EXPERIMENTAL RESEARCH ON HEAT TRANSFER OF ALUMINIUM OXIDE NANOFLUIDS

Andreea Kufner, Viviana Filip, Ioana Dulamă
Valahia University of Târgovişte, Doctoral School, 18th Unirii Street, Târgovişte, Romania,
E-mail: kufner_georgiana@yahoo.com,
Valahia University of Târgovişte, Multidisciplinary Research Institute for Science and Technologies, 18th Unirii Street, Târgovişte, Romania, E-mail: v_filip@yahoo.com, dulama_id@yahoo.com

Abstract. *In this paper the process of obtaining nanofluids with 0.1%, 0.5% and 1% concentration of aluminium oxide (Al_2O_3) was studied by mechanical stirring, vibrations and magnetic stirring. The samples extracted during the process were analyzed with the quartz crystal microbalance (QCM), in terms of homogenization and stability. Also, a thermal transfer study with the reactor station and a comparison between the thermal 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 thermal transfer due to the nanoparticles of Al_2O_3.*

Keywords: *nanofluid, mechanical stirring, magnetic stirring, heat transfer*

1. INTRODUCTION

Pure alumina (>99.5%) has been used since the beginning of the '70s, as material for implants, especially for joint prosthesis (mostly hips) and teeth, due to its good mechanical properties and biocompatibility with the tissues.

The advantages of nano-alumina can be seen by comparing the micro and nano alumina particles. The smaller particles offer a higher specific surface for the collisions at molecular level and therefore increase the reactivity, which leads to a better catalyst and reactant.

The nanoparticles of Al_2O_3 used to develop and to study the conductivity of nanofluids have average diameters between 8 and 150nm and the nanofluids have been prepared by direct vaporization in a single step (direct vaporization and nanomaterials' condensation in the base fluid are made to produce stable nanofluids) or by two-step method (the nanoparticles are obtained by different means and then dispersed in a base fluid).

A special attention has been given to the influence nanoparticle volume fraction on the conductivity of nanofluids. Some of the base fluids that have been used in particular were distilled water, ethylene glycol and propylene glycol and seldom 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 size of nanoparticles defines the surface-to-volume ratio, and for the same volume concentration the smaller particles suspensions the higher solid/liquid interface. The nanoparticle size influences the viscosity of nanofluids. Generally, this increases as the nanoparticle volume concentration is increased. Studies regarding the suspensions with the same volume concentrations but with different sizes have shown that viscosity decreases as the nanoparticle size decreases also. This behavior is connected to the structured layers along the solid/liquid interface that makes the nanoparticles move simultaneously with the base fluid. In order to obtain an increase in conductivity nanoparticles of greater size should be used, with a higher conductivity and lower viscosity. The major disadvantage of greater nanoparticles is that the suspensions tend to become unstable. Estimations to the sedimentation speed were computed and it was confirmed that the stability of a suspension can be improved if the solid material density is close to the one of base fluid, if the viscosity of the suspension is high and if the nanoparticle radius is as small as possible.

2. EXPERIMENTAL PROCEDURE

The selected nanoparticles to obtain the nanofluid, have an average size of 10nm (according to the supplier's specifications), a specific surface of 160 m^2/gr and density of 3.7 gr/cm^3 (Figure 1, a). Being very small the nanoparticles are as a very fine white powder (Figure 1, b):

Figure 1. a) TEM image of Al_2O_3 nanoparticles; b) Al_2O_3 nanoparticles, 10nm size

Considering the purchased quantity of Al_2O_3 nanoparticles (500 grams) and in order to obtain the nanofluid in the reactor station, to analyze its capacity of heat transfer, 8 liters are needed, it was decided to make three nanofluids with different volume concentrations of nanoparticles (0.1%, 0.5% and 1%).

Following the experimental results after making the base fluid (distilled water and glycerin), the conclusion was that the mixture with the lowest glycerin concentration (5.4%) was the most stable and homogenous. In terms of temperature and stirrer speed, at 35°C and 700, respectively 2000 rpm the mixture's behavior is homogenous and stable in time.

From the literature some information about these parameters 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) [4] and at room temperature [5], although there are some studies that report the analyses of nanofluids at different temperatures (20°C, 35°C and 50°C) [6]. When referring to time, this varies a lot according to the amount of nanofluid that is intended to be achieved [7], [8], [9], [10].

To achieve the nanofluid with 0.1% volume concentrations, the base fluid consists of 94.55% distilled water and 5.35% glycerin.

