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## The effect of activated carbon granules and potassium hydroxide (KOH) solution on welding particulates and gases in air filtration

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### Abstract

Hazard Identification, Risk Assessment and Risk Control (HIRARC) is the process of identifying hazards that can occur in routine or non-routine activities in a company or workplace, and then carrying out a risk assessment of these hazards. From the risk assessment, the hazard in the welding workshop that has a moderate risk and is interesting for researchers to innovate is from the source of the danger caused by fumes resulting from welding activities, causing workers to experience respiratory problems and eye irritation. Researchers created a smoke filtration device generated from welding with a system where the welding smoke is channeled into the potassium hydroxide (KOH) solution to reduce the number of air particles and reduce the levels of toxic substances in the welding smoke, then to keep the KOH solution always clean, a circulation system was created through the carbon to remove dirt and keeps the solution water from being dirty and colorless. Once all the tools are ready, measurements can be made to measure several chemical elements in the welding smoke from the point before it enters the filter and after going through the filtration process. Among the elements measured are carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), particulate PM 2.5 (2.5 microns), and particulate PM 10 (10 microns). Based on research and data testing carried out using the Anova test and Fisher Pairwise Comparisons, it can be concluded that to produce the best and cleanest air results, the composition is K4 C1 or KOH 10% with carbon active 2-3 mesh. If activated carbon with a mesh size larger than 2-3 mesh, it will affect the quality of the KOH solution because the granules are too small and contaminate the KOH solution. And the higher the KOH solution level, the more effective it is at reducing the dangerous elements in welding fumes.

### Keywords:

Activated carbon, KOH solution, air filtration, carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), PM 2.5 particulates (2.5 microns), and PM 10 particulates (10 microns).

### 1 Introduction

Hazard Identification, Risk Assessment, and Risk Management (HIRARC) is the process of identifying hazards that may occur during routine or non-routine activities in a business or workplace and then conducting a risk analysis of those hazards. The risk analysis results are useful in creating a risk management program so that the company or workplace can minimize the potential level of risk to prevent accidents at work [1]–[3].

Besides that, in the era of globalization, world industries are becoming more advanced, one of which is the welding sector.

Welding activities are widely used in the field of fabrication, construction, automotive, shipping, aircraft, manufacturing, and others. Welding technology is still popular because building construction and machine fabrication by welding technique is easier and simpler in the manufacturing process [4].

The welding business has also increased and has become one of the businesses whose services are really needed by the people. Because, as the population increases, the need for houses or buildings also increases. In the process of building a house, welding services are needed, such as making trellises, canopies, iron fences, iron stairs, etc.

In the health regulations in the work environment according to the Minister of Health of the Republic of Indonesia Decree number 1405/MENKES/SK/XI/2022 concerning Health Requirements for Office and Industrial Work Environments, the maximum amount of dust content in room air is 10 mg/m<sup>3</sup>, as well as the maximum content of room air pollutant gases. Carbon monoxide production process 9000mg/m<sup>3</sup> and carbon monoxide 115 mg/m<sup>3</sup>.

Meanwhile, welding activities produce welding smoke and dust with very small particulates of around 0.005 μm – 20 μm. In previous research, solid emissions resulting from welding produced dust particulates of 310 mg/m<sup>3</sup>, from these results the dust particulates had exceeded the clean air threshold issued by the Indonesian Ministry of Health [5].

Welding smoke dust measuring 0.5 μm or more can be inhaled and retained in the nose hairs and finer welding smoke dust will enter the lungs, especially without using a welding mask or other safety equipment. Also, carbon monoxide is a gas that is odorless, colorless, tasteless, and has potentially dangerous toxic properties due to its ability to form strong bonds with hemoglobin pigment, especially when workers and people work in the environment for a long time.

So, from this background, researchers are interested in conducting research on welding activities with the dangerous impacts they cause and the preventative steps that will be taken in a welding workshop at one of the Vocational High Schools in East Java.

Job Safety Analysis (JSA) is a hazard analysis technique used to identify the dangers that exist in a person's job and develop appropriate controls to reduce risks. JSA is also an analysis that produces a recommendation from a more detailed review of the hazard process [6], [7].

