Research Article

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Stability enhancement of Al_2O_3, ZnO, and TiO_2 binary nanofluids for heat transfer applications

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Abstract: Primary goal of this research is to enhance stability of nanofluids which is vital for maintaining consistent thermophysical properties during various applications. Nanofluid stability is essential for obtaining the uniform thermophysical properties during its application. X-ray diffraction and zeta potential were performed to characterize three nanoparticles, namely TiO_2, Al_2O_3, and ZnO. Experimental work was carried out under several trials to enhance the stability of nanofluids. Initially, deionized water was used as base fluid for stability analysis, but nanoparticles agglomerate within after 5 h. Second, alkaline water was selected as base fluid at different pHs ranging from 7 to 14 to analyze the stability of the nanofluids. Finally, the effect of surfactant addition on the stability of prepared nanofluids was also investigated. Observations revealed that at pH 11, nanoparticles exhibited enhanced stability compared to other pH levels. This stability can be attributed to the high zeta potential, fostering electrostatic repulsion between individual particles. It was concluded from the results that zeta potential increases in cases of (TiO_2 + ZnO) and (Al_2O_3 + ZnO) from −44.2 to −47.8 mV and −42.4 to −44.1 mV with the addition of surfactant, respectively. In the case of (Al_2O_3 + TiO_2), zeta potential decreases slightly from −47.7 to −44.9 mV with the addition of surfactant.

Keywords: nanofluid preparation, binary nanofluids, stability, stability enhancement, zeta potential

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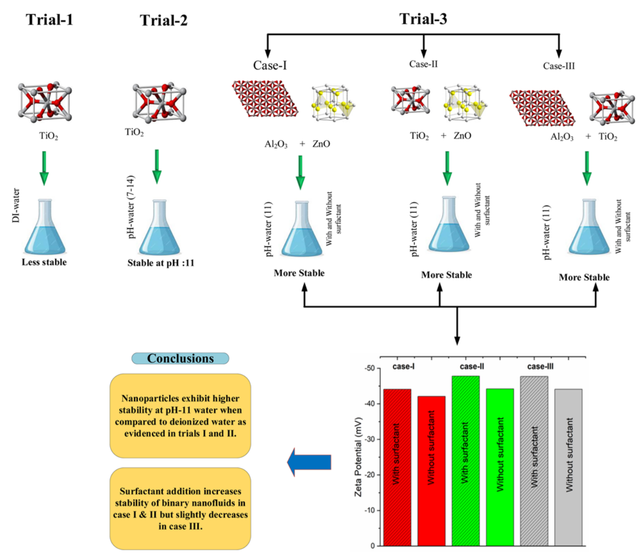


Graphical abstract

Abbreviations

DI	deionized water
EDLRF	electrical double layer repulsive force
MF	magnetic field
MWCNT	multi-walled carbon nanotubes
UV-DRS	UV-diffuse reflectance studies
SDS	sodium dodecyl sulfate
XRD	X-ray diffraction

1 Introduction

The enhancement of heat transfer is essential for optimizing the efficiency of thermal systems for sustainable industrial development. Thermal system involves the use of different working fluids like water, engine oil, and ethylene glycol, which shows poor thermophysical properties [1]. Historically, water has been widely utilized as the primary working fluid in thermal systems owing to its abundant availability and relatively low cost. Nevertheless, a limitation of water lies in its relatively limited heat conductivity. In order to augment this particular attribute, the

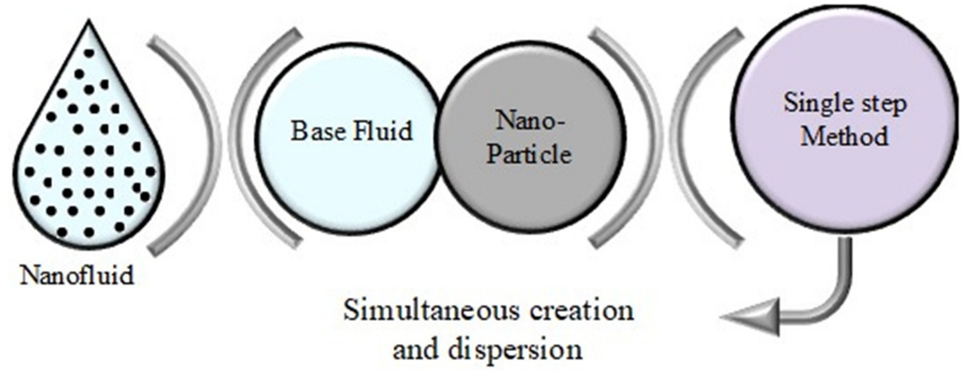


Figure 1: Single-step method of nanofluid preparation.

incorporation of nanoparticles into the fundamental fluid can be employed, hence enhancing its thermophysical properties [1–3]. The primary obstacle faced in preparation of stable nanofluids is the tendency for nanoparticles sedimentation or agglomeration due to their high surface energy. Following the production of the nanofluid, the subsequent tasks involve guaranteeing its stability and augmenting its properties. Techniques adopted for stable nanofluid preparation include sonication, magnetic agitation, homogenization, and surfactant as dispersant agents. Among these, the use of surfactants has the potential to significantly reduce agglomeration and enhance stability.

