EXPERIMENTAL ANALYSIS OF THE EFFECTS OF USING DIFFERENT WATER-ETHYLENE GLYCOL MIXTURE RATES ON HEAT TRANSFER PERFORMANCE IN A HEAT EXCHANGER

Bahadır GEMİCİOĞLU [1*], Tolga DEMİRCAN [2]

[1] Kırıkkale University, Faculty of Engineering and Architecture, Mechanical Engineering, 71450 KIRIKKALE
ORCID No : http://orcid.org/0000-0001-8403-1848
[2] Kırıkkale University, Faculty of Engineering and Architecture, Mechanical Engineering, 71450 KIRIKKALE
ORCID No : http://orcid.org/0000-0003-4805-6428

Keywords

Heat exchanger
Heat transfer
Ethylene glycol
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Automobile radiator

Abstract

In this study, the effects of using different water-ethylene glycol mixture rates on heat transfer performance put in an automobile radiator as a liquid is experimentally analysed. Ethylene glycol is added in water volumetrically and experiments are conducted for 0%, 25%, 50%, 75% and 100% volumetric ratio of ethylene glycol. For all these mixture rates, 300 experiments are conducted for fluid inlet temperature between 40-80 °C, fluid inlet flow rate between 10-22 l/min and cooling air between 1-4 m/s. As a result of the experiments, it is observed that as ethylene glycol mixture ratio passing from the radiator increased, heat transfer decreased. However, as cooling air velocity, fluid inlet flow rate and radiator inlet temperature increased, heat transfer increased as well. When water-ethylene glycol mixture is used in the radiator instead of water, it is observed that radiator fluid freezing temperature decrease and radiator heat transfer performance is negatively impacted. As a result, optimum cooling performance for the automobile radiator was determined at 0% EG mixture (only water), fluid inlet temperature of 80°C, the flow rate of 22 l/min and air velocity of 4 m/s.

BİR ISI DEĞİŞTİRİCİSİNDE FARKLI SU-ETİLEN GLİKOL KARIŞIMI KULLANIMININ ISI TRANSFER PERFORMANSINA ETKİLERİNİN DENEYSEL ANALİZİ

Anahtar Kelimeler

Isı değiştiricisi
Isı transferi
Etilen glikol
Antifriz
Otomobil radyatörü

Öz

Bu çalışmada bir otomobil radyatöründe akışkan olarak farklı karışım oranlarında su-etilen glikol karışımının kullanımının, radyatörün ısı transfer performansı üzerindeki etkileri deneysel olarak incelenmiştir. Bu amaçla, su içerisine hacimsel olarak etilen glikol ilave edilmiş ve etilen glikolün hacimsel oranı %0, %25, %50, %75 ve %100 olduğu durumlar için deneyler gerçekleştirilmiştir. Tüm bu karışım oranları için, akışkan giriş sıcaklığı 40-80 °C aralığında, akışkan giriş debisi 10-22 l/dk aralığında ve soğutma hava ise 1-4 m/s aralığında değiştirilmek üzere toplam 300 adet deney gerçekleştirilmiştir. Yapılan deneyler sonucunda etilen glikolün karışım oranının artması durumunda radyatörden gerçekleşen ısı transferinin azaldığı gözlemlenmiştir. Ancak soğutma hava hızı, akışkanın giriş debisi ve radyatör giriş sıcaklığı arttıkça, gerçekleşen ısı transferinde de artış olduğu belirlenmiştir. Dolayısıyla radyatörlerde su yerine su-etilen glikol karışımının kullanılması durumunda, radyatör akışkanının donma nokta sıcaklığının düşürülmesi sağlanırken, radyatörün ısı transfer performansının olumsuz olarak etkilendiği gözlemlenmiştir. Sonuç olarak, radyatörün optimum soğutma performansının % 0 EG karışımı (sadece su), 80 ° C sıvı giriş sıcaklığı, 22 l/dak akış hızı ve 4 m/s hava hızı için gerçekleştiği belirlenmiştir.

