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Research Article

A Prototype Electrofilter Design and Fabrication for Electricity Generation and Emission Reduction from Flues

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Abstract

With the increase in population and the rapid development of industrialization, there has been an increase in the use of fossil fuels. As a result of this use, some harmful gases and materials such as sulfur dioxide, carbon dioxide and particles are emitted to the environment. If these harmful pollutants are not cleaned, the air quality of the relevant place will be adversely affected. Especially, environmental pollution has occurred with harmful particle release from the flues in the facilities. In addition, heat release in the flue is lost for the system. In this study, it is aimed to decrease pollution and to contribute to energy efficiency by using electrofilter, which is an electronic method. Experimental studies are carried out on the prototype created in the laboratory. The performance of electrofilter is studied for different properties of electrodes such as width, length, and the number. According to the results, it is seen that the amount of emission can be reduced by increasing the electrode surface area. Electricity can also be generated by harvesting waste heat inside the flue with appropriate electronic equipment and it can be used to energize the system when necessary. Besides, prototype has a user interface and wireless communication features. Thus, an environmentally friendly and remotely observable system is acquired.

Keywords: Electrofilter, Flue gas, Thermal power plant, Energy harvesting

1. Introduction

Flues used in industrial plants, solid-liquid-gas-fired thermal power plants, and restaurants emit dirty and harmful emissions into the air if they have no cleaning systems. This pollution negatively affects the life of living creatures near the facilities. Flue gas cleaning is divided into two to control particle and gaseous pollutants. It is necessary to use filtering equipment such as gravitational settling chambers, electrofilters, fabric filters, gas scrubbers, cyclones, etc. in order to protect the environment and living creatures against particle-based air pollution [1, 2].

Electrofilter or electrostatic precipitators (ESP), which is one of the methods used to reduce harmful flue emissions, have advantages such as high particle collection efficiency, wet-dry particle collection, high-temperature operation, and minimum moving parts. On the other hand, they have disadvantages with high cost, high voltage requirement, and a decrease in efficiency over time. Electrofilters work according to the principle of static electricity, and they can reduce the emission of polluted air to the external environment by loading the particles passing through the air with high voltage. [2, 3].

S. Vukosovic [3] has developed a 70 kV high-frequency high voltage power supply to improve ESP's particle collection and energy efficiency. This power supply consists of a 3-phase rectifier, full-bridge inverter, high-frequency transformer, and filter circuits. As a result of experimental studies, it has been observed that high-frequency power supplies reduce particle emission by twice as compared to conventional thyristor-based power supplies. J. Zhu et al. [4] have studied a hybrid particle cleaning system consisting of an ESP with a single-phase 55 kV, three-phase 71 kV power supply, and fabric filter techniques. It is stated that the particle emission decreases with the increase of applied voltage. D. F. Sierra et al. [5] have developed the ESP prototype for use in a coal mine. This prototype has a user interface, data logging, and wireless communication features. However, in this system, the AC voltage is increased by a transformer with a conversion ratio of 1:20 and given to the rectifier stage. As a result of this study, it is stated that ESP systems can be prototyped in a laboratory environment and that high flue temperature is an important issue. S. Fan et al [6] have simulated and experimentally designed a 60 kV multi-module, half-bridge power supply for ESP. However, no trials have been made on an ESP system. R. B. Kolembekar et al. [7] have used thermoelectric generators (TEGs) to harvest the internal waste heat. However, in this study, unlike our study, the result of emission reduction has not been reported. In the majority of these studies, harvesting the waste heat inside the flue and recovering it as electrical energy have not been found.

In this study, an electrofilter is designed in a laboratory environment to provide clean air to nature as much as possible by reducing the emission of polluted air from the flues of factories, industrial furnaces, thermal power plants, etc. This prototype has a user interface and wireless communication features. Its voltage level is 60 kV. The effect of electrodes with different properties on electrofilter performance has been experimentally performed. It has also been shown that electricity can be produced from waste heat with the help of a thermocouple operating on the principle of thermoelectric effect.