The hazard identification phase is carried out through direct field observations and brainstorming sessions with employees and contractors. The purpose of this hazard identification is to identify a source of danger in each work phase that can cause possible accidents and occupational diseases in the workplace according to Tables 1, 2, and 3.

After identifying hazards at each stage of work, a risk assessment is then carried out to determine the risk level according to AS/NZS 4360:2004. At this stage, a likelihood scale assessment (the chance of occurrence) and a consequences scale assessment (the extent of the impact caused) of the production process are carried out. Likelihood or probability level has 5 levels, namely the almost certain level (almost always happens), the likely level (often happens), the possible level (is expected to happen), unlikely (rarely happens), and rare or almost never happens. Level A has the highest value, namely 5, level B with a value of 4, level C with a value of 3, level D with a value of 2, and the smallest is level E with a value of 1. The value obtained will then be used as the likelihood value (L) [3], [6], [7].

Then, consequences (C) or severity levels have 5 levels, starting from level 1 which is called insignificant, namely no injury or slight financial loss, has a value of 1. Level 2 minor, namely minor injury or slight financial loss, has a value of 2, level 3 moderate, namely moderate injury, requiring medical treatment, major financial loss has a value of 3, level 4 major, namely serious

injury > 1 person, major loss, production disruption has a value 4, and the highest is the catastrophic level, namely fatal > 1 person,

serious loss. Large and the impact is very broad, up to the cessation of all activities, which has a value of 5 [3], [6], [7].

Table 1. Identification of hazards in the measurement process [6], [7]

Activities	Hazards	Risk
Choosing and moving materials	Transferring heavy and sharp material	Workers have the potential for injuries, broken bones and scratched hands
Taking measurements	Using meter roller iron	Hand worker scratched

Table 2. Identification hazards on process cutting material [6], [7]

Activities	Hazards	Risk
Preparing material to be cut	Transferring heavy and sharp material	Workers can be injured
Turning on the machine cut off the iron	Using source of electricity	Workers have the potential to be electrocuted
Do material cutting	The cables on the floor are not neat	Worker stumble
	Loud voice generated by machine cut	Hearing disorders
	Using sharp blade	Hand worker scratched
	Using an appropriate cutting tool	The cutting machine blade broke and injured the worker
Turning off machine cut	Use source of electricity	Workers have the potential to be electrocuted
Moving material that has been cut	Transferring heavy and sharp material	Workers can be bumped, hit, and scratched by material

Table 3. Identification hazards on process assembly [6], [7]

Activities	Hazards	Risk
Preparing material to be welded	Heavy and sharp material	Workers have the potential for injuries, broken bones and scratched hands
Cleaning surface of the material to be welded	Dusty material	Respiratory infections among workers
Connecting pliers	Clamping unsuitable pliers mass	Tool cannot work and workers have the potential for injuries
Installing electrode	Wet-hand condition which touching the metal of the electrode holder	Workers have the potential to be electrocuted
Turning on machine welding and setting the amperage	Hand worker in condition wet or sweaty	Workers have the potential to be electrocuted
Do welding	Infrared and ultraviolet radiation	Eyes and face irritation
	Splash flower fire welding	Potential to be a source of fire
	Smoke from welding activities	Respiratory infections among workers and eyes irritation
Cool welding results	The cables on the floor are not neat	Worker got electrical shock
Clean results weld	Hot metal after welding process	Workers have the potential for injuries
	Cleaning welding product	The worker's eyes were hit by iron particulate

After obtaining the likelihood and consequences values, the risk score is calculated using the Risk Matrix. The results obtained from the risk assessment in welding workshop activities can be seen in Table 4, so the researchers were interested and focused on

the problems caused by exposure to welding fumes which were dangerous for breathing and the environment around the workshop.

