Steel Wire Cleaning using Cold Plasma

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Abstract.
Current galvanizing process used hydrochloric acid to remove oxide layer and mild acidic bath to remove oil on metal wire surface. These cleaning processes are compulsory before steel wire coated with zinc. These chemicals cleaning technique cause ecological harm and produce toxic waste. To consider of minimizing these problems, cold plasma was introduced for metal wire cleaning. Previous research already proves that cold plasma capable to remove oil by using dielectric barrier discharge (DBD) and remove oxide layer on copper by using RF plasma discharge. Therefore, in this research, the same plasma discharge system that is DBD was used to remove oil and oxide layer on steel wire. 8kV of voltage and air was used to generate plasma. By using copper and steel wire as electrode, it can remove oil around 82% and oxide layer around 54%.

1. Introduction

Galvanizing is the process where steel was coated with zinc to prevent corrosion on steel. Before the steel is coated with zinc, it went through degreasing and pickling process. These processes were applied on steel in order to remove any contaminants such as oil and oxide layer by using hot alkali and hydrochloric acid, respectively. Using this traditional method can cause ecological harm, high energy cost, produce toxic waste and pollutant gases [1,2,3]. Mr. Lim Guan Eng as a Finance Minister state that allocation of RM 2 billion to incentivise investment in green technology [4]. This allocation shows the government committed in order to protect the environment. Therefore, it is of ultimate necessity to switch from chemical methods to environmental friendly procedures.

To avoid using chemical for metal surface cleaning, plasma technology was introduced because it provides a better alternative. Plasma technology are widely used in many industrial application areas such as electrical engineering, optics printing technology and many more [5]. A big advantage of using plasma is that its by-products are harmless to the environment, mostly making CO_2 and H_2O molecules out of large hydrocarbon molecules [11]. The advantage of using plasma rather than chemical cleaning, plasma is more environmental friendly, less energy consumption and less pollution produced [12]. Therefore, it can be concluded that using plasma cleaning is better than using chemical treatment due to plasma did not produce any toxic waste that are harmful to the environment.

Previous research on cold plasma cleaning on metal wire has already been published that were used to remove oil on aluminium and copper wire [14,15] as shown in Table 1. Both research using dielectric barrier discharge (DBD) as discharge type with low frequency where frequency used is between 20-45kHz. Besides that, cold plasma also can be used to remove oxide layer on metal surface

[16] as shown in Table 2. This research using radio frequency (RF) glow discharge as a discharge type with radio frequency around 27.12MHz. These showed that by using cold plasma, oil and oxide layer can be cleaned but it can be cleaned by using different type of plasma discharge and different type of frequency.

Therefore, in this research, the same type of cold plasma discharge system that is DBD will be used for removing oil and oxide layer on metal wire. Then, this setup can be used during galvanizing process where it can be applied on degreasing and pickling process. Previous research use aluminium, copper and stainless steel as electrode. Based on three material, copper is the highest in term of conductivity. So, this research will use copper as electrode.

Table 1. Parameters for oil cleaning using plasma

Authors	Choi *et. al* [11]	Tran *et. al* [12]
Discharge Type	DBD	DBD
Voltage (kV)	9-11	8-10
Electrode	Stainless Steel	Aluminium
Dielectric	Teflon	Glass
Gap Length (mm)	0.3-3.2	4.9
Type of Gas	Atmospheric Air	Ar/He/N_2
Gas flowrate (l/m)	-	5
Substrate	Aluminium (Ø 1.6mm)	Copper (Ø 0.2mm)

Table 2. Parameters of plasma oxide layer removal

Author	Kotzamanidi *et al*. [16]
Discharge Type	RF glow discharge
Power (kW)	4
Electrode	Copper
Type of Gas	H_2, CH_4, N_2
Treatment duration	1-20 hours
Substrate	Carbon steel Plate

2. Methodology

In this study, DBD was used to generate plasma. Several parameters were considered when using DBD system such as type of dielectric material, gas (type, flowrate and pressure), type of electrode, air gap, power supply (voltage and frequency), and treatment time. Table 3 is the summary for DBD parameters used to design the system for generating plasma.