The techniques used to achieve a homogeneous and stable in time nanofluid are mechanical stirring, mechanical vibration and magnetic stirring. The process was developed continuously as it is described below.

Mechanical stirring: distilled water together with glycerin and nanopowder were mixed in the reactor station (Figure 2, a), firstly at room temperature 21°C, and secondly at 50°C, maximum rotational speed of 3300 rpm, for 2 hours after I withdrew a sample to be analyzed with the quartz microbalance – QCM.

To avoid higher clusters a sieve with very small mesh wire fixed to a circular frame (Figure 2, b) was used. In Figure 2, c can be seen the solid/liquid interfaces as the Al_2O_3 nanoparticles are dispersed in the base fluid (water glycerin mixture).

Figure 2. Process of nanoparticle dispersion and mechanical stirring
a) reactor station; b) nanoparticle dispersion in base fluid; c) solid/liquid interface formation

Mechanical vibration: from the reactor station, where the mechanical stirring took place, I withdrew 200ml nanofluid that was submitted to mechanical vibration (Figure 3) during 2 hours. The device operates with rechargeable batteries NiMH AA HR6, 1.2V, 2600mAh. The calculated power of the device is 3.12W. A sample was withdrawn for QCM analysis and the remaining amount was submitted to magnetic stirring for 2 hours after which I withdrew sample NM-C1.

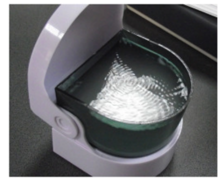

Figure 3. Nanofluid submitted to mechanical vibration

The device for *magnetic stirring* (Figure 4) consists of a motor that rotates a disc on which two magnets are mounted. On the surface above the disc with magnets I placed a recipient with the amount of nanofluid and in the nanofluid I put another magnet. When starting the motor, 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.

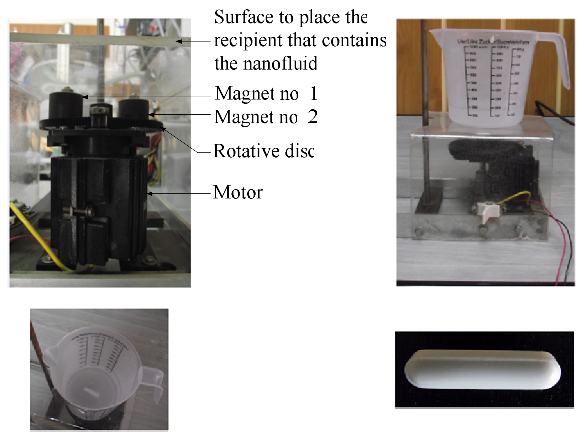

Figure 4. Device for magnetic stirring, magnet coated with polytetrafluoroethylene (teflon)

3. EXPERIMENTAL RESULTS

The first nanofluid consists of 7.56 liters of distilled water, 0.43 liters of glycerin and 29.63 grams of Al_2O_3 nanopowder. These were stirred mechanically in the reactor station at 21°C, at maximum rotational speed of 3300rpm, for 2 hours and sample NA-C1 was withdrawn. 200ml nanofluid was submitted to mechanical vibrations for two hours and then NV-C1 sample was withdrawn. The amount left was transferred to the recipient from Figure 6 and submitted to magnetic stirring for two hours. The sample NM-C1 was withdrawn and together with the other samples were analysed using the quartz microbalance.

The above procedure was repeated at 50°C and three more samples were withdrawn. The parameters are shown in Table no. 1 and the result of QCM analyses are presented graphically in Figure 5 and 6.

The samples are named as follows:

- NA-C1: sample withdrawn from nanofluid with 0.1% Al_2O_3 vol. concentration, after mechanical stirring at 21°C;
- NV-C1: sample withdrawn from nanofluid with 0.1% Al_2O_3 vol. concentration, after mechanical vibration at 21°C;
- NM-C1: sample withdrawn from nanofluid with 0.1% Al_2O_3 vol. concentration, after magnetic stirring at 21°C;
- NAT-C1:sample withdrawn from nanofluid with 0.1% Al_2O_3 vol. concentration, after mechanical stirring at 50°C;
- NVT-C1: sample withdrawn from nanofluid with 0.1% Al_2O_3 vol. concentration, after mechanical vibration at 50°C;
- NMT-C1sample withdrawn from nanofluid with 0.1% Al_2O_3 vol. concentration, after magnetic stirring at 50°C;

For the nanofluid with 0.5% volume concentration Al_2O_3, C2 notation was used and for 1% volume concentration Al_2O_3, it was used C3 notation.