Table 4. Evaluation risk on process assembly [3], [6], [7]

Activities	Hazards	Risk	L	C	Risk rate
Preparing material to be welded	Heavy and sharp material	Workers have the potential for injuries, broken bones and scratched hands	D	1	Low
Cleaning surface of the material to be welded	Dusty material	Respiratory infections among workers	C	1	Low
Connecting pliers period	Clamping pliers mass which not suitable	Tool cannot working and workers have the potential for injuries	D	1	Low
Installing electrode	Wet-hand condition which touching the metal of the electrode holder	Workers have the potential to be electrocuted	C	1	Low
Turning on machine welding and set the amperage	Hand worker in condition wet or sweaty	Workers have the potential to be electrocuted	C	1	Low
Dowelding	Infrared and ultraviolet radiation	Worker caught irritation on eyes and face	C	1	Low
	Splash flower fire welding	Potential to be a source of fire	C	1	Low
	Smoke from welding activities	Respiratory infections among workers and eyes irritation	C	2	Moderate
Cool welding results	The cables on the floor are not neat	Worker stumble	C	1	Low
	Hot metal after welding process	Workers have the potential for injuries	D	1	Low
Clean results weld	Cleaning welding product	The worker's eyes were hit by iron particulate	D	1	Low

To avoid the risk of welding fumes causing respiratory problems and eye irritation to workers, researchers are creating a device to filter welding fumes with a system where the welding fumes are embedded in a potassium hydroxide(KOH) solution as described in Table 5. The filtration system can reduce the amount of air particles and the concentration of toxic substances in welding fumes[8], [9], [9]–[13].

Table 5. Traits physics and KOH chemistry [8], [9]–[13]

Molar mass	56.11 g/mol
Being	Solids white
Specific gravity	2,044
Point melt	380°C
Point boiling	1320°C
Solubility in water	97 gr/L gr H <sub>2</sub> O (H <sub>2</sub> O = 0°C)
Acidity (pKa)	0

Then, to keep the KOH solution always clean, a circulation system was created through the carbon as in Fig. 1 to remove dirt and keep the solution water from being dirty and colorless [10], [14], [15].



Fig. 1. Activated carbon in various mesh sizes.

This research is a development of previous research from 2012 to 2017 carried out by different researchers, then the author conducted research on the topic of filtration equipment using different filtration materials, namely using activated carbon and solutions for the same object, namely reducing welding smoke emissions, which were created and developed from previous research.

Hyun-Woo Cho and Chung Sik Yoon's (2012) research with the title "workplace field testing of the pressure drop of particulate respirators using welding fumes" is related to current research which examines welding fume filtration systems, using an absorbent solution that uses NaCl. In empirical theory, it was found that the absorption effectiveness of absorbent solutions that use KOH captures more gas emissions in welding fumes [16].

"Optimization of one stage electrostatic precipitator for welding fume filtration" by S. M. Remaoun, A. Tilmatine, N. Hammadi, F. Miloua, K. Mendes (2012) in this study found that this tool could only reduce solid emissions from welding but not gas emissions from welding. The level of safety for using tools with high electrical voltage and when open does not meet K3 requirements in welding workshops which are also close to sources of heat and electricity [17].

"Design and performance analysis of fume extraction and filtration equipment" by Kiran Kumar Rokhade, Hament Kumar, Kanteyya, and Raghavendra (2015). In this research, the thing that was evaluated was the installation of a filtration device used on one welding machine, whereas in the current research, the use of a filtration device for several welding machines was added with a ducting method that sucks smoke from each welding machine to direct it to the gas exhaust pipe [18].

"Design, fabrication and analysis of fume extraction and filtration equipment" by Ramakrishnan, H. and P. Vinoth (2017) in this research The use of absorbent materials is often changed because the absorption of crystalline silicon and alum filter paper can accommodate 4 hours of welding activities, while in the current study, absorbent materials were used for longer because the filtration process used water solution media and activated carbon absorbents which accommodated a lot of gas emissions and particulates resulting from welding. The absorbent material for alum filter paper is also made by you because this material is not available on the market. Meanwhile, in the current research, absorbent materials can be easily found and sold on the market, making it easier to obtain them [17].

