# Experimental Comparison Between Conventional Coolants and (TiO2/Water) Nano fluid to select the best Coolant for Automobiles in Iraq's Summer Season

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## ABSTRACT

This work, presents nanofluids as a new coolant technology in automobile engines compared with other conventional coolants (Ethylene glycol/water (antifreeze), distilled water) experimentally. The increase in thermal conductivity of the base fluid (water) by adding nanoparticles in certain ratios led to more absorption of heat from engine block. The experimental results indicated that the drooping in exit engine coolant temperatures was about (18.5%) by using $(0.3\%TiO_2/water)$ nanofluid, and about (9%) by using distilled water comparative with Ethylene glycol/water (50/50) at the test end. The increasing in radiator (heat exchanger) effectiveness was about (51%) with using nanofluid, and about (29%) with using distilled water comparative with Ethylene glycol/water (50/50) at the test end. The results indicated also that the increasing in Nusselt's number at entrance of radiator hose was about (42.8%) with using nanofluid and about (30.5%) with using distilled water compared with Ethylene glycol/water (50/50). This led to increase convection heat transfer coefficient at entrance of radiator hose by about (65%) with using nanofluid and about (49.5%) with using distilled water compared with Ethylene glycol/water (50/50).

**Keywords:** Automobiles; Effectiveness; Coolant; TiO2/water; Nanofluid.

**Nomenclature:**
$C_p$ = specific heat (kJ/kg.K).
$C_{peff}$ = Effective specific heat of nanofluid (kJ/kg.K).
$C_{pf}$ = Specific heat of fluid (coolant) (kJ/kg.K).
$C_{pnp}$ = Specific heat of the nanoparticle (kJ/kg.K).
$C_{pw}$ = Specific heat of water (kJ/kg.K).
$D$ = Radiator hose diameter (m).
$h_c$ = Convection heat transfer coefficient(W/m$^2$.K).
$k$ = Thermal conductivity (W/ m.K).
$k_{np}$ = Thermal conductivity of the nanoparticle (W/ m.K).
$k_{eff}$ = Effective thermal conductivity of nanofluid (W/ m.K).
$k_f$ = Thermal conductivity of fluid (coolant) (W/ m.K).
$k_w$ = Thermal conductivity of water (W/ m.K).
$m_{np}$ = Nanopartical mass (kg).
$m_w$ = Water mass (kg).
Q = Heat energy transferred (W).

**912**

*Eng. &Tech.Journal, Vol.34,Part (A), No.5,2016*    **Experimental Comparison between Conventional Coolants and**
**(TiO2/Water)Nanofluid to select the best Coolant for**
**Automobiles in Iraq's Summer Season**

$Q_{max}$= Maximum heat energy transferred (W).
T =Temperature (°C).
$T_a$ =Air temperature (°C).
$T_c$ =Cold fluid temperature (°C).
$T_h$ =Hot fluid temperature (°C).
$V_f$ = Velocity of the coolant fluid (m/s).
$V_{np}$ = Volume of the nanoparticles (m$^3$).
$V_T$ = Total volume (m$^3$).
$\rho$=Density(kg/m$^3$).
$\rho_{eff}$= Effective density of nanofluid (kg/m$^3$).
$\rho_f$= Density of fluid (coolant) (kg/m$^3$).
$\rho_{np}$= Density of nanoparticle (kg/m$^3$).
$\rho_w$=Density of water.
$\mu_{eff}$= Effective viscosity of nanofluid (N/m.s)
$\mu_w$ = Water viscosity(N/m.s)
$\phi$ = Volumetric concentration ratio of the nanoparticles (%).
$\in$= Heat exchanger (radiator) effectiveness.

## INTRODUCTION

Increasing power from engines in smaller bonnet spaces makes a problem because of insufficient rates of heat dissipation in automotive radiators. More than 35% of the energy produced by the engine through internal combustion is lost as heat. The overheating in engines is a result of insufficient heat dissipation from these engines that leads to breakdown of lubricating oil, engine parts weakening, and wear between these parts. To keep or eliminate the problems in the engine resulted from high heat generated from combustion, automotive radiators must be more effective to have high levels of heat transfer performance to reject heat or the coolant fluid must be more effective. Production power within the engine comes through combustion of fuel and air mixture. Just a portion of the total power generated is actually power supplied to the automobile; the rest is wasted in the form of heat and exhaust. If this excess heat is not rejected, the engine temperature will overheat and breakdown lubricating oil viscosity, which lead to damage the engine. The automobile cooling system consists of a radiator, water pump, cooling fan, pressure cap of radiator, and thermostat. The cooling fluid (coolant) plays important roles in the cooling mission (coolant moves through the engine's cylinder block and accumulates heat to reject it through the radiator).Conventional automobile cooling fluids, such as water, ethylene glycol, etc. have poor heat transfer performance (such as thermal conductivities), that lead to more problems in automobile engines in summer season in hot climate regions such as Iraq. Therefore high tightness and effectiveness of heat transfer systems are important to enhance the rate of heat transfer.

There are many noticeable studies for enhancement of the application of heat transfer fluid. Recently many researchers found that dispersing high thermal conductivities nanometer size (diameter of 1–100 nm) particles into the liquids gives highest thermal conductivity liquid compared with the (base) original liquid, these fluids are called nanofluids, **Taylori et al [1]**.
**Eastman et al [2]** showed that thermal conductivity of ethylene glycol with 0.3% concentration ratio of (Cu) nanoparticles can be improved up to 45% compared with ethylene glycol(EG).
**Y.Ding et al [3]** showed that convection coefficient heat transfer of nanofluids was higher at the tube entrance length. But it decreases with axial length and consummate the fully developed region at a constant value. Carbon nanoparticles offer highest improvement at a taken nano particle concentration and flow.

Eng. &Tech.Journal, Vol.34,Part (A), No.5,2016          Experimental Comparison between Conventional Coolants and
(TiO2/Water)Nanofluid to select the best Coolant for
Automobiles in Iraq's Summer Season

**Zeinali et al [4]** investigated experimentally convective heat transfer to (Al$_2$O$_3$/water) nanofluids in laminar flow inside a circular tube at constant wall temperature with different concentrations of nanoparticles. The study obtained an increase in coefficient of heat transfer nanofluid with increase of nanoparticle concentration. The study also indicated greater heat transfer coefficient of nanofluid in comparison with water base fluid at a constant Peclet's number.

