Study of reducing fuel acidity inside the boiler of power plants using PentoMag and reducing the percentage of toxic emissions

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Abstract

Corrosion of steam boilers in fuel-fired power plants poses a significant operational and economic challenge, primarily caused by the formation of acidic gases during fuel combustion. The aim of this investigation is to examine the effect of PentoMag (supplied by Pentol Renewable Energy Projects) on fuel behavior and its role in mitigating boiler corrosion at the Wasit Power Plant, Unit 6. The experimental work extended over eight weeks, during which the pH of ash solutions, free acid levels, and concentrations of emitted gases (SOx and CO) were systematically analyzed. The results revealed that, prior to treatment, the pH values of the ash solutions were strongly acidic (1.99–2.3), which directly contributed to corrosion caused by the formation of sulfuric acid inside the boiler. After adding the treated material, pH values increased to 3.8–4.2, reflecting a shift toward a less aggressive acidic medium. Likewise, free acid concentrations dropped significantly from 5.8 - 6 to negligible values (0–0.0040). Gas analysis further confirmed the positive impact of the treatment, with carbon monoxide concentrations reduced from 17–33 ppm to 4–12 ppm, and sulfur oxides decreased from 168–189 ppm to 49–90 ppm. Overall, the application of PentoMag as a fuel additive demonstrated apparent effectiveness in mitigating fuel acidity, reducing harmful emissions, and enhancing boiler efficiency and lifespan, offering a practical solution for sustainable operation in power plants.

Keywords: PentoMag ،Acidity، Power Plants.

دراسة خفض حموضة الوقود داخل غلايات محطات توليد الطاقة باستخدام مادة PentoMag وتقليل نسبة الانبعاثات السامة

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الخلاصة :

يُعدّ تآكل غلايات البخار في محطات توليد الطاقة التي تعمل بالوقود من التحديات التشغيلية والاقتصادية الكبيرة، ويعزى ذلك أساسًا إلى تكوّن الغازات الحمضية أثناء عملية احتراق الوقود. يهدف هذا البحث إلى دراسة تأثير مادة (PentoMag المقدمة من شركة Pentol Renewable Energy Projects)على سلوك الوقود ودورها في الحد من تآكل الغلايات في محطة واسط للطاقة – الوحدة السادسة.

امتد العمل التجريبي لمدة ثمانية أسابيع، تم خلالها تحليل الرقم الهيدروجيني (pH) لمحاليل الرماد، ومستويات الأحماض الحرة، وتركيزات الغازات المنبعثة (أكاسيد الكبريت وأول أكسيد الكربون) بطريقة منهجية.

أظهرت النتائج أنه قبل المعالجة كانت قيم الرقم الهيدروجيني لمحاليل الرماد شديدة الحموضة (1.99–2.3)، مما ساهم مباشرة في حدوث التآكل الناتج عن تكوّن حمض الكبريتيك داخل الغلاية. وبعد إضافة المادة المعالجة، ارتفعت قيم الرقم الهيدروجيني إلى 3.8–4.2، مما يشير إلى تحول نحو وسط أقل حموضة وأكثر استقرارًا.

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كذلك، انخفضت تركيزات الأحماض الحرة بشكل ملحوظ من 5.8–6 إلى قيم شبه معدومة.(0–0.0040)
وأكّد تحليل الغازات أيضًا التأثير الإيجابي للمعالجة، إذ انخفضت تراكيز أول أكسيد الكربون (CO) من 17–33 جزءًا في المليون إلى 4–12 جزءًا في المليون، كما انخفضت أكاسيد الكبريت (SOx) من 168–189 جزءًا في المليون إلى 49–90 جزءًا في المليون.
بصورة عامة، أظهر استخدام PentoMag كمادة مضافة للوقود فعالية واضحة في تقليل حموضة الوقود، وخفض الانبعاثات الضارة، وتحسين كفاءة الغلايات وإطالة عمرها التشغيلي، مما يوفر حلًا عمليًا ومستدامًا لتشغيل محطات توليد الطاقة.
الكلمات المفتاحية: PentoMag، الحامضية، المحطات البخارية .

1. Introduction

One of the most important factors is the acidity inside the boiler, which results from the formation of acidic gases during fuel combustion within the burners. The most important of these gases is sulfur oxide in the form of sulfur dioxide and sulfur trioxide, which results in the formation of sulfuric acid inside the boiler. This causes corrosion of the boiler's internal walls, leading to a decrease in the boiler's lifespan and efficiency over time.