Hussain *et al.* considered the thermal impact on varied convection flow in hybrid nanofluids and concluded that the hybrid nano fluidity gets improved with the volume variation of nanoparticles [4]. Sun *et al.* [5] analyzed the effect of magnetic field (MF) on heat transfer by Fe_3O_4 ferrofluid with swirl flow inside the tube at various Reynolds numbers. The MF was applied to three different sections of the tube: near the entrance, in the middle of the tube, and near the outlet. The results demonstrate that applying a MF increases the convective heat transfer coefficient (h) by 1.1, 11.13, and 39.42%, respectively. Braut *et al.* [6] demonstrated experimentally optical properties of nanofluids by temperature, surfactant content, and ultrasonication period. After 7 days of sample preparation enhancement, transmittance was more visible at lower concentrations (0.0004%). Noor and Alshehry analyzed the nanofluid boundary layer flows over a bidirectional in both convective and MF environments and concluded that temperature distribution is reduced by increasing the Prandtl number [7]. Rao *et al.* [8] showed the effect of size of nanoparticle by selecting 1–2 nm on thermal conductivity enhancement and results revealed that thermal conductivity increases as particle size decreases. Recently, Peyghambarzadeh *et al.* [9] studied Al_2O_3/water unary nanofluid in car radiators and achieved 45% higher heat transfer than pure water. Kumar *et al.* [10] conducted an experimental investigation of water-based hybrid nanofluid Al_2O_3-SiO_2 at three different concentrations: 0.2, 0.4, and 0.6 wt%. The results demonstrate that the nanofluid with a concentration of 0.2 wt% exhibits extremely weak stability. In contrast, the nanofluid with a concentration of 0.4 wt% demonstrates moderate stability, while the nanofluid with a concentration of 0.6 wt% shows relatively good stability even after being kept under static conditions for 30 days. Martínez *et al.* [11] characterized water-based nanofluid using ZnO nanoparticles with a size of 17 nm.

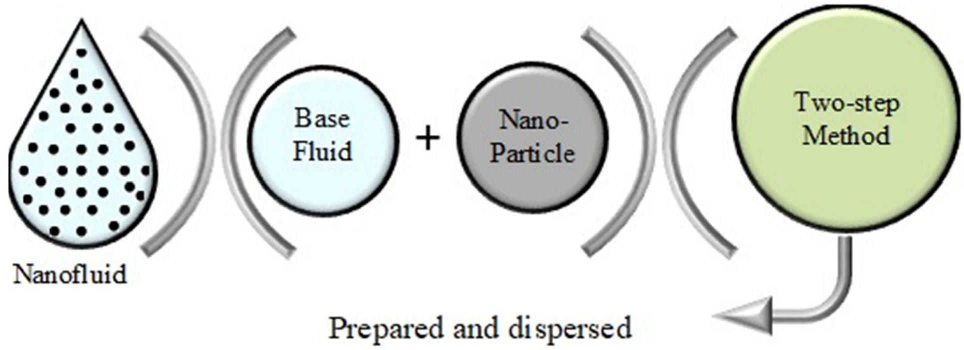


Figure 2: Two-step method of nanofluid preparation.

The viscosity and thermal conductivity of nanofluid were analyzed over a temperature range of 5–25°C for two different concentrations 1 and 3 wt%. The results indicated that the sample with 3 wt% concentration exhibited improved stability than 1 wt% concentration and it took 7 days to decrease its absorbance by the same amount as the 1 wt% sample. Nine *et al.* [12] analyzed the effect of nanoparticle shape on thermal conductivity of hybrid nanofluid consisting of Al_2O_3-multi-walled carbon nanotubes (MWCNTs)/water. The findings indicate that the thermal conductivity was enhanced by increasing the ratio of MWCNTs in hybrid nanofluid. Further, cylindrical-shaped nanoparticles demonstrated more significant enhancement in thermal conductivity compared to spherical-shaped particles. Nguyen *et al.* [13] conducted experiment using Al_2O_3/water with nanoparticle concentration of 6.8% by volume in car radiator and achieved 40% increase in heat transfer coefficient.

It has been concluded from literature review that most of the researchers focused their study on unary nanoparticles dispersed fluids. Researchers have only marginally investigated the thermal properties of binary and ternary types of nanofluids especially in terms of stability analysis. Considerable research efforts have been dedicated to investigating the thermophysical properties and practical applications of nanofluids containing a single type of nanoparticle. However, a significant research gap exists in examining nanofluids, including two or three different types of nanoparticles. The literature has only provided a limited exploration of the stability analysis of these increasingly intricate nanofluids. In light of this identified need, the present investigation endeavors to concentrate on the amalgamation and delineation of binary nanofluids, exploring six distinct permutations using Al_2O_3, ZnO, and TiO_2. The aim of this research is to provide new insights and optimizations to the area by further investigating the stability enhancement of nanofluids through the utilization of binary combinations.