**Hwang et al [5]** reported that the nanofluids thermal conductivity depends on the thermal conductivity and concentration ratio of nanoparticles and base fluid.

**Lee  et al [6]** studied the thermal conductivity of nanofluids with low concentration ratio produced by the two step method. The study indicated that the nanofluid thermal conductivity increases with increasing (Al$_2$O$_3$) particles.

**Mintsa et al [7]** studied the influence of changing temperatures, nanoparticles concentration ratios, with size of nanoparticles on thermal conductivity of (Al$_2$O$_3$/water) and (CuO/water) nanofluids. They indicated that the thermal properties can be improved by increasing the nanoparticles concentration ratios. They found that the nanoparticles with small sizes gave higher nanofluid thermal conductivity at the same concentration ratio.

A numerical study of heat transfer with turbulent flow on three types of nanofluids (SiO$_2$, Al$_2$O$_3$ and CuO) in water and ethylene glycol at a circular section tube under constant heat flux was done by **Namburu et al [8]**. The theoretical results showed that the nanofluids with smaller nanoparticles diameter gave highest value of viscosity and Nusselt number, and the higher nanoparticles concentration ratio gave increasing in Nusselt numbers.

**Yu et al [9]** studied experimentally the heat transfer of nanofluids containing particles with (170nm) of silicon carbide with (3.7%) volume fraction ratio. The study indicated that the nanofluids heat transfer coefficients were 50-60% higher than base fluids with constant Reynolds number.

**Bozorgan et al [10]** studied numerically the use of (20 nm) (CuO/water) nanofluid with volume concentrations up 2% in a Chevrolet Suburban diesel engine radiator, The results indicated that the pumping power and overall heat transfer coefficient are approximately 23.8% and 10% more than that of base fluid (water) at 6000 Reynolds number and automotive speed 70 km/hr.

**Leong et al [11]** studied the effect of using (2% Cu /water) nanofluid as coolant in cars radiator compared with traditional ethylene glycol. The results indicated that the heat transfer rate in heat exchanger (Radiator) was enhanced by about 3.8% by using nanofluid at Reynolds number of 5000 and 6000 for coolant and air, respectively.

Based on literature, the aim of this study is to make experimental comparison between conventional coolants (water, ethylene glycol) with (TiO$_2$/water) nanofluid for best choice in automobile engines at hot climate regions such as Iraq. The main idea arises from the features of using nanofluid to absorb large amounts of heat energy from engines and reject it to the surrounding by radiator heat exchanger, to keep engine temperature low.

**Mathematical formulation**

The effectiveness of heat exchanger (radiator) is determined by applying the equation **[12]**.

$$\text{Radiator effectiveness } (\epsilon) = \frac{\text{actual heat energy transfered}}{\text{Max. possible heat energy transfer}} \tag{1}$$

The actual heat energy transferred (lost) by the hot fluid (coolant) to the air is:

$$Q = m_h C_h (T_{h1} - T_{h2}) = m_c C_c (T_{c2} - T_{c1}) \tag{2}$$

And the maximum possible heat transfer is expressed as:

$$Q_{max} = (m \cdot C)_{min}(T_{h_{inlet}} - T_{c_{inlet}}) \qquad (3)$$

The minimum fluid is always the one experiencing the larger temperature difference in the heat exchanger (air in this case). The maximum temperature difference in the heat exchanger is always the difference in inlet temperatures of the hot (coolant fluid) and cold (air) fluids; therefore the effectiveness of the cross flow heat exchanger (Radiator) used in this study can be reduced to:

$$\in = \frac{(T_{outa} - T_{ina})}{(T_{inh} - T_{ina})} \qquad (4)$$

The well-known Dittus-Boelter equation was used to obtained Nusselt number (*Nu*) at entrance of heat exchanger with different types of coolants to relate the heat transfer coefficient **Leong et al [11]**.

$$Nu = 0.023Re^{0.8}Pr^{0.4} \qquad (5)$$

$$h_c = \frac{Nu\, k_f}{D_H} \qquad (6)$$

The Prandtl (*Pr*) number and Reynolds (*Re*) number are given by:

$$Pr = \frac{C_p\, \mu_f}{k_f} \qquad (7)$$

$$Re = \frac{\rho_f V_f\, D}{\mu_f} \qquad (8)$$

In this study, using of nanopartical with water to produce nanofluid led to changes in the physical prosperities of water. The main important aim of utilizing the nanoparticles is to enhance the thermal conductivity of the conventional fluid (coolant).The effective nanofluid's thermal conductivity ($k_{eff}$) can be calculated by **Yu** and **Choi [13]**, which is expressed in the following form:

$$k_{eff} = [\frac{k_{np} + 2k_w - 2(k_w - k_{np})\phi}{k_{np} + 2k_w - (k_w - k_{np})\phi}]k_w \qquad (9)$$

The effective viscosity of the nanofluid can be calculated by **Drew** and **Passman [14].**

$$\mu_{eff} = (1 + 2.5\phi)\mu_w \qquad (10)$$

The effective density of the nanofluid can be calculated by **Pak et al [15]**.

$$\rho_{eff} = (1 - \phi)\rho_w + \phi\rho_{np} \qquad (11)$$

And the effective specific heat is calculated from **Xuan et al [16]** as following:

$$Cp_{eff} = \frac{(1-\phi)(\rho Cp)_w + \phi(\rho Cp)_{np}}{\rho_{eff}} \qquad (12)$$

But $\phi$ refers to the volumetric concentration ratio of the nanoparticles in base fluid, which is defined as follows:

$$\phi = \frac{V_{np}}{V_T} = \frac{m_{np}\big/\rho_{np}}{m_{np}\big/\rho_{np} + m_w\big/\rho_w} \qquad (15)$$

