

DESIGN PARAMETERS TO OBTAIN Al_2O_3 NANOFLUID TO ENHANCE HEAT TRANSFER

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Abstract

The study of nanostructures gained more and more ground in the past years due to the acceptable electrical conductivity, mechanical flexibility and low cost manufacturing potential (mixing, mechanical stirring, ultrasonication, vacuum chambers). The process of obtaining nanofluids with 0.1%, 0.5% and 1% concentration of aluminium oxide (Al_2O_3) was studied by mechanical stirring (in the reactor station - static process equipment fitted with a stirring device in order to obtain solutions, emulsions, to make or to activate chemical reactions and physic-chemical operations and to increase the heat exchange), vibrations and magnetic stirring. The selected nanoparticles have an average size of 10 nm and were dispersed in base fluids consisting of distilled water and low concentration of glycerin (5.4%, respectively 13%). The samples extracted during the process were analyzed with the quartz crystal microbalance (QCM – modern alternative to analyze the complex liquids from water and copolymers to blood and DNA and the dynamic viscoelasticity of fluids can be determined), in terms of homogenization and stability (behavior in time). Also, a heat transfer study with the reactor station and a comparison between the heat transfer of the carrier fluid (consisting of water and 5.4% glycerin) and the heat transfer of the antifreeze used in solar panels installations was conducted. This study showed a decrease of the time consumed with heating the nanofluids and an improvement of the heat transfer due to the nanoparticles of Al_2O_3 .

Index Terms: nanopowder, mechanical stirring, cluster, QCM, stability, sedimentation

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1. INTRODUCTION

Nowadays, alumina is one of the most used oxides due to its use in many areas such as thin film coatings, heat-resistant materials, and advanced ceramic abrasive grains. Improved devices using nanoscale structures requires the understanding of thermal, mechanical electrical and optical properties of nanostructures involved and also their manufacturing process.

The size of the nanoparticle defines the surface-volume ratio, and for the same concentration, the suspension of particle size would result in as small an area as possible to the interface solid / liquid. Nanoparticle size affects the viscosity of nanofluids. In general, viscosity increases as the concentration of nanoparticles is increased. Studies on the suspension with the same concentration of nanoparticles, but nanoparticles of different sizes, have shown that the viscosity of the suspension decreases as the nanoparticle size decreases. Particular attention was given to the influence of nanoparticle size on thermal conductivity concentration of nanofluids. As base fluids have been used, in particular, distilled water, ethylene glycol and propylene glycol and engine oil in which were added nanoparticles in a concentration of less than 5% [1]. Increases of around 32% in thermal conductivity were reported in case of nanofluids based on water and around 30% of the ones based on ethylene glycol; in both cases a 4% volume load of nanoparticles was used. Other researchers reported that the thermal conductivity enhancement was decreased as concentration increased from 6% to 10% [2]. The

same phenomena was observed also when the thermal conductivity was increased as concentration increased from 2% to 10% [3], Al_2O_3 nanoparticles even though the particle size was almost the same in both the cases. The great disadvantage of larger nanoparticles is that suspensions tend to become unstable. Experiments have shown that nanofluids were able to enhance the thermal conductivity and convective heat transfer by large margins [4]. Reducing particle size from micro to nanometer, the development of new materials with improved properties could be achieved and many researchers reported results on nanoparticles dispersed in a viscous fluid and on homogeneity [5], [6].

2. MATERIALS AND METHODS

2.1 Formulation of nanofluids

The reactive mixtures between two or more fluids are a vast research field. The study of the optimal composition of heat or cooling carriers from the solar water heating, from heat exchangers, from cooling systems of engines and generators, from thermal stations is a challenge because it must fulfill some conditions, such as: high thermal transfer coefficient, high specific heat (in case of heating carriers), no corrosion of the pipes or metallic parts in contact etc. The most used heat carriers are: burning gases, hot air, water vapors (steam), hot water, engine oil, mineral oils and melted salts.

The selected nanoparticles to obtain the nanofluid have an average size of 10nm (according to the supplier's specifications), a specific surface of 160 m²/gr and density of 3.7 gr/cm³ (Fig -1).

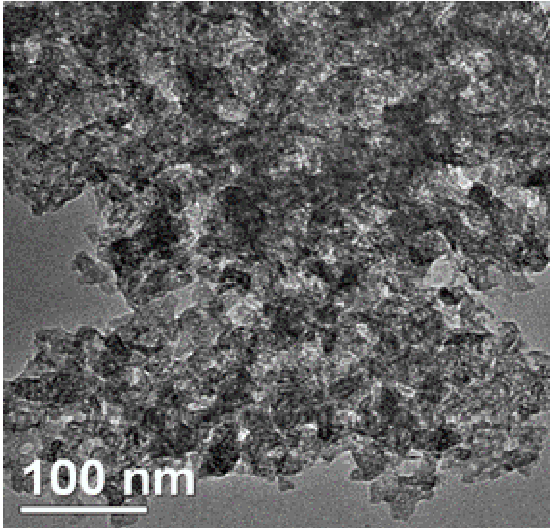


Fig -1: TEM image of Al₂O₃ nanoparticles

From the literature some information about the main parameters that have influence on mixtures was selected (temperature, speed and mixing time), and most of the researchers report that nanoparticle's dispersions in different base fluids are made at maximum speed (depending on the devices) [7] and at room temperature [8], [9] although there are some studies that report the analyses of nanofluids at different temperatures (20°C, 35°C and 50°C) [10]. When referring to time, this varies a lot according to the amount of nanofluid that is intended to be achieved [11], [12], [13] [14]

The shape of the reactor's bottom can have a significant effect on the hydrodynamic conditions inside it and hence the ability to achieve a homogeneous suspension. Cylindrical shaped tanks to lead to increased mass of particles in suspension by eliminating areas that are "dead" at the intersection of the tank wall. "Dead" areas or regions of segregation are found at the intersection of walls, especially in flat-bottomed tanks [15].

