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ORIGINAL ARTICLE

Stability studies of hybrid TiO$_2$ based nanofluids

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ABSTRACT – This article studies the stability of hybrid TiO$_2$ based nanofluid by varying the ultrasonication time, weight fraction between carbon and TiO$_2$ and type of surfactant. The objective of this research are synthesise volume fraction of 0.1% C - TiO$_2$ hybrid nanofluid with 15ml of distilled water and study the effect of weight fraction between C and TiO$_2$, type of surfactant and ultrasonication time to the stability of hybrid nanofluid. Weight fraction between C – TiO$_2$ will be varied at 0% - 100%, 10% - 90%, 50% - 50%, 90% - 10% and 100% - 0%. Different ultrasonication time will be used which are 1, 3 and 5 hours to determine the optimum ultrasonication time for the hybrid nanofluid. Sodium dodecyl sulphate (SDS) and Triton X-100 will be added into hybrid nanofluid to determine the effect of surfactant to the stability of hybrid nanofluid. The morphology and particle size characteristic of TiO$_2$ and carbon powder is evaluated by using X-ray diffraction and FESEM. It is shown that TiO$_2$ has particle size of around 30nm while carbon powder used is flat shaped. In this research, two steps method is used to synthesise the hybrid nanofluid. After mixing the two powder together, it will be mixed with distilled water by magnetic stirring for 3 hours. Then ultrasonication is included in synthesise of hybrid nanofluid to prevent agglomeration of particles. The pH values of each hybrid nanofluid is measured by using pH meter. Two stability evaluations are carried out which are centrifugation and zeta potential measurement. Centrifugation is carried out right after hybrid nanofluid is done ultra-sonicated for 30 minutes at 2000 RPM. Hybrid nanofluid that is ultra-sonicated for 3 hours resulted to achieve highest stability with highest value of zeta potential of -21.8 mV. 100% C - 0% TiO$_2$ hybrid nanofluid has the highest zeta potential measurement of -37.6 mV. Finally, for type of surfactant, SDS able to enhance stability of hybrid nanofluid more than Triton X-100. The zeta potential of hybrid nanofluid after addition of SDS reached -47.0 mV which is higher than Triton X-100 which only achieve zeta potential measurement of -24.3 mV. In conclusion, a stable hybrid TiO2 based nanofluid can be made by controlling the weight fraction and ultrasonication time. It also can be enhanced by adding surfactant to the nanofluid.

INTRODUCTION

Nanofluids are fluids in which nanoparticles are dispersed in a base fluid such as water, ethylene glycol and oil. Metal, metal oxides, ceramics and non-metals such as carbon nanotubes and graphene are often been chosen as nanoparticles, whereas base fluid like water, ethylene glycol, oil and polymer solutions are used [1]. Since solid particles have better thermal properties, by adding them into fluid will improve the properties of fluid [2]. Moreover, it is observed by researchers that nanofluids have better heat transfer performance compare to that of conventional fluid. Nanofluids have been found to have properties in improving thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients compared to those of conventional fluids [3]. Nanoparticles are particles in the size range of less than one hundred nanometre and have larger exposed area. This is the reason in which nanofluid can achieve a better heat exchange performance and have better thermal conductivity [4]. Besides, the larger surface area of nanoparticles can reduce erosion and clogging. Thermal conductivity of nanofluids can be varied by various factors. The factors include concentration, size, shape, aspect ratio and material of nanoparticles, temperature, base fluid, pH value, surfactants and others [5].

Nanoparticles such as Al$_2$O$_3$, CuO, TiO$_2$ are often being used added into based fluids to produce nanofluid. TiO$_2$ nanoparticles are chemically and physically stable, low cost and easy to be found in market as well as not hazardous to health [6]. Hence, TiO$_2$ nanofluids can be categorised to be a satisfying heat transfer medium. There are researchers who found that with the increase in nanoparticles concentration, the thermal conductivity will also increase. Reported by [7], there is a heat transfer enhancement in the range of 33% and 30% over the base fluids using 10nm and 15nm particles respectively at 5% solid volume fraction of TiO$_2$ nanoparticles in water.

Adding more than one nanoparticles can help to improve the stability and thermal conductivity of nanofluid. Method to synthesize hybrid nanofluid is the same as synthesize of nanofluid which are one step and two steps method. However, two steps method is use more widely by researchers [8]. In two steps method, production of nanoparticles will undergo

first then followed by dispersing the nano particles into base fluid. Typical hybrid nanofluids such as carbon nanotube, alumina-copper and others are commonly used to investigate by researchers [9]. Hybrid nanofluids have significant enhancement in heat transfer and can lead to cost reduction due to energy saving [10]. Researchers did a study on heat transfer enhancement and friction factor of MWCNT-Fe_3O_4 water hybrid nanofluids with surfactant (NanoSperse AQ)[4]. From their research, the thermal conductivity of MWCNT-Fe_3O_4 water hybrid nanofluids is enhanced by 29% while friction factor for 0.3% MWCNT-Fe_3O_4 water hybrid nanofluids is 1.11 times and 1.18 times in Reynolds number of 3000 and 22000 respectively compared to water.