Steam boiler failure is a common occurrence in fossil fuel-fired power plants. The contribution of one or more factors is responsible for failures, which can culminate in partial or complete plant shutdowns. The use of fuels containing high levels of sulfur and vanadium, along with poor maintenance and exceeding the design temperature and pressure limits during operation, has a detrimental effect on plant performance. This has led to frequent failures of furnace tubes in power plant boilers. These problems take various forms, including lateral wall corrosion, waterside corrosion, rupture, wall thinning, and cracking [1]. The problem of high-temperature corrosion in steam boilers that burn fossil fuels is a significant concern if the fuel contains sulfur, chlorine, sodium, potassium, and vanadium [2]. High-temperature corrosion occurs in boiler components. The function of the boiler is to convert water into superheated steam, which is also delivered to the steam turbines. Coal and oil are burned. Natural gas and hot air enter the furnace. Combustion gases flow through the furnace and evaporate water into steam inside the furnace's waterwall tubes. At the furnace surface, the gas flows horizontally through banks of superheater and reheater tubes. The gases then move downward, where they encounter a horizontal, low-temperature, energy-efficient superheater [3]. High-temperature corrosion of the various critical boiler components is primarily classified into two broad categories:

1. Superheater and reheater tubes are prone to corrosion caused by the heat.
2. Corrosive impurities (such as alkali metals, sulfur, or vanadium) present in the fuel are responsible for corrosion caused by the heat [4].

1.1 Work Site

This topic was studied at the Wasit Thermal Power Plant due to the large size of the power plant, which in turn leads to increased boiler maintenance costs during annual maintenance.

1.2 Objectives

This study aims to evaluate the effectiveness of a treated fuel additive (PentoMag, supplied by Pentol Renewable Energy Projects) in reducing boiler corrosion, improving fuel quality, and minimizing harmful gas emissions in fuel-fired power plants. The investigation was conducted at the Wasit Power Plant, Unit 6, due to the high operational costs and corrosion issues associated with its large steam boiler.

2. Methodology

The study site was chosen at the Wasit Power Plant, Unit 6, due to the large size of the steam boiler and the high economic cost of boiler maintenance. Therefore, it was deemed appropriate to study the factors that cause boiler corrosion.

2.1 Materials

In this study, only one treatment material (PentoMag) was used without any other chemical additives, because the experimental design aimed to evaluate the efficiency of this specific material in reducing acidity and emissions. The sample, or fly ash, is prepared after the combustion process by creating an opening inside the outlet of gases and vapors. The treated material is in the form of tanks equipped by Pentol Energy Projects. Sodium hydroxide (0.1%) is prepared by dissolving 0.4% of sodium hydroxide in a 100 ml beaker and filling the volume to the mark. The station's staff prepares the injected ash in the form of tanks and deionized water.

2.2 Tools and Equipment

A pH meter, a device for measuring gases emitted into space, pumps for injecting and mixing the treated material with the incoming slurry in the incinerator, an electronic balance, a magnetic stirrer, a burette, various-sized beakers, a conical flask, filter paper, gloves, and magnetic stir bars. "The components of the exhaust gases emitted from the main chimney were measured using a portable gas analyzer (model Testo 350), with measurements taken weekly before and after the addition of PentoMag, over a period of eight weeks.

3. Results

After obtaining the ash remaining from the combustion process inside the boiler or the designated combustion area and collecting it by the company's staff, it is brought to the laboratory for acid function measurements. The sample is first cleaned of impurities using a clip. After the cleaning process, one gram of the sample is weighed and dissolved in a 100 ml beaker of distilled water. After that, a piece of magnet is placed inside the solution, and the beaker is placed on a motor-driven mixer to ensure a complete dissolution process. This was done during two time periods, 5 minutes and 55 minutes, to ensure complete dissolution of the sample. After the dissolution process, the solution is filtered through filter paper, and a clear solution is prepared to measure its acidity, as shown in Table No. (1). The results showed that the acid function values ranged from 1.99 to 2.3 in both periods and over the weeks allocated for the experiment. We concluded from the results that the sample had a strongly acidic environment before adding the treatment material.

Table 1 : shows the pH measurements before adding the treated substance.

