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Effect of plasma jet technique on potentially toxic metals removal from wastewater

Einas.Y.Hosny *[a] ,Sayed.A.Shama [a] &Hossam S. Jahin[b]

*[a] Chemistry Department, Faculty of Science, Benha University, Benha 13815, Egypt

*[b] Central Laboratory for Environmental Quality Monitoring, National Water Research Center, Elkantir 13621, Egypt

Corresponding author: E-mail address: ennaalyas2000@gmail.com
Tel.: +20 1112555217

Abstract :

Plasma with various reactor geometries has been studied for wastewater treatment applications. This research aims to study the effect of underwater plasma jet treatment on water contaminated by potentially toxic metals were used. The contaminated samples were processed under plasma jet treatment then the final concentration after this process was determined to get the whole rate of the treatment. It was found that underwater plasma jet is an effective method to eliminate the metal contaminates. The use of non-thermal plasma jet technology for the removal of potentially toxic metals can have a positive impact on water quality, particularly in areas where heavy metal contamination is a concern. The removal of potentially toxic metals can improve the safety and taste of drinking water, as well as reduce the risk of environmental contamination from industrial wastewater or groundwater remediation.

Keywords:

Potentially toxic metals, Plasma jet, Water Treatment, Toxic Pollutants, Nickel, Iron, Copper and lead- wastewater.

1. Introduction:

Water contamination is the contamination of water bodies that include lakes, rivers, oceans, aquifers, reservoirs, and groundwater. It results from human activities and it negatively affects our usage [1]. Numerous types of contaminants can threaten drinking water. They include everything from chemicals to pesticides to animal waste to industrial waste injected into the ground. Naturally occurring substances, such as arsenic, radon and fluoride, can also contaminate groundwater. Water contamination can cause water-borne diseases for people using polluted water for drinking, bathing, washing, or irrigation. Water pollution reduces the ability of the water body to provide the ecosystem services (such as drinking water) that could be provided [2]. Toxins could be classified into organic toxics as phenols, pigments and pharmaceutical compounds and inorganic toxics as heavy metals and salts as barium and magnesium compounds. Heavy metals are defined as metals with relatively high densities, atomic weights, or atomic numbers. The earliest known metals: iron, copper, tin, and precious metals such as silver, gold, and platinum are also heavy metals. Heavy metals can come from motor vehicles through urban and mining runoff. Toxic Effects of heavy metals include cancer, brain damage and death, rather than the harm they may cause to one or more of the skin, lungs, stomach, kidneys, liver, or heart. Some of heavy metals are highly toxic or damaging to the environment. While others are toxic only if taken in excess forms. [3,4]

Copper Toxicity: Copper is toxic for humans due to redox cycling and the generation of reactive oxygen species that damage DNA. Autosomal recessive mutations in copper can disable human transport protein systems, leading to Wilson's disease with copper accumulation and cirrhosis of the liver. Elevated copper levels have also been linked to symptoms of Alzheimer's disease.

Lead Toxicity: Lead is a highly poisonous metal (inhaled or swallowed). Lead effects on every organ and system in the human body. Lead can cause severe damage to the brain and kidneys leading to death .It degrades the myelin sheaths of neurons, reduces their numbers, interferes with neurotransmission routes, and decreases neuronal growth. Most ingested lead reaches to the bloodstream. The primary causes of its toxicity that lead interfere with the function of the living being enzymes. The sulfhydryl groups found on many enzymes bind and displace other metals which act as cofactors in many enzymatic reactions. [4]

Nickel Toxicity: Nickel is found naturally in the environment: Typical background concentrations do not exceed 10 µg/L in freshwater and 1 µg/L in seawater. Human pollution and activities can increase the environmental concentrations of nickel. It is not a cumulative poison because the daily average exposure does not form a threat to human health. Most of the nickel absorbed every day by humans is removed by the kidneys and passed out of the body through urine or is eliminated through the gastrointestinal tract without being absorbed but larger doses or chronic inhalation exposure may be toxic, even carcinogenic, and constitute an occupational hazard. Nickel compounds are human carcinogenic because it increases the risks of the respiratory cancers. Nickel increases lungs. Nitrates and phosphates, from sewage and agriculture

Sediments (Slit) in runoff from construction, agricultural and urban runoff [5].

Iron Toxicity: The presence of iron in excessive quantities in water can harm skin cells, leading to infection and wrinkles. Move over, such water does not rinse off the soap residue from the body, causing clogged skin pores and buildup of oil in the skin, results in many skin problems such as eczema or acne.

a low level of iron cannot harm your health, it contains bacteria. In addition to this, high iron levels in water content leads to an overload which can cause diabetes, hemochromatosis, stomach problems, and nausea, It can also damage the liver, pancreas and heart [6].