Stability is the property of a body that causes it when disturbed from a condition of equilibrium or steady motion to develop forces or moments that restore the original condition. Stability is another property that might bring changes in performance of nanofluids and hybrid nanofluids. Investigations on stability of nanofluids is important as it might give impact on various thermal properties [8]. The aggregation of nanoparticles will cause sedimentation and clogging and reduce the thermal conductivity of nanofluids [8]. Hybrid nanofluids can be poor in transferring heat if nanoparticles tend to coagulate in base fluid [11]. However, there are previous studies showed that hybrid nanofluids to be stable with less sedimentation for different time periods ranging from few hours to months [8]. To enhance stability, there are a few methods that are available including choosing the right surfactant, controlling pH value and ultrasonication.

The methods that are commonly used are addition of surfactant and ultrasonication. Surfactants help in improving stabilization of the nanofluids and evenly distribution of suspended nanoparticles [10]. Adding surfactants or dispersants is an easy and economical method to enhance the stability of the nanofluids [10]. Surfactants can be categorised into non-ionic groups, cationic group and anionic group and lastly atmospheric dispersants [8]. It is important to select a suitable dispersant. For example, the dispersant for polar solvent should be water soluble. Non-ionic surfactants with higher values of hydrophilelipophile balance are more soluble in water while that of with lower hydrophile-lipophile balance values are more soluble in oil [8]. Baojie Wei et. al uses oleic acid as surfactant in their experiment about SiC / TiO_2 nanofluids [12].

Table 1. Type of hybrid nanofluids

Nanoparticle	Base fluid	Surfactant	Volume or weight fraction	Preparation / Stability	Reference
Fe_3O_4 -CNTs	Deionised Water	-	CNTs: 0.05 – 1.35% Fe_3O_4 : 0.1 – 0.9%	5 minutes sonication	[13]
Al_2O_3- MWCNTs	Water	-	0.125 – 1.5%	1 hour sonication, 7 days stable	[14]
MWCNT- Fe_3O_4	Water	NanoSperse AQ	0.5 – 3%	-	[4]
SiO_2 - TiO_2	Water	-	0.5 – 3%	2 hours sonication	[15]
TiO_2 - CNTs	Water	SDBS	0.1 – 0.2%	15 minutes sonication	[16]
SiC - TiO_2	Diathermic oil	Oleic acid	0.1 – 1 vol%	2 hours of sonication, 10 days stable	[12]

MATERIALS AND METHODOLOGY

The material used in this study is TiO_2 and carbon powder (C). TiO_2, C and 15g distilled water are weighed by using precision weight balance according to the calculated weight fraction between TiO_2 and C. Firstly, weight of TiO_2 in 0.1% weight fraction between TiO_2 and 15ml distilled water is calculated by using equation 1. Then from the weight of TiO_2 obtained, 5 different weight fraction between TiO_2 and C is calculated. For the sixth specimen with weight fraction of 100% C, the same equation 3.1 is used to calculate the weight of C used by substituting the density of C in the equation.

$$\varphi = \frac{(W/\rho)_{TiO2}}{(W/\rho)_{TiO2} + (W/\rho)_{distilled\ water}} \tag{1}$$

where φ is the volume fraction, W is weight and ρ is density.

Table 2. Weight of TiO$_2$ and C according to weight fraction.

| No.	Weight Fraction (TiO$_2$ – C)	Weight of TiO$_2$ (g)	Weight of Carbon (g)	Weight of distilled water (g)
1	90% - 10%	3.84	0.43	100
2	70% - 30%	2.99	1.28	100
3	50% - 50%	2.135	2.135	100
4	30% - 70%	1.28	2.99	100
5	10% - 90%	0.43	3.84	100
6	0% - 100%	0	2.28	100

Particle size characterisation and stability tests were carried out. Before dispersing nanoparticles into distilled water, TiO$_2$ and C will undergo particle size and shape characterisation test by using Field-Emission Scanning Electron Microscope (FESEM) and X-ray diffraction (XRD).