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Sorumlu yazar; e-posta : bahadirgemicioglu@kku.edu.tr

1. Introduction

Internal combustion engines can reach high temperatures during operation. While this decreases engine operation performance, thermal stress and friction might decrease the engine lifecycle. Therefore, it is extremely important to cool the engines to safe operating temperatures and preserve these temperature rates. For this purpose, liquid cooling systems are commonly preferred in internal combustion engines. Liquid cooling systems operate by transferring the high temperature generated by engine operation to a liquid with engine cooling channels and decreasing the engine temperature.

Automobile radiators are the most critical element automobile cooling systems. Radiators work as heat exchangers. While the high-temperature fluid passes from the internal radiator pipes, cold air is sent to the outer surface of the radiator with a fan. Thus, a heat exchange occurs between the fluid and air and fluid temperature decreases. The cool fluid exiting the radiator is sent back to the engine with a pump to continue cooling.

When the literature is reviewed, there are various studies on automobile radiators. These studies especially focused on cooler fluid flow rate, inlet temperature, fluid type, airflow rate, radiator fin geometry and pipe structure. The related literature is reviewed in line with the subject of this study. In the majority of the studies, it was seen that fixed water+ethylene glycol mixture rate is used as radiator fluid or nanoparticles are added to this mixture. Some of the studies in the literature are presented below.

2. Scientific Literature Survey

The effects of nanofluid usage in an automobile radiator was analysed on the heat transfer characteristics. The base fluid was determined as ethylene glycol-water mixture in their study and nanoparticles were added to this mixture. The fluid flow rate was changed between 4-7 l/min range and the airflow rate was fixed constant at 4.9 m/s for the experiments. Cu and TiO_2 were added as nanoparticles. As a result, the authors found that nanofluid usage improved heat transfer coefficient by 24.5% and the heat transfer rate by 13.9% (Harsh et al., 2018). Carboxyl was used graphene nanofluid in an automobile radiator and analysed the thermal performance. For this purpose, carboxyl-graphene nano-material was added to traditional ethylene glycol base fluid. As a result, authors observed improvement in Nusselt coefficient and radiator efficiency however, the authors stated that is was not possible to change radiator design based on these results (Ponangi, Sumanth, Krishna, Seetharam and Seetharamu, 2018). Nanofluids were used to increase cooling performance in an automobile radiator. For this purpose, Al_2O_3 and TiO_2 nanoparticle added 50%-50% water-ethylene glycol mixture was analysed. The authors conducted a comprehensive analysis of thermophysical properties (size, density, viscosity, thermal conductivity, corrosive behaviour). As a result, authors determined 0.3% volumetric that Al_2O_3 usage as a cooling fluid increased radiator thermal performance approximately by 24.21% (Said et al., 2019).

Experimental and numerical analysis of a modified hot water radiator with improved performance was studied. The authors modified and desingned radiator with fin. They used five fins in their design. CFD results were validated with experimental results. Validation was almost same. Conclusion simulations of new modified of radiator output of heat was greater than original radiator (Rahmati and Gheibi, 2020). Improving the cooling performance of automobile radiator with Al_2O_3/water nanofluid was investigated. The authors experimentally compared to water based nanofluid forced convective heat transfer with pure water in automobile radiator. 5 different concentrations of nanofluids were prepared. Volumetric flow rate was changed to 2-5 l/min which correspond to turbulent flow. Inlet flow temperature was varied to 37°C-49°C. Results showed increasing volumetric flow and low concentrations of nanofluids were improved heat transfer (Peyghambarzadeh, Hashemabadi, Jamnani and Hoseini, 2011). Fe_2O_3-TiO_2/water hybrid nanofluid was investigated in aluminum tube automotive radiators for convective heat transfer optimization. Three nanoparticle concentration was prepared. Fluid inlet temperature and volumetric flow rate were varied to examine to heat transfer rate. Results showed that maximum value of concentration, volumetric flow and inlet temperature conditons heat transfer rate increased (Abbas et al., 2021).