*Eng. &Tech.Journal, Vol.34,Part (A), No.5,2016*          **Experimental Comparison between Conventional Coolants and**
**(TiO2/Water)Nanofluid to select the best Coolant for**
**Automobiles in Iraq's Summer Season**

$$(13)$$

## Experimental Part
### System configuration
In this work, the experimental procedure was done on Nissan sunny automobile produced (2009) with engine specifications: (16-valve, 4-cylinder in line, Max. power-110hp/6000 rev. per min.). The automobile was provided with cross flow aluminum heat exchanger (radiator) and geometric specifications as shown in table (1) and figure (1). Engine cooling system capacity is about (4) litters. The first test was done by using ethylene glycol/water (50/50) as coolant fluid, the second test was done by using distilled water as coolant fluid, and the third test was done by using $(TiO_2/water)$ nanofluid with concentration ratio (0.3%). The amount of nanoparticles to product (4) litters at this concentration ratio was (48.75gm) using equation (13) with (10nm) particles size. The $(TiO_2/water)$ nanofluid was prepared by ultrasonic homogenizer type (JY92-IIN) in the laboratories of University Malaya/ Malaysia. Figure (2) shows ethylene glycol/water (50/50) and $(0.3\%TiO_2/water)$ nanofluid samples with ultrasonic homogenizer. Table (2) shows the properties of conventional coolants and nanoparticle at 27 $^{o}$C. To show the rising in the coolant temperature gradually with operating engine, thermostat valve was removed from engine cooling system to allow the coolant fluid circulate from engine block to radiator when starting the test. The engine speed was seated at constant speed (1500 rev/min) for each test, and inlet coolant mass flow rate in the radiator was checked (0.25 L/s) at this engine speed, while cooling fans are seated to give constant air velocity through radiator (4.26 m/s) with engine start.

### Experimental Measurements
The three tests were done at (15-17/ august/2015) with long time (38min) for each test. Four K-type thermocouples with accuracy (±0.4%) were used in this experiment, to measure the changes in temperatures with different types of coolants. These thermocouples were put at inlet and outlet heat exchanger (radiator) hose for coolant fluid, and at inlet and outlet cooling air respectively. The thermocouples were connected to digital data taker type (TM-946) with accuracy (±0.02%) to record data. Figure (3) shows the complete system and its schematic diagram. Fan's air velocity was measured by anemometer type (Kaindl /wind master) with accuracy (±4%).

### Discussion of Results
Figures (4, 5) and (6) show the changes in coolant (Ethylene glycol/water (50/50), water) physical properties (density, specific heat, thermal conductivity) respectively, compared with (0.3% $TiO_2/water$) nanofluid at (32 $^{o}$C). The enhancing in thermal conductivity of nanofluid led to improve thermal performance of nanofluid as automobile coolant. Figure (7) shows the changes in dynamic viscosity of the used coolants with time as the temperature was rising with engine work. It was seen that Ethylene glycol/water (50/50) had highest value of dynamic viscosity at starting of test compared with others. Figures (8) and (9) give the coolants temperature at engine exit (entrance radiator) and entrance (radiator exit) with time, respectively. The percentage drop in exit engine coolant temperature was about (9%) for distilled water and about (18.5%) for $(TiO_2/water)$ nanofluid compared with Ethylene glycol/water (50/50) at the test end, and it was about (10%) for distilled water and about (21%) for $(TiO_2/water)$ nanofluid compared with Ethylene glycol/water (50/50) at engine entrance (radiator exit) at the test end. The increasing in thermal conductivity led to increasing in radiator effectiveness as shown in figure (10). The percentage increasing in radiator effectiveness was about (29%) with using distilled water and about (51%) with using $(TiO_2/water)$

*Eng. &Tech.Journal, Vol.34,Part (A), No.5,2016*    Experimental Comparison between Conventional Coolants and
(TiO2/Water)Nanofluid to select the best Coolant for
Automobiles in Iraq's Summer Season

nanofluid compared with Ethylene glycol/water (50/50) at the test end. Figure (11) shows the heat energy lost from radiator by the different coolants (hot fluid) with time depending on equation (2). The increasing in cooling air temperature passing through radiator with time as the types of coolant fluid is shown in figure (12).

Figures (13, and 14) show the changes in Prandtl and Reynolds numbers at entrance of radiator hose with different types of coolants depending on equations (7) and (8). Figures (13, and 14)a are at $32^{o}C$ for both Prandtl and Reynolds numbers. But from figures (13, and 14)b for both Prandtl and Reynolds numbers, the changes in physical proprieties of coolants such as dynamic viscosities, etc with time as rising in temperature led to changes of these values with time as shown. The last reason leads to changes in Nusselt's number and convection heat transfer coefficient at entrance of radiator hose as rising in temperature with time at different types of coolant as shown in figures (15, 16) b, depending on equations (5) and (6), but figures (15,and 16)a were at $32^{o}C$. The percentage increasing in Nusselt's number was about (30.5%) with using distilled water and about (42.8%) with using ($TiO_2$/water) nanofluid compared with Ethylene glycol/water (50/50). This leads to increasing in convection heat transfer coefficient about (49.5%) with using distilled water and about (65%) with using ($TiO_2$/water) nanofluid compared with Ethylene glycol/water (50/50).

## CONCLUSIONS

Thermal conductivity of the selective coolant fluid is more important to keep or eliminate the problems in the engine as a result of high heat generated from combustion; the main important conclusions from the present research can be summarized in the following:

1- The use of nanoparticles to produce coolant fluid (nanofuid) has thermal conductivity higher than distilled water and are more effective as coolant fluid, but nanoparticles are used in certain ratios depending on the type of nanoparticles to avoid the side effect of increasing of others physical properties such as (density, dynamic viscosity).

2- Using a commercial antifreeze coolant such as Ethylene glycol/water as coolant in automobile at winter season or in low temperature climate countries is to avoid coolant freezing inside engine block. But in hot climate countries especially in summer season is less effective compared with distilled water.

3- Automotive radiators must be more effective and have high levels of heat transfer performance to reject heat, and using of selective nanofluid in certain ratios lead to increasing in radiator effectiveness.

