Review Of Heat Transfer Enhancement In Energy Conversion Systems; Nanotechnology

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Abstract. Different heat transfer fluids with very high thermal stability are highly desirable for heat exchangers. Inadequate understanding on the basic principle of nanofluid flow, unsatisfactory experimental data on nanofluid heat transfer and general context for heat transfer correlation is yet to be established. The work under focus will be on highlighting working principles, problems hindering practical application of unconventional heat exchangers devices, and the various means of utilizing nanotechnology in improved efficiency. The study investigates experiments on heat exchangers in the last decade, the gap in knowledge and future applications of nanotechnology in improving heat transfer. This review summarizes, the significant advances of various nanotechnology in heat transfer application of recent energy conversion system.

1. Introduction
It is almost impossible to go through any industry today without noticeably seeing the presence of heat transfer, this is cause wherever there is a difference in the temperature that exists in a medium or within medium there is bound to be that tendency that will cause the more energy medium to transfer some of its heat to the less energetic medium the main objective of this for the entire system to achieve equilibrium or uniformity. Whether its air conditioning, refrigeration, ventilation, heating or its just coolant trying to stabilize the temperature of a machine. Almost a century since Maxwell (1973) started working on millimeter or micrometer particles but, ever since this concept (theory) of finding better development of material for engineering. There has been tremendous growth in this area especially with the development nanomaterials. With its characteristics of been fast economical and also finding new applications in various forms we never thought of, this margin is likely to grow in near future. Researchers all over the world are toiling all day and night to get new ways to better establish and give new meaning and application to nanofluid as engineering materials. (Fakehinde, 2019) Energy is a wealth generator as such the reason for interest the world shows on it. As at the time fossils fuel was first discovered we were only interested in in usage but as the years progressed more development came in with researchers pushing for the optimization of these system at later years prediction of expected depletion was also forecasted was also hinted and also continued threats of global warming and the resulting green as effects, experts have been on the look trying finds ways of mitigating the challenges posed to the world. Nanomaterial have been seen as an option in enhancing energy systems in conversion. Apart from the reduction of greenhouse gases effects, its cost-effective attribute and so many that will be further elaborated later.

The exchange of heat between physical systems is one of the most vital operations being utilized in industries, finished products and machines. Furthermore, large compactness and effectiveness of heat transfer systems are required to obtain an essential heat transfer of liquids with poor performance. The application of additives to liquids with solid particles less than 100nm constitute a major part towards improving of heat transfer and heat properties of devices. This technology comes either as nanocomposites or nanofluids.

Nanofluid with enhanced thermal Conductivity are of tremendous benefits in the application of heat exchange between physical systems since they do not clog the path of flow while inducing a little drop in pressure. The erratic movement of nanoparticles in base fluid makes nanofluids relatively stable, due to the continuous collision from molecules of the medium (Angayarkanni & Philip, 2015; Sarviya & Fuskele, 2017). The tendency of a material to allow heat to pass through it is known as heat conductivity. In addition, nano particles surface to volume ratio is higher than micro particles while nano fluids is the most preferred in thermal heat transfer applications due to its higher ability to conduct than and microfluid (Bhattacharya et al., 2004; Tawfik, 2017).
A heat transfer device is capable of transferring heat from one medium of fluid to another. They have great heat removal capability which makes them work over an extensive range of temperatures when being used. Heat exchangers have been discovered to be important in technologies. Like all other devices, performances of heat exchangers depend strongly on the properties of the material that it employs for heat transfer and energy storage (Dai et al., 2012). Environmentally benign devices are required to complement the new heat transfer systems, due to an intermittent feature on most heat exchangers, thus the need for nanofluids, nanoelectrodes, nanowires, nanocatalysts and other improved nanotechnology.

### 2.0 Nanotechnology in Heat Transfer

The blending of infinitesimal particles with a base fluid led to the improvement of convection and heat conductivity (Maxwell paper, 1987). However, some constraints caused by sedimentation, erosion, clogging and drop in high-pressure has kept the technology far from practice. The essence of thermal transfer improvement for fluid containing a small quantity of nanosized particles is to increase the heat conductivity and turbulence through the suspended nanoparticles (Godson et al., 2010). Functional materials made up of particulates with at least one dimension below 100 nanometers (nm) can be categorized into organics and inorganics where the former is made up of carbon nanotubes, graphite and nanofibers. (Scida et al., 2011). Nanofluids are classified as engineered colloids with possibility of replacing the upcoming generation medium of heat transfer (Sarkar, 2010) while the latter comprises of aluminum, zinc, copper, iron, aluminium oxide, iron oxide, titanium oxide (Dreizin, 2009).