2 Method and materials

2.1 Nanofluids preparation

Preparation of stable nanofluid is not just a simple process of mixing the nanoparticles into the base fluid; it is still a challenging task for researchers. Generally, there are two basic methods to prepare nanofluids: the single-step preparation method and the two-step preparation method. In the single-step method, nanoparticles are prepared and suspended in the base fluid simultaneously as shown in Figure 1.

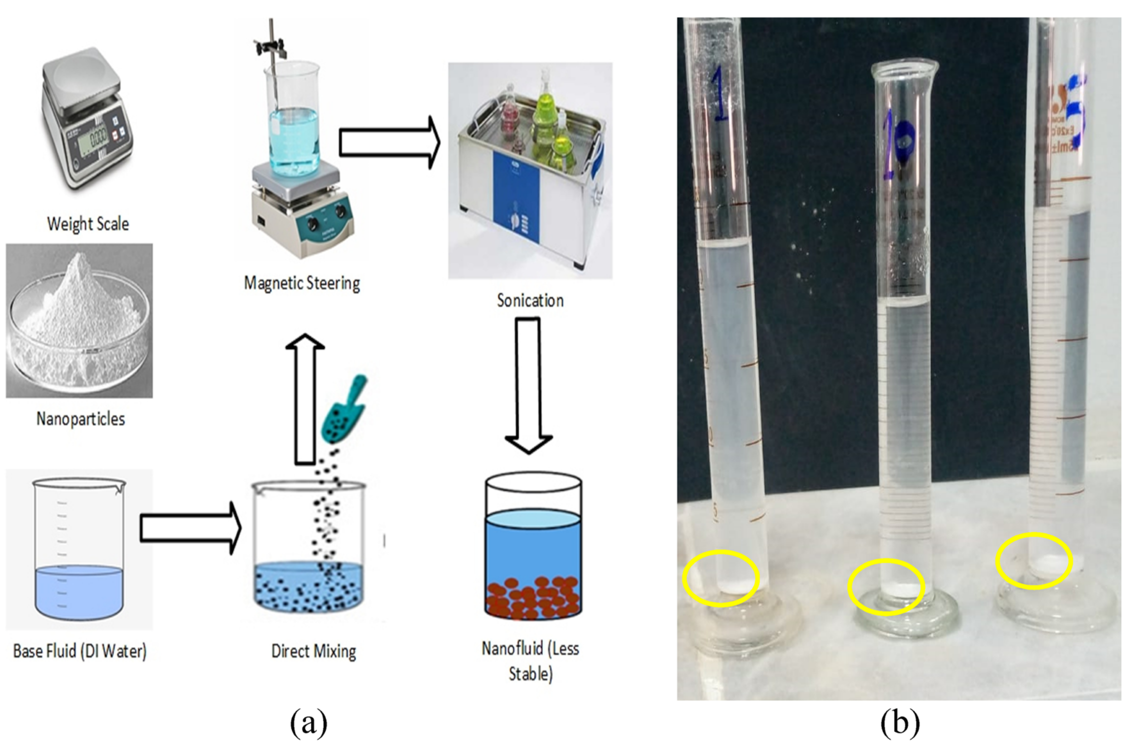
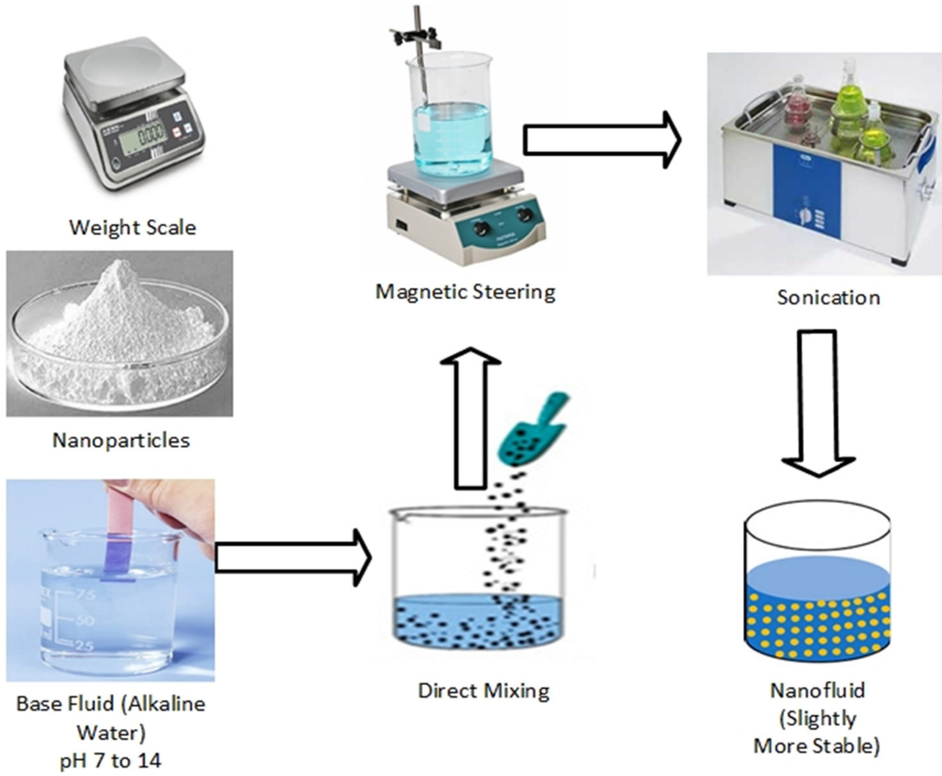
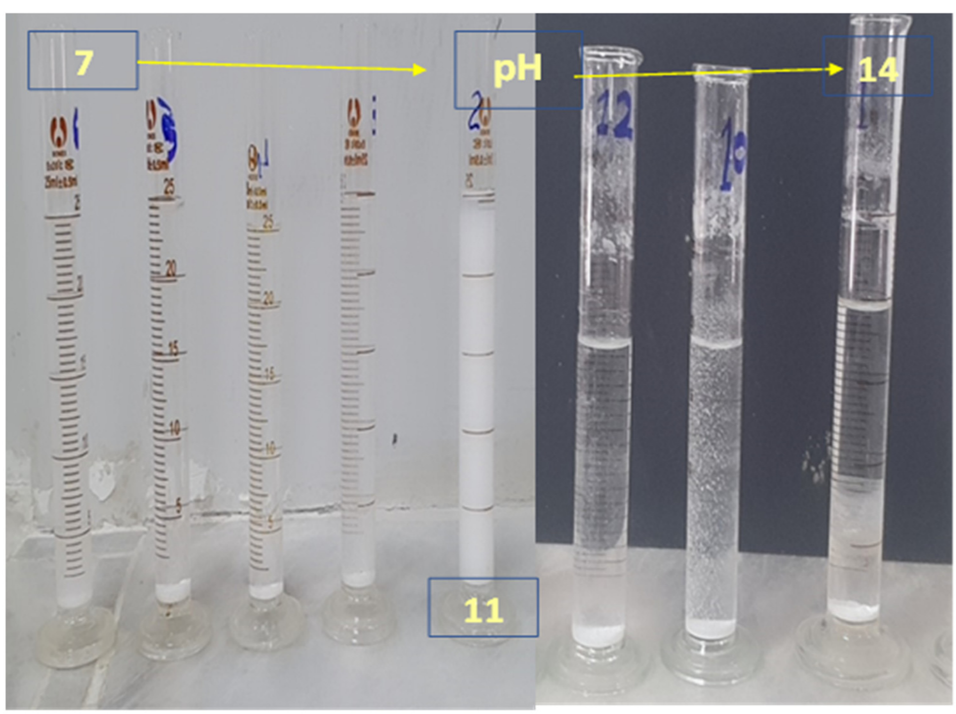