**Table (1): Specification of Nissan sunny car radiator was used in this experiment.**

| Content | Dimension |
|---|---|
| Radiator length ($R_{leng}$) | $68.8 \times 10^{-2}$m |
| Radiator width, ($R_{wid}$) | $38 \times 10^{-2}$m |
| Radiator height($R_h$) | $18 \times 10^{-3}$m |
| Tube width ($t_{width}$) | $18 \times 10^{-3}$m |
| Tube height ($t_{height}$) | $1.5 \times 10^{-3}$m |
| Fin width ($F_{wid}$) | $18 \times 10^{-3}$m |
| Fin height ($F_h$) | $8 \times 10^{-3}$m |
| Fin thickness ($F_{th}$) | $2.5 \times 10^{-5}$m |
| Distance between fins ($F_{dis}$) | $2 \times 10^{-3}$m |
| No. of tubes | 84 |
| Inlet & Exit radiator hose diameter (D) | $3 \times 10^{-2}$m |

*Eng. &Tech.Journal, Vol.34,Part (A), No.5,2016*     Experimental Comparison between Conventional Coolants and
(TiO2/Water)Nanofluid to select the best Coolant for
Automobiles in Iraq's Summer Season

**Table (2) Properties of conventional coolants and nanoparticle at 32 $^{o}$C.**

| Coolants | Density, $\rho$ [kg/m$^3$] | Thermal Conductivity, $k$ [W/mK] | Specific heat, $Cp$ [J/kg.K] | Dynamic viscosity, $\mu$ [N/m.s] |
|---|---|---|---|---|
| Water | 995.6 | 0.6177 | 4176.9 | 0.000844 |
| Ethylene glycol/water (50/50) | 1068.9 | 0.3745 | 3328.7 | 0.002774 |
| (TiO$_2$) nanoparticles | 4050 | 11.8 | 697 | — |
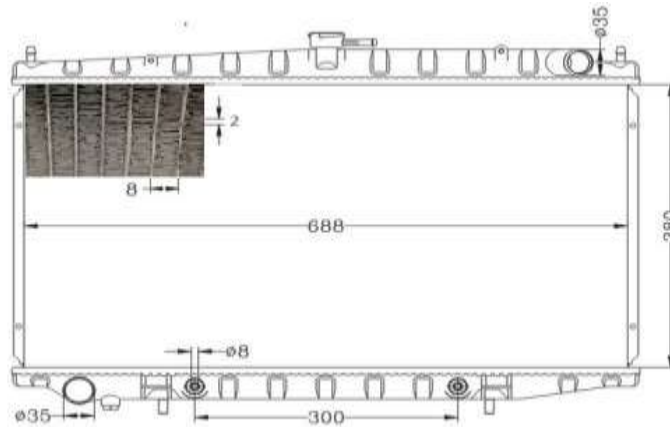


**Figure(1) geometry description of Nissan sunny car radiator**



**Figure(2) Ethylene glycol/water (50/50) and (0.3% TiO2/water) nanofluid samples with ultrasonic homogenizer**

Eng. &Tech.Journal, Vol.34,Part (A), No.5,2016

Experimental Comparison between Conventional Coolants and
(TiO2/Water)Nanofluid to select the best Coolant for
Automobiles in Iraq's Summer Season



(a)
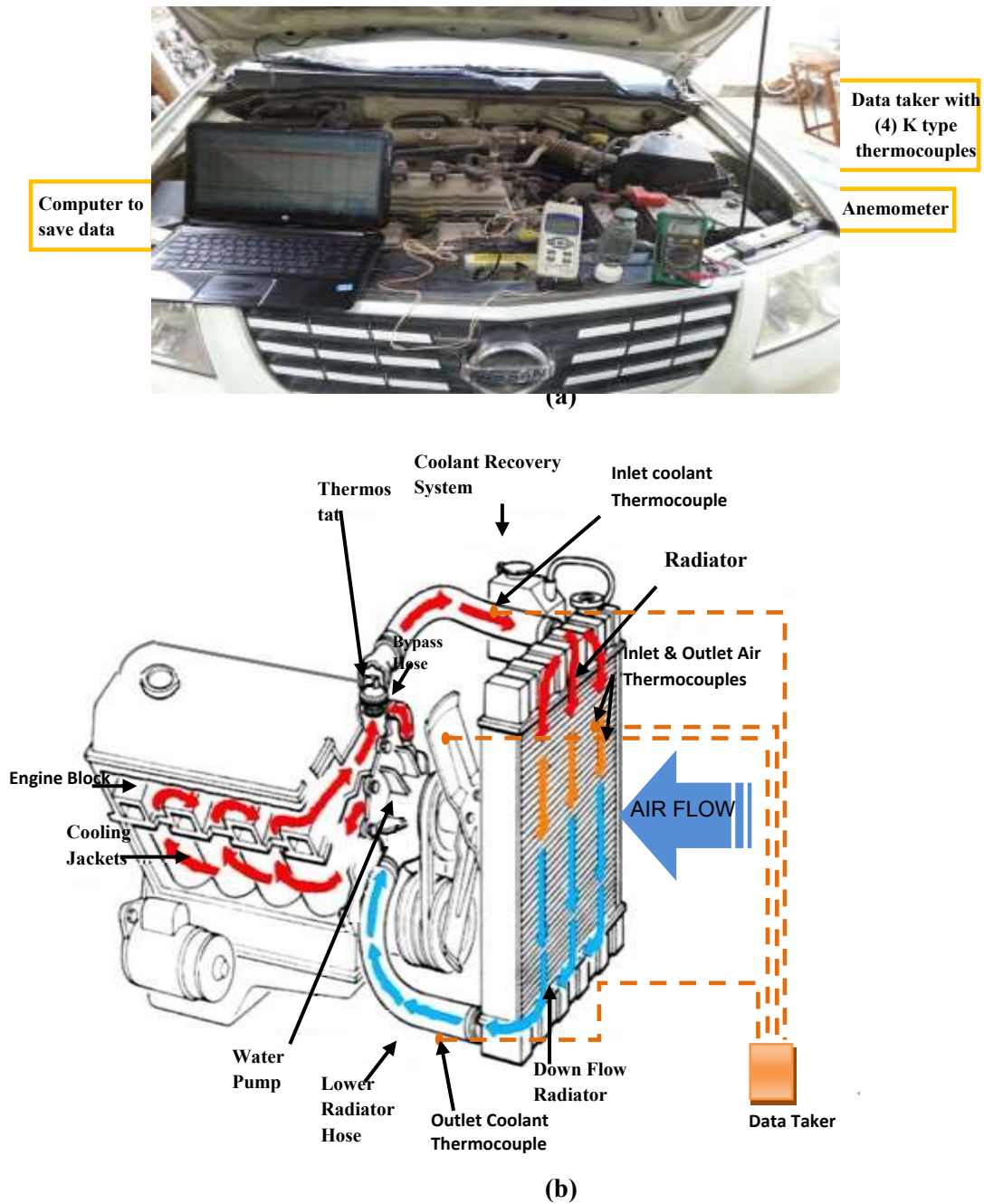
Figure(3) (a) The complete system, (b) Schematic diagram of the complete system