### 2.1 Nanocomposites and Nanomaterials

The major driving force for nanotechnology researches lay in its vast range of applications and inert potentials. Nanocomposites can be organics or organics based such as paraffin blended nanocomposites, fatty acid blended nanocomposites, HDPE blended nanocomposites etc. They are also referred to as polymer composites (Wang et al., 2010; Socher et al., 2011). Nanofluids are nanoscale colloidal suspensions containing nanomaterial such as nanofibers, nanorods, nanosheets, nanoparticles, nanodroplets, nanowires or nanotubes in a conventional base fluid like water, bio-fluids and other common coolants. Nanofluids possess a higher specific surface area, dispersion stability, thermal conductivity, surface wettabiliy, reduced particle clogging and pumping (Hussain et al., 2013).

#### 2.1.1 Carbon Nanomaterials

Carbon is known to exist in three forms, namely amorphous carbon, graphite and diamond. The arrangement and bond of carbon atoms in the crystal lattice strongly affects the properties.

#### 2.1.2 Graphene

It contains two-dimensional (2D) shape of hexagonally lattice carbon atoms (Hu et al., 2015). The unique structure of graphene with large theoretical specific surface area (ca. 2600 m²/g⁻¹) (Luo et., 2012) and outstanding diffusiveness of Li⁺ ranging from 10⁻³ to 10⁻⁶ cm²s⁻¹ further accounts for its uses in various high-power-density which includes lithium ion batteries, fuel cells, and solar cells (Yuan & Shi, 2013).
2.1.3 Other Nanomaterials

Thermophysical properties of nanomaterials includes heat conductivity, heat diffusivity and convection coefficients (Yu & Xie, 2011). (Behroyan et al., 2016). Below are some of the numerous properties of organic and inorganic nanomaterials in the operation of heat exchangers.

Table 1: Properties of organic and inorganic nanomaterials in heat exchangers

| Characteristics of Thermal Transfer in Nanofluids |
|--------------------------------------------------|
| Nanotechnology has been attractive to researchers in the past decades for reasons best attached to their superior thermophysical advantage. In terms of its application to energy conversion devices, there are little or no limitation in pressure fall (Raja et al., 2016). When describing the characteristics of heat transfer in nanofluids, some major properties which includes convective heat transfer, heat capacity and heat conductivity are to be considered during analysis. |