Table 1. Samples withdrawn during achieving the nanofluid with 0.1% volume concentration of Al_2O_3

No.	Sample	Vol. concentration			Parameters						
		Water [%]	Glycerin [%]	Al_2O_3 [%]	Mechanic			Vibration		Magnetic	
					Rotative 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

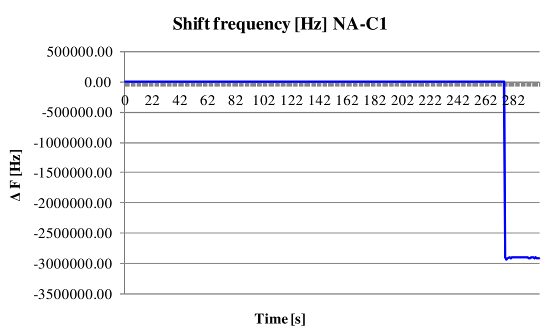

Figure 5. Shift frequency depending on time for the nanofluid with 0.1% vol. concentration Al_2O_3 mechanically stirred at 21°C

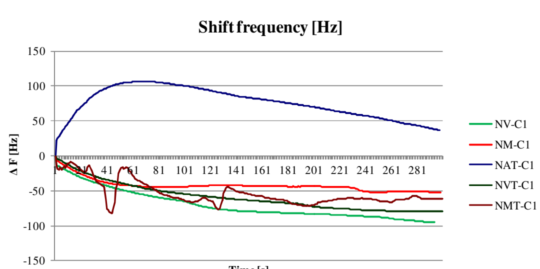

Figure 6. Shift frequency depending on time, for different samples of nanofluid with 0.1% vol. concentration of Al_2O_3 obtained by mechanical stirring, mechanic vibration and magnetic stirring at 21°C, respectively 50°C

Mechanical stirring of 0.1% concentration of Al_2O_3 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 (Figure 5), which means the nanoparticules haven't been completely dispersed and their tendency is to form sediments, hence clusters.

From Figure 6, it can be seen that 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 mixtures of water and glycerin, we can consider that after 180s can draw conclusions about the behavior of nanofluids. The content of glycerin and of nanoparticles is estimated by subtracting the QCM frequency.

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% Al_2O_3, 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.

Considering the results obtained after QCM analyses for the nanofluid with 0.1% vol. concentration Al_2O_3 and the fact that the specific field literature mentions about researches on nanofluids with base fluid consisting of distilled water of mixture of 50/50 water and a more viscous fluid (e.g. ethylene glycol), I've decided to increase the volume concentration of glycerin for the next nanofluid having 0.5% vol. concentration of Al_2O_3. For this, I've been considering the QCM experimental results for the base fluid with 13.4% glycerin. The concentrations of water and glycerin for the nanofluid with 0.5% vol. concentration of Al_2O_3 are shown in Table 2 and the QCM analyses and graphically presented in Figure 7.

Table 2. Samples withdrawn during achieving the nanofluid with 0.5% volume concentration of Al_2O_3

No	Sample	Concentration			Parameters						
		Water [%]	Glycerin [%]	Al_2O_3 [%]	Mechanic			Vibration		Magnetic	
					Rotative speed [rpm]	Temp. [°C]	Time [min]	Power [W]	Time [min]	Power [W]	Time [min]
1	NA-C2	86.13	13.38	0.5	3300	21	120	-	-	-	-
2	NV-C2	86.13	13.38	0.5	-	-	-	3.12	120	-	-
3	NM-C2	86.13	13.38	0.5	-	-	-	-	-	60	120
4	NAT-C2	86.13	13.38	0.5	3300	50	120	-	-	-	-
5	NVT-C2	86.13	13.38	0.5	-	-	-	3.12	120	-	-
6	NMT-C2	86.13	13.38	0.5	-	-	-	-	-	60	120

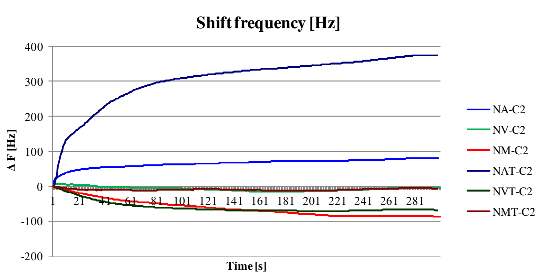

Figure 7. Shift frequency depending on time, for different samples of nanofluid with 0.5% vol. concentration of Al_2O_3 obtained by mechanical stirring, mechanic vibration and magnetic stirring at 21°C, respectively 50°C

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 Al_2O_3 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.

