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Flat Cap Atomizer Performance in Filtering Welding Fume

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Abstract

To suppress or filter the harmful contaminants contained inside welding fumes, air filters are the essential device. This study focuses on the filter's performance in a local exhaust ventilation system (LEV) by using an internal mixing atomizing nozzle. Experimental work will be carried out to determine the atomizer's performance according to the correct method and procedure to ensure a valid result and data are achieved. The type of internal mixing atomizing nozzle implemented in this experiment is a Flat Cap Atomizer. The instalment of internal mixing atomizing nozzle to the LEV system creates a difference in the pressure of air inside the ducting system. When the welding process starts, the welding fume will be suck by the LEV system and going through a filter box attached with the atomizer which produces water mist to act as a filter before being released into the environment. At the end of this study, the data collected from experimental works are proved using laboratory testing which is by using the Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) method and were compared to the previous study. The internal mixing atomizing nozzle performance can be said to be the most efficient used for the local exhaust ventilation system (LEV).

1. Introduction

Welding fumes are produced in various industrial manufacturing processes. The fume in the air is not only hazardous to workers' health, but it also jeopardies working productivity. According to OSHA fact sheet, the journal Controlling Hazardous Fume and Gases during Welding, breathing welding fumes can cause irritation to the eyes, nose, and throat, dizziness and nausea, lung damage, and numerous types of cancer, including lung, larynx, and urinary tract cancer, as well as suffocating [1]. As a result, adopting efficient welding fumes management techniques to limit fumes concentration in industrial sites is critical. Ventilation, fumes extraction and removal, spray technology, and dust separation are currently the most common air management methods used at industrial sites around the world. A proper and functional ventilation system should be built in the workplace to reduce air or smoke contamination. To reduce the percentage of hazard that would indirectly affect workers, specific regularity of control must be stressed. The Local Exhaust Ventilation System (LEV) with spray technology is an appropriate and practical technical solution. By catching emissions at the source and transporting them to a safe emission site, this technology aims to reduce worker exposure to contaminants.

In reducing the air contaminant of fumes in workplace, it is preferable to install a viable and appropriate ventilation system using fine spray technology. To reduce the percentage of hazard that would indirectly harm workers, specific uniformity of control must be stressed. Local Exhaust Ventilation System (LEV) is an appropriate and practical technical solution. The goal of this system is to reduce worker exposure to contaminants by catching emissions at the source and transporting them to a safe emission site. In general, the purpose of a local exhaust ventilation system is to catch contaminants at or near their source before they are spread throughout the workspace.

Dust or fumes reduction via spraying is the most popularly used fume-control technology in industrial production places. Because of its inexpensive equipment, easy operation, broad applicability, and high reduction efficiency, spray technology for dust or fumes reduction is widely employed in industrial production [2].

In this research, the atomization properties of the internal mixing air-assisted atomizing nozzle were systematically and fully explored using experimental methods, considering the shortcomings of previous studies on the influence of air supply pressure. The flow fields inside the nozzle and at the nozzle's exit, as well as the properties of the nozzle's external spraying field were studied. Furthermore, the experiments were carried out to investigate the relationship between air supply pressure with fume suppression efficiency, and the trends of fume-suppression performance parameters such as total of contaminants parameters. The findings of this work can be used to provide theoretical guidance and a design basis for internal-mixing atomizing nozzles in industrial applications. Studies have shown that the use of LEV can lower fume exposure [3].

This study is expected to provide information about the performance of a flat cap atomizer filtering for a local exhaust ventilation system. Moreover, the results were compared to previous study, and this will expose the level of efficiency of the system. The results obtained through the experiment become a reference to improve the design of the air filters.

2. Methodology

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Data Collection

The average total pressure drop in the local exhaust ventilation system (LEV) has been determined by analyzing certain significant data, including static pressure and velocity pressure. To measure airflow in pipes, ducts, stacks, and open channels, pitot tube anemometers were utilized. This apparatus, for instance, may be used to measure the air velocity that a centrifugal fan sucked into a duct.