Weeks	pH at 55 minutes	pH at 5 minutes	free acid
Week one	2.2	2	5.88
Week two	2.2	2.1	5.93
Week three	2.3	2.2	6
Week four	2	2	5.99
Week five	2.12	2.1	5.97
Week six	2.2	2.2	5.98
Week seven	2.1	2.01	5.97
Week eight	2.2	1.99	5.99

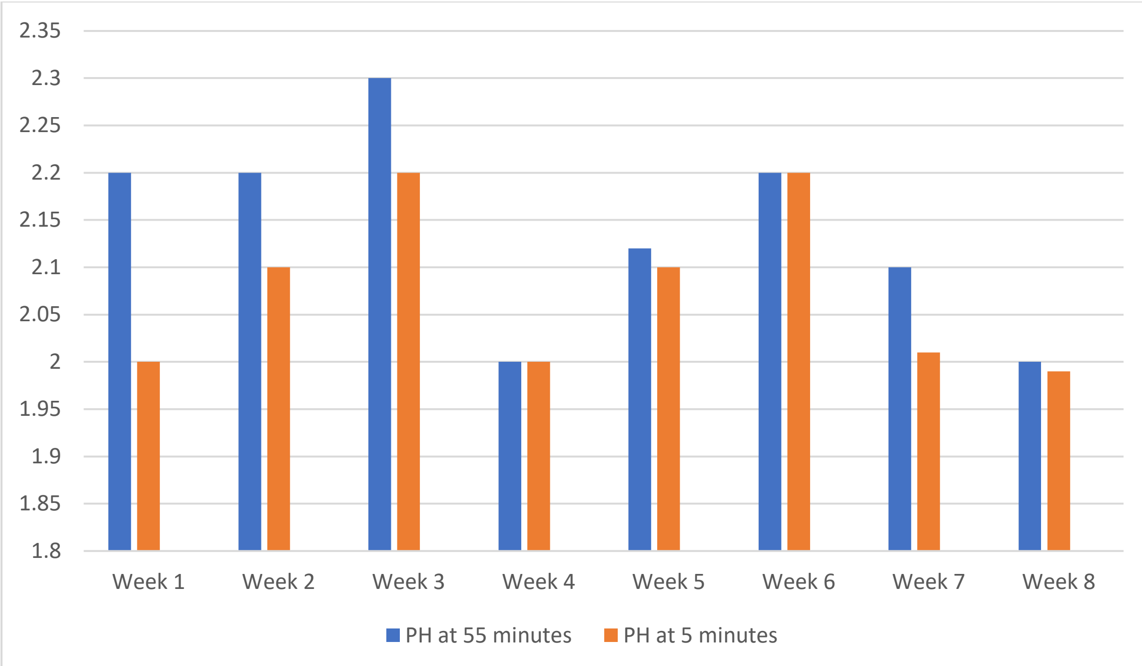

Figure 1: shows the pH measurements before adding the treated substance.

Figure 1 illustrates the results obtained over the eight weeks. The blue column represents the pH values over 55 minutes, while the orange column shows the pH values over the 5 minutes. The sample results prove that the medium is strongly acidic.

Table 1 shows the amount of free acid for each sample obtained over the eight weeks. This was done immediately after the acid function measurement process. If the sample was taken to measure its acidity after mixing it for 55 minutes, we did not take the 5 minutes to ensure complete dissolution of the sample. This was done by using a concentration of (0.1N) sodium hydroxide, where the basic solution is placed inside the burette and is irrigated with the sample solution after measuring its acidity at a mixing time of 55 minutes. The irrigation process begins with sampling and monitoring the volume being dispensed from the burette. With each addition of 0.5 ml of the descending basic solution, we measure the acid function value until reaching the endpoint of the reaction, at which the acid function of the solution becomes greater than four degrees. Using the free acid ratio law and multiplying the volume coming down from the burette, at which the acidity of the solution became four, by the free acid factor (0.49), we extract the free acid ratio, as shown in Equation 1. Table 1 showed that the free acid ratio ranges from 5.8 to 6 degrees during the trial period before adding or mixing the treated material with the burning fuel.

