Analyzing greenhouse gas emissions in the ohmic heating drying process of sour orange juice

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Abstract: An ohmic heating device was fabricated. For the heating process in three input voltage gradients and three percent weight loss of the sample were selected. During the thermal process, the power consumption was calculated and then using the ratios of pollution in power plants, the amount of NO_x, SO_2, and CO_2 in three Steam, Gas turbine and Combine cycle power plants was calculated. All experiments were performed in three replications using completely random design (CRD) statistical design and the results were analyzed using SAS software. The highest amount of NO_x was first in the Gas turbine plant and then in the Combine cycle power plant and Steam power plant, respectively. The amount of SO_2 in Heavy gas used in the Steam power plant is more than the other two power plants, and then the highest amount of SO_2 is obtained in Gas turbine power plant and finally in Combine cycle power plant. Also, the amount of CO_2 in the Combine cycle power plant was less than the other two types of power plants. In general, when the factors of ohmic voltage and weight loss percentage are considered for the ohmic process, natural gas and Combine cycle power plant create the best possible state.

Keywords: sour orange juice; ohmic heating; pollution; power plant, processing

Citation: Vahedi Torshizi, M., M. Azadbakht, and M. Kashaninejad. 2024. Analyzing greenhouse gas emissions in the ohmic heating drying process of sour orange juice. Agricultural Engineering International: CIGR Journal, 26(3): 124-133.

1 Introduction

Nowadays, there is a great deal of focus on reducing greenhouse gases because they cause global warming. Due to the increasing food needs and energy consumption in this sector, we are causing an increasing increase in greenhouse gases. These factors will cause climate change, deterioration of living conditions, disease and other problems and is considered as one of the most important challenges in the development of human society (Tonini et al., 2016; Wang et al., 2016).

Over the past 20 years, global carbon dioxide has risen rapidly from 2.7 billion tons in 1990 to 33.9 billion tons in 2011. Reducing greenhouse gas emissions is now seen as a major mitigation measure in the fight against climate change. In recent years, tracking greenhouse gas emissions has become an important aspect of global research on climate change because these data inform national and international political, economic, and environmental negotiations (Liu et al., 2017; Pleßmann and Blechinger, 2017).

On the other hand, electricity generation and

Received date: 2023-12-12 **Accepted date:** 2024-06-05

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power plants are one of the factors polluting the environment because electricity generation requires different fossil fuels, each with its own pollution. Due to the fact that agricultural products need to be processed, electricity is consumed in this sector, which also causes some minor pollution (Ramezani et al., 2018). One of the processing processes of agricultural products is thermal processes which in these processes are done by using the mechanism of heat transfer by conduction, convection and radiation (Azadbakht et al., 2017). The resistance of products to heat conduction leads to a significant loss of quality, therefore, alternative technologies should be used to solve these problems, which ohmic heating method is an alternative method for food processing operations in which the heat inside the food is generated by the passage of electricity (Pleßmann and Blechinger, 2017; Duan et al., 2011; Ozkan et al., 2007).

The ohmic method is a process that directly requires electricity, so the ohmic process, in turn, produces some environmental pollution with electricity consumption. Also, thermal and non-thermal technologies based on physical methods of food preservation have the potential to meet consumer demands and provide high quality products with long life which are free of additives and have not been treated with high heat (Varghese et al., 2014; Vahedi Torshizi et al., 2020a). Ohmic heating is a very fast alternative method and occurs when an alternating electric current passes through a food and the heat generated in it is due to the electrical resistance of the food (Shynkaryk et al., 2010). On the other hand, the ohmic heating method is based on alternating current (AC) and produces heat from the resistance of the product. Initially, AC voltage is applied to the electrodes, and the resulting heat rate is directly proportional to the square of the electric field strength and electrical conductivity. The electric field strength can be changed by adjusting the electrode distance or the applied voltage, however, the most important factor is the electrical conductivity of the product and its temperature dependence. If the product has more than one phase, the electrical conductivity of all phases must be considered.

Electrical conductivity increases with increasing temperature, which could theoretically lead to heating. The difference in electrical resistance and its temperature dependence between the two phases can greatly complicate the thermal properties of the system. Also, since the electrical conductivity is affected by the ionic content, the electrical conductivity of the product (both phases) with the ion surface (e.g., salt) is effective in achieving ohmic heat (Golob et al., 2002).

One of the advantages of ohmic heat is the creation of a uniform heating and the production of high quality products with minimal changes in structural and nutritional properties. It is also an environmentally friendly method that has been considered due to its beneficial properties(Saberian et al., 2017). The use of heating technology historically dates back to the nineteenth century, but its most successful commercial applications in the food heating process took shape after the 1900s. At this time, ohmic heating was used for the first time to pasteurize milk and became known as the electropore process (Anderson and Finkelstein, 1919).