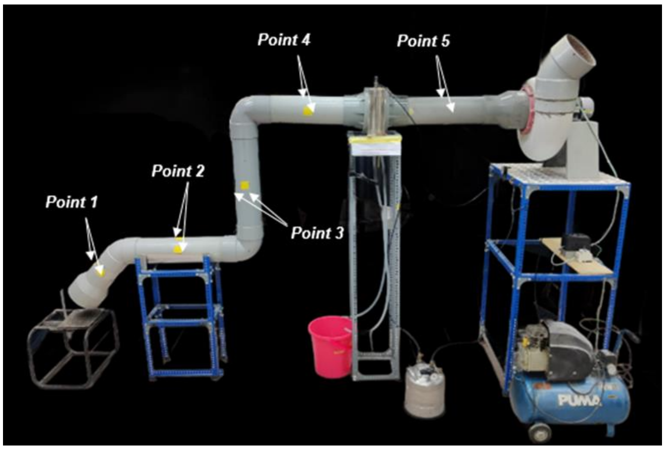

Fig. 1 *Traverse point location of LEV system*

Figure 1 shows the LEV system that is complete with the air filter box. There are five traverse points in this LEV system to take the data by using the pitot tube anemometer. At each point will take the digital readings of static pressure and velocity pressure by using the device. In this data collecting process, the LEV system was installed and running with the flat cap atomizer while the speed of the centrifugal fan is also used at different speeds in RPM.

2.2 Methods Analysis of Solid Elements

ICP-OES is an optical emission spectrometry technology that employs sample molecule emission spectra to identify and quantify the elements present. The equipment is made up of two components an inductively coupled plasma and an optical emission spectrometer. The sampler, pump, nebulizer, spray chamber, ICP torch, monochromator/polychromator, and detector are the primary components of the ICP-OES apparatus, and they are placed in a certain order.

Based on a new study conducted by Nicole S. Olgun in 2020, the ICP-OES method is suitable for gas type emission. Other researchers have utilized this approach. The United States Environmental Protection Agency Method 200.7, version 4.4, was used to calculate the amount of metals contained in the soluble fraction using inductively coupled plasma-optical emission spectroscopy (ICP-OES) apparatus [4]. It is proven that the 316L stainless steel welding contain huge amount of hexavalent chromium (Cr(VI)) would potentially be most harmful to human respiratory [4][5]. It is reliable for this type of experiment. Because it detects photons rather than ions of specified mass, the ICP-OES approach is free of isobaric and polyatomic inference issues [6].

The process of this experiment was started by setting up the experiment equipment such as the welding machine, electrode, sampling pump set, stainless steel plate, and the atomizing nozzle. The welding procedure took place at the ducting system's inlet. The sample cassette and the sampling pump, which was used to collect a sample of the fumes, were placed at the LEV's outlet. During the process of extracting the welding fumes, the centrifugal fan's speed was raised to its maximum setting of 1488 (RPM). The sampling pump takes a sample at a constant flow rate of 3.6 liters per minute. Five electrodes were utilized in this experiment for the sample, and each sample is expected to take 30 to 40 minutes. The sampling pump will be activated in three minutes to vacuum the welding fume as the sample. The atomizer nozzle will act as a filter to trap the contaminants from the welding fume by producing water mist inside the filter box. When the sampling pump was collecting sample from the fume, the condition of the sample collector inside the cassette were eventually getting darker. Figure 3.25 shows the example of a sampling cassette which has been used compared side by side to a new sampling cassette. After all samples have been collected, the samples must be carefully packaged and sealed.

3. Results and Discussion

This chapter discovered whether the objectives of this study were achieved. The key findings of the investigation were also examined and described in depth. The results were presented in graphs, tables, and figures to display the research data and show trends or relationships between the results. The velocity pressure performance between unfiltered with filtered system in Local Exhaust Ventilation System (LEV) was explained detailed in this chapter. When the atomizer nozzle was installed on the Local Exhaust Ventilation System (LEV), the nozzle's performance was also explained based on the ICP-OES results. The optimal option for reducing the solid components in welding fume was then determined by comparing the findings.