Welding fumes contain elements that can harm workers' health if inhaled or swallowed. Therefore, the chemical composition of welding fume should be checked when considering the toxicity of the fume. The base metal used in welding activities is steel, all steel contains manganese while stainless steel also contains chromium and nickel. Pure manganese in large doses can cause manganese poisoning (neurotoxin) while chromium and nickel can cause carcinogenic or cancer triggers if people in the welding environment inhale welding fumes, the size of welding fume particulates is around 0.005-20 microns as shown in Fig. 2 [15], [19]–[21].

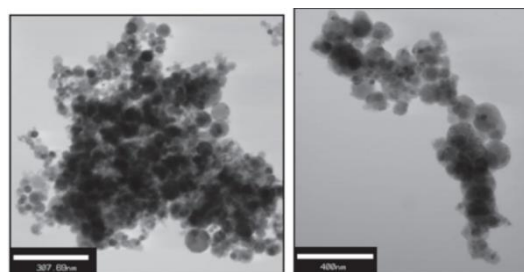


Fig. 2. Welding smoke. (a) GMAW welding smoke, (b) SMAW welding smoke.

## 2 Research Methods

### 2.1 Research Process Flow

The research method process can be described below:

1. Start. This is the first step in the process of making various tool preparations and one must understand the background of tool making.
2. Identification of problems. Based on field studies and literature studies, the main points will be obtained from problems and problem solving.
3. Define the problem. Look for the main problem and solve the problem based on it identify problems that have been done previously.
4. Design (air filtration). Create the design of air filtration based on actual conditions and dimensions (Fig. 3).
5. Fabrication. In this step, the design will be fabricated in the workshop.
6. Tool testing and installation. This is a tool-testing step to check whether the design is different and the fabrication results are the same, if it fails then steps must return to the tool creation step, if successful we can proceed to the data retro collection step.
7. Materials preparation. This is a step in preparing the air filter material and the welding process to observe the results of the air coming out.
8. Data collection. This is a data collection step, namely the activity of collecting data to monitor changes in the data taken.
9. Data validation. This is a step that aims to validate the data that has been obtained taken from the previous step to ensure that the data has been entered appropriately and can be processed and there is no abnormal data, if no then you have to go back to the data collection step.

10. Data analysis. Is an activity carried out to analyze the result data of air filtration that has been taken.
11. Conclusion. This is a step to making conclusions about the entire process from start to finish.
12. Finish. This is the end of the all research process.

### 2.2 Research Variables

This type of research is quantitative research with an experimental approach. Experimental research uses several groups that are given certain treatments that are tailored to the objectives of the research being conducted. This research aims to test the influence provided by the following variables:

1. The independent variables in this study which are determined as independent variables are the size of the activated carbon granules and the concentration of the solution to be manipulated, observed and measured so that the effect on the dependent variable is known.
2. The dependent variable in this study which is determined as the dependent variable is smoke emissions from welding, namely in the form of CO, CO<sub>2</sub>, NO<sub>x</sub>, and particulate gases, to evaluate the results of variable manipulation and independent variables.
3. The control variables in this study which are determined as control variables are the SMAW welding process, SMAW welding time, machine unit, data collection time, active carbon specifications, and filtration material (solution, activated carbon) made new for each specimen test on each variable free. So the influence of the independent variable on the dependent variable is not influenced by external factors that are not studied.

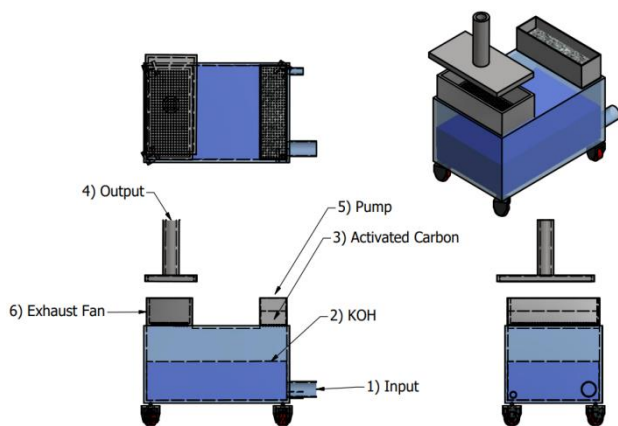


Fig. 3. Design of welding smoke filtration equipment. 1) Welding fume inlet, 2) KOH solution, 3) activated carbon, 4) filtration fume outlet, 5) pump, 6) exhaust fan.