Figure 3: (a) Experimental trail 1 for stability enhancement in DI water. (b) Sedimentation of TiO_2 nanoparticles after 5 h in DI water.



(a)



(b)

Figure 4: (a) Experimental trail 2 for stability enhancement in pH water. (b) Sedimentation of TiO_2 nanoparticles after 1 day at different pH water.

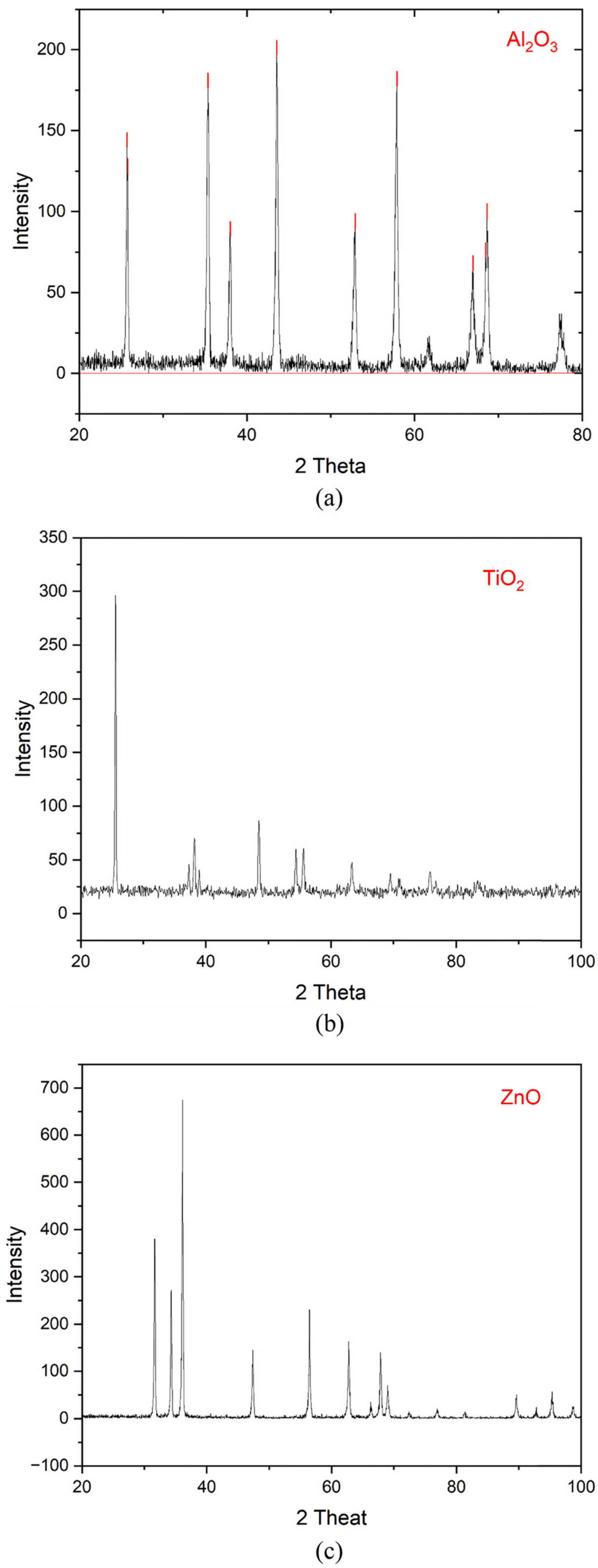


Figure 5: (a) XRD analysis of Al_2O_3 nanoparticle. (b) XRD analysis of TiO_2 nanoparticle. (c) XRD analysis of ZnO nanoparticle.

Table 1: Specifications of different combinations of binary nanofluid

Sample #	TiO_2	Al_2O_3	ZnO	Surfactant	pH
6	10 mg	10 mg	X	X	11
7	10 mg	X	10 mg	X	11
8	X	10 mg	10 mg	X	11
9	10 mg	10 mg	X	Sodium dodecyl sulfate (SDS)	11
10	10 mg	X	10 mg	SDS	11
11	X	10 mg	10 mg	SDS	11

Two-step method is widely used to produce nanofluids for commercial purposes. In this method, initially, nanoparticles in dry powdered form are prepared with the help of physical and chemical processes. Then, this dry powder is blended with liquid to form nanosuspension. The attractive feature of this method is that it produces nanofluids for industrial applications economically. Further, Figure 2 demonstrates the basic steps involved in two-step method.

2.2 Stability of nanofluids

Once the nanofluids are synthesized, the next challenge for researchers is their stability and enhancement. Nanofluids stability is important for obtaining the same thermophysical properties. Nanofluid's stability is the function of van der Waals force of attraction and electrical double layer repulsive force (EDLRF). Van der Waals attractive forces must be smaller than EDLRF to obtain stable nanofluid [14]. The major problem with two-step method is the agglomeration of particles in base fluid. Due to this, pH control, the addition of surfactants, and ultrasonication techniques are used to avoid or reduce the agglomeration effect.

TiO_2 nanoparticles are initially selected for nanofluid preparation with deionized water (DI) water during this experimental trail as shown in Figure 3(a). First, nanoparticles were blended with the help of a magnetic stirrer, and then sonication is applied for 2 h to achieve stability, but after 5 h nanoparticles were agglomerated at the lower portion of conical flask as shown in Figure 3(b).

In another trial, similar to the previous one, TiO_2 nanoparticles were selected for nanofluid preparation with water having different pH from 7 to 14 to enhance the stability of nanofluids. The result concluded that at pH 11, nanoparticles were quite stable as compared to the rest of the pH samples; this is due to higher zeta potential, which leads to electrostatic repulsion of individual particles, as shown in the Figure 4(b).