Free acid= 0.49 x v(ml) ….............…. (1)

v(ml)= The volume coming out of the burette

Acidity coefficient=0.49

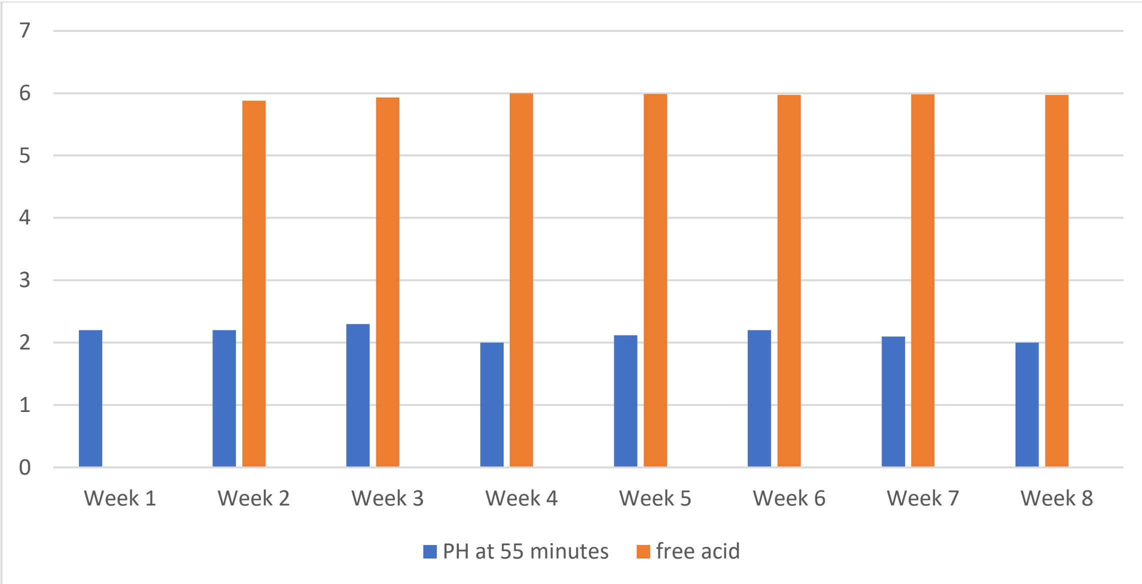

Figure 2 : shows the free acid before adding the treated substance.

Figure 2 shows the results taken from Table 2. The orange column shows the amount of free acid, and the blue column shows the acid function values at a mixing time of 55 minutes.

Table 3 : shows the Concentration of gases before adding the treated substance.

Weeks	Gas SO_X (ppm)	Gas CO (ppm)
Week one	178	23
Week two	188	35
Week three	180	26
Week four	177	18
Week five	179	19
Week six	168	33
Week seven	189	12
Week eight	176	17

Table 3 presents the measurement of the percentage of gases emitted during the combustion process after creating an opening at the gas outlet inside the station. After the process of preparing the opening, the emitted gases are measured by a gas measuring device equipped by the company. If these values were measured from the first week to the eighth week and the results showed that the percentage of carbon monoxide gas ranged from 17 to 33 parts per million and the values of sulfur oxides ranged from 168 to 189 parts per million, these values were measured before the process of adding the treated material to the fuel used in the combustion process.