3.1 Total Pressure and Face Velocity Pressure

The pressure that formed inside the local exhaust and ventilation system, particularly at the chosen places, is included in the experimental process data. The fan speed was adjusted to provide the necessary suction for welding fumes. The examination of airflow pattern should be highlighted as it functions to carry air from a higher pressure point to a lower pressure point, making it one of the greatest alternatives to examine and determine to enhance the local exhaust system with a smooth and consistent rate of suction.

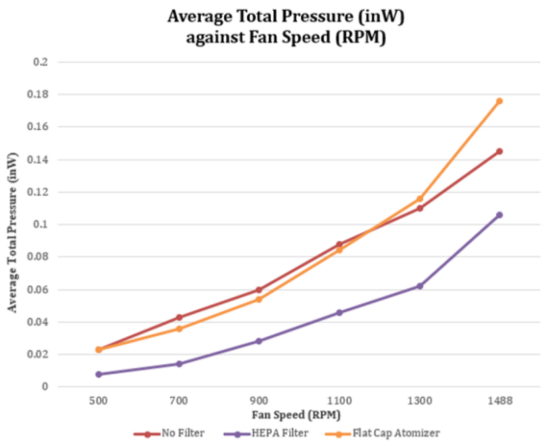

Fig. 2 *Average Total Pressure (inW) against Fan Speed (RPM) for LEV system*

Based on Figure 2, the line graph shows a detailed comparison of the average total pressure rate of the LEV without any filter, with HEPA filter and attached with flat cap atomizer. The data were taken at five separate measuring points inside the Local Exhaust Ventilation System (LEV) as shown in Figure 2.1. The average total pressure shows a substantial rise in relation to the motor rotational speed. For example, over the motor rotational speed of 900 RPM, the average total pressure for the Flat Cap Atomizer is 0.054 inW.g while the average total pressure for the HEPA Filter is 0.028 inW.g. The average total pressure of the Flat Cap Atomizer at 1488 RPM is higher because the air pressure from the air compressor assists it. The graph for every point position keeps growing when the fan motor runs at its highest speed. In addition, when the fan speed was set up to 1300 RPM and 1488 RPM, the pressure loss for the Flat Cap Atomizer were both at 0%. However, there were increments of air pressure which were 5% and 21% respectively.

For a detailed value observation of this comparison, Table 1 below shows the numerical values comparison of the average total pressure. not supplied separately.

Table 1 *Average total pressure of no filter, HEPA filter and Flat Cap Atomizer*

Fan Speed (RPM)	Average Total Pressure, inW				
	No Filter	HEPA Filter	Loss Percentage	Flat Cap Atomizer	Loss Percentage
500	0.023	0.008	65%	0.023	0%
700	0.043	0.014	67%	0.036	16%
900	0.060	0.028	53%	0.054	10%
1100	0.088	0.046	48%	0.084	5%
1300	0.110	0.062	44%	0.116	0% (Increases 5%)
1488	0.145	0.106	27%	0.176	0% (Increases 21%)