Table 2: Summary of thermophysical properties of nanofluids

| Investigators       | Thermophysical Properties | Nanoparticle/Base Fluid | Empirical Correlation / Relevant Information |
|---------------------|---------------------------|-------------------------|---------------------------------------------|
| Ghazvini et al. (2011) | Specific Heat Capacity | Nanodiamond: engine oil | $C_{p,nf} = 2.62 - 6 \times 10^{-3} T + 2 \times 10^{-5} T^2$ |
|                     |                           |                         | $270 \leq T \leq 373$                       |
| Sekhar and Sharma (2013) | Specific Heat Capacity | Al$_2$O$_3$: water     | $C_{p,nf} = 0.8429 \left(1 + \frac{T_{nf}}{50}\right)^{-0.3037}$ |
|                     |                           |                         | $1 + \frac{\phi}{50} \left(1 + \frac{\phi}{100}\right)^{-0.4167}$ |
|                     |                           |                         | $20^\circ C < T_{nf} < 50^\circ C$ |
|                     |                           |                         | $0.01\% < \phi < 4.0\%$                     |
| Pakdaman et al. (2012) | Specific Heat Capacity | MWCNT: heat transfer oil | $C_{p,bf} - C_{p,nf} = (0.0128 \times T + 1.9382) \times \phi^{0.4779}$ |
| Shin and Banerjee (2014) | Specific Heat Capacity | Al$_2$O$_3$: alkali carbonate salt eutectics | $C_{p,nf} = 0.1 < \theta < 0.4$ vol. % |
| Khanafar and Vafai (2011) | Specific Heat Capacity | Al$_2$O$_3$: water | $C_{p,nf} = \frac{\rho_p \phi C_{p,p} + \rho_{salt} \phi_{salt} C_{p,salt} + \rho_{n2} \phi_{n2} C_{p,n2}}{\rho_p + \rho_{salt} \phi_{salt} + \rho_{n2} \phi_{n2}}$ |
| Kumaresan and Velraj (2012) | Specific Heat Capacity | MWCNT/EG: water | $C_{p,nf} = \frac{(1 - \theta) \rho_{bf} C_{p,bf} + \theta \rho_{p} C_{p,fg}}{\rho_{bf} + \theta \rho_{p}}$ |
| Pantzali et al. (2009) | Convective Heat Transfer | CuO: water (6.0 vol.%) | $Nu = 0.248 \theta^{-0.75} \phi^{0.4}$ |
| Pandey and Nema (2012) | Convective Heat Transfer | Al$_2$O$_3$/EG: water | $Nu = (0.26 + 0.020 - 0.0051 \theta^2) \phi^{0.27}$ |
Ray et al. (2014) investigated convective heat transfer for and Gulenoglu et al. (2014) convective heat transfer for nanofluids. Salman et al. (2012) investigated the specific heat of single-phase and two-phase treatments. The specific heat of fluids containing small quantities of nanoparticles were determined based on the volume fractions determined as:

\[ C_{\text{nf}} = \varnothing C_{\text{n,p}} + (1 - \varnothing)C_{\text{n,f}} \]

and

\[ (\rho C_p)_{nf} = \varnothing (\rho C_p)_{p} + (1 - \varnothing) C_p \]

Where \( \varnothing \) = density and \( C = \) specific heat capacity. Elia et al. (2014) were able to deduce a reduction in the specific heat of nanofluid with a rise in its volume concentration from experimental study where the specific heat energy was intensified by a rise in temperature.

3.2 Convective Heat Transfer

The governing parameters for the convective heat transfer model are dimensionless variables. Convection coefficient in this study can be obtained from (Faizal et al., 2013)

\[ h = \frac{Q_s}{A_p(T_p - T_0)} \]

According to Zoubida et al. (2011) assessed on the natural convection of nanofluids and arrived at a summary shown in the table below.
Table 3: Experimental study on nanofluids with different heat transfer configuration

| Authors                  | Configuration                                                                 | Experiment Title / Method                                                                 | Particle / Base Fluid | Observations                                                                                                                                 |
|--------------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Das et al                | ![Image](image1.png)                                                        | Nanofluids Science and Technology (Finite volume method)                                | Cu – water            | Nusselt number and highest flow rate of mass at output are the increasing parameters of solid concentration.                                  |
| Khanafer et al           | ![Image](image2.png)                                                        | The utilization of nanofluids for the purpose of improving buoyancy-driven heat transfer in a two-dimensional enclosure (Finite-volume approach) | Cu – water            | Volume fraction of nanoparticles was noticed to rise with the rate of heat transfer of nanofluid                                            |
| Jang and Choi            | ![Image](image3.png)                                                        | Improved heat conductivity of nanofluids through an irregular motion of particles (Theoretical study) | Cu/Diamond – water    | Stability and greater heat transfer coefficient was observed from nanofluids                                                                    |
| Hwang, Lee and Jang      | ![Image](image4.png)                                                        | Buoyancy-driven heat transfer of water-based Al2O3 nanofluids in a rectangular cavity (Theoretical study) | Al2O3 – water         | Reduced thermal transfer with an increasing nanoparticles                                                                                   |
| Ho et al.                | ![Image](image5.png)                                                        | Mathematical Simulation of nanofluid natural convection in a square enclosure: impacts caused by the risk of viscosity and heat conductivity (Finite volume method) | Al2O3 – water         | Dissimilarity between an improvement in the dynamic viscosity being evaluated from the two formulas led to contradictory heat transfer of nanofluid. |
| Oztop and Adu-nada       | ![Image](image6.png)                                                        | Mathematical study of natural convective heat transfer in a partially heated rectangular container being occupied with nanofluid (Finite volume method) | Al2O3/Cu/ TiO2 – water | Thermal transfer improves with the volume of nanoparticles fraction                                                                       |
| Abu-nada and Oztop       | ![Image](image7.png)                                                        | Impacts of tilt angle on natural convection in an enclosure occupied with Cu – water nanofluid (Finite volume method) | Cu – water            | Impact of concentrating nanoparticle on Nusselt number was noticed at a large volume fraction                                              |
| Abouali and Falahatpisheh| ![Image](image8.png)                                                        | Impacts of unsteady viscosity and heat conductivity of Al2O3 – water on improving heat transfer in natural convection (Finite volume method) | Al2O3 – water         | Thermal conductivity showed drop in natural convective heat transfer.                                                                      |
4.0 Models for Computing Thermal Conductivity