For the nanofluid with 1% vol. concentration, the quantities of water and glycerin were decreased with 0.25% each. The same procedures for dispersing the nanoparticles were applied, the parameters controlled and monitored during the process are according to Table 3 and the QCM results are shown graphically in figure 8 were a similar evolution can be observed for the samples withdrawn after the mechanical stirring at 21, respectively la 50°C from the nanofluids with 0.5, respectively 1% Al_2O_3. But the negative influence of the increased concentration of the nanoparticles can also be observed.

Table 3. Samples withdrawn during achieving the nanofluid with 1% volume concentration of Al_2O_3

No	Sample	Concentration			Parameters						
		Water [%]	Glycerin [%]	Al_2O_3 [%]	Mechanic			Vibration		Magnetic	
					Rotative speed [rpm]	Temp. [°C]	Time [min]	Power [W]	Time [min]	Power [W]	Time [min]
1	NA-C3	85.88	13.13	1	3300	21	120	-	-	-	-
2	NV-C3	85.88	13.13	1	-	-	-	3.12	120	-	-
3	NM-C3	85.88	13.13	1	-	-	-	-	-	60	120
4	NAT-C3	85.88	13.13	1	3300	50	120	-	-	-	-
5	NVT-C3	85.88	13.13	1	-	-	-	3.12	120	-	-
6	NMT-C3	85.88	13.13	1	-	-	-	-	-	60	120

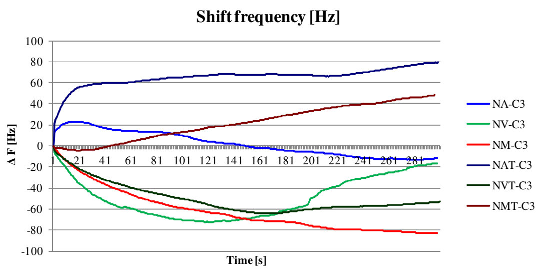

Figure 8. Shift frequency depending on time, for different samples of nanofluid with 1% vol. concentration of Al_2O_3 obtained by mechanical stirring, mechanic vibration and magnetic stirring at 21°C, respectively 50°C

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.

Regarding the dispersions techniques used to obtain the nanofluids and also the QCM analyses, 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, as it can be seen in Figure 9.

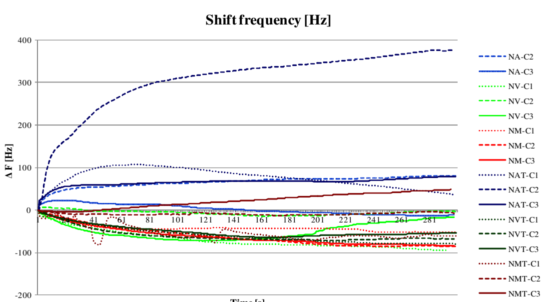

Figure 9. Shift frequency depending on time, fot three nanofluids (volume concentrations of 0.1%, 0.5% and 1% Al_2O_3, achieved by mechanical stirring, vibrations and magnetic stirring at 21°C, respectively 50°C)

4. EXPERIMENTAL RESULTS ON HEAT TRANSFER OF NANOFLUIDS WITH 0.1%, 0.5% AND 1% VOLUME CONCENTRATION OF AL_2O_3 NANOPARTICLES

The heat transfer simulation achieved by using water through a heat carrier (nanofluid) in a solar collector was done with the reactor station. 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 nanprticles. 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% vol. concentration of nanoparticles. The nanofluid was heated with the heating unit from 19°C to 50°C.

The temperature displayed on the thermometer of the auxiliary system was monitored. It reached 50°C in approximately 10 minutes and 44 seconds. When the nanofluid reached 50°C the recirculation pump was turned on. The nanofluid is evacuated by the bottom and discharged at the top so that the mantle in continuously filled.

