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ROLE OF ZETA POTENTIAL IN AEROSOL PARTICLE AGGREGATION AND DEPOSITION: IMPLICATIONS

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Abstract
Aerosol particles play an essential role in ambient air quality, climate change, and human environment especially on human health. This study therefore investigates particle size aggregation influence by zeta potential at pH activeness at its acidity, neutrality and basicity using optical particle counters, pH meter and stop watch in hourly interval for 8 hours at the Bayelsa State Ekeki intra-modern motor at random positions. The results show that, at total average of acidity, neutrality and basicity, the zeta potential and particle size aggregation were 22.9, 9.25, 30.5 mV and 4.83, 6.94. 3.0 µm respectively. On percentage, the total average zeta potential to pH total average acidity, neutrality and basicity were 36, 15, and 49 %, while acidity and basicity was 71 and 29 %. Similarly, the total average zeta potential to pH total average acidity, neutrality and basicity were 36, 15, and 49 %, while acidity and basicity records 71 and 29 %. Furthermore, the particle size aggregation to acidity, neutrality and basicity shows 33. 47 and 20 %, while acidity and basicity records 41 and 59 %. The results show that in the 8-hour investigation, zeta potential influences on the particle size aggregation were on basicity to neutrality to acidity which recorded as 3.0, 4.83 and 6.94 µm respectively, indicting possible deep penetration into the lungs as the particle size were less than 10 µm which can't be filtered out by the nasal easily, therefore proves hazardous to personal exposures.

***Keywords**: Zeta Potential, Aerosol, Particle size, Aggregation, Acidity, Neutrality, Basicity, Investigation and Hourly Intervals.*

i. Introduction

Aerosol particles are complex systems consisting of various chemical components, including organic and inorganic compounds, metals, and biological materials (Donaldson et al., 2013). The organic and inorganic compounds are considered as Secondary Organic Aerosols (SOAs) formed through the oxidation of volatile organic compounds (VOCs) (Canagaratna et al., 2015), trailed by gas-particle partitioning of semi-volatile products (Seinfeld & Pandis 2016). These aerosols are commonly emitted from automotive emissions, industrial processes, and biomass burning (Seinfeld & Pandis 2016). And the by-products of these emissions include sulphates, nitrates, and ammonium which are dominant species in secondary inorganic aerosols, contributing to localized haze formation (Zhang et al., 2015). On the other hand, the metal components are classified under Chalcophilic Metals (MCs) which includes Lead (Pb), Antimony (Sb), Cadmium (Cd), Selenium (Se), Arsenic (As), Zinc (Zn), and Molybdenum (Mo) (Wang & Shen.2020). These metals can be found in aerosols (Ge et al., 2012), often emanating from industrial activities and fossil fuel combustion (Seinfeld & Pandis 2016). Other Lithophilic Metals such as Manganese (Mn) and Zirconium