The effects of fin shape, antifreeze and nanoparticles on fin piped heat exchanger were numerically analysed in automobile radiators. For this purpose, the authors determined three different fin design and compared the obtained results with flat fin type. Additionally, the effect of 40%-50%-60% volumetric antifreeze was analysed. When compared with other fin types, authors found that louvred fin had the highest heat transfer ratio and enabled 24.6% improvement compared to flat fin. Authors also observed that antifreeze addition decreased heat transfer ratio while nanoparticle addition increased this ratio (Habibian, Abolmaali and Afshin, 2018). The effects of Co_3O_4 and Al_2O_3 nanofluid usage in an internal combustion engine on heat transfer performance and friction factors were experimentally analysed. The author changed the particle mixture rate between 0.02-0.2% in the experiments. Additionally, ethylene glycol/water ratio in the base fluid was changed as 0-100%, 10-90% and 20-80% respectively. As a result, the author observed that cobalt oxide based nanofluid usage showed higher thermal performance than alumina-based nanofluid usage. Higher performance values were observed in high Reynolds number and low concentration ratio. The author expressed that increased ethylene glycol addition in the cooling fluid decreased Nusselt number and increased pumping power compared to pure water (Elsaid, 2019). Automobile radiator cooling performance was aimed to increase by using ethylene glycol-water based TiO_2 nanofluid. In their study, TiO_2 nanofluid forced heat transfer coefficient was experimentally measured and compared with base fluid data. 60% water and 40% glycol mixture was used as the base fluid and TiO_2 particle was added to this mixture to experiment for 0.1%, 0.3% and 0.5% volumetric concentrations. As a result of that study, the authors determined that increased fluid velocity to the radiator improved heat transfer performance however, increased fluid temperature to the radiator had almost no effect on heat transfer performance (Sandhya, Reddy, and Rao, 2016).

The improvement provided by graphene-based mixtures on the total heat transfer coefficient was analyzed of an automobile radiator. As the base liquid, 70% water and 30% ethylene glycol mixture was used. The authors repeated the experiments for 5 different flow rate and 2 different inlet temperatures with different concentration rates. Authors stated that the nanofluid mass flow rate increased heat transfer coefficient with increased inlet temperature and graphene ratio (Selvam, Lal and Harish, 2017). Al_2O_3 was added to water-ethylene glycol base fluid of an automobile radiator and experimentally studies to increase heat transfer. Ethylene glycol+water mixtures were analysed for 90/10 and 80/20 mixture ratios and the authors observed that heat transfer decreased by 20% and 25% respectively. Additionally, the authors added 0.1% Al_2O_3 particle to 80/20 base mixture and authors found that this improved heat exchange performance by 37%. As a result, the authors observed that increased ethylene glycol in the cooling fluid decreased radiator heat exchange performance and nanoparticle addition increased this performance (Nambeesan et al., 2015). The thermal performance of air-cooled heat exchanger was numerically investigated. The authors accepted that MgO-MWCNTs/EG hybrid nanofluid flows from the air outside the exchanger. The authors analysed fluid concentrations and inlet temperatures for different pipe geometries. As a result of their analysis, the authors observed that the vertical piped radiator was 10% more efficient than the horizontal piped radiator. Additionally, the authors stated that 25% less pressure drop was observed in the heat exchanger of circular pipes and 10% higher Nusselt number value was achieved in ellipse pipes. Results showed that increased nanofluid concentration increased Nusselt number and pressure drop (Karimi, and Afrand, 2018).

