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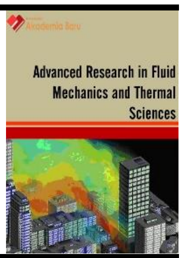

Application of Air Ionizer to Remove Electrostatic Discharge (ESD) Dust for Plastics Material in Automotive Painting Process

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ABSTRACT

In the painting production process, repairing of painted defects by running the part through repeat process, together with the essential requirement of quality control routines, contribute for a very large proportion for the operating costs. The dust and fibre defects which ranged between 40% and 50% found to be the highest rejection in of the local painting line manufacturer. Both defect not only affected the visual appearance but also the of the parts performance. The objective of this research is to explore the effectiveness of the air ionizer device to reduce the electrostatic value of the painted material that attract the foreign particle to fall into painted surface. By doing so, the rejection contributes by dust and fibre particle in the automotive painting can be reduce. The ionizer is an effective application to replace the conventional methods which applied the air blow process to remove dust and fibre particle before painting process. The experiment has been conducted by measuring the electrostatic value of the raw material before and after the ionizer treatment. The correlation between the static value and the production pass rate also has been examined. The result shows 0.34% reduction of the fibre particle after the implementation of the ionizer device.

1. Introduction

Controlling dust contamination in production lines becomes crucial in order to maintain the quality of the product, part performance yield and effect on workers' health [1]. By benchmarking the fundamental and practice applied in electronic clean room environment, the air ionizer have been introduced to control dust contamination by applying the static eliminator in automotive painting line. The Chrysler [2] is the first auto maker whom found the effectiveness of the clean room application to reduce the defect and production line downtime. Therefore, it's allowed the transmission plant to offer 50 000 mile guarantee on the transmission systems.

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The main rejection for painting line in automotive industry are comes from dust and fibre defect which contribute by range of 40% ~ 50% (see, Figure 1 and 2) [3] from the total defect. 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.

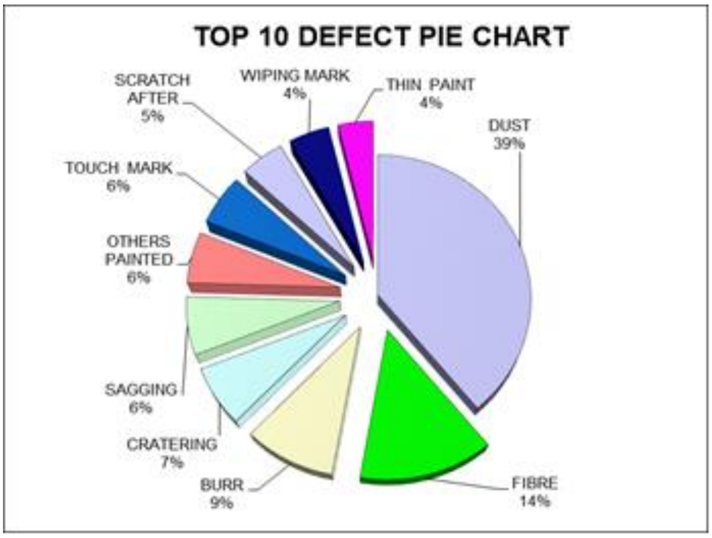

Fig. 1. Pie chart of defect distribution for 2015 (Source from Combat Coating (M) Sdn Bhd 2015)

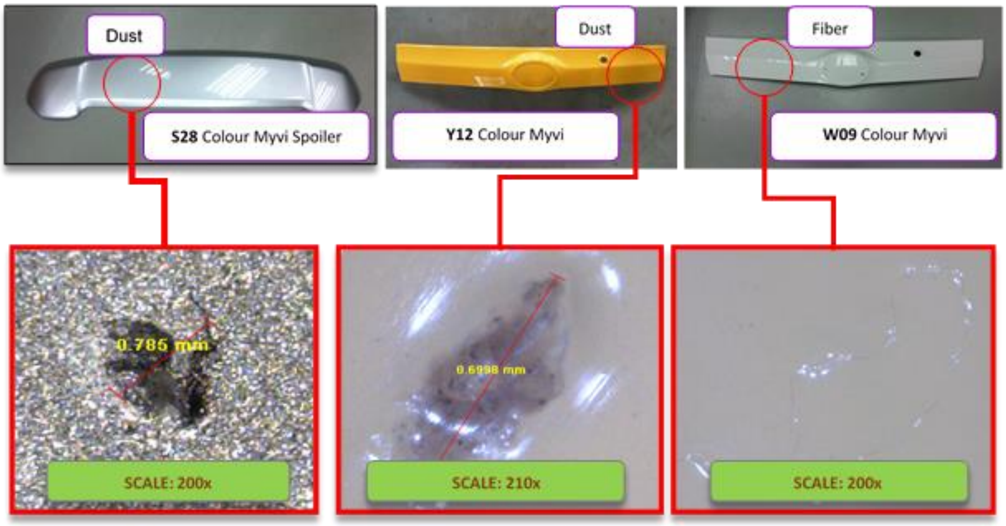

Fig. 2. Sample contamination of dust and fibre in painting line(Source from Combat Coating (M) Sdn Bhd)