The stirred tanks have many applications in the mechanical, physical, chemical and biochemical processes where mixing is important for the whole process performance, such as: hydrodynamic operations (mixing, deposition, filtering, washing, decanting, centrifuging), heat transfer operations (heating, cooling, condensation, vaporization), mass transfer operations (drying, distillation and rectifying, absorption and adsorption, adsorption and desorption, crystallization, sublimation).

The techniques used to achieve a homogeneous and stable in time nanofluid are mechanical stirring, mechanical vibration and magnetic stirring.

Mechanical stirring: distilled water together with glycerin and nanopowder were mixed in the reactor station (Fig -2), firstly at room temperature 21°C, and secondly at 50°C, maximum rotational speed of 3300 rpm, for 2 hours. The withdrawn samples were analyzed with the quartz microbalance – QCM (Fig -3).

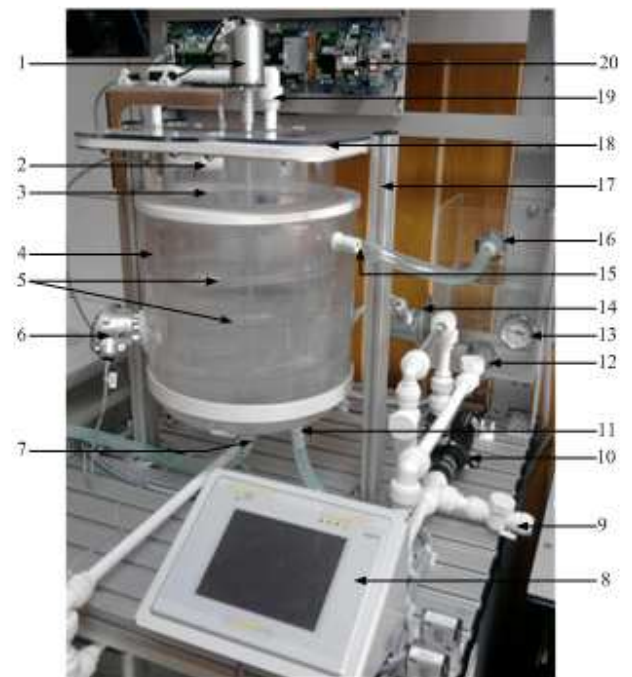


Fig -2: Reactor station with auxiliary heating system
 1 – stirrer; 2 – float; 3 – inner recipient; 4 – mantle; 5 – serpentine; 6 – temperature sensor; 7 – mixture evacuation outlet; 8 – display; 9 – heat carrier outlet tap; 10 – supplying and recirculation pump; 11 – inferior inlet; 12 – heat carrier evacuation outlet; 13 – thermometer; 14 – heating unit; 15 – superior inlet; 16 – heat carrier supplying inlet from mantle; 17 – profiled rail; 18 – cap; 19 – supplying pipeline; 20 – data acquisition board and connections

The QCM (Fig -3), is an extremely sensitive sensor capable of measuring mass changes in the spectrum of nanogram/cm². The lowest detectable mass change is usually of a few ng/cm² and is limited by the noise specifications of the crystal oscillator and frequency counter resolution used to measure frequency shifts [16].

The results show a decrease in the frequency shift and an increase in the resistance which means that the quartz microbalance is an outstanding device to analyze the fluid properties.



Fig -3: Quartz crystal microbalance

Mechanical vibration: from the reactor station, where the mechanical stirring took place, 200ml nanofluid was withdrawn and submitted to mechanical vibration for 2 hours. The device for magnetic stirring consists of a motor that rotates a disc on which two magnets are mounted. The disc rotates the two magnets and these, in turn, are rotating (stirring) the magnet from the nanofluid by attraction/rejection leading to breakage of the possible clusters remained after mechanical stirring and vibrations and to a better dispersion of the nanoparticles in the base fluid. The device is connected to a stabilized source that operates at maximum voltage of 12V and hence the maximum power that can be achieved for magnetic stirring is 60W. Information about the parameters controlled and monitored during the process of obtaining the nanofluids, is presented in **Table -1**.

Table -1: Samples withdrawn during the process of obtaining the nanofluids with 0.1%, 0.5% and 1% volume concentration of Al_2O_3

No	Sample	Concentration			Parameters						
		Water [%]	Glycerin [%]	Al_2O_3 [%]	Mechanical			Vibrations		Magnetically	
					Rotational speed [rpm]	Temp. [°C]	Time [min]	Power [W]	Time [min]	Power [W]	Time [min]
1	NA-C1	94.55	5.35	0.1	3300	21	120	-	-	-	-
2	NV-C1	94.55	5.35	0.1	-	-	-	3.12	120	-	-
3	NM-C1	94.55	5.35	0.1	-	-	-	-	-	60	120
4	NAT-C1	94.55	5.35	0.1	3300	50	120	-	-	-	-
5	NVT-C1	94.55	5.35	0.1	-	-	-	3.12	120	-	-
6	NMT-C1	94.55	5.35	0.1	-	-	-	-	-	60	120
7	NA-C2	86.13	13.38	0.5	3300	21	120	-	-	-	-
8	NV-C2	86.13	13.38	0.5	-	-	-	3.12	120	-	-
9	NM-C2	86.13	13.38	0.5	-	-	-	-	-	60	120
10	NAT-C2	86.13	13.38	0.5	3300	50	120	-	-	-	-
11	NVT-C2	86.13	13.38	0.5	-	-	-	3.12	120	-	-
12	NMT-C2	86.13	13.38	0.5	-	-	-	-	-	60	120
13	NA-C3	85.88	13.13	1	3300	21	120	-	-	-	-
14	NV-C3	85.88	13.13	1	-	-	-	3.12	120	-	-
15	NM-C3	85.88	13.13	1	-	-	-	-	-	60	120
16	NAT-C3	85.88	13.13	1	3300	50	120	-	-	-	-
17	NVT-C3	85.88	13.13	1	-	-	-	3.12	120	-	-
18	NMT-C3	85.88	13.13	1	-	-	-	-	-	60	120

