>2</sup>                             | Reference            |
|---|---|---|--|----------------------|
| NO <sub>3</sub> and SO <sub>4</sub> in absorbing liquid                 | Absorption and ion chromatography (Standard Methods 4110)   | Ion chromatograph, (DIONEX ICS 1500)    | 2.7 µg/L for NO <sub>3</sub> <sup>-</sup> (2)<br>18 µg/L SO <sub>4</sub> <sup>2-</sup> (2) | (Eaton et. al. 2005) |
| Nitrogen oxides in the gas phase NO <sub>x</sub> (NO, NO <sub>2</sub> ) | Electrochemical cell method   | Flue Gas Analyzer (VISIT 01 LR)         | 0-4000 ppm <sup>(1)</sup>  | (EPA, 1995)          |
| CN <sup>-</sup> in absorbing liquid                                     | Absorption and wet chemistry (Chloramine T-Pyridine/ Barbituric acid colorimetric analyze method) | Spectrophotometer (Hach Dr2800)         | 20-2000 µg/L <sup>(1)</sup> (for 1cm cell)   | (Eaton et. al. 2005) |
| Waste gas velocity  | Pitot tube-inclined manometer method (differential pressure measurement)                          | Pitot tube-inclined manometer mechanism | -100-+100 hPa <sup>(1)</sup>   | (EPA, 1994)          |

### 3. RESULTS

#### 3.1 Measurements Made in PRM 001 Equipment Gas Phase

At the sampling points opened in the inlet and outlet pipes of the gas absorption device, waste gas velocities, gas temperature and flue gas flow rate were measured and given in Table 3.

Gas measurements were made according to the electrochemical cell method and the results are given in Table 4 below. In this context, the oxygen values in the waste gas have a saturation value of 21%, so the measured values are taken as they are.

**Table 3. Waste gas measurement results of Permaksan PRM 001 waste gas washing equipment**

| Sampling Location | Stack Diameter, m | Flue Gas Velocity, m/sec. | Flue Gas Temperature, °C | Flow Rate of Flue Gas, m <sup>3</sup> /hour | Flow Rate of Flue Gas, Nm <sup>3</sup> /hour |
|-------------------|-------------------|---------------------------|--------------------------|---|--|
| Input             | 0.15              | 4                         | 28.1                     | 254.5                                       | 231  |
| Output            | 0.15              | 4                         | 30.7                     | 254.5                                       | 229  |

**Table 4. Results of waste gas treatment efficiency tests in Permaksan PRM 001 waste gas washing equipment by electrochemical method**

| Contaminant     | Input, mg/Nm <sup>3</sup> | Output, mg/Nm <sup>3</sup> | Absorption Efficiency, % |
|-----------------|---------------------------|----------------------------|--------------------------|
| NO <sub>x</sub> | 29                        | 7                          | 75                       |
| SO <sub>2</sub> | 3                         | 0                          | 100                      |

### 3.2 Measurements Made with Absorption Mechanism

At the input and output of the device, the gas streams were separately adsorbed by passing them through an alkali solution (NaOH), and  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$  were measured in the obtained input and output absorption solutions. In the experiment, absorption was carried out using 250 mL of 0.1 N NaOH solution on two successive gas absorbing bottles. In this case, the total amount of absorption solution is 0.5 liters. These substances were also measured in the original solution as a blank used in the absorption to control. The value found is subtracted from the value found for the samples to avoid interferences. For each experiment, flow rates of the gases that passed through the gas absorption bottles were measured (Eaton et. al. 2005 ).

### 3.3 Efficiency Calculations in Absorption Process

The calculation of treatment efficiency of  $\text{HNO}_3$  and  $\text{H}_2\text{SO}_4$  acid emissions obtained on PRM 001 device is given in Table 5.

**Table 5. Calculations of refining efficiency of  $\text{HNO}_3$  and  $\text{H}_2\text{SO}_4$  acid emissions on PRM 001 Device**

| Parameter     | Sample Location | Measured Solution Concentration, mg/L | Flow Rate of Suctioned Gas, L | $\text{NO}_3$ Concentration in Gas Flow, $\text{mg/m}^3$ | Collecting Efficiency, (%) |
|---------------|-----------------|---------------------------------------|-------------------------------|--|----------------------------|
| $\text{NO}_3$ | Input           | 5.34                                  | 232                           | 11.51  | -                          |
|               | Output          | 0.394                                 | 300                           | 0.62   | 94.5                       |
| $\text{SO}_4$ | Input           | 3.1                                   | 232                           | 6.7  | -                          |
|               | Output          | 0.47                                  | 300                           | 0.78   | 88.3                       |

### 3.4 Measurements Made in The Gas Phase of PRM 002 Equipment

Flow rate measurements of PRM 002 device used for treatment of waste gases are given in Table 6 and the calculation of treatment efficiency is given in Table 7.

