Air ionizer application for electrostatic discharge (ESD) dust removal in automotive painting industry

M H Yosri[1], P Muhamad[1], M A Ismail[1] and N H M Yatim[2]

[1]Intelligent Dynamics & System Research Lab, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, 54100 Kuala Lumpur, Malaysia
[2]Department of Mechanical Engineering, Kulliyyah of Engineering, International Islamic University Malaysia, 50728 Kuala Lumpur, Malaysia

Email: hafizanyosri@yahoo.com

Abstract. Dust and fiber have been identified among the highest contributor for the defect in automotive painting line with range from 40% to 50% of total defect breakdown. Eventually, those defects will effect on both visual appearance and also the performance of the parts. In addition, the significance of controlling dust in an assembly line is crucial in order to maintain the quality of the product, part performance yield and effect on workers' health [1]. By considering the principle and technology applied in electronic clean room technology, the ionizer have been introduce to control dust contamination in automotive painting line. The first auto maker industry whom found the effectiveness of the clean room application to reduce the defect and production line downtime was Chrysler [2]. By doing so, it's allowed the transmission plant to offer 50 000 mile guarantee on the transmission systems. The main objective of this research is to verify the effectiveness of ionizer device in order to reduce the rejection contribute by dust and fiber particle in the automotive painting line. Towards the main objective, a few sub areas will be explored, as a supporting factor to ensure the result gain from this study is solid and constructive. The experiment start by verifying the electrostatic value of the raw material (substrate) before and after the ionizer treatment. From here the correlation of the electrostatic value generated by the raw material that effect to production pass rate can be explored. At the meantime, the performance of the production pass rate after the ionizer treatment which related to the painted surface area can be determined.

1. Introduction

Recently, the top and highest rejection for almost all painting line in automotive industry is contributed from dust and fibre. The rejection contributed by dust and fibre range from 40% ~ 50% (see, figure 1 and 2) [9]. For coating industries, dust and fibre have effects on appearance issue and also contribute to the cost of poor quality. The rejection due to this defect will directly increase the operational cost to reworked and repair the defective parts which indirectly impact on the company revenue. By taking example and practice from electronic, the implementation of ionizer application in clean room environment to control dust and fibre can be adapted into painting line in automotive industry. A few considerations should be taken into account to ensure the method and technology is suitable for automotive application.
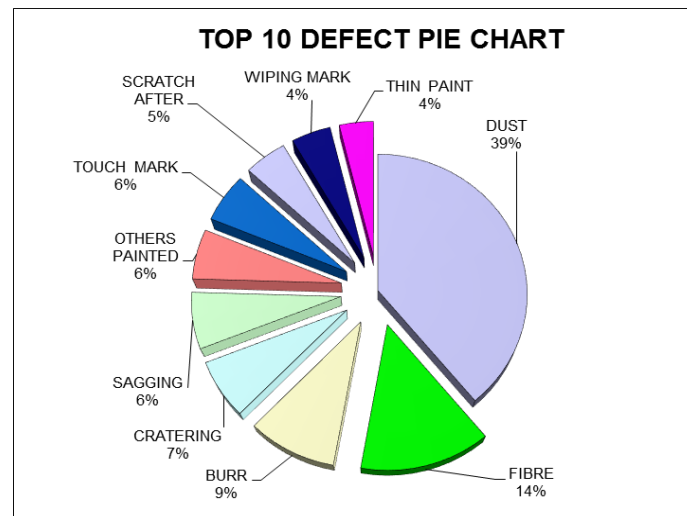
Figure 1. Pie chart of defect distribution for 2015 (Source from Combat Coating (M) Sdn Bhd 2015).

Figure 2. Sample contamination of dust and fibre in painting line (Source from Combat Coating (M) Sdn Bhd).