2. Materials and Methods

The operation of the electrofilter is based on the principle of collecting ash particles by electrical charging and removing them from the system. There are many plates parallel to each other in the vertical position in the electrofilters. Flue gases pass between these plates. There are charge electrodes placed between the plates to create an electric field between the plates. Discharge electrodes between the plates are connected to a high-voltage DC power source and have a negative pole. As the flue gases pass through this area, the ash pieces are loaded with a negative charge. These charged ash particles are attracted by the collecting surfaces and spread over the surface. The chemical properties of ash affect their ability to be electrically charged [2].

The schematic diagram of the experimental setup used in this study is given in Figure 1. The prototype system is made of aluminum plates and the electrodes are placed. A metal tray is located under the flue to create smoke. To prevent the flame from entering the flue, sufficient space is left between the tray and the flue starting point, and necessary insulation is made.

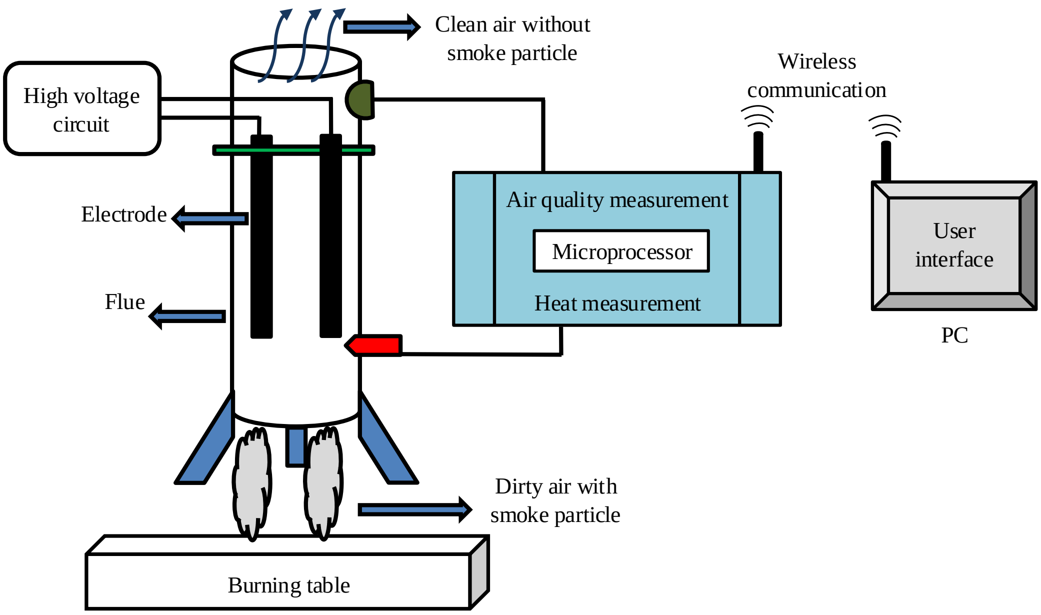
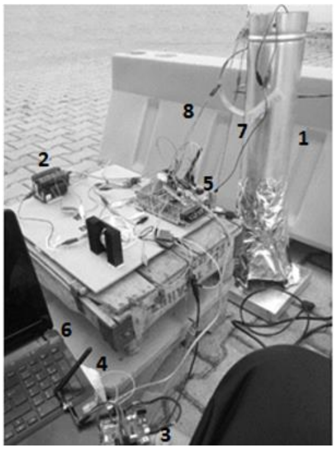


Figure 1: Schematic diagram of the experimental setup for the prototype electrofilter system

The photos of the studied system and electrodes with different physical properties are given in Figure 2 and Figure 3, respectively. The material used for plate electrodes is aluminum while the wire electrode is steel. The heights of the plate electrodes and wire electrode are 0.1 cm and 0.2 cm, respectively. In addition, the length of the wire electrode is about 35 cm. The width and length of are 2.3 cm x 27 cm for thick-long, 1.1 cm x 27 cm for thin-long, 2.3 cm x 13.4 cm for thick-short and 1.1 cm x 13.4 cm for thin-short electrode. The effect of these electrodes on electrofilter performance is examined.