Next, the synthesis of nanofluid is carried out continuously to obtain the most stable nanofluid of each parameter. Firstly, nanofluid with three different weight fraction between TiO$_2$ and C will be synthesised with different ultrasonication time which are 1, 3 and 5 hours to figure out the most optimum ultrasonication time for synthesis of nanofluid. Stability test will be carried out for all specimens to obtain the specimen with highest stability. Centrifugation and zeta potential measurement are used for stability evaluation in this study. Then after obtaining the optimum ultrasonication time, five nanofluid with different weight fraction between TiO$_2$ and C will be synthesis. After that, stability test will be carried out again to obtain the specimen with highest stability. The specimen with highest stability will be synthesized again with addition of surfactant which are Triton X-100 and sodium dodecyl sulphate (SDS).

RESULT AND DISCUSSION

Morphology and particle size evaluation

The structural characteristic of particles was conducted by using X-ray diffractometer and FESEM. Figure 1 show the photomicrograph of TiO$_2$ by using FESEM. From Figure 1(a), it shows the range of particle size for TiO$_2$ is around 30 nm and the particle morphology is spherical. The particles are loosely agglomerated and have higher possibilities to be dispersed in distilled water easily. On the other hand, Figure 1(b) shows the photomicrograph of carbon. In Figure 1(b), C can be seen to be in cluster form.
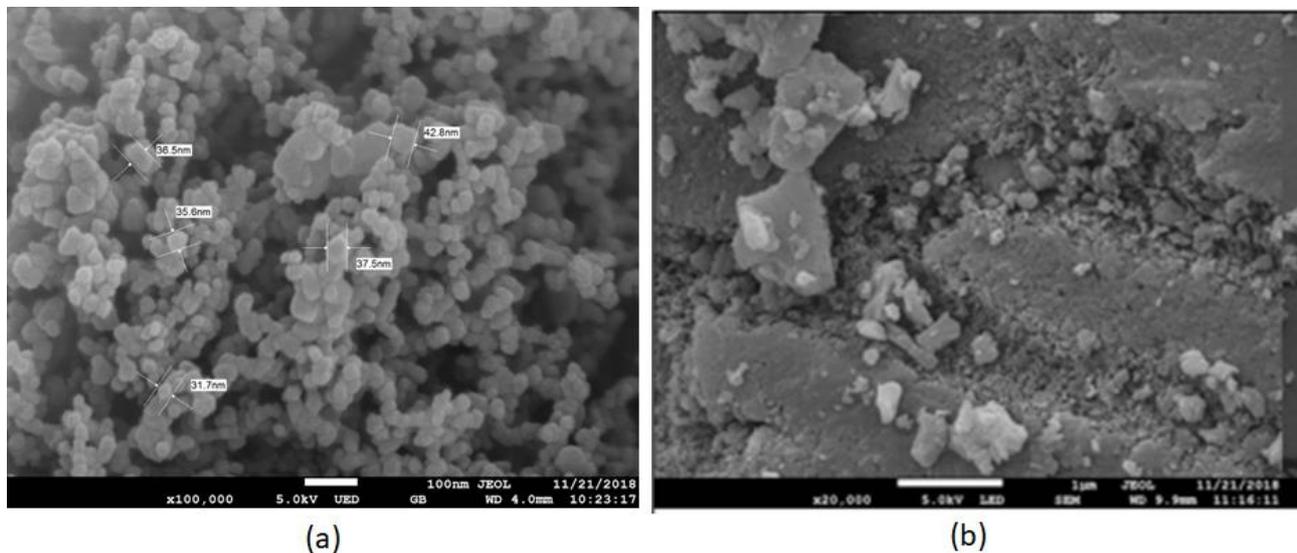
Figure 1. Morphology of (a) TiO$_2$ and (b) C

Figure 2 shows the graph from X-ray diffraction for TiO$_2$ and C, respectively. The average crystalline size of particle can be calculated from the peak of graph. As the size of peak width of graph increases, the particle size of specimen decreases. Furthermore, there is only diffraction peaks shown due to the pure anatase phase. The peak width in falls on the range of 20 nm and 30 nm. On the other hand, another picture in Figure 2, there is no highest intensity graph can be seen because C is a non-crystalline particle.
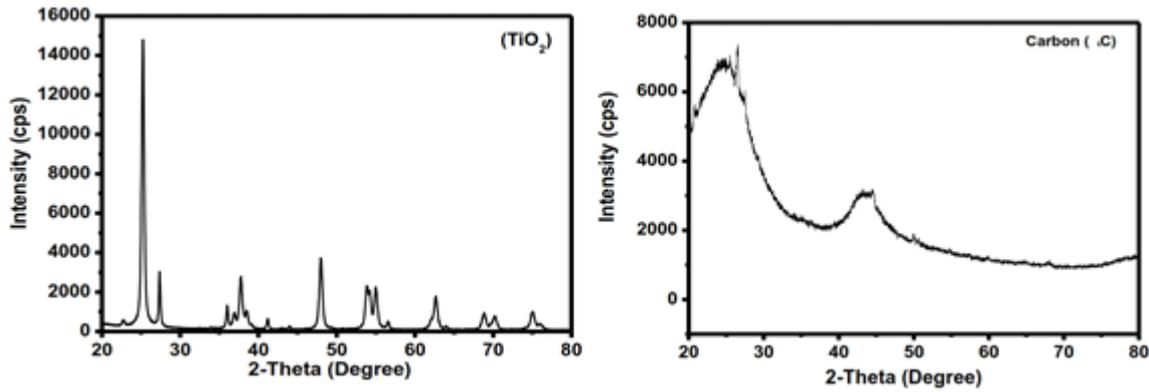
Figure 2. XRD pattern of TiO$_2$ and C

