

# A Review :- Carbon nanotubes: Properties and Viscosity of Nanofluids

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**Abstract:** The aim of this paper is to present the broad range of nanofluid based current and future applications. Some barriers and challenges are also focused for implementing these new class of working fluids. The major developments in both the basic research and the industrial application of the carbon nanotubes are reviewed. The theoretical efforts are directed to the understanding the amazing mechanical, electronic, transport, vibration, thermal, etc., properties most of them owing their uniqueness to the quasi-one-dimensional sp<sup>2</sup>-bonded structure of the carbon nanotubes.

**Keywords:** Nanofluid, Nanotubes.

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## 1. INTRODUCTION

Elemental carbon in the sp<sup>2</sup> hybridization can form a variety of amazing structures. Apart from the well-known graphite, carbon can build closed and open cages with honeycomb atomic arrangement. First such structure to be discovered was the C<sub>60</sub> molecule by Kroto et al. [1]. Although various carbon cages were studied, it was only in 1991, when Iijima [2] observed for the first time tubular carbon structures. The nanotubes consisted of up to several tens of graphitic shells (so-called multi-walled carbon nanotubes (MWNTs)) with adjacent shell separation of 0.34 nm, diameters of 1 nm and large length/diameter ratio. Two years later, Iijima and Ichihashi [3] and Bethune et al. [4] synthesized single-walled carbon nanotubes (SWNTs). Nowadays, MWNTs and SWNTs are produced mainly by three techniques: arc-discharge, laser-ablation, and catalytic growth. The synthesized nanotube samples are characterized by means of Raman, electronic, and optical spectroscopies.

Nanofluid is a two-phase system consisting of a carrier medium (liquid or gas) and nanoparticles. The term nanofluid was first used by Choi [11] to describe a suspension consisting of carrier liquid and solid nanoparticles. In our papers [12-15], nanoparticle suspensions in gases (gas nano- suspensions) are also called nanofluids. This is done for several reasons: 1) both gas and liquid nanosuspensions have extensive practical applications; 2) many properties of nanofluids and gas nanosuspensions are very similar, especially if the carrier gas is dense; 3) in some cases, transport processes in gas and liquid suspensions of nanoparticles are studied using the same methods or models. For example, the procedure of molecular dynamics simulation is the same in both cases. Typical carrier fluids are water, organic liquids (ethylene glycol, oil, biological liquids, etc.), and polymer solutions. The special properties of nanoparticles are due to their small size. Nanofluids have peculiar transport properties. In contrast to large dispersed particles, nanoparticles do not sediment and erode the channels in which they move. For these and some

other reasons, nanofluids have already been successfully used in various applications.

### I. Types of Carbon Nanotubes:-

#### 1. Single -walled nanotubes (SWNTs)

Most single-walled nanotubes (SWNTs) have a diameter of close to 1 nanometer, with a tube length that can be many millions of times longer. The structure of a SWNT can be conceptualized by wrapping a one-atom-thick layer of graphite called graphene into a seamless cylinder. The way the graphene sheet is wrapped is represented by a pair of indices (n,m). The integers n and m denote the number of unit vectors along two directions in the honeycomb crystal lattice of graphene. If m = 0, the nanotubes are called zigzag nanotubes, and if n = m, the nanotubes are called armchair nanotubes. Otherwise, they are called chiral. The diameter of an ideal nanotube can be calculated from its (n,m) indices as follows

$$d = \frac{a}{\pi} \sqrt{(n^2 + nm + m^2)} = 78.3 \sqrt{((n+m)^2 - nm)} \text{ pm},$$

where a = 0.246 nm.

SWNTs are an important variety of carbon nanotube because most of their properties change significantly with the (n,m) values.

#### 2. Multi-walled nanotubes (MWNTs):-

Multi-walled nanotubes (MWNTs) consist of multiple rolled layers (concentric tubes) of graphene. There are two models that can be used to describe the structures of multi-walled nanotubes. In the Russian Doll model, sheets of graphite are arranged in concentric cylinders, e.g., a (0,8) single-walled nanotube (SWNT) within a larger (0,17) single-walled nanotube. In the Parchment model, a single sheet of graphite is rolled in around itself, resembling a scroll of parchment or a rolled newspaper. The interlayer distance in

multi-walled nanotubes is close to the distance between graphene layers in graphite, approximately 3.4 Å.

Double-walled carbon nanotubes (DWNTs) form a special class of nanotubes because their morphology and properties are similar to those of SWNTs but their resistance to chemicals is significantly improved. This is especially important when functionalization is required to add new properties to the CNT. In the case of SWNTs, covalent functionalization will break some C=C double bonds, leaving "holes" in the structure on the nanotube and, thus, modifying both its mechanical and electrical properties.