Figure 1 shows the design of the cold plasma discharge system. It consists of copper electrode and glass tube as dielectric material. Figure 2 shows schematic diagram that was used for plasma discharge system. In this research, PVM500 Plasma Resonant and Dielectric Barrier Corona Driver was used as high voltage power supply. High voltage power supply connected with copper electrode. Voltage probe used was Testec high voltage probe and current probe used was Fluke 80i-400 AC Current Clamp. Both probes were connected to oscilloscope (PicoScope 2208) to read voltage and current used.

Table 3: Parameters summary

Discharge System	DBD
Gas	Compressed Air
Flowrate	5 sccm
Electrode Material	Copper and Steel
Dielectric Material	Glass
Power Supply	8kV
Electrode Gap	5 mm
Treated Product	Galvanized steel wire – Oil Contaminants Steel wire – Oxide Layer
Treatment time	5 – 35 sec

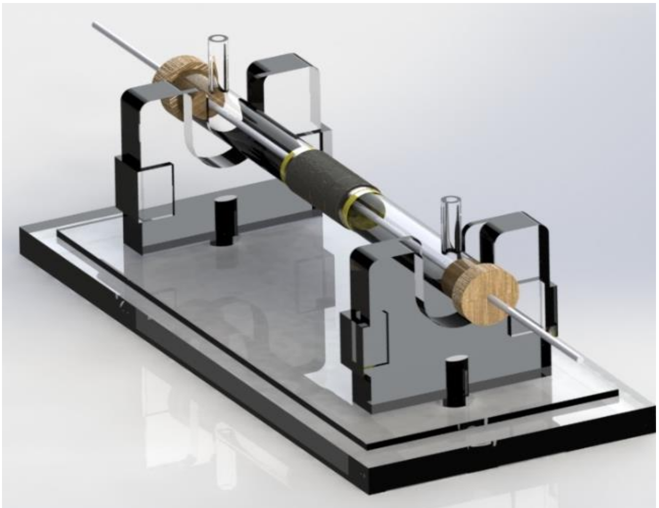

Figure 1: Design of cold plasma discharge system

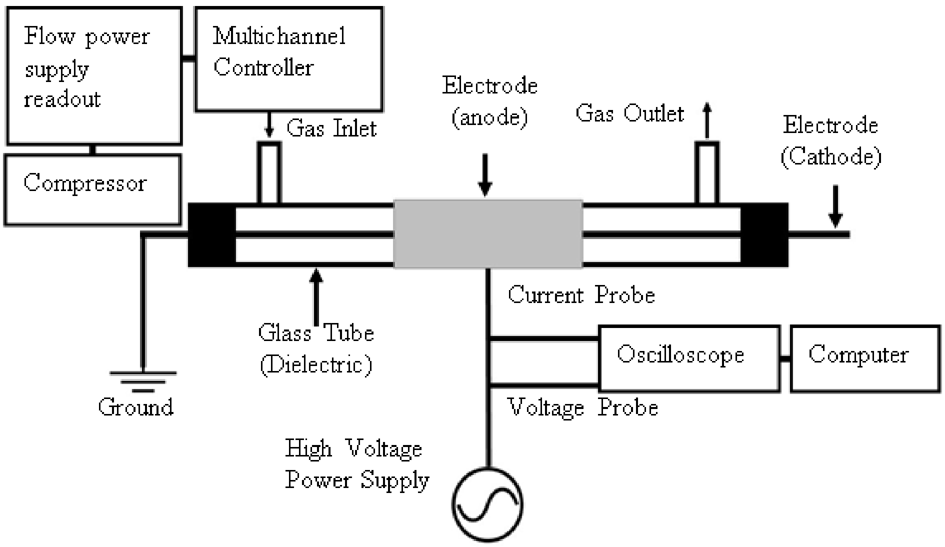

Figure 2: The schematic of cold plasma discharge system

Two equipment were used in this experiment to analyse the samples. The analysis on sample before and after plasma cleaning was performed using FTIR (Fourier Transform Infrared Spectroscopy) and surface roughness test. FTIR was used to analyse oil while surface roughness test to analyse oxide layer on metal wire surface.