(Zr) are common metals that are also presence in aerosols, often originating from natural sources in soil and minerals (Lide (2005). Similarly, Biological Materials are considered under Pollen and Mould Spores. These Biological aerosols are pollen, mould spores, and other plant and animal materials (Gregory (1973). Others are bacteria and viruses which are microorganisms also present in aerosols, potentially leading to health concerns (Cox & Wathes (1995). Also, biological materials can also include sea salt and soil particles, which can become airborne through natural processes like ocean waves and wind erosion (Hinds 2012). Furthermore, Zeta Potential plays major roles in aerosol particle aggregation. That is, zeta potential of aerosol particles influences their aggregation performance, which in turn affects their size distribution, shape, and deposition patterns and negatively charged particles are more stable and less likely to aggregate, which can lead to deeper penetration into the lungs (Lee et al., (2013), deposit more efficiently in the lungs, possibly leading to increased toxicity (Chen et al., (2017), as well as induce oxidative stress and inflammation in the lungs and cardiovascular diseases (Pope et al., 2013), intensifying respiratory diseases (Zhang et al., (2019). In the same vein, positively charged particles most likely to aggregate and can lead to larger particles, though are easily filtered out by the lungs (Lee et al., 2013), it also deposit less efficiently in the lungs, potentially reducing toxicity (Nel et al., 2006), and induce less oxidative stress and inflammation in the lungs as compared to negatively charged particles (Zhang et al., (2019). Similarly, Neutral particles aggregate moderately, and this leads to moderate deposition in the lungs (Lee et al., (2013), and possibly leading to moderate toxicity (Chen et al., 2017). That is, the zeta potential of aerosol particles has significant effects on human health (Nakao et al., 2012), depending on whether the particles are negatively or positively charged as indicated by some researchers (Ahmad et al., 2025). Studies have shown that particles with high zeta potential values tend to aggregate more rapidly, leading to the formation of larger particles which have found that aerosol particles with high zeta potential values (>30 mV) aggregated more rapidly than those with low zeta potential values (<10 mV) (Lee et al., 2013). A study by Chen et al., 2017 demonstrated that the zeta potential of aerosol particles influenced their aggregation behaviour in the presence of humidity. In aerosol particle deposition, the zeta potential of aerosol particles also influences their deposition behaviour, which is critical for understanding their chances and transport in the atmosphere. Zeta potential values tend to deposit more efficiently on surfaces of aerosol particles with high zeta potential values (>20 mV) deposited more efficiently on a stainless steel surface than those with low zeta potential values (<10 mV) (Zhang et al. 2019). It is also demonstrated in a prevalent condition that the zeta potential of aerosol particles influences their deposition behaviour in a turbulent flow (Li et al., 2020). Equally, in understanding the implications for air quality and pollution control, the role of zeta potential in aerosol particle aggregation and deposition is critical for developing accurate air quality models and effective pollution control strategies. That is, when zeta potential is incorporated into air quality models, it will enable researchers and its allies discipline to have a better prediction in understanding the transport of aerosol particles from place to place in the atmosphere. According to Wang et al., (2018) the incorporation of zeta potential into an air quality model improved the prediction of aerosol particle concentrations and deposition patterns. The zeta potential incorporation has helped to optimize aerosol particle removal in an electrostatic precipitator and improved the overall efficiency of the system (Liu et al., 2020). This could be helpful in the prediction of human health base on personal exposure to environment prone to discharge particles (Oberdörster et al., 2005), as particle aggregation affects the lungs especially as particles size plays a significant role, regardless of their charge. And in general, particles larger than 10 micrometres are mostly filtered out through the nasal passages and throat, while particles smaller than 2.5 micrometres can possibly penetrate deep into the lungs (Lee et al., 2013). In this vein, this study is investigating the role of zeta potential of aerosol particles concentration at the Bayelsa Sate Ekeki intra-modern Motor Park Yenagoa, as a hop of transportation automobiles.

ii. Methodology

A. Study Area description

This study was carried out at the Ekeki intra-modern motor park, Bayelsa State Yeanagoa in southern Nigeria. The Ekeki intra-modern motor is a central intra transport transit in the capital city of the State, and geographically, it lies between located within latitudes 4°49'North and 5°23'North and also within longitudes 6°10' East of the Equator (Fig1). This location put the Yenagoa the capital city of Bayelsa State definitely on the equatorial climatic belt which is characterized by its high temperate nature, humidity and heavy rainfall (Opololaoluwa & Sakwe 2023). The motor park is about 250 by 200 square meters which conveys passengers to various towns within the State as well as the interstate motor park located at Igbogene, Yenagoa Bayelsa State. The motor park is densely populated with passengers and various vehicles that transit people in and out especially at the early and evening hours daily. The motor park entrance and exit is directly facing the Melford Okilo's Road while adjacently, faced the Bayelsa State Media house route, commonly called Ekeki Police Station Road. The park is design with a story building lockup store on both roads.