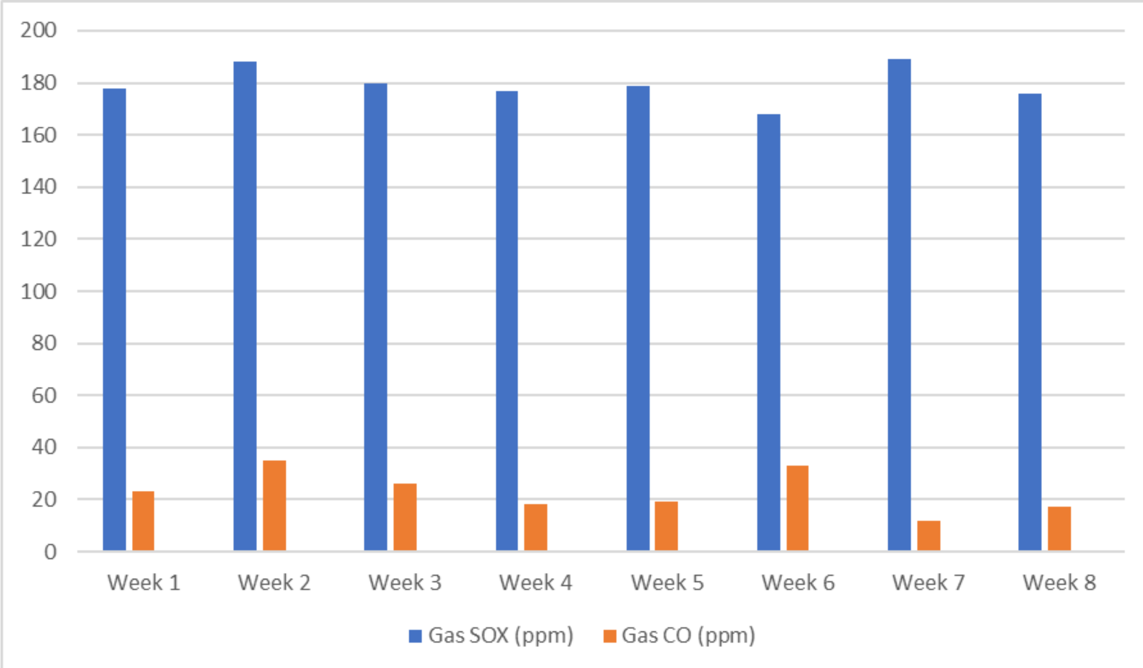

Figure 3 shows the Concentration of gases before adding the treated substance.

Figure 3 shows the results obtained from Table 3. The blue column shows the values of sulfur oxides, and the orange column shows the values of carbon monoxide emitted during the fuel combustion process.

Table 4 shows the free acid values after the injection of the treated material with the fuel. The results shown in the table indicate that the free acid values of the sample decreased after treatment, as they ranged from 5.8 to 6 degrees before treatment. However, after adding the treated material, the values ranged from 0 to 0.0040 at a mixing time of 55 minutes, when the acid function values ranged from 3.8 to 4.2.

Table 4 shows the results obtained after the process of injecting the treated material with the fuel used in the combustion process during the experimental period, after taking the sample from the designated place and analyzing it inside the laboratory to know the acid function values and the effect of the treated material after mixing it with the fuel. If the results showed a clear difference in the acid function values, as they were before treatment, ranging from 1.99 to 2.3, but after treatment, the results ranged from 3.8 to 4.2, meaning that the acid function of the sample became less acidic after adding the treated material.

Table 4 : shows the pH measurements after adding the treated substance.

Weeks	pH at 55 minutes	pH at 5 minutes	free acid
Week one	3.88	3.8	0.049
Week two	3.97	3.9	0.0098
Week three	3.99	3.89	0.0049
Week four	4	3.88	0
Week five	4	3.99	0
Week six	4.2	4	0
Week seven	4.3	4.2	0
Week eight	3.88	3.8	0.049