3. Results and discussions

This section shows result of oil and oxide layer removal on wire using plasma treatment process. Oil analysis used the FTIR and oxide layer analysis utilized the surface roughness test. This experiment was performed at voltage 8kV, air as carrier gas, flowrate 5sccm and time treatment from 5s to 35s.
The wire surface was analysed using FTIR before coated with oil, after coated with oil and after plasma cleaning as shown in Figure 3. Since raw wire was cleaned without oil, no peak on the graph was displayed. Wire coated with oil shows high peak of methylene CH_2, asymmetric and symmetric stretching signals at wavenumber 2923 cm^{-1} and 2854 cm^{-1}, respectively [11]. A strong absorption band corresponding to a rocking mode of methylene (CH_2) was found at 722 cm^{-1}, which indicates a typical long chain $(CH_2)n$ paraffinic structure. Oxygen contains compound C=O (carbonyl group) and C-O were found at high intensity peaks at 1745 cm^{-1} and 1161 cm^{-1}, respectively [11]. This mixture of hydrocarbons came from the oil layer was $C_xH_yO_z$.

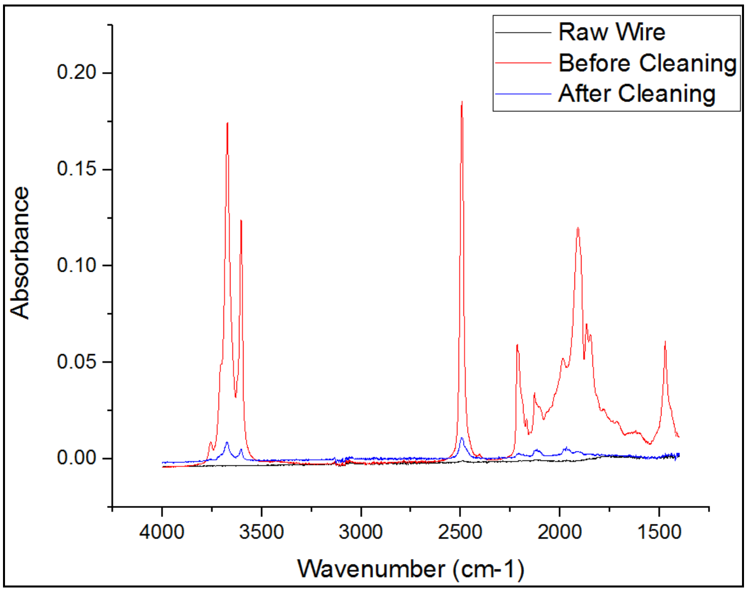

Figure 3: Treatment analysis on metal wire using FTIR

The wire surface was analysed using FTIR before coated with oil, after coated with oil and after plasma cleaning. Oil loss percentage was identified by area under the graph of oil loss (after treatment (A_{at}) minus before treatment ((A_{bt})) and divided with oil on metal (after treatment (A_{at}) minus raw wire ((A_{raw})) and multiplied with hundred as shown in Equation 1. Figure 3 shows the results of loss percentage of oil on steel wire surface. Oil loss percentage increases with the increase of treatment time. By using copper electrode, high loss percentage of oil is at 35th seconds about 82% of loss percentage of oil and lowest at 15th seconds around 13% of loss percentage of oil.

$$\text{Oil Loss Percentage } (\%) = \frac{A_{at} - A_{bt}}{A_{at} - A_{raw}} \times 100 \qquad \textbf{(Equation 1)}$$

