Study of the effects of Shockwaves on Nano fluids

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Abstract. Nanofluids are fluids with nanoparticles dispersed in them. Due to the presence of Nano particles, these fluids exhibit unique properties that can used in various applications such as heat exchangers and in medical fields. However, due to agglomeration, the size of these particle increases, reducing their efficiency. In order to break the agglomeration, we are passing shockwaves in the fluid. Shockwaves theoretically carry energy which can be used to break the agglomerating particles. In this paper, silver nanoparticles were synthesized using silver nitrate. Tri sodium citrate was used as the reducing agent. Shock waves were passed to the fluid containing silver Nano particles. The changes in the Nano fluid was measured by a UV-Vis Spectrophotometer. With each shock passed, the fluid's absorbance and wavelength peak was measured and compared with Nano fluid without shock.

1. Introduction

Nanoparticles dispersed in a base fluid are called Nano fluids. Metals, Oxides, Carbides or Carbon nanotubes are used as nanoparticles in Nano fluids. Common base fluids include water, ethylene glycol and oil. Different methods are available to synthesize nano particles. Chemical synthesis of silver nano particles have been adopted in this paper. Shock waves are usually associated with supersonic flight. Recently, they have made their way for numerous applications in medicine and Industry [1]. In Industry, shock waves have been used to achieve strain rates in excess of 10^2/sec by high velocity forming. Kosing and skews [2, 3] made research on free forming and shape forming by using liquid shock tube. Kumara et al [4] have tried to increase the stability of gold nano particles using shock waves. Nagaraja S R et al [5] have made research on metal forming using diaphragm-less shock tube. S R Nagaraja et al [6] have made research in bio medical applications by optimizing thin metallic diaphragms for a micro blast wave assisted deformation. S.G Rakesh et al [7] have developed a device to deliver dry particles and liquid jet in to different targets which uses shock waves energy. Jagadeesh et al [8] have delivered vaccines using shock waves.

2. Set up

The model of the shock tube used for the simulation is borrowed from an existing shock tube used in the Shockwave and Hypersonic Flow Research Laboratory at Amrita School of Engineering, Bangalore campus. As it is not feasible to pass shock to a liquid sample in horizontal position, an additional member with 'L' shaped bend is attached to the open end of the shock tube.

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Figure 1. L - Bend

Figure 2. Driven Section

Figure 3. Driver Section

Computer software COMSOL V 5.2 was used to study the effect of the L bend on shock waves. Using this study, proper length of the L-bend was decided. The purpose of this study was to investigate the pressure loss in the shock wave due to the additional member. The shock tube consists of a driver and driven section which are coupled using a flange coupling, which also has the provision for housing the diaphragm. A straight tube of internal diameter 26.5mm and length of 0.3m for the driver section and 1.7m for driven section was used. The pressure input for the analysis was taken as 10 bar in the driver section and atmospheric pressure in the driven section. The fluid in the tube is air. The bend has a length of 30cm and has an internal diameter of 26.5mm and outer diameter of 33.4mm. The material of the tube is A340 stainless steel.

3. Experiment

Silver nanoparticles were produced through chemical synthesis. In this process, silver nitrate [$AgNO_3$] was used as the base material while Tri Sodium Citrate [$C_6H_5O_7Na_3$] was used as a reducing agent. 100ml of 0.001M $AgNO_3$ solution was heated on a magnetic stirrer until it reaches the boiling point. 5ml of 1% Tri Sodium Citrate was added to the solution drop by drop while the Nitrate solution is stirred vigorously. The colour of the solution changed from clear to pale yellow indicating the formation of silver nanoparticles. Once this colour appeared, the heater was switched off and the solution was allowed to cool to room temperature while being stirred.

Figure 4. Sample

The experiment was conducted in two batches. Each batch of solution was prepared separately and the two batches had the same number of shocks passed through them with same time intervals. This was to ensure that the results obtained had similar trend. The UV spectrometer was used to observe the changes happing to the particles after every shock. The first batch had a UV spectrometer reading taken right

after synthesis. This acted as the base curve for the experiment. Once the reading was taken, one shock was passed through the liquid and its effect was observed. The liquid was then left for a day to observe short term effect on the liquid. The very next day, one reading was taken before the second shock was passed. Five consecutive shocks were passed with a reading taken between each shock to observe the changes after each shock. After the sixth shock, the liquid was again left for another day to observe short term changes. The next day, another reading was taken before passing the seventh shock. After observing the results of the seventh shock, the decision was made to stop applying shocks and the liquid was observed for few days. Spectrometer readings of the liquid were taken at an interval of 48 hours. Finally, after eleven days of observation, eighth shock was applied. The final reading was taken to conclude the results. However, to confirm the results obtained from batch 1, a fresh batch of fluid was prepared and the same procedure was followed.