Stability evaluation- Effect of ultrasonication time studies

Ultrasonication is one of the method to obtain nanofluid with higher stability. However, ultrasonication time for each nanofluid is different. Figure 3 shows the nanofluids containing different weight fraction. In each figure, there are three nanofluids which were synthesised using different ultrasonication time of 1, 3 and 5 hours. These solutions have been centrifuged for 30 minutes under 2000 RPM to evaluate stability and obtain the most optimum ultrasonication time. After evaluating nanofluids with different weight fraction by centrifugation, 3 hours of ultrasonication time can help TiO$_2$ -C hybrid nanofluid to achieve highest stability. From Figure 3, sample 10% C - 90% TiO$_2$ is most cloudy when it is ultrasonicated for 3 hours while has the lowest stability when it is ultrasonicated for 5 hours. Sample of 50% C - 50% TiO$_2$ and sample 90% C - 10% TiO$_2$ respectively also showed that the nanofluid which are synthesised by using 3 hours ultrasonication time has the highest cloudiness.
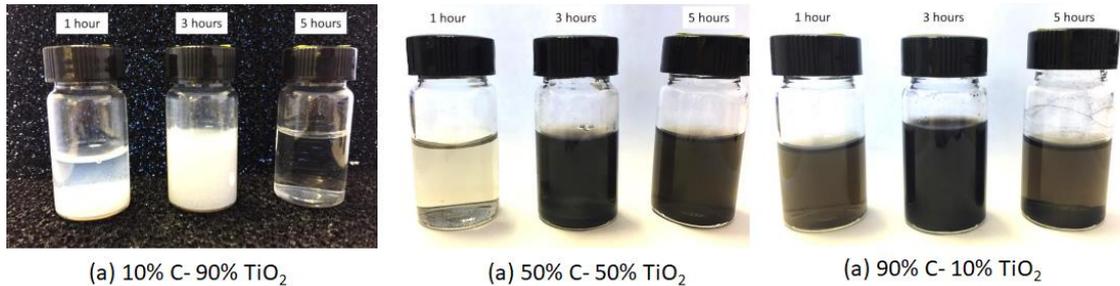

Figure 3. Photo of sedimentation test for different samples at different ultrasonication time.

Table 3 shows the pH and zeta potential value for sample 90% C - 10% TiO$_2$ with different ultrasonication time. The pH value is the highest for nanofluid synthesized using 3 hours ultrasonication which is pH 7.21. On the other hand, nanofluid which synthesised using 5 hours ultra-sonication time is the lowest with the pH of 6.80. Table 3 also shows the zeta potential in millivolt obtained from zeta potential measurement. Sample 90% C - 10% TiO$_2$ with 3 hours ultrasonication time has larger the value of zeta potential (- 21.8 mV), shows the most stable of nanofluid. The stability characteristic of it falls on threshold of delicate dispersion. On the other hand, sample with only 1 hour ultrasonication time has the lowest zeta potential (-15.0 mV) which threshold of agglomeration might occur. At ultrasonication time of 5 hours, the zeta potential measurement dropped to -18.9 mV with the stability characteristic of threshold of delicate dispersion. Thus, from the results obtained from zeta potential measurement, the optimum ultrasonication time to achieve highest stability for nanofluid is 3 hours.

