

Numerical Investigation of Turbulent Convective Heat Transfer of Various Nanofluids in Tube

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ABSTRACT: Fluids are used for heat transfer in many engineering equipment. Water, ethylene glycol and propylene glycol are some of the common heat transfer fluids. Over the years, various techniques have been employed to improve the heat transfer rate of these fluids. Addition of milli or micro sized particles to the heat transfer fluid is one of the ways of improving heat transfer rate. Though this looks simple, this method has practical problems such as high pressure loss, clogging and erosion of the material of construction. These problems can be overcome by using nanofluids, which is a dispersion of nanosized particles in a base fluid. Nanoparticles increase the thermal conductivity of the base fluid manifold which in turn increases the heat transfer rate.

In this study, the flow field and heat transfer behaviour of $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$, $\text{Cu}_2\text{O- H}_2\text{O}$ & $\text{TiO}_2\text{-H}_2\text{O}$ nanofluids at turbulent flow in a tube are investigated. Simulations are carried out for Reynolds numbers from 20000, 40000 to 100000 at 0.01 volume fraction. The finite volume based CFD technique is used to solve the governing equations numerically. The numerical results showed that with increasing Reynolds number average Nusselt number increases for given volume fraction for all nanofluids. The average nusselt number is more in $\text{TiO}_2\text{-H}_2\text{O}$ nanofluids compared to $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$ & $\text{Cu}_2\text{O- H}_2\text{O}$ nanofluids. The thermal conductivity increases with increasing Reynolds number and is more in $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$ nanofluids compared to $\text{Cu}_2\text{O- H}_2\text{O}$ & $\text{TiO}_2\text{-H}_2\text{O}$ nanofluids. The pressure drop increases with enhancing the Reynolds number for given volume fraction. The convective heat transfer coefficient increases with increasing Reynolds number and most increment is absorbed in $\text{TiO}_2\text{-H}_2\text{O}$ nanofluid.

KEYWORDS: Nanofluids, Turbulent flow, Forced convection, Numerical solution, Pressure drop

I. INTRODUCTION

Rapid increase in energy demand of worldwide for more efficient energy storage materials and inherently low thermal conductivity engender the strong need in many industrial field to intensifying heat transfer process and reducing energy loss by developing advanced heat transfer fluid with high thermal conductivities than are presently available.

Basically, heat must be transferred either to input energy into a system or to remove the energy produced in a system. Therefore, thermal conductivity is one of the important requirements of enhancement of energy heat transfer in industries such as transportation industry, microelectronics, industrial cooling system and thermal management, industrial heat exchanger coolants, electronic coolant and etc. For the transport of energy system like coolant, thermal conductivity is needed in order to preventing the overheating cooling. Further than that, thermal conductivity also needed to maintain the desired performance and reliability of a wide variety of product like computer, car engines, power electronics and laser or x-rays. Therefore, recently there were a lot of investigation and researches for improving the heat transfer characteristic have been constrained because traditional heat transfer fluids used in today's thermal management systems such as water, oils, ethylene glycol have inherently poor thermal conductivities, orders of magnitude smaller than those of most solids.

Due to the development of nanoscience and nanotechnology field, many researches and investigation on nanofluids have been carried out actively whereby nanofluids is a mixture consisting of solid nanoparticles with size

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typically of 1-100nm and fibers dispersed in a liquid which can be made from chemical stable metal such as metallic and nonmetallic solid which have high thermal conductivity and stability than those of the conventional heat transfer fluid or the suspensions of micro-sized particles. In order for it to dispersed in base fluid like distilled and de-ionized water, engine oil, acetone, and ethylene glycol, the thermal conductivity should be high ($k_{\text{liquid}} \ll k_{\text{solid}}$). Therefore, the determination of nanofluids thermal conductivity has great importance whereby it can produce more stable suspension to reduce the coagulation of nanoparticles in the nanofluid rather than enhanced the problem encountered like clogging in slurries; erosions and sedimentation beside it give opportunity in enhancement of energy heat transfer. Hence, to formulating a stable nanofluid with controlled properties like thermal conductivity, viscosity, and wettability for heat transfer application. It is also depends on the properties of the base fluid and the dispersed phase, particle concentration and size.