B. Investigation Description and Equipment

The main equipment used for the investigation were

i. Optical Particle Counters (Aerotrak Handheld Particle Counter 9306) ii. Zeta Potential analyzer (Malvern Zetasizer Nano zs) iii. Portable pH meter (PH-P210E)

iv. Stop Watch (Laboratory Stop Watch)

Aerotrak Handheld Particle Counter 9306 was employed in generating the aerosol particles by tracking the particle size distribution and concentration of the particles, and the Zeta Potential analyzer (Malvern Zetasizer Nano zs) were used to measure the electrostatic charges of the particle sizes, while the pH meter monitors the pH activeness in acidity, neutrality and basicity of the aerosol suspension in hourly intervals using the stop watch. The Optical Particle Counters was clamped and suspended about six feet height during the random investigation at different location (both inside and outside). There were 8 points at was these equipment were set up in one hour per point with reading intervals of ten minutes making a total sampling of 8 hours. The average values of the determination of the pH, Zeta Potential, Size particle and time are expressed in table 3.

iii. Results

Table 1: pH value Active Perspective

S/NO	pH	Criteria
1	0-1	Strongly acidic
2	2-3	Acidic
3	4-5	Weakly acidic
4	6-7	Neutral
5	8-9	Weakly basic
6	10-12	Basic
7	13-14	Strongly basic

Table 2: Particle size aggregation Range with Time Interval Investigation

S/No	Particle Size	Time (hour)
1	5.0-10	6:30 – 7:30 am
2	0.1-10	8:00 – 9:00 am
3	0.5-2.5	9:30 -10:30 am
4	1.0-5.0	11:00 – 12:00 pm
5	0.5-3.0	12:30 – 1:30 pm
6	0.5-2.0	2:00 – 3:00 pm
7	10.0-20.0	3:30 – 4:30 pm
8	5.0-12	5:00 – 6:00 pm

Table 3: pH, Average Zeta Potential, and Particle Size Value in Hourly

S/No	pH	Zeta Potential (mV)	Particle Size (μm)	Time (hours)
1	1	30.0	7.5	1
2	3	15.6	5.5	1

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3	6	23.1	1.5	1
4	7	30.5	3.0	1
5	9	25.9	4.0	1
6	11	-20.0	1.25	1
7	13	10.0	15	1
8	14	21.0	7.5	1

Table 4: Hourly Averages of Zeta Potential and Particle Size Aggregation

Time (hour)	Zeta Potential (mV)	Particle Size (µm)
1	30.0	7.5
2	15.6	5.5
3	23.1	1.5

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4	30.5	3.0
5	25.9	4.0
6	-20.0	1.25
7	10.0	15
8	21.0	7.5

Table 5: Total Average pH to Zeta Potential and Particle Size Aggregation

S/No	pH Criteria	Zeta Potential (mV)	Particle Size (µm)
1	Total Average Acidity	22.9	4.83
2	Total Average Basicity	9.25	6.94
3	Total Average Neutrality	30.5	3.0

