SVEUČILIŠTE U ZAGREBU
FAKULTET KEMIJSKOG INŽENJERSTVA I TEHNOLOGIJE
SVEUČILIŠNI DIPLOMSKI STUDIJ

Antonio Alcázar López

PREPARATION AND CHARACTERIZATION OF OIL BASED NANODISPERSIONS AS HEAT TRANSFER FLUIDS

DIPLOMSKI RAD

Voditelj rada: prof. dr. sc. Ante Jukić

Članovi ispitnog povjerenstva:

prof. dr. sc. Ante Jukić
dr. sc. Fabio Faraguna
prof. dr. sc. Sanja Lučić Blagojević

Zagreb, lipanj 2018.

Antes que nada, agradecer a mis padres por permitirme estudiar donde quisiera y confiar en mí, a pesar de la distancia.

Muchas gracias Dr. sc. Fabiu Faraguni por la paciencia, ayuda y muchos asuntos que me ayudaron enormemente a comprender cosas más allá de este trabajo y me inspiraron a pensar.

Muchas gracias a este país y a su gente por acogerme.

HVALA!

ABSTRACT

Preparation and characterization of oil based nanodispersions as heat transfer fluids

Heat transfer fluids are key elements in any industry where heat source is required. Because of its importance in the industry recently, it has been developed a new kind of fluids called nanofluids. These are conventional heat transfer fluids with nanoparticles added. Last nanoparticles allow nanofluid to behave as a fluid while also their thermophysical properties are enhanced.

The aim of this master's final project consists of the preparation and selection of nanofluids, whose purpose is to be used as quenching heat transfer fluid or metal working fluid. Therefore, the study will be based on the selection of those mixtures whose characteristics of thermal conductivity and stability are the best.

In a first phase, the experimental work of fluid preparation will be carried out and data of the characteristics will be collected, for later, in the second phase, we will select that mixture that obtains the best results.

Content

1. Introduction

The heat transfer fluids are basic elements in industry, where a heat transfer is necessary. Recently, a series of working fluids called nanofluids have been developed. The nanofluids are characterized by nano-sized particles added; these nanoparticles allow the nanofluid to behave like a fluid, while improving its thermal physical properties such as convection, viscosity and conductivity.

Therefore, the need arises to carry out a study about art of nanofluids, analysis of their properties, as well as applications of these nanofluids now and in the future.

The development of nanofluids which have high surface-to-volume ratio compared with conventional flow system, represent a strong interest for the requirement of enhancing heat transfer. Therefore, the management of thermal convection, which is the most important heat transfer mode, has been widely investigated. It is recognized that the main factor influencing heat transfer efficiency of thermal convection is the thermal conductivity of heat transfer fluids. Low thermal conductivity of conventional fluids, such as water, oil and ethylene glycol is a primary limitation in the development of energy-efficient heat transfer medium. [1]

The procedure carried out begins with the synthesis of the polymer surfactants, but this task is not included in this final master project. Obtained surfactants are then mixed with a certain amount of oil. To obtain a nanofluid, nanoparticles are added to the mentioned mixture and mixed with ultrasonic mixer. In this thesis non-functionalized and oxidized multiwall carbon nanotubes are used as nanoparticles. Visual stability, rheological and thermal properties are studied to determine which of the two is the most stable.

Once the mixture is made, the fluid is divided into five test specimens, in order to be able to take samples under the same conditions on days 0, 1, 4, 7, 14 after mixing. In this way, we can study the evolution of its stability. In turn, photographs of all the specimens will be taken both in natural light and against light in order to study the evolution of the precipitation of nanoparticles in the fluid, then, we will do the absorbance tests to determine the concentration, the rheological tests to know the viscosity and the thermal conductivity tests. With all this data we can determine which of prepared nanofluids has the best properties.

2. Theoretical part

2.1. Nanofluid

Nanofluids are a relatively new class of fluids, which consist of a base fluid with nano-sized particles (1–100 nm) suspended within them. With such ultrafine nanoparticles, nanofluids can flow smoothly in a micro channel without clogging and the size of the heat transfer system can be reduced for the use of nanofluids with high heat transfer efficiency. [1]

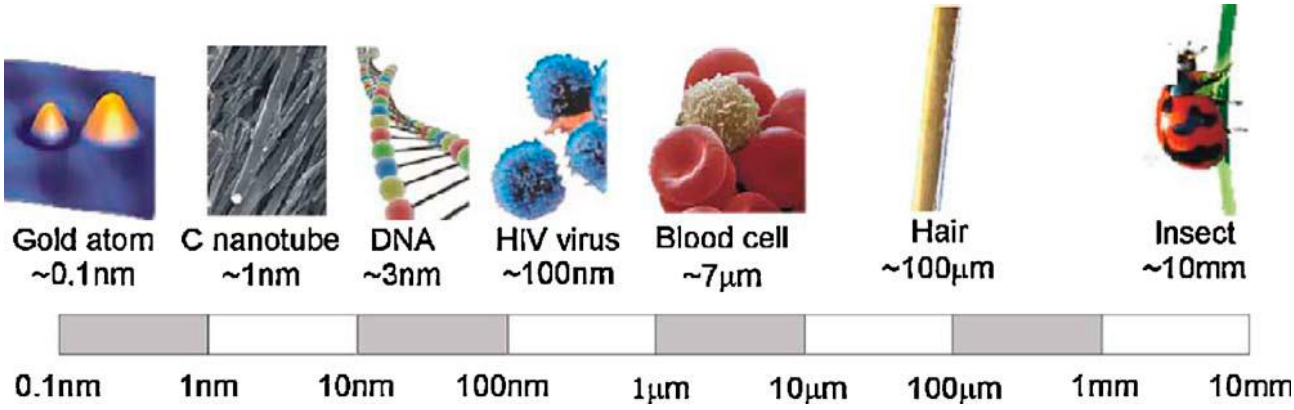

Figure 2-1 Length scale and some examples related [2]

Usually nano-particles are metal or metal oxide based; they modify the properties of viscosity and conductivity, among other characteristics. Nanoparticles have often been used to prepare nanofluids reported in literature are metallic particles or non-metal particles.

Nanotechnology is being used or considered for use in many applications targeted to provide cleaner, more efficient energy supplies and uses. While many of these applications may not affect energy transmission directly, each has the potential to reduce the electricity´s need, petroleum distillate fuel, or natural gas that, otherwise, would be moved through energy transmission system. More efficient energy generation and use may decrease the amount of construction, maintenance, repair, and decommissioning activities. Examples of how nanotechnology may be integrated into each of these technological areas are highlighted in the following specific applications [3]: engine cooling, engine transmission oil, in diesel electric generator as jacket water coolant, boiler exhaust flue gas recovery, heating and cooling of buildings, cooling of electronics, cooling of welding, nanofluids in transformer cooling oil, nuclear systems cooling, solar water heating, nanofluids in drilling, refrigeration (domestic refrigerator, chillier), high-power lasers, microwave tubes, biomedical applications, drilling, lubrications, thermal storage, drag reductions

The base fluids commonly used are water, oil, acetone and ethylene glycol. Generally, the thermal conductivity of solid is typically higher than liquid´s conductivity (Table 1).

Table 1 Description of thermal conductivity of additives and base fluids

Material		Thermal conductivity (W/mK)
Metallic solids	Cu	401
	Al	237
	Ag	428
	Au	318
	Fe	83.5
Nonmetallic	Al_2O_3	40
	CuO	76.5
	Si	148
	SiC	270
	CNTs	~3000(MWCNTs) ~ 6000(SWCNTs)
Base fluids	H_2O	0.613
	Ethylene glycol	0.253
	Engine oil (EO)	0.145

2.2. Metal working fluids

In various manufacturing processes, metalworking fluids (MWFs) are applied to ensure work piece quality, to reduce tool wear, and to improve process productivity. The specific chemical composition of an applied MWF should be strongly dependent on the scope of application. Even small changes of the MWF-composition can influence the performance of MWFs in manufacturing processes considerably. Besides defined variations of the composition, the MWF-chemistry furthermore changes over the service life of the fluid. This project presents the current state of the art regarding the assumed working mechanisms of MWFs including the effects of desired and undesired changes of the MWF properties.

Besides the general functionality of MWFs, which includes the ability to cool and to flush the contact zone between tool and work piece, decisive effects which improve the performance of MWFs are based on chemical working mechanisms. Even though the use of MWFs has a long tradition, not all of the mostly empirically obtained effects of MWFs are fully understood until today. Furthermore, the model-based theories dealing with potential working mechanisms are still discussed very controversially.

Figure 2-2 Metal working fluids [4]

The tribological systems “machining” and “forming” are characterized by the surfaces of a tool and a workpiece that are in moving contact together with an intermediate medium (MWF) which significantly influences the tribological conditions.[Figure 2-3] gives an overview regarding the tribological system and the relevant physical and chemical aspects [5].

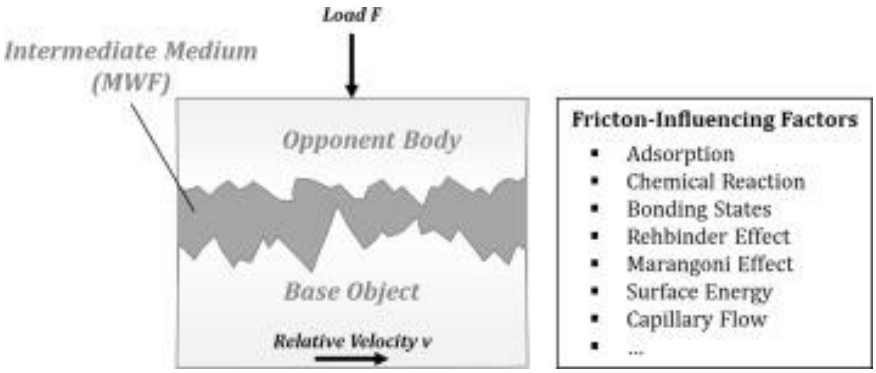

Figure 2-3 Tribological system [5]

During machining, the most likely effects are highlighted:

Rehbinder effect and microcracks: implies a relation between the free energy of a surface which is generated in a machining process and the strength of the solid. In the early 20th century, Griffith investigated “The Phenomena of Rupture and Flow in Solids” (at e.g. metal and glass) and established a quantitative relation in case of cracks:

$$\sigma = const \sqrt{\frac{\epsilon_\gamma \gamma_\delta}{L_c}} \quad (1)$$

Equation 1 Fracture stress

Where σ_s=ultimate strength (fracture stress), E_γ=Young modulus, γ_s=surface free energy per unit area and L_c=length of an initial surface crack.

Surface free energy and surface tension: An approach to describe the wettability of MWFs at metal surfaces is the analysis of the surface free energy and the surface tension by measuring the contact angle Θ. The specific surface free energy and surface tension between phases in contact are used to explain wetting processes in the thermodynamic adhesion theory.

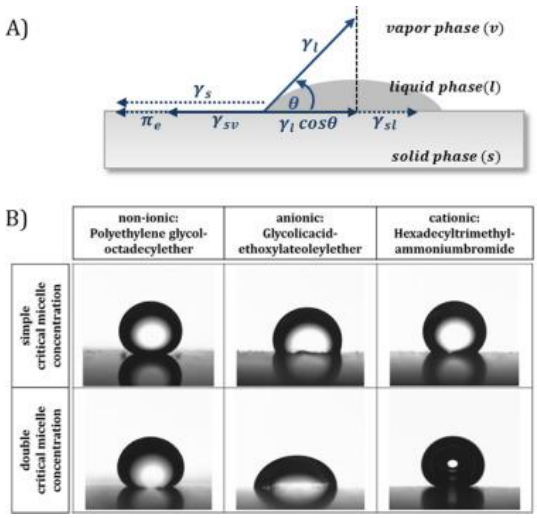

Figure 2-4 Contact angle Θ of a sessile drop [5]

Young realized the relationships between forces and energies at the interfaces of the three different phases: solid, liquid and vapor. He postulated the Young equation, which describes the state of equilibrium at the interfaces of phases

$$\gamma_S - \pi_e = \gamma_l \cos\theta + \gamma_{sl} \quad (2)$$

Equation 2 Young equation equilibrium at the interfaces of phases

where γ_l = surface tension of the liquid phase, γ_s = surface free energy of the solid phase, γ_{sl} = surface energy at the interface of the solid/liquid phase; γ_{sv} = surface energy at the interface of the

liquid/vapour phase; Θ = contact angle and π_e = spreading pressure.

Marangoni effect: The Marangoni effect/convection is a physical interrelation, which describes the behavior of fluids depending on the temperature gradient in the surrounding area. This effect is a surface-tension-driven phenomenon, as the surface tension is depending on the temperature.

$$d\sigma/dT \equiv -\sigma T < 0 \qquad (3)$$

Equation 3 The Marangoni effect

This leads to thermocapillary fluid flow and instabilities in non-isothermal free surface systems as theoretically illustrated.

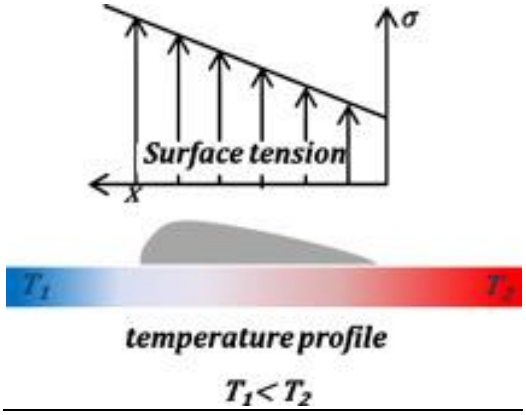

Figure 2-5 Marangoni effect

Viscosity: The viscosity has to be taken into account in relation to the Rehbinder effect, the surface energy and the Marangoni effect. It is the main factor influencing the capability of oils to maintain a satisfactory lubricating film, but also the oil's ability to flow. In general, two types of viscosity are differentiated: dynamic and kinematic viscosity. The temperature-dependent dynamic viscosity is defined as the ratio of the shear stress acting on the fluid to the shear rate. The kinematic viscosity is defined as the ratio of the dynamic viscosity to fluid density. MWF-producers widely use the kinematic viscosity to characterize MWFs [5].

2.3. Carbon nanotubes

Carbon nanotube (CNT) is one form of carbon, with nanometre-sized diameter and micrometre-sized length, where the length to diameter ratio can exceeds 1000 times. The atoms are arranged in hexagons, the same arrangement as in graphite. The structure of CNT consists of enrolled

cylindrical graphitic sheet (called graphene) rolled up into a seamless cylinder with diameter of the order of a nanometre. It is understood that CNT is the material lying in between fullerenes and graphite as a quite new member of carbon allotropes [6].

Carbon nanotubes are members of the fullerene structural family, which also includes buckyballs. Whereas buckyballs are spherical in shape, a CNT is cylindrical, the ends of some CNTs are open; the others are closed with full fullerene caps. CNTs name is derived from their size, since the diameter of a CNT is on the order of a few nanometres (approximately 50,000 times smaller than the width of a human hair), while they can be up to several micrometre in length. Commercial applications for CNT have been rather slow to develop, however, primarily because of the high production costs of the best quality CNTs.

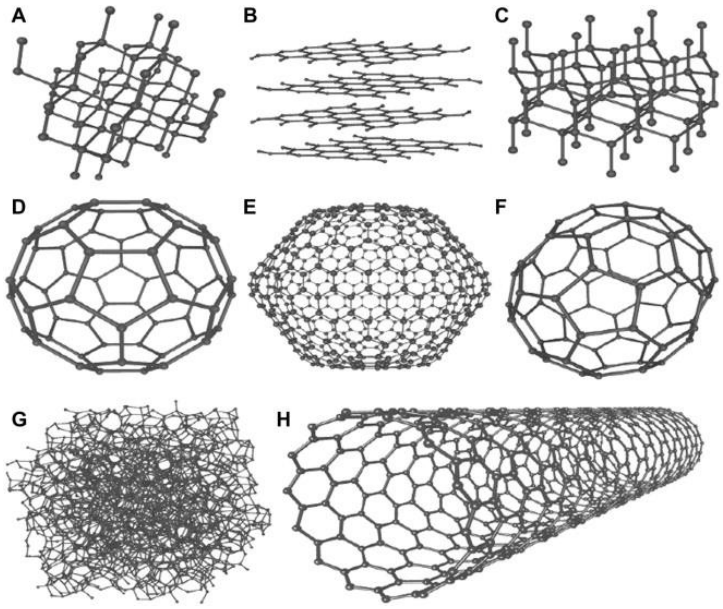

Figure 2-6 The structures of eight allotropes of carbon: (A) Diamond [3D], (B) Graphite [2D] , (C) Lonsdaleite, (D) C60 [0D] (E) C540 Fullerene, (F) C70 Fullerene, (G) Amorphous carbon, (H) Single-walled carbon nanotube [1D]©

The two main types of CNT are the single and multi-walled (there are some other rare types such as fullerite, torus, and nanoknot).