In nanotechnology applications in heat exchangers, properties of nanofluids being utilized are high thermal conductivities and absorption properties (Yu & Xie, 2011). Thermal conductivity constitutes a significant parameter when evaluating the energetic performance of nanofluids. When referring to nanotechnology, interest corresponding to heat transfer will include the nanomaterials consisting of nanoparticles or nanoarchitectured material for the device (Arico et al., 2015).

Several factors are responsible for heat conductivity of nanofluids, they include nominal temperature of the nanofluid (Ariana, Vaferi & Karimi, 2015; Ahmadi et al., 2018; Alirezaie et al., 2018; Alade et al., 2018), level of sonication of nanofluid (Shahsvar et al., 2017), size of the nanoparticles (Ren et al., 2005; Li & Peterson, 2007), concentration of solid phase (Akilu2017; Toghraie & Afran, 2018), aspect ratio (Kumar et al., 2017), nanoparticles size and shape (Sarviya & Fuskele, 2017). Numerous investigations have been done on heat conductivity of nanofluids so as to examine the functional parameters. Magnetic field strength of the nanoparticle is among the properties that affects heat conductivity of nanofluids. Moreover, thermal conductivity is directly proportional to the magnetic field strength of a nanoparticle which varies with operating temperature of the nanofluid (Nurdin, Yaacob & Johan, 2016).

4.1 Measurement of Heat Conductivity

The heat conductivity of hybrid nanofluids can be estimated in a number of ways. Various techniques that have being utilized to measure the heat conductivity of nanofluids in recent years, they include: thermal constant analyzer, $\omega$ method, constant-state parallel plate technique and transient hot wire technique which is the commonest (Sarviya & Fuskele, 2017). All existing devices like the hybrid nanofluids employ one of the above methods, they include and not limited to LAMBDA, KD2-Pro thermal analyzer.

a. Transient Plane Source (TPS) method

TPS principle is applied by heat constant analyzer to evaluate the heat conductivity of nanofluids. The approach employs TPS element of an electrically transmitting thin foil as shown in Fig. 1. TPS works on the Fourier law of heat conduction as the basic principle for measuring heat conductivity. Heat conductivity is measured by a thermometer which also measures the resistance of the Transient Plane Source element immersed vertically in a container having steady temperature bath of nanofluid as shown in Fig. 2 (Kumar et al., 2015).

\[ k = \frac{q}{4\pi (T_2 - T_1) \ln \left( \frac{t_2}{t_1} \right)} \]

Fig. 1. TPS sensor (Paul et al., 2015)

b. Transient hot-wire (THW) method

This technique works on the concept of measuring the degree of hotness and time reaction of wire that are being subjected to an abrupt pulsating electrical current. In the THW approach, probe was refer to as a lengthy thin platinum wire. The wire is immersed into the nanofluid to measure the rise in temperature as constant current is supplied through resistive heating. According to Fourier’s law of heat conduction, an increase in fluid temperature is proportional to the heat conductivity. Therefore the fluid heat conductivity (Eq. 1) was derived from the correlative variation in wire resistivity measured through four wire resistive measurement system shown in Fig. 3 (Kumar et al., 2015; Paul et al., 2015).
Where $k_n$ = nanofluid heat conductivity, $q$ = ratio of applied electric energy to wire length, and $i$= temperature difference between time $t_1$ and $t_2$.