Numerous investigations and researches on colloidal dispersions also have been conducted by the researchers in view of particles motion analysis in various flow conditions and sedimentation characteristic studies on suspended nanoparticles in base fluids. Beside than that, by studying the properties of surfactants like laurate salts, thiols and Oleic acid as it been added to nanofluids as an additive was known to be very effective to homogenously disperse nanoparticles in the base fluids and reduce the particles agglomeration due to van der Waals forces of attraction.

II. RELATED WORK

Many experimental studies have shown that nanofluids have much higher thermal conductivities than those predicted by macroscopic models. The first work on convective flow and heat transfer of nanofluids, was presented by Pak and Cho[1] before Choi and his group introduced the term nanofluids. The first observation they made was a substantial increase in the heat transfer coefficient in the turbulent flow regime the experiment showed the applicability of the Dittus-Boelter for pure water flow and substantial increase in the heat transfer coefficient for flow with the particles suspended. Also, their overall depiction is much more gloomy. They found that the Darcy friction factor follows the Kays correlation. Thus, due to a rise in viscosity, there is a substantial rise in frictional pressure drop. This means that although the heat transfer coefficient increases in nanofluids, the pressure-drop penalty is substantial. In convection heat transfer applications there is always competition between enhancement of heat transfer and the resulting pressure penalty.

Buongiorno[2] theoretically investigated the Nusselt number increase for forced convection in a duct and related this heat transfer enhancement to reduction of viscosity caused by nanoparticle transport within the boundary layer. He introduced seven transport mechanisms that cause relative velocity between nanoparticles and fluid. By comparing the diffusion timescale of transport mechanisms, he showed that the Brownian motion and thermo-phoresis are the two most important mechanisms.

Wesley Williams et al.[3] investigated the turbulent convective heat transfer behaviour of alumina and zirconia nanoparticle dispersions in water experimentally in a flow loop with a horizontal tube test section. They find that the convective heat transfer and pressure loss behaviour of nanofluids can be predicted by the traditional correlations and models, as long as the effective nanofluid properties are used in calculating the dimensionless numbers. They observe, no abnormal heat transfer enhancement. Namburu et al.[4] numerically analysed turbulent flow and heat transfer of Al_2O_3 , CuO , and SiO_2 nanoparticles suspended in ethylene glycol and water based fluids in a straight circular tube. They indicated that SiO_2 with nanoparticle diameter of 20 nm provides the highest thermal conductivity enhancement due to higher viscosity value of lower nanoparticle diameter. Fotukian and Nasr Esfahany[5,6] investigated Turbulent convective heat transfer and pressure drop of Al_2O_3 /water and CuO /water nanofluid inside a circular tube experimentally. They indicated the addition of small amount of nanoparticles to the base fluid augmented heat transfer remarkably. Increasing the volume fraction of nanoparticles in the range studied in their work did not show much effect on heat transfer enhancement. They showed that the pressure drop for the dilute nanofluid was much greater than that of the base fluid. They also predicted that ejection of nanoparticles from the wall to the bulk of the flow may be responsible for considerable augmentation of heat transfer by addition of small amounts of nanoparticles to the base fluid. Demir et al.[7] investigated numerically forced convection flow of TiO_2 and H_2O nanoparticles suspended in pure water in a horizontal tube. It was found that convective heat transfer coefficient, pressure drop and wall shear stress increase with increasing Reynolds number and high pressure drop