A single-walled carbon nanotubes (SWCNTs) can be considered to be formed by the rolling of a single layer of graphite (called a graphene layer) into a seamless cylinder (long wrapped graphene sheets). As stated before, CNTs generally have a length to diameter ratio of about 1000 and more so they can be considered as nearly one-dimensional structure. Most SWCNTs have a diameter of close to 1 nm. SWCNTs are a very important variety of a CNT because they exhibit important electric properties that are not shared by the MWCNT variants. The most basic building block of

these systems is the electric wire, and SWCNTs can be excellent conductors.

SWCNTs are still very expensive to produce, and the development of more affordable synthesis techniques is vital to the future of carbon nanotechnology. If cheaper means of synthesis cannot be discovered, it would make it financially impossible to apply this technology to commercial scale applications.

Multi-walled carbon nanotubes (MWCNTs) can be considered as a collection of concentric SWCNTs (consist of multiple layers of graphite rolled in on themselves to form a tube shape) with different diameters. The length and diameter of these structures differ a lot from those of SWCNTs and, of course, their properties are also very different [7].

MWNTs have excellent properties and are being employed in a large number of commercial applications [8]. MWNTs are highly conductive when properly integrated into a composite structure. One must note that the outer wall alone is conducting, and the inner walls are not conductive. MWNTs have a high aspect ratio with lengths typically more than 100 times the diameter, and in certain cases much higher. Their performances and applications are based not only on aspect ratio, but also on the degree of entanglement and the straightness of the tubes, which in turn is a function of the both the degree and dimension of defects in the tubes. MWNTs have an excellent tensile strength and when integrated into a composite, such as a thermoplastic or thermoset compounds, can significantly increase its strength. MWNTs have a thermal stability more than 600 °C, based on the level of defects and to certain extent on the purity as residual catalyst in the product can also catalyze decomposition. MWNTs are an allotrope of sp^2 hybridized carbon similar to graphite and fullerenes and as such have high chemical stability. However, one can functionalize the nanotubes to enhance both the strength and dispersibility of composites.

A large problem with CNT application is next to large-scale synthesis and the purification. In all the CNT preparation methods, the CNTs come with a number of impurities whose type and amount depend on the technique used. The most common impurities are carbonaceous materials, whereas metals are another types of impurities generally observed [9].

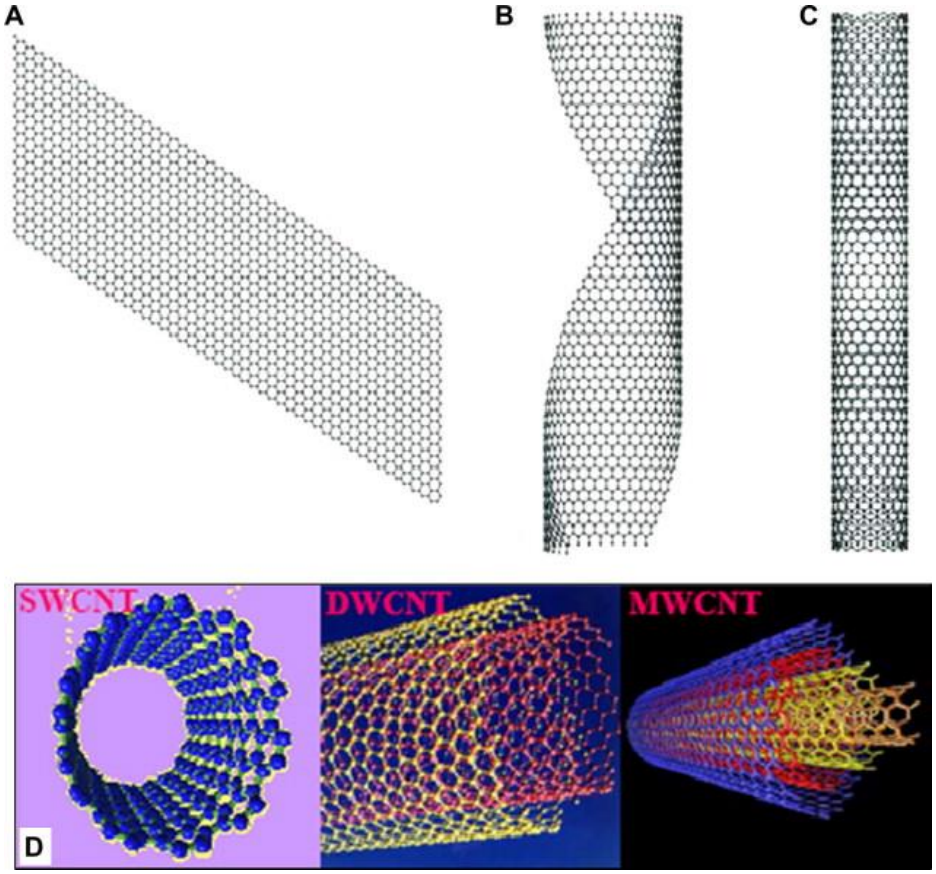

Figure 2-7 Schematic diagrams showing different types of CNTs and other carbon structures: (A) Flat sheet of Graphite, (B) Partially rolled sheet of graphite, (C) SWCNT, (D) Structures of the three CNT types; SWCNT, DWCNT, and MWCNT, respectively.

Oxidative treatment of the CNTs is a good way to remove carbonaceous impurities or clear the metal surface. The main disadvantages of oxidation are that not only the impurities are oxidized, but also the CNTs. Luckily the damage to CNTs is less than the damage to the impurities. These impurities have relatively more defects or a more open structure. Another reason why impurity oxidation is preferred is that these impurities are most commonly attached to the metal catalyst, which also acts as oxidizing catalyst. Altogether, the efficiency and yield of the procedure are highly depending on a lot of factors, such as metal content, oxidation time, environment, oxidizing agent and temperature.

The study of functionalized carbon nanotubes has a very important signification especially in the dispersion of carbon nanotubes, the compatibility of composite materials, interfacial strength, the glass transition temperature, compatibility with biological materials, in addition to other aspects.

For example, the composition of functional multi-walled carbon nanotubes and polymer materials has better interfacial bonding strength and better dispersion, also adding the amount of functional multi-walled tubes material could be reduced a lot. Therefore, functionalized carbon

nanotubes can be better fully to reveal carbon nanotubes outstanding properties.

Furthermore, functionalized carbon nanotubes, due to function group enable the next step for the modification of carbon nanotubes that is of great convenience role. The performance of non-functionalized carbon nanotubes on the surface is relatively stable and is somewhat difficult to directly modify on their surface. However, the functionalized carbon nanotube, as if inserted branch on the carbon nanotubes surface, greatly increase the carbon nanotube surface activity, more easier links to other needs groups modified.

In the biological field, functionalized carbon nanotubes have better biocompatibility and stronger effect on cell viability.

The -OH and -COOH groups are hydroxyl MWCNTs and carboxyl MWCNTs. Their properties are: better interfacial bonding strength, better dispersion, better fully to reveal carbon nanotubes outstanding properties, better biocompatibility, stronger effect on cell viability, better flexibility, high strength carbon nanotubes, could be used in intumescent fire retardant coating to delay in the heat transfer to the substrate to prevent the body temperature from rising and the body strength from decreasing, better surface activity and carbon nanotubes are more easier links to other needs groups modified.

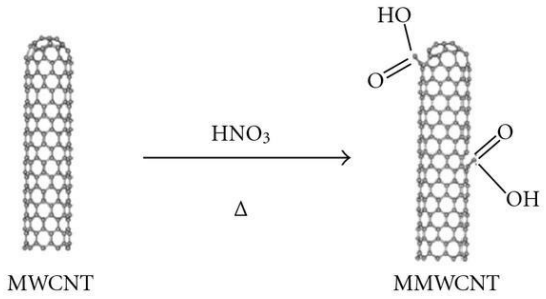

Figure 2-8 Chemical modification of carbon nanotubes (MWCNTs) through thermal oxidation

3. Experimental part

3.1. Materials

Oil Kalenol 22

INA Kalenol is an oil for heat treatment of metals. The composition is adapted to specific thermal conditions metal processing, enriched with additives to prevent oxidation and aging in high-performance the temperature is more acceptable for the environment because they do not contain barium. INA Kalenol has a very wide range of applications; it is used for hardening tools and construction parts from non-alloy and low-alloy steels and for hardening after cementation.

Table 1 Quality - specification level Kalenol 22

Properties	INA Kalenol 22				Method
ISO VG	22	32	68	100	
Appearance and coloor	Clear yellow oil				visually
Density at 15 °C, g/cm^3	0.867	0.874	0.882	0.885	ASTM D 4052
Kinematic viscositic mm^2/s					
At 40 °C	22	32	68	100	ISO 3104
At 100 °C	4.3	5.5	8.4	11	
Viscosity index	97	98	95	94	ISO 2909
Flash point, (COC), °C	197	224	240	250	ISO 2592
Water content and mech. impurity, vol.%.	Not contain				ISO 3734

Polymer

A polymer is a large molecule made up of chains or rings of linked repeating subunits, which are called monomers. Polymers usually have high melting points. Because the molecules consist of many monomers, polymers tend to have high molecular masses. We used six different types of polymers as surfactants: DF0, DF2.5, DF5, DF10, MD0 F5-K3, SD0 F5-K1.

CNT

As we have already explained in the section 2.3, there are several types of CNTs and each of them have different properties.

- **MWCNT**

Table 2 Properties MWCNT

Properties	
Length	10-20 μm
Purity	95%
Diameter	>50 nm

- **MWCNT COOH**

Table 3 Properties MWCNT-COOH

Properties			
Length	~50 μm	**SSA**	>117 m^2
Purity	99.9%	**EC**	>10^2 s/cm
-COOH	1.28 wt%	**MFG code**	GMC2/50/20
OD	8-15 nm	**Ash**	<0.1wt%

3.2. Devices

Ultrasonic Devices

Ultrasonic cavitation is used to disperse nano-size particles into liquids, such as water, oil, solvents or resins. The application of ultrasonics to nanomaterials has manifold effects; the most obvious is the dispersing of materials in liquids in order to break particle agglomerates.

Another process is the application of ultrasound during particle synthesis or precipitation. Generally, this leads to smaller particles and increased size uniformity. Ultrasonic cavitation

improves the material transfer at particle surfaces, too. This effect can be used to improve surface functionalization of materials having a high specific surface area. Nanomaterials, e.g. metal oxides, nanoclays or carbon nanotubes tend to be agglomerated when mixed into a liquid. Effective means of deagglomerating and dispersing are needed to overcome the bonding forces after wetting the powder. The ultrasonic breakup of the agglomerate structures in aqueous and non-aqueous suspensions allows utilizing the full potential of nanosize materials. Investigations at various dispersions of nanoparticulate agglomerates with a variable solid content have demonstrated the considerable advantage of ultrasound when compared with other technologies, such as rotor stator mixers (e.g. ultra turrax), piston homogenizers, or wet milling methods, e.g. bead mills or colloid mills.

Figure 3-1 Ultrasonic device used to disperse nanomaterials

Dispersion and deagglomeration by ultrasonication are a result of ultrasonic cavitation. When exposing liquids to ultrasound the sound waves that propagate into the liquid result in alternating high-pressure and low-pressure cycles. This applies mechanical stress on the attracting forces between the individual particles. Ultrasonic cavitation in liquids causes high speed liquid jets of up to 1000km/hr. Such jets press liquid at high pressure between the particles and separate them from each other. Smaller particles are accelerated with the liquid jets and collide at high speeds. This makes ultrasound an effective means for the dispersing but also for the milling of micron-size and sub micron-size particles. [10].

The operation of this device consists in introducing the metallic cylindrical part inside a test tube, where, the oil mixed with the surfactant and the MWCNT, and let it act for about 5 minutes.

During the process it must be controlled that the temperature and the energy transmitted to the mixture is adequate.

Spectrophotometer UV-1800

A spectrometer is a device for measuring wavelengths of light over a wide range of the electromagnetic spectrum. It is widely used for spectroscopic analysis of sample materials. The incident light from the light source can be transmitted, absorbed or reflected through the sample. The changes occurred during the interaction of incident light with the sample reveals the sample characteristics.

Two types of radiation sources are generally employed in spectrometer – continuous and line sources. Continuous sources are heated solid substances or lamps that emit light over a wide wavelength range and line sources are specialized lamps and lasers.

Figure 3-2 Spectrometer UV-1800

The procedure of use consists of introducing small samples of the mixtures and performing a test for each one. We make a spectrogram between the wave lengths 700-350 nm. Then, we save the graphs obtained in various formats to be able to represent and study them later. The basic law on which the absorption method is based is the Lambert-Beer Law (2). The amount of radiation absorbed in the solution is an exponential concentration function and the radiation pathway through the solution. This law gives the function relationship between the size measured by the absorption method (A) and the size being determined, the concentration (c). The effect of the interaction between the photons and the particles they absorb is to reduce the intensity of radiation with I0 to I. Lambert - Beer 's law can be represented as:

$$A = \log\left(\frac{I_0}{I}\right) = \varepsilon \times b \times c \qquad (4)$$

Equation 4 Lambert-Beer Law

Where A is the absorbance at the given wavelength of light, ε is the molar absorption (extinction) coefficient (cm^2 mg^{-1}), characteristic of each molecular type and dependent on the wavelength of light, b is the length of the light path through the sample (cm) soluble matter (mg cm^{-3}). Molar extinction coefficient for carbon nanotubes at 500 nm is 28.6 cm^2 mg^{-1} [11]. In this way the absorbance is related to the stability of nanofluids, we can study the precipitation of CNT during the process.

Rotational rheometer

Knowledge of the viscosity is very important as this will give information about:

- Pumpability: The ability to be pumped between for example storage containers or tanks and the manufacturing plant.
- Mixability: The ability to be properly mixed with additives, fillers and other components during the manufacturing process.
- Workability: The ability of the resultant Hot Mix Asphalt (HMA) to be placed and compacted with reasonable effort.

The Anton Paar Rotational Rheometer RheolabQC RheolabQC is a rotational rheometer designed especially for the quality control, featuring a high precision encoder and a highly dynamic EC motor. It can be chosen between operating the rheometer stand-alone or software-controlled with RheoCompass™, highly intuitive rheometer software that includes templates for asphalt testing. Measurements with concentric cylinder measuring systems according to ISO 3219 and DIN 53019 were performed. To keep cleaning to a minimum, disposable aluminum measuring cups can be used. This means the measuring cup no longer requires cleaning and furthermore pre-heating of the sample in an oven is easily possible. High sample throughput with minimum required cleaning is guaranteed [11].

Figure 3-3 The Anton Paar Rotational Rheometer RheolabQC ©

The Anton Paar Rotational Rheometer will provide us the data of dynamic viscosity, shear stress and torque according to the temperature, the first study ramp will include from 25ºC to 100ºC and the second will be the inverse.

Thermal conductivity measuring device

Thermal conductivity or conductivity is the physical size defined as the amount of heat in the unit of time, i.e. the thermal flow passing through some substance through the cross section. It is measured with a Linseis - THB (Transient Hot Bridge) measuring device between 0.01 and 1 W m-1 K-1 with accuracy of more than 2% and at temperatures from -150 °C to 200 °C.

Figure 3-4 Thermal conductivity measurement device

THB6K98 was used with a 30 s measurement time and 0.048 A current. After setting the parameter, the sensor was immersed in 50 mL of sample. The device is accompanied by an increase in the temperature sampled by the resistance inside the circuit, by performing the heat in the sample and the time. Special algorithms calculate the value of thermal conductivity.

Measurement of kinematic viscosity

Viscosity is an important physical feature of all petroleum products, particularly when it comes to oil lubricants, whose lubrication properties depend to a great extent on viscosity. Kinematic viscosity (v) is a measure of resistance to flow under the influence of gravity. It is determined by measuring the flow time of the liquid through the capillary of known dimensions, and is the ratio of dynamic viscosity and density ($\frac{\eta}{\rho}$).

The viscometer (Figure 3.7) is filled with liquid and thermostated for 20 minutes at 40 °C in a water bath, then measure the time of passage of liquid through the capillary.

Figure 3-5 Viscometer

The kinematic viscosity (v, $mm^2\ s^{-1}$) is counted as a specimen of the calibration constant of the viscometer (C, $mm^2\ s^{-2}$) and the flow time of the liquid (t, s):

$$v = C \times t \qquad (5)$$

Equation 5 Kinematic viscosity law

The viscosimeter constant used for determining viscosity is 0.11591 $mm^2\ s^{-2}$.

3.3. Procedure

For the realization of this project we have carried out several phases, from the mixing or preparation of the compounds, their homogenization and the study of the evolution of different characteristics.