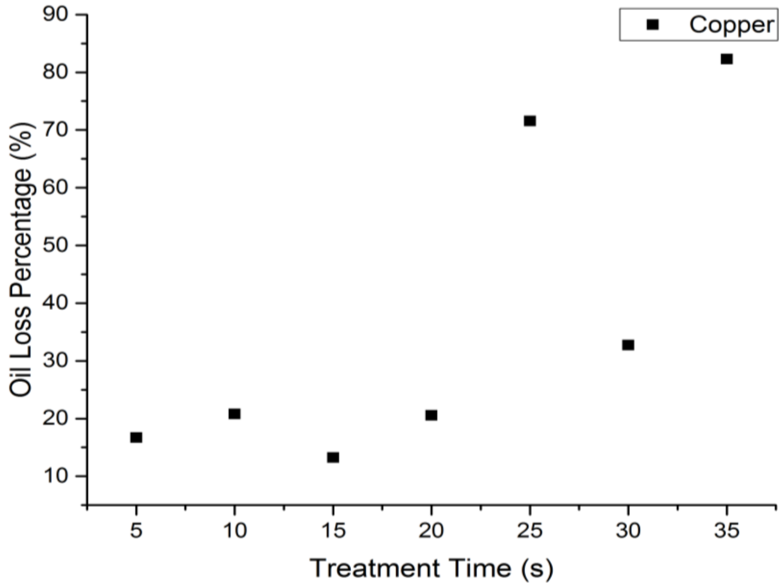

Figure 4: Loss percentage of oil on steel wire

Surface roughness test to analyse oxide layer was performed by Lin and Chang [12]. Percentage reduction of oxide layer is determined by reduction of roughness (roughness before (R_{bt}) minus after treatment(R_{at})) divided with roughness before (R_{bt}) treatment and multiplied with hundred as shown in Equation 2. Results of reduction of oxide layer is shown in Figure 4. There is an increment of oxide layer loss when increasing treatment time. All treatment times can remove oxide layer above 30%. Highest percentage reduction of oxide layer is with copper electrode is 54% at 20 seconds of treatment time. While low percentage reduction of oxide layer at 25th second around 32%.

$$\text{Percentage Reduction } (\%) = \frac{R_{bt} - R_{at}}{R_{bt}} \times 100 \qquad \textbf{(Equation 2)}$$

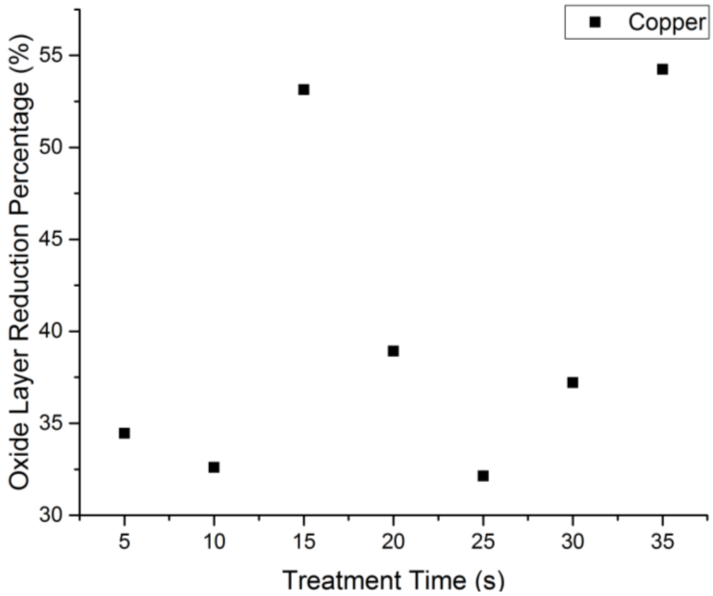

Figure 5: Reduction percentage of oxide layer on steel wire

4. Conclusion

From this experiment, it can be concluded that by using the same plasma setup, it capable to remove oil and oxide layer on metal wire. By using this setup, it capable to remove 82% of oil and 54% oxide layer by using copper as electrode. In order to achieved 100% oil and oxide layer removal, some modification need to be made or change the parameter of plasma generation.

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