### 2.3 Experimental Procedure

After the design of the filtration equipment has been completed, the next step is fabrication of the filtration equipment which will be installed in the welding workshop area as in Fig. 4.

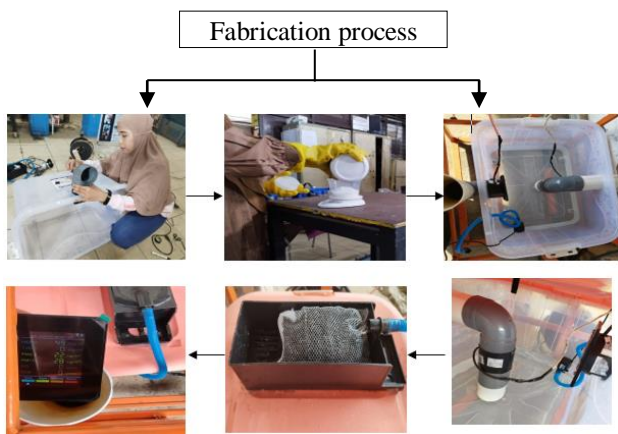


Fig. 4. Welding smoke exhaust pipe installation process.

After the filtration device is installed, several steps need to be taken, namely:

1. Make sure the filtration device is installed correctly and functions normally
2. Fill the filter tank with 30 liters of water
3. Prepare several KOH mixture percentage scenarios using a digital scale
4. Mix KOH into the water
5. Prepare several types of carbon for air circulation that have been dissolved in KOH for circulation with a pump through the carbon
6. Carry out welding activities, so that as quickly as possible the weld results enter the chimney and pass through the KOH solution
7. Take data as soon as possible after passing through the KOH solution
8. Recording data
9. Data analysis using Anova.

Next is the fabrication of a filtration device which will later act as a container for the KOH solution to be passed through by welding fumes whose water is circulated through the activated carbon as in Fig. 5.

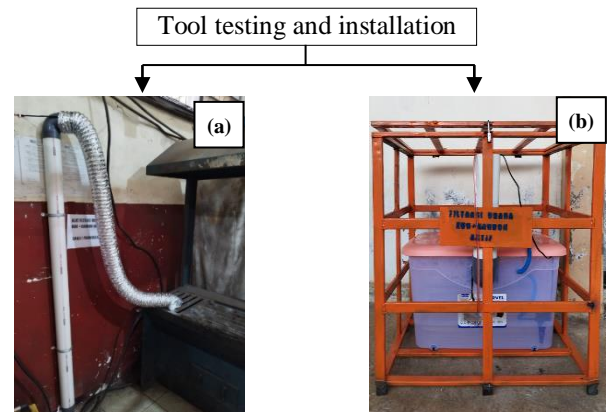


Fig. 5. (a) Welding fume inlet, (b) Welding fume filter unit.

After all the equipment is installed, the next step is to make a KOH solution with a percentage of 1%, 3%, 5%, and 10% of the total volume of water in the tub. The process of making the solution is assisted by using a scale as shown in Fig. 6.



Fig. 6. Process for making KOH solution.

Then, after the KOH solution is made, the next step is to add activated carbon as a filter for circulating KOH so that it doesn't get dirty and has a cloudy color. There are several types of activated carbon added for analysis, namely 2-3 mesh, 4-8 mesh, 6-12 mesh, and powder size as shown in Fig. 7.

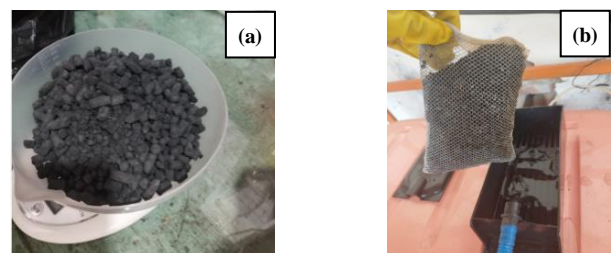


Fig. 7. (a) Activated carbon weighing process, (b) activated carbon installation process.