**Table 6. Flow rate measurement results of waste gas washing equipment on Permaksan PRM 002**

| Sample Location | Stack Diameter, m | Flue gas velocity, m/sec. | Flue Gas Temperature, $^{\circ}\text{C}$ | Flow Rate of Flue Gas, $\text{m}^3/\text{hour}$ | Flow Rate of Flue Gas, $\text{Nm}^3/\text{hour}$ |
|-----------------|-------------------|---------------------------|--|---|--|
| Input           | 0.15              | 2.5                       | 25.0                                     | 160   | 147  |
| Output          | 0.15              | 2.5                       | 23.7                                     | 160   | 147  |

**Table 7. Bombing process emissions treatment efficiency calculations on PRM 002**

| Sample Location | $\text{CN}^-$ Concentration Measured in Solution, mg/L | Flow Rate of Suctioned Gas, L | $\text{CN}^-$ concentration in the gas stream, $\text{mg/m}^3$ | Absorption Efficiency (%) |
|-----------------|--|-------------------------------|--|---------------------------|
| Gas Input       | 19.1   | 270                           | 70.8   | -                         |
| Gas Output      | 0.5  | 270                           | 0.9  | 98,7                      |



In terms of wet scrubber systems, removal efficiencies vary for each pollutant, solvent and type of gas absorber used. While the most absorbers have removal efficiencies in higher than 90%, the packed tower absorbers may achieve efficiencies as high as 99.9% for some pollutant-solvent systems. According to literature, removal efficiencies of sulphuric acid mists varied between 76.8-89.9 in packed bed towers related with the gas flow rate and liquid/gas mass ratio (Jafari et. al., 2002). According to another literature, spray dryer absorber systems have efficiency much more than 98% on SO<sub>2</sub>, SO<sub>3</sub>, HCl and HF removal from waste gas streams ([https://www.babcock.com/-/media/documents/products/pollution-control/so2-acid-gases/e101-3221\\_so2-and-acid-gas-control.ashx?la=en&hash=C7A3B2F80858E0759EFE65ED21392328F0E0742B](https://www.babcock.com/-/media/documents/products/pollution-control/so2-acid-gases/e101-3221_so2-and-acid-gas-control.ashx?la=en&hash=C7A3B2F80858E0759EFE65ED21392328F0E0742B)).

A bench-scale study was conducted on the simultaneous removal of SO<sub>2</sub>, NO<sub>x</sub>, and mercury from a simulated coal flue gas using a wet calcium carbonate scrubber. The results showed a maximum scrubbing of 100% for SO<sub>2</sub> and Hg species and near complete NO oxidation with about 60% scrubbing of the resulting NO<sub>x</sub> species (Hutson et. al., 2008). When achievements of this study compared with literature findings, it can be seen that the removal efficiencies of the wet scrubbing systems were enough and output pollutant concentrations were below the limit values given in the Table 1.

#### 4. EVALUATION AND CONCLUSION

Iron/copper solvation and waste gas washing equipment of PRM 001 device that belongs to Permaksan Company and bombing and wastewater washing equipment of PRM 002 which belongs to the same company have been examined for treatment efficiency. In this context, waste gas flow is determined for both equipment and samples are taken from the inputs and outputs of the treatment unit.

HNO<sub>3</sub> and H<sub>2</sub>SO<sub>4</sub> acids are used in iron and copper solvation in PRM 001 equipment. The acids are heated to 80-90 °C with an electric heater without boiling. It was accepted that NO<sub>x</sub> gases (NO + NO<sub>2</sub>) and nitric acid mists as well as SO<sub>2</sub> / SO<sub>3</sub> and SO<sub>4</sub> mists were generated as gas emission. Especially NO<sub>x</sub> gases are measured by electrochemical method and 75% efficiency value is obtained. It has been determined that only NO<sub>x</sub> emissions can be measured with this method, nitric acid mist can not be measured. Therefore this measurement does not show the actual efficiency value. In the measurement test made with 0.1 N NaOH absorption solution, treatment efficiency was found as 94.5%. In the removal of SO<sub>2</sub>/SO<sub>3</sub> and SO<sub>4</sub> mists, over 88% treatment efficiency was determined. For PRM 001 equipment this efficiency is in the expected range and can be regarded as an average value that can be achieved. The structure of the system is very compact and it has the potential to meet the needs of the sector and ensure the safety of work. With simple modifications to be made, efficiency can be further increased. PRM 002 equipment, which is used to control the bombing process emissions, also treat HCN gas emissions with an efficiency rate of 98.7%. This value is also an average and representative efficiency value for PRM 002. The volume control of the KCN and H<sub>2</sub>O<sub>2</sub> solutions is an advantage in terms of study design.