The target of this project is study two different CNT, which have been mixed with 6 different types of polymer surfactant solutions on oil. The polymers are mixed with the oil, and then left in the magnetic mixer during 24 hours to stabilize it. Later, the CNTs are added, in the desired proportion, using a high precision balance. Once the CNT are added, it is not necessary to let the mixture rest, we directly pass to disperse it.

In this project, we mainly differentiate mixtures of MWF with 0.01wt% CNTs, in the first experimental part we mixed 130 g of nanofluids which means about 13 mg of CNT are added in all cases. For the correct homogenization of the mixture, we used the homogenizer, previously described; this process consists of applying up to 60 kJ of energy to the mixture that equals about 5 minutes. During the process, we measure the values of energy and temperature each one-minute

interval, to check the evolution of the process and be able to study it later

The first study consist on perform a visual test; we took photos of the different nanofluids, in order to study how sedimentation evolves in each one of them. Later, we will perform an absorbance test to obtain numerical results of the precipitation of the CNT. According to the Equation 4 Lambert-Beer Law, the greater the absorbance, the greater the stability. Then, we can select, according to the stability criteria, which of all the nanofluids is the most recommended.

Once we selected the nanofluid, with a certain CNT and polymer dissolution, we must perform tests to determine the appropriate amount of surfactant and the amount of MWCNT, to study how they interact and how they affect the properties of the fluid.

During all these processes it is vitally important that each test is performed every day in the same conditions, therefore, the test tubes must be conditioned to the room environment where the tests are carried out. Since, the project has been carried out for a long period and the outside temperature ranges from -15 ºC during the winter and 30 ºC during the summer, the temperature of each room has been controlled with air conditioners to ensure that there are no large changes in temperature, which could affect test results.

4. Results

Next, the results obtained in each of these tests performed will be shown. As previously mentioned, mixtures of MWF with different polymers and different concentrations of CNT have been made.

4.1. Stability of nanofluids based on MWCNT

In this first part of the project, the polymers have been used are: DF0 0.5%, DF2.5 0.5%, DF5 0.5%, DF10 0.5%, DF2.5 0.1%, DF5 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%. All of them were mixed with 13 mg of MWCNT.

4.1.1. Mixing of nanofluids based on MWCNT

During the mixing process, data of energy transmitted to the fluid and temperature were taken in one minute intervals.

Table 4 Ultrasonic measurement of nanofluids based on MWCNT

Data						
Time (min)	*0*	*1*	*2*	*3*	*4*	*5*
Energy (kJ)	*0*	*12*	*24*	*36*	*48*	*60*
Types/temperatures						
DF0 0.5%	*22*	*42*	*58*	*63*	*77*	*90*
DF2.5 0.5%	*22*	*58*	*75*	*91*	*105*	*115*
DF5 0.5%	*22*	*50*	*70*	*85*	*100*	*111*
DF10 0.5%	*22*	*53*	*71*	*85*	*100*	*112*
DF2.5 0.1%	*22*	*50*	*66*	*82*	*97*	*109*
DF5 0.1%	*22*	*48*	*67*	*83*	*97*	*109*
SDP5-K1.9 0.1%	*22*	*48*	*63*	*78*	*91*	*103*
MD0F5-K3 0.1%	*22*	*43*	*61*	*75*	*89*	*100*

After taking all the data during the process, we observe that the energy transmitted in all cases is the same, so we can represent all the cases in one.

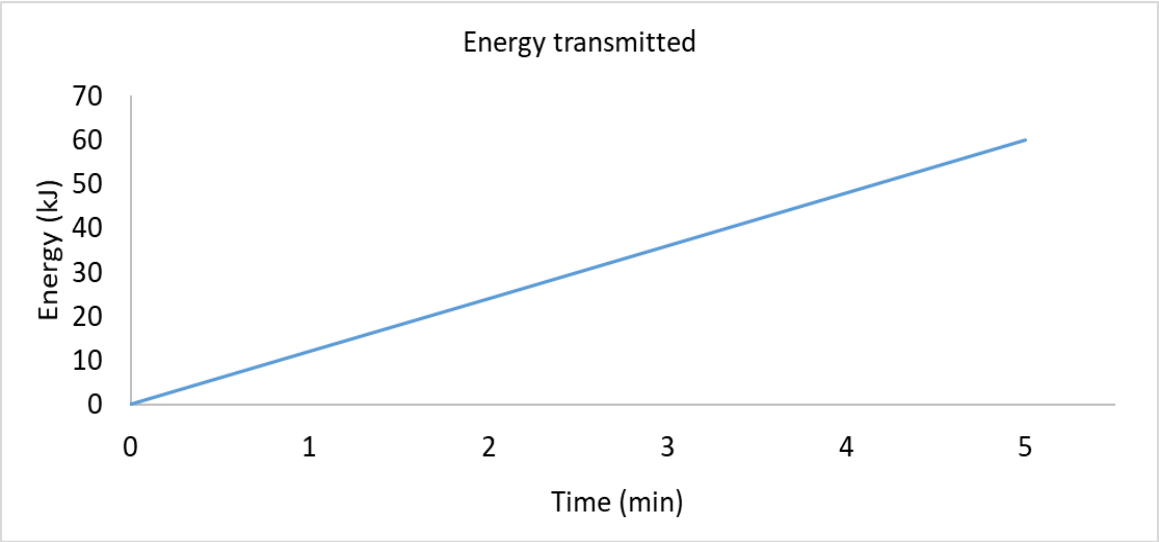

Figure 4-1 Energy transmitted to the nanofluids based on MWCNT during the mixing process

The temperatures were plotted separately, although the difference is not entirely relevant. We took these data to ensure that the mixing was carried out under optimum conditions.

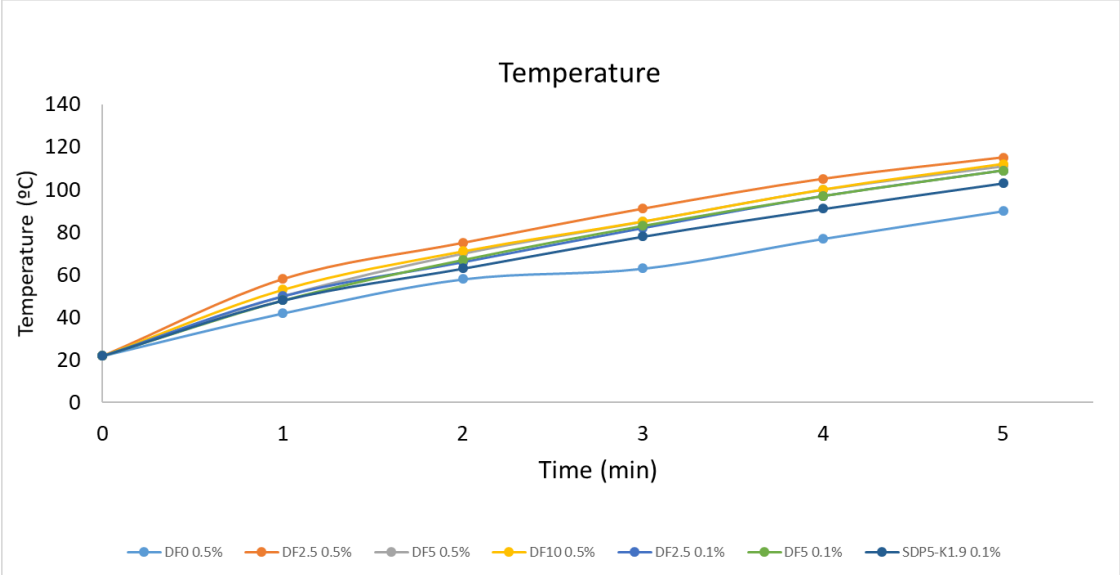

Figure 4-2 Evolution temperature mixing of nanofluids based on MWCNT

At the beginning of each process the temperature corresponds to the ambient temperature of the room where the mixing was carried out (22 ºC), and after transmitting 60 kJ of energy to the nanofluid, the temperature difference between the hottest and the coldest fluid is 25 ºC. This difference is not relevant, since, the energy transmitted to the fluid corresponds in all cases, about 60 kJ after 5 minutes, and it is due to the continued use of the mixing apparatus.

4.1.2. Visual study of stability of nanofluids based on MWCNT

The evolution of the CNT precipitation over time was studied by visual method. We took two different types of photographs: the first one is on natural light and the second one is taken backlighting.

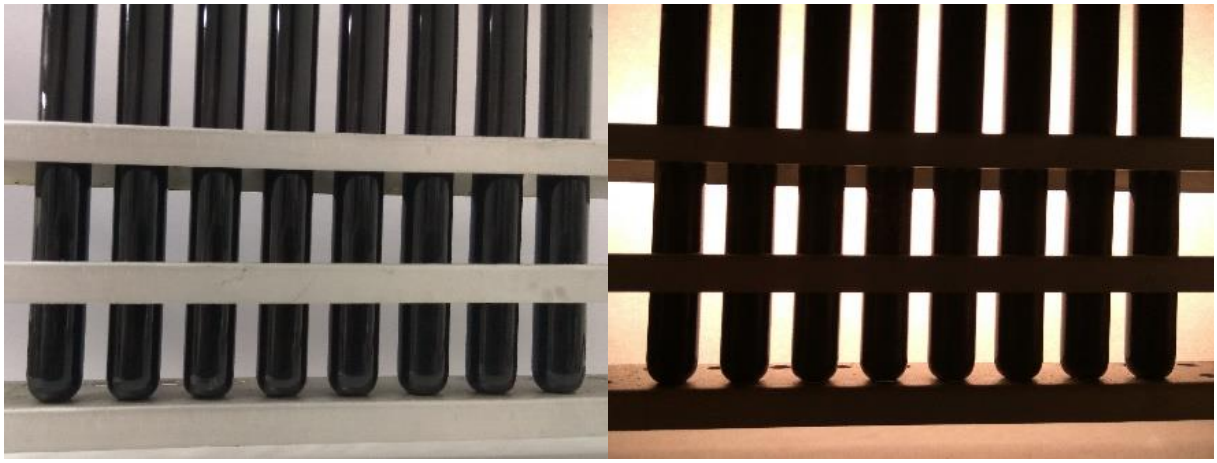

Figure 4-3 Nanofluids based on MWCNT Day 0, left to right (DF0 0.5%, DF2.5 0.5%, DF5 0.5%, DF10 0.5%, DF2.5 0.1%, DF5 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%)

Figure 4-4 Nanofluids based on MWCNT Day 1, left to right (DF0 0.5%, DF2.5 0.5%, DF5 0.5%, DF10 0.5%, DF2.5 0.1%, DF5 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%)

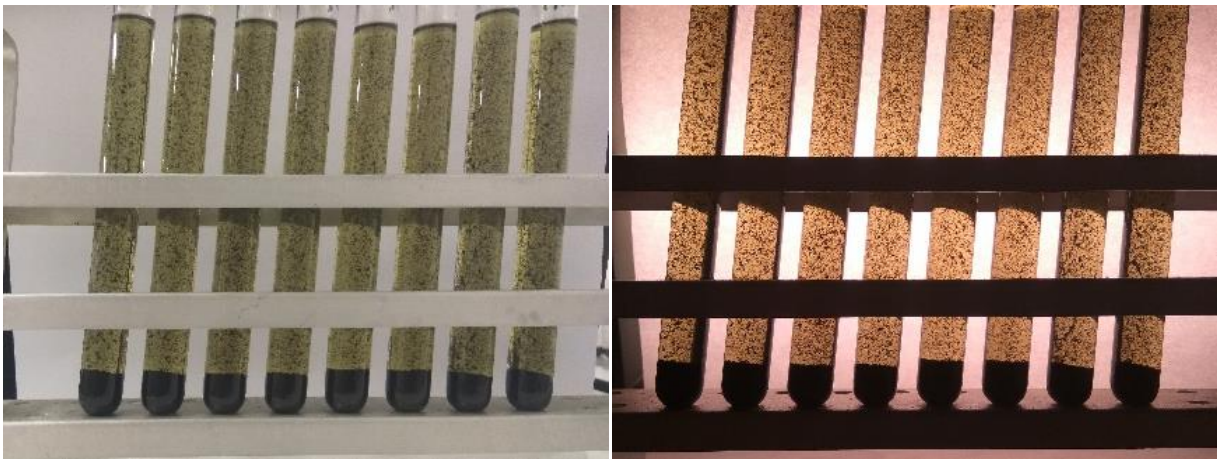

Figure 4-5 Nanofluids based on MWCNT Day 4, left to right (DF0 0.5%, DF2.5 0.5%, DF5 0.5%, DF10 0.5%, DF2.5 0.1%, DF5 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%)

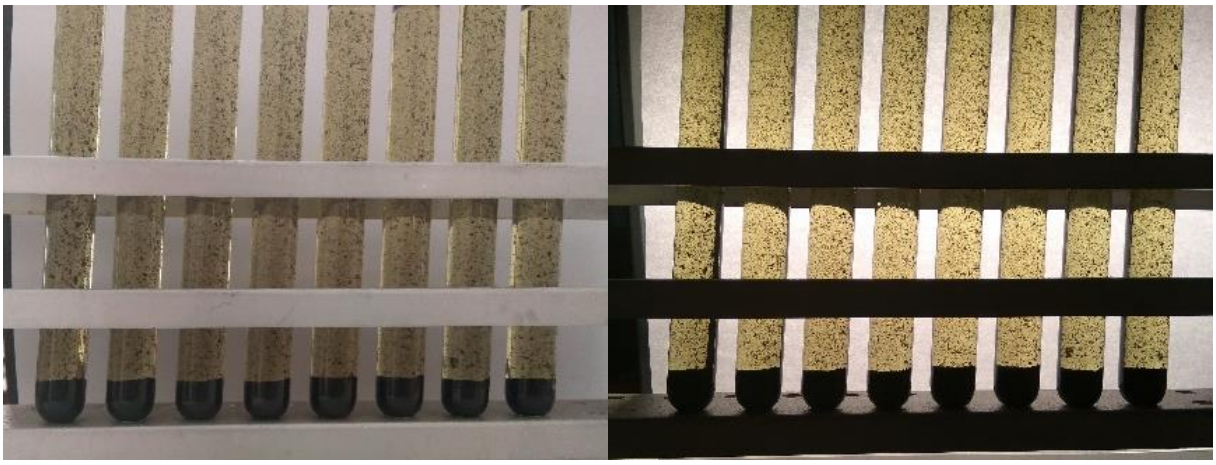

Figure 4-6 Nanofluids based on MWCNT Day 7, left to right (DF0 0.5%, DF2.5 0.5%, DF5 0.5%, DF10 0.5%, DF2.5 0.1%, DF5 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%)

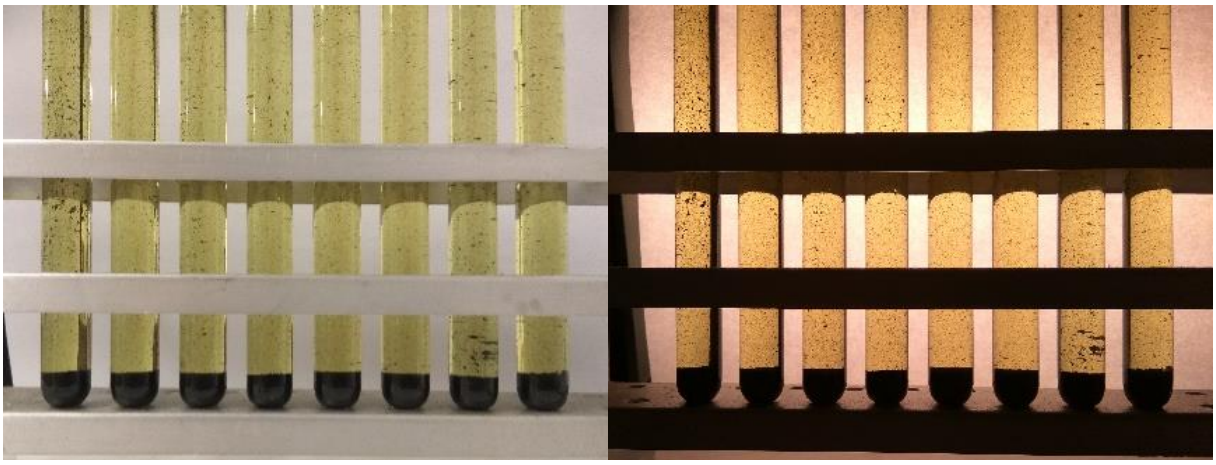

Figure 4-7 Nanofluids based on MWCNT Day 14, left to right (DF0 0.5%, DF2.5 0.5%, DF5 0.5%, DF10 0.5%, DF2.5 0.1%, DF5 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%)

The photographs show how the eight nanofluids present a totally opaque appearance on the day of the mixing, the day after mixing the nanofluids with a concentration of 0.5% of polymers presents a greater precipitation of MWCNT and nanofluids with a concentration of 0.1% maintain an opaque appearance. Nevertheless, on the fourth day after mixing, the eight nanofluids appear very transparent, where most MWCNT have precipitated completely. On the seventh and fourteenth day there is no apparent evolution.