1- Flue
2- Flyback transformer
3- Microprocessor 1
4- Receiver RF module
5- Transmitter RF module-microprocessor 2
6- PC
7- Electrode cables
8- Thermocouple cables

Figure 2: Image of the flue and the circuit

Figure 3: The different types of electrodes (from up to down: wire, thick-long, thin-long, thick-short, thin-short)

In this study, the converter circuit containing the flyback transformer in Figure 4 is used to obtain a DC voltage of approximately 60 kV [8]. The feeding of this converter circuit is made with adjustable DC power supply and its amplitude value is set to 12 V. Arduino platform with ATmega328 processor is preferred as the central controller. 2N3055 is a BJT NPN transistor with a maximum collector current of 15 A and a maximum base current of 7 A and has been used for controlled switching [9]. To prevent overheating of the transistor, a 7x7.8 cm aluminum heatsink is used. UF5408 is an ultrafast diode with forward-current 3 A and DO-41 sheath. The primary winding number of the flyback transformer is in two parts and the wire cross-section is 1 mm^2. R1 resistor is 220 Ω/2 W, and R2 resistor is 22 Ω/5 W. INA219 sensor which can measure current in the range of ± 3.2 A and measure voltage up to 26 V is used for electrical measurements. MQ-135 sensor is preferred for air quality measurements.

If any conductor is subjected to a temperature gradient, a voltage is obtained. This phenomenon is called the thermoelectric effect. As a result of this phenomenon, thermocouples are devices used to obtain electric current by heating the junction surfaces of two different metals (such as chromel and alumel). The electric current generated in the thermocouple depends on the temperature of the junction point and comes from the different electrical and thermal properties of the metals. In other words, electrons in the high-temperature zone contain high thermal energy, and these electrons move towards the cold zone. As a result of this process, a voltage of microvolt and millivolt level arises at the output ends [10, 11]. AD8495 is also used for temperature measurement. The internal structure of AD8495 is given in Figure 5 and is only compatible with K type thermocouple. The temperature measurement range is between -25 °C and + 400 °C [12]. With this module, the DC output voltage depending on temperature can be obtained. During the experimental study, a dirty release was created with a suitable method and it was tested whether the filter reduces the emission amount through electrical, particle, and temperature measurements.

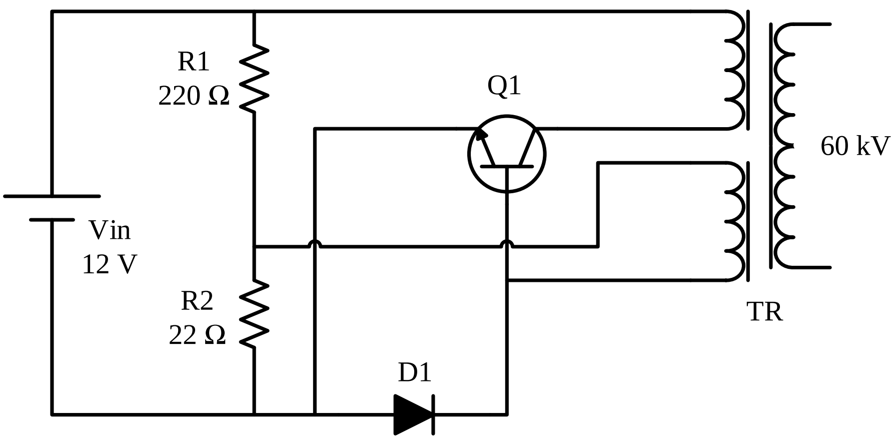


Figure 4: 12 V-60 kV Flyback booster [8]