The heat transfer potential of an automobile radiator that uses Al_20_3/Water-Mono Ethylene Glycol fluid waas experimentally analysed. For this purpose, the authors selected 50%-50% volumetric water and mono ethylene glycol mixture ratio as the main fluid. Al203 particle was added to this main fluid. The authors repeated the experiments for 0.2%-0.8% volumetric mixture rate range, 4-9 litre/min cooling fluid volumetric flow rate range and 65-85 °C fluid inlet temperature range. As a result, authors determined that Al_20_3 particle addition increased radiator heat transfer performance. The authors observed that the highest heat transfer increase of 30% was observed in the lowest volumetric nanofluid concentration of 0.2% (Subhedar, Ramani and Gupta, 2018). The effects of using a winding wire in addition to Al_2O_3-ethylene glycol in an automobile radiator on heat transfer was analysed. Al_2O_3 volumetric concentration of 0.08%, 0.5% and 1% were considered. As a result, the authors determined that using winding wire approximately increased heat transfer by 9% (Goudarzi and Jamali, 2017). The effects of CuO/Water nanofluid as a radiator fluid usage on heat transfer to improve the thermal performance of a radiator was analysed. For this purpose, the authors numerically and experimentally analysed CuO/Water mixture volumetric ratio for 0.025-0.05% range, Reynolds number of 8000-25000 range and inlet temperature of 50-60 °C range and compared the obtained results. As a result, the authors determined that using CuO/water as a radiator fluid increased heat transfer compared to using water only (Ravisankar, Venkatachalapathy and Alagumurthy, 2015). The effect of the geometry in a compact louvred heat exchanger was experimentally analysed. The authors designed the test samples to form two types of fin configuration. As a result of their study, the authors stated that symmetrical louvred fins had 9.3% heat transfer performance increase and 18.2% pressure decrease compared to asymmetrical positioning. Additionally, the authors found 17.6% fin weight decrease for constant heat transfer ratio and pressure drop in symmetrical fin positioning (Vaisi, Esmaeilpour and Taherian, 2011).

The effect of oval and circular pipe configuration in fin-pipe type heat exchanger was numerically analysed. As a geometric parameter, the authors analysed louver angle, louver level and louver length. As a result, the authors stated that pressure loss tends to increase with increased louver angle. Additionally, the authors observed that optimum value for the heat transfer performance was at lower and upper louver surfaces due to thermal boundary layer development differences. The authors determined that heat transfer and friction performance increased with louver length (Leu, Liu, Liaw and Wang, 2011). The effects of natural convection of heat exchanger slop angle was analysed on thermal performance. The authors stated that as the slope angle increased, the exchanger heat transfer performance often decreased. When the slop angle was 30°-45°, the authors observed that heat transfer performance significantly decreased. Additionally, the authors determined that heat transfer performance decreased as the number of pipe rows increased (Nuntaphan, Vithayasai, Kiatsiriroat and Wang, 2007). The thermal performance of the PCCP panel radiator for different connection positions were experimentally and numerically analysed. For this purpose, the authors investigated the effects of convector metal sheet thickness, convector height, the distance between opposite convectors (d), convector trapezoidal length and convector tip radius on thermal performance. As a result, the authors found that experimental results and numerical results matched. The authors stated that transfer fin (convector) radiators have an important effect on heat transfer and total weight and observed that heat transfer increased when the convector metal sheet thickness and length increased (Calisir, Yazar and Baskaya, 2019).

The thermophysical properties and heat transfer characteristics when water/ethylene glycol and Al_2O_3/CuO based fluid was used in an automobile radiator was numerically analysed. Each study used ethylene glycol and water with 50% concentration as the base fluid. The authors attempted to assess the heat transfer characteristics by adding Al_2O_3 and CuO particles with 0.05%, 0.15% and 0.3% to base fluid. As a result, the authors stated that the highest thermal transfer performance is with CuO addition. When CuO was added to the base fluid, heat transfer coefficient was 36384.41 W/(m^{2}K), heat conductivity coefficient was 1,241 W/(mK), Nusselt number was 208.71 and heat transfer ratio was 28.45 W (Tijani and Sudirman, 2018). The heat transfer performance of an automobile radiator with Cu and Ag added TiO_2 base fluid was attempted to improve The authors considered 5 different particle types such as pure TiO_2, 0.1% Ag added TiO_2, 0.3% Ag added TiO_2 and 0.1% Cu added TiO_2. These particles were added to 50%-50% volumetric water-ethylene glycol mixture with 0.3%, 0.5%, 1% and 2% ratio. The authors evaluated the study both experimentally and theoretically. As a result, the authors stated that Ag addition to cooling fluid improved heat transfer properties (Soylu, Atmaca, Asiltürk and Doğan, 2019).