Atuonwu et al. (2018) investigated comparative assessment of innovative and conventional food preservation technologies: process energy performance and greenhouse gas emissions. The results show that for the same product quality, the innovative technologies are more energy- and non-renewable primary resource-efficient, with ohmic heating performing best, followed by high pressure processing at high fill-ratios (Atuonwu et al., 2018).

Ghnimi et al. (2021) evaluated on life cycle assessment and energy comparison of aseptic ohmic heating and appertization of chopped tomatoes with juice. The uncertainty analysis results indicated that the global warming potential for appertization of 1 kg of packaged chopped tomatoes with juice ranges from 4.13 to 4.44 kg CO2eq. In addition, the global warming potential of the ohmic heating system ranges from 2.50 to 2.54 kg CO_2eq. This study highlights that ohmic heating presents a great alternative to conventional sterilization methods due to its low environmental impact and high energy efficiency.

Stojceska et al. (2019) reported ohmic and conventional drying of citrus products: energy efficiency, greenhouse gas emissions and nutritional properties. The results revealed that there was a positive increase of the ETC over time in both samples, resulting in higher values of 700°C for the orange samples and 1000°C for the grapefruit samples. The moisture content of the samples was significantly (p<0.05) reduced during ohmic and thermal dehydration over time while no significant difference was detected in terms of pH and Vitamin C level. The analysis of energy consumption showed that thermal dehydration was between 3.5 and 5 times higher than ohmic dehydration. Similar trend was observed in terms of cost and GHG emissions (Stojceska et al., 2019).

Given that the study of energy and greenhouse gas emissions is very important in the industry, in this research the ohmic process has been investigated, which is a common process for heating in the food industry and this process converts electrical energy into heat. The greenhouse gases of three power plants, Steam, Gas turbine and Combine cycle, which is a common power plant in Iran, have been studied in order to study and evaluate the changes in the amount of greenhouse gases NO_x, SO_2 and CO_2 produced in different voltages and weight changes of ohmic process.

2 Materials and methods

2.1 Sample preparation and testing

To perform the ohmic process, drying sour orange juice was selected. The sour oranges were obtained from a garden located in Gorgan city, Golestan province, Iran. All the experiments were conducted in the Bio system Mechanics Department of Agricultural Sciences and Natural Resources of Gorgan University.

The sour oranges were washed and the sour orange juice was taken. The prepared sour orange juice was poured into a transparent plastic cell (6 × 6 × 6 cm), with two stainless steel on either side. The initial temperature of the sample was recorded and voltage was applied to the set by a variable transformer (3 kW, 0–300 V, 50 Hz, MST – 3, Toyo, Japan). A power analyzer (Lutron DW-6090) is also used to monitor and control the energy behavior of the system, also, a thermocouple, and a computer were used. A scale with an accuracy of 0.01 g was used to measure weight during the experiments.

To perform the heating process, three voltage gradients of 8.33, 10.83 and 13.33 V cm^{-1} were selected and about 10%, 20% and 30% of the total weight of the sour orange juice samples poured were evaporated during the heating process (Figure 1).

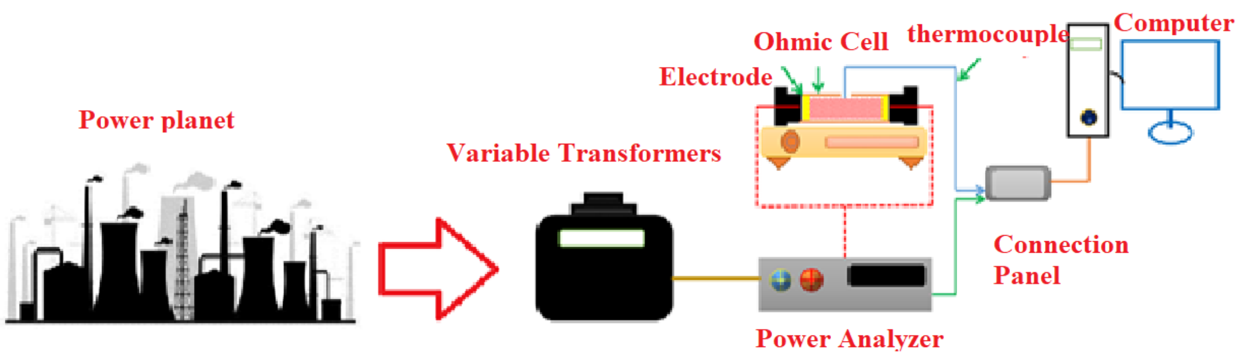

Figure 1 Schematic of equipment used for the ohmic heating processs and power planet

Power consumption was also calculated using Equation 1 (Vahedi Torshizi et al., 2020b):

$$P = V\times I \quad (1)$$

Which, P is the power consumption (W), V is voltage (V) and I is current flow(A).