Eng. &Tech.Journal, Vol.34,Part (A), No.5,2016          Experimental Comparison between Conventional Coolants and
(TiO2/Water)Nanofluid to select the best Coolant for
Automobiles in Iraq's Summer Season
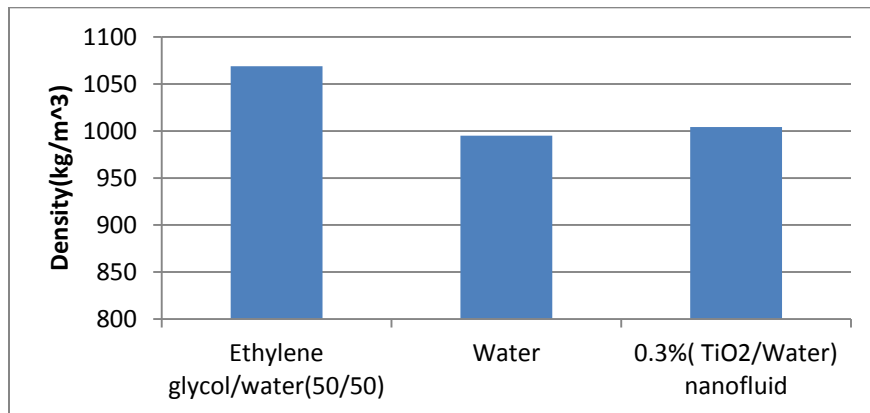


**Figure(4) Coolants density that used in this experiment comparative with nanofluid at 32 $^{o}$C**
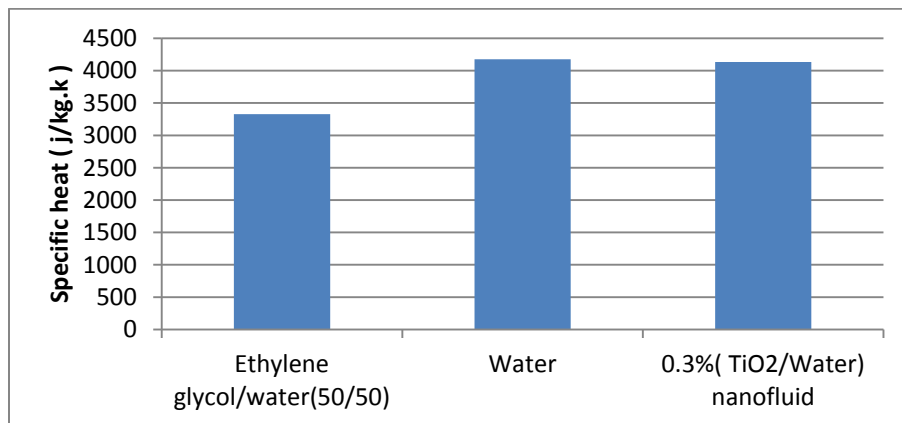


**Figure(5) Coolants specific heat that used in this experiment comparative with nanofluid at 32 $^{o}$C**
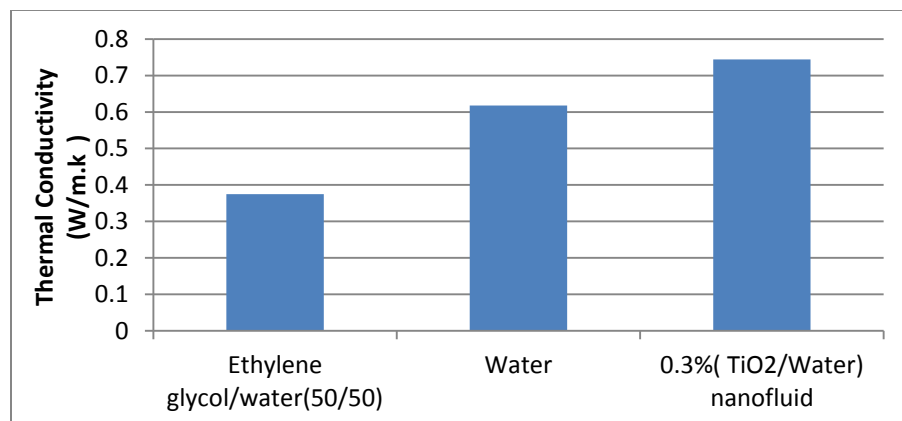


**Figure(6) Coolants thermal conductivity that used in this experiment comparative with nanofluid at 32 $^{o}$C**
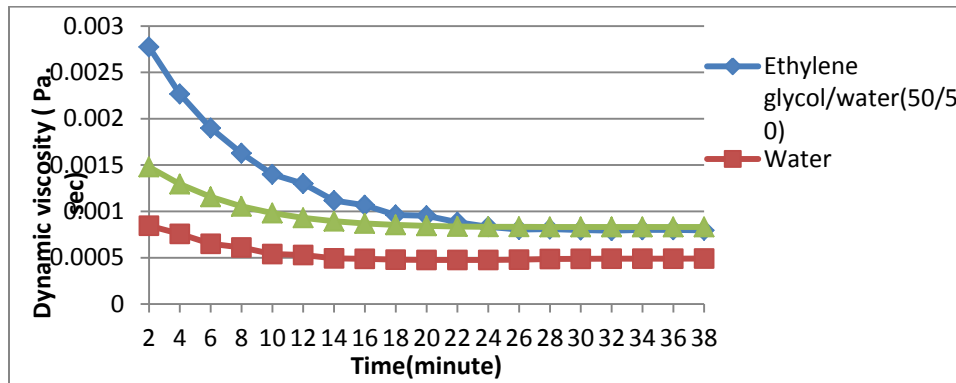
**Figure(7) the changes in dynamic viscosity of three types of coolants with time as rising in temperature**
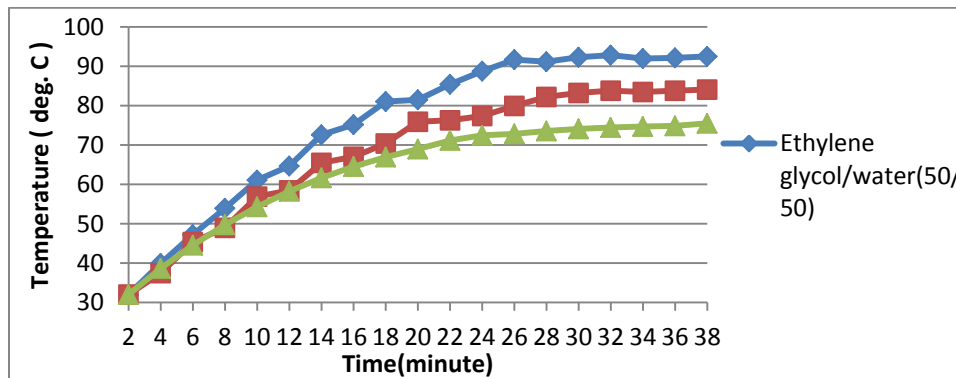