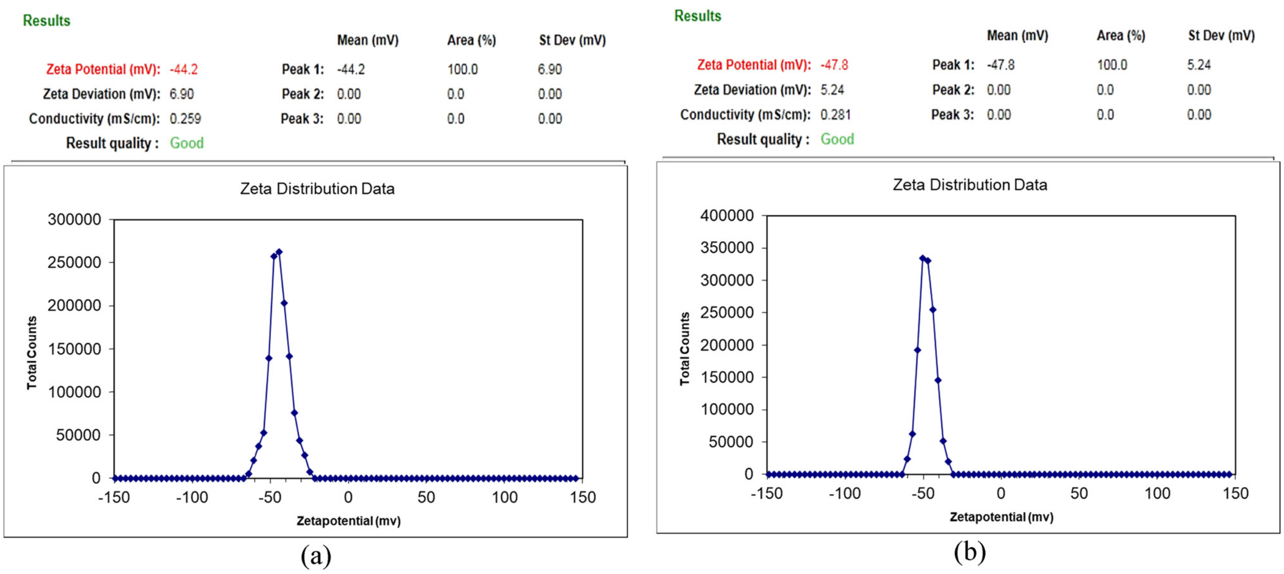


Figure 6: Zeta potential curves for binary TiO_2 + ZnO nanoparticles (a) without surfactant and (b) with surfactant.

3 Results and discussion

3.1 Characterization

Characterization of nanoparticles is carried out using X-ray diffraction (XRD) and zeta potential. XRD is a widely used technique for characterizing the crystal structure of materials, including nanomaterials. Zeta potential absolute values determine the stability of nanofluid.

XRD and zeta potential characterize the nanoparticles. Figure 5(a)–(c) illustrates the XRD images of nanoparticles. The high resultant particle peaks of Al_2O_3, TiO_2, and ZnO particles appear near 2θ equal to 25.7°, 35.3°, 38.00°, 43.57°, 52.92°, 57.89°, and 66.95° for Al_2O_3 similarly, 25.53°, 38.12°, 48.44°, 54.35°, 55.48°, and 63.2° for TiO_2 and 31.68°, 34.35°, 36.09°, 47.38°, 56.43°, 62.5°, and 67.7° for ZnO nanoparticle, respectively.

3.2 Zeta potential of binary nanofluid

Zeta potential is the potential that develops between fluid medium and charged nanoparticles. Its absolute value

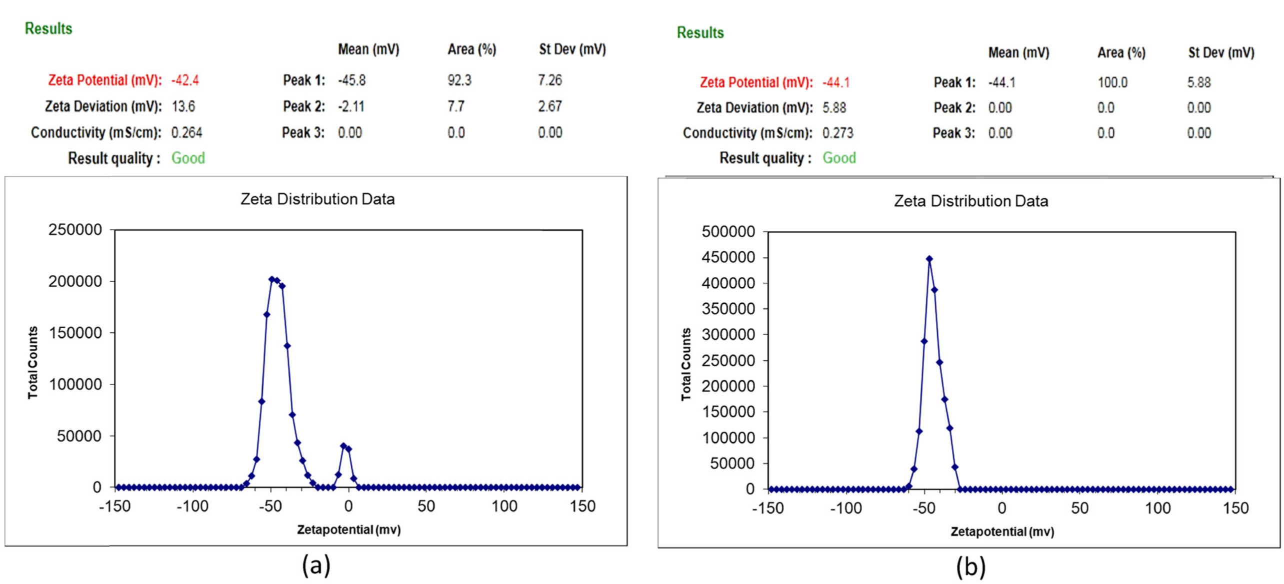


Figure 7: Zeta potential curves for binary Al_2O_3 + ZnO nanoparticles (a) without surfactant and (b) with surfactant.