The energy given to the system was calculated according to Equations 2 and 3 (Srivastav and Roy, 2014):

$$E_{given} = E_{taken} + E_{loss} \quad (2)$$

$$\sum(VIT) = mc_p(T_f - T_i) + E_{loss} \quad (3)$$

In this formula, E_{given} is the energy of system (J), T_f is the final temperature (℃), E_{taken} is the energy taken from the system (J), T_i is the input temperature (℃), E_{loss} is the energy lost in the system (J). Specific heat of the sample C_p is the coefficient of performance system, m is the mass of the sample (kg).

2.2 Greenhouse gas emissions

The amount of greenhouse gas emissions per 1 kg of electricity generation in different power plants was calculated using gas production factors reported by reputable organizations (Ministry of Energy of Iran, Energy Balance of Iran and International Energy Organization).

It should be noted that the indirect method has been used to calculate the gas emission based on the electricity consumption of the drying process. To find the amount of energy produced in different power plants to extract 1 kg of water during the ohmic process of sour orange juice, first the energy requirements of each experimental treatment were determined. After determining the energy needs of the experimental treatments for the ohmic system and preheating, the power transfer coefficient of 13.13% (of the total energy production) from the power plant to the point of consumption was selected.

The internal consumption coefficient (3.2% of the total energy production) of the power plants was used to determine the total electricity production. Then it was used to calculate the emission of pollutants per 1 kW h of electricity consumption (Kaveh et al., 2020).

Table 1 shows the average amount of greenhouse gas emissions (SO_2, CO_2 and NO_x) from different power plants classified by fuel type for energy production of 1 kW h.

Table 1 The amount of greenhouse gases produced per one kWh of electricity generated in power plants with different fuels (Nazari et al., 2010)

Power house type	Fuel type	Greenhouse gas (g (kw h)$^{-1}$)		
		NO_x	SO_2	CO_2
Steam	Natural gas	2.69	0	636
	Heavy oil	2.52	15.25	1025
Gas turbine	Natural gas	1.91	0	782
	Gas oil	5.79	3.84	1048
Combined cycle	Natural gas	2.95	0	450
	Gas oil	3.78	2.32	622

2.3 Experimental design

The amount of electricity consumed in kW h was examined. In order to evaluate the amount of electricity consumption, three voltages and the percentage of weight loss of different samples in the ohmic process were evaluated, which were independent factors. After examining the amount of energy consumed, the amount of greenhouse gas emissions in three power plants: Steam, Gas turbine, Combine cycle in two different types of fuels were compared in terms of emissions using completely random design (CRD) statistical design and the results were analyzed using SAS software.

3 Results and discussion

3.1 Statistical study and comparison of all three power plants in the amount of greenhouse gas emissions during the ohmic process

This section provides an overview of the effect of power plants, ohmic voltage and weight changes on NO_x, SO_2 and CO_2 values. Figure 2 shows the amount of NO_x produced in different power plants with the fuels used in it. According to Figure 2, gas turbine plant using gas oil had the highest amount of NO_x production. Comparing the natural gas fuel in the three power plants, it can be stated that there was no difference between the amounts produced by NO_x in the two power plants, Steam power plant and Combine cycle power plant, but the Gas turbine plant had a significant difference with these values and the lowest amount of NO_x produced also belonged to the same power plant and type of fuel. In general, it can be said that the highest amount of NO_x was first in the Gas turbine plant and then in the Combine cycle power plant and Steam power plant, respectively.