Table 3. pH and zeta potential value for sample of 90 % C- 10 % TiO$_2$ with different ultrasonication time.

| Ultrasonication time(hour)	pH Value	Zeta potential (mV)
1	6.87	-15.0
3	7.21	-21.8
5	6.80	-18.9

Figure 4 shows the overlay and bar graph to show the comparison of pH value and zeta potential between nanofluids with ultrasonication time of 1, 3 and 5 hours. It is shown that nanofluid with 3 hours ultrasonication time has the highest pH value and largest value of zeta potential. Zeta potential of each nanofluid will be varied by pH values due to the charges in solution. If the pH value of solution is far away from the isoelectric point of TiO_2, which is pH 6.5, the charges will be stronger and resulted in higher stability. From 1 hour to 3 hours of ultrasonication time, the zeta potential measurement increases. This is due to ultrasonication is usually used as to produce repulsive force to prevent nanoparticles to agglomerate. Nanoparticles will agglomerate and form cluster if there's Van Der Waals forces between them. As the ultra-sonication time increases, there will be greater repulsive force preventing nanoparticles to form cluster and suspend in base fluid. Hence, when the ultrasonication time of C – TiO_2 hybrid nanofluid increases from 1 hour to 3 hours, the stability of nanofluid increases. However, the value of zeta potential decreases when ultrasonication time increases from 3 hours to 5 hours. Same goes to pH value of each nanofluids with different ultrasonication time. The pH value decreases when ultrasonication time increases from 3 hours to 5 hours. This is because re-agglomeration might occur if ultrasonication time exceeded the optimum time of nanofluid. Due to the strong repulsive force formed during ultra-sonication, the collision of particles increases which causes the particles to agglomerate when there is collision between them. This happens when the ultrasonication time for C – TiO_2 hybrid nanofluid increases from 3 hours to 5 hours. Every nanofluid will have different optimum ultrasonication time depending on the type of nanoparticles, characteristic of nanoparticles as well as ultrasonic treatment used. Since every nanofluid has different optimum ultrasonication time, hence, evaluation needed to be done to achieve and find out the most optimum ultrasonication time.
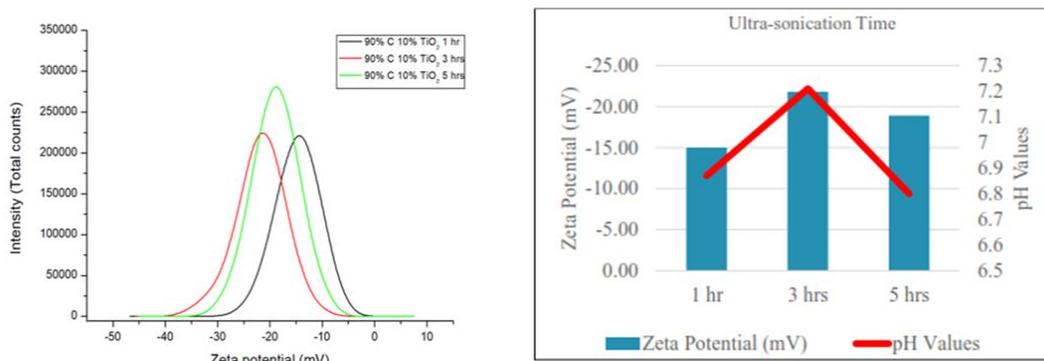
Figure 4. Overlay and bar graph of zeta potential distribution and pH value of sample 90 % C – 10% TiO_2 at different ultrasonication time

Stability evaluation- Effect of weight fraction studies

Hybrid nanofluid consists of more than one type of nanoparticles in it. Different weight fraction between C and TiO_2 are synthesised to evaluate the effect of weight fraction on the nanofluid stability. Figure 5 shows nanofluid with different weight fraction before it undergoes centrifugation and after being centrifuged. The figures were taken right after it has done ultrasonication and after centrifugation for 30 minutes at 2000 RPM. From the figure, it shows that sample of 0% C - 100% TiO_2, the cloudiness of nanofluid dropped drastically and has obvious difference after it was centrifuged. On the other hand, 10% C - 90% TiO_2 sample shows that after centrifugation cloudiness is higher than that of 0% C - 100% TiO_2 sample but still there is obvious decrement in cloudiness of solution. On the contrary, sample 50% C - 50% TiO_2, the solution after centrifuged is cloudy and seem to have higher stability compared to sample before. Sample 90% C- 10% TiO_2 does not show an obvious change between before centrifuged and after centrifuged. It has high intensity of cloudiness even after undergo centrifugation. Sample 100% C – 0 % TiO_2 does not show any changes after being centrifuged. Thus, by evaluating using centrifugation testing, as the weight fraction of carbon increases, the stability of solution increases as well.
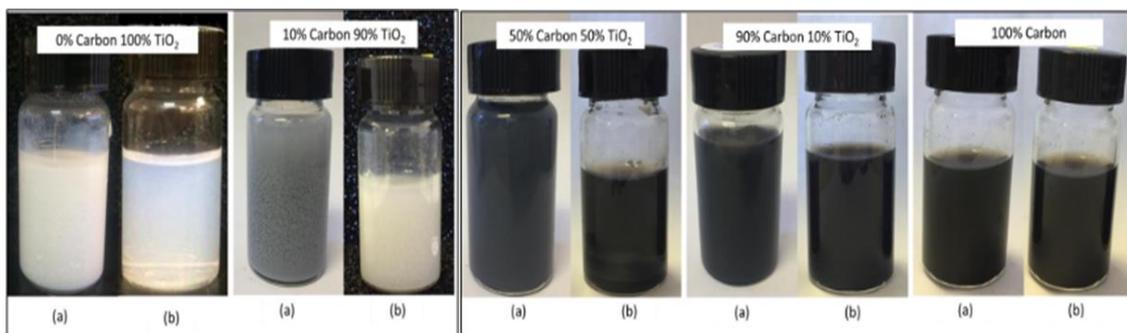