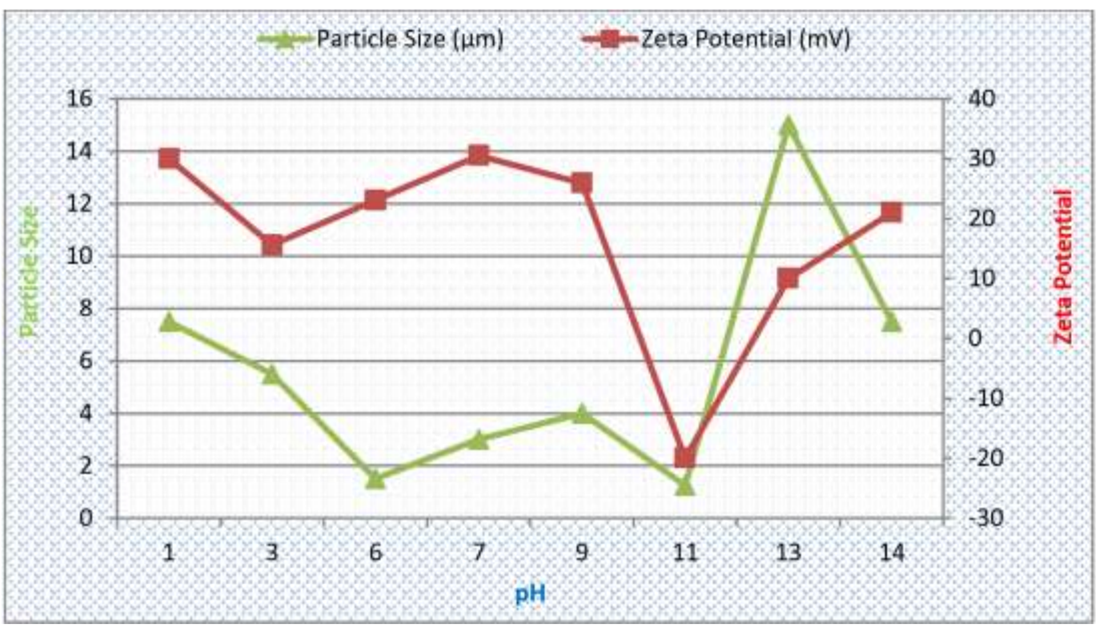

Figure 1: pH to Zeta Potential and Particle Size Aggregation

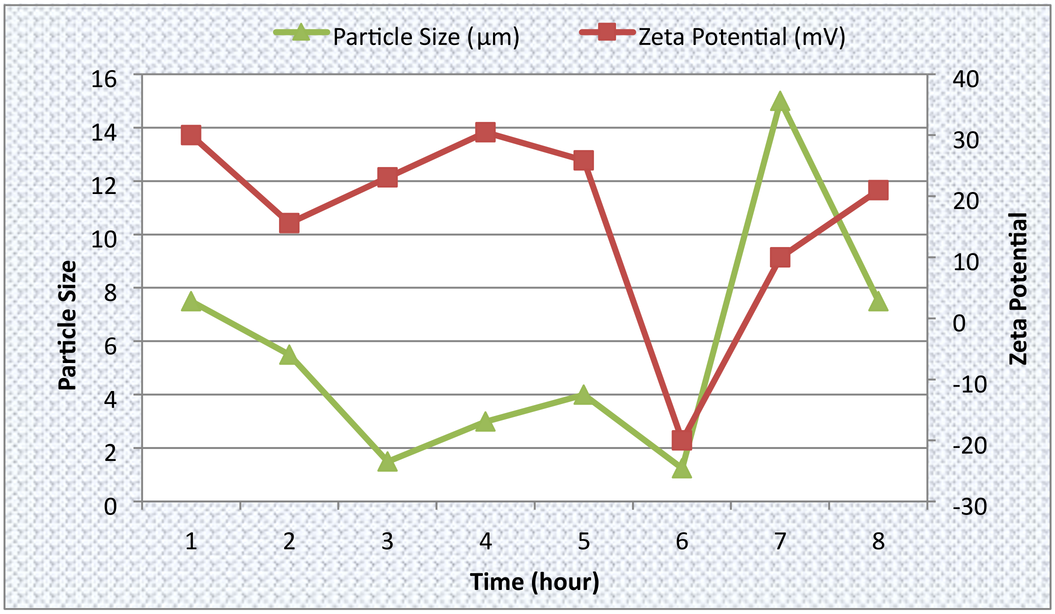

Figure 2: Time to Zeta Potential and Particle Size Aggregation