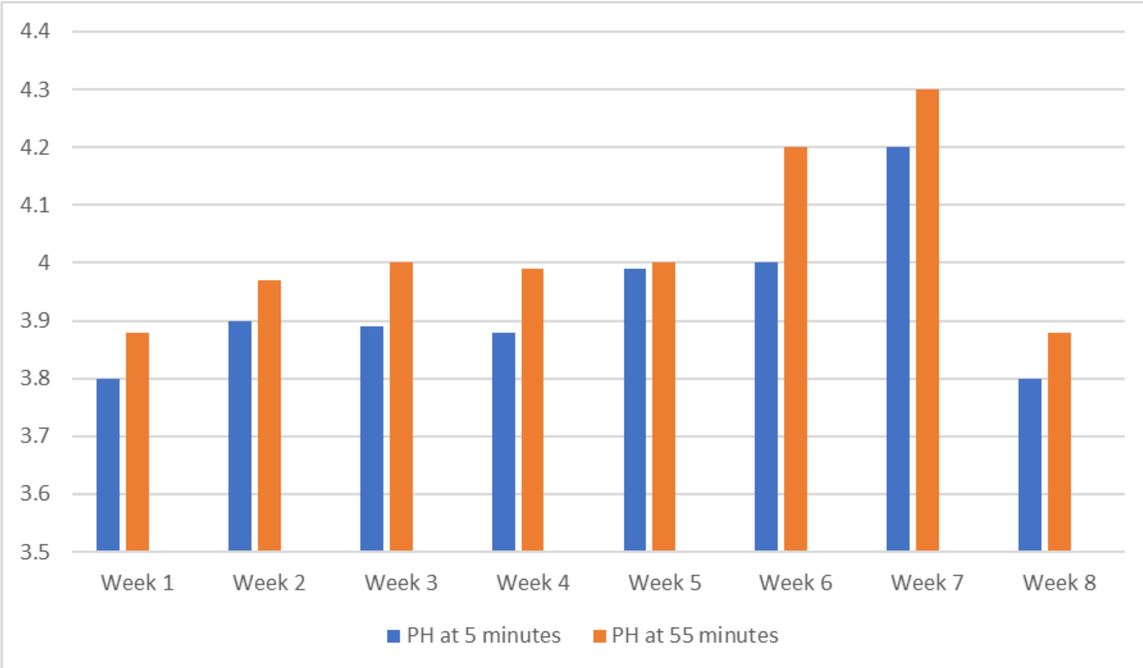

Figure 4: Shows the pH measurements after adding the treated substance.

Figure 4 shows the results obtained after adding the treated material to the fuel used during the eight-week experiment. The blue column represents the acid function values after treatment and during a 5-minute mixing period, while the orange column shows the acid function results after mixing the sample for 55 minutes.

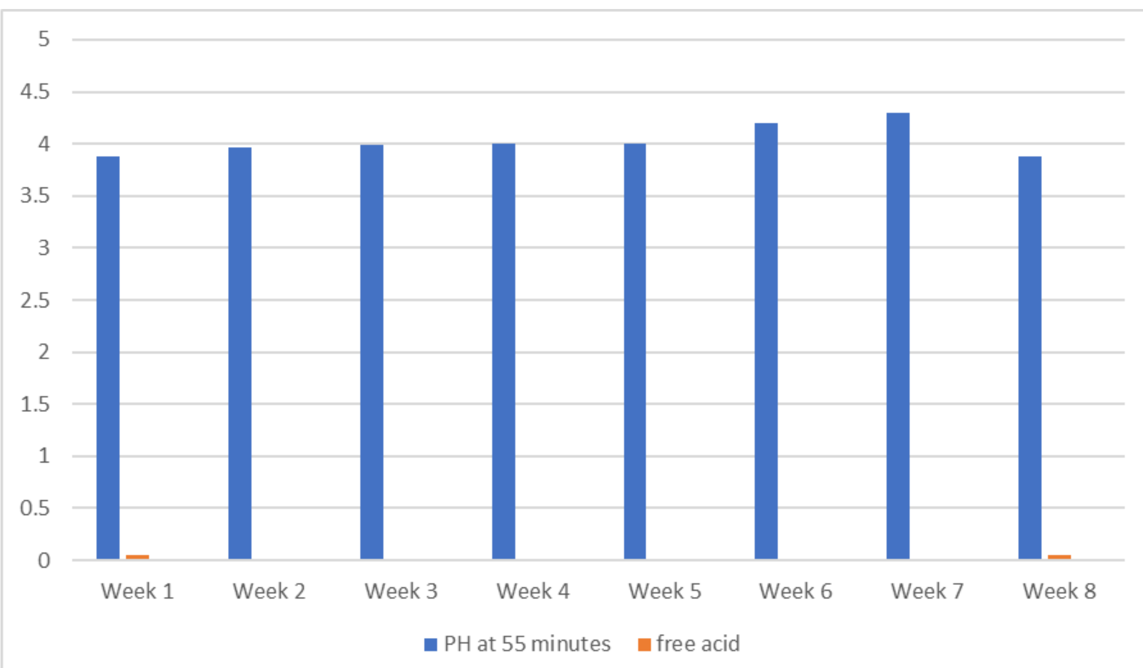

Figure 5: Showing the free acid after adding the treated substance.

Figure 5 shows the results obtained from Table 5. The orange column represents the free acid values, while the blue column shows the acid function values at a mixing time of 55 minutes.
Table 6 shows the gas concentration obtained after the treatment process with the used fuel. By comparing the results, the gas concentrations before adding the treated material ranged from 17 to 33 parts per million for carbon monoxide and from 168 to 189 parts per million for sulfur oxides. However, after treatment and the addition of the treatment, the difference is evident in Table 6, as the Concentration of carbon monoxide ranged from 4 to 12 parts per million. In comparison, the Concentration of sulfur oxides ranged from 49 to 90 parts per million.

Table 6: Shows the Concentration of gases after adding the treated substance.