4.1.3. Investigation of the stability of MWCNT nanofluids by UV-VIS

After the mixing process, the absorbance of the nanofluids has been studied. They have been studied daily, to appreciate the general evolution, and by type of compound, to check the particular evolution of each of them.

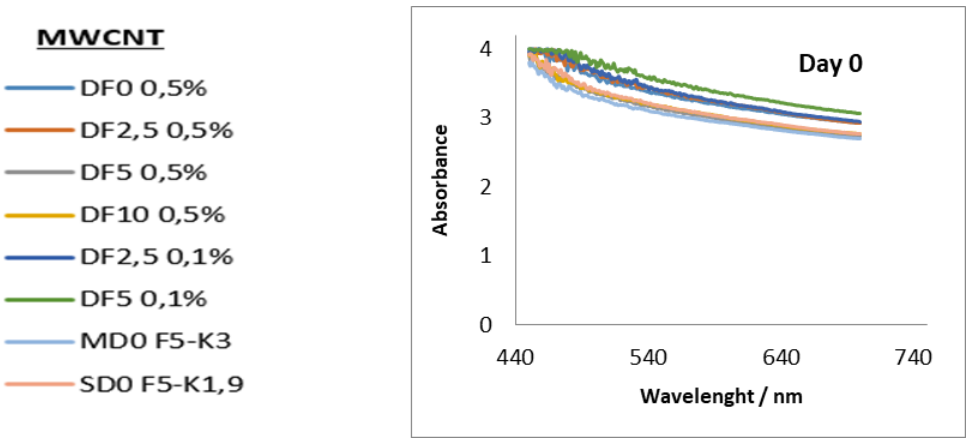

Figure 4-8 Absorbance of nanofluids based on MWCNT; day 0

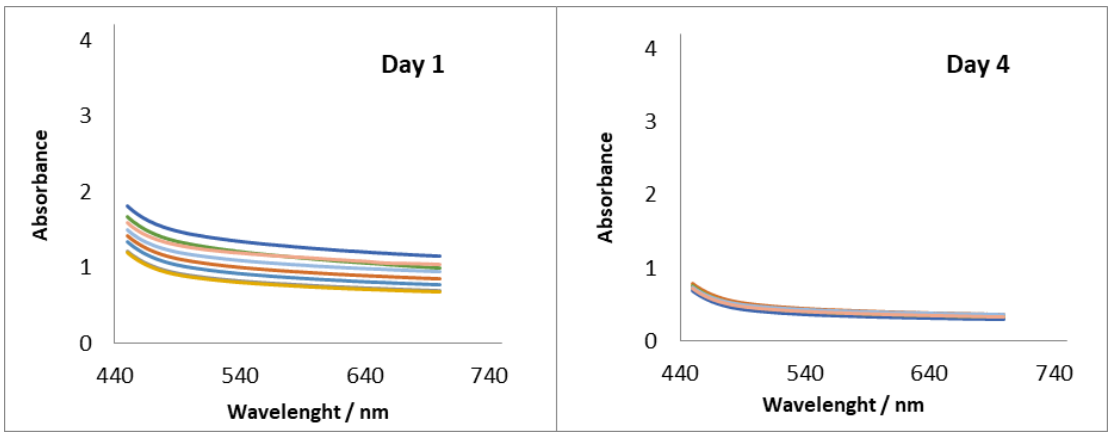

Figure 4-9 Absorbance of nanofluids based on MWCNT; days 1 and 4

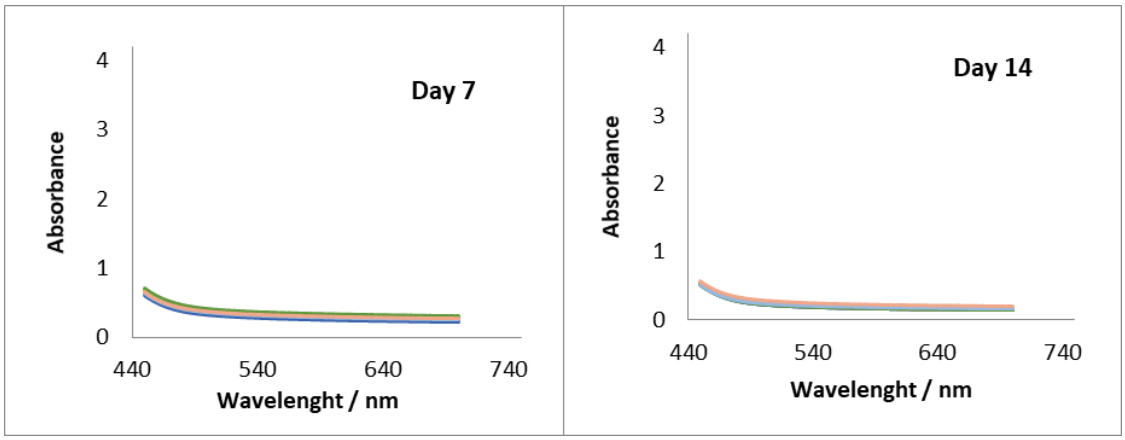

Figure 4-10 Absorbance of nanofluids based on MWCNT; days 7 and 14

The graphs show us how all nanofluids have a similar behaviour: the zero day values of absorbance are between three and four, the day one between one and two of absorbance, the fourth day around point zero five and the seventh and fourteenth day all of them have values very close to zero.

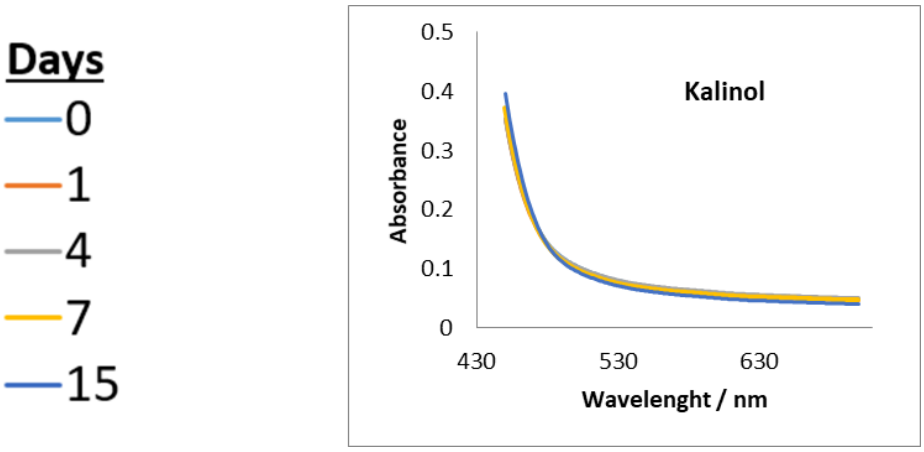

Figure 4-11 Pure Kalenol absorbance; days 0, 1, 4, 7 and 14

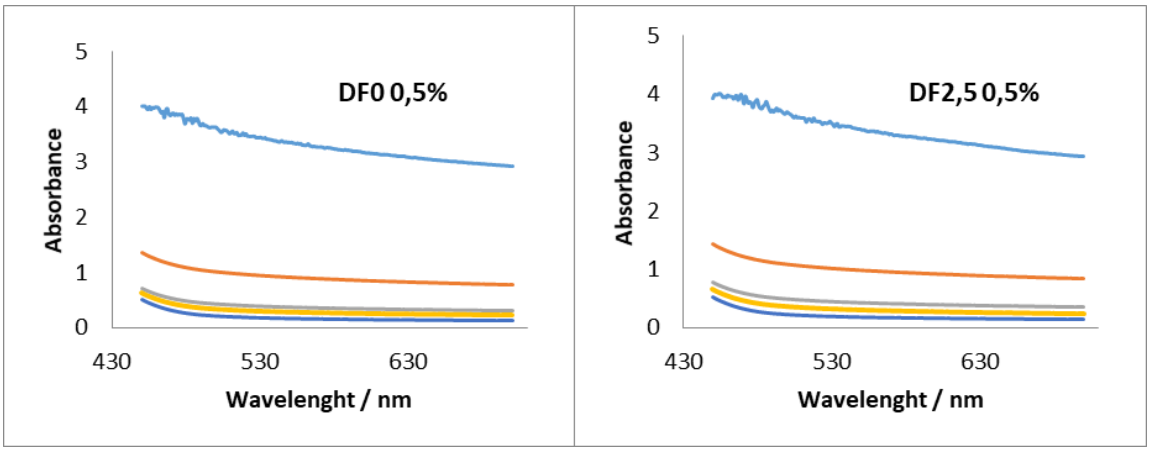

Figure 4-12 DF0 0.5% and DF2.5 0.5% absorbance days 0, 1, 4, 7 and 14

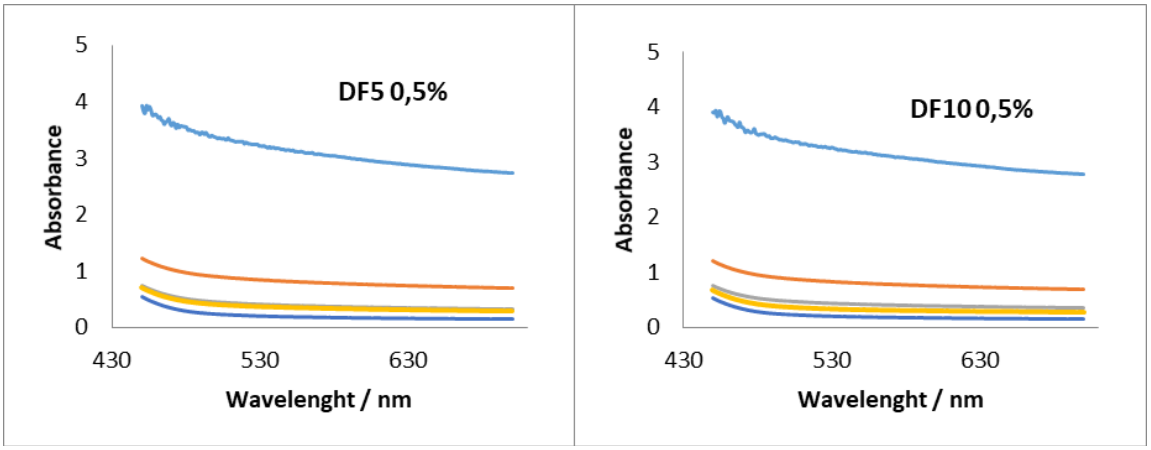

Figure 4-13 DF5 0.5% and DF10 0.5% absorbance days 0, 1, 4, 7 and 14

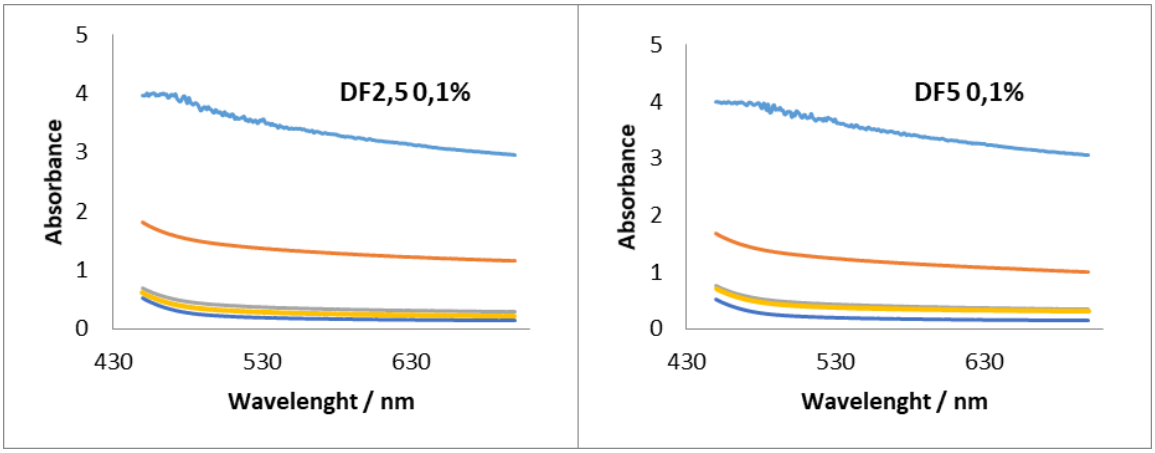

Figure 4-14 DF2.5 0.1% and DF5 0.1% absorbance days 0, 1, 4, 7 and 14

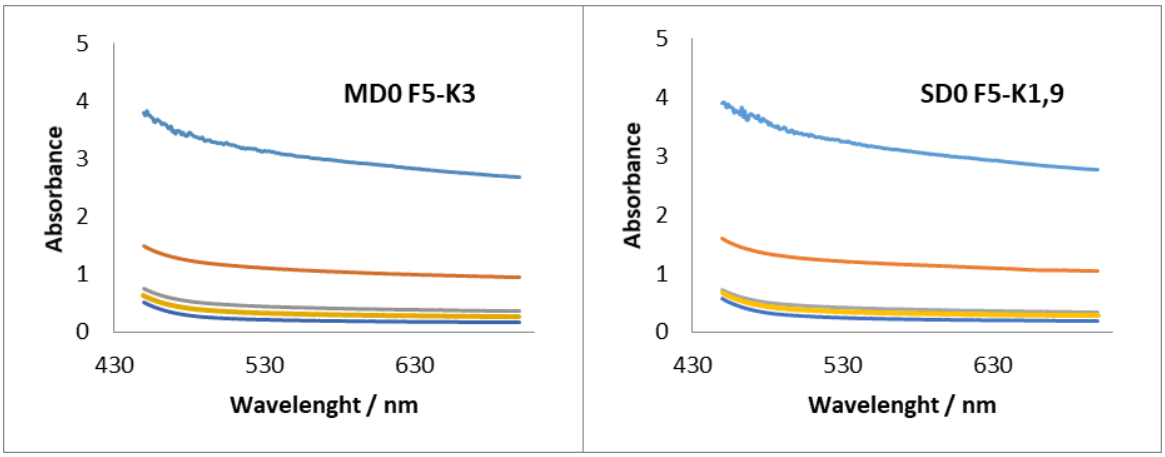

Figure 4-15 MD0 F5-K3 0.1% and SD0 F5-K1.9 0.1% absorbance days 0, 1, 4, 7 and 14

When we study each case separately, we can make sure that their evolutions are similar. The mixing day the absorbance values are around four, but one day after the mixing, we could observe an important reduction of the absorbance, until reaching values around one. From this day, the absorbance values reduce is minimal, until reaching values of point zero two on the fourteenth day.

These graphs show that all the mixtures have the same behaviour, so it would be inaccurate to decide which of them is the most stable without performing some mathematical calculations, in order to determine which of them has minor losses.

Thanks to the above tables, we have taken the absorbance data at a wavelength at five hundred nanometres for all samples on all test days.

Table 2 Absorbance at 500 wavelenght of nanofluids based on MWCNT

MWCNT/Days	0	1	4	7	14
DF0 0,5%	3.621	1.013	0.437	0.347	0.222
DF2,5 0,5%	3.655	1.093	0.496	0.363	0.24
DF5 0,5%	3.367	0.899	0.449	0.407	0.239
DF10 0,5%	3.399	0.886	0.477	0.377	0.228
DF2,5 0,1%	3.719	1.446	0.412	0.322	0.218
DF5 0,1%	3.819	1.314	0.467	0.409	0.226
MD0 F5-K3	3.278	1.176	0.48	0.365	0.24
SD0 F5-K1,9	3.412	1.269	0.46	0.382	0.283

In order to determine the relative precipitation of each nanofluid, we calculate the concentration of each one thanks to Equation 4. In this way, we can determine which nanofluid is the most stable from the mixing day.

Table 3 Concentration for nanofluids based on MWCNT ($\frac{mg}{ml}$)

MWCNT/Days	0	1	4	7	14
DF0 0,5%	0.126608	0.03542	0.01528	0.012133	0.007762
DF2,5 0,5%	0.127797	0.038217	0.017343	0.012692	0.008392
DF5 0,5%	0.117727	0.031434	0.015699	0.014231	0.008357
DF10 0,5%	0.118846	0.030979	0.016678	0.013182	0.007972
DF2,5 0,1%	0.130035	0.050559	0.014406	0.011259	0.007622
DF5 0,1%	0.133531	0.045944	0.016329	0.014301	0.007902
MD0 F5-K3 0,1%	0.114615	0.041119	0.016783	0.012762	0.008392
SD0 F5-K1,9 0,1%	0.119301	0.044371	0.016084	0.013357	0.009895

Once calculated concentrations for each nanofluid/day, we studied the percentage values of the concentration losses. For that purpose, we determine the theoretical initial concentration, dividing the amount of CNT added, in milligrams, and the amount of oil, in milliliters. Comparing this calculated values and the concentrations given in Table 5, we obtain the values of the initial dispersion and the relative losses for each day.