Once all the tools are ready, measurements can be made to measure several chemical elements in the welding smoke from the point before it enters the filter and after going through the filtration process. Among the elements measured are carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), particulate PM 2.5 (2.5 microns), and particulate PM 10 (10 microns) using a measuring instrument as in Fig. 8.



Fig. 8. Tools for measuring chemical elements in welding operations.

### 3 Results and Discussion

After the filtration equipment and measuring instruments are ready, the next step is to collect data from each manipulated variable to see differences and changes in chemical elements in the welding smoke to find the best parameters to produce a maximum filtration system.

Tests were carried out one by one to see changes in carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), PM 2.5 particulates (2.5 microns), and PM 10 particulates (10 microns).

In Fig. 9, through the Anova test, the element carbon monoxide (CO), for Factor K because P-value (0.000) <  $\alpha$  (0.05), then H<sub>0</sub> is rejected. Thus, the addition of KOH to the filtration system affects reducing CO levels. And for Factor C, because P-value (0.073) >  $\alpha$  (0.05), then H<sub>0</sub> is accepted. So, the addition of active carbon to the filtration system does not affect reducing CO levels.

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Faktor K	3	20.1071	6.70238	450.40	0.000
Faktor C	3	0.1071	0.03571	2.40	0.073
Faktor K*Faktor C	9	0.3214	0.03571	2.40	0.017
Error	96	1.4286	0.01488		
Total	111	21.9643			

Fig. 9. Anova test on carbon monoxide (CO) observations.

In Fig. 10, through the Anova test, the element carbon dioxide (CO<sub>2</sub>), for Factor K because P-value (0.000) <  $\alpha$  (0.05), then H<sub>0</sub> is rejected. Thus, the addition of KOH to the filtration system affects increasing CO<sub>2</sub> levels. And for Factor C because P-value (0.073) >  $\alpha$  (0.05), then H<sub>0</sub> is accepted. So, the addition of active carbon to the filtration system does not affect increasing CO<sub>2</sub> levels.

In Fig. 11, through the Anova test, the particulate element PM 2.5 (2.5 microns), for Factor K because P-value (0.000) <  $\alpha$  (0.05), then H<sub>0</sub> is rejected. So, the addition of KOH to the filtration system affects reducing PM 2.5 levels. And for Factor C because P-value (0.000) >  $\alpha$  (0.05), then H<sub>0</sub> is rejected. Thus, the addition of active carbon to the filtration system affects reducing PM 2.5 levels.

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Faktor K	3	0.023200	0.007733	21.71	0.000
Faktor C	3	0.000899	0.000300	0.84	0.474
Faktor K*Faktor C	9	0.002446	0.000272	0.76	0.650
Error	96	0.034195	0.000356		
Total	111	0.060741			

Fig. 10. Anova test on carbon dioxide (CO<sub>2</sub>) observations.

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Faktor K	3	0.423858	0.141286	550.97	0.000
Faktor C	3	0.005510	0.001837	7.16	0.000
Faktor K*Faktor C	9	0.007985	0.000887	3.46	0.001
Error	96	0.024617	0.000256		
Total	111	0.461970			

Fig. 11. Anova test on PM 2.5 particulate observations.

In Fig. 12, through the Anova test, the particulate element PM 10 (10 microns), for Factor K because P-value (0.000) <  $\alpha$  (0.05), then H<sub>0</sub> is rejected. So, the addition of KOH to the filtration system affects reducing PM 10 levels. And for Factor C, because P-value (0.002) >  $\alpha$  (0.05), H<sub>0</sub> is rejected. Thus, the addition of KOH to the filtration system affects reducing PM 10 levels.

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Faktor K	3	0.095627	0.031876	96.20	0.000
Faktor C	3	0.005504	0.001835	5.54	0.002
Faktor K*Faktor C	9	0.012962	0.001440	4.35	0.000
Error	96	0.031811	0.000331		
Total	111	0.145903			

Fig. 12. Anova test on PM 10 particulate observations.