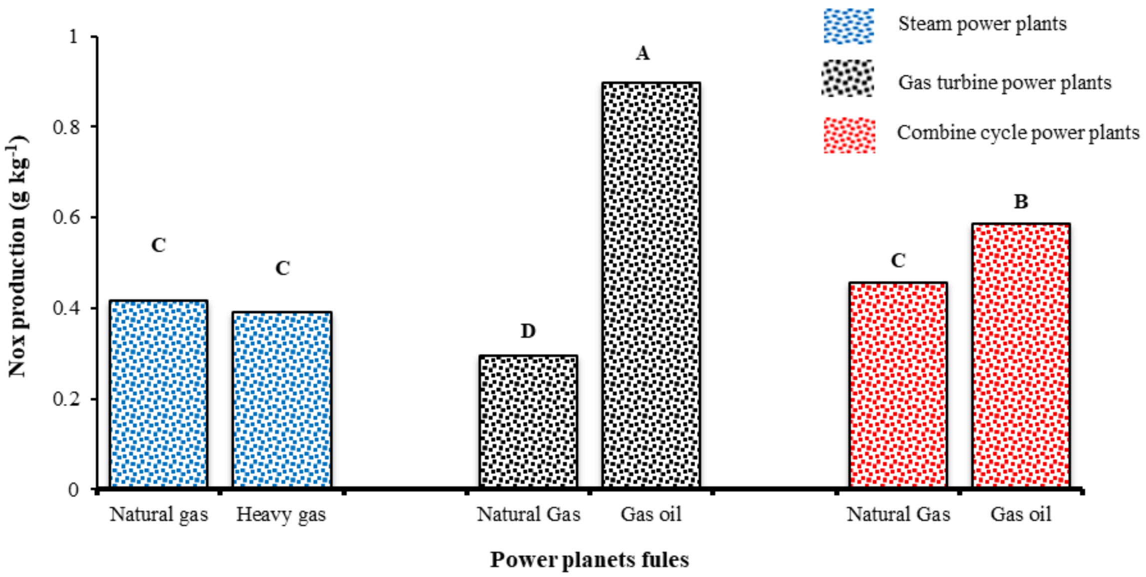

Figure 2 Comparison of NO_x averages in different power plants

For the amount of SO_2 (Figure 3), the amount of SO_2 for natural gas in all power plants was zero, and comparing the two types of fuel gas oil and heavy gas, the results were as follows that the amount of SO_2 in heavy gas used in Steam power plant is more than the other two power plants, and then the highest amount of SO_2 is obtained in Gas turbine power plant and finally in Combine cycle power plant. Also, all three power plants were statistically significant.

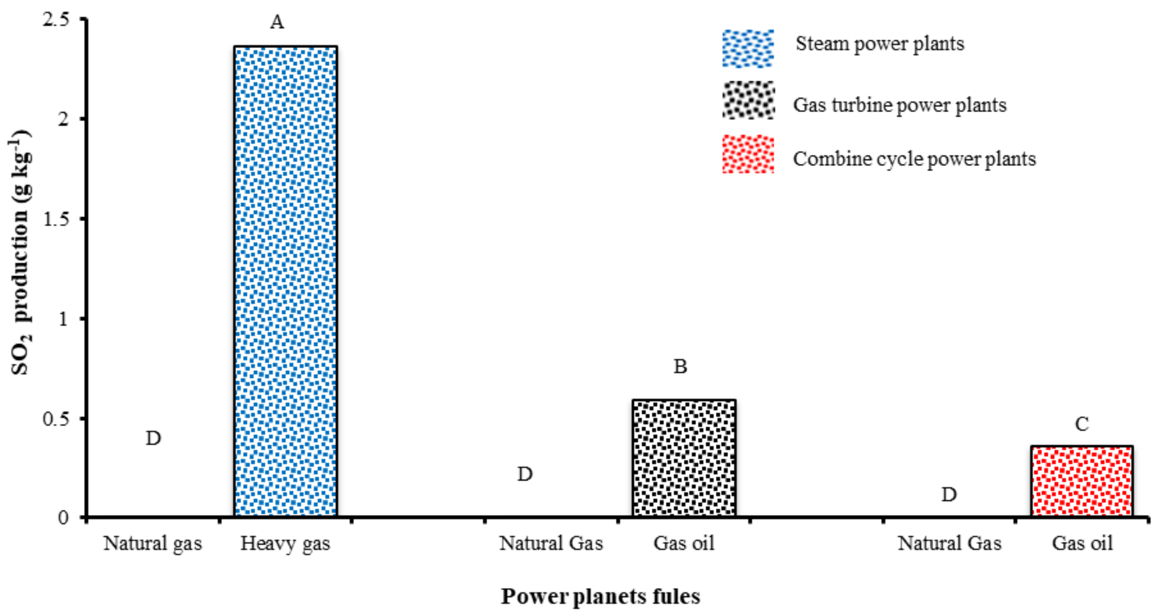

Figure 3 Comparison of SO_2 averages in different power plants

Finally, the CO_2 values shown in Figure 4 indicate that the amount of CO_2 in the Combine cycle power plant was lower than in the other two types of power plants and both types of fuel used in this power plant had lower amounts than other power plants. The lowest amount is obtained in natural gas of this same power plant. There was a significant difference between the three natural gas in all three power plants for the amount of CO_2, but there was no significant difference between gas oil in Gas turbine power plant and heavy gas in Steam power plant and these two types of fuels in the two power plants were significantly different from gas oil in the Combine cycle power plant.