Table 4 Relative concentration losses of nanofluids based on MWCNT

MWCNT/Days	0	1	4	7	14
DF0 0,5%	107%	30%	13%	10%	7%
DF2,5 0,5%	108%	32%	15%	11%	7%
DF5 0,5%	99%	27%	13%	12%	7%
DF10 0,5%	100%	26%	14%	11%	7%
DF2,5 0,1%	110%	43%	12%	10%	6%
DF5 0,1%	113%	39%	14%	12%	7%
MD0 F5-K3 0,1%	97%	35%	14%	11%	7%
SD0 F5-K1,9 0,1%	101%	37%	14%	11%	8%

Thanks to the obtained values, we can affirm that the most stable compound in a period of two days is the DF2.5 0.1%. This nanofluid presents a concentration of 43% the day after the mixing,

being the highest. In addition, we must comment that greater stability is observed in those nanofluids whose concentration of polymer surfactant is 0.1%

4.2. Stability of nanofluids based on MWCNT-COOH

In this second part of the project, the polymers have been used are: DF0 0.1%, DF2.5 0.1%, DF5 0.1%, DF10 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%. All of them mixed with 13 mg of MWCNT-COOH.

4.2.1. Mixing of nanofluids based on MWCNT-COOH

During the mixing process, data for energy transmitted to the fluid and related temperature were taken in one-minute intervals.

Tabla 5 Ultrasonic measurement MWCNT-COOH

a						
Time (min)	*0*	*1*	*2*	*3*	*4*	*5*
Energy (kJ)	*0*	*12*	*24*	*36*	*48*	*60*
Types/temperatures						
DF0 0.1%	*23*	*40*	*57*	*72*	*86*	*99*
DF2.5 0.1%	*23*	*45*	*61*	*76*	*90*	*101*
DF5 0.1%	*23*	*43*	*60*	*75*	*88*	*100*
DF10 0.1%	*23*	*44*	*61*	*74*	*90*	*102*
SDP5-K1.9 0.1%	*23*	*42*	*60*	*76*	*89*	*101*
MD0F5-K3 0.1%	23	*41*	*59*	*74*	*88*	*100*

We repeat the same process as in the previous case, and we obtain for the MWCNT-COOH nanofluids the same values of transmitted energy but different temperatures during the process.

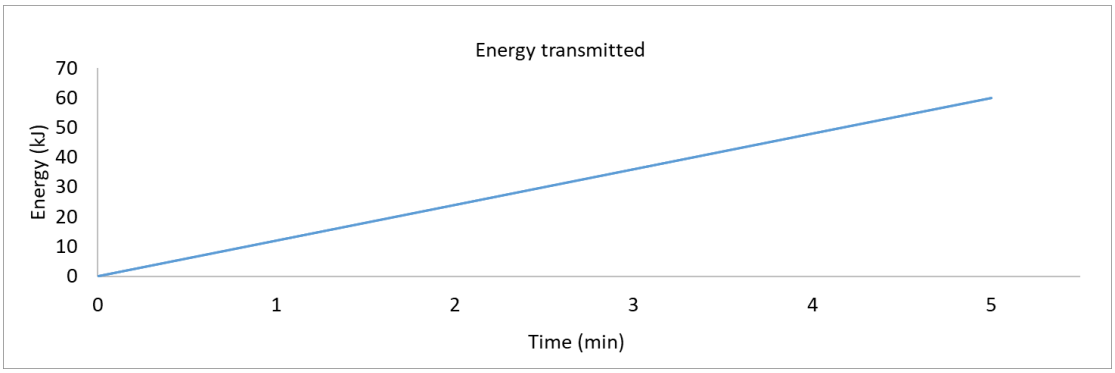

Figure 4-16 Energy transmitted to the MWCNT-COOH nanofluids during the mixing process

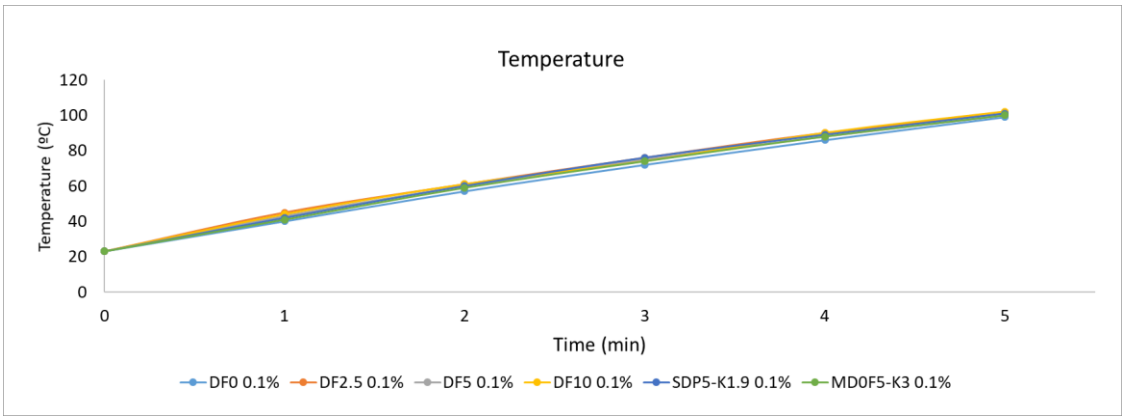

Figure 4-17 Increase of temperature during the mixing of nanofluids based on MWCNT-COOH nanoparticles

At the beginning of each process the temperature corresponds to the ambient temperature of the room where the mixing was carried out (22 ºC), and after transmitting 60 kJ of energy to the nanofluid, the temperature difference between the hottest and the coldest fluid is minimal.

4.2.2. Visual study of stability of nanofluids based on MWCNT-COOH

We repeat the same process carried out with the other type of CNT; the photos are taken on the following days: zero, first, fourth, seventh and fourteenth.

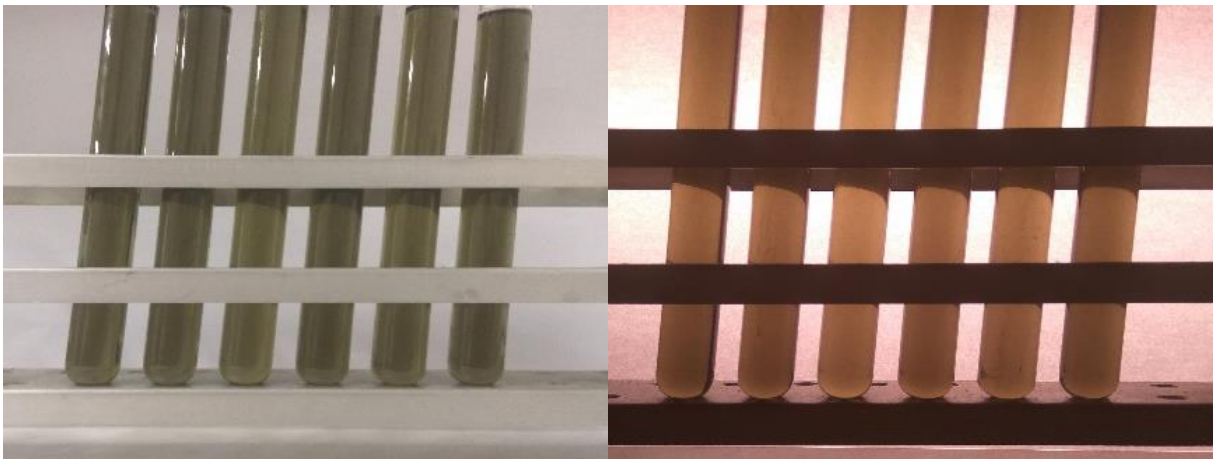

Figure 4-18 Nanofluids based on MWCNT-COOH Day 0, left to right (DF0 0.1%, DF2.5 0.1%, DF5 0.1%, DF10 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%)

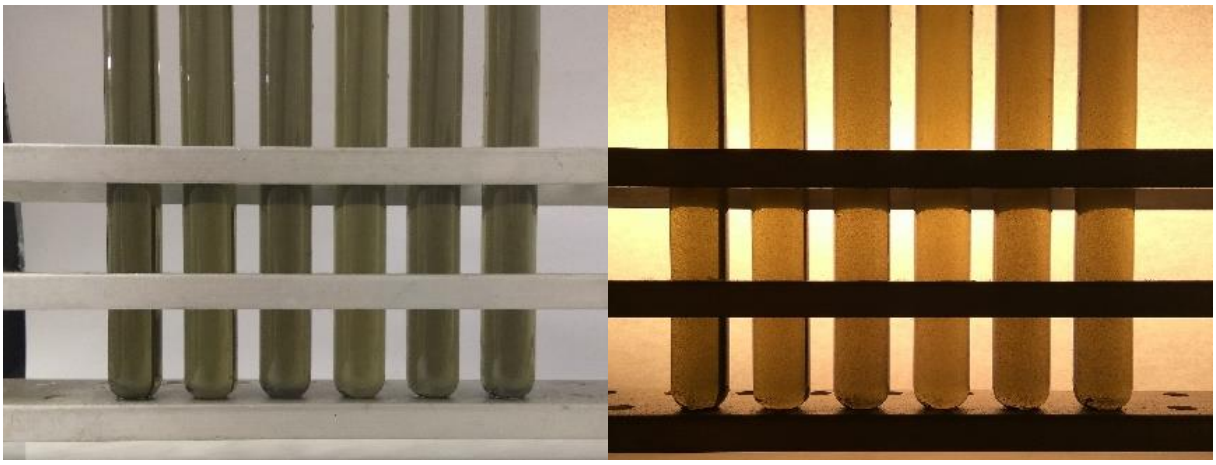

Figure 4-19 Nanofluids based on MWCNT-COOH Day 1, left to right (DF0 0.1%, DF2.5 0.1%, DF5 0.1%, DF10 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%)

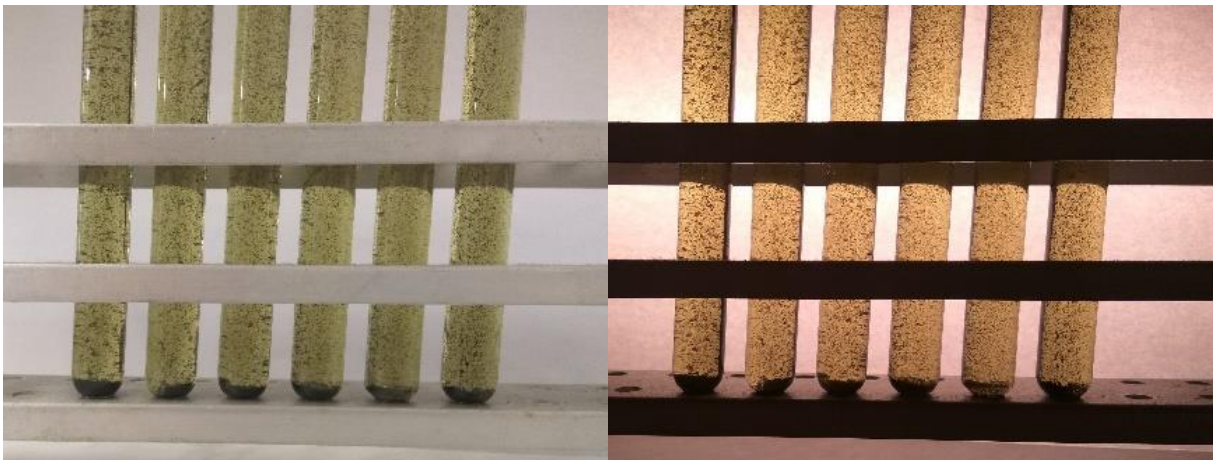

Figure 4-20 Nanofluids based on MWCNT-COOH Day 4, left to right (DF0 0.1%, DF2.5 0.1%, DF5 0.1%, DF10 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%)

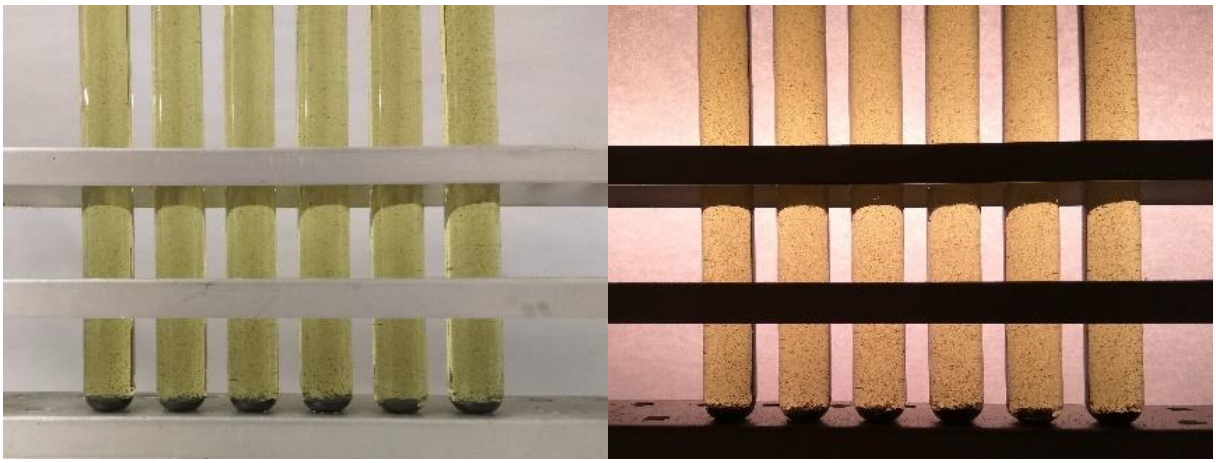

Figure 4-21 Nanofluids based on MWCNT-COOH Day 7, left to right (DF0 0.1%, DF2.5 0.1%, DF5 0.1%, DF10 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%)

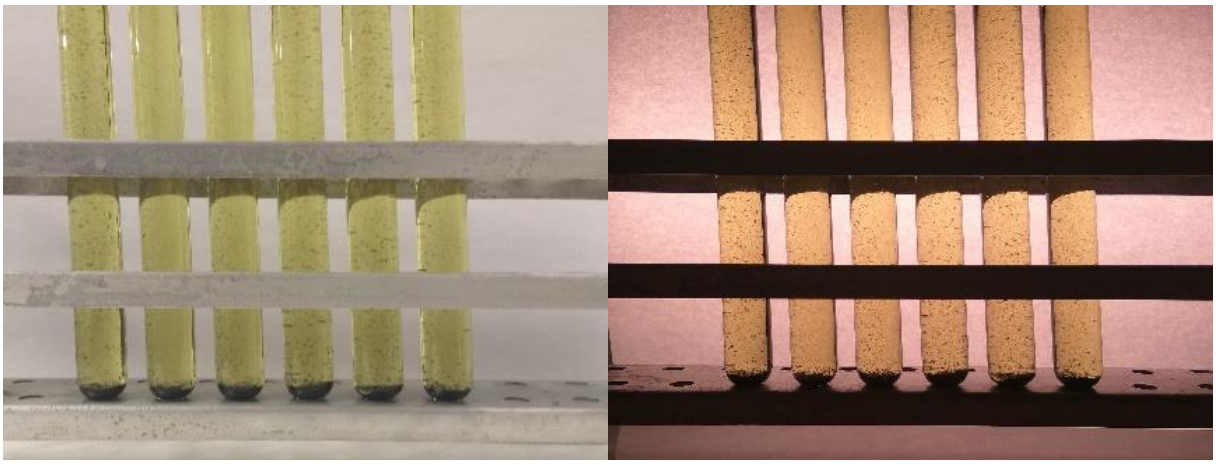

Figure 4-22 Nanofluids based on MWCNT-COOH Day 14, left to right (DF0 0.1%, DF2.5 0.1%, DF5 0.1%, DF10 0.1%, MD0 F5-K3 0.1%, SD0 F5- K1.9 0.1%)

Although, the same weight of CNTs has been mixed, we can see a great difference in the transparency of the tests tubes, since the mixing day the transparency of the mixture is very different than MWCNT obtained. On the day of mixing and the day after that, the six nanofluids have the same uniform transparency, but on the fourth day, we can appreciate how the precipitation begins and these nanofluids become transparent. For the seventh and fourteenth day, the precipitation is almost total and there are no differences between these.