S. Arnold [4] suggests the best practice to reduce and control the ESD (electrostatic discharge) and contamination is by applying air ionization in clean room as shown in figure 3. Finding shows there is no laminar air flows able to reduce particle deposition in the clean room itself. The ESD and particle attraction are recognized as the major problem caused by the static charge in semiconductor manufacturing. The air ionization can reduce the contamination by creating a balance quantities of both negative (-) and positive (+) ions. The clean room and laminar air flows are installed with overheads ceiling or bar type ionizers to control the static charges to get better and effective results. Ionizers can make particle produced during certain production processes easier to be removed. Ionizers are used to control static electricity, which usually situated in the roof that can allow the static charge to dissipate. Bapat [5] presented the application of electrostatic precipitators (ESP) for controlling cement dust while Hindy [6] concluded that the application of ESP is very effective to control the cement dust.
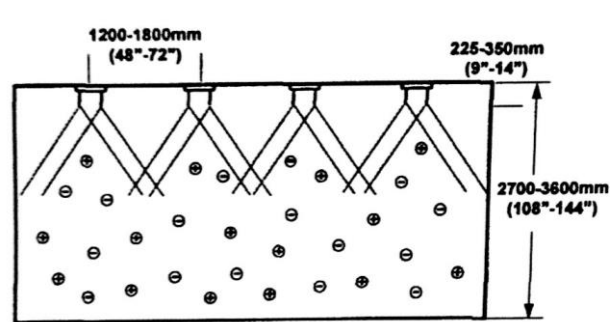
Figure 3. Typical installation of ionizers on a clean room ceiling.

G.W. Penney et al. [7] found the charged particles suspended in the air room create a space charge potential. The resulting voltage gradient drives the charged particle towards the wall. The chain effect from this condition will contribute to high dust particle where the effectiveness of the air cleaning device is not realized. This situation can be resolved by introducing the high efficiency cleaning and neutralizing space charge device such as the air ionizer [8].

Electrostatics phenomenon occurs when the particular object contacts with other surface and escalates the electrostatics charge of ion on the surface of objects. Even though electrostatics occur during the surfaces contact and separate, the effects of electrostatic flows charge exchange are usually happen when one of the object surfaces has a high resistance to electrical flow. The reason of this phenomenon is due to the charges that are embedded and trapped in the object surface for a certain period of time for the effects to be observed. These electrostatics charges are kept and preserved on the surface object until they either flow off to the ground or neutralized by a discharger [3]. An ion exposed to an electric field E will move with an average drift velocity v proportional to E, that is,

$$v = kE, \tag{1.1}$$

where k is the mobility of the ion.

Theoretically, when the air ion exposed to an electric field with a strength of 1 V/cm, its will moves at a velocity of about 1 cm/sec in the range of 1.0–2.0 cm2/V•s (centimeter^2 per volt-second). In addition, the movement of the negative ions is approximately 15% higher compared to positive ions. In summary, the air concentration n of positive ions with the mobility k and charge e, an electric field E will make the electric current to flow in the direction of E with the density j.

$$j = enkE = \lambda E \tag{1.2}$$

The constant λ that represent to enk, is the positive conductivity of the air or in another words the polar conductivity that contribute by the positive ions. In another hands, negative ions will flow in the opposite direction of the field. Nevertheless, the current density from negative ions can be calculate using equation (1.2) when e is taken as the numerical value of the ion charge.

Theoretically, an electric field is generate surrounding the object depends on the given charge, either positive or negative polarity. For example, whenever the objects is surrounded with air that contains both polarities, the opposite polarity air ion will moves and flows towards the object. However the same polarity will flow against and opposite of its. Even though the field will different from every position and area in space, it is always proportional to q. The movement of charge is an electric current. The neutralization current which is equivalent to the charge and to the relevant opposite conductivity of the surrounding air is moving toward to the object while carried by ions of polarity opposite to q.

The charge neutralization relative rate is constant in the event of the air conductivity does not change, while the charge will reduce proportionally with a time constant τ that rely on the air conductivity. Given an initial charge q_0, the charge remaining at a later time is given by

$$q = q_0{}^{-t/\tau,}$$ (1.3)

where the time constant τ is equal to the permittivity of the air ε0 divided by the air conductivity, λ.

$$\tau = \varepsilon_0/\lambda$$ (1.4)

thus, referring to equation (1.3),

$$q = q_0{}^{-t(enk/\varepsilon 0)}$$ (1.5)

resulting the rate of charge neutralization proportional to the ion concentration.