When the recirculation started (the heat transfer started), the nanofluid's temperature dropped to 41°C as the amount in the mantle was 19°C as the water in the inner recipient. During recirculation I recorded information on the evolution of temperature of water and nanofluid. The water from the inner recipient reached 50°C in 2 hours and 21 minutes. These are shown in the graph in Figure 10:

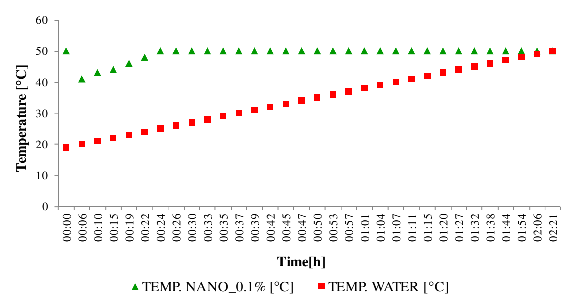

Figure 10. Time evolution of water temperature (that receives heat) and temperature of the heat carrier – NANO_0.1% (that gives heat)

The recirculation process was stopped when the water in the inner recipient reached 50°C. Below is shown the temperature evolution of the water and heat carrier during cooling off.

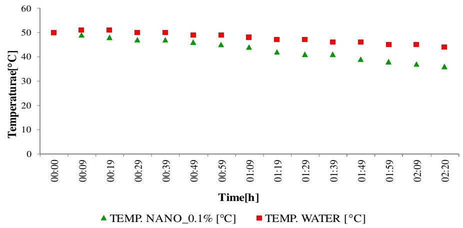

Figure 11. Time evolution of water temperature depending on heat carrier temperature (during cooling off)

It is noted that the cooling process of the water is slower than the one of heat carrier – NANO_0.1%.

The experiment on nanofluid with 0.5% vol. concentration (NANO_0.5%) took place in the same conditions as for the one with 0.1% vol. concentration. The heat carrier NANO_0.5% was heated by heating unit from 19°C to 50°C. The process lasted for about 10 minutes and 40 seconds. After heat carrier NANO_0.5% reached 50°C the recirculation pump was turned on. Its temperature dropped to 36°C (compared to NANO_0.1% that dropped to 41°C). During recirculation I recorded information on the evolution of water and nanofluid NANO_0.5% temperature. These are shown in the chart from Figure 12 and as it can be seen, the water from the inner recipient reached 50°C in 2 hours and 12 minutes.

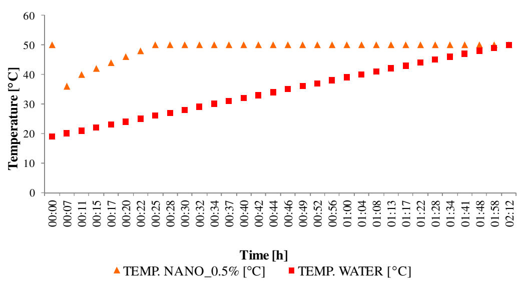

Figure 12. Time evolution of water temperature (that receives heat) and temperature of the heat carrier – NANO_0.5% (that gives heat)

The recirculation process was stopped when the water in the inner recipient reached 50°C. Below is shown the temperature evolution of the water and heat carrier NANO_0.5% during cooling off (Figure 13). As in the case of heat carrier NANO_0.1%, it can be observed that the cooling process from the inner recipient is slower than for the heat carrier NANO_0.5%. The data was recorded during 2 hours and 20 minutes duration in which the water temperature dropped to 44°C when using NANO_0.1%, and to 45°C when using NANO_0.5%. The NANO_0.1% heat carrier temperature dropped to 36°C and the temperature of NANO_0.5% dropped to 37°C. In both cases, in the first 30 minutes of cooling off, the temperature of the water in the inner recipient increases to 51°C than it drops slowly.

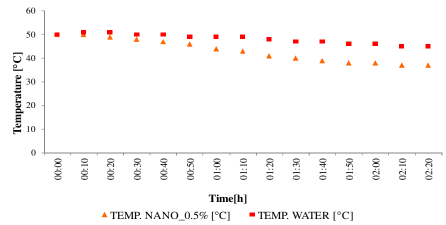

Figure 13. Time evolution of water temperature depending on heat carrier temperature (during cooling off)

Also in this case it is noted that the cooling process of the water is slower than the one of heat carrier – NANO_0.5% and the temperature drops are similar to the case of using NANO_0.1%.