4. Results

The instrument used for observing the results was a UV-Vis Spectrophotometer. It measures the intensity of the light that passes through the sample (I), and compares it to intensity of the light that passes through a reference fluid (I_0). The ratio I / I_O is called transmittance and is expressed as percentage (%T). The absorbance, A, is based on the transmittance: $A = - log (\%T)$. For our experiment, $AgNO_3$ solution was used as a reference fluid as it was the base fluid upon which the silver nanoparticles were synthesized. The experimental results are shown on a graph with absorbance on the Y – axis and wavelength on the X – Axis. After analysis, a curve appears with a peak and a valley. At lower wavelengths, the curve shows an abnormal increase in absorbance however that is attributed to noise and other contents in the fluid. Since the silver nanoparticle peak is observed at a specified range of wavelength [350 nm – 500 nm], this will be the main focus of the results.
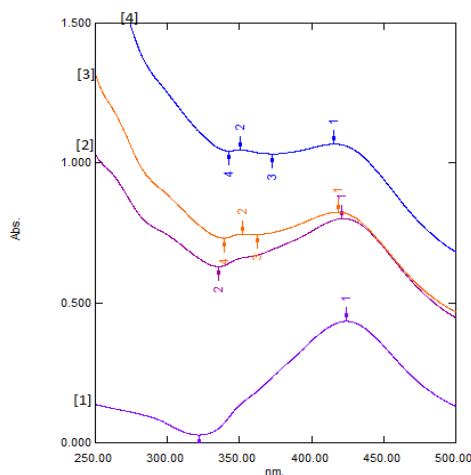
4.1. Shock 1, shock 3 and shock 7

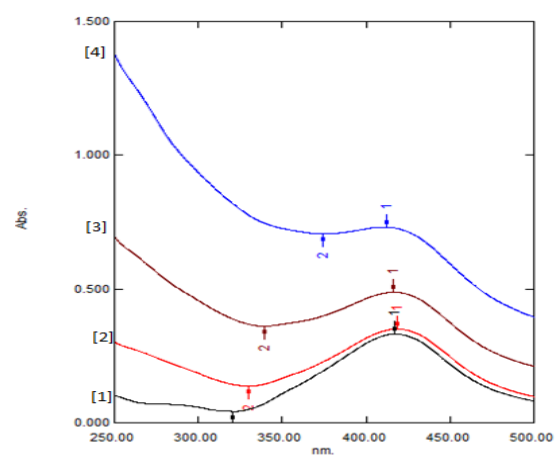**Figure 5.** Batch 1 – Shock 1, 3 and 7

Figure 6. Batch 2 – Shock 1, 3 and 7

Table 1. Batch 1 – Shock 1,3 and 7

	Wavelength	Absorbance
[1]New Sample	424.0 nm	0.434
[2]Shock 1	421.2 nm	0.801
[3]Shock 3	418.6 nm	0.824
[4]Shock 7	415.6 nm	1.068

Table 2. Batch 2 – Shock 1,3 and 7

	Wavelength	Absorbance
[1]New Sample	417.2 nm	0.332
[2]Shock 1	417.6 nm	0.353
[3]Shock 3	416.4 nm	0.488
[4]Shock 7	411.8 nm	0.731

From the Figures 5 & 6, we can observe that upon passing the first shock there is a significant increase in the absorbance and left shift in the wavelength. This confirms that the passing of shock into the fluid breaks down the particles, increasing the number of particles. The left shift of wavelength implies that the size of particles decreased due to the shock. Application of consecutive shocks increase the absorbance of the liquid and the left shift in the wavelength can be observed too. The second batch was subjected to the same procedure and number of shocks. It can be observed here that a similar pattern follows. Variation in absorbance levels can be attributed to the difference in synthesis timings.
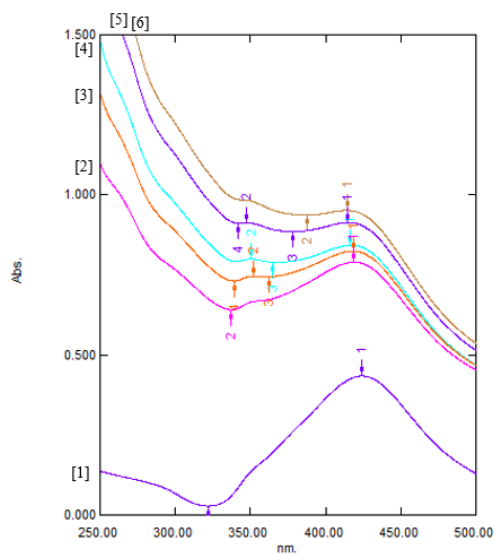
4.2. Shock 2 to shock 6

Figure 7. Batch 1 – Shock 2 to 6

Figure 8. Batch 2 – Shock 2 to 6

Table 3. Batch 1 – Shock 2 to 6.