2.1 Analysis of nanofluids

The result of QCM analyses are presented graphically in Charts 1 and 2.

- NA-C1: sample withdrawn from nanofluid with 0.1% Al₂O₃ vol. concentration, after mechanical stirring at 21°C;
- NV-C1: sample withdrawn from nanofluid with 0.1% Al₂O₃ vol. concentration, after mechanical vibration at 21°C;
- NM-C1: sample withdrawn from nanofluid with 0.1% Al₂O₃ vol. concentration, after magnetic stirring at 21°C;
- NAT-C1: sample withdrawn from nanofluid with 0.1% Al₂O₃ vol. concentration, after mechanical stirring at 50°C;
- NVT-C1: sample withdrawn from nanofluid with 0.1% Al₂O₃ vol. concentration, after mechanical vibration at 50°C;
- NMT-C1: sample withdrawn from nanofluid with 0.1% Al₂O₃ vol. concentration, after magnetic stirring at 50°C;

For the nanofluid with 0.5% volume concentration Al₂O₃, C2 notation was used and for 1% volume concentration Al₂O₃, it was used C3 notation.

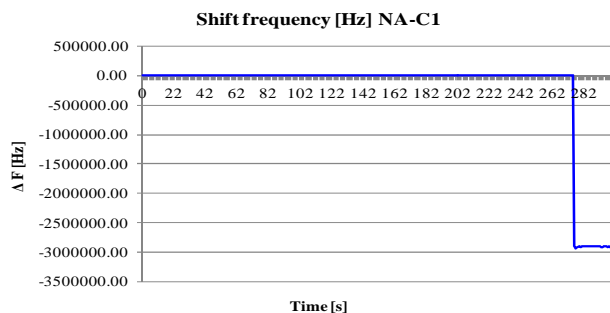


Chart -1: Shift frequency depending on time for the nanofluid with 0.1% vol. concentration of Al₂O₃, mechanically stirred at 21°C

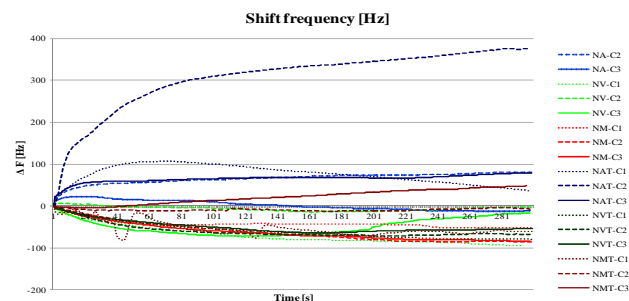


Chart -2: Shift frequency depending on time, for three nanofluids (volume concentrations of 0.1%, 0.5% and 1% Al₂O₃, achieved by mechanical stirring, vibrations and magnetic stirring at 21°C, respectively 50°C)

3. RESULTS AND DISCUSSION ON FORMULATION AND ANALYSIS OF AL₂O₃ BASED NANOFLUIDS

The influence of increased concentration of nanoparticles can be observed from the above chart. If in the case of nanofluid with 0.1% vol. concentration of nanoparticles we did not consider the curve for sample NA-C1 (mechanical stirring at 21°C) since it was unstable towards NAT-C1 (mechanical stirring at 50°C), but for the nanofluid with 0.1% vol. concentration Al₂O₃ a considerable improvement of QCM oscillation damping phenomena can be observed for the samples mechanically agitated in the reactor station.

The mechanical stirring of 0.1% concentration of Al₂O₃ nanopowder in a base fluid with 5.35% glycerin has not influenced the homogenization process, on the contrary, following the analyses, it was observed QCM oscillation damping phenomena, which means the nanoparticles haven't been completely dispersed and their tendency is to form sediments, hence clusters. Mechanical stirring at 50°C has a positive influence over the homogeneity of nanofluid, but still the higher temperature gives higher frequency shifts, which means that the nanofluid has unstable areas. On the other hand, a nanofluid submitted to mechanical vibrations, regardless the temperature is homogenous, and at higher temperatures the nanoparticles are better dispersed in the base fluid, achieving an in-time stable nanofluid. As in the case of water and 5.4% glycerin mixture the stability is observed between ΔF=-170 Hz, ΔF=-130 Hz, and by adding 0.1% Al₂O₃, this stability is observed between ΔF=-90 Hz, ΔF=-40 Hz. This confirms the selected techniques and also the settles parameters to achieve the nanofluid.

If in the case of nanofluid with 0.1% vol. concentration of nanoparticles the result for sample NA-C1 (mechanical stirring at 21°C) was not considered, since it was unstable towards NAT-C1 (mechanical stirring at 50°C), but for the nanofluid with 0.1% vol. concentration Al₂O₃ a considerable improvement of QCM oscillation damping phenomena can be observed for the samples mechanically agitated in the reactor station. But due to the positive values of the frequency shift they cannot be considered homogenous neither stable in time since the principle rules quartz crystal microbalance is based on the fact that the amount of mixture applied to the surface of the resonator is associated with the flow (movement) of the fluid and thereby a decrease of frequency shift is observed.