**Figure(8) the rising in coolants temperature at exit of engine (entrance of automobile radiator) with time**
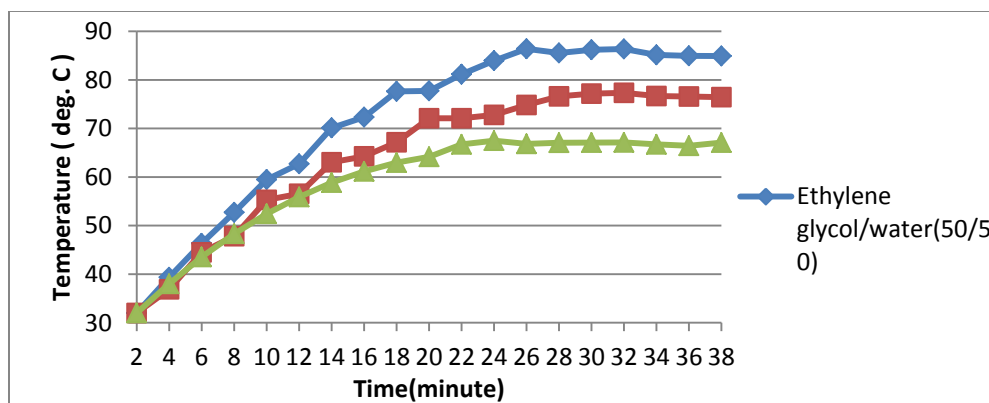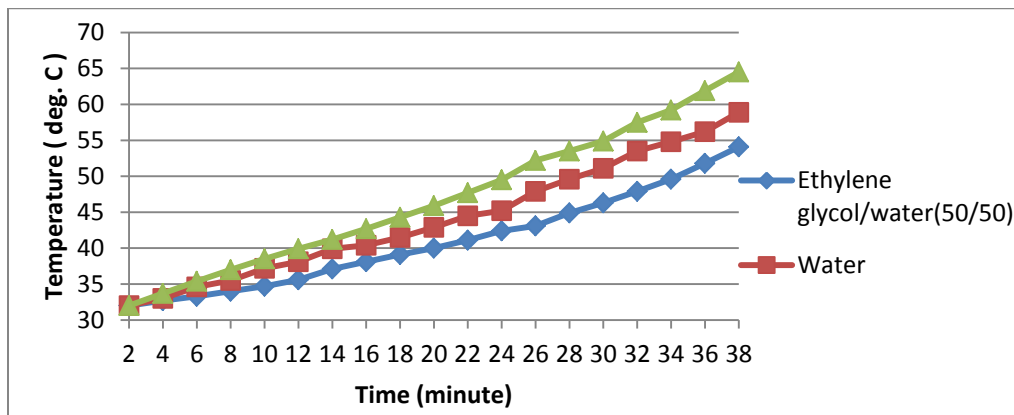


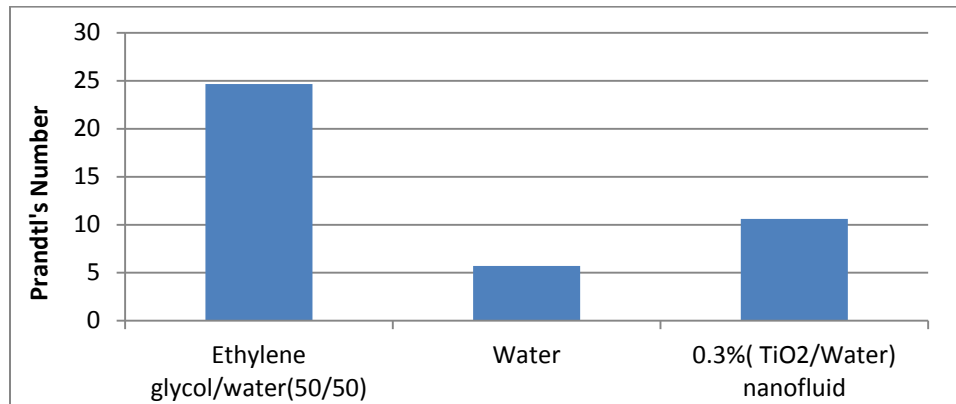**Figure(9) coolants temperature at entrance engine (exit of automobile radiator) with time**
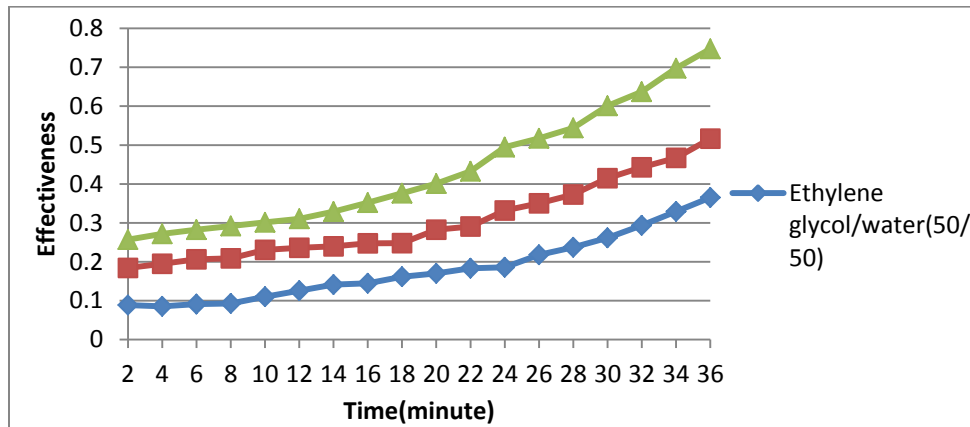
**Figure(10) heat exchanger effectiveness (radiator) with different types of coolant with time as rising in temperature**
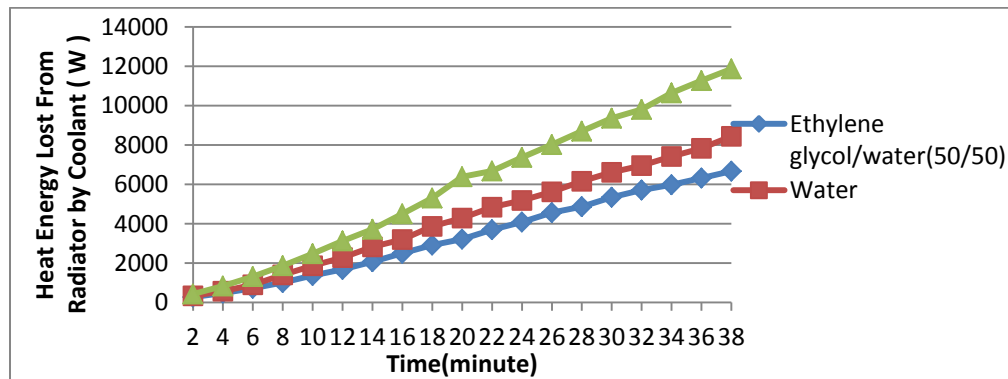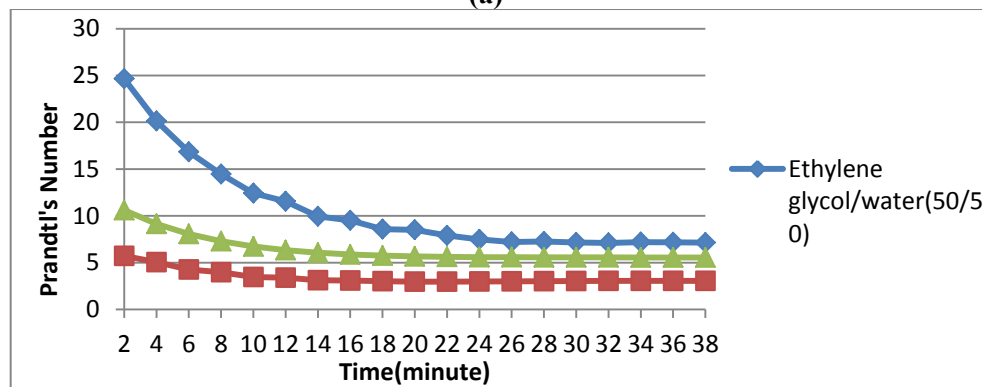