	Wavelength	Absorbance
[1]New Sample	424.0 nm	0.434
[2]Shock 2	418.6 nm	0.790
[3]Shock 3	418.6 nm	0.824
[4]Shock 4	416.4 nm	0.843
[5]Shock 5	414.4 nm	0.914
[6]Shock 6	414.2 nm	0.952

Table 4. Batch 2 – Shock 2 to 6

	Wavelength	Absorbance
[1]New Sample	417.2 nm	0.332
[2]Shock 2	417.8 nm	0.450
[3]Shock 3	416.4 nm	0.488
[4]Shock 4	414.6 nm	0.577
[5]Shock 5	413.4 nm	0.656
[6]Shock 6	412.4 nm	0.685

On the second day, 5 shocks were passed through the fluid continuously. After every shock, the fluid was analysed for changes. From the graphs, it can be seen that the absorbance continued to increase and the wavelength continued to shift left. Thus, application of shock continues to have an impact on the particle size.

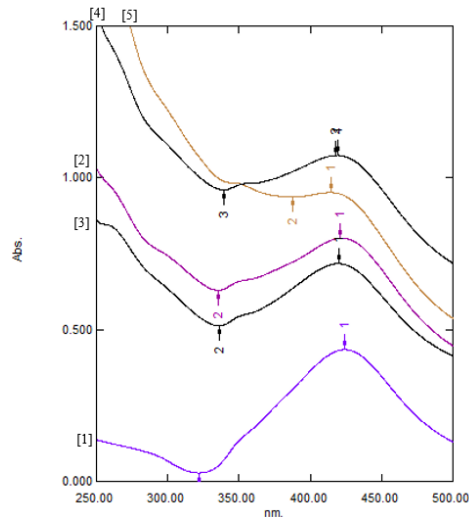### 4.3. Gap after shock 1 and shock 6
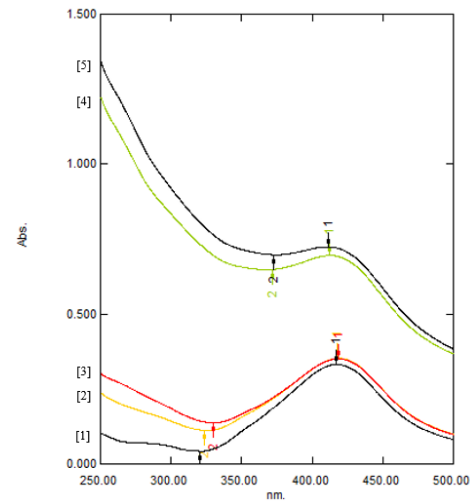

Figure 9. Batch 1 – Gaps

Figure 10. Batch 2 – Gaps

Table 5. Batch 1 – Gap after shock 1 and shock 6

	Wavelength	Absorbance
[1]New Sample	424.0 nm	0.434
[2]Shock 1	421.2 nm	0.801
[3]Shock 1 Gap	419.8 nm	0.717
[4]Shock 6	414.2 nm	0.952
[5]Shock 6 Gap	419.2 nm	1.068

Table 6. Batch 2 – Gap after shock 1 and shock 6

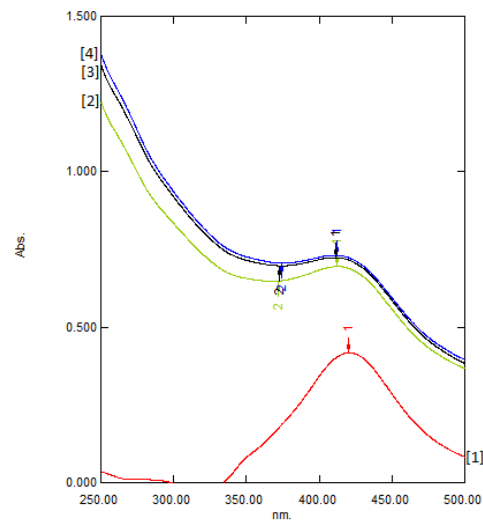|	Wavelength	Absorbance
[1]New Sample	417.2 nm	0.332
[2]Shock 1	417.6 nm	0.353
[3]Shock 1 Gap	418.4 nm	0.350
[4]Shock 6	412.4 nm	0.685
[5]Shock 6 Gap	411.0 nm	0.724