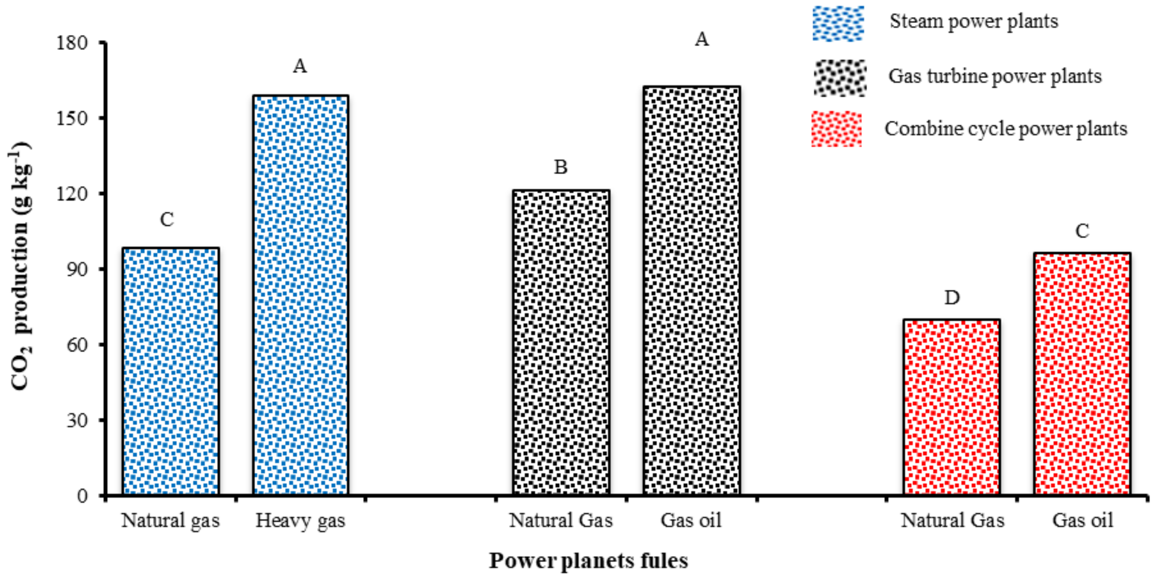

Figure 4 Comparison of CO_2 averages in different power plants

3.2 Comparison of averages of greenhouse gases generated in power plants and different voltages in the ohmic process

Figure 5 shows the NO_x values at different voltages as well as different power plants. According to Figure 5, the highest amount of NO_x was obtained in the Gas turbine power plant and in the type of gas oil of this power plant, and the amount of NO_x in all three voltages of 50, 65 and 80 V had the highest amount of NO_x compared to other fuels and power plants. After this power plant, there was the highest amount of NO_x in all three voltages for the type of gas oil in the Combine cycle power plant, which in this type of power plant was 50, 65 and 80 V more than the rest of the power plant. From the statistical results, it can be stated that for 80 V of Steam power plant in any type of fuel used and natural gas fuel in Combine cycle power plant, the value of NO_x has not shown almost significant difference. But the other modes differed significantly in terms of NO_x output, and for a voltage of 65 V, statistically similar results were obtained at 85 volts. For a voltage of 50 V in terms of NO_x production, it can be seen that a significant difference is obtained only in gas oil for the Combine cycle power plant.

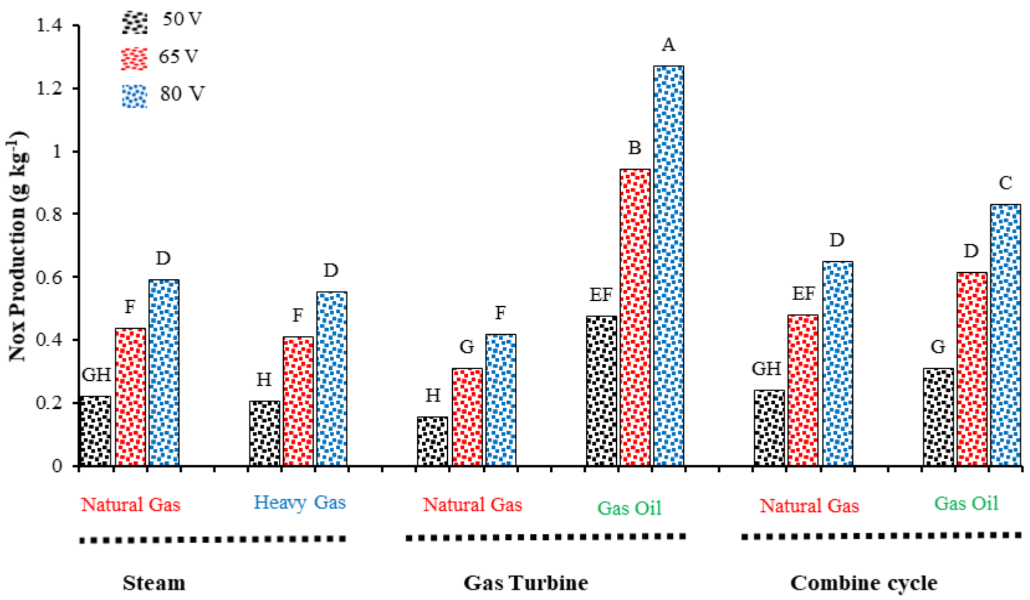

Figure 5 Comparison of NOx averages at different power plants and voltages

Figure 6 also shows the amount of SO_2, which as shown in the figure, the amount of natural gas in all three power plants was zero and there was a significant difference between all fuels and power plants. The highest amount of SO_2 was obtained in Steam power plant and heavy gas fuel and the lowest amount of SO_2 was obtained in Combine cycle power plant with gas oil fuel. There was a statistically significant difference between all three voltages in all power plants.