The samples were submitted to visual analysis, from which we can see the lack of homogeneity, due to sedimentation of nanoparticles. These samples as well as some of the steps from obtaining the nanofluid with 0.1% Al₂O₃ are shown in Fig -4 and for the nanofluid with 0.5% in Fig -5:

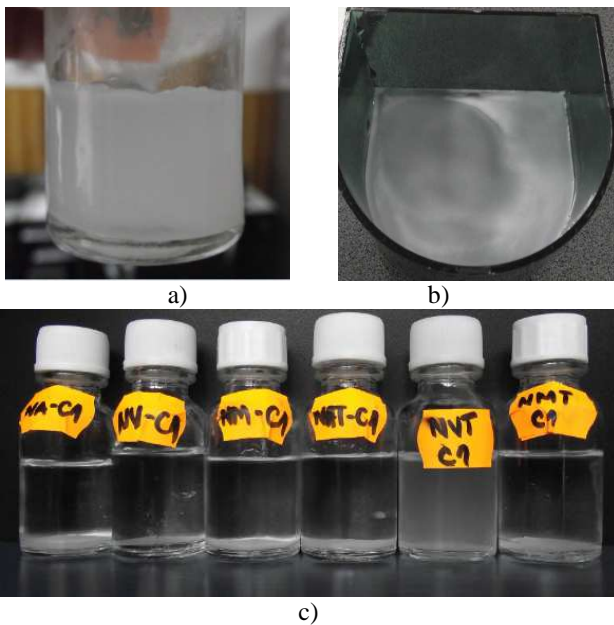


Fig -4: Achieving 0.1% vol. conc. Al₂O₃ nanofluid
 a) NA-C1 sample extracted after mechanical stirring; b) nanoparticle sedimentation after submission to vibrations; c) nanofluid with 0.1% vol. conc. – 1 day after formulation

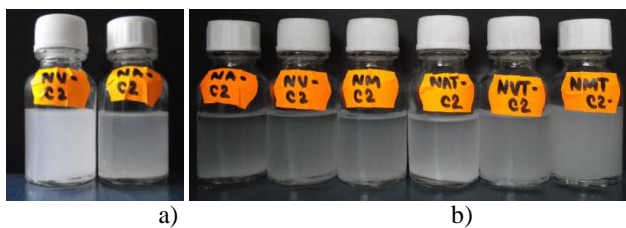


Fig -5: Achieving 0.5% vol. conc. Al₂O₃ nanofluid
 a) after extraction of sample NV-C2 and 2 hours after extracting sample NA-C2; b) samples extracted from nanofluid with 0.5% vol. conc. Al₂O₃

For the nanofluid with 1% vol. concentration, the quantities of water and glycerin were decreased with 0.25% each and similar evolution can be observed for the samples withdrawn after the mechanical stirring at 21, respectively 50°C from the nanofluids with 0.5, respectively 1% Al₂O₃. But the negative influence of the increased concentration of the nanoparticles can also be observed. From the QCM analyses no stabilization trend is visible for nearly all samples. It may be noted that regardless of the concentration, a nanofluid mechanically stirred at 50°C, which is then submitted to mechanical vibrations has stable areas after 180s.

Fig -6 shows some of the samples containing 0.1%, 0.5% and 1% vol. conc. of Al₂O₃ after achieving the nanofluid with 1% Al₂O₃:

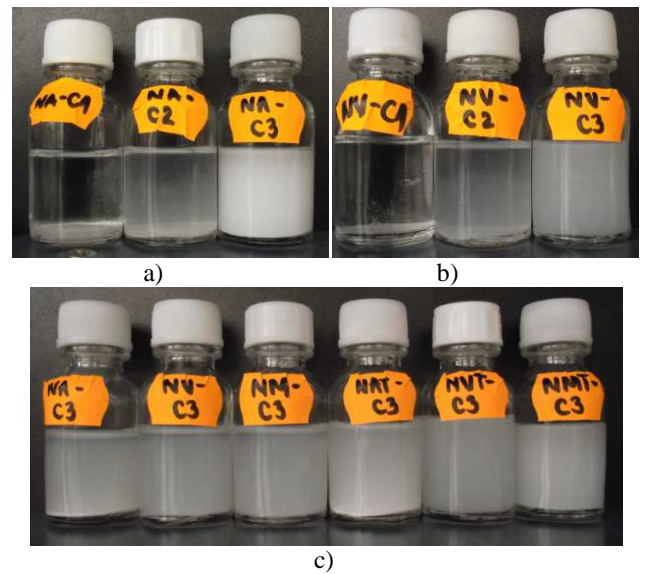
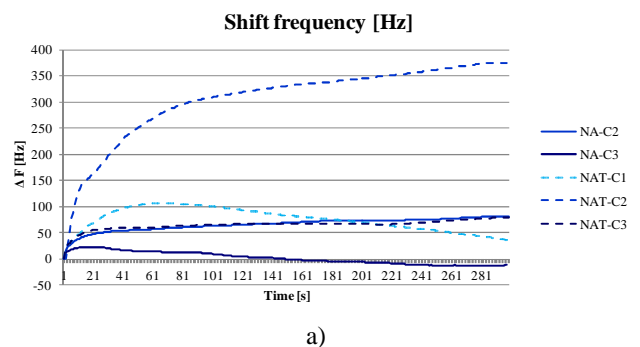
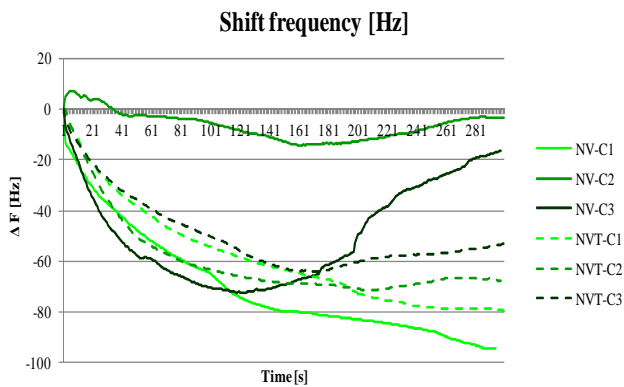