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reported by using nanofluids due to increment on viscosity of the mixture. Bianco et al.[8] analysed numerically the turbulent forced convection nanofluid with Al_2O_3 nanoparticles suspended in water passing through a circular tube. They concluded that increasing the particles concentration would increase the heat transfer coefficient. Sajadi and Kazemi[9] study the turbulent heat transfer behaviour of titanium dioxide/water nanofluid in a circular pipe under the constant wall temperature condition, experimentally. Their results showed that the heat transfer coefficient increased about 22% at a Reynolds number of 5000, for 0.25% volume fraction of TiO_2 , while the pressure drop was about 25% greater than that of pure water. Zamzamian et al.[10] study the effect of forced convective heat transfer of nanofluids of aluminium oxide and copper oxide prepared in ethylene glycol in turbulent flow. They find considerable enhancement in convective heat transfer coefficient of the nanofluids as compared to the base fluid. Moreover, their results indicate that with increasing nanoparticles concentration and nanoparticle temperature, the convective heat transfer coefficient of nanofluid increases. Nasiri et al.[11] investigated the turbulent heat transfer performance of $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$ and $\text{TiO}_2\text{-H}_2\text{O}$ nanofluids through square channel with constant wall temperature boundary condition experimentally. They reported that convective heat transfer coefficient and Nusselt number of nanofluids are higher than those of distilled water. They revealed that the convective heat transfer and pressure drop of nanofluids tested in fully developed turbulent flow region can be predicted with the help of traditional correlations and models, provided that the effective nanofluid properties are used in calculating the dimensionless numbers. Corcione et al.[12] study heat transfer of nanoparticles suspensions in single-phase turbulent pipe flow theoretically. They extended the convective heat transfer correlations available in the literature for single phase flows to nanoparticle suspensions, provided that the thermo-physical properties appearing in them are the nanofluid effective properties calculated at the reference temperature. He investigated both cases of constant pumping power and constant heat transfer rate for different operating conditions, nanoparticle diameters, and solid-liquid combinations. The fundamental result obtained is the existence of an optimal particle loading for either maximum heat transfer at constant driving power or minimum cost of operation at constant heat transfer rate. Roy et al.[13] investigated turbulent heat transfer and hydrodynamic behaviour of various types of water based nanofluids inside a typical radial flow cooling device numerically. They evaluated several turbulence models and choose the RANS-based k-e SST turbulence model for subsequent simulations. Their results show that although heat transfer enhancement was found for all the types of nanofluids considered, their overall performance seems to indicate that their usage in practical applications may not be as beneficial as originally hoped for due to the corresponding increases in pumping power. Naik et al.[14] analysed turbulent convection flow of Cu nanofluids of propylene glycol-water as the base fluid and flowing in a circular tube, subjected to a constant and uniform heat flux at the wall, numerically. They found that nanofluids containing more concentrations have shown higher heat transfer coefficient. They found that the nanofluids containing more concentrations have shown higher heat transfer coefficient. They compare the numerical results with the experimental data and reasonable good agreement is achieved.

III. THEORETICAL ANALYSIS

It is well known that nanoparticles have very high thermal conductivity compared to commonly used coolant. Thus, the thermal conductivity and other fluid properties are changed by mixing the particle in fluid. The changed properties of the nanofluids improve the heat transfer performance of the circular tube with nanofluids. This point is illustrated in this chapter by doing the computational fluid dynamics (CFD) to investigate the convective heat transfer of various nanofluids at turbulent flow in the circular tube.

A. SPECIFICATION OF PROBLEM

The schematic of the geometry studied is shown in figure. The geometrical configuration consists of a tube with length (L) of 1m and circular section with diameter (D) equal to 0.02m. The problem under investigation is a two-dimensional, steady, forced turbulent convection flow of nanofluid flowing inside straight circular tube. It is subjected to a constant and uniform temperature at the wall $T_w=310\text{K}$. At the tube inlet section, uniform axial velocity V_{in} , temperature $T_{in}=300\text{K}$ turbulent intensity and hydraulic diameter have been specified. At the outlet section the flow and temperature fields are assumed fully developed. The Reynolds number was varied from 20,000 to 1,00,000.