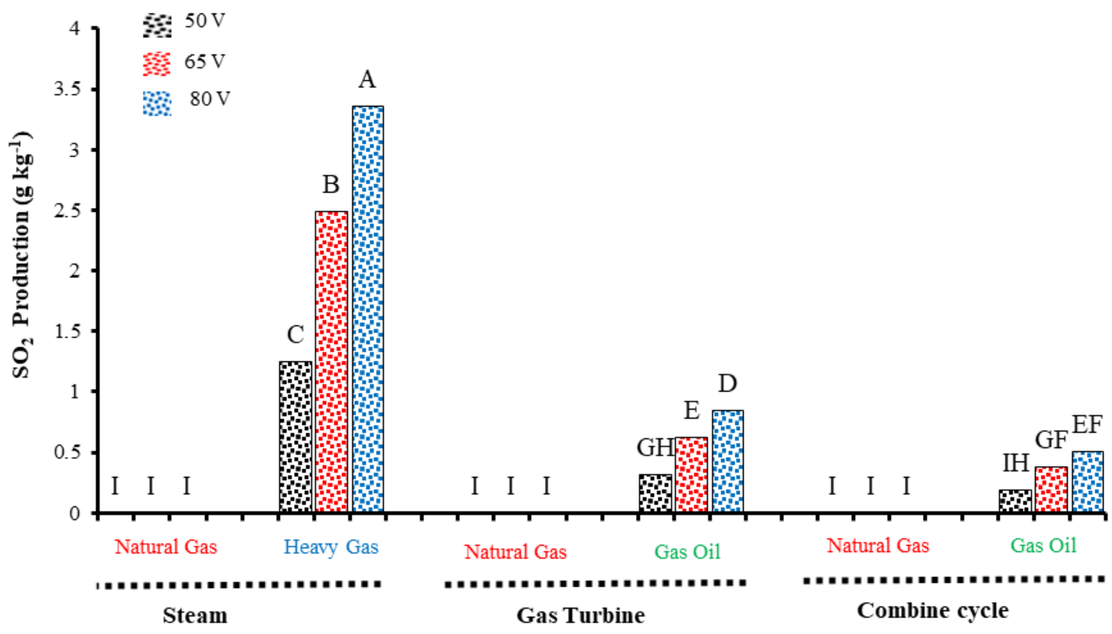

Figure 6 Comparison of SO_2 averages in different power plants and voltages

The statistical analysis of the amount of CO_2 production in power plants, fuels and different voltages shown in Figure 7 shows that there was a statistical difference between all the voltages in all power plants and the fuels in them. Examining the voltage of 80 V in the amount of CO_2, it is observed that there is no significant difference between heavy gas and gas oil in the Gas turbine power plant, and this lack of significant difference for natural gas fuels in the Steam power plant and gas oil in the Combine cycle power plant have seen. The rest of the fuels differed significantly in this voltage. At 65 and 50 volts, exactly the same conditions as 80 V in similar power plants and fuels are statistically obtained for CO_2 production.