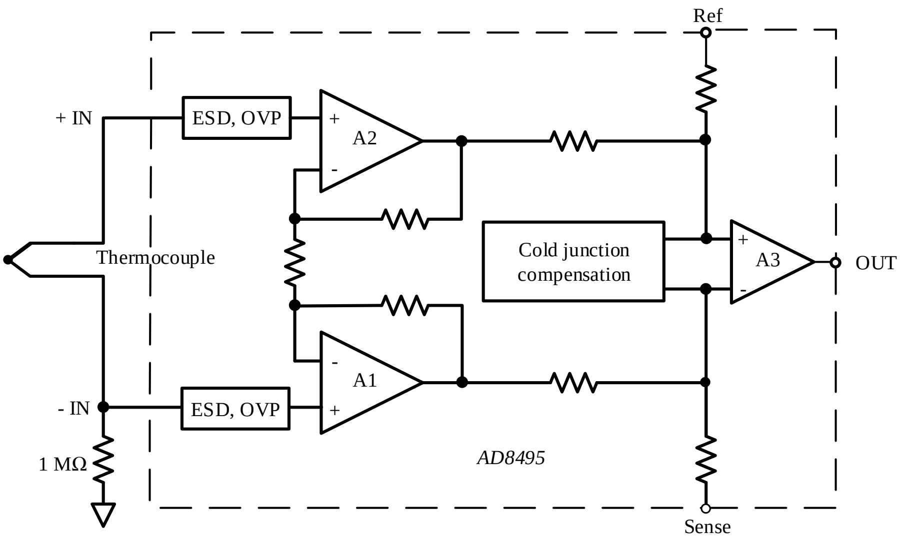


Figure 5: Internal structure of AD8495 [12]

Moreover, the system has the feature of wireless communication with the RF technique. An nRF24L01 module is used for this purpose. This module has a digital RF wireless communication chip that works both as a receiver and a transmitter in the 2.4 GHz frequency band developed by the Nordic company. The photo of this module and antenna are given in Figure 6. According to the characteristics of the datasheet of nRF24L01, measurement results can be obtained from a distance of 1 km in the open field [13]. Finally, a user interface is created with the C # program and the system is controlled and monitored via computer.

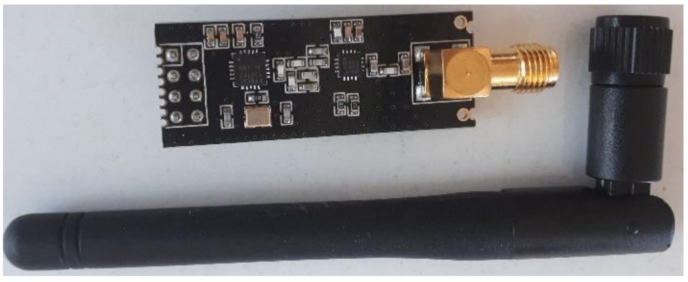


Figure 6 :. nRF24L01 module and antenna

3. Results and Discussion

Firstly, the flue prototype is made and the placement of the electrodes is performed. In the electrode layouts, five different electrode assemblies were used, such as wire, thin-short, thick-short, thin-long, and thick-long. Here, multiple factors such as width, length, and the number of electrodes were also examined. In the basic application, two electrodes from each electrode structure are placed parallel to each other in the flue. By using different electrodes in Figure 3, which electrode system gives better results has been examined. The results obtained by taking into account whether the ESP is active or not are given in Table 1. The fire and smoke conditions under the flue are not naturally equal in each electrode change. For this reason, other measurements were taken at the moments when the air pollution measurements made in the system without electrofilter were equal as much as possible. And then electrofilter was switched on.

According to the measurements given in the Table 1, with the activation of the electrofilter in the wire electrode structure, the emission pollution degree drops from 434 ppm to 361 ppm. The reduction rate here is about 17%. Similarly, the decrease rates are about 24%, 40%, 30%, and 61% in thin-short, thick-short, thin-long, and thick-long electrode structures, respectively. Therefore, the best performance in terms of cleaning the flue release is obtained in the thick-long electrode, and the worst performance is obtained in the wire-type electrode. As the electrode surface area increases, the emission decreases because the particle collection capacity increases [3]. According to the temperature measurements made inside the flue, the electrode structures did not have a significant effect on the temperature value. However, a decrease in temperature values was observed because of the decrease in release with the switched-on of ESP in general. For example, DC voltage decreases from 1.85 V to 1.76 V in the thick-long electrode study while the temperature decreases from 119.14 ℃ to 102.54 ℃. Thus, this decrease caused the DC voltage value produced by the harvest of the waste heat in the flue to decrease in general. With the energy harvest, an average DC voltage of 1.8 V was produced for each type of electrode. According to the results, as the amount of temperature inside the flue increases, the value of this voltage obtained with energy harvest will increase. Waste heat-based voltage can be used for the feeding of the converter and DC voltage source can be selected at a lower amplitude. The generated voltage value is approximately 15% of the amplitude value of the 12 V DC voltage source used in this study. By using this voltage to contribute to the converter input voltage, it can be recycled and contributed to energy efficiency.