Figure 5. different composition of nanofluid for (a) before and (b) after centrifugation test.

Table 4 shows pH and zeta potential value taken for each sample with different weight fraction after ultrasonication. Sample 100% C - 0% TiO_2 has the highest value of pH (8.0), followed by sample of 90% C - 10% TiO_2, 50% C - 50% TiO_2 and 10% C - 90% TiO_2. As weight fraction of carbon increases, the pH value increases too. However, the pH value for 0% C - 100% TiO_2 which is pH 6.91 is higher than that of 10% C - 90% TiO_2. The value of zeta potential increases with the increase in weight fraction of carbon. However, sample 0% C - 100% TiO_2 is not in trend and achieved a higher zeta potential of -10.5mV than sample 10% C - 90% TiO_2 with zeta potential of -4. 5mV. According to the zeta potential measurement stability range, sample 0% C - 100% TiO_2 which has zeta potential of -10.5 mV is in the range where there is threshold of agglomeration while sample 10% C - 90% TiO_2 is in the range in which there is strong agglomeration and precipitation. For 50% carbon 50% TiO_2 nanofluid, the zeta potential is measured to be -14.2 mV which falls in the range where threshold of agglomeration occurs. Next, sample 90% C - 10% $_{TiO2}$ reached the zeta potential of -21.8 mV. Its stability characteristic falls on the range in which threshold of delicate dispersion occur. Lastly, sample 100% C - 0% TiO_2 has stability characteristic of moderate stability with zeta potential of -37.6 mV.

Table 4. pH value and zeta potential for sample of different weight fraction of C and TiO_2.

| Weight fraction (C-TiO_2)	pH Value	Zeta Potential (mV)
0 % - 100 %	6.91	-10.5
10 % - 90 %	6.89	-4.5
50 % - 50 %	7.08	-14.2
90 % -10 %	7.21	-21.8
100 % - 0 %	8.01	-37.6
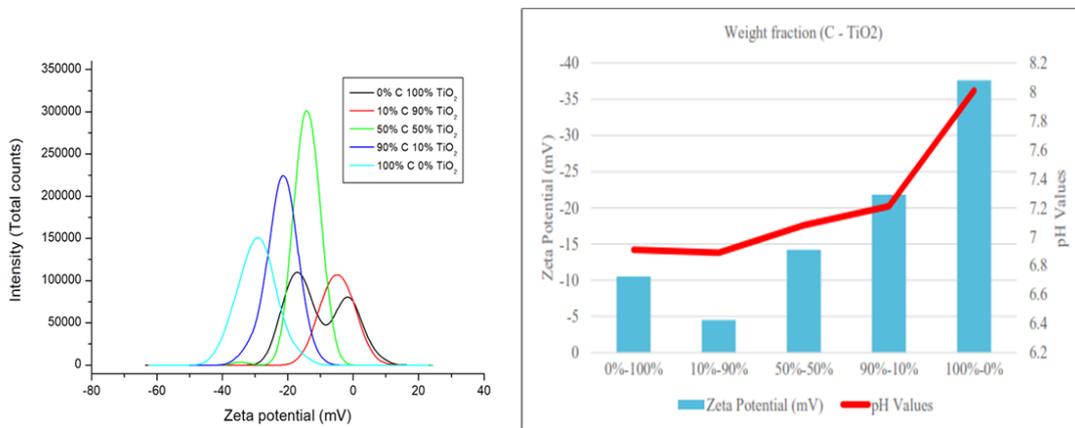
Figure 5. Overlay and bar graph of zeta potential distribution and pH value of different weight fraction of C and TiO_2.