3.1.1 Inlet Face Velocity of Local Exhaust Ventilation System

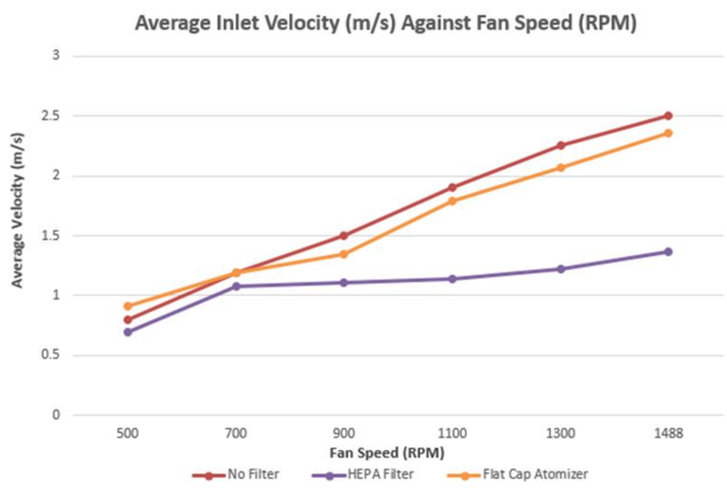

Fig. 3 *Average Inlet Velocity (m/s) against Fan Speed (RPM)*

The comparison of average face velocity for the inlet part of the LEV system of this experiment and the previous study is shown in Figure 3. As can be observed in this figure, No Filter and Flat Cap Atomizer showed a directly proportional line, while the HEPA Filter showed a steady increase. This is caused by the fact that when the HEPA Filter was introduced in the LEV, it created resistance to the air flow [7].

The detailed comparison of average face velocity for the inlet part of the LEV system of this experiment and the previous study is shown in Table 2. The HEPA Filter loss percentage was significantly higher than the Flat Cap Atomizer. For example, the HEPA Filter loss percentage was 45% at the speed of 1488 RPM while the Flat Cap Atomizer loss percentage was only 6%. This was caused by the presence of resistance to the air flow by the HEPA Filter [7].

Table 2 *Comparison of Average Inlet Velocity*

Fan Speed (RPM)	Average Total Pressure, /s				
	No Filter	HEPA Filter	Loss Percentage	Flat Cap Atomizer	Loss Percentage
500	0.80	0.69	14%	0.91	0% (Increases 14%)
700	1.19	1.08	9%	1.19	0%
900	1.50	1.11	26%	1.34	11%
1100	1.90	1.14	40%	1.79	6%
1300	2.25	1.22	46%	2.07	8%
1488	2.50	1.37	45%	2.36	6%

3.1.2 Outlet Face Velocity of Local Exhaust Ventilation System

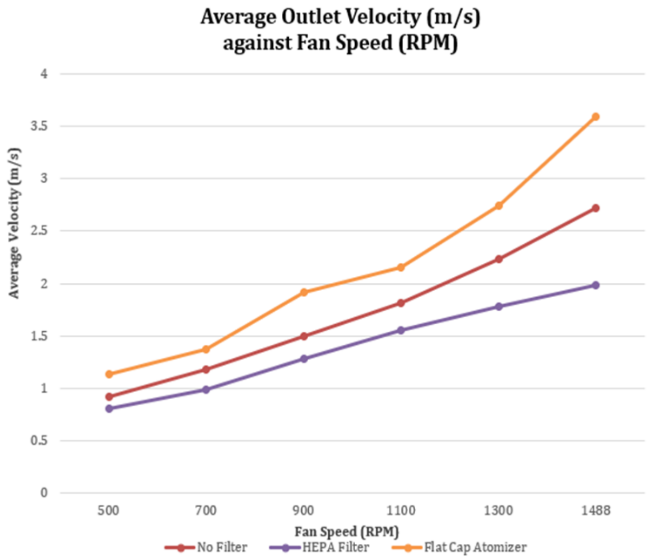

Fig. 4 *Average Outlet Velocity (m/s) against Fan Speed (RPM).*

The detailed comparison of average face velocity for the outlet part of the LEV system of this experiment and the previous study is shown in Table 4.3. The Flat Cap Atomizer loss percentage was shown to be negative due to the absence of significant air loss. The reason for this was that it is aided by the air compressor's pressure. The loss obtained by the HEPA Filter was caused by the presence of resistance to the air flow [7].