Physical and chemical methods could be achieved in order to decrease the level of contamination inside the water. Cold discharge plasma is one of the most widely studied and developed physical processes for water treatment, owing to its low energy cost and easy to operate [7]. The recent combination of discharge plasma decontamination and other processes in both post and pre-treatment configuration are reported. Some applications of water treatment based on discharge plasma at the pilot scale have been addressing [8].

This research was done to show the advantages of water treatment by plasma and why this method can be considered one of the best methods comparing to other chemical methods. Water treatment by plasma can be operated without any extra chemicals using electricity. The purpose of this study is to investigate the impact of underwater plasma jet technique on water contaminated with potentially toxic metals such as nickel, lead, copper, and iron.

2. Materials and Methods

Chemicals and Reagents

Ferric Sulfate $Fe_2(SO_4)_3$ is an inorganic compound , grayish-white crystals, Molar mass 118.702 g/mol ,molecular weight is 399.8778 a.m.u . Purity . Extra Pure 98% . Resource : Alfa Chemicals

Copper sulfate $CuSO_4.5H_2O$. it's inorganic compound forms hydrates . It's shape is blue in Pentahydrate Molecular weight is 259.7644 a.m.u. Resource : Agrofeat factory , Zain for seeds

Nickel carbonate $NiCO_3 .2Ni(OH)_2.4H_2O$ it describes one or a mixture of inorganic compounds containing the nickel and carbonate , It's appearance is light green powder - Molecular Weight is 376.23 a.m.u. Purity 44-47%. Resource : Alfa chemical

Nickel Chloride hexahydrated pure $NiCl_2.6H_2O$ The more familiar hydrate compound is green . Its Molecular Weight is 308.59708 a.m.u – Purity : 98% Resource : Alfa Chemicals

Lead Acetate Trihydrate $Pb(CH_3COO)_2.3H_2O$ also known as lead diacetate , Plumbous acetate , sugar of lead – It's a white crystalline chemical compound , it has a slightly sweet taste like many other lead compounds - Molecular weight is 379.33388 a.m.u. – Purity :99%. Resource: Alfa chemical group.

Secondly ionized water 1L bottle of De-ionized water. Used to rinse pH electrodes and Conductivity probes. DI water is suitable for many applications, including autoclaves, hand-pieces and laboratory testing. Purification removes contaminants that may interfere with processes, or leave residues on evaporation.

Aqua Chemical Misr for disinfectants and chemicals, Sadat City ,Egypt.

Argon gas_ This gas is a chemical element with the symbol Ar and the atomic number 18, and it's the third-most abundant gas in the atmosphere (and the most abundant in the crust). Almost all of the argon found in the atmosphere is radiogenic argon-40 and, in space, the most common argon isotope is argon-36. The Used Argon gas was Collected by Egypt Factory for industrial gases Co., Cairo , Egypt with purity 99.95%

Plasma jet It's a non-thermal discharge generated by the application of high voltages across small gaps wherein a non-conducting coating prevents the transition of the plasma discharge into an arc.

A common usage of this discharge is in a plasma actuator for vehicle drag reduction. It is also widely used in the web treatment of fabrics, plastics functionalizes , water treatment

Place of Experiment : Egypt , Faculty of science , Benha university Plasma Physics laboratory Results were analyzed in The Central Laboratories for Environmental Quality Monitoring, National Water Research Center, Egypt.

Sampling

The experiment aims to discover the effect of cold plasma jet on different heavy metals (as pollutants) on water .

Preparation of stock solution

*Calculation of sample weight "in solid state"

Wt/M.wt = Concentration

Assume concentration is **0.001 M**

then weight of each sample is equal to concentration in M *M.wt of each sample

Conditions

After calculation of heavy metals weight ..

* dissolving each specific sample weight in one liter of secondly deionized water to get a homogeneous solution.

* All solutions "50 ml" will be exposed to the same conditions "same flow rate / same voltage / same current "under plasma reactor for a Fixed period of time **5 minutes then 7 .**

*Setting the Plasma Reactor Flow Rate at **20 ml.gm/L.**

*Setting the Voltage Plasma Reactor at **5 KV** for all of the samples

*Knowing that the output frequency RF is 34 Hz

Method :

50 ml is processed under plasma jet treatment

Refilling each sample in a suitable conical flask to get rest under the plasma jet.

The jet flam penetrates the surface of the sample continuously for 5minutes noting that the flame " jet needle " should not penetrate the surface of the liquid but directly above the surface of it .

The rest of the solution will be zero solution ..

After the Treatment Both samples will be processed under **ICP-OS type perkin Elmar dv 5300 USA**

To : 1- Confirm zero sample concentration as 0.001 M

2. Finding out the concentration of the treated sample.

3. Find a comparison between the concentrations of samples before and after treatment.

During Nickel Chloride Treatment, The jet flame became so bright for 2.5 minute, then the brightness disappeared and the sample color turned to yellow . while the brightness appeared, it was seen through the surface of the sample flask.