Weeks	Gas SO_X (ppm)	Gas CO (ppm)
Week one	89	8
Week two	78	9
Week three	90	8
Week four	76	12
Week five	56	7
Week six	76	11
Week seven	49	6
Week eight	56	4

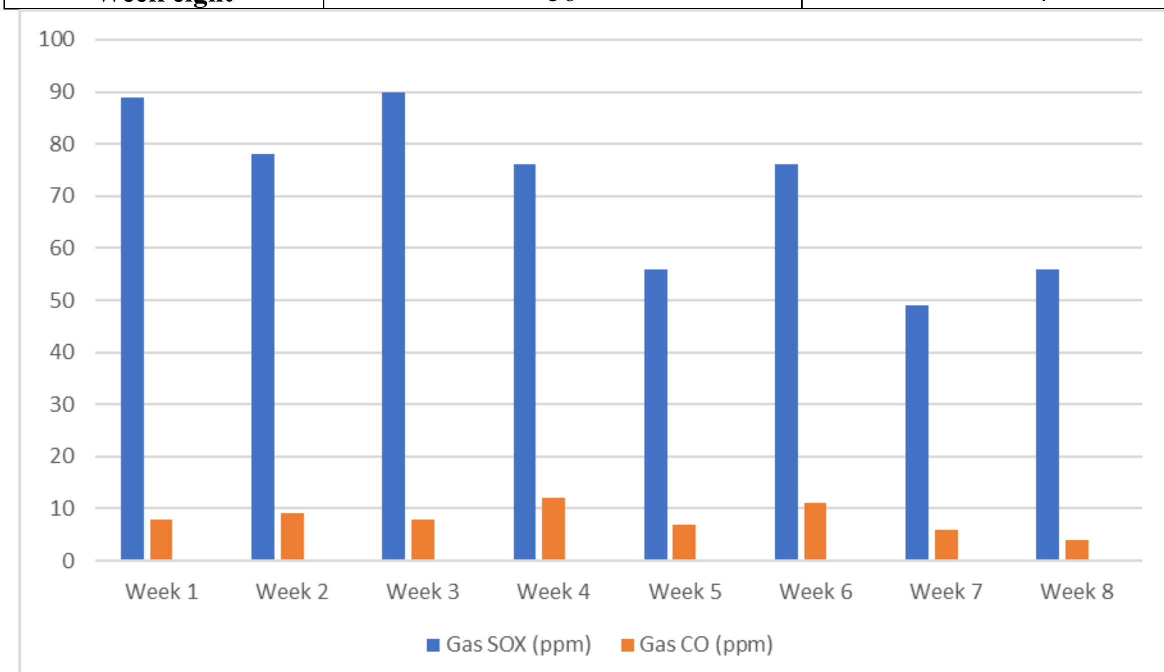

Figure 6 shows the Concentration of gases after adding the treated substance.

Figure 6 shows the results in Table 6. The blue column represents the concentrations of sulfur oxides in parts per million, and the orange column shows the concentrations of carbon monoxide in parts per million after adding the treated material and mixing it with the fuel used in the combustion process.

4. Results and Discussion

The most important of these gases is sulfur oxide in the form of sulfur dioxide and sulfur trioxide, which results in the formation of sulfuric acid inside the boiler. This causes corrosion of the boiler's internal walls, leading to a decrease in the boiler's lifespan and efficiency over time. Pentol Renewable Energy Projects supplied the treated material. The chemical composition of this material (PentoMag) was not detailed, nor was its operation described, out of respect for the company's privacy. A significant part of the reaction that occurs with the fuel was explained, without mentioning the other components. During the experiment, pH was examined before injecting the treated material with the fuel for eight weeks.

Table and Figure No. (1, 2) show the effect of the combustion products of the raw material inside the boiler before the addition of the treated material. We note from the pH measurements of (1.98-2.1) and the percentage of free acid shown in the table that the medium is acidic and that the boiler environment is acidic throughout the experiment. The fuel used contains a high percentage of sulfur, which, upon combustion, is converted into sulfur dioxide (SO_2). This SO_2 can react with moisture in the air to produce sulfuric acid.