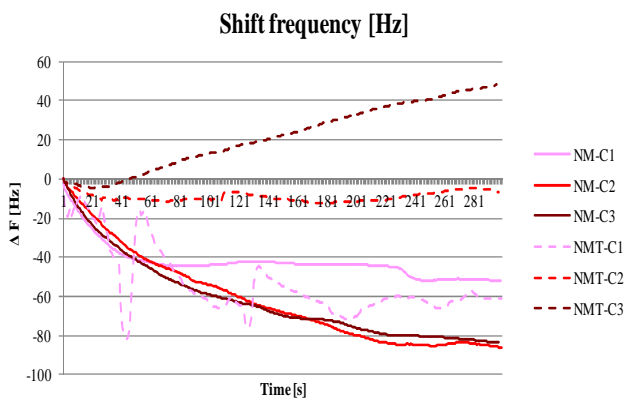
Fig -6: Achieving 1% vol. conc. Al₂O₃ nanofluid
 a) samples from nanofluids after mechanical stirring at 21°C, from right to left: with 1% Al₂O₃ after formulation, with 0.5% Al₂O₃ after one day after formulation, 0.1% Al₂O₃ two days after formulation; b) samples from nanofluids submitted to mechanical vibrations at 21°C, from right to left: with 1% Al₂O₃ after formulation, with 0.5% Al₂O₃ after one day after formulation, 0.1% Al₂O₃ two days after formulation; c) samples from nanofluid with 1% vol. conc. of Al₂O₃ after formulation

One can say that submitting a nanofluid to vibrations has a very good influence on the homogeneity and stability in time comparing to mechanic and magnetic stirring. Only mechanical stirring is not sufficient to obtain a homogeneous nanofluid and magnetic stirring is not totally breaking the agglomerates formed, which affect stability of the nanofluids. A higher temperature (in this case 50°C) has a better influence on the stability of nanofluids comparing to the one obtained at room temperature. **Chart -3** shows the QCM results for the three nanofluids on dispersion techniques (mechanical stirring, vibrations and magnetic stirring at 21°C, respectively 50°C).

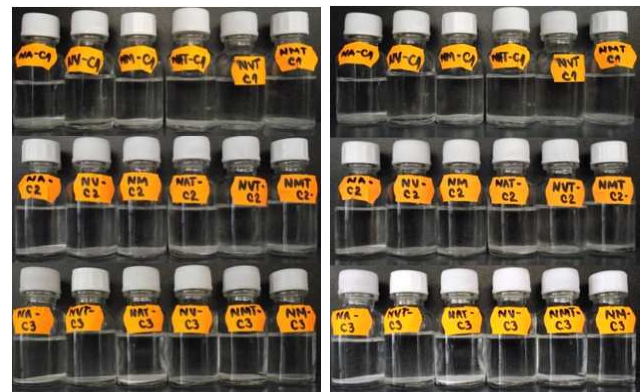




b)

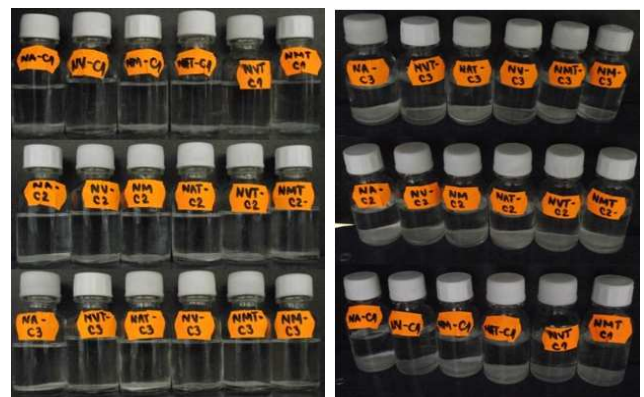


c)



c)

d)



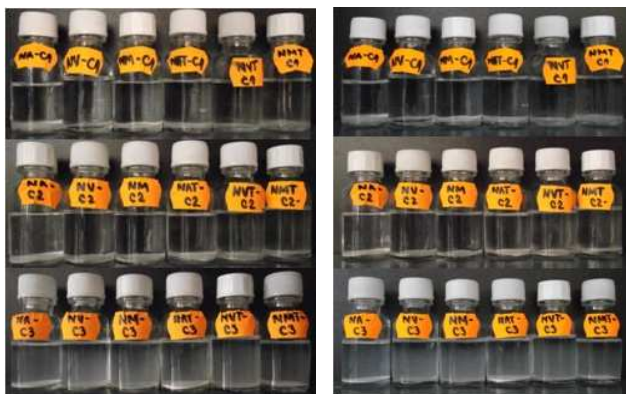
e)

f)