Removal efficiency results of the two systems were suitable with literature and output pollutant emissions were below the TIAPCR and NER limit values.

It is important that the equipment has the necessary control opportunities to maintain the supply they have at the beginning of the process. This may be possible if the absorption capacity of the absorption solution (sodium hydroxide or carbonate) is always maintained. This requires the continuous monitoring of the pH values of the solutions in the equipment and addition of fresh wash solution without allowing the pH to fall below a certain value. In this way, it is possible to maintain the above-mentioned efficiencies during operation. In this scope; PRM 001 has this advantage which is having a pH meter on it that allows continuous control of the effectiveness of the washing solution. On the other hand, PRM 001 and PRM 002 also provide an advantage

in terms of control and refining of wastes since they have wastewater collecting structures for weakened washing solutions and accumulating wastewater resulted from washed substances.

## REFERENCES

1. Alp, K., Toröz, İ., Avşar, E., (2007) Permaksan Makina-Hediyelik Eşya Kuyumculuk San. ve Tic. Ltd. Şti. PRM 001 VE PRM 002 Atıkgaz Yıkama Ekipmanları Verimlilik Test Çalışmaları Raporu, Tarih ve No: 09.04.2007, 950, T.C. İstanbul Teknik Üniversitesi İnşaat Fakültesi Çevre Mühendisliği Bölümü, İstanbul.
2. Corti, C.W. (2002) Recovery and Refining of Gold Jewellery Scraps and Wastes, *The Santa Fe Symposium on Jewelry Manufacturing Technology*, Albuquerque, 111-129.
3. Corti, C.W. and Holliday, R.J. (2004) Commercial Aspects of Gold Applications: From Materials Science to Chemical Science, *Gold Bulletin*, 37(1-2), 20-26. doi: 10.1080/10643380390814451
4. Eaton, D.A., Clesceri, L.S., Rice, E.W. and Greenberg, A.E. (2005). *Standard Methods for the examination of water and wastewater 21st Ed.*, American Public Ass., Missouri.
5. Giannetti, B.F., Bonilla, S.H., Silva, I.R. and Almeida, C.M.V.B. 2008 Cleaner production practices in a medium size gold-plated jewelry company in Brazil: when little changes make the difference, *Journal of Cleaner Production*, 16, 1106-1117. doi: 10.1016/j.jclepro.2007.06.002
6. Hutson, N.D., Krzyzyska, R. and Srivastava, R.K. (2008). Simultaneous Removal of SO<sub>2</sub>, NO<sub>x</sub>, and Hg from Coal Flue Gas Using a NaClO<sub>2</sub>-Enhanced Wet Scrubber, *Ind. Eng. Chem. Res.*, 47, 5825–5831. doi: 10.1021/ie800339p
7. Jafari, M.J., Ghasemi, R., Mehrabi, Y., Yazdanbakhsh, A.R. and Hajibabaei, M. (2012) Influence of liquid and gas flow rates on sulfuric acid mist removal from air by packed bed tower, *Iranian Journal of Environmental Health Sciences & Engineering*, 9:1-7. doi:10.1186/1735-2746-9-20
8. Kaspın, S. (2013) Small Scale Gold Refining: Strengths and Weaknesses, *International Conference on Technology, Informatics, Management, Engineering & Environment*, Bandung, 32-36.
9. Klotz, U.E. (2010) Metallurgy and processing of coloured gold intermetallics – Part I: Properties and surface processing, *Gold Bulletin*, 43, 4-10. doi: 10.1007/BF03214961
10. Müezzinoğlu A. (2003) A Review of Environmental Considerations on Gold Mining and Production, *Critical Reviews in Environmental Science and Technology*, 33(1), 45-71. doi: 10.1080/10643380390814451
11. Thammaraksa, C., Wattanawan, A. and Prapasongsa, T. (2017) Corporate environmental assessment of a large jewelry company: From a life cycle assessment to green industry, *Journal of Cleaner Production*, 164, 485-494. doi: 10.1016/j.jclepro.2017.06.220
12. Yannopoulos, J.C. (1991) *The Extractive Metallurgy of Gold*, Van Nostrand Reinhold, New York.
13. Yue, C., Sun, H., Liu, W.J., Guan, B., Deng, X., Zhang, X. and Yang, P. (2017) Environmentally Benign, Rapid, and Selective Extraction of Gold from Ores and Waste Electronic Materials. *Angew. Chem. Int. Ed.*, 56, 9331–9335. doi: 10.1002/anie.201703412