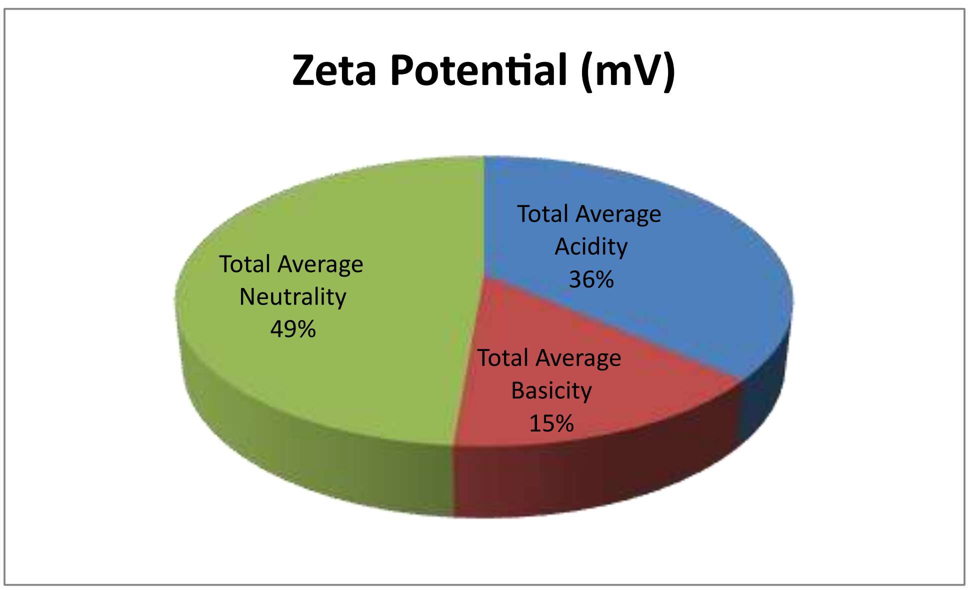

Figure 3: Percentage of Zeta Potential in pH Activeness

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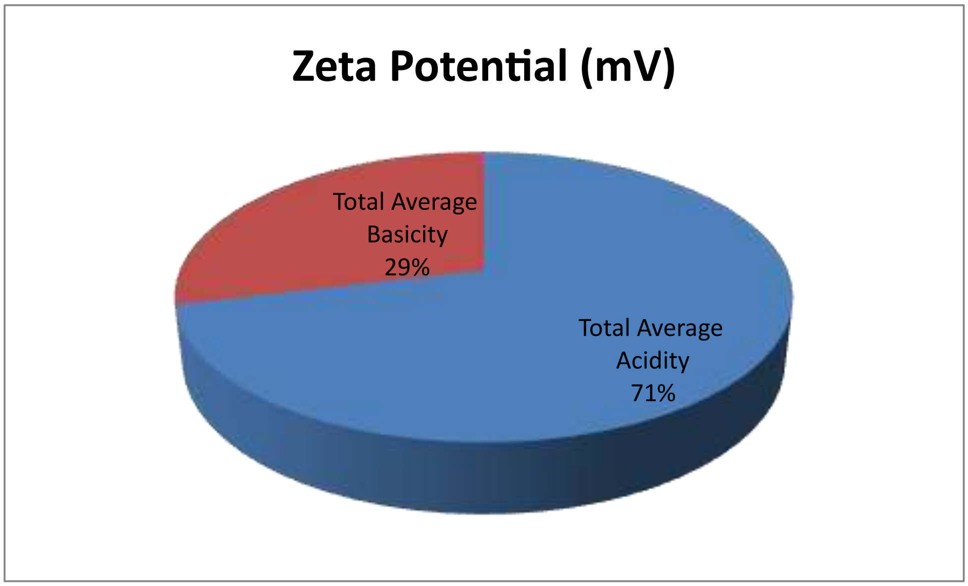