4.2.3. Investigation of the stability of MWCNT-COOH nanofluids by UV-VIS

After the mixing process, the absorbance of the nanofluids was studied. At the time of representing it they have been studied in group, to see the general evolution, and by type of compound to see the particular evolution of each of them.

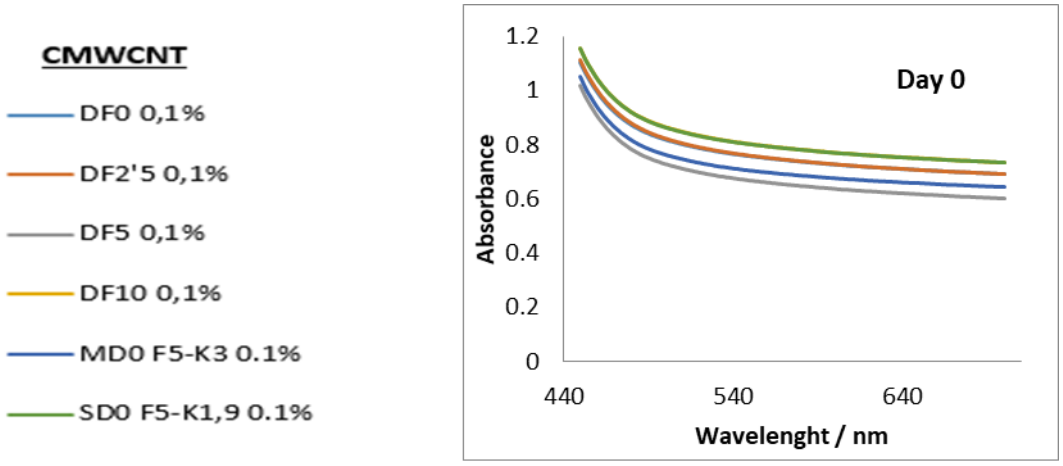

Figure 4-23 Absorbance for nanofluids based on MWCNT-COOH particles day 0

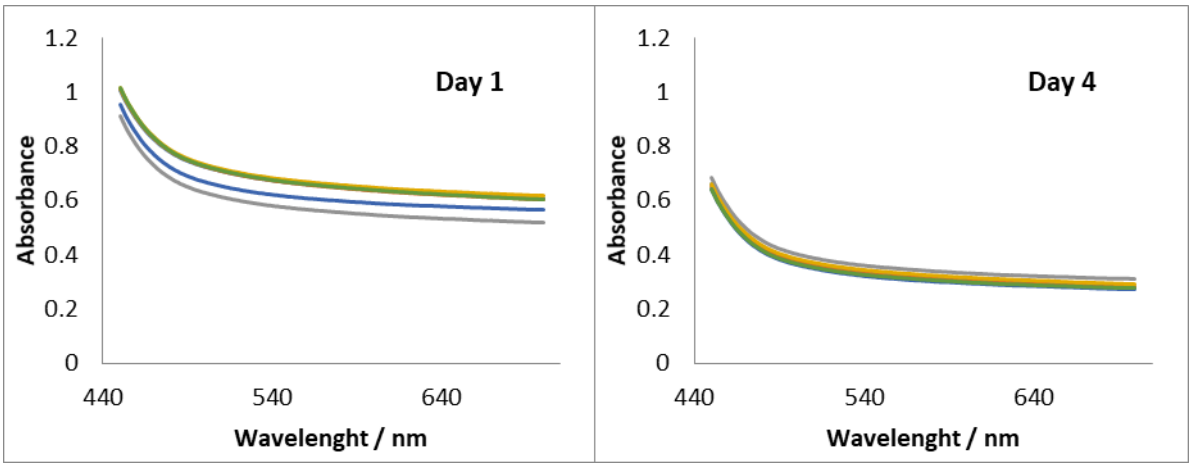

Figure 4-24 Absorbance for nanofluids based on MWCNT-COOH particles days 1 and 4

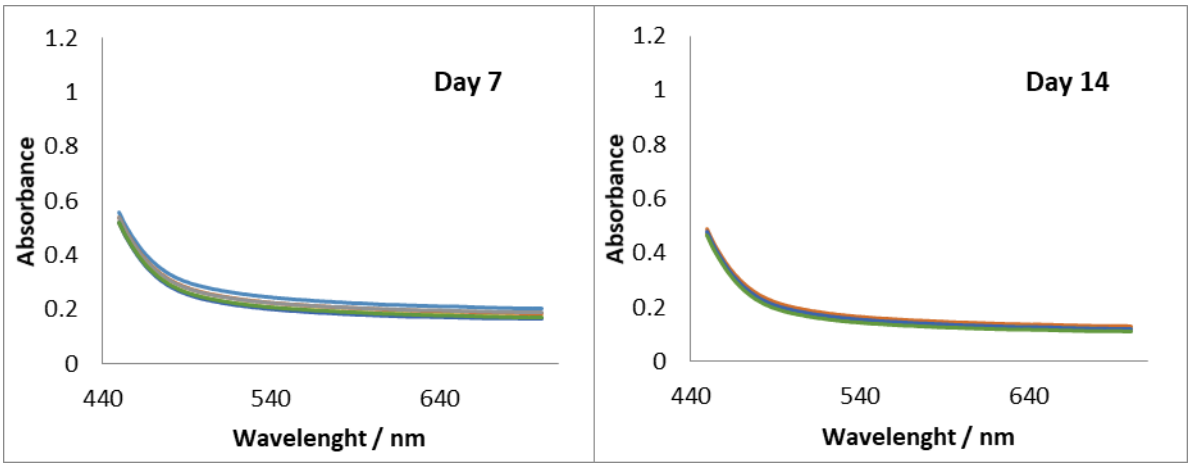

Figure 4-25 Absorbance for nanofluids based on MWCNT-COOH particles days 7 and 14

In the case of MWCNT-COOH, the initial absorbance values range from one to point zero seven, although, we obtained small differences depending on the samples. The day after mixing the absorbance is reduced for around twelve percent in all cases, keeping those small differences depending on the polymer surfactant used. On the fourth day the absorbance for all the cases is reduced around fifty percent and in all cases, we got very similar values, and on the seventh and fourteenth day the reduction is seventy and eighty percent respectively, with almost identical values for all the mixtures.

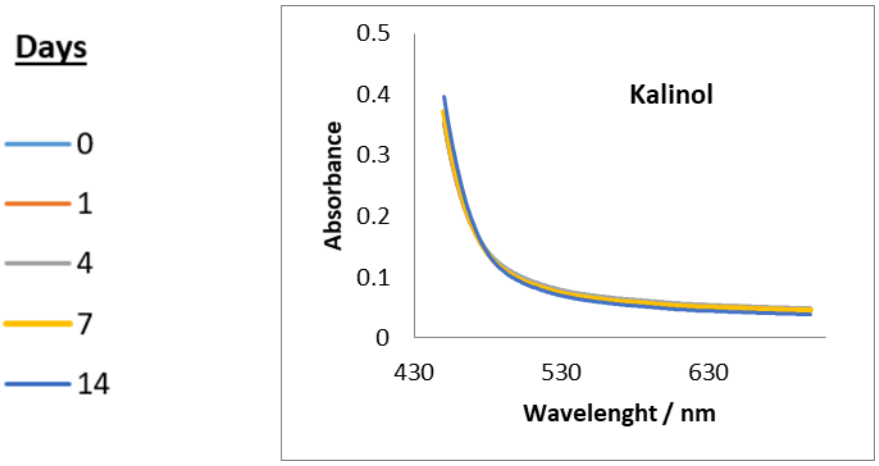

Figure 4-26 Pure Kalenol daily absorbance

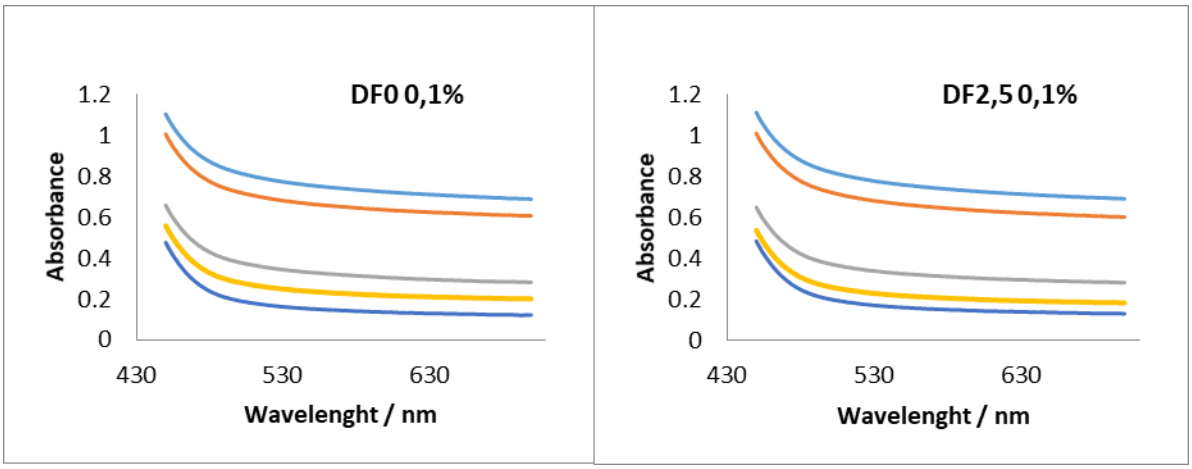

Figure 4-27 Nanofluids based on DF0 0.1% and DF2.5 0.1% daily absorbance

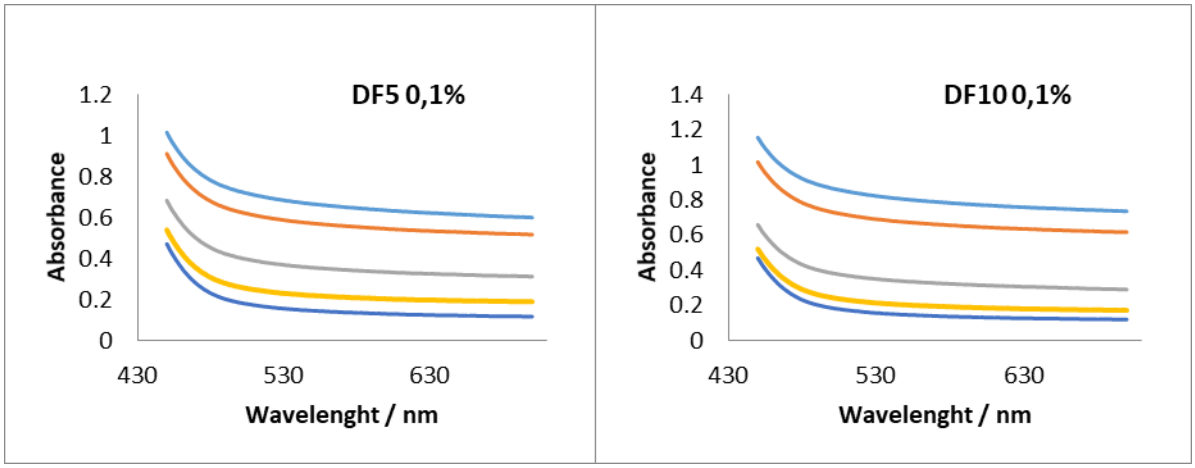

Figure 4-28 Nanofluids based on DF5 0.1% and DF10 0.1% daily absorbance

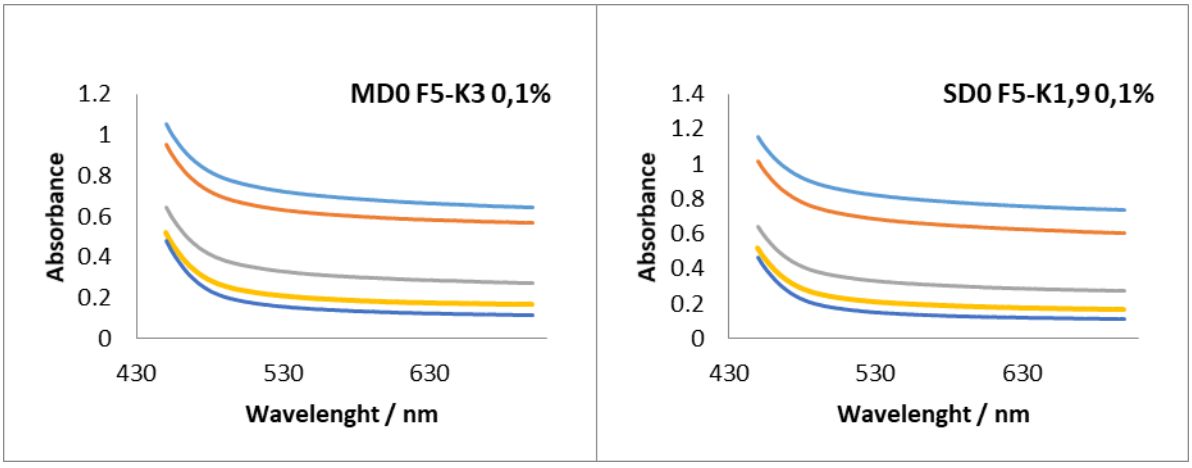

Figure 4-29 Nanofluids based on MD0 F5-k3 0.1% and SD0 F5-K1.9 daily absorbance

By representing each case separately, we can see how they all evolve in a similar way. The day of the mixing and the first day have close values, but from the fourth day the absorbance values are

reduced considerably.

In the case of nanofluids based on MWCNT-COOH particles, not all the values of Equation 4 Lambert-Beer Law are known, so the relative losses were calculated according to their absorbance. To calculate relative losses we took the absorbance of the nanofluids for a wavelength of 500 nm.

Table 6 Absorbance at 500 wavelenght for nanofluids based on MWCNT-COOH

MWCNT/Days	0	1	4	7	14
DF0 0,1%	0.818	0.723	0.380	0.282	0.192
DF2'5 0,1%	0.824	0.725	0.375	0.262	0.202
DF5 0,1%	0.727	0.628	0.404	0.261	0.184
DF10 0,1%	0.867	0.732	0.384	0.244	0.185
MD0 F5-K3	0.763	0.669	0.364	0.239	0.188
SD0 F5-K1,9 0.1%	0.866	0.729	0.366	0.244	0.178

We calculated the percentage of absorbance losses respect to the zero day of each of the mixtures. Then, we can determine which one gets the least lost.

Table 7 Relative absorbance loses for nanofluids based on MWCNT-COOH particles

MWCNT/Days	0	1	4	7	14
DF0 0,1%	0%	12%	54%	66%	77%
DF2'5 0,1%	0%	12%	54%	68%	75%
DF5 0,1%	0%	14%	44%	64%	75%
DF10 0,1%	0%	16%	56%	72%	79%
MD0 F5-K3 0,1%	0%	12%	52%	69%	75%
SD0 F5-K1,9 0.1%	0%	16%	58%	72%	79%

Among all nanofluids in which we use MWCNT-COOH, the most stable is the nanofluid based on DF5 0.1%. During the first 4 days after mixing, it presents relative loss of 44%, which is 10% less than is obtained for rest of the nanofluids.

4.3. Results of selection process

Once obtained the results, we proceed to select the most stable one on terms of precipitation of CNT, viscosity and thermal conductivity properties. The stability of the mixture does not depend only on the type of CNT, but also on the polymer used. To make the selection of the most stable mixture, we compared the concentrated results and the relative concentration losses for each

nanofluid.

It should be mentioned that none of nanofluid is completely stable, because on the fourth day we can notice 80% of absorbance decrease in the case of MWCNT and 50% decrease for MWCNT-COOH, which is directly correlated with sedimentation of carbon nanotubes. Therefore, it is contemplated that the use of this nanofluid be in a period of two days from its mixture.

Comparing the absorbance results, we can observe that the values obtained for MWCNT are much higher than for MWCNT-COOH, point three five and point zero eight, respectively. On the other hand, the relative absorbance losses are five times higher in the case of MWCNT.

Taking into account all these results, we have selected the nanofluid with DF2.5 0.1% polymer and MWCNT nanotubes. Since the possible use is in a short period, this mixture has a high absorbance that counteracts its relative losses.

4.3.1. Rheology results for nanofluids based of MWCNT particles

Once the most stable nanofluid is determined, we must study the influence of concentration of MWCNT on nanofluid. We performed thermal conductivity and viscosity tests for three concentrations of MWCNT: 0.01wt%, 0.1wt% and 1wt%.

To perform mentioned tests we have mixed the nanofluids; first, we will mix the polymer DF2.5 0.1% with Kalenol 22 during 24 h, then we will disperse the MWCNT with the help of the ultrasonic device. During the process, temperature and energy data were collected to verify that the process was carried out under stable conditions. During the process we mix 170 mg of nanofluid, therefore the time and energy applied is greater than that obtained in the subsequent studies.