**Figure(11) the heat energy lost from radiator by coolants (hot fluid) with time**



**Figure(12) the rising in air temperature at exit of automobile radiator with time**

*Eng. &Tech.Journal, Vol.34,Part (A), No.5,2016*          Experimental Comparison between Conventional Coolants and
(TiO2/Water)Nanofluid to select the best Coolant for
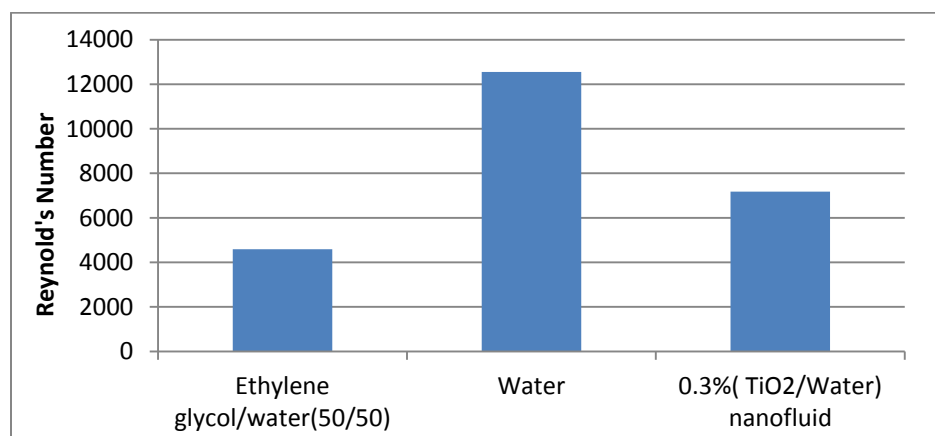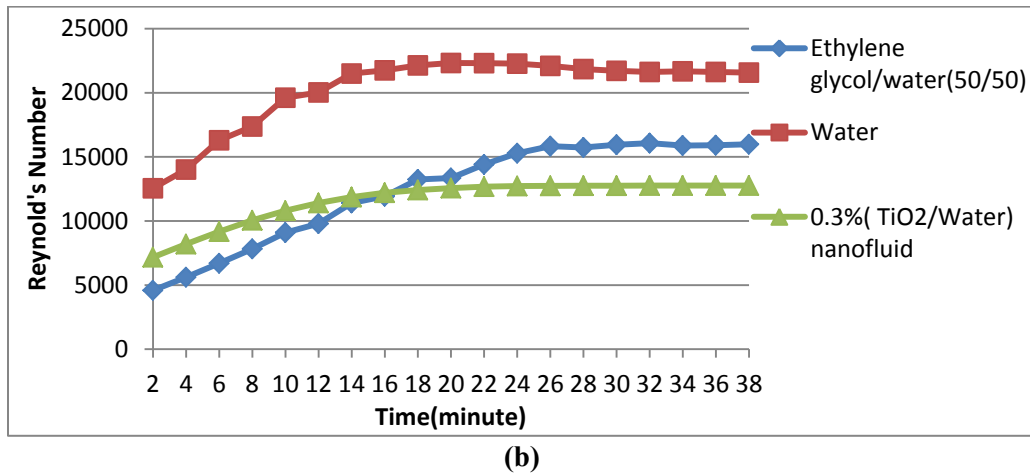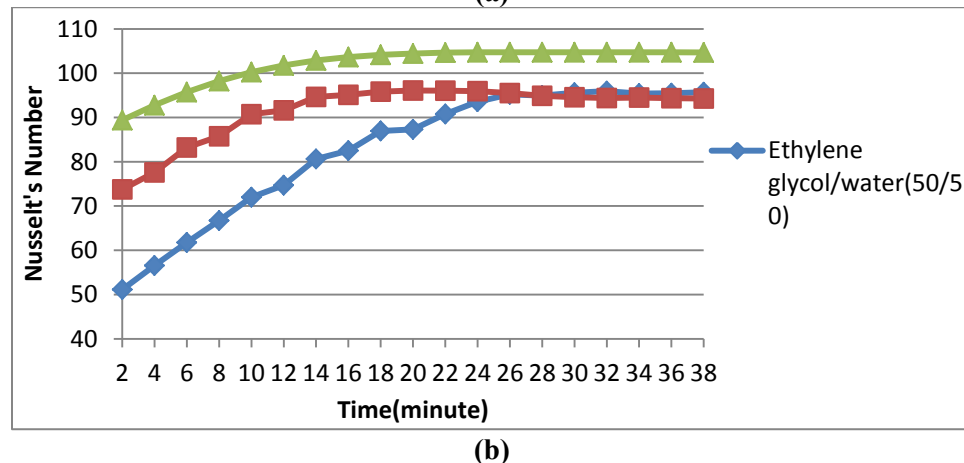Automobiles in Iraq's Summer Season