-During Nickel Carbonate treatment, the brightness of the sample was so obvious and a dense foam appeared on the surface of the liquid sample .

-During Nickel sample treatment, the jet brightness increased .

-While the treatment of the samples that contain Fe, Pb, Cu, Boiling appeared on the surface of the liquid . The Jet brightness remained the same.

-After the treatment was processed, the samples were let to settle down . After a while a precipitate was formed for each of the samples.

Substance's Name	Metal Radical	Type	Molecular weight (a.m.u)	Weight (gm)
[redacted]				
Cupper Sulfate $CuSO_4.5H_2O$	Cu Cupper	Heavy Metal	259.7644 a.m.u	0.2597 gm
[redacted]				
Nickel Chloride $NiCl_2.6H_2O$	Ni Nickel	Heavy Metal	308.59708. a.m.u	0.3085 gm
[redacted]				

Table 1: Weight calculations for heavy metals

-During Cupper Sulfate sample treatment, effervescence and dense foam formed .

-Filtration was applied for all of the samples to get rid of the residues.

Concentration (gm/L) = Concentration(M) *Molecular weight

Concentration (gm/L)*1000 = Concentration (mg/L).

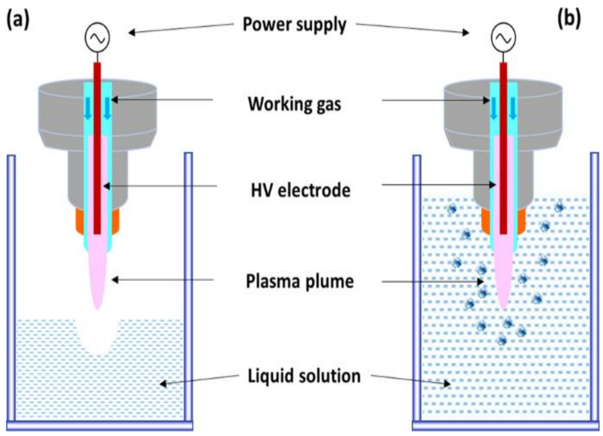

Figure 1: Water sample treatment under plasma jet

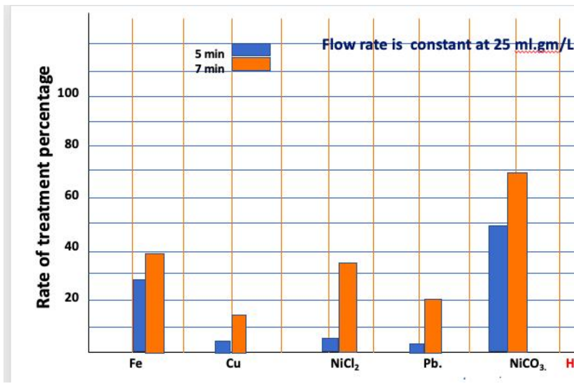

Chart 1: Comparison between heavy metals highest rate treatment

Table 2: Samples treatment under same conditions

Sample	**Flow Rate**	**Exposure Time for plasma Jet " Treatment time"**	**Concentration After treatment**	**Treatment rate in Percentage**
[redacted]				
Cupper Sulfate	20 ml.gm/L	5 min	'll be measured	Conc.after/Conc.before*100
[redacted]				
Nickel Chloride	20 ml.gm/L	5 min	'll be measured	Conc.after/Conc.before*100
[redacted]				

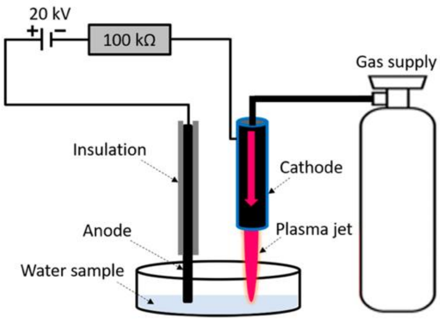

Figure 2: Deionization of gas molecules for plasma generation treatment

Table 3: Heavy metal sample treatment at 5 then 7 minutes

Substance's Name	Metal Radical	Concentration before treatment mg/L	Concentration after 5 min treatment mg/L	Concentration after 7 min treatment mg/L	Rate of Treatment in Percentage for 5 min.	Rate of treatment in percentage for 7 min.
Ferric Sulfate **$Fe_2(SO_4)_3$**	Fe Iron	24.25	17.92	12.6	26.1%	49%
Cupper Sulfate **$CuSO_4.5H_2O$**	Cu Cupper	138.87	134.7	117.87	3%	15.122%
Nickel Chloride **$NiCl_2.6H_2O$**	Ni Nickle	37.08	35.56	24.76	4.099%	33.22%
Lead Acetate **$Pb(CH_3COO)_2.3H_2O$**	Pb Lead	641.3	637.4	514	0.6%	20%
Nickel Carbonate **$Ni_4CO_3(OH)_6(H_2O)_4$**	Ni Nickle	0.475	0.248	0.143	47.79%	69.89%

3.Results and Discussion:

Plasma jet has been investigated as a potential technology for the removal of heavy metals, including iron, lead, copper, and nickel, from water due to its ability to generate highly reactive species that can oxidize and break down the metals. The effectiveness of non-thermal plasma jet for heavy metal removal depends on various factors, including the initial metal ion concentration, and treatment time.