After applying shock 1 and shock 6, a day gap was given to observe what would happen if the fluid was allowed sit ideal for a period of 24 hours or 1 day. It can be observed that there is a decrease in absorbance in one case. This can be attributed to agglomeration of the particles when left ideal. However, after shock 6, there is an unexpected increase in absorbance. It has been theorized that after applying five consecutive shocks, the energy from these remained in the liquid during the ideal time, accounting for the increase in absorbance.

4.4. Shock 7

Upon letting the fluid sit for 24 hours, the 7th shock was passed through the fluid and analysed. It was noted that there was no significant change in the absorbance in the fluid. When the same procedure was done to batch 2, we saw similar results. The 7th shock had no impact showing that the fluid had reached saturation. This shows that the fluid has reached saturation and there is no impact of future application of shockwaves.

Figure 11. Batch 1 – Shock 7
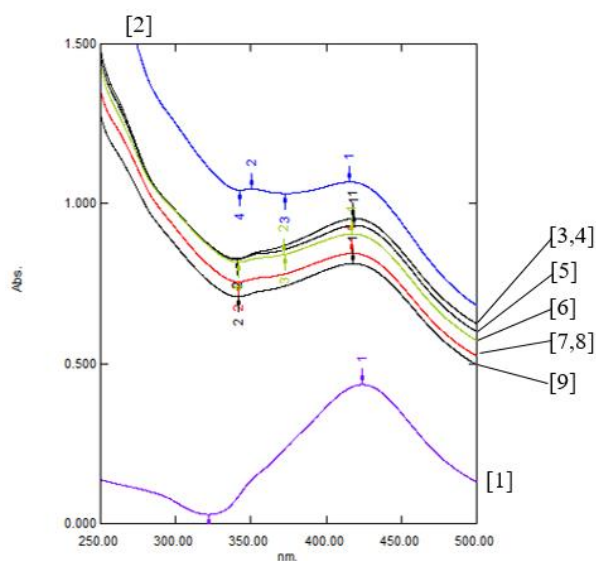

Figure 12. Batch 2 – Shock 7

Table 7. Batch 1 – Shock 7

	Wavelength	Absorbance
[1]New Sample	424 nm	0.434
[2]Shock 6	414.2 nm	0.952
[3]1 day gap	419.2 nm	1.074
[4]Shock 7	415.6 nm	1.068

Table 8. Batch 2 – Shock 7

	Wavelength	Absorbance
[1]New Sample	417.2 nm	0.332
[2]Shock 6	412.4 nm	0.685
[3]1 day gap	411.0 nm	0.724
[4]Shock 7	411.8 nm	0.731

4.5. Batch 1 after shock 7

Upon passing the seventh shock, we continued to take sample readings. For every 48 hours, the changes

Table 9. Batch 1 – After Shock 7

	Wavelength	Absorbance
[1]New Sample	424 nm	0.434
[2]27th April	415.6 nm	1.068
[3]29th April	418.8 nm	0.954
[4]1st May	417.8 nm	0.954
[5]2nd May	416.8 nm	0.906
[6]4th May	417.2 nm	0.845
[7]6th May	418 nm	0.813
[8]8th May	418 nm	0.780
[9]9th May	417.8 nm	0.767

Figure 13. Batch 1 – After Shock 7

were observed. It can be seen here that although the absorbance continued to decrease continuously, the wavelength shift shows an erratic behaviour. Also as the numbers of days increases, the gap between absorbance decreases. This shows that the agglomeration approaches stagnation as days increase.

4.6. Shock 8

After letting the batch 1 fluid sit ideal for 11 days, the 8th and final shock was passed through the fluid. It can be observed that the final shock did not have much effect on the fluid. This can be accounted due the fact that the agglomeration was reaching a stagnation point thus additional shocks do not have much effect on it.
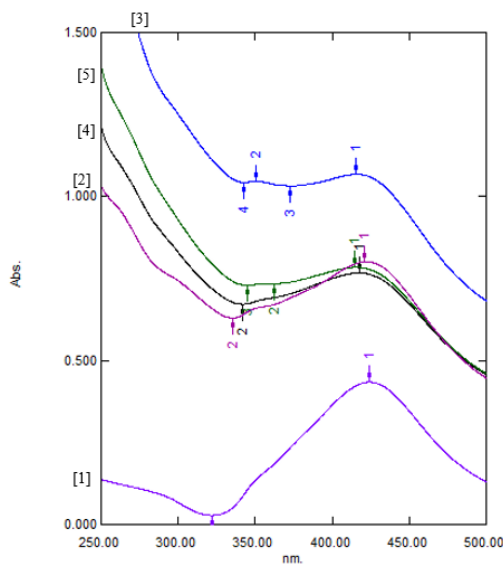