Then, from several Anovatest analyzes to find the best KOH content and the best mesh size of active carbon, a further test was carried out using Fisher Pairwise Comparisons as in Fig. 13.

Fisher Pairwise Comparisons: Faktor K*Faktor C					
Grouping Information Using Fisher LSD Method and 95% Confidence					
Faktor	K*Faktor	C	N	Mean	Grouping
K1	C3	7	-0.614642	A	
K1	C2	7	-0.631773	B	
K1	C4	7	-0.647759	B C	
K1	C1	7	-0.651075	C	
K2	C1	7	-0.756417	D	
K2	C2	7	-0.763075	D E	
K3	C3	7	-0.764500	D E F	
K2	C3	7	-0.772537	D E F G	
K4	C3	7	-0.775734	E F G	
K3	C2	7	-0.776157	E F G	
K2	C4	7	-0.777641	E F G	
K3	C4	7	-0.781346	F G	
K4	C4	7	-0.781346	F G	
K3	C1	7	-0.784430	G	
K4	C2	7	-0.787459	G	
K4	C1	7	-0.807814	H	

*Means that do not share a letter are significantly different.*

Fig. 13. Advanced test using Fisher Pairwise Comparisons.

From the Fisher Pairwise Comparison results in Fig. 13, the best is in the bottom row, namely K4 C1 or KOH 10% with cabonactive 2-3 mesh as shown in Fig. 14.

## % Reduction of CO, PM2.5, and PM 10

Impacted by 10% KOH and 2-3 Mesh Carbon Active

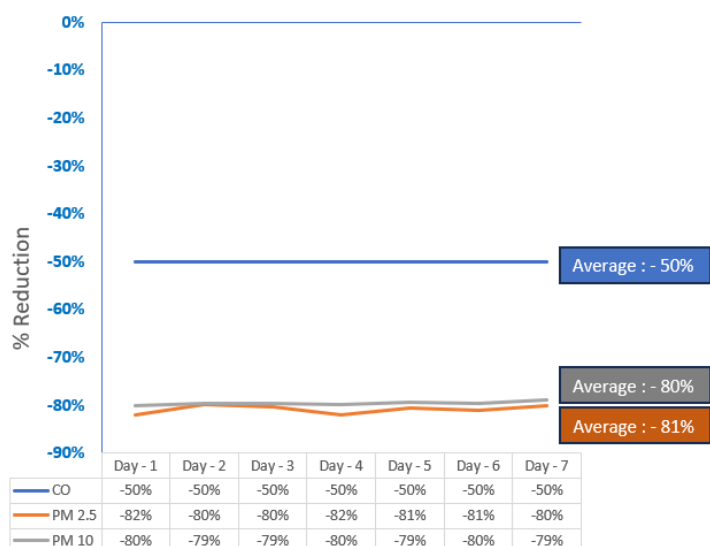


Fig. 14. The best graph of reduction.

## 4 Conclusion

Based on research and data testing carried out using the Anova test and Fisher Pairwise Comparisons, it can be concluded that to produce the best and cleanest air results, the composition is K4 C1 or KOH 10% with carbon active 2-3 mesh.

If activated carbon with a mesh size larger than 2-3 mesh will affect the quality of the KOH solution because the granules are too small and contaminate the KOH solution. And the higher the KOH solution level, the more effective it is at reducing the dangerous elements in welding fumes. With detailed conclusions as follows:

1. The addition of KOH to the filtration system affects reducing CO levels.
2. The addition of KOH to the filtration system affects increasing CO<sub>2</sub> levels.
3. The addition of KOH to the filtration system affects reducing PM 2.5 levels.
4. The addition of KOH to the filtration system affects reducing PM 10 levels.

## Acknowledgment

From the research that has been carried out and the conclusions that have been obtained, there are several points that can be made for improvements in subsequent research, namely 1) making a larger filtration system so that it can be used for industry, 2) create a real-time monitoring system so that it can be observed in more detail and data can be analyzed and retrieved more easily.

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