Figure 4: Percentage of Zeta Potential in pH Activeness in Acidity and Basicity

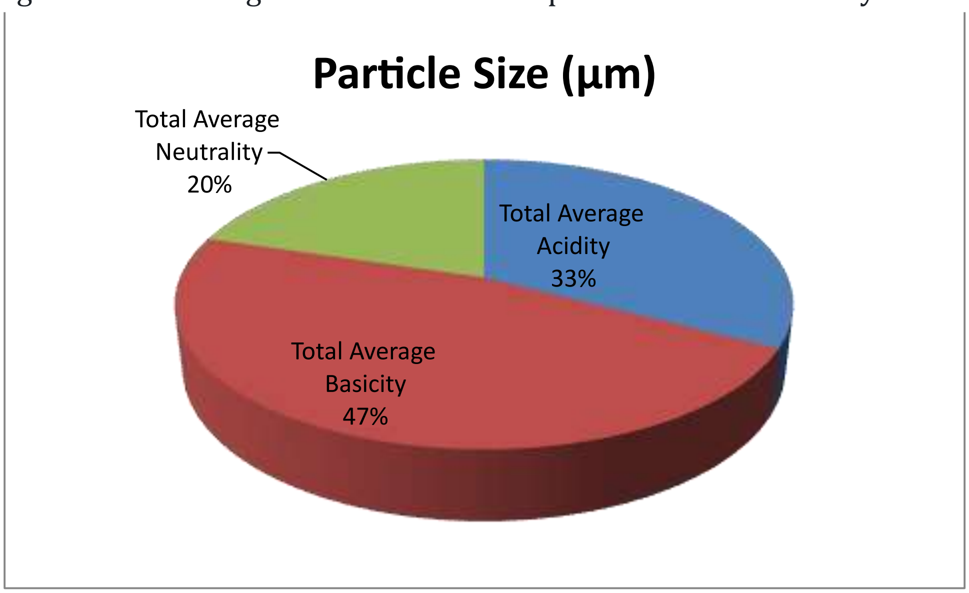

Figure 5: Percentage of Particle Size Aggregation in pH Activeness

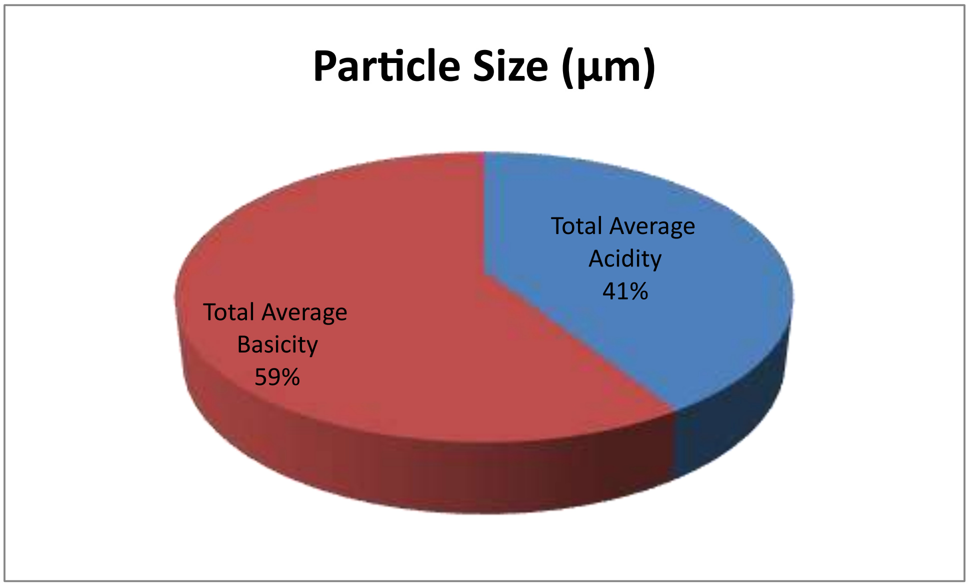

Figure 6: Percentage of Particle Size Aggregation in pH Activeness in Acidity and Basicity

iv. Discussion

Table 1 shows the general ranges of pH values in capacity effect in terms of its acidity and basicity criteria that also determine the effect of zeta potential in particle size aggregation. Similarly, table 2 shows the total time of occurrence from 6:30 am to 6:00 pm that is on 8 hours period based on the random method that was used, which indicates ranges of particle size aggregation within the time of investigation. On the other hand, table 3 shows the average occurrence of the zeta potential and the average particle size aggregation in per hour period with respect to pH values on acidity, neutrality and basicity. While table 4 shows the average values of zeta potential and particle size aggregation within the 8 hour investigation period. In the same vein, table 5 expresses the total averaging occurrence of pH (acidity, basicity and neutrality) values with respect to averaging zeta potential and particle size.