Fig. 3. Schematics of transient hot wire practical structure (Kumar et al., 2015)

Different models are represented to suggest heat conductivity of nanofluids. Each of these models are expansions to the four foundational models - Maxwell model (Maxwell, 1873) which considers spherical particles, Hamilton & Crosser model for any particle with shape factor, Yu & Choi model which considers the nanolayer and Koo & Kleinstreuer model factors the size of particle, particle, temperature dependence, base properties of fluid and the particle subjected to an erratic random movement (Sarviya et al., 2017).

Table 4: Other models utilized to ascertain the heat conductivity of nanofluids

| Authors                      | Nanoparticle/Base Fluid | Empirical Correlation                                                                 |
|------------------------------|-------------------------|---------------------------------------------------------------------------------------|
| Minsta et al. (2009)         | Al$_2$O$_3$: water      | $\frac{k_{nf}}{k_{bf}} = 1.72.0 + 1$                                                  |
| Khanaf and Vafai (2011)      | Al$_2$O$_3$: water      | $k_{nf} = 1 + 1.0112.0 + 2.4375.0\left(\frac{47}{d_p(\text{nm})}\right) - 0.0248.0\frac{k_p}{0.613}$ |
| Yiamsawasd et al. (2012)     | Al$_2$O$_3$: water      | $\frac{k_{nf}}{k_{bf}} = A0^pT^c\left(\frac{k_{nf}}{k_{bf}}\right)^5$                |
|                              |                         | $A = 0.946887, B = 0.073528, C = 0.03616, D = -0.016229$                              |
| Patel et al. (2010)          | Metal and metal oxides  | $k_{nf} = \left[ 1 + 0.135\left(\frac{k_p}{k_{bf}}\right)^{0.273}\left(\frac{T}{20}\right)^{0.547}\left(\frac{10}{d_p}\right)^{0.234}\right] k_{bf}$ |
|                              |                         | $A = 0.916205, B = 0.066817, C = 0.018789, D = 0.016229$ Applicable to TiO$_2$: water |
4.2 Conventional Nanofluids

a. TiO$_2$ nanofluids

Maheshwary et al., (2017) measured the impacts of concentration, temperature and size of nanoparticles on the heat conductivity of TiO$_2$/water. The study included the use of cubic, rod and spherical nanoparticle of TiO$_2$. However, it was the cubic shaped nanoparticle that gave the highest thermal conductivity, with spherical nanoparticle performing better in thermal conductivity than the rod-shaped TiO$_2$ nanoparticle. Sonawane, et al., (2015) quantified the impact of ultrasonication time on heat conductivity of titanium dioxide. It was observed that the time application of sound energy to agitate particles would enhance an erratic random motion of particles in the suspension. Selah et al., (2014) found out an increases in heat conductivity; in addition to surfactants improving dispersion of nanofluids,. The result demonstrated the thermal conductivity to be higher when using SDS as stabilizer compared to CTAB; and CTAB has improved its tendency to conduct heat over Span-80. Duangthongsuk & Wongwises, (2009) discovered volume fraction of TiO$_2$ deposited in water to increase by 1.8% while the improvement in thermal conductivity increased by 6%.

b. Al$_2$O$_3$ nanofluids

Sharifpur et al., (2017) examined the impacts of concentration, temperature and particle size on the heat conductivity of Al$_2$O$_3$/glycerol nanofluid. The sizes of particle involved in study was limited and the results indicated reduction in the ratio of heat conductivity of the nanofluid with an increasing particle size. Alawi et al., (2018) examined the heat conductivity behaviour of various nanofluids shape of Al$_2$O$_3$ using distilled water at different capacity. The best heat conductivity of Al$_2$O$_3$ nanoparticle in distilled water with increasing volume fraction was observed; platelets nanoparticle was discovered to be the least while blade nanoparticle, bricks nanoparticle, cylindrical nanoparticle and spherical nanoparticle are the best of the Al$_2$O$_3$ nanomaterial.

c. Cu/CuO nanofluids

Li and Peterson, (2006) found out the impact of volume fraction and temperature of CuO-water nanofluids on heat conductivity. Xuan et al., (2002) had carried out similar experiment on heat conductivity of Cu-water nanofluid and observed its enhancement to increase by 9% in 1% volume loading when temperature rises.