Fig -7: Samples extracted from the Al₂O₃ based nanofluids: a) after one week of formulation; b) after two weeks of formulation; c) after three weeks of formulation; d) after four weeks of formulation; e) after five weeks of formulation; f) after six weeks of formulation

Chart -3: Shift frequency depending on time, for three nanofluids (process type): a) mechanical stirring; b) vibrations; c) magnetic stirring

The samples extracted for visual analysis were stored in dark areas because strong light favors cluster formation. After two – six weeks the samples are as in Fig -7:



a)

b)

4. ENHANCED HEAT TRANSFER ACHIEVED WITH FIVE DIFFERENT CARRIERS

A simulation of the heat transfer achieved was done helped by the reactor station. This simulation aims to evidence the heat transfer in a solar collector. For this, the reactor station was used to test five heat carriers (base fluid of the nanoparticles, antifreeze and three nanofluids). During the experiments the following parameters were monitored:

- time of heating the carrier in the auxiliary system, done by the heating unit;
- time of heat transfer from carrier to water (through the mantle's walls);
- temperature of water and heat carrier during cooling off

The objective is a comparative analysis on the heat transfer between heat carrier and water and then an evaluation of the nanofluids' performance having different concentrations of nanoparticles. The results are compared with the ones obtained in the same conditions for the mixture with 94.6% water and

5.4% glycerin and the antifreeze used in solar panel installations. During the experiments the reactor station was used to determine the heat transfer of nanofluids with different concentrations of nanoparticles. The inner recipient was filled with 8 liters of water and the auxiliary system with 8 liters of nanofluid with 0.1%, 0.5% and 1% vol. concentration of nanoparticles (Fig -8). The nanofluids were heated with the heating unit from 19°C to 50°C. The temperature displayed on the thermometer of the auxiliary system was monitored.

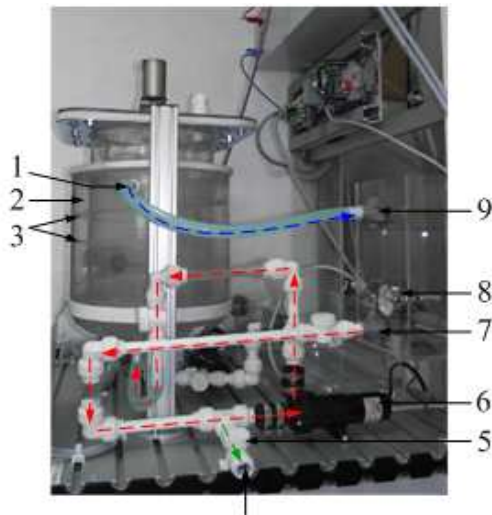


Fig -8: Path of heat carrier from the auxiliary system to the mantle

1 – superior connection; 2 – mantle; 3 – serpentine; 4 – heat carrier evacuation outlet from the auxiliary heating system; 5 – heat carrier exhaust valve; 6 – supply and recirculation pump; 7 – inferior connection to supply the mantle with heat carrier; 8 – thermometer; 9 – inlet for the recovery of the heat agent with low temperature from the mantle.

The first step of this experiment consists in heating the five carriers (mixture with 94.6% water and 5.4% glycerin, antifreeze used in solar panels installations and three nanofluids with different volume concentrations of nanoparticles); these were heated in the auxiliary system by heating unit. The heating times for the five heat carriers are shown graphically in **Chart -4**:

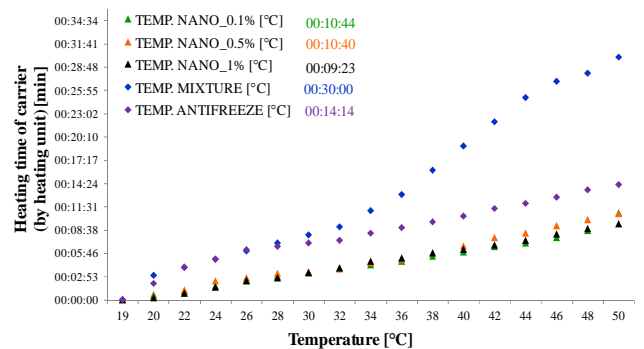


Chart -4: Heating times for five heat carriers (using the heating unit)

As it can be seen in the above chart, the antifreeze heats in approximately 14 minutes and the mixture in almost two-fold. It can not specify with certainty the difference between heating times of nanofluids with 0.1% and 0.5% Al₂O₃; they are very close in value. Nanofluids with concentration of 1% nanoparticles showed the least time for heating, which would be very low power consumption when it is tested in the reactor station, and a rapid rise in temperature by means of solar heat rays for use in solar collectors. The heating process of the five heat carriers is shown schematically in **Fig -9**:

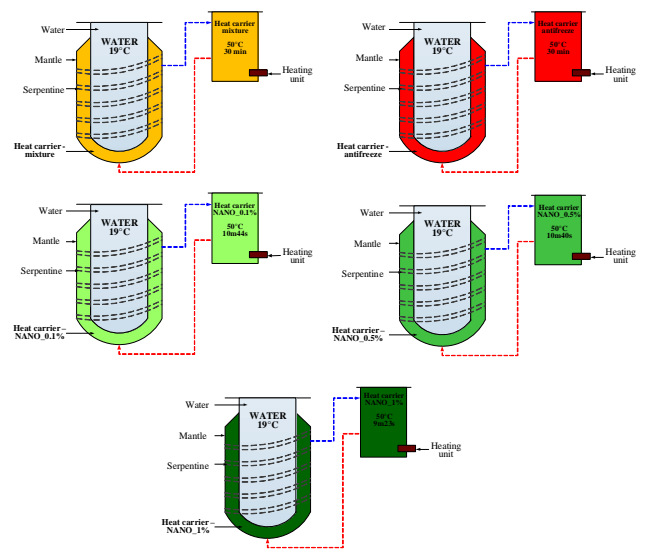


Fig -9: Heating times for five heat carriers

Regarding the heat transfer of the carriers to water in the reactor station, through the mantle's walls (both made out of Veralite - transparent plates based on thermoplastic polyesters produced by extrusion), it was recorded the duration until the water reaches 50°C (thermodynamic equilibrium state between water and heating)