The same experimental procedure was applied for the last nanofluid with 1% volume concentration of Al_2O_3 nanoparticles. This was heated by the heating unit from 19°C to 50°C. The process lasted for about 9 minutes and 23 seconds. After NANO_1% heat carrier reached 50°C the recirculation pump was turned on. Its temperature dropped to 40°C since the amount in the mantle had 19°C as the water in the inner recipient. During recirculation I recorded information on the evolution of temperature of water and nanofluid NANO_1%. These are shown in the chart from Figure 14 and as it can be seen, the water from the inner recipient reached 50°C in 1 hours and 58 minutes.

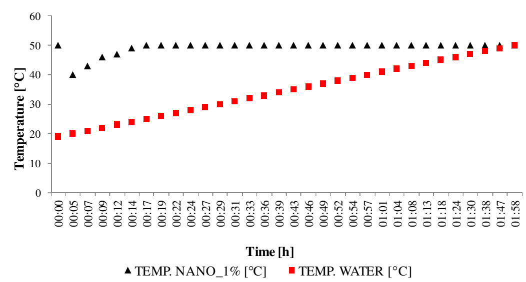

Figure 14. Time evolution of water temperature (that receives heat) and temperature of the heat carrier – NANO_1% (that gives heat)

The recirculation process was stopped when the water in the inner recipient reached 50°C. In Figure 15 we can see the temperature evolution of the water and heat carrier NANO_1% during cooling off.

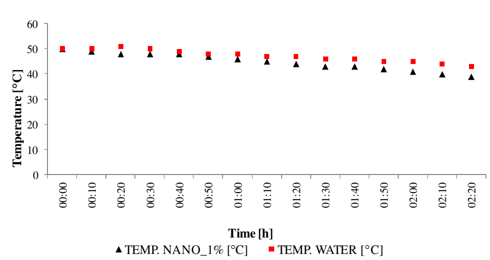

Figure 15. Time evolution of water temperature depending on heat carrier temperature (during cooling off)

As in the previous cases it can be noted that the cooling process of the water is slower than the one of heat carrier – NANO_1%. In the first 20 minutes the water temperature is maintained at 50°C, after that it increases by 1 degree for only 10 minutes. The data was recorded during 2 hours and 20 minutes, duration in which the water temperature dropped 43°C and the heat carrier temperature dropped to 39°C.

5. COMPARATIVE ANALYSIS BETWEEN THE HEAT TRANSFER ACHIVED WITH MIXTURE BASED ON 5.4% GLYCERIN, ANTIFREEZE AND NANOFLUIDS WITH 0.1%, 0.5% AND 1% VOLUME CONCENTRATION OF AL_2O_3 NANOPARTICLES

The objective of this analysis is to monitor the heating and cooling time of the heat carriers and the time of heat transfer from heat carrier to water in the reactor station and to select the optimum heat carrier to test it in a solar collector.

The first step of this experiment consists in heating these 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 Figure 16:

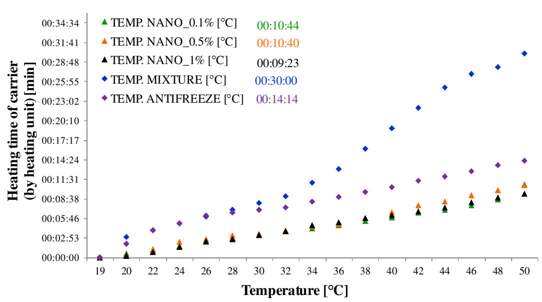

Figure 16. Heating times for five heat carriers (using the heating unit)

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% Al_2O_3, 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 Figure 17:

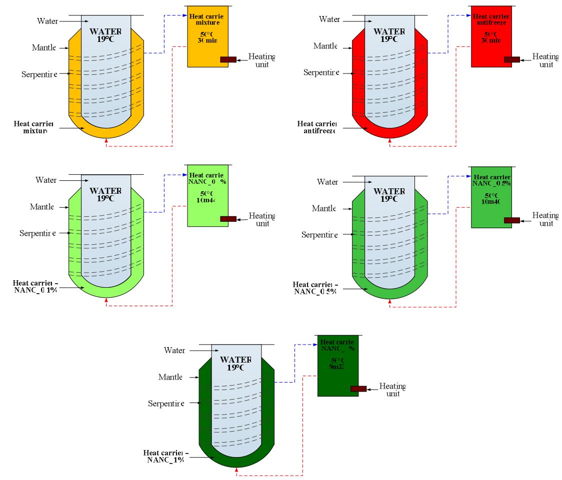

Figure 17. Heating times for five heat carriers

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)