d. SiO$_2$/SiC nanofluids

In a natural square enclosure of a heat exchanger, Jahanshahi et al., (2010) investigated the impact of the heat conductivity of Silica–water nanofluid on the properties of heat transfer through an iterative experiment. They used model suggested by Hamilton et al., (1962) and derived a rise the Nusselt number and heat conductivity when using SiO$_2$–water nanofluid (Haddad et al., 2012).

e. CNTs and Graphene nanofluids

Ding et al. (2009) observed a significant improvement of heat conductivity of CNT nanofluids. The enhancement of it was noticed to increase by 69% for 0.49% nanofluid When there is a rise in temperature. In the work of Assael et al., (2005) they discovered that, heat conductivity increased by over 30% if 0.6% of CNTs is mixed with water.

f Other Nanofluids

Since nanofluids operate under varying experimental conditions, heat conductivity of other used nanofluids for heat transfer applications are presented in Fig. 4. Other group novel nanofluids called hybrid nanofluids are surfacing in the area of nanotechnology research. Hybrid nanofluids are fluids made from more than one nanoparticle that have been synthesized in either one base fluid or homogenized base fluids. Table 5 shows works and conclusions of some researcher using hybrid nanofluids in heat transfer applications.
4.3 Effects of heat Conductivity on Heat Exchangers

The need of fluids with better thermal conductivity is on the increase, many sectors like energy production, provision of clean water, increasing power of microprocessors and other heat application components are in search for a more efficient heat dissipating system. Improving performance of heat transfer enhancement methods or heat exchange systems can be of help to reduce the energy consumptions at industries and in a long run make things economical. Nguyen et al., (2007) observed the effects of nanoparticles on a heat block of a microprocessor and noticed an increasing volume concentration with temperature decrease. Rise in the flow rate of working fluid makes the coefficient of energy transfer for pure liquid and nanofluid better whereas the difference in temperature of heat transfer to the radiator was caused by changes in inlet temperature of the liquid (in the range tested (Peyghambarzadeh et al., 2011). This supports the observation made by Nguyen et al., (2007) that increase in mass flow rate can better improve the heat conductivity of nanofluids.
### Table 5: Research summary on thermal performance of heat exchangers

| Authors              | Title of Experiment                                                                 | Results /Knowledge                                                                 |
|----------------------|--------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Huminic and Huminic (2011) | Heat exchange properties of a two-phase closed thermosyphons using nanofluid       | The nanoparticles were discovered to have a crucial impact on the improvement of heat conductivity of two-phase closed thermosyphons using nanofluid (TPCT). |
| Alizad et al. (2012) | Heat performance and functional startup properties of flat-shaped heat pipes using nanofluid | They discovered better heat performance of heat pipes with flat shape using CuO, Al2O3 and TiO2 with high volume concentrations. |
| Arun Kumar, Pradynuma & Jahar (2013) | Performance comparision when several nanofluids are utilized | The improvement in the heat efficiency of heat pipe for nanofluid was limited to laminar fluid conditions and no pH was considered. |
| Vermalumoudi et al. (2014) | Practical examination on the performance of thermal transfer of image/water nanofluid in an air-finned heat exchanger | They noticed a peak improvement of few percentage in the total heat transfer coefficient |
| Hussein et al. (2014) | Improvement in thermal transfer by utilizing nanofluids in an automotive cooling system | Nanofluids works properly with automotive radiator. Also, the Nusselt number was noticed to rise with volume flow rate. The result was conducted for a crossed flow type heat exchanger and no consideration on pH. |

### 5.0 Conclusion

The possibility of nanofluids enhancing heat transfer will lead to the advancement of more compact and effective heat transfer equipment in engineering. Researchers in the field, suggests that in improving the thermal efficiency of heat exchangers using nanotechnology attention should be placed on the following:

1. Similarity of nanomaterials and the base fluids by altering the boundary attributes of two phases might be among the paths to solving problem
2. The benefits of additives shape in nanofluids for the properties
3. Suspension stability for scientific findings and experimental use.

In conclusion, improvement of thermal transfer by nanofluids depends on different factors comprising of; thermal conductivity increase, random motion of nanoparticles, variations and interface. It is necessary to examine the products of nanofluid made from blending types with equal volume fraction for augmentation of heat transfer improvement and application.

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