Table 8 Mixing concentration data for nanofluids based on of MWCNT

Data								
Time (min)	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*6´40*
Energy (kJ)	*0*	*12*	*24*	*36*	*48*	*60*	*72*	*80*
DF 2.5 0.1%				***Types/temperatures***				
0.01wt% MWCNT	*23*	*46*	*62*	*77*	*86*	*96*	*110*	*118*
0.1wt% MWCNT	*23*	*43*	*60*	*75*	*82*	*92*	*99*	*108*
1wt%MWCNT	23	46	*66*	*87*	*95*	*108*	*110*	*114*

Thanks to the collected data, we graphed all the cases to verify that the process was in stable conditions.

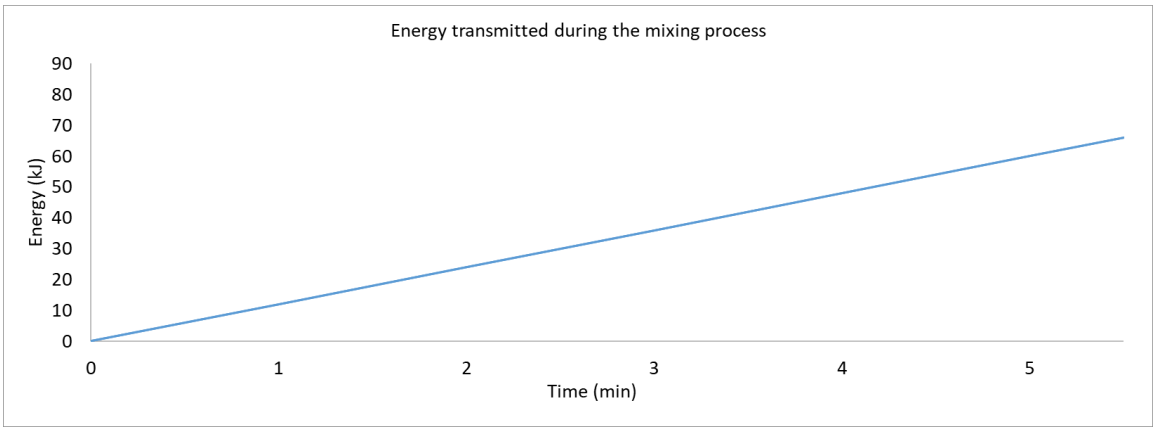

Figure 4-30 Ultrasonic device energy for different concentration nanofluids based on MWCNT

We obtained a straight line since the process followed a linear relationship between the application of energy and time.

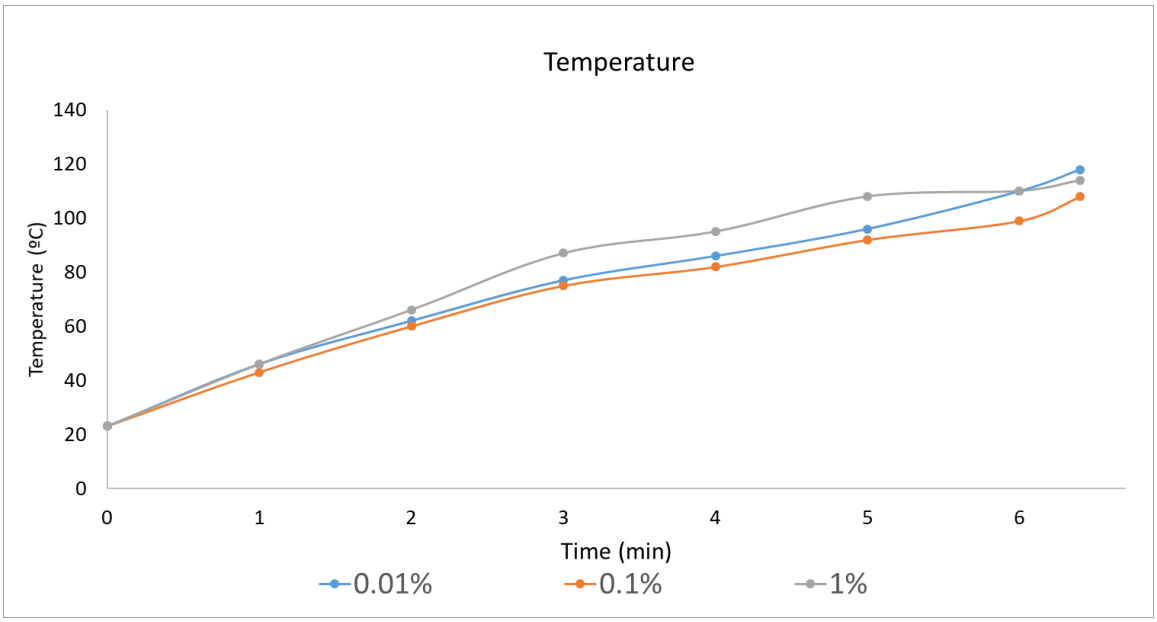

Figure 4-31 Temperature evolution for mixing nanofluids based on MWCNT

In this graph, it is observed that the initial temperature of the three nanofluids corresponds to the ambient temperature. The evolution of these three nanofluids are similar, but highlighting that the one corresponding to 0.01% of MWCNT obtains higher temperatures than the nanofluid with a concentration of 0.1% MWCNT.

In these cases, we did not test the absorbance, since it has been accepted that the range of use of these nanofluids would be between zero and one day, during that interval the concentration would be opaque. Since, ten and a hundred multiply the amount of MWCNT respect to the first case study.

First, we carried out viscosity tests to determine the relationship between the amount of MWCNT and the viscosity of the nanofluids, for which, we use the aforementioned rheometer. On this experiment, the viscosity and shear force were determined by varying the temperature of the nanofluids.

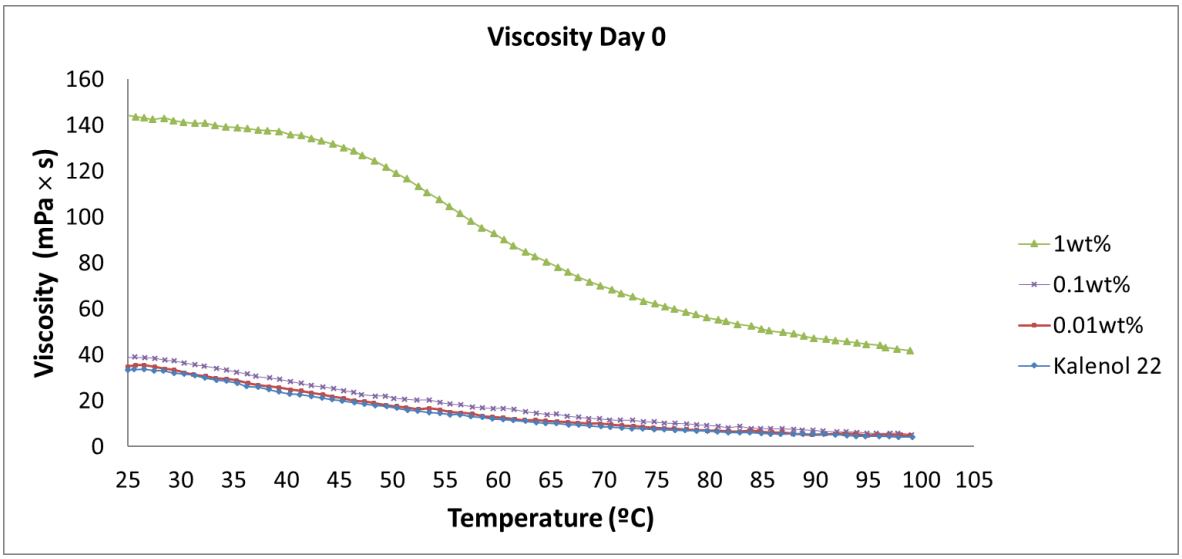

Figure 4-32 Absolute viscosity of nanofluids based on MWCNTs Day 0

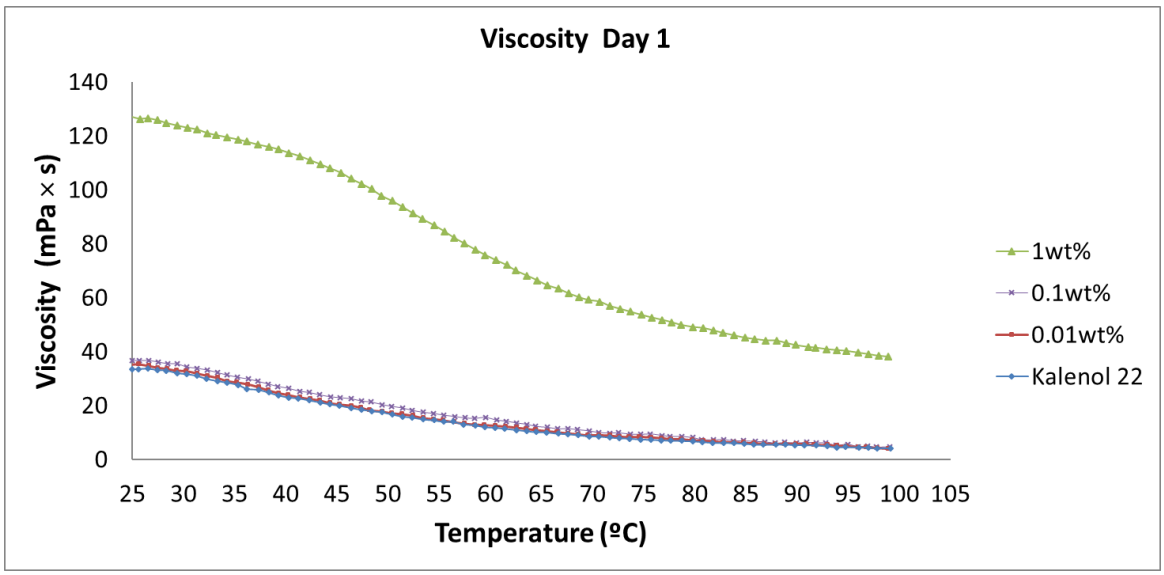

Figure 4-33 Absolute viscosity of nanofluids based on MWCNTs Day 1

The obtained values of absolute viscosity for the four nanofluids, the mixing day and the day after it, present the same evolution between temperature and viscosity. The values obtained for the concentrations of 0.01 % and 0.1 % of MWCNT and Kalenol 22 are very similar; at 25 ºC the values obtained around 35 mPa×s, decreasing appreciably up to values of 4 mPa×s at 100 ºC. In the case of the concentration of 1wt% of MWCNT at 25 ºC it presents values point three six times higher, at 100 ºC values eight times higher than those obtained by the rest of the nanofluids.

4.3.2. Rheology results for polymers

As in the previous section, we must check the relationship, if it exists, between the amount of polymers added to the dissolution and its properties. Therefore, we have performed kinetic viscosity and dynamic viscosity tests.

First, we perform the kinetic viscosity test thanks to the measuring device, viscometer, described in section Devices.

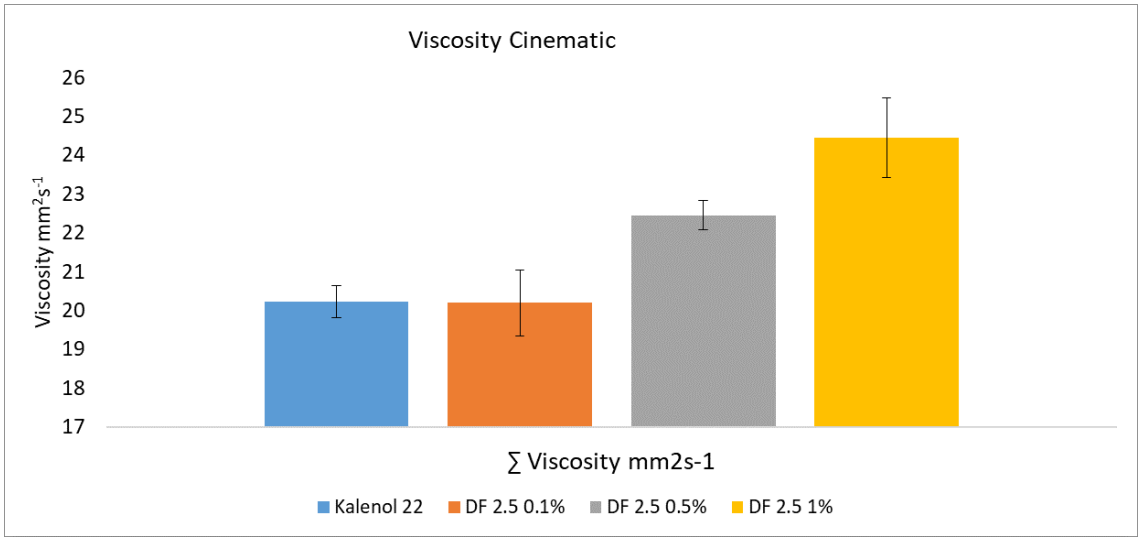

Figure 4-34 Kinematic viscosity test, left to right (Kalenol 22, 0.1%, 0.5%, 1%)

Table 9 Data for polymers solutions.

Nanofluids	∑ Viscosity mm^2s^{-1}	Variation Kalenol%	Standard deviation
Kalenol 22	20.23	0.0%	±2.07%
DF 2.5 0.1%	20.19	-0.167%	±4.17%
DF 2.5 0.5%	22.45	10.980%	±1.67%
DF 2.5 1%	24.45	20.860%	±4.18%

The results showed that the polymer dissolution 0.1wt% has almost identical viscosity to that of pure Kalenol 22. On the other hand, 0.5wt% and 1wt% concentrations obtained higher results, with an increase of 10% and 20% respectively. Secondly, we perform the dynamic viscosity tests for different temperatures (25-100 ºC).

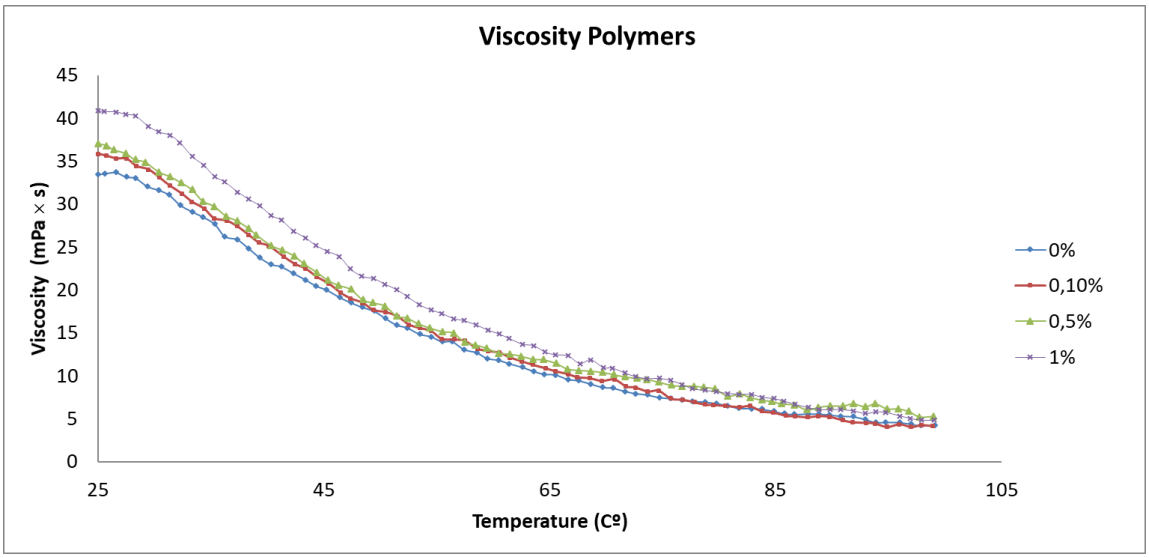

Figure 4-35 Absolute viscosity of polymers dissolution day 0

Once the data is obtained, we calculated the variation of each one with respect to Kalenol 22, in order to determine the existing relationship according to the temperature.