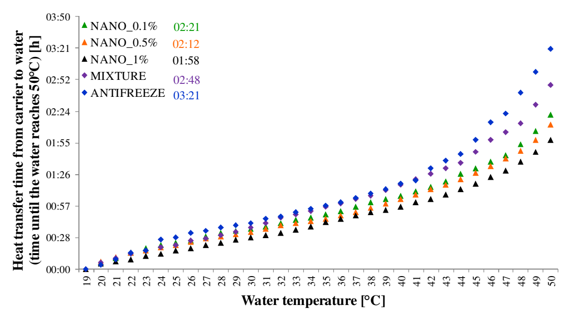

Figure 18. Heat transfer time of five heat carriers

From Figure 18 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 Figure 19:

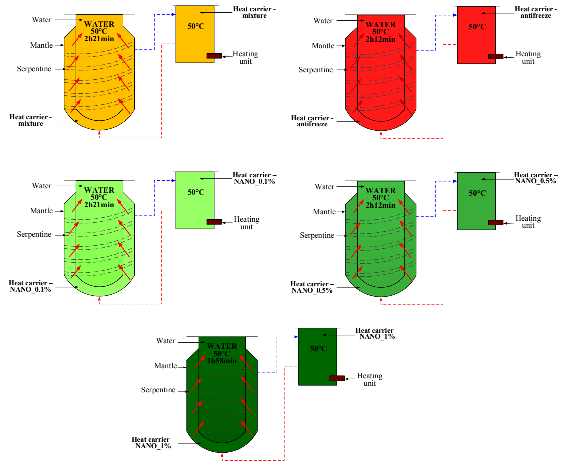

Figure 19. Heat transfer time of five heat carriers

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 Figure 20.

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 (Figure 21). 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% nanoparticles, or 0.5% 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°C was reached (the lowest of the three nanofluids), it kept hot water at the highest temperature (39°C) during the cooling time.

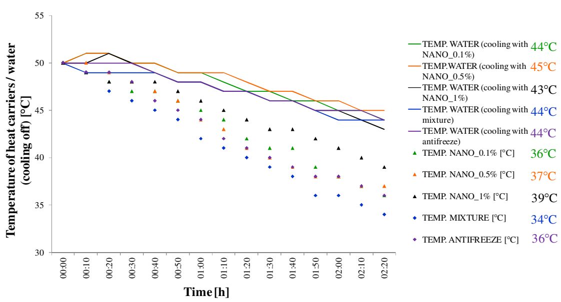

Figure 20. Time evolution of water temperature depending on the temperature of five heat carriers (during cooling off process)

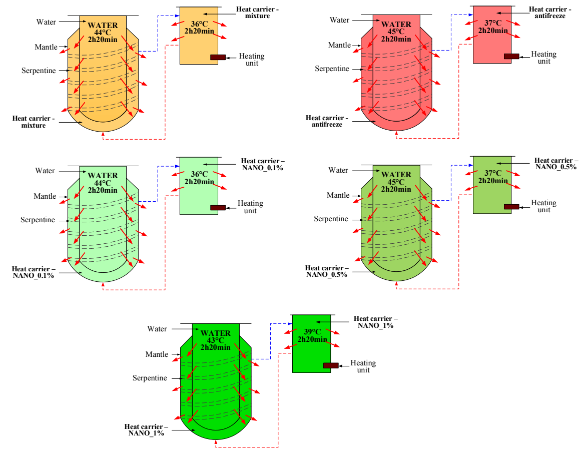

Figure 21. Time evolution of water temperature depending on the temperature of five heat carriers (during cooling off process)

6. CONCLUSIONS

In this article the parameters to achieve nanofluids were determined and also the dispersion techniques to minimize the formation of any nanoparticle agglomerate (clusters).

Based on the curves resulting from QCM analysis we can conclude firstly, that mechanical agitation is an important process of dispersing nanoparticles in a base fluid, preferably having a viscosity greater than water, but this process is sufficient to obtain a homogeneous and stable in time nanofluid. The base fluid consisting of distilled water and 5.4% glycerin does not favor the complete suspension of Al_2O_3 nanoparticles.