Figure 14. Batch 1 – Shock 8

Table 10. Batch 1 – shock 8

	Wavelength	Absorbance
[1]New Sample	424 nm	0.434
[2]Shock 1	421.2 nm	0.801
[3]Shock 7	415.6 nm	1.068
[4]Before Shock 8	417.8 nm	0.767
[5]Shock 8	414.8 nm	0.784

5. Conclusion

The results obtained from our experiment and subsequent analysis show how the fluid reacts to the shockwaves passed through them. It can be noted that the shockwaves do have an effect on the molar concentration and particle size of the silver nanoparticles. With every shock we see an increase in absorbance level, accounting for the increase in molar concentration, and the left shift in wavelength shows the reduction in particles size. However, it can be seen that even this process reaches a saturation level. The gain in absorbance reduced until it was capped of at shock 7 which did not have any significant increase in absorbance or left shift of wavelength. It can also be noted that upon letting the fluid sit ideal can cause agglomeration of the particles, reducing the molar concentration and increasing particle size. However, letting the liquid stay for much longer shows that the agglomeration begins to stagnate and the fluid stabilizes. Even after applying more shocks, no significant increase in absorbance was observed. Another interesting observation here shows how the energy from the shocks remain in the fluid after passing the shocks. This is seen when there is an increase in absorbance after applying five consecutive shocks and letting the fluid sit ideal for a day. In general, it can be concluded that the nanofluids show some positive change when exposed to shock waves and paves way to carry out research in this topic.

6. Acknowledgement

7. References

[1] V. Menezes, K. Takayama, T. Ohki and G. Jagadeesh (2005) Laser-ablation-assisted micro particle acceleration for drug *delivery Applied Physics Letters*. **87**.

[2] O E Kosing and B W Skews 1997 The use of liquid shock waves for metal forming *21st International Symposium on shock waves*.

[3] O E Kosing and B W Skews 1998 An investigation of high speed forming of circular plates in a liquid shock tube *Int. J. Impact Engg*. **21** 801- 816

[4] H.K.T. Kumara, V. Jayaram, K.P.J. Reddy (2015) Dispersion and Size Reduction of Nanoparticles in Nanofluids Using Shock Waves. In: Bonazza R., Ranjan D. (eds) *29th International Symposium on Shock Waves*

[5] S R Nagaraja1, J K Prasad, and G Jagadeesh (2013) Theoretical-experimental study of shock wave assisted metal forming process using diaphragmless shock tube *Proc. IMechE, Part G: J. Aerospace Engineering* **226** 1534-1543.

[6] S.R. Nagaraja, S.G. Rakesh, J.K. Prasad, P.K. Barhai, G. Jagadeesh (2012) Investigations on micro-blast wave assisted metal foil forming for biomedical applications *International Journal of Mechanical Sciences* **61** 1–7

[7] S. G. Rakesh, Divya Prakash Gnanadhas, Uday Sankar Allam, Karaba N. Nataraja, P. K. Barhai, Gopalan Jagadeesh, Dipshikha Chakravortty (2012) Development of micro-shock wave assisted dry particle and fluid jet delivery system *Appl Microbiol Biotechnol* **96** 647–662

[8] Gopalan Jagadeesh, G. Divya Prakash, S. G. Rakesh, Uday Sankar Allam, M. Gopala Krishna, Sandeepa M. Eswarappa, and Dipshikha Chakravortty (2011) Needleless Vaccine Delivery Using Micro-Shock Waves *Clinical and Vaccine Immunology* **18** 539–545

[9] Dr. Pallab Ghosh, Preparation of Nanomaterials *NPTEL − Chemical Engineering − Interfacial Engineering*

[10] Y. Hwang, J.-K. Lee, J.-K. Lee, Y.-M. Jeong, C. Seong-ir, A. Young-Chull, H.K. Soo: Production and dispersion stability of nanoparticles in nanofluids *Powder Technology* 186, 145– 153 (2008)

[11] K.V. Wong, O.D. Leon: Applications of Nanofluids: Current and Future *Advances in Mechanical Engineering, Article ID 519659* (2010)