The objective of this research is to measure and evaluate the effectiveness of the air ionizer device to reduce the electrostatic value on the painted material. The electrostatic charge will create a magnetic field for the foreign particle to attract and fall into painted surface which contribute the dust and fibre rejection in the painting process. The ionizer device can be effective applications to replace the conventional methods which applied the air blow process to remove dust and fibre particle before painting process. Theoretically the ionizer device can neutralize the painted material electrostatic charge and minimize the attraction of foreign particle to fall into painted material, instead of conventional air blow application which applied normal air blow process which generate more electrostatic field during wiping process. Apart from that, the ionizer device can eliminate operator headcount to do the air blow process by standalone ionizer device installation.

By taking example and practice from electronic, the implementation of ionizer application in clean room to control dust and fibre can be adapted into painting line in automotive industry. However, a few considerations should be taken into account to ensure the method and technology is suitable for automotive application.

Arnold [4] suggests the best practice to reduce and control the ESD (electrostatic discharge) is by applying air ionization in clean room as shown in Figure 3. His 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 quantity 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 install at the ceiling area which 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.

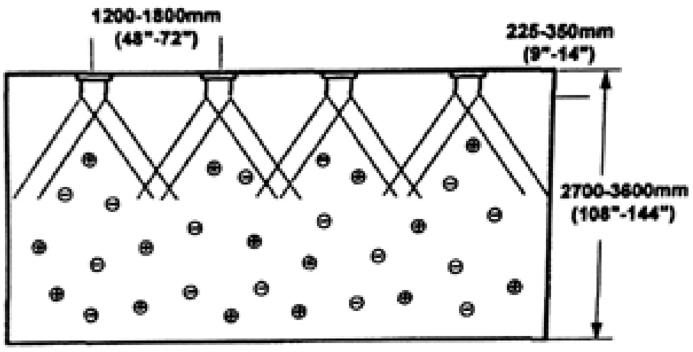

Fig. 3. Typical installation of ionizers on a clean room ceiling

Penney *et al.,* [7] discovered 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]. Shu-Ye Jiang *et al.,* [9] conducted an experiment that found the Negative air ions (NAIs) could be used to reduce the particle concentration and freshen the indoor air quality. With the application of air ionizer, the air ions charges polarity can be control and neutralize simultaneously. Kuo-Pin Yu *et al.,* [10] investigated the effect of particle characteristics and turbulence intensity on the deposition of submicron particles that enhanced by the negative air ionizer (NAI). Conclusively, the NAI is found more efficient to purifier the air particles and performance better under lower turbulence intensity.

Buddhi *et al.,* [11] tested the efficiency of a small negative ion generator (Aironic AH-202) in removing ultrafine particles from the indoor environments. The ionizer was operated within a closed chamber of volume 1m^3. The result shows that 70% of the particles were removed by the ionizer within 15 min. It was observed that, the ionizer removed not only the large particles but also the ultrafine particles too for all sizes. However, it's noticed that the particle removal efficiency of the ionizer decreased as the room size increased. Hence that, the selection of proper ionizer device is really crucial to ensure the effectiveness of the applications. Enze Tian *et al.,* [12] developed a compact electrostatic assisted air (cEAA) coarse filter, where the particle removal performance is enhanced by the synergistic effect of ionizer charging field and a polarizing field. It's proven that, the ionizer device can improve the filtration efficiency by enhanced conventional filter to trap the foreign particle by the ionizing function to neutralize the particle charge.

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 when the two surfaces contact and separate, the effects of electrostatic flows charge exchange are usually occured 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. These electrostatics charges are kept and preserved on the surface object until they either flow off to the ground or neutralized by a discharger [13].

An ion exposed to an electric field E will move with an average drift velocity v proportional to E, that is,

$$v = kE, \tag{1}$$

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/Vs (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.

$$j = enkE = \lambda E \tag{2}$$

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 Eq. (2) when e is taken as the numerical value of the ion charge.