Graph of zeta potential and pH values against weight fraction between carbon and titanium dioxide is shown in Figure 5. Zeta potential measurement increases as weight fraction of carbon increases. However, sample 10% C - 90% TiO_2 achieved lower zeta potential measurement than sample 0% C - 100% TiO_2, causing there's a drop on second bar of the graph. Although the pH value for sample 10% C - 90% TiO_2 is slightly lower than that of sample 0% C - 100% TiO_2 but the zeta potential measurement between the two nanofluids have an obvious difference shown in bar chart in Figure 5. Holistically, as weight fraction of C increases, pH values of solutions and zeta potential measurement increases too. As shown in Figure 5, pH value taken for solution with 100% C is the highest with pH 8.01. It shows that carbon particles used is a basic. Hence, as the weight fraction of carbon in nanofluid increases, the pH values of solution increase too. Since pH value is not adjusted in this research, hence zeta potential measurement is affected by pH values of each solution. When zeta potential measurement has high positive or negative values, then there is repulsion between particles which lower down the possibilities for particles to agglomerate and precipitate. On the other hand, when zeta potential measurement is low, there is no repulsive force preventing particles from agglomerating. The isoelectric point of TiO_2 is at pH 6.5. Thus, if the nanofluid has a pH value of close to or equal to pH 6.5, there will be zero charge in the solution which leads to cluster forming and precipitation of nanoparticles. This is because there is no net charge between particles to keep them repelling from each other. When clusters are formed, the nanoparticles are no longer stable in solution which leads to sedimentation. On contrary, if the pH value of solution is further or disperse away from isoelectric point, the value of zeta potential is larger which resulted in higher colloidal stability. When the pH value of solution is disperse away from isoelectric point, the charge density on the surface of nanoparticles will produce a greater repulsive force between them. A great repulsive force between particles prevents particles from agglomerate and form cluster. Hence, the nanofluid with highest pH value has the highest stability among all. However, for sample 0% C - 100% TiO_2 and 10% C - 90% TiO_2, the zeta potential measurement does not follow the trend due to the condition of solution when zeta potential measurement is being carried out. This might be caused by environmental error due to unfixed condition when synthesising nanofluids. Sample 100% C - 0% TiO_2 solution which achieve highest pH values can be concluded to have pH value furthest from isoelectric point of TiO_2.

Stability evaluation- Effect of different surfactant studies

Two different type of surfactants are added into sample 90% C - 10% TiO$_2$ to show the effect of surfactant on stability of nanofluid. Triton X-100 is a non-ionic surfactant while sodium dodecyl sulphate (SDS) is an anionic surfactant. Figure 6 shows sample 90% C - 10% TiO$_2$ with different type of surfactant after being centrifuged. By observing the nanofluids after centrifugation test, the three nanofluids do not show any visible differences. Besides, there is no any sediment can be seen on the bottom of bottles for all of the nanofluids. Hence, centrifugation test is not suitable to be used to evaluate the stability of nanofluid for this parameter. Quantitative results needed to be carried out to find out the stability of the nanofluids.
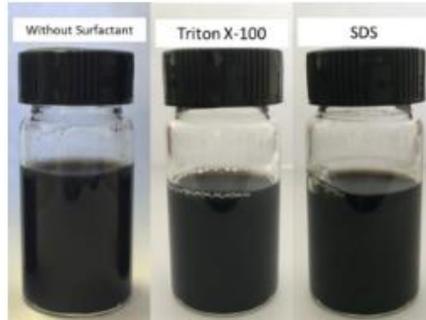

Figure 6. 90 % C - 10 % TiO$_2$ hybrid nanofluids with and without surfactant

Table 5 shows the pH values for sample 90% C - 10% TiO$_2$ without surfactant, with addition of SDS and Triton X-100. The pH values were measured right after the ultrasonication of 3 hours. The pH value of nanofluid with addition of SDS which achieved pH 8.08. This is due to the anionic properties of SDS surfactant that provides negative charges to the nanofluids. Without adding any surfactant, the pH value of nanofluid is the lowest which is pH 7.21. However, adding Triton X-100 into the sample 90% C - 10% TiO$_2$ does not bring huge difference in pH value compared to that of without surfactant which is pH 7.56. This is because Triton X-100 which is non-ionic surfactant does not have any charges that enhance repulsive force between particles in nanofluids.

Table 5. pH value and zeta potential for sample 90 % C- 10 % TiO$_2$ with and without surfactant.