Table 3 *Comparison of Average Outlet Velocity*

Speed (RPM)	Average Total Pressure, m/s				
	No Filter	HEPA Filter	Loss Percentage	Flat Cap Atomizer	Loss Percentage
500	0.92	0.81	12%	1.14	0% (Increases 22%)
700	1.18	0.99	16%	1.37	0% (Increases 16%)
900	1.50	1.28	15%	1.92	0% (Increases 28%)
1100	1.81	1.55	14%	2.15	0% (Increases 19%)
1300	2.23	1.78	20%	2.74	0% (Increases 23%)
1488	2.72	1.98	27%	3.59	0% (Increases 32%)

3.2 Inductively Coupled Plasma Optical Emission Spectroscopy Results

ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy) is a type of equipment that can examine the solid elements contained in welding fumes by taking a sample using a sampling pump. The environment, petrochemical, clinical, agricultural, and pharmaceutical samples may all be tested using this technique. This study solely focuses on a few solid aspects in the welding fume of shield metal arc welding (SMAW) to weld the stainless-steel plate and utilize stainless steel electrodes.

In this experiment, twenty solid elements were chosen to be studied. Arsenic (As), Beryllium (Be), Calcium (Ca), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Magnesium (Mg), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Antimony (Sb), Selenium (Se), Strontium (Sr), Titanium (Ti), Thallium (TI), Vanadium (V) and Zinc (Zn). Therefore, by utilizing the Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) method, the findings for the flat cap atomizer will be provided using the ICP-OES machine from the University Malaysia Pahang's central laboratory (UMP).

3.2.1 ICP-OES results for Flat Cap Atomizer

These were the results of the testing using the Flat Cap Atomizer installed on the LEV system. While the welding process was in progress, a sample was obtained using the sampling pump and deposited at the end of the local exhaust ventilation system (LEV). The sample pump's air flow rate was adjusted at 3.6 l/min to suction the welding fume through the PVC tube and cassette filters. The goal is to explore and evaluate the solid components in welding fumes after they have been filtered by the Flat Cap Atomizer.

Table 4 *ICP-OES parameter results of Flat Cap Atomizer*

No	Parameter	Result	Unit	Test Method
1	Arsenic (As)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
2	Beryllium (Be)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
3	Calcium (Ca)	1303.45	ppm	In-house Method based on APHA 3010
4	Cadmium (Cd)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
5	Cobalt (Co)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
6	Chromium (Cr)	206.90	ppm	In-house Method based on APHA 3010
7	Copper (Cu)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
8	Iron (Fe)	591.95	ppm	In-house Method based on APHA 3010
9	Magnesium (Mg)	239.08	ppm	In-house Method based on APHA 3010
10	Manganese (Mn)	118.39	ppm	In-house Method based on APHA 3010
11	Molybdenum (Mo)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
12	Nickel (Ni)	122.99	ppm	In-house Method based on APHA 3010
13	Lead (Pb)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
14	Antimony (Sb)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
15	Selenium (Se)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
16	Strontium (Sr)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
17	Titanium (Ti)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
18	Thalium (Tl)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
19	Vanadium (V)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010
20	Zinc (Zn)	Not Detected (Less than 0.1)	ppm	In-house Method based on APHA 3010