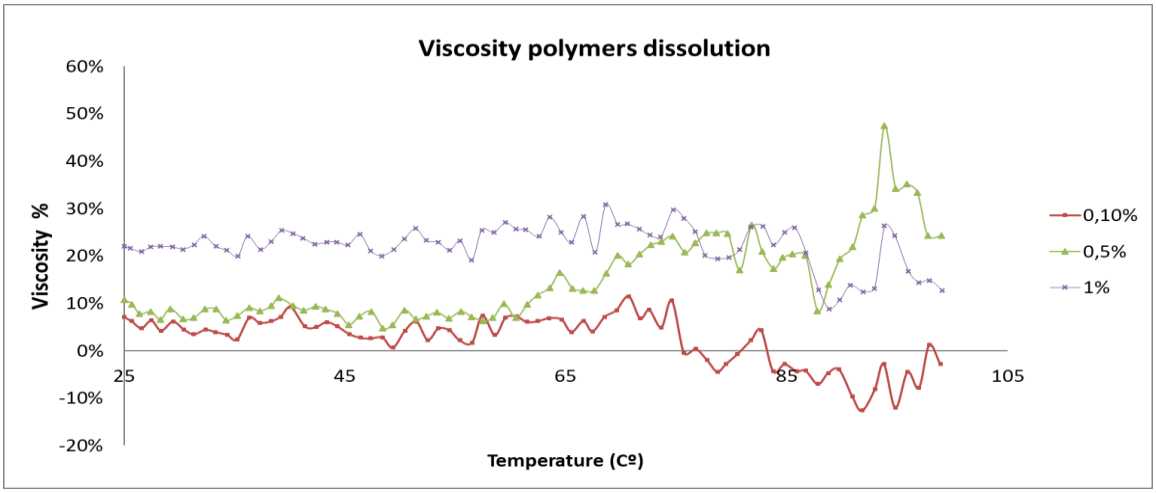

Figure 4-36 Variation from Kalenol of polymers dissolution

The nanofluid with 0.1wt% concentration of polymer has a viscosity variation less than 7%, until reaching temperatures around 75 °C, then it get between -10% and 0%, till 100 ºC. The second one with 0.5wt% presents an opposite behaviour, between 25 and 60 ºC the viscosity variation is around 10%, from this temperature the difference increases up to average values of 25%, between 60 ºC and 100 ºC. The last nanofluids with 1wt%, returns to behave in a similar way to the first, until 75 ºC the variation of the viscosity is around 20%, and between 75 ºC and 100 °C the variation of the viscosity decreases appreciably to values of 10%.

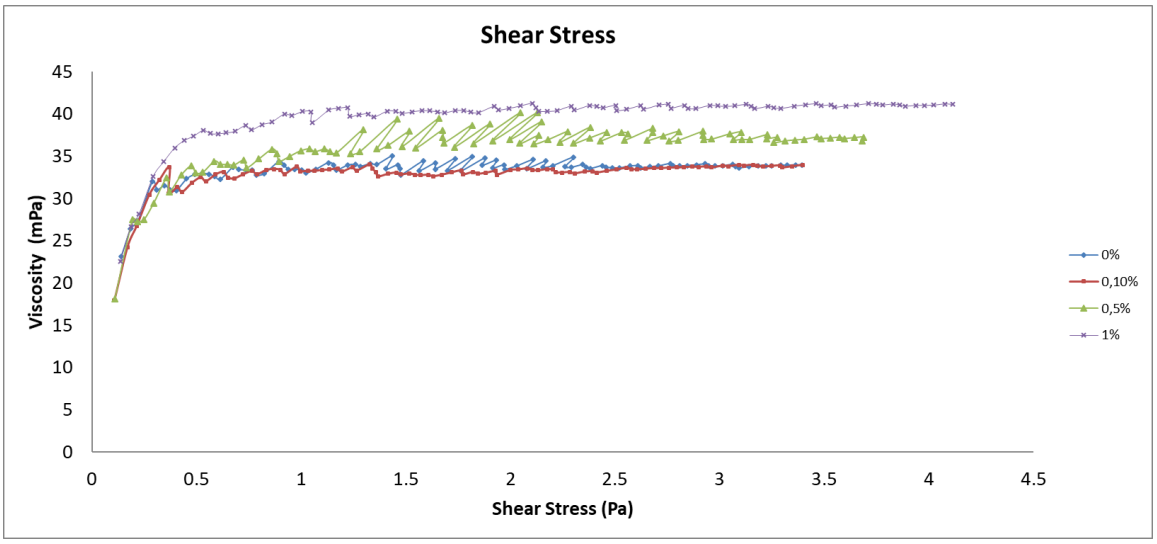

Figure 4-37 Shear stress evolution for different concentration of polymers

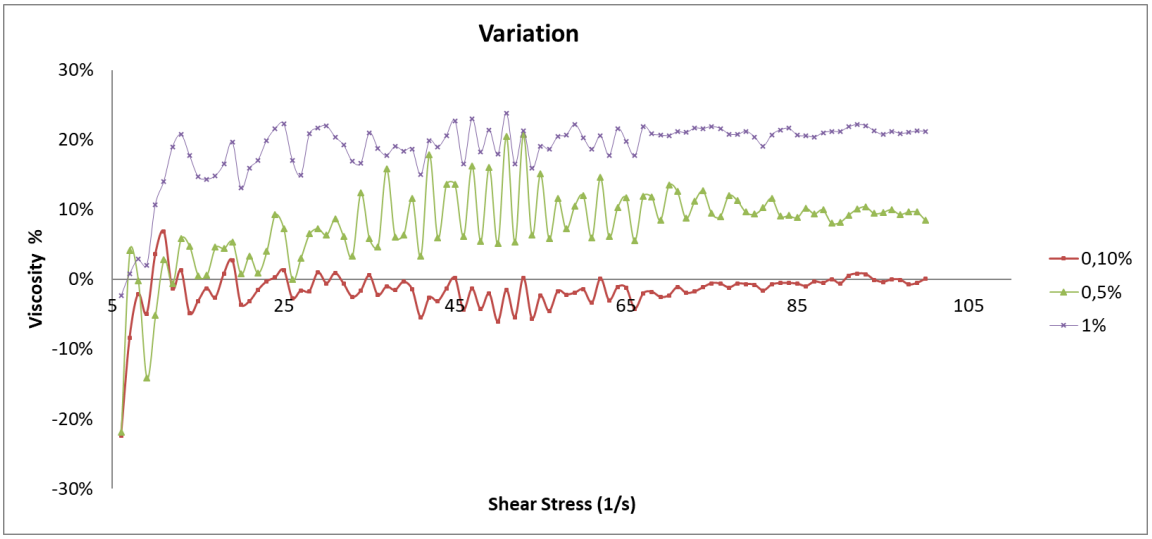

Figure 4-38 Shear stress variation from Kalenol of polymers dissolution.

The results of the shear stress show no variation influence for 0.1wt%, although for 0.5 wt% and 1wt% the variation from Kalenol is 10% and 20% respectively.

4.3.3. Thermal conductivity results

Finally, we did thermal conductivity tests for three nanofluids and three polymer dissolutions, in order to determine if there is any influence between the concentration of MWCNT or polymer dissolution over thermal conductive properties. We used the measuring device described on section 0.

We started by the polymers dissolution; there are three different concentrations: 0.01wt%, 0.1wt% and 1wt%.

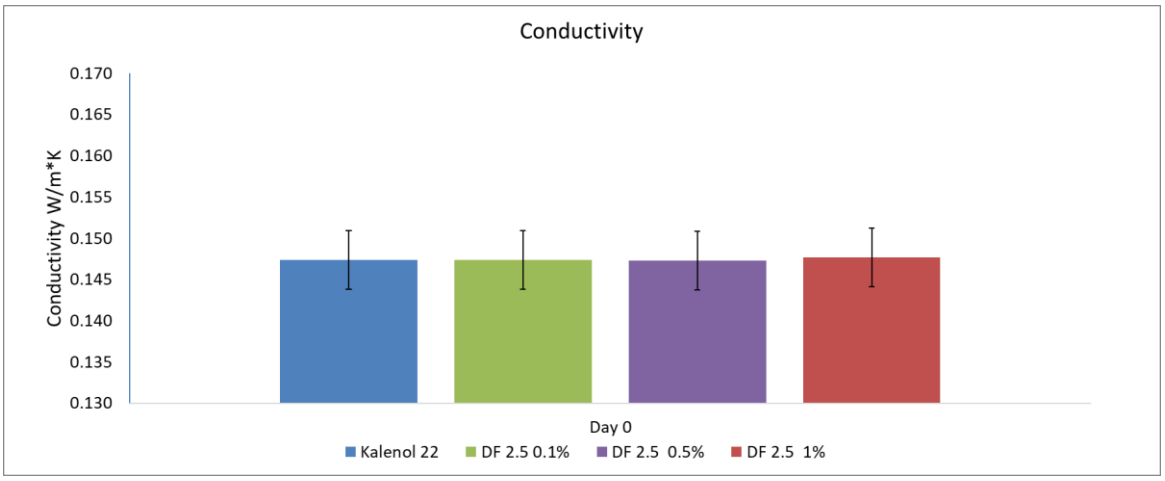

Figure 4-39 Thermal conductivity test day 0, left to right (Kalenol 22, 0.1%, 0.5%, 1%)

Table 10 Average conductivity, standard deviation, and relative variation from Kalenol 22 for polymers dissolution

		Kalenol 22	DF 2.5 0.1%	DF 2.5 0.5%	DF 2.5 1%
∑ Conductivity W/m*K	Day 0	0.1474	0.1474	0.1473	0.1477
Standard desviation ±%	Day 0	2.3978	2.3889	2.4089	2.4056
Variation from Kalenol %	Day 0	0%	0.0057%	-0.0452%	0.2092%

As the results show, there is no significant influence, on the mixing day, between thermal conductivity and polymer concentration. For all the cases studied, the variation in the results is less than 0.2%.

To conclude this research project, we studied the relationship between the concentration of MWCNT and the thermal conductivity.

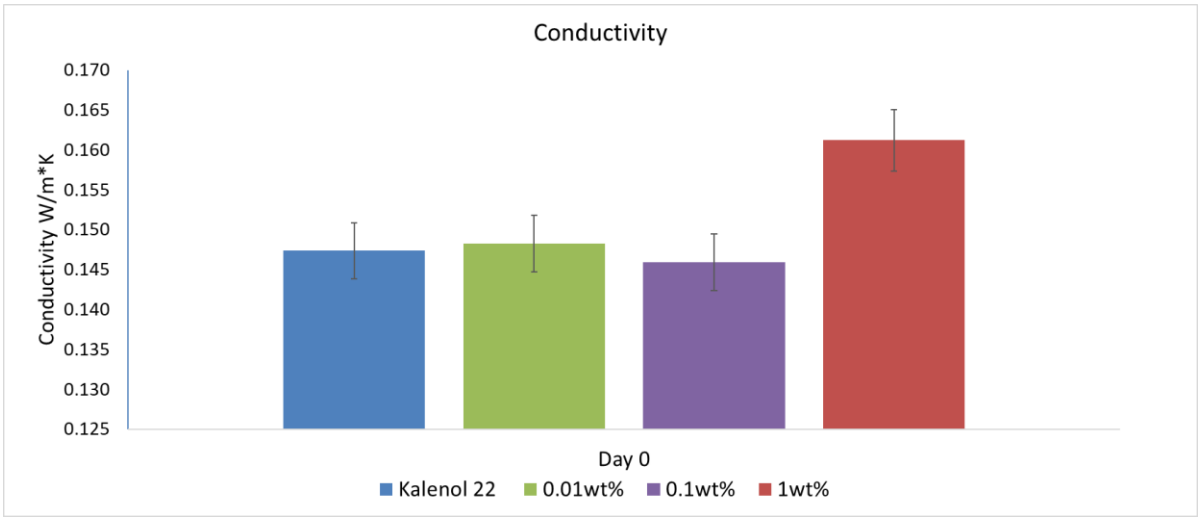

Figure 4-40 Thermal conductivity test day 0, left to right (Kalenol 22, 0.01wt%, 0.1wt%, 1wt%)

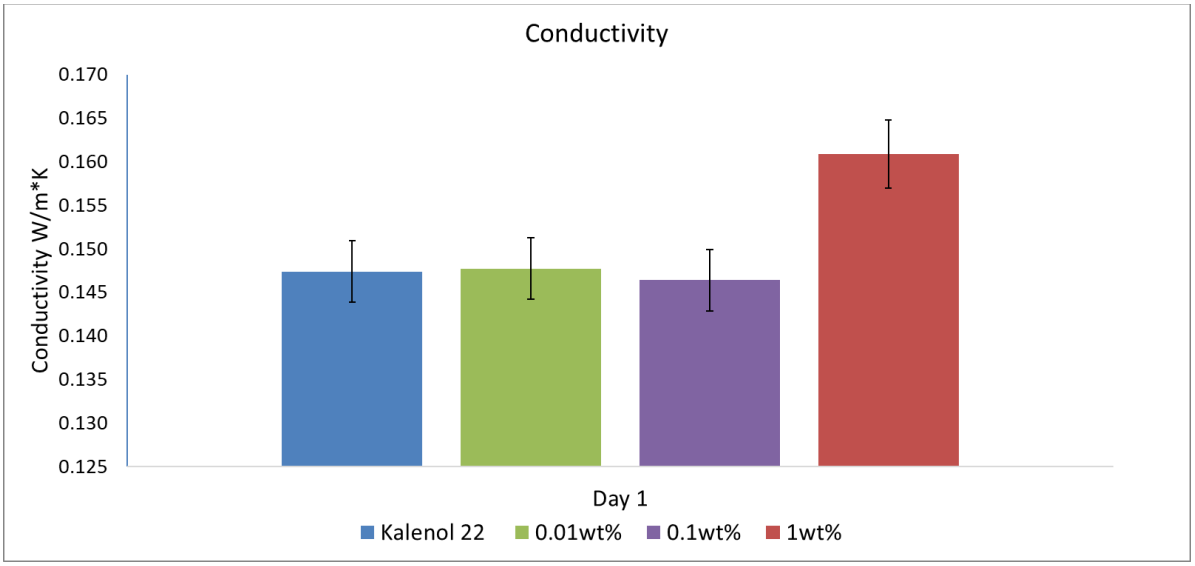

Figure 4-41 Thermal conductivity test day 1, left to right (Kalenol 22, 0.01%, 0.1%, 1%)

Table 11 Conductivity and error data related to MWCNT concentration

		Kalenol 22	DF 2.5 0.1% 0.01wt%	DF 2.5 0.1% 0.1wt%	DF 2.5 0.1% 1wt%
∑Conductivity $\frac{W}{m \times K}$	Day 0	0.147	0.1482	0.1459	0.1612
	Day 1	0.147	0.1477	0.1464	0.1609
Standard desviation ±%	Day 0	2.398	2.411	2.420	2.410
	Day 1	2.398	2.391	2.404	2.416
Variation from Kalonol 22 %	Day 0	0%	0.596%	-0.970%	9.38%
	Day 1	0%	0.241%	-0.647%	9.15%

The values obtained, on the mixing day, for the nanofluids with 0%, 0.01wt% and 0.1wr% concentrations, have a very similar thermal conductivity values, around 0.147 W/mK, the variation from Kalenol differences between them are lower to 1% respect. Nevertheless, in the case of nanofluid with 1% concentration, the difference is considerable, reaching values of 0.1612 W/mK, which is an increase of close to 10% in respect to Kalenol 22.

5. Conclusion

As first conclusion of this research project, I have to affirm that no nanofluid is stable on precipitation of CNT during a period greater than two days since its preparation or mixing day. Because in all the nanofluids majority of CNTs precipitates in two or three days after the mixing, therefore, it is recommended that the nanofluids should be used in a short period, so the rest of the study was based on the properties of nanofluids obtained in this period.

When it comes to selecting between the two CNT types studied, MWCNT and MWCNT-COOH, it can be concluded that MWCNT have a three-fold higher absorbance for the same weight of dispersed CNT. Due to the density of the MWCNT, they obtain a higher concentration with lower amounts of CNT, so we chose the MWCNT to continue with the study.

About all the surfactants studied, the decision is based on the precipitation stability of the CNT in corresponding nanofluid. Of all the nanofluids, the lowest relative losses of concentration for the period of three days since their mixing is in the nanofluid based on DF 2.5 surfactant.

Regarding the influence of surfactant quantity on thermal conductive properties of nanofluids, it is stated that there is no influence of amount of surfactant added and that the values obtained are similar in all surfactant solutions, up 1 wt% of polymer (which equals to 2 wt% of surfactant). Concerning the kinematic viscosity of nanofluids, for 0.1 wt% concentration of polymer solution of DF 2.5, no difference in the results was observed in respect to the base fluid, quenching oil Kalenol 22. But, for concentrations of 0.5 wt% and 1 wt% we have an increase of 10% and 20% in value of kinematic viscosity, respectively. Nanofluids with 0.01 wt%, 0.1 wt% and 1 wt% of MWCNT have 5%, 16% and 320% higher dynamic viscosity compared to Kalenol. Also, we can affirm that the more MWCNT present in nanofluid, the more viscous the fluid is. In addition, we can conclude that, at high shear stress, the dynamic viscosity of polymer solutions of 0.1 wt%, 0.5 wt% and 1 wt% present an increase, compared to Kalenol 22, of 0%, 9% and 21% respectively.

Thermal conductivity of nanofluid with concentration of 1wt% of MWCNT has an increase of 9% while the other two nanofluids (0.1 and 0.5 wt% of MWCNT) show no change when comapred to Kalenol 22

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