## II. Synthesis of CNTs

The MWNTs were first discovered in the soot of the arc-discharge method by Iijima [2]. This method has been used long before that in the production of carbon fibers and fullerenes. It took 2 years to Iijima and Ichihashi [3], and Bethune et al. [4] to synthesize SWNTs by use of metal catalysts in the arc-discharge method in 1993. A significant progress was achieved by laser-ablation synthesis of bundles of aligned SWNTs with small diameter distribution by Smalley and co-workers [5]. Catalytic growth of nanotubes by the chemical vapor decomposition (CVD) method was first used by Yacaman et al. [6]. The industrial application of the carbon nanotubes requires the development of techniques for large-scale production of defect-free nanotubes. Major techniques will be considered as follows:-

### a) Arc-discharge

In 1991, Iijima reported the preparation of a new type of finite carbon structures consisting of needle-like tubes [2]. The tubes were produced using an arc-discharge evaporation method similar to that used for the fullerene synthesis. The carbon needles, ranging from 4 to 30 nm in diameter and up to 1 mm in length, were grown on the negative end of the carbon electrode used for the direct current (dc) arc-discharge evaporation of carbon in an argon-filled vessel (100 Torr) (see Fig. 1). Transmission electron microscopy (TEM) revealed that each of the needles comprised coaxial tubes of graphitic sheets, ranging in number from 2 to about 50, later called multi-walled carbon nanotubes. On each of the tubes the carbon-atom hexagons were arranged in a helical fashion about the needle axis. The helical pitch varied from needle to needle and from tube to tube within a single needle. The tips of the needles were usually closed by curved, polygonal, or cone-shaped caps. A growth model was proposed in which the individual tubes have spiral growth steps at the tube ends.

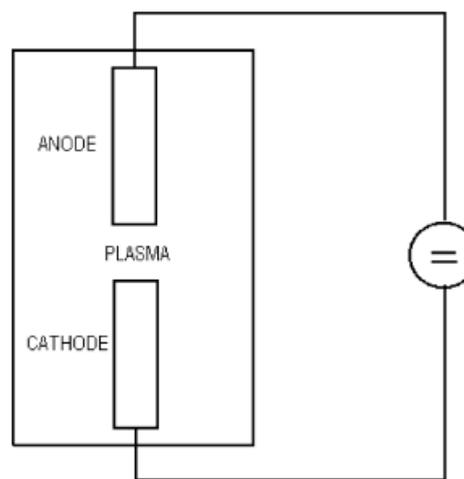


Fig. 1. Arc-discharge scheme. Two graphite electrodes are used to produce a dc electric arc-discharge in inert gas atm.

### b) Laser-ablation

In 1996, Smalley and co-workers produced high yields (>70%) of SWNTs by laser-ablation (vaporization) of graphite rods with small amounts of Ni and Co at 1200 8C [5] (see Fig. 2). The Xray diffraction and TEM showed that the synthesized nanotubes were remarkably uniform in diameters and that they formed ropes (or bundles) 5–20 nm in diameter and tens to hundreds of micrometers long. The ropes formed a two-dimensional (2D) triangular lattice with lattice constant  $a = 1.7$  nm through van der Waals bonding. The ropes were metallic and it was argued that a particular tube (10, 10), might be the dominant component. The growth of the nanotubes was explained by a "scooter" mechanism (Fig. 3). In this mechanism a single Ni or Co atom chemisorbs onto the open edge of a nanotube. The metal atom must have a sufficiently high electronegativity as to prevent formation of fullerenes and it must be highly effective in catalyzing the nanotube growth. The metal atom circulates ("scoots") around the open-end of the tube and absorbs small carbon molecules and converts them into graphite-like sheet. The tube grows until too many catalyst atoms aggregate on the end of the nanotube.

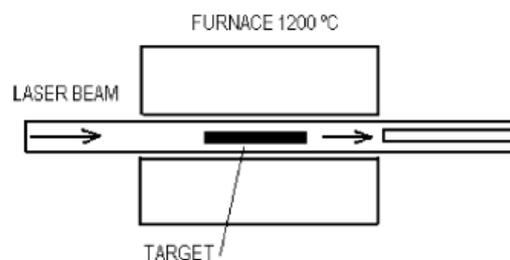


Fig. 2. Laser-ablation scheme. Laser beam vaporizes target of a mixture of graphite and metal catalyst (Co, Ni) in a horizontal tube in a flow of inert gas at controlled pressure and in a tube furnace at  $\_1200$  °C. The nanotubes are deposited on a water-cooled collector outside the furnace.