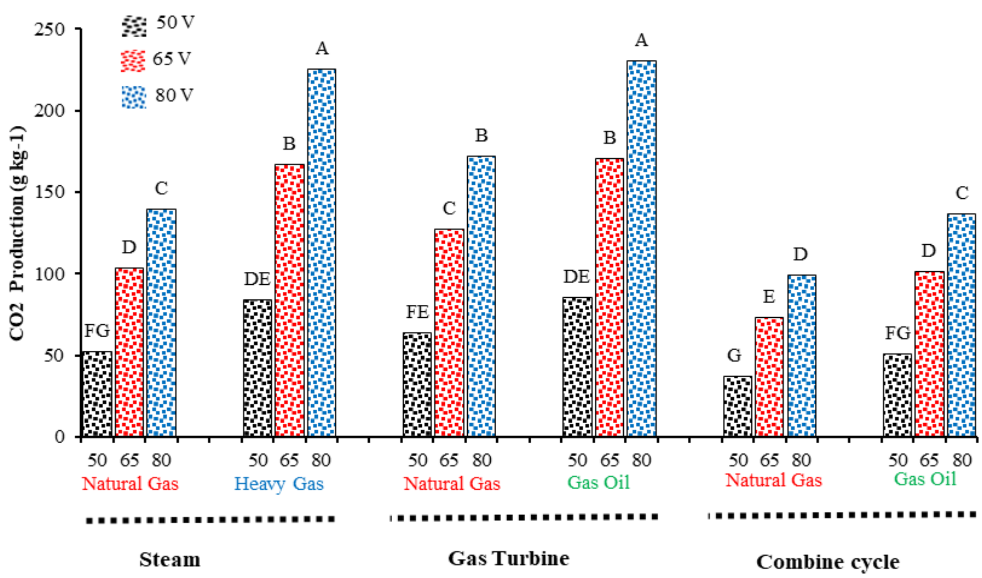

Figure 7 Comparison of CO_2 averages at different power plants and voltages

3.3 Comparison of averages of greenhouse gases generated in power plants and different weight changes in the ohmic process

Figure 8 shows the comparison of the mean for the effect of weight changes in the ohmic process and the amount of NO_x production in power plants and fuels used in each power plant. According to Figure 8, it can be seen that the highest amount of NO_x production in the Gas turbine power plant was with gas oil, which was significantly different from other power plants and fuels. The lowest amount of NO_x production has been observed in the same power plant with the type of natural gas fuel, and after this power plant, the highest amount of NO_x has been observed for the Combine cycle power plant in both types of fuel consumed. Of the three plants surveyed for the NO_x value, Steam power plant produced the lowest NO_x when weight changes in the ohmic process were considered.

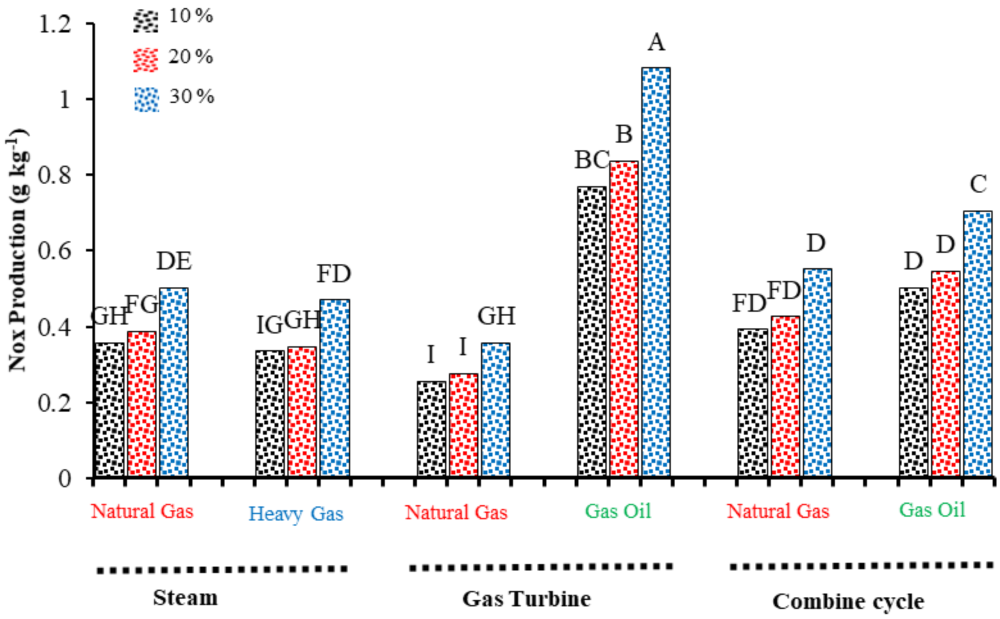

Figure 8 Comparison of NO_x averages in power plants and different weight changes