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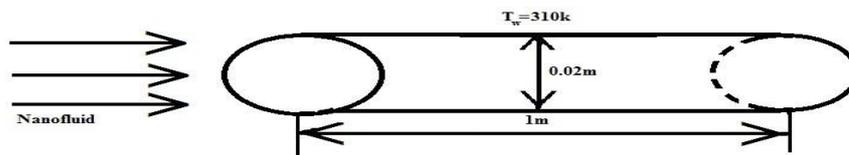


Figure 3.1

The considered nanofluids are composed of $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$, $\text{Cu}_2\text{O-H}_2\text{O}$ and $\text{TiO}_2\text{-H}_2\text{O}$ with diameter 33nm and 0.01 volume fraction. The nanofluid is treated continuous and dilute Newtonian mixture which has variable physical properties. The compression work, dispersion and viscous dissipation are assumed negligible in the energy equation and heat conduction is represented by Fourier Law. Nanoparticles are in thermal equilibrium with base fluid and there are not any external force, heat source, chemical reaction and radiative heat transfer in the problem.

The properties of various nanofluids are listed in the following table

| Nanofluids | Density(Kg/m^3) | Specific heat(J/Kg.K) | Molar mass(gm/mol) |
|--|----------------------------|----------------------------------|-------------------------------|
| $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$ | $1.025 \cdot 10^3$ | $4.054 \cdot 10^3$ | 18.855 |
| $\text{Cu}_2\text{O-H}_2\text{O}$ | $1.047 \cdot 10^3$ | $3.965 \cdot 10^3$ | 19.266 |
| $\text{TiO}_2\text{-H}_2\text{O}$ | $1.027 \cdot 10^3$ | $4.033 \cdot 10^3$ | 18.634 |

IV. METHODOLOGY

ANSYS program is self-contained general purpose finite element program developed and maintained by Swason analysis systems Inc .the program contain many routines, all inter related and all for main purpose of achieving a solution to an engineering problem by finite element method.

ANSYS finite element analysis software enables engineers to perform the following tasks:

1. Build computer model or transfer models of structures, products, components, or system.
2. Apply operating loads or other design performance conditions.
3. Study physical responses, such as stress levels, temperature distributions, or electro-magnetic fields.
4. Optimize a design early in the development process to reduce production costs.
5. Do prototype testing in environments where it otherwise would be undesirable.

The ANSYS program has a compressive graphical user interface (GUI) that gives users easy, interactive access to program functions, commands, documentation and reference material. An intuitive menu system helps users navigate through the ANSYS program. Users can input data using a mouse, a keyboard, or a combination of both. A graphical user interface throughout the program, to guide new users through the learning process and provide more experienced users with multiple windows, pull-down menus, dialog boxes, tool bar and online documentation.

Computational Fluid Dynamics (CFD) provides a qualitative (and sometimes even quantitative) prediction of fluid flows by means of

1. Mathematical modeling (partial differential equations)
2. Numerical methods (discretization and solution techniques)
3. Software tools (solvers, pre- and postprocessing utilities)

The following steps are involved in CFD analysis

1. Problem statement
2. Mathematical model
3. Discretization process
4. Iterative solver
5. CFD simulations
6. Post-processing
7. Verification

V. RESULTS

Fig.5.1 shows the variation of average Nusselt number in terms of Reynolds number for fixed volume fraction of $Al_2O_3-H_2O$ nanofluid. For the given volume fraction the average Nusselt number increases with increasing Reynolds number