As can be seen, a comprehensive literature review has been conducted on the effects of cooling fluid type in the radiators on heat transfer. It was observed that the majority of these studies were applications that mixed antifreeze (water+ethylene glycol) and nanoparticles in different ratios. There are only few studies investigating the cooling performance of only water+ethylene glycol fluid mixtures without nanoparticle addition. In this sense, this study focuses on the effects of water+ethylene glycol mixture ratio as a cooling fluid in the radiators on heat transfer performance. For this purpose, an experiment setup was designed and implemented. With this setup, experiments were conducted for different water+ethylene glycol mixture ratios, different fluid inlet temperatures, different inlet flow rates and airflow rates. Based on the data obtained from the experiments, the thermal performance of the radiator was analysed.

3. Experimental Method

In this study, the principles of scientific research and publication ethics complied. Used in the study in sections 3.1, 3.2, 3.3 and 3.4 methods are explained.

3.1 Introduction of Experimental Setup

Within the scope of this study, an experimental setup was designed and established to represent an automobile radiator operation. With this experimental setup, experiments were conducted by changing cooling fluid type, fluid inlet flow rate, fluid inlet temperature and air velocity and radiator operating performance were analysed experimentally. The schematic form of the designed experiment setup is given in Figure 1 and the photographs of the actual setup are given in Figure 2.

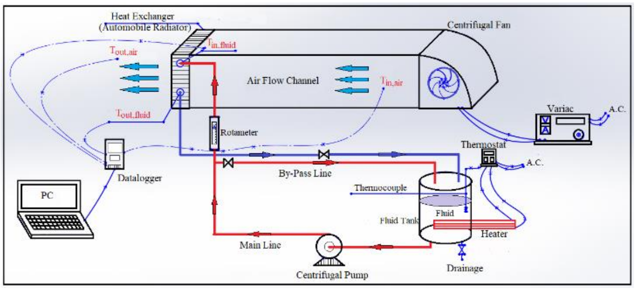

Figure 1. Experiment Setup Schematic Representation

Figure 2. Photographs of Experiment Setup

The experiment setup consisted of 2 independent flow line which was cooling fluid flow line and airflow line. Additionally, 1 data retrieval and storage unit was on the experiment setup to collect data. Basic equipment and measurement devices on the experiment setup are given in Figure 3.

Cooling fluid flow line was the line that enables the water+ethylene glycol used as the cooling fluid to flow inside the radiator by circulation with a centrifuge pump. This flow line consisted of a fluid tank with resistance where cooling fluid is stored and used for heating cooling fluids, centrifugal water pump, flow rate adjusting valves, buoy-type flow meter to measure cooling fluid flow rate, an automobile radiator and piping where the cooling fluid flows.

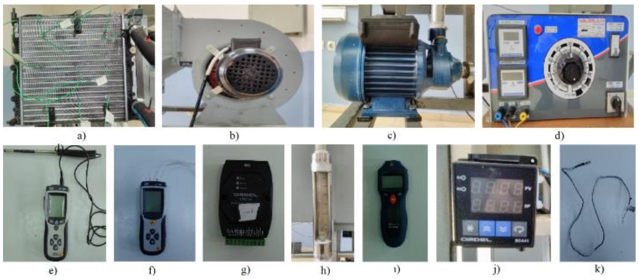

Figure 3. Basic Equipment And Measurement Devices On The Experiment Setup: a) Radiator, b) Centrifuge Fan, c) Pump, d) Variac, e) Hotwire Anemometer, f) Manometer, g) Datalogger, h) Flowmeter, i) Tachometer, j) Thermostat, k) K-Type Thermocouple

Airflow line was the line where the air flow is supplied to an air channel via a centrifugal fan. This flow line consisted of centrifugal fan that sends the air to the system, variac that changes the centrifugal fan inlet voltage to adjust air velocity, an air channel where the air passes and an automobile radiator. Hotwire anemometer was used to measure air velocity and and tachometer was used to centrifugal fan's rpm. As expressed above, the automobile radiator is a common element for both the airflow line and cooling fluid flow line. Water+ethylene glycol mixture flows from the automobile radiator inner pipes and cold airflows from the outer surface.