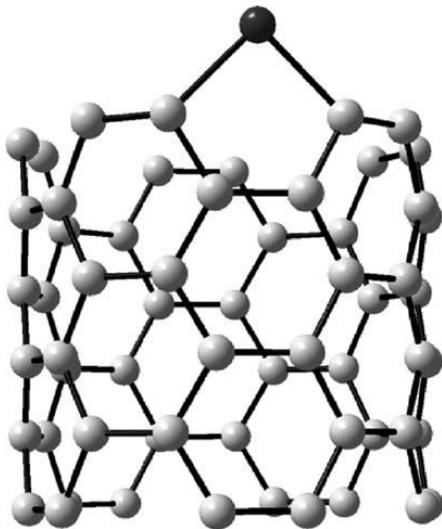


Fig. 3. Illustration of the “scooter” mechanism for growth in the case of a (10, 10) SWNT assisted by a Ni atom chemisorbed onto the open edge of the nanotubes.

### c) Catalytic growth

Carbon filaments and fibers have been produced by thermal decomposition (or chemical vapor decomposition) of hydrocarbons in the presence of a catalyst since the 1960s (see, e.g. [7,8]). A similar approach was used for the first time by Yacaman et al. [6] in 1993 and in 1994 Ivanov and co-workers [9,10] to grow MWNTs. The CVD technique has been subsequently improved and optimized. Generally, the CVD process includes catalyst-assisted decomposition of hydrocarbons, usually ethylene or acetylene, in a tube reactor at 550–750 °C and growth of carbon nanotubes over the catalyst upon cooling the system (see Fig. 4). Best results are obtained with Fe, Ni or Co nanoparticles as catalyst. The same catalysts are found optimal in the arc-discharge and laserablation techniques, which is in favor of a common nanotube growth mechanism. It was argued that the nanotubes grow out of the catalyst nanoparticle embedded in the pores by tip growth or base growth depending on the contact force between the catalyst particles and the substrate [7,10].

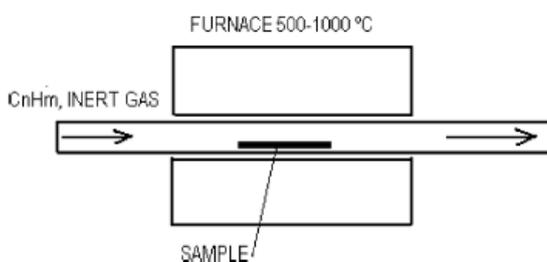


Fig. 4. Catalytic growth scheme. Hydrocarbon gas is decomposed in a quartz tube in a furnace at 550–750 °C over a transition metal catalyst (a CVD reactor).

### III. Preparation of nanofluids:-

To prepare nanofluids by suspending nanoparticles into base fluids, some special requirements are necessary such as even suspension, durable and stable suspension, low agglomeration of particles and no chemical change of fluid. There are three general methods used for preparation of stable nanofluid: (1) Addition of acid or base to Change the pH value of suspension (2) Adding surface active agents and/or dispersants to disperse particles into fluid (3) Using ultrasonic vibration.[20] The most common two step preparation process is shown in Figure 5.

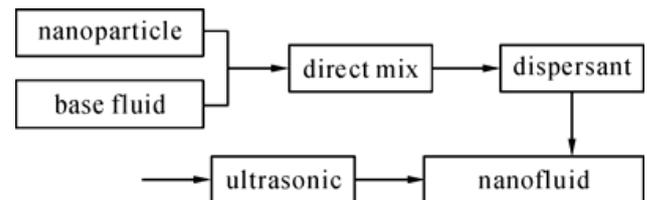


Fig 5: Two step preparation process of nanofluid

### IV. Benefits of use of nanofluids

Nanofluids possess the following advantages as compared to conventional fluids which makes them suitable for various applications[21]

1. Absorption of solar energy will be maximized with change of the size, shape, material, and volume fraction of the nanoparticles.
2. The suspended nanoparticles increase the surface area and the heat capacity of the fluid due to the very small particle size.
3. The suspended Nanoparticles enhance the thermal conductivity which results improvement in efficiency of heat transfer systems.
4. Heating within the fluid volume, transfers heat to a small area of fluid and allowing the peak temperature to be located away from surfaces losing heat to the environment.
5. The mixing fluctuation and turbulence of the fluid are intensified.
6. The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid.
7. To make suitable for different applications, properties of fluid can be changed by varying concentration of nanoparticles.

### V. Applications of Nanofluids:-

#### 1. Applications in automotive:-

In automobile arena, nanofluids have potential application as engine coolant, automatic transmission fluid, brake fluid, gear lubrication, transmission fluid, engine oil and greases. The first application in cooling automatic power

transmission system done by Senthilraja et al (2010) show that CuO nanofluids have the lowest temperature distribution and accordingly the best heat transfer performance.