3.2.2 Comparison of ICP-OES Results with Previous Study

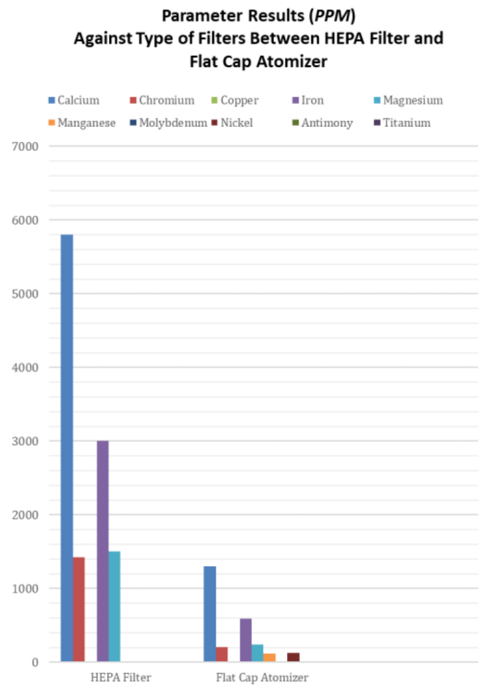

Fig. 5 *ICP-OES results of Flat Air Cap and HEPA Filter*

The result of ICP-OES testing for the Flat Cap Atomizer compared to the HEPA Filter is shown in Figure 5 above. It shows that the amount of parameters in PPM of calcium (Ca) is 1303.45, chromium (Cr) is 206.90, iron (Fe) is 591.95, magnesium (Mg) is 239.08, manganese (Mn) is 118.39 and nickel (Ni) is 122.99. The atomizer managed to suppress contaminants well enough compared to previous study which uses HEPA filter.

Table 5 compares the findings of previous research [7] to the sample results obtained with the Flat Cap Atomizer testing using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP OES) equipment.

Table 5 *ICP-OES parameter results of Flat Cap Atomizer*

Parameters	Parameter Results (PPM)		
	No Filter	HEPA Filter	Flat Cap Atomizer
Calcium (Ca)	7063.76	5802.88	1303.45
Chromium (Cr)	22661.07	1427.88	206.90
Copper (Cu)	174.50	0.00	0.00
Iron (Fe)	42449.66	3004.81	591.95
Magnesium (Mg)	4664.43	1504.81	239.08
Manganese (Mn)	13751.68	0.00	118.39
Molybdenum (Mo)	694.63	0.00	0.00
Nickel (Ni)	5093.96	0.00	122.99
Antimony (Sb)	342.23	0.00	0.00
Titanium (Ti)	9050.34	0.00	0.00
Total (PPM)	105946.26	11740.38	2582.76
Percent Reduce	-	89%	98%

The table showed that the Flat Cap Atomizer managed to reduce 98% of the contaminants of the welding fume while the HEPA Filter managed to reduce about 89% of contaminants. There was about 9% difference between the systems. However, the Flat Cap Atomizer only managed to minimize the amount of Manganese (Mn) and Nickel (Ni) compared to the HEPA Filter which was able to reduce both elements completely. This was due to the fact that from the previous study, the HEPA Filter was combined with activated carbon. The activated carbon was effective in removal or absorption of manganese (Mn) and nickel (Ni) [8].

3.2.3 Water flow rate of the Flat Cap Atomizer

This research was carried out with air and water pressure set at 6 bar and 5 bar respectively which is the optimum pressure. Based on the previous study which was held by Han Han, the suitable pressure for both air and water supply should be between 0.4 MPa and 0.6 MPa since that the compressed air pressure at the industrial site was frequently in the range [2].

The atomizing nozzle installed on the local exhaust ventilation system (LEV) was powered by air and water. When fume passes through the ducting system, the water works as a trap for welding fume contaminants. With that, the amount of water used by the system was then recorded for further analysis. The recording was taken at an interval of 30 seconds per take. The water was also collected and Figure 6 shows the condition and colour of the water after the process. Table 6 below shows the amount of water consumption by the system.

Table 6 *Water consumption of atomizing nozzle*

Reading (30 Seconds)	1	2	3	4	5	Average
Water Consume (mL)	120	105	110	110	110	111