An electric field is generate surrounding the object depends on the given charge, either positive or negative polarity. For example, whenever the objects are surrounded with air that contains both polarities, the opposite polarity air ion will move 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

$$q = q_0{}^{-t/\tau}, \tag{3}$$

where the time constant τ is equal to the permittivity of the air ε_0 divided by the air conductivity, λ.

$$\tau = \varepsilon_0/\lambda \tag{4}$$

thus, referring to Eq. (3),

$$q = q_0^{-t(enk/\varepsilon 0} \quad (5)$$

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

2. Methodology

2.1 Experimental Procedures

In total there were 550 pieces of sample from 9 type of parts. From there, the sample has been grouped into 3 main sub-groups which are small, medium and big parts (Figure 4). The purpose of dividing these 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 considered 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 of the air ionizer was completed on earlier January 2016. From there, the machine was continuously used during normal production time.

Fig. 4. Part position during ionizing process

The ionizer machine was installed as replacement for manual air blow process at preparation area. The main objective is 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 customize the coverage area of ionizing for all plastic parts on the painting jig condition. With 45-degree position, the painting surface coverage with the ionizer treatment reaches almost 98% whereas the rest area is hidden due to the parts geometry and non-critical area for painting process. The ionizer device was installed after the wiping process as refer to Figure 5. This is the final process before the parts enter the production line for the primer coating. The experiment was conducted in actual painting line environment using exiting parameter setting for painting line. The air flow was supplied from Air Supply Unit (ASU) with the speed of 0.20 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 air blow process. This model operates by generate the pulse of AC method that applies alternating high voltage to the electrode probe which producing ions of both polarities.

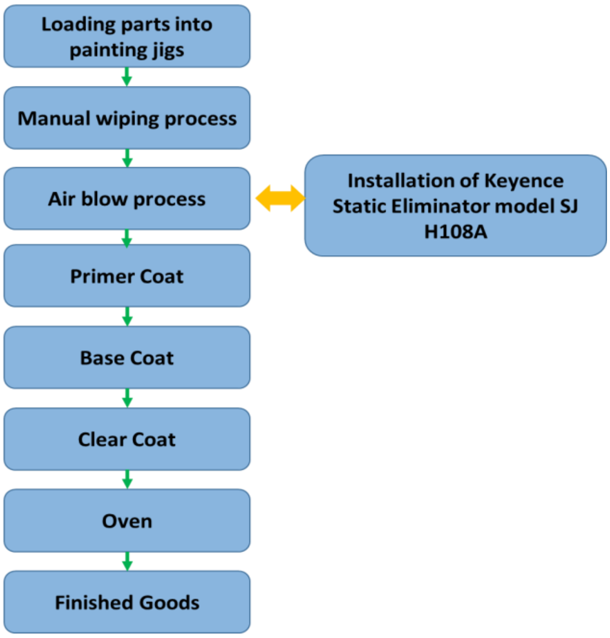

Fig. 5. Flow chart of painting process with introduction of ionizer device

3. Results and Discussion

The initial data for the electrostatic value of the raw parts was collected to compare the values before and after the ionizer treatment. Most of the raw parts provide zero electrostatic value, which reflect the effectiveness of the ionizer to neutralize the electrostatic charge on the raw parts. From Table 1, 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 new 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	Ave 2016	Ave 2015
Pass Rate	91.1	91.56	91.45	91.17	88.76	87.5	91.1	93.3	93.95	92.2	87.2	91.21	91.36
Dust	4.33	3.93	4.32	3.94	5.86	6.8	4.06	3.23	2.3	2.55	4.55	4.13	3.21
Fibre	0.75	0.76	0.84	0.88	1.11	1.4	0.95	0.77	0.7	0.9	1.45	0.91	1.25

(Table 2) Acrylonitrile butadiene styrene (ABS) material shows the acceptable average pass rate of 82.5% even with high electrostatic value range from -2.6 kV to 2.6 kV. Polybutylene terephthalate (PBT) material provides the highest pass rate of 95.0% at 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 perform well to neutralize the electrostatic value of the parts despite the highest value shows at ABS material. From the experimental result, the material type has no significant 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. 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 which is manufactured from ABS material with high electrostatic value still manage to get a good production pass rate (88.4%).

Referring to the three groups of material classification used for production in the tested painting line, in average the Polybutylene terephthalate (PBT) material provide the lowest electrostatic value before the ionizer treatment followed by Polypropylene (PP) and Acrylonitrile butadiene styrene (ABS). The electrostatic field which generate surrounding the object is different between the material type. Theoretically, whenever the parts are surrounded with the particles that contains both polarities, the opposite polarity of the particles will move and flows towards the object. However, the same polarity will flow against and opposite of each other's. In this case, the higher electrostatic value will cause more tendency of particle to attach to the painted material which can be reduce by the ionizer application. As for the production pass rate, the Polybutylene terephthalate (PBT) material shows the highest reduction of the dust defect which justify the correlation between the electrostatic value with the decrement of particle dispersion into painted parts.