## 2. Nanofluid as coolant:-

The use of nanofluids as coolants would allow for smaller size and better positioning of the radiators. There would be less fluid due to the higher efficiency, coolant pump could be shrunk and truck engines could be operated at higher temperatures allowing for more horsepower.

## 3. Nanofluid in Fuel:-

It was shown that the combustion of diesel fuel mixed with aqueous aluminum nanofluid increased the total combustion heat while decreasing the concentration of smoke and nitrous oxide in the exhaust emission from the diesel engine. It is due to the high oxidation activity of pure Al which allows for increased decomposition of hydrogen from water during the combustion process.

## 4. Nanofluid in Brake Fluids:-

During the process of braking, the produced heat causes the brake fluid to reach its boiling point, a vapor lock is created that retards the hydraulic system from dispersing the heat caused from braking. It will create a brake malfunction and poses a safety hazard in vehicles. Nanofluids with enhanced characteristics maximize performance in heat transfer as well as remove any safety concerns.

## VI. Viscosity of Molecular Mixtures and Gas Nanosuspensions

Nanoparticle size varies within two orders of magnitude. At the lower limit are nanoparticles with characteristic sizes of one to a few nanometers. These particles are only a few times larger than conventional inorganic molecules and are similar in size to some organic molecules. At the upper limit are nanoparticles with sizes of 80 - 100 nm. In fact, they are close in size to usual Brownian particles (in Perrin's experiments [16], the size of Brownian particles was  $10^{-4}$  -  $10^5$  cm). For this reason, it is clear that the mechanisms of transport of small nanoparticles should be close to those of conventional molecules, the mechanisms of transport of large nanoparticles should be similar to those of Brownian particles. However, the indicated mechanisms of transport processes are significantly different. Therefore, to clarify the momentum transfer characteristics of nanofluids that determine their viscosity, it is necessary to analyze both molecular systems and disperse systems with large macroscopic particles.

## VII. Viscosity of Coarse Suspensions

Considering the motion of a small particle in a fluid, he determined the flow field perturbations caused by it, then calculated the effective stress tensor, and, as a result, obtained formula for the effective viscosity coefficient.

$$\eta = \eta_0 [1 + 2.5\phi]$$

$\eta_0$  = Viscosity of the carrier fluid

$\phi$  = volume fraction of dispersed particles.

The volume concentration of particles was assumed to be small enough to take into account the perturbations caused by an isolated particle. Thus, the additional momentum transfer in the liquid due to the presence of dispersed particles was determined only by hydrodynamic processes. This hydrodynamic interaction leads to an increase in the energy dissipation of viscous friction. As a result, the viscosity increases linearly with increasing particle concentration. Theory incorporating these effects was developed by Batchelor [17]. In addition, he took into account the contribution of Brownian motion to the average stress and obtained the following formula for the effective viscosity, accurate to the second order in concentration [18]

$$\eta = \eta_0 [1 + 2.5\phi + b\phi^2]$$

Where the coefficient  $b = 6.2$

## VIII. Dependence of Nanofluid Viscosity on Nanoparticle Concentration and Size of Nanoparticles

The viscosity of nanofluids has been persistently investigated over about fifteen years in more than thirty groups throughout the world. However, a universal formula that would describe the viscosity coefficient of any nanofluid has not been derived. Moreover, measurements often lead to diametrically opposite results. It was long thought, and is still being argued by many, that similarly to the viscosity of conventional suspensions, the viscosity of nanosuspensions is determined only by the mass concentration of particles.

Experimentalists came to the understanding that nanoparticle size can affect the viscosity of nanofluids. Determining the dependence of the viscosity on nanoparticle size is much more difficult than determining viscosity for a particular size. First, measurements should be performed simultaneously for, at least, three or four sizes of nanoparticles in the same base fluid. Second, one has to carefully monitor the particle size distribution in the nanofluid. Third, it is possible that many have been discouraged by conflicting information on the influence of nanoparticle size. Thus, it was concluded that the viscosity increases with increasing size of nanoparticles [19]

## IX. Conclusion:-

It is now a widely-shared view that carbon-based materials are likely to be a major field in the twenty first century technology. The problems of nanoparticle aggregation, settling, and erosion all need to be examined in detail in the applications. We can say that once the science and engineering of nanofluids are fully understood and their full potential researched, they can be reproduced on a large scale and used in many applications. All experimental data and molecular dynamics simulations suggest that at a fixed volume concentration of nanoparticles, the nanofluid viscosity is significantly higher than the viscosity of conventional suspensions.

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