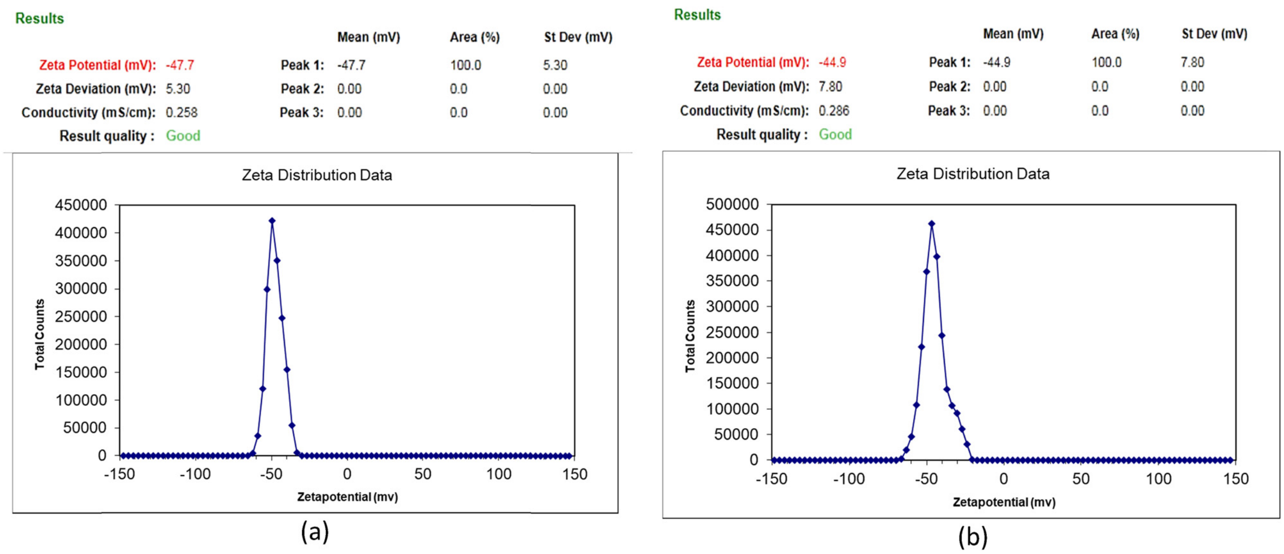


Figure 8: Zeta potential curves for binary Al_2O_3 + TiO_2 nanoparticles (a) without surfactant and (b) with surfactant.

shows the degree of repulsive forces between the particles in the fluid. For stable colloids, the zeta potential must be higher (either positive or negative). Low zeta colloids tend to agglomerate. Zeta potential of the nanofluids were measured to determine the stability of nanofluids using Malvern Zeta sizer. The charged particles' electrophoretic movement calculates zeta potential under an electric field's influence [15] (Table 1).

In this study, three nanoparticles were selected TiO_2, Al_2O_3, and ZnO to prepare six combinations of binary nanofluids as mentioned in the above table. The main objective of the study is to enhance the stability of nanofluids, that is why different trails were conducted with and without surfactant addition at pH water.

Figure 6 illustrates the zeta potential curves for binary nanofluid sample (TiO_2 + ZnO) without and with the