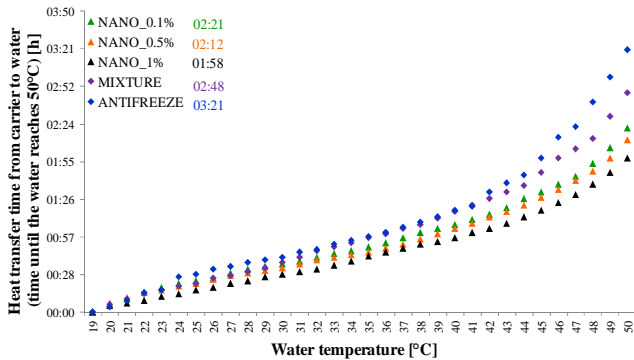


Chart -5: Heat transfer time of five heat carriers

From Chart -5 it can be seen that the nanofluid with highest concentration of nanoparticles gives the fastest heat transfer. Comparing to the mixture of water and 5.4% glycerin and with the antifreeze, the heat transfer curves have a similar trend but it can be observed the improvement in thermal transfer by adding nanoparticles in a base fluid. The heat transfer process is shown schematically in Fig -10:

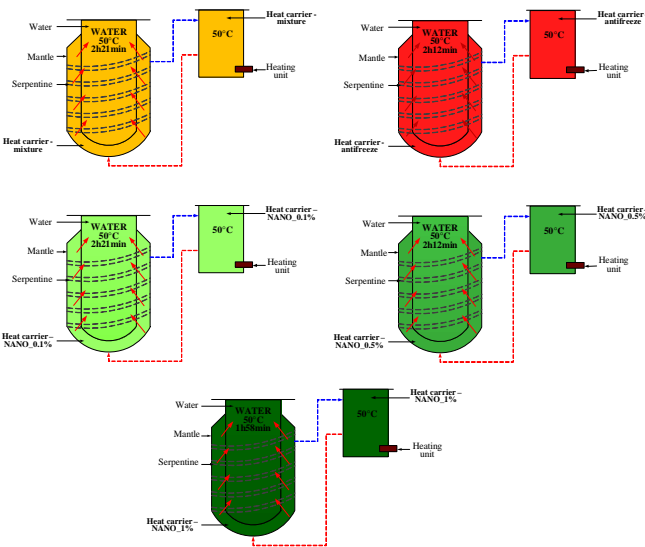


Fig -10: Heat transfer time of five heat carriers

After reaching the thermodynamic equilibrium state, I stopped the recirculation and the heat carriers were left to cool off during 2 hours and 20 minutes.

Keeping the water warm, but also the high temperature of the heat carrier was best achieved using nanofluids with the highest concentration of nanoparticles, as shown in Chart -6. In all cases, the water temperature of the heat carriers decreased faster than that of the water in the inner recipient of the reactor station (Chart -6). When using nanofluids, in the first 20 minutes of cooling, the water temperature rose with

one degree, something that didn't happen when using water-glycerin mixture or antifreeze. A nanofluid with minimum concentration of 0.1% or 0.5% nanoparticles of Al_2O_3 , behave similarly in terms of maintaining the hot water in time. In turn, 1% concentration of nanoparticles has a positive influence on the process of heat transfer. While a temperature of $43^\circ C$ was reached (the lowest of the three nanofluids), it kept hot water at the highest temperature ($39^\circ C$) during the cooling time (Fig -11).

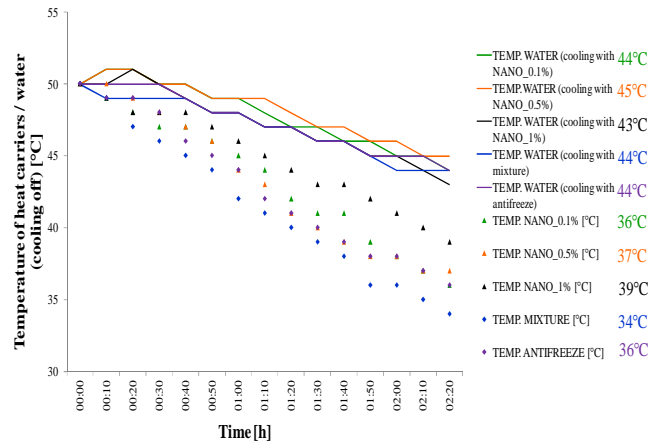


Chart -6: Time evolution of water temperature depending on the temperature of five heat carriers (during cooling off process)