Among external factors that might influence the efficiency of the ionizer device is due to the static charge developed by wiping process. As normal practice before painting process, there was a manual wiping process before the air blow process which was replaced by air ionizer in this experiment. The distance between these two processes is less than 2 meters with 60 seconds of cycle time between the carriers at the conveyor line. Hence that, there was a possibility that the wiping process will generate electrostatic charge and reduce the efficiency of the device [14]. Furthermore, the distance and gap for the conveyor to travel after the ionizer treatment to the first painting process (primer booth) will provide a possibility for the particle to fall down into the parts. In other words, even though the parts have been properly neutralized using the ionizer device, there was possibility that the particle will attach back to the part due the above mention factor.

Dust concentration mostly depending from a few factors such as the frequencies of movement and density of occupants in a working station with addition of natural build up due to less ventilation in closed environment. Ismail *et al.,* [15] found the dust concentration can be reduced if by increasing the frequencies of vacuum process. This finding can be additional precaution measure to be add on into preventive maintenance of automotive painting line but practically the painting line already have the air ventilation system that function to circulate out the foreign particle from the environment. In addition, the influence of door opening during operator movement into the painting line may also effect on the particle concentration. Hamid *et al.,* [16] conducted numerical studied on the three dimensional of uni-directional flow in an operating room with ceiling supply and side exhaust grills with focusing on the effect of gradual door opening. It is seen that the gradual door opening causes an increasing in the mean age of the air which reduce the air quality by increasing the foreign particle. The finding assures that doors must be closed throughout the time of operation.

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 during the changing process of the ceiling filter which caused the dust and fibre particle that has previously settled down in idle condition and exposed to the painting line environment. Moving forwards, the turbulence impact on the efficiency of the ionizer device shall be consider. As mention by Kuo-Pin Yu *et al.,* [10], the deposition of submicron particles by the air ionizer is found more efficient under lower turbulence intensity which cannot be determined during the time where the experiment is conducted. Hence that, further investigation on the turbulence intensity shall be done using the Computational Fluid Dynamics (CFD) in order to understand the actual turbulence concentration in the painting booth. Another factor that should be consider is the coverage of the ionizing treatment. Even though the ionizing device has been positioning at the appropriate location to get the most efficient coverage, but the removal efficiency of the ionizer may decrease since the size of the spray booth area was not put into consideration. This is aligned with the finding from Buddhi *et al.,* [11] that confirm the particle removal efficiency of the ionizer decreased as the room size increased.

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

No	Parts	Before (kV) (+)	Before (kV) (-)	Material Type	PASS RATE (%)	Average Pass Rate	Average Ionizer Value (+)	Average Ionizer Value (-)
1	Bumper	1.5	-2.0	Polypropylene (PP)	49.3	68.9	1.1	-1.1
2	Tail Gate	0.5	-0.4	Polypropylene (PP)	68.1			
3	Rocker Panel	0.5	-0.4	Polypropylene (PP)	93.1			
4	Side Sill	1.7	-1.6	Polypropylene (PP)	65.1			
5	Door Handle	1.4	-0.2	Polybutylene terephthalate (PBT)	95.0	95.0	1.4	-0.2
6	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			

4. Conclusions

The efficiency of ionizer device to reduce the rejection contributes by dust and fibre particle in the automotive painting line have been tested experimentally in actual environment. The outcome from this experiment is determined by 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 device. However, the rejection trend for dust defect increases around 2%. Nevertheless, the result obtain from this period was doubtful due to uncertainty that contribute by the replacement of the ceiling filter on July 2016 where the highest rejection for dust particle is recorded. Others factor that should be considered are the parts geometry and painting jig design which has the correlation to the painted surface area that exposed to the environmental contaminated. Hence that, further study needs to be focus on the simulation using the Computational Fluid Dynamic (CFD) [17] method to identify the air flow and turbulence pattern that may help to understand the particle concentration and movement in the painting line. Hafizan *et al.,* [18] investigate the airflow and particle distribution in automotive painting line using CFD by referring to different mechanical design of ventilation system in order to understand the air flow characteristics. The results confirmed that by adding more exhaust fan at opposite direction can improve the air flow circulation and reduce the particle concentration in the painting line.

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