2. Experimental procedures

In total there were 550 pieces of sample from 9 type of parts. From there, the entire sample can be grouped into 3 sub-groups which are small, medium and big parts. The purpose of dividing the parts into 3 categories is to monitor the factor that will potentially affect the quantity of dust particle to fall down into the painted parts. Among the factors are the painted surface area and geometrical design of the parts. The monitoring period had started from January to August 2016 when the installation was completed on earlier January 2016. From there, the machine were continuously used during normal production time.
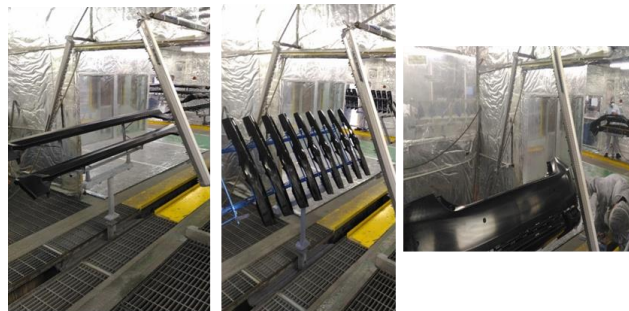

Figure 4. Part position during ionizing process.

The ionizer machine was installed after the cleaning process in preparation area. The main objective was to monitor the effectiveness of ionizer machine to neutralize the electrostatic charge at the raw material before the painting process. The device was installed on a static condition with 45-degree angle to communize with all plastic parts. Consideration has been made based on the coverage of the ionizer air distribution with the painting jig position. With 45-degree position, the painting surface coverage with the ionizer treatment reaches almost 98% where the rest is hidden due to the parts' geometry and non-critical area for painting process. The ionizer device was installed after the air blow/ tag rag process. This was the last process before the parts enter the production line for the first primer coating. The experiment was conducted in actual painting line environment with fixed and constant parameter using exiting setting for current production. The air flow was supplied from Air Supply Unit (ASU) with the speed of 0.25 m/s while the temperature and humidity was set at 27.1 Celsius and 85% RH (relative humidity).

In this experiment, the Keyence Static Eliminator model SJ H108A was installed after the wiping process and before the first layer of primer coating. The SJ Series has adopted the pulse AC method that applies alternating high voltage to the electrode probe, producing ions of both polarities.

3. Results and Discussion

The initial data for the electrostatic value for the raw parts was collected to compare the values before and after the raw parts gone through the ionizer treatment. Most of the raw parts show zero value, which reflect the effectiveness of the ionizer to neutralize the electrostatic value on the raw parts. From table 1, it is seen that the production pass rate shows a slight reduction from 91.4% on 2015 to 90.8% on 2016 (data collected until August 2016) while the rejection trend for dust increases from 3.2% to 4.6%. However, the fibre defect shows some reduction from 1.3% to 0.9% in 2016. The lowest pass rate and highest rejection for dust and fibre is recorded on June 2016 exactly after the replacement of the ceiling filter. The data shows the production pass rate is reduced to 87.5% while the dust and fibre increased to 6.8% and 1.4%. However, the production pass rate recovers back on the next following month until August 2016 (Production pass rate: 93.3%, Dust: 3.2%, Fibre: 0.8%).

Table 1. Production Pass Rate.

Month	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Average 2016	Average 2015
Pass Rate	91.10	91.56	91.45	91.17	88.76	87.50	91.10	93.30	93.95	92.20	87.20	91.21	91.36
Dust	4.33	3.93	4.32	3.94	5.86	6.80	4.06	3.23	2.30	2.55	4.55	4.13	3.21
Fiber	0.75	0.76	0.84	0.88	1.11	1.40	0.95	0.77	0.70	0.90	1.45	0.91	1.25

Table 2. Summary of correlation result of electrostatic value, material type and production pass rate.

No	Parts	Before (kV)		Material Type	PASS RATE (%)	Average		
		(+)	(-)			Pass Rate	(+) kV	(-) kV
1	Bumper	1.5	-2.0	Polypropylene (PP)	49.3	68.9	1.1	-1.1
3	Tail Gate	0.5	-0.4	Polypropylene (PP)	68.1			
4	Rocker Panel	0.5	-0.4	Polypropylene (PP)	93.1			
5	Side Sill	1.7	-1.6	Polypropylene (PP)	65.1			
6	Door Handle	1.4	-0.2	Polybutylene terephthalate (PBT)	95.0	95.0	1.4	-0.2
2	Spoiler	0.1	-0.1	Acrylonitrile butadiene styrene (ABS)	68.2	82.5	2.6	-2.6
7	Mirror Hood	0.7	-0.3	Acrylonitrile butadiene styrene (ABS)	87.2			
8	Scull Cap	3.1	-4.4	Acrylonitrile butadiene styrene (ABS)	86.1			
9	Back Door	6.4	-5.6	Acrylonitrile butadiene styrene (ABS)	88.4			