Data collection unit consisted of thermocouples, dataloggers, a computer and a hotwire anemometer. In this context, thermocouples were placed in radiator inlet-outlet pipe, and air inlet-outlet section. Thermocouples were linked datalogger, and datalooger was connected to computer. Within this scope, a total of 17 thermocouples with 9 on the radiator, 2 each on-air inlet-outlet and 2 each on cooling fluid inlet-outlet were positioned on the experiment setup. During the experiments, water+ethylene glycol mixture prepared with different volumetric ratios were used as cooling fluid.

3.2 Mathematical Equations

Data obtained from the experiments conducted on the experiment setup designed and implemented within the scope of this study were analysed by using the mathematical equations below. Thus, the effects of different water+ethylene glycol mixture ratio on cooling performance in an automobile radiator considered in this study were experimentally investigated. The water+ethylene glycol mixture, air volumetric and mass flow rates were determined by using the following equations (Çengel and Boles, 2006)

$$\dot{V}_a = V_a A_c \quad (1)$$

$$\dot{V}_f = V_f A_p \quad (2)$$

$$\dot{m}_f = \rho_f \dot{V}_f \quad (3)$$

$$\dot{m}_a = \rho_a \dot{V}_a \quad (4)$$

Reynolds number of air and water+ethylene glycol mixture was calculated by using the following equations (Çengel and Cimbala, 2006).

$$\mathrm{Re}_f = \frac{\rho_f V_f D_h}{\mu_f} \quad (5)$$

$$\mathrm{Re}_a = \frac{\rho_a V_a D_h}{\mu_a} \quad (6)$$

$$D_h = \frac{4A}{P} \quad (7)$$

Here D_h represents hydraulic diameter, P represents the perimeter by the fluid, A represents the cross-section area that the fluid flows. The heat transferred from high-temperature water+ethylene glycol mixture to the low-temperature air is calculated with Equation (8) and (9) (Kakaç, Liu and Pramuanjaroenkij, 2012). Here $T_{f,in}$ represents the temperature of the fluid entering in the radiator, $T_{f,out}$ represents the temperature of the fluid exiting the radiator.

$$\dot{Q} = \dot{m} c_p \Delta T = \dot{m} c_p (T_{f,in} - T_{f,out}) \quad (8)$$

$$\dot{Q} = \dot{m} c_p (T_{f,in} - T_{f,out}) = hAF\Delta T_{lm} \quad (9)$$

Here, F is the logarithmic temperature correction factor (Kakaç et al., 2012) and the value is set as 1. ΔT_{lm} is the logarithmic mean temperature difference and it is determined by Equation (10). This value can be calculated with the help of ethylene glycol mixture and air inlet-outlet temperature to the radiator (Kakaç et al., 2012).

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{In(\frac{\Delta T_1}{\Delta T_2})} \quad (10)$$

$$\Delta T_1 = T_{f,in} - T_{a,out} \quad (11)$$

$$\Delta T_2 = T_{f,out} - T_{a,in} \quad (12)$$

Water+ethylene glycol mixture average heat transfer coefficient is determined by Equation (13) (Kakaç et al., 2012), Nusselt number is determined by Equation (14) (Incropera, Dewitt, Bergman and Lavine, 2007)

$$h = \frac{\dot{m}c_p(T_{f,in} - T_{f,out})}{AF\Delta T_{lm}} \quad (13)$$

$$Nu = \frac{hD_h}{k} \quad (14)$$

3.3 Thermophysical Properties

The thermophysical properties required to make various calculations with the help of the data obtained during the experimental study are taken from Table 1. Table 1 shows the density, specific heat, dynamic viscosity and thermal conductivity coefficients of different types of fluids according to the changing temperature characteristics. The bulk temperature approach was used in the calculations. In the batch temperature approach, the thermophysical properties are based on the principle of reading the value corresponding to the temperature value in Table 1 by averaging the temperature values at the inlet and outlet of the fluid.