The reference voltage according to the temperature value calculation equation in the datasheet of the module is 1.25 V and corresponds to 1.5 V at 50 °C [12, 14]. The temperature is calculated by the equation (1). According to the sample calculation given below (Table 1), the temperature value measured at an output voltage of 1.74 V is 98 °C.

$$T_{Mj} = \frac{V_{out} - V_{Ref}}{5\frac{mV}{℃}} \quad (1)$$

$$T_{Mj} = \frac{1.74 - 1.25}{0.005} = 98\ ℃$$

Table 1: Measurements in different electrode structures

Electrode type	Emission pollution degree (ppm)		Voltage (V)		Temperature (°C)	
	Without filter	With filter	Without filter	With filter	Without filter	With filter
Wire	434	361	1.79	1.79	107.37	108
Thin-short	448	339	1.82	1.74	113.67	98.79
Thick-short	414	247	1.79	1.74	107.85	98.67
Thin-long	428	298	1.76	1.77	101.81	103.23
Thick-long	452	178	1.85	1.76	119.14	102.54

According to Table 1, where the two-electrode results are shown, the lowest emission is obtained from the work with electrodes in the thick-long structure. Therefore, the effect of increasing electrode number has been tested in this configuration. At this stage, as a result of the work carried out with a four-electrode structure, the emission pollution degree is measured as 408 ppm while the ESP is off and 205 ppm when the electrofilter is on. According to these results, with the activation of electrofilter, a reduction of 50% in the amount of emission is achieved. Furthermore, there is a 10% improvement in the level of emissions compared to two electrodes.

The measurement values taken from the system are sent via radio waves to the receiver nRF24L01 module with an antenna on the computer side. These values are displayed in a simple and user-friendly interface prepared with the C# program. The visual of this interface is given in Figure 7.

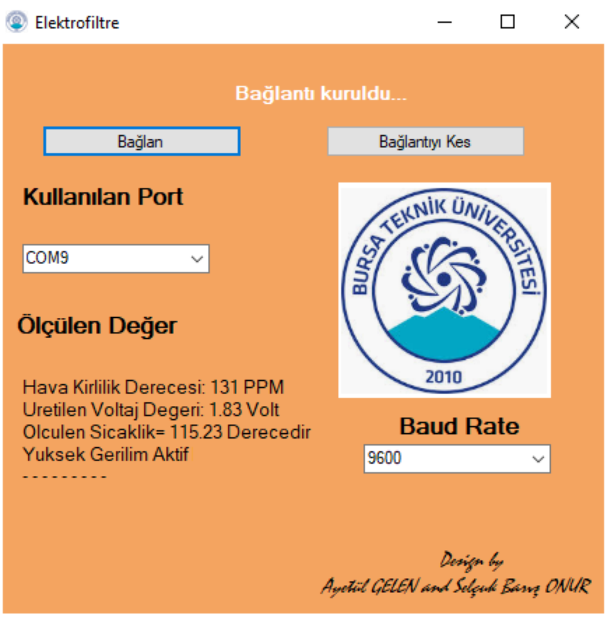


Figure 7: PC user interface

4. Conclusion

In this study, it is aimed to reduce the harmful particles released from the flues to a minimum level by electronic method. It has also been shown that electricity can be produced from waste heat inside the flue via a suitable converter working with the thermoelectric effect. Moreover, it is recommended that harvested energy can be used to charge the electrodes when necessary. In the study with four thick-long electrode, the emission pollution degree is 408 ppm and 205 ppm with the electrofilter off and on, respectively. A reduction of 50% in the amount of emission is achieved with the activation of electrofilter. Furhermore, there is a 10% improvement in the level of emissions compared with the two-electrode configuration. As a result of the experimental studies, it has been observed that the particle cleaning performance increases with the increase in the surface area and the number of electrodes used in the flue. Heat losses are reduced with the harvest of waste heat. Thus, a system that is both environmentally friendly and sustainable is obtained, and it is also remotely observable through user interface.

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