Acrylonitrile butadiene styrene (ABS) material shows the average pass rate is 82.5% even with high electrostatic value range from -2.6 kV to 2.6 kV. Polybutylene terephthalate (PBT) material shows the highest pass rate of 95.0% even with the lowest electrostatic value range from -0.2 kV to 1.4 kV while Polypropylene (PP) material shows the lowest pass rate of 68.9% with average electrostatic values ranging from -1.1 kV to 1.1kV. Ionizer machine shows good result to neutralize the electrostatic value of the parts despite the highest value shows at ABS material. From the experimental result, the material has no big influence to affect the outcome of the production pass rate with the application of the ionizer when the static value is neutralized to zero value after the treatment. However, other factors such as the part geometry and the painted surface provide higher potential for the dust particle to fall down into the surface. It aligns with the experimental result when the PP material parts especially bumper that has bigger painted surface provides less production pass rate due to this matter. In opposite of that, Back Door Garnish that is manufactured from ABS material with high electrostatic value still manage to get a good production pass rate (88.4%).

Among external factors that might influence the efficiency of the ionizer device is due to the static charge carrier during wiping process. As normal process flow, the wiping process was conducted be-

fore the ionizing process with a distance less than 2 meter between both stations and 60 seconds of time cycle between the carriers in the conveyor line. Hence, there was a possibility that the wiping process will generate electrostatic charge and reduce the efficiency of the device [11]. Furthermore, the distance and gap for the conveyor to travel after the ionizer treatment to the first painting booth (primer booth) will provide a chance for the particle to fall down into the parts. In other words, even though the parts were properly neutralized using the ionizer device, there was no guarantee that the particle will attach back to the part due the above mention factor.

However, the main cause that contributes to the downtrend of the production pass rate still cannot be determined. The only suggested hypothesis at this moment is due to the mechanical movement of the dust and fibre particle that has previously settled down in idle condition and is exposed to the painting line environment during the changing process of the filter itself.

4. Conclusion

The efficiency of ionizer device to reduce the rejection contributes by dust and fiber particle in the automotive painting line have been tested experimentally in actual environment. The outcome from this experiment is determined from the production pass rate after the ionizer treatment. Referring to the results from the actual manufacturing process, it shows a minor reduction of the fibre particle after the implementation of the ionizer machine. However, the rejection trend for dust defect increases around 2%. Nevertheless, the result gain from this period was doubtful due to uncertainty especially during the replacement of the ceiling filter on July 2016, which shows the highest rejection for dust particle. Further monitoring should be conducted in order to get more solid and certain data for the effectiveness of the ionizer application to control the dust and fibre particle. Other factors that should be considered are the parts' geometry and painting jig design which correlate to the painted surface area that is exposed to the environment which carries out the dust and fiber particle. In addition, the air flow, turbulence and particle concentration in paining line after the ionizing process shall be determined using a Computational Fluid Dynamic (CFD) [10] in order to improve the mechanical design of the painting jig, working layout and parameter setting of the painting line.

References
[1]   Rosmaini Ahmad, S.K., Zahid A. Khan, Mohzani Mokthar, Indra Putra Almanar 2006 *Management of Environmental Quality, an International Journal* **7** pp 390-408
[2]   Holbrook, D., 2009 *H.a. Technology Editor* pp 173-191
[3]   Arnold Steinman 2006 Compliance Engineering, Annual Reference Guide, Copyright 2006 Canon Communications LLC
[4]   Arnold., S.,1995 *EOS/ESD Symposium* pp 95-245
[5]   Bapat, J.D., 2001 Journal of Hazardous Materials, **B81** pp 285-308
[6]   Hindy, K.T. *Utilization of controlled cement dust as a concrete material in the United Arab Emirates*. in *Environmental Management and Health*. 1997
[7]   Hewitt., G.W.P.G.W.,1949 *AIEE Transactions*
[8]   Inculet, I. I., & Topping, D. R. 1971 *IEEE Transactions on Industry and General Applications* **2** pp 314-317.
[9]   Combat Coating (M) Sdn Bhd, *Outgoing Quality Inspection Passrate Report*, 2015~2016
[10] Thongsri, J., & Pimsarn, M. 2015 *International Journal of Precision Engineering and Manufacturing* **16** pp 509-515
[11] Noh, K.C., Kim, H. S., and Oh, M. D. , 2010 *Building and Environment* **45** pp 825-831.