This acid contributes to the acidity of the fuel and affects the surrounding environment's acidity [5]. As for Table and Figure No. (3) After adding the treated material, the results indicate a difference in the acidity value. Before treatment, let us consider, for example, the seventh day, when the acidity value was 2.1 at a mixing time of 55 minutes and a free acid percentage of 5.97%. However, during treatment, due to the presence of magnesium oxide (MgO) in the treated material, the acidity value increases, i.e., it approaches a basic medium. This is when comparing the acidity value on the first day before treatment and the first day after treatment, as it was equal to 2.1 on the seventh day before treatment. However, on the seventh day after treatment, the value increased to 4.3, as the magnesium oxide present in the treated material works is to absorb sulfur oxides and converts them into solid magnesium salts that can be disposed of effectively [6].

The following are the most significant chemical reactions that occur within the boiler before and after the addition of the treatment substance.

1. Oxidation of sulfur in fuel to sulfur oxides:

$S\,(s) + O_2\,(g) \longrightarrow SO_2$ .... (2)

then:

$2SO_2\,(g) + O_2\,(g) \longrightarrow 2SO_3$ .... (3)

Sulfur dioxide reacts with oxygen inside the boiler to generate sulfur trioxide, as illustrated in Equations (2) and (3).

2. The reaction of sulfur dioxide and sulfur trioxide with water vapor to form sulfuric acid:

$SO_3\,(g) + H_2O\,(l) \longrightarrow H_2SO_4$……….(4)

The latter subsequently reacts with water vapor or moisture to produce free sulfuric acid, i.e., sulfuric acid not bound to any compound. This free acid is the primary source of acidity responsible for corrosion, as shown in equation (4) [7,8].

3. Magnesium oxide (found in PentoMag) reacts with acid to form a sulfate salt

$MgO + H2SO_4 \longrightarrow MgSO_4 + H_2O$ ……..(5)

4. Magnesium oxide reacts with sulfur dioxide to form sulfates directly.

$MgO + SO_2 + 1/2\ O_2 \longrightarrow MgS + 2O2$ ……….(6)

Upon the addition of a treatment agent containing magnesium compounds, the acid is neutralized, as presented in equation (5,6) [9,10]:

5. Combustion of carbon monoxide into carbon dioxide

$2CO + O_2 \longrightarrow 2CO_2$ …….....….(7)

5-Reaction of nitrogen oxides at high temperatures (within the resulting gases)

$N_2 + O_2 \longrightarrow 2NO$ ……..........… (8)

then

$2NO + O_2 \longrightarrow 2NO_2$ ……..........… (9)

These reactions illustrate the mechanism by which sulfur and carbon compounds are transformed into harmful gases and the role of magnesium oxide in neutralizing them and converting them into stable salts, which leads to a reduction in emissions and internal boiler corrosion.

From this reaction, it is evident that magnesium oxide combines sulfuric acid to yield magnesium sulfate, a basic salt. Consequently, the acidity is reduced, thereby mitigating the corrosion induced by the presence of free acid.

PentoMag is a specialized chemical additive developed by the German company Pentol for use in industrial boiler systems. Its primary purpose is to mitigate acidity, corrosion, and deposit formation that arise from the combustion of fossil fuels. Chemically, PentoMag consists of micronized magnesium oxide (MgO), formulated as a slurry in either an oil- or water-based medium. The formulation also includes selected organic surfactants and dispersing agents that enhance the dispersion, stability, and adhesion of the active components on the metallic surfaces of the boiler. The main function of PentoMag is to neutralize acidic gases generated during fuel combustion—particularly sulfur trioxide (SO_3) and sulfuric acid(H_2SO_4)—thereby reducing the corrosive effects of these gases on internal boiler components. Furthermore, it promotes the conversion of solid combustion residues into a friable and non-adherent form, facilitating easy mechanical cleaning, improving heat transfer efficiency, and extending the operational lifespan of the boiler system.

pH: A scale that quantifies the degree of acidity or alkalinity of a solution, expressed as the Concentration of hydrogen ions (H^+) in the medium.

Free acid: Refers to the fraction of sulfuric acid present in the medium in an unbound or unnaturalized state, not combined with bases or other chemical species.

5. Conclusion

This study confirms that using PentoMag as a fuel additive effectively reduces boiler corrosion in fuel-fired power plants by increasing pH and lowering acid formation. It also decreases harmful gas emissions (CO and SOx), improving both boiler performance and environmental sustainability. Overall, PentoMag enhances efficiency, extends service life, and supports cost-effective power generation.

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