3.2.4 Differentiation of water

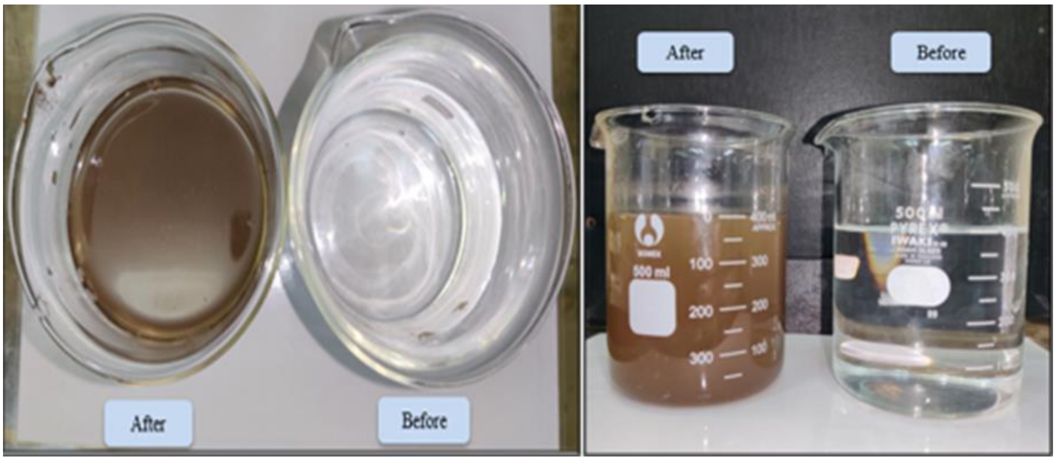

Fig. 6 *Condition of water after and before the experiment*

The condition of water collected after the experiment and the normal water condition were shown in Figure 6. It is seen that the water after the experiment was very muddy or dirty. This was due to the fact that when the atomizer works, it produced water mist which traps the contaminants from the welding fume.

During this experiment, the mass of the water was also weighed. Detailed data of the weight of water recorded from the weighing process and the density of water were presented in Table 6. The mass of water increases after the experiment was conducted. This was because the contaminants trapped by the water mist produced by the atomizer were content in the water. The density of water can be calculated using the formula shown below where the volume of water weighted is 100 ml.

Table 6 *Water Mass and Density*

Condition of water	Before Experiment	After Experiment	Difference
Mass of water in gram (g)	104.1433	106.7365	2.5932 g
Density of water, ρ (kg/m^3)	1041.433	1067.365	25.932 kg/m^3

4. Conclusion

In this study, firstly, the velocity pressure performance between unfiltered with filtered system (HEPA filter and Flat Cap Atomizer) in Local Exhaust Ventilation System (LEV) were investigated. It was then found out that the LEV system flow with Flat Cap Atomizer was more efficient than the LEV system attached with HEPA Filter. It has something to do with the fact that when applying the HEPA Filter inside the LEV system, it has gained more resistance towards the flow rate inside the ducting. On this basis, we could say that the lower the velocity inside a ducting system, the lower velocity of the air inside the ducting system. Furthermore, the LEV system attached to the atomizer was more efficient because the pressure inside the ducting was assisted by the air pressure which came from the air compressor. Hence, gaining an efficient flow throughout the system. In order to carry out the proper experimental procedure and method, the Department of Occupational Safety and Health Ministry of Human Resources Malaysia (DOSH) has established occupational safety and health guidelines for the design, inspection, testing, and examination of local exhaust ventilation systems.

Secondly, an atomization process in the welding exhaust ventilation system to remove air contaminants from a welder's breathing zone and work area was performed. Additionally, the efficiency of the filter has been evaluated using the ICP-OES testing method, which can examine the solid components in welding fumes. A PVC ducting system was used in its development since it was perfect for incompressible gases. Capture hoods have the purpose of sucking in gases or fumes. The results for the Flat Cap Atomizer came out were competent enough. However, the testing detected a little amount of Manganese and Nickel compared to the HEPA Filter. Those elements can cause people to suffer from Parkinson's disease and cancer. Nevertheless, the results from Flat Cap Atomizer managed to reduce about 98% of the contaminants rather than 89% for the HEPA Filter. The primary elements that guarantee the volume of gases sucked flowing effectively towards the system's exit were the centrifugal fan, an alternating current motor, and ducting those transports impurities through the system.

Finally, it was proven from comparison that the flat cap atomizer which acts as a filter was able to suppress the harmful contaminants content in the fumes. Although the results were not so significant, the atomizer nozzle brought down a larger amount of number for the parameters tested. In my opinion, without careful planning and preparation, this study's accomplishment will likely result in a few unfavorable results.

Acknowledgement

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