Type of surfactant	pH value	Zeta potential (mV)
None	7.21	-21.8
Sodium dedocyl sulphate (SDS)	8.08	-47.0
Triton X-100	7.56	-24.3

Figure 7 shows the overlay and bar graph of pH and zeta potential value distribution with different type of surfactant. The overlay graph has an apparent results of nanofluid with addition of SDS tends to achieve large value of zeta potential. It shows big difference in zeta potential measurement compared to 90% C 10% TiO$_2$ nanofluids as well as nanofluid with the addition of Triton X-100.
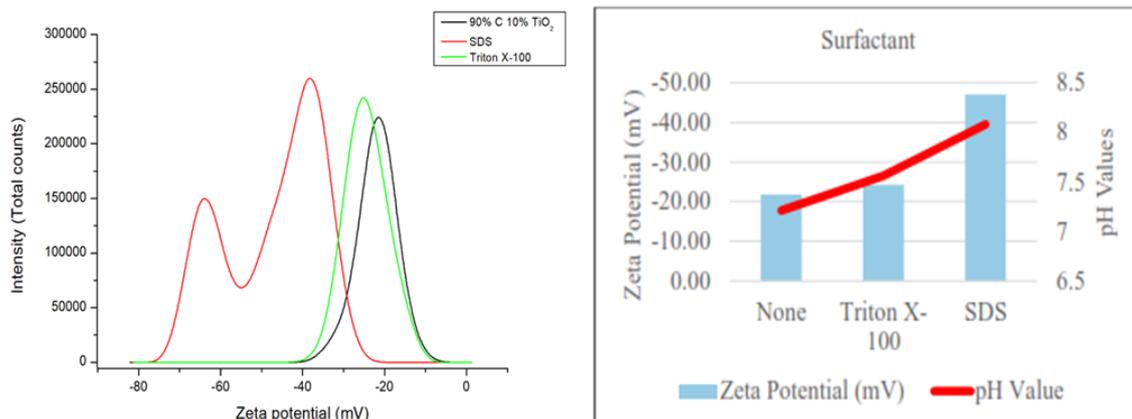
Figure 7. Overlay and bar graph of zeta potential distribution and pH value of sample 90 % C- 10 % TiO$_2$ with and without surfactant.

The type of surfactant in bar graph is arranged in the sequence of without surfactant, Triton X-100 and SDS. From the bar chart shown, with addition of SDS the solution reached the highest value of zeta potential which exceeded -40 mV while the other two solutions only exceeded -20 mV with lower stability. By comparing zeta potential and pH values,

nanofluid with addition of SDS resulted to have highest pH values and zeta potentials which once again proved that as pH values increases, zeta potential measurement will increase as well.

As shown in Figure 7, with the addition of SDS, sample 90% C - 10% TiO_2 achieved the highest stability with -47.0 mV of zeta potential measurement. However not much changes in zeta potential measurement when Triton X-100 is added in. This is because SDS is an anionic surfactant which is negatively charged and contain of hydrophilic heads that provides electrostatic repulsion to nanoparticles. The repulsion provided able to stabilise nanofluid by preventing van der Waals forces between particles from attracting each other. When there is repulsive force against the van der Waals forces between particles, agglomeration and cluster forming can be prevented. In this research. Triton X-100 which is a non-ionic surfactant only manage to slightly enhance the stability of 90% C - 10% TiO_2 nanofluid. This is due to non-ionic properties of Triton X-100 that will not provide electrostatic repulsion to nanoparticles.

CONCLUSION

After synthesising hybrid nanofluid with different weight fraction using different ultrasonication time, 3 hours is the most optimum. The results are proved qualitatively and quantitatively by centrifugation method and zeta potential measurement respectively. As longer ultrasonication time can provide greater repulsive force to particles from forming cluster, 3 hours ultra-sonication is chosen over that of 1 hour but when the ultrasonication time is too long, particles will tend to collide and agglomerate. Hence, 5 hours is not suitable for carbon TiO_2 hybrid nanofluid in this research.

Different weight fraction between TiO_2 and C are used to determine the most stable weight fraction for hybrid nanofluid. From the result of previous parameter, 3 hours ultrasonication time is used to synthesis hybrid nanofluid with different weight fraction between TiO_2 and C. Sample 0% C - 100% TiO_2 and 100% C - 0% TiO_2 is synthesised to compare with hybrid nanofluid with 10% C - 90% TiO_2, 50% C - 50% TiO_2 and 90% C - 10% TiO_2, 10% C - 0% TiO_2 resulted to have highest stability due to its characteristic of high basicity with highest pH value. By adding C will increase pH value of nanofluid as well as lead it further away from IEP to achieve higher zeta potential measurement.

Surfactant such as SDS and Triton X-100 were used to increase the stability of nanofluid. SDS is an anionic surfactant while Triton X-100 is a non-ionic surfactant. Surfactant is used to reduce the surface tension of nanoparticles so that it can be suspended in base fluid. The hydrophilic head in SDS tends to provide electrostatic repulsion to against Van der Waals forces between particles. By doing so, particles will not agglomerate and form cluster as well as maintain high stability.

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