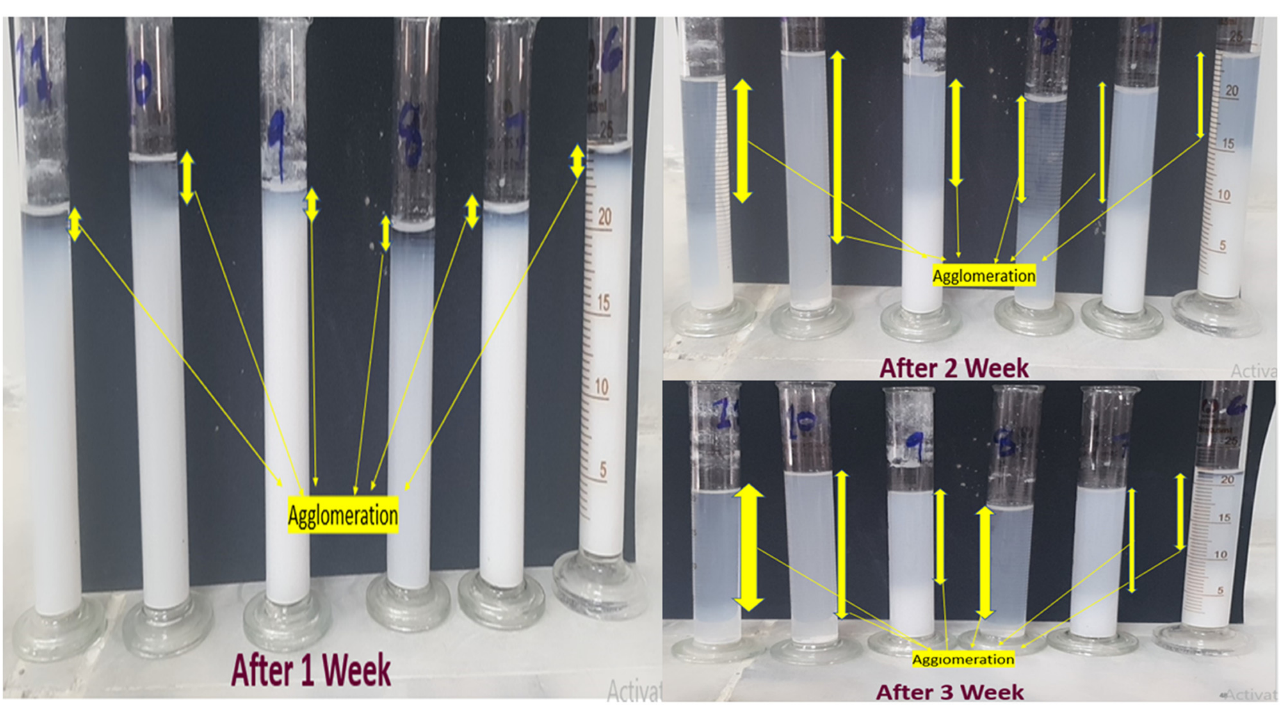


Figure 9: Sedimentation photograph test of binary nanofluid.

addition of a surfactant environment. The nanofluid stability increases with the addition of surfactant, which is reflected in high intensity peak of zeta potential. According to experimental results, its zeta potential increases from −44.2 to −47.8 mV with the addition of surfactant. Higher zeta potential is due to long alkyl chain which contributes to steric stability by creating strong repulsive forces between nanoparticles and base fluid. This effect prevents agglomeration thus resulting in higher stability (Rehman *et al.* [16]).

Figure 7 illustrates the zeta potential curves for binary nanofluid sample (Al_2O_3 + ZnO) without and with the addition of a surfactant environment. The nanofluid stability increases with the addition of surfactant, which is reflected with high-intensity peak of zeta potential. According to experimental results, its zeta potential increases from −42.4 to −44.1 mV with the addition of surfactant. This long-term stability is due to long alkyl chain which contributes to steric stability by creating strong repulsive forces between nanoparticles and base fluid. This effect prevents agglomeration thus resulting in higher stability (Rehman *et al.* [16]).

Figure 8 illustrates the zeta potential curves for binary nanofluid sample (Al_2O_3 + TiO_2) without and with the addition of a surfactant environment. According to experimental results, its zeta potential slightly decreases from −47.7 to −44.9 mV with the addition of surfactant. Furthermore, the selected binary nanofluid (Al_2O_3 + TiO_2) without any surfactant shows good dispersion; this is because, in polar liquids, Al_2O_3 can develop a significant amount of surface charge that can enhance dispersion stability by electrostatic repulsion [17]. Since, both Al_2O_3 and TiO_2 nanoparticles carried a positive charge, when a negatively charged surfactant was introduced, it absorbed onto the nanoparticles, thereby modifying their surface charges. This led to an overall increase in the negative charge on the nanoparticle surface, causing repulsive forces to become less strong. Consequently, there was a slight reduction in the zeta potential.

Figure 9 demonstrates the stability of binary nanofluid with and without surfactant for 3 weeks. It was observed that the addition of surfactant increases stability except in polar liquids containing Al_2O_3.

4 Conclusion and future work

This study presents the preparation, stability, and enhancement of binary nanofluid experimentally to achieve uniform thermophysical properties during heat transport applications. XRD and zeta potential were carried out to characterize Al_2O_3, TiO2, and ZnO nanoparticles. Based on this study, the conclusions are as follows:

- The nanofluid stability was considerably week when DI water was used as base fluid.
- Stability of the nanofluid was discovered to increase in pH water than in DI water and achieved best value at pH 11.
- The zeta potential of binary nanofluid increases with the addition of surfactant, except in case of polar liquids containing Al_2O_3.
- The binary nanofluid achieved good stability even after 2 weeks, as evident from the sedimentation photograph method.

Finally, the following challenges are identified for future work:

- Most of the literature focused on the thermophysical properties of nanofluid, but long-term stability is still a significant challenge for industrial applications and commercialization.
- The optimum sonication and magnetic stirring time are not yet determined for different nanofluid types.
- More research is required to select an optimum surfactant concentration for different nanofluid types.
- More research is needed on the corrosive and erosive effects of magnetic nanomaterial.

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