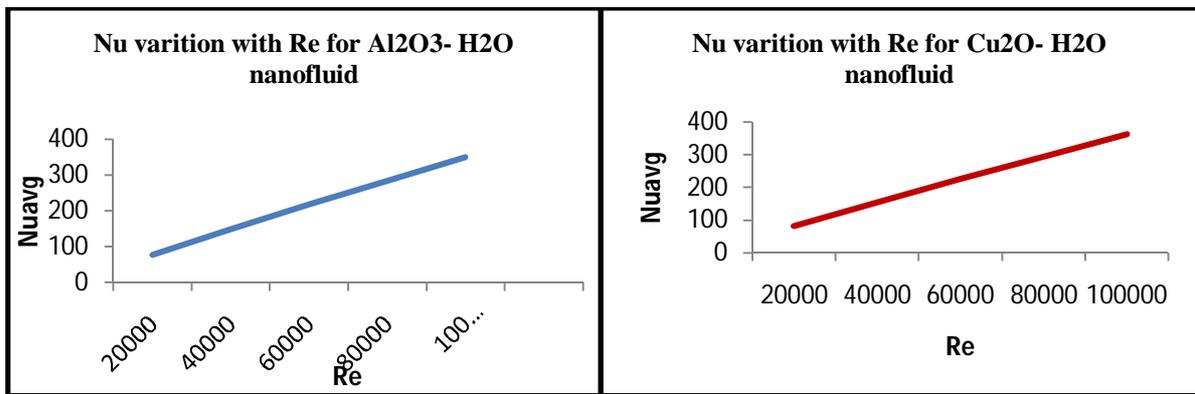


Fig 5.1 Average Nusselt number variation with Reynolds number for $Al_2O_3-H_2O$

Fig 5.2 Average Nusselt number variation with nanofluid Reynolds number for Cu_2O-H_2O nanofluid

In Fig.5.2 the variation of average Nusselt number in terms of Reynolds number for fixed volume fraction of Cu_2O-H_2O nanofluid. From the figure it is observed that the average Nusselt number increases with increasing Reynolds number

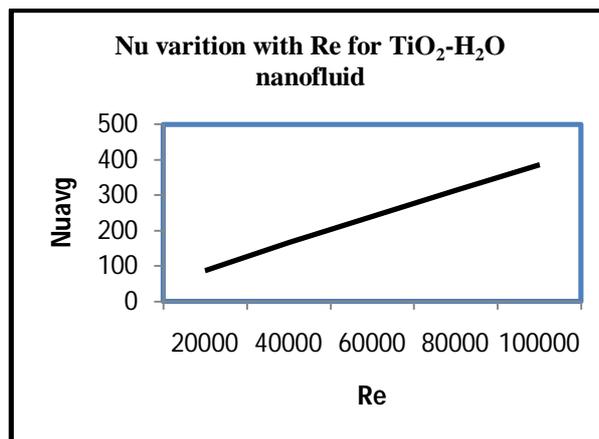


Fig 5.3 Average Nusselt number variation with Reynolds number for TiO_2-H_2O nanofluid

In Fig.5.3 the variation of average Nusselt number in terms of Reynolds number for fixed volume fraction of TiO_2-H_2O nanofluid. The average Nusselt number increases with increase in Reynolds number.

The variations of average Nusselt number in terms of Reynolds number at fixed volume fraction for all three nanofluids. The average Nusselt number increases with increment in Reynolds number for all three nanofluids. The most increment in the average Nusselt number for a fixed volume fraction takes place in TiO_2-H_2O nanofluid. From the figure it is observed that TiO_2-H_2O nanofluid has largest average Nusselt number compared to other two different nanofluids.