14. Zhang, X.J., Tong, K.K., Chan, P. and Tan, M. (1995) Gold Jewellery Casting: Technology Design and Defects Elimination, *Journal of Materials Processing Technology*, 48, 603-609. doi:10.1016/0924-0136(94)01699-2
15. [https://www.dtsc.ca.gov/.../Jewelry/.../HWM\\_FS\\_Jewelry\\_P2\\_Recommendations.pdf](https://www.dtsc.ca.gov/.../Jewelry/.../HWM_FS_Jewelry_P2_Recommendations.pdf), Access Date: 25.09.2017, Subject: *Jewelry Manufacturing Pollution Prevention Recommendations*.
16. <http://www.who.int/ipcs/publications/cicad/en/cicad61.pdf>, Access Date: 25.09.2017, Subject: *World Health Organization, Hydrogen Cyanide and Cyanides: Human Health Aspects*.
17. <https://www.atsdr.cdc.gov/ToxProfiles/tp117-c1-b.pdf>, Access Date: 25.09.2017, Subject: *Agency for Toxic Substances and Disease Registry, Public Health Statement Sulfur Trioxide and Sulfuric Acid*.
18. <https://www.ncbi.nlm.nih.gov/books/NBK230439/>, Access Date: 25.09.2017, Subject: *Assessment of Exposure-Response Functions for Rocket-Emission Toxicants*.
19. [http://sgb.csb.gov.tr/mevzuat/dosyalar/r\\_20130929233746779\\_7ef68822-c2b0-41fc-b125-916a43b480a2.pdf](http://sgb.csb.gov.tr/mevzuat/dosyalar/r_20130929233746779_7ef68822-c2b0-41fc-b125-916a43b480a2.pdf), Access Date: 25.09.2017, Subject: *Ministry of Environment and Urbanization, Turkish Industrial Air Pollution Control Regulation*.
20. [http://eippcb.jrc.ec.europa.eu/reference/BREF/stm\\_bref\\_0806.pdf](http://eippcb.jrc.ec.europa.eu/reference/BREF/stm_bref_0806.pdf), Access Date: 25.09.2017, Subject: *European Commission, Reference Document on Best Available Techniques for the Surface Treatment of Metals and Plastics*.
21. [www.infomil.nl/publish/pages/63235/lvoc-annexviii.pdf](http://www.infomil.nl/publish/pages/63235/lvoc-annexviii.pdf), Access Date: 25.09.2017, Subject: *Dutch NeR Classification system*.
22. [https://www.babcock.com/-/media/documents/products/pollution-control/so2-acid-gases/e101-3221\\_so2-and-acid-gas-control.ashx?la=en&hash=C7A3B2F80858E0759EFE65ED21392328F0E0742B](https://www.babcock.com/-/media/documents/products/pollution-control/so2-acid-gases/e101-3221_so2-and-acid-gas-control.ashx?la=en&hash=C7A3B2F80858E0759EFE65ED21392328F0E0742B), Access Date: 25.09.2017, Subject: *Air pollution control equipments*.
23. <https://www3.epa.gov/ttnemc01/ctm/ctm-022.pdf>, Access Date: 25.09.2017, Subject: *EPA (1995) Emission Measurement Center, Conditional test method: Determination of nitric oxide, nitrogen dioxide and NOx emissions from stationary combustion sources by electrochemical analyzer, (CTM022)*.
24. <https://www.epa.gov/emc/method-1-sample-velocity-traverses>, Access Date: 25.09.2017, Subject: *EPA (1994) Method 1: Sample and Velocity Traverses for Stationary Sources, 9/30/94: F1-1*.