(a)



(b)

**Figure(13) the changes in Prandtl's number by different types of coolant at entrance of radiator hose, (a) at 32$^{o}$C, (b) with time as rising in temperature**



(a)

*Eng. &Tech.Journal, Vol.34,Part (A), No.5,2016*     Experimental Comparison between Conventional Coolants and
(TiO2/Water)Nanofluid to select the best Coolant for
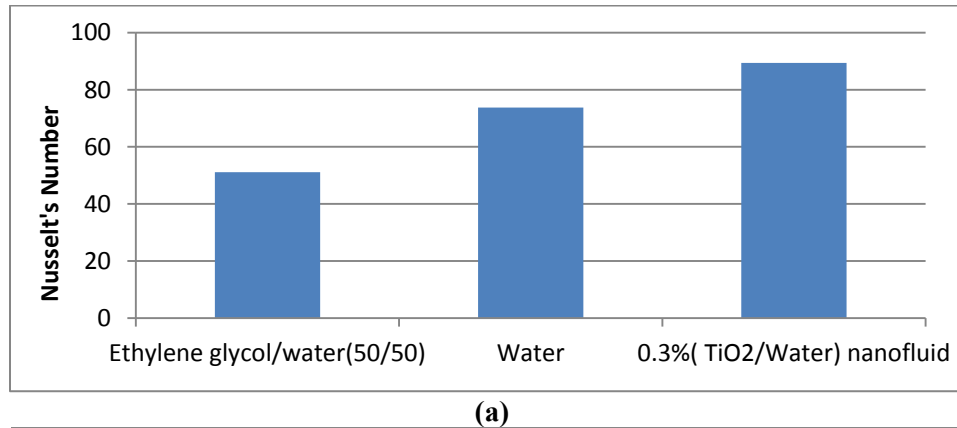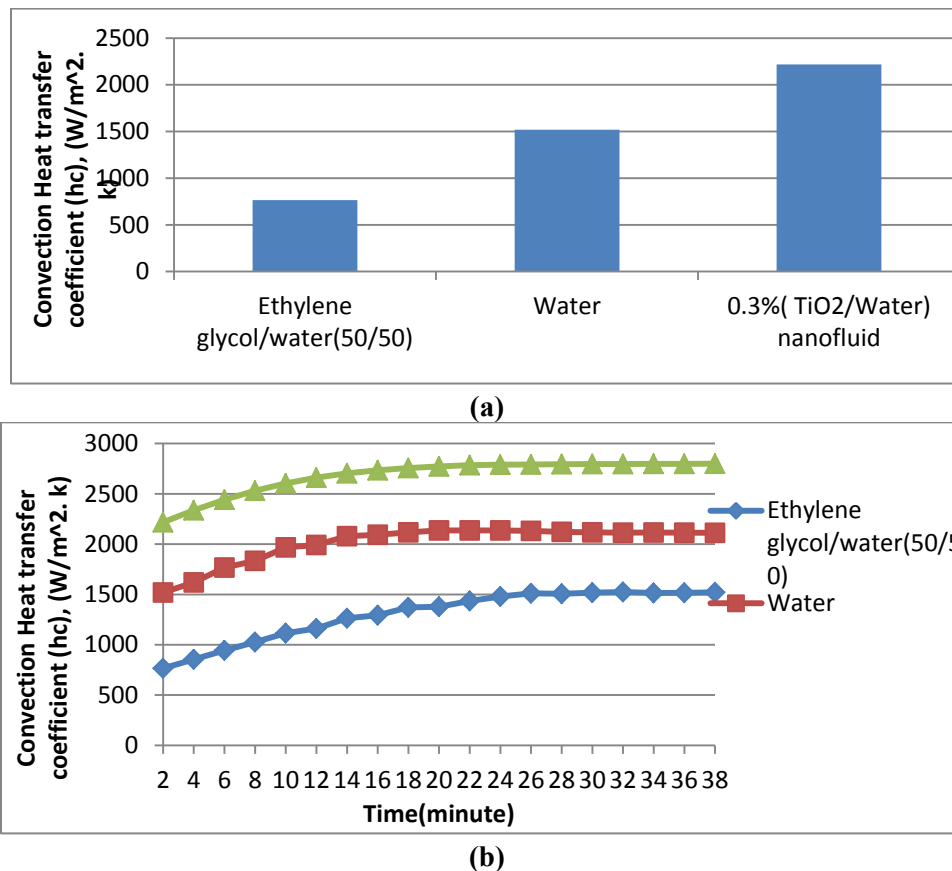Automobiles in Iraq's Summer Season



**(b)**

**Figure(14) the changes in Reynold's number by different types of coolant at entrance of
radiator hose, (a) at 32$^o$C, (b) with time as rising in temperature**



**(a)**



**(b)**

**Figure(15) the changes in Nusselt's number by different types of coolant at entrance of
radiator hose, (a) at 32$^o$C, (b) with time as rising in temperature**

924

**(a)**



**(b)**

**Figure(16) the changes in convection heat transfer coefficient by different types of coolant at entrance of radiator hose, (a) at 32°C, (b) with time as rising in temperature**

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*Eng. &Tech.Journal, Vol.34,Part (A), No.5,2016*          **Experimental Comparison between Conventional Coolants and
(TiO2/Water)Nanofluid to select the best Coolant for
Automobiles in Iraq's Summer Season**

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