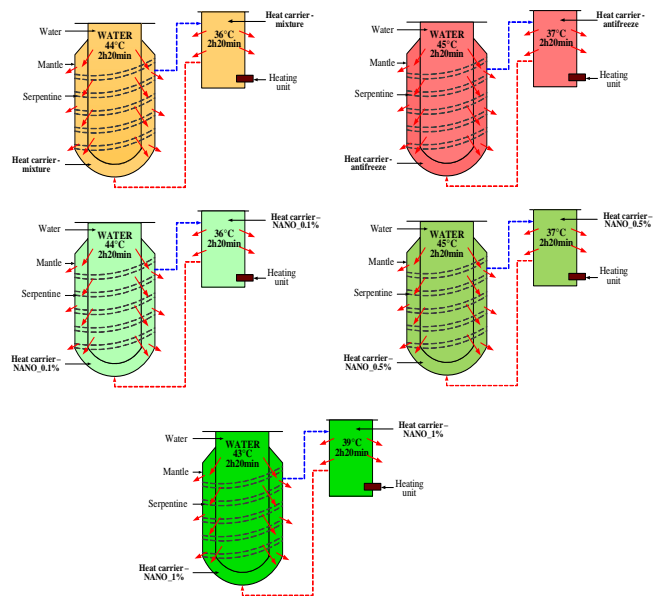


Fig -11: Time evolution of water temperature depending on the temperature of five heat carriers (during cooling off process)

5. DISCUSSION ON ENHANCED HEAT TRANSFER

In the second part of the article a comparative analysis of the heat transfer between a heat carrier and water was made. We followed the thermal transfer properties of the three nanofluids carried out by the three techniques (mechanical stirring, vibration, magnetic stirring) in comparison with the properties of a mixture consisting of 5.4% glycerin and distilled water and an anti-freeze used in the installation with solar panel. It was found that adding an amount of nanoparticles in a heat carrier has a significant influence on the heat transfer through the walls of the reactor body mantle.

Thus, on heating the carriers by heating unit, the antifreeze reached the temperature of 50°C in about 53% of the time in which the mixture of water with 5.4% glycerin heated. But at the time of starting the circulation pump the antifreeze temperature dropped to 36°C, than that of the mixture dropped to 40°C, and during the process of recirculation, the antifreeze temperature stabilized again at 50°C slower than that of the mixture, which is 29 minutes to 22 for the mixture.

In case of nanofluids, starting the recirculation has about the same effect in terms of lowering the temperature and time of stabilization, except that the nanofluid with the highest concentration of nanoparticles (1%) stabilizes at 50°C in the shortest time.

Taking into account that the nanofluid NANO_1% heats up about 30% of the time in which is heated the mixture, namely 35% of the antifreeze heating time, we can say that a higher concentration of nanoparticles dispersed in a carrier fluid, it reduces time spent on heating.

Following the experiments, I found that the anti-freeze heats more rapidly than the water-glycerin mixture, but the heat transfer from the heating agent to the water is faster for the water-glycerin mixture than in the case of the anti-freeze (heats water in a time of 83% of the time in which antifreeze is heating). As for maintaining the water hot water the water-glycerin mixture and antifreeze behave the same.

In terms of heat transfer through the walls of the reactor's mantle, the antifreeze heated the water in 3 hours and 21 minutes. With reference to this figure, we can say again that nanoparticles positively affect heat transfer. The simple addition of 0.1% nanoparticles in a mixture of water with 5.4% glycerin, improved heat transfer with 16.07% as compared to that of the carrier fluid and by about 30% than that of the antifreeze. So, the higher amount of nanoparticles in a nanofluid, the better heat transfer is.

6. CONCLUSIONS AND FURTHER RESEARCH

An extensive research on the parameters that influence the homogeneity and stability of nanofluids was conducted using

distilled water with low concentration of glycerin, as base fluid. Also, three dispersion techniques were applied in order to avoid clusters formation.

Effect of concentration of nanoparticles, temperature, rotational speed and mixing time were systematically investigated. Finally, the samples were analyzed by means of quartz crystal microbalance. The conclusions that can derive from here are:

- Mechanical stirring is an important step in achieving nanofluids by dispersing nanoparticles in a base fluid, preferably with higher viscosity than of water but it is no sufficient to obtain a homogenous and stable nanofluid.
- The process of vibrations has a very good influence on dispersing ultra-fine nanoparticles in a base fluid. It also influences the time-behavior of nanofluid.
- By dispersing the nanoparticles at a higher temperature (in this case 50°C), a more stable nanofluid can be achieved.
- The base fluid with distilled water and 5.4% glycerin does not favor the complete suspension of Al₂O₃ nanoparticles.
- Increasing glycerin concentration but also nanoparticles, the samples extracted while making the nanofluid with 05% volume concentration of Al₂O₃ has some stable areas after 2 hours of vibrations at 21°C.
- Increasing nanoparticle concentration to 1% has a negative influence on the stability and homogeneity of nanofluid.
- Except the graph made for the samples extracted after mechanical stirring at 21°C and after vibrations at 50°C, that have a slight trend in stabilizing after 180s, the rest of the samples show some frequency bounce which means that the nanoparticles are settling, forms clusters which lead to an inhomogeneous nanofluid.
- Due to the sedimentation observed after obtaining the nanofluid with 0.1% Al₂O₃, for the next nanofluids with 0.5%, respectively 1% Al₂O₃ the glycerin concentration was increased to 13%.

The samples were stored for visual analysis (in a dark area in order to avoid sedimentation) and it was observed a sedimentation layer on the bottom of the sample bottles.

Due to the increasing concentration of nanoparticles the time of heat transfer to the water in the reactor body decreased and sedimentation problems and clusters formation were diminished. In terms of maintaining hot water as long as possible, following the experiments made using nanofluids with the highest concentration of nanoparticles (NANO_1%), led to a decrease of up to 39°C in 2 hours and 20 minutes to the next tested heat carrier, with the best results at 37°C (NANO_0.5%).

These novel and important findings issued from this work are expected to provide useful recommendations to formulate

stable nanofluids that could be used as heat carriers in solar panel installations.

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BIOGRAPHIES



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