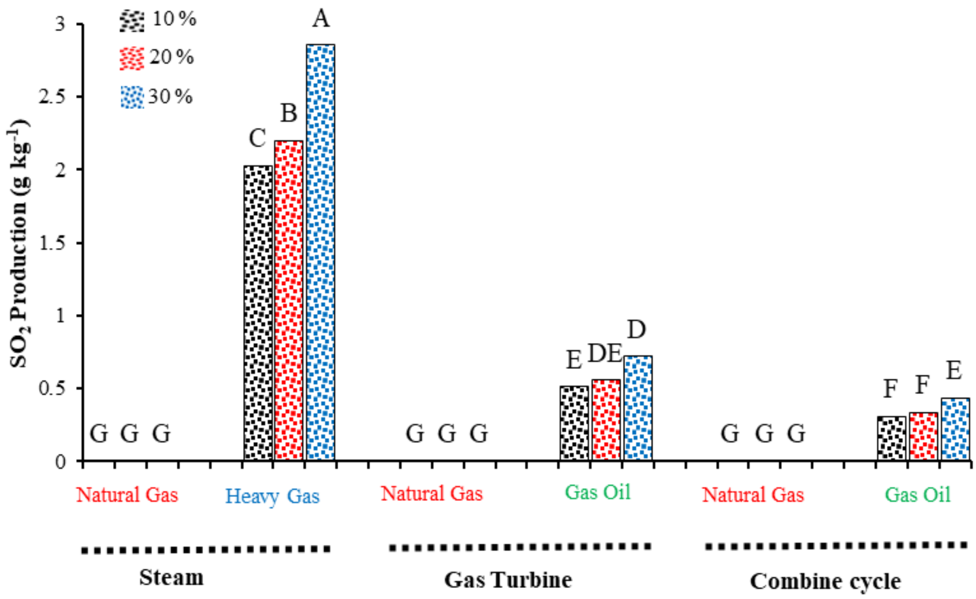

Figure 9 Comparison of SO_2 averages in power plants and different weight changes

The amount of SO_2 production in different weight changes is shown in Figure 9. According to the figure, there is a significant difference in the amount of SO_2 between all three power plants for all weight changes and the increase in weight changes has increased the amount of SO_2production in all three power plants. The highest amount of SO_2 was obtained in Steam power plant, which even in this power plant, a significant difference was observed between different weight changes. This means that the use of different weight changes during the ohmic process causes significant changes in SO_2 production and for the Gas turbine power plant there was a significant difference between the weight changes, but for the Combine cycle power plant, there was no difference between the weight of SO_2 produced between the weight changes of 10% and 20% and the lowest amount of SO_2 has been observed in the same power plant.

Figure 10 also shows a statistical comparison between three power plants using different fuels and different weight changes during the process for CO_2 production. According to the figure, it can be said that the use of gas oil and gas heavy fuel in Gas turbine and Steam power plants showed similar CO_2 values that are in the same statistical group and no difference was observed between these two power plants and fuel. However, the rest of the fuels in other power plants were significantly different from each other and the lowest amount of CO_2 in the Combine cycle power plant was obtained with the type of natural gas fuel. In general, the use of this gas fuel had less CO_2 than other fuels in similar power plants.

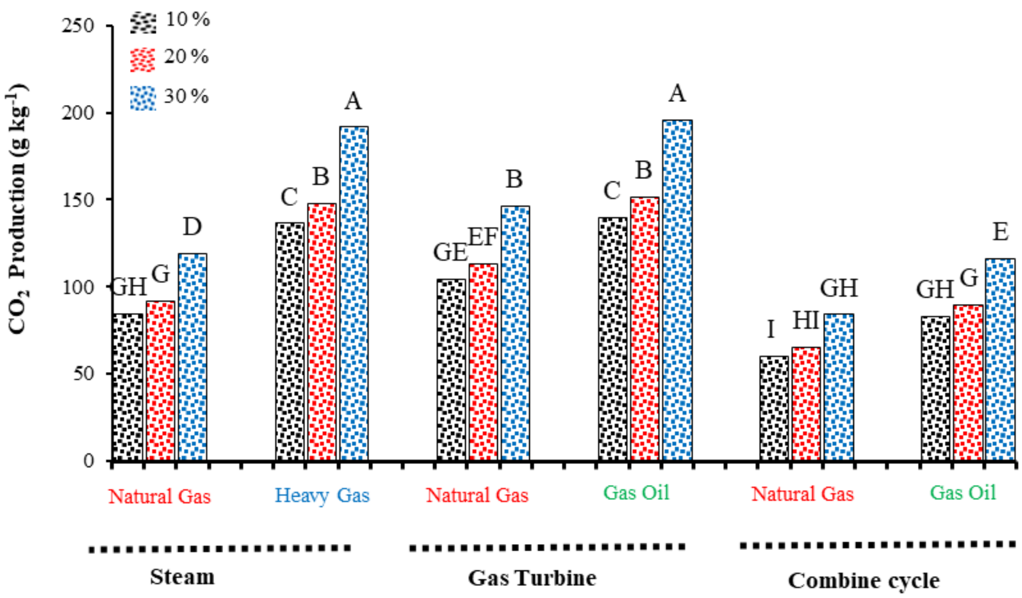

Figure 10 Comparison of CO_2 averages in power plants and different weight changes

4 Conclusion

In total, comparing the three power plants, it can be stated that the use of Steam power plant to generate electricity produced less NOx, SO_2, and to produce CO_2, the least amount was for the Combine cycle. Among the fuels used, natural gas was more suitable for electricity generation because it had less pollution in power plants. Also, in statistical comparison of ohmic voltages and pollutant production in three power plants with different fuels, the lowest amount of pollution was in 50 V and Gas turbine power plant for NO_x, Also CO_2 and SO_2 in Combine cycle power plant were the lowest amount in natural gas fuel. Finally, it can be said that when the ohmic voltage and weight loss factors are considered for the ohmic process, natural gas and the Combine cycle power plant create the best possible state.

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