The curves based on the QCM analyses for the samples of nanofluid with lowest concentration of nanoparticles (0.1%), that were submitted to vibrations and magnetic stirring show some unstable areas, regardless the temperature of the process. By increasing the concentration of glycerin but also nanoparticles, the samples withdrawn during obtaining nanofluids with 0.5% vol. concentration of Al_2O_3, show some stable areas after two hours of mechanical vibrations but also after magnetic stirring at 21°C. While increasing the concentration of the nanoparticles to 1%, a negative influence on the homogeneity of the nanofluids could be observed. Also in this case, mechanical stirring is not sufficient to achieve a nanofluid, it serves as a process for uniformly dispersing the nanoparticles, and as pre-stage of vibration. With the exception of the samples withdrawn after magnetic stirring at 21°C and mechanical vibrations at 50°C that have a slight stabilization after 180s, the remaining samples show some frequency bounces meaning that the nanoparticles are settling, and thus forming agglomerates and an inhomogeneous nanofluid.

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.

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.

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%).

7. REFERENCES

[1] V. Sridhara și L. N. Satapathy, „Al2O3-Based Nanofluids: a review," Nanoscale Research Letters, ISSN: 1556-276X, vol. 6, p. 456, 2011.

[2] J. H. Lee, K. S. Hwang, S. P. Jang, B. H. Lee, J. H. Kim, U. S. Choi Stephen și C. J. Choi, „Effective Viscosities and Thermal Conductivities of Aqueous Nanofluids Containing Low Volume Concentrations of Al2O3 Nanoparticles," International Journal of Heat and Mass Transfer, ISSN: 0017-9310, vol. 51, nr. 11-12, pp. 2651-2656, 2008.

[3] E. V. Timofeeva, Gavrilov, A. N., McCloskey, J. M. și Y. V. Tolmachev, „Thermal Conductivity and Particle Agglomeration in Alumina Nanofluids: Experiments and Theory," Physical review. E, Statistical, nonlinear, and soft matter physics, ISSN: 1539-3755, vol. 76, nr. 1, pp. 061203.1-061203.16, 2007.

[4] X. Wang, X. Xu și U. S. Choi Stephen, „Thermal Conductivity of Nanoparticle - Fluid Mixture," Journal of Thermophysics and Heat Transfer, ISSN: 0887-8722, vol. 13, nr. 4, pp. 474-480, 1999.

[5] M. P. Beck, Y. H. Yuan, P. Warrier și A. S. Teja, „The effect of particle size on the thermal conductivity of alumina nanofluids," Journal of Nanoparticle Research, ISSN: 1388-0764, vol. 11, nr. 5, pp. 1129-1136, 2009.

[6] I. Tavman, A. Turgut, M. Chirtoc, H. P. Schuchmann și S. Tavman, „Experimental Investigation of Viscosity and Thermal Conductivity of Suspensions Containing Nanosized Ceramic Particles," Archives of Materials Science and Engineering, ISSN: 1897-2764, vol. 34, nr. 2, pp. 99-104, 2008.

[7] P. C. Mukeshkumar, J. Kumar, S. Suresh și K. Praveen babu, „Experimental Study on Parallel and Counter Flow Configuration of a Shell and Helically Coiled Tube Heat Exchanger Using Al2O3 / Water Nanofluid," Journal of Materials and Environmental Science, ISSN: 2028-2508, vol. 3, nr. 4, pp. 766-775, 2012.

[8] A. Jomphoak, T. Maturos, T. Pogfay, C. Karuwan, A. Tuantranont și T. Onjun, „Enhancement of Thermal Conductivity with Al2O3 for Nanofluids," Journal of Research and Applications in Mechanical Engineering, ISSN: 2229-2152, vol. 1, nr. 1, pp. 3-5, 2011.

[9] O. Zeitoun și M. Ali, „Nanofluid impingement jet heat transfer," Nanoscale Research Letters, ISSN: 1556-276X, vol. 7, nr. 139, pp. 1-13, 2012.

[10] D. W. Oh, A. Jain, J. K. Eaton, K. E. Goodson și J. S. Lee, „Thermal Conductivity Measurement and Sedimentation Detection of Aluminum Oxide Nanofluids by Using the 3ω Method," International Journal of Heat and Fluid Flow, ISSN: 0142-727X, vol. 29, nr. 5, pp. 1456-1461, 2008.

This work was supported by the Operational Programme for Human Resources Development 2007-2013. Priority Axis 1 "Education and training in support of economical growth and social development based on knowledge". Major area of intervention 1.5. "Doctoral and postdoctoral programs in support of research". Project title: "Doctoral preparing of excellence for the knowledge society PREDEX". POSDRU/CPP 107/DMI1.5/s/77497