Several studies have reported good removal efficiencies for heavy metals using non-thermal plasma jet technology. For example, this study reported removal efficiencies of up to 69.89% for Nickel.

Other studies indicated up to 85% for copper and nickel, at an initial metal ion concentration of 50 ppm and a treatment time of 30 minutes using a jet reactor. Another study reported removal efficiencies of up to 99% for lead and copper, and up to 97% for nickel, at an initial metal ion concentration of 100 ppm and treatment time of 60 minutes using a plasma jet reactor [9,10]

The effectiveness of non-thermal plasma jet for heavy metal removal can be influenced by various factors, including the pH of the water. The optimal pH for heavy metal removal using non-thermal plasma jet may vary depending on the metal ion, with a pH of 7 being optimal for some metals and a pH of 3 being optimal for others. The presence of other ions in the water, such as chloride and sulfate, can also impact the effectiveness of heavy metal removal using non-thermal plasma jet [11].

Overall, non-thermal plasma jet technology offers a promising approach to heavy metal removal from water, providing a cost-effective and efficient method for removing contaminants and improving the quality of water.

However, further research is needed to optimize the technology for specific heavy metal removal applications and to evaluate its long-term effectiveness and sustainability. Additionally,

the potential formation of byproducts during the heavy metal removal process should be carefully monitored and controlled to ensure that any byproducts are effectively removed or treated before the treated water is released into the environment [12].

The mechanism of heavy metal removal using plasma jet involves the generation of highly reactive species, such as hydroxyl radicals, which can oxidize and break down the heavy metal ions. The heavy metal ions can be transformed into less toxic or non-toxic forms, such as metal oxides or hydroxides, which can be removed from the water by precipitation or filtration [13].

Factors Affecting Heavy Metal Removal:

Several factors can affect the effectiveness of heavy metal removal using plasma jet, including the initial metal ion concentration, pH, treatment time, and plasma power. Increasing the treatment time and plasma power can increase the removal efficiency, while decreasing the initial metal ion concentration can also improve the removal efficiency. The optimal pH for heavy metal removal may vary depending on the metal ion, and the presence of other ions in the water can also impact the effectiveness of heavy metal removal using a non-thermal plasma jet [14].

Plasma Jet technology has potential applications in various water treatment settings for heavy metal removal, including drinking water treatment, industrial wastewater treatment, and groundwater remediation. The technology can be used to remove heavy metals, such as iron, lead, copper, and nickel, from water to improve water quality and protect public health and the environment. Further research is needed to optimize the technology for specific heavy metal removal

applications and to evaluate its long-term effectiveness and sustainability [15].

Overall, plasma jet offers a promising approach to heavy metal removal from water, providing a cost-effective and efficient method for removing contaminants and improving the quality of water.

By optimizing the treatment parameters and reactor design, non-thermal plasma jet technology can be developed and applied to various heavy metal removal applications to improve water quality and protect public health and the environment [12].

Effect on Water Quality:

The use of plasma jet technology for the removal of heavy metals can have a positive impact on water quality, particularly in areas where heavy metal contamination is a concern.

The removal of heavy metals can improve the safety and taste of drinking water, as well as reduce the risk of environmental contamination from industrial wastewater or groundwater remediation. However, it is important to monitor the quality of the treated water to ensure that any potential byproducts are effectively removed or treated before releasing the water into the environment [16, 17].

4. Conclusions

The non-thermal plasma jet offers an approach to the removal of heavy metals, including iron, lead, copper, and nickel, from wastewater. The technology generates highly reactive species, such as hydroxyl radicals, which can oxidize and break down heavy metal ions, resulting in their transformation into less toxic or non-toxic forms that can be removed from the water by precipitation or filtration. Plasma jet technology offers several advantages over other treatment methods for heavy metal removal, such as lower energy consumption, lower chemical usage, and good removal efficiency. However, further research is needed to optimize the technology for specific heavy metal removal applications and to evaluate its long-term effectiveness and sustainability. By optimizing the treatment parameters and reactor design, plasma jet technology can be developed and applied to various heavy metal removal applications to improve water quality and protect public health and the environment.

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