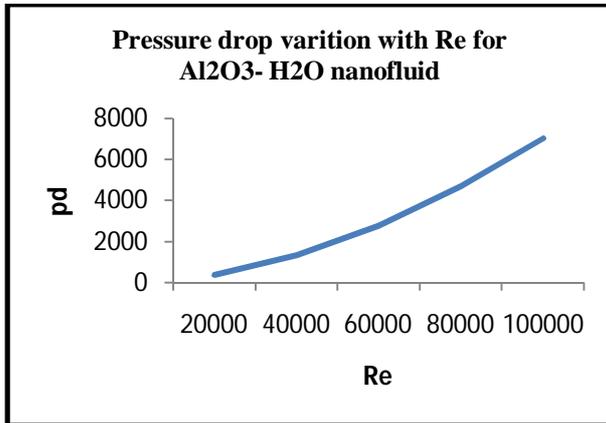


Fig 5.4 Pressure drop variation with Reynolds number for Al₂O₃-H₂O nanofluid

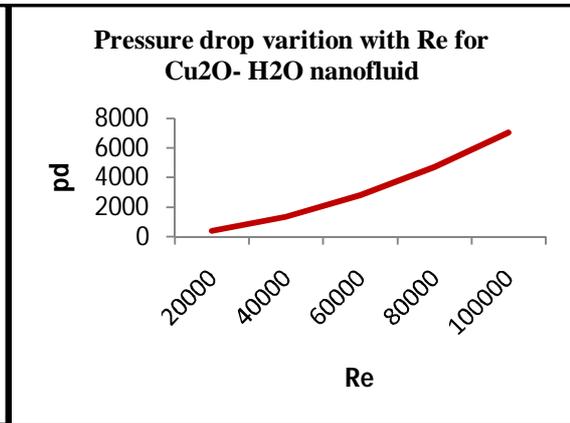


Fig 5.5 Pressure drop variation with Reynolds number for Cu₂O-H₂O nanofluid

Fig.5.4 presents the pressure drop in terms of the Reynolds number for fixed volume fraction of Al₂O₃-H₂O nanofluid. From figure it is observed that the pressure drop increases with increase in Reynolds number for fixed volume fraction.

Fig 5.5 presents the pressure drop in terms of the Reynolds number for fixed volume fraction of Cu₂O-H₂O nanofluid. From figure it is observed that the pressure drop increases with increase in Reynolds number for fixed volume fraction.

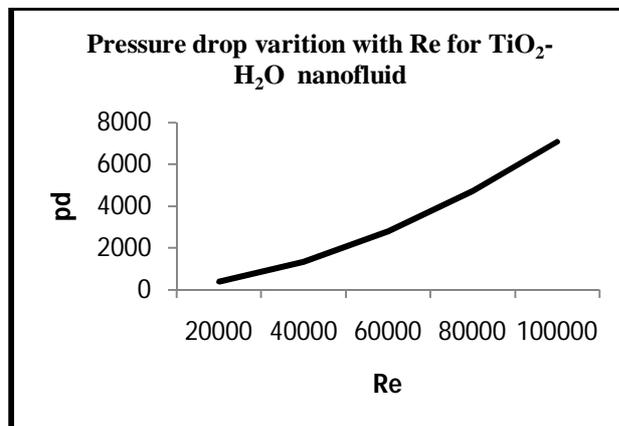


Fig 5.6 Pressure drop variation with Reynolds number for TiO₂-H₂O nanofluid

Fig 5.6 shows the pressure drop in terms of the Reynolds number for fixed volume fraction of TiO₂-H₂O nanofluid. From figure it is observed that the pressure drop increases with increase in Reynolds number for fixed volume fraction.

For all three nanofluids it is observed that there is not much variation in pressure drop for fixed volume fraction. It shows that with increment of the Reynolds number at fixed volume fraction has no noticeable effect on the pressure drop. The most and least pressure drop with increasing Reynolds number for fixed volume fraction is takes place at TiO₂-H₂O nanofluid and Al₂O₃-H₂O nanofluid.

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VI. CONCLUSION

In this study the convective heat transfer of $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$, $\text{Cu}_2\text{O-H}_2\text{O}$ and $\text{TiO}_2\text{-H}_2\text{O}$ nanofluids inside a circular tube for Reynolds numbers varying from 20000 to 100000 at 0.01 fixed nanoparticle volume fraction has been considered. The lateral surface of pipe is held at 310 K and the inlet nanofluid flow temperature is at 300 K. Based on numerical results,

1. For all three nanofluids the average Nusselt number increases with increase in Reynolds number for fixed volume fraction.
2. The most increment in the average Nusselt number for fixed volume fraction takes place in $\text{TiO}_2\text{-H}_2\text{O}$ nanofluid and the least increment is observed in the $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$ nanofluid.
3. By the increment of Reynolds number for all three nanofluids the pressure drop increases for fixed volume fraction.
4. It is observed that there is not much variation in pressure drop takes place for three nanofluids at fixed volume fraction.
5. The most and least pressure drop with increasing Reynolds number for fixed volume fraction is takes place at $\text{TiO}_2\text{-H}_2\text{O}$ nanofluid and $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$ nanofluid.
6. Increasing Reynolds number at fixed volume fraction causes increment in the Thermal conductivity of the nanofluid for all three nanofluids.
7. For all three nanofluids it is observed that with increment in Reynolds number for fixed volume fraction $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$ nanofluid has high thermal conductivity followed by $\text{TiO}_2\text{-H}_2\text{O}$ nanofluid and $\text{Cu}_2\text{O-H}_2\text{O}$ nanofluid.

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