On the roles and impact, the pH value strength has a significant impact on the zeta potential and particle size aggregation. At strongly acidic pH (0-1) and strong basicity (13 and 14), particles tend to aggregate and form larger clusters, resulting in a positive zeta potential (30, 21 and 10 mV) and increased particle size (5.0-10.0, 0.5-20 and 10 -20 µm), on average (7.5 µm, and 7.5 and 1.5) respectively. This occurs at the first, seventh and eighth hour of the investigation (figure 1 and 2). As the pH increases to acidic (2-3) and to basicity (8-9) values, the zeta potential has a reverse phenomenon. While the zeta potential (23.1 mV) increases positively on the acidic value, the zeta potential at the basicity become very negative (-20 mV), indicating increased electrostatic repulsion and the particle sizes remain relatively small (0.5-2.5 and 0.5-20 µm) on average (5.5 and 1.25 µm). This occurs at the second and sixth hour's investigation period (figure 1 and 2). In the weakly acidic pH range (4-5) and weakly basicity (8-9), the zeta potential increases sharply on positive direction (23.1 and 25.9 mV), indicating cohesiveness between particle sizes, leading to bigger particle size range on the weakly basicity (0.5-3.0 µm), on particle size average (4.0 µm), though on the weakly acidity, the pH value was still positive but had a further decrease of particle size range (0.5-2.5 µm) on average (1.5 µm). This occurred at the third and fifth hour's investigation period respectively (figure 1 and 2).

At neutral pH values (6-7), the zeta potential increases further sharply in positive direction (30.50 mV) indicating strong cohesiveness between particle size aggregations (1.0-5.0 µm). This clearly shows that the particle sizes increase by double (3,0) as it cascade form weakly acidity to the neutrality, while as it escalate from weakly basicity to neutrality the particle size reduces by 1 µm (3.0 µm). However, the result shows that the zeta potential actually increases positively (figure 1 and 2).

Figures 3 shows the percentage averaging results of the zeta potential charges on acidity having 36%, basicity 15 % and neutrality as 49%, demonstrating that the zeta potential was more active on the particle size at neutrality over acidity and basicity as least, while on figure 4 demonstrate the zeta potential on the averaging occurrence of acidity and basicity. The result shows that average acidity was 71% and basicity 29 % respectively.

Similarly, figures 5 illustrate the percentage averaging results of particle sizes on acidity having 33 %, basicity 47 % and neutrality as 20 %, demonstrating that the particle were more cohesive in aggregation at basicity over acidity and lowest under neutrality, while figure 6 demonstrate the particle size on the averaging occurrence of acidity and basicity with result showing that average acidity was 59 % and basicity 41 % respectively.

On the overall, the pH value strength plays a vital role in determining the zeta potential and particle size aggregation. The acidic pH value results totally positivity in zeta potentials with varying particle sizes and the strongly acidic and basic pH values led to positive zeta potentials having larger particle size particle aggregation, negatively zeta potential were observed under basicity (table 3, 4 and figure 2) which occurred at the 6^{th}.

Comparatively, it is an established that particles > 10 µm are mostly filtered out by nasal passages and throat, while particles within 2.5-10 µm are deposited in the upper respiratory tract. And as observed by Lee et al.. 2013, particle size smaller than 2.5 micrometres can possibly penetrate deep into the lungs. Therefore, from the investigation, the total average particle size under acidity, basicity and neutrality were 4.83, 6.94 and 3.0 respectively. This result demonstrates that the all fall in the range within 2.5-10 µm which particle size aggregation could affect the lungs base on personal exposure within the environment under investigation and it suggest personal exposure to the environment under investigation are prone to discharge particles that could affect the lung. Therefore, the zeta potential of aerosol particles influences their aggregation behaviour, which in turn affects their size distribution, shape, and deposition patterns.

v. Conclusion

Aerosol particles play an essential role in ambient air quality, climate change, and human environment specifically under the influence of zeta potential and understanding the behavioural aggregation of aerosol particles is very important in developing effective and efficient strategies in mitigating its possible adverse effect. This could be helpful in the prediction of human health bases, as particle aggregation affects the lungs especially particles sizes less than 10 micrometres which are not easily filtered out through the nasal passages and throat. In this regards the investigation on the influence of zeta potential on particle size aggregation with respect to pH activeness in hourly interval indicates that the particle size aggregation were less 10 micrometres at pH basicity, acidity and neutrality which is considered to be adverse to personal exposures at the investigation environment.

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