Table 1
Thermophysical Properties of Fluids (Çengel and Cimbala 2006; Incropera et al., 2007; Çengel, 2004).

Fluid Type	Temperature (°C)	Density (kg/m³)	Specific Heat (J/kg°C)	Thermal Conductivity (W/m°C)	Dynamic Viscosity (kg/ms)
Water	40	992.1	4179	0.631	0.653x10^{-3}
	50	988.1	4181	0.644	0.547x10^{-3}
	60	983.3	4185	0.654	0.467x10^{-3}
	70	977.5	4190	0.663	0.404x10^{-3}
	80	971.8	4197	0.67	0.355x10^{-3}
Air	20	1.204	1007	0.02514	1.825x10^{-5}
	30	1.164	1007	0.02588	1.872x10^{-5}
	40	1.127	1007	0.02662	1.918x10^{-5}
	50	1.092	1007	0.02735	1.963x10^{-5}
	60	1.059	1007	0.02808	2.008x10^{-5}
EG	40	1101.45	2473.5	0.2559	0.00976
	50	1094.19	2518.2	0.2586	0.00698
	60	1087.79	2563.4	0.2603	0.00522
	70	1082.36	2609	0.2610	0.00404
	80	1077.5	2650.5	0.2610	0.00323

3.4 Uncertainty Analysis

There might be certain errors in the measurement results obtained from the experimental studies due to the selected experiment method and measurement device-related problems. Therefore, error analysis should be conducted for the validity and reliability of the measurement results. For this purpose, Equation (15) was used for uncertainty analysis (Holman, 2012). Here R, x and w represent the considered size, the number of variables affecting this size and the uncertainty amount of each variable respectively.

$$w_R = \left[\left(\frac{\partial R}{\partial x_1}w_1\right)^2 + \left(\frac{\partial R}{\partial x_2}w_2\right)^2 + \ldots\ldots + \left(\frac{\partial R}{\partial x_n}w_n\right)^2\right]^{1/2} \quad (15)$$

Equation (15) and Table 2 were used to calculate experiments uncertainties. Uncertainty analysis was conducted for the basic parameters to be found in the experiments.

Table 2
Uncertainties of Measured Parameters.

Quantity	Unit	Uncertainty
Density	kg/m³	± 0.03%
Volumetric Flow Rate	m³/s	± 3,33*10-6
Specific Heat	kJ/(kgK)	± 2.5%
Temperature	°C	± 0.15
Area	m²	±10-6
Diameter	m	±10-3
Dynamic Viscosity	Pas	±1.5%
Air Velocity	m/s	±4%
Fluid Velocity	m/s	±3.33*10-6

By using the values given in Table 2, uncertainties for mass flow rate ($\dot{m}$), heat transferred from the radiator (Q_{out}), average heat transfer coefficient (h), Nusselt number (Nu) and Reynolds number (Re) respectively and these values are given in Table 3. As it can be seen from the table, the highest uncertainty was calculated for the Nusselt number as 5.4669%. Therefore, based on the uncertainty analysis results, it is possible to state that data obtained from this study has acceptable uncertainty.

Table 3
Uncertainties Of Calculated Parameters

Calculated Parameters	Uncertainty (%)
$w_{\dot{m}}$	1.9988
$w_{\dot{Q}_{out}}$	3.5877
w_h	3.6241
w_{Nu}	5.4669
w_{Re_a}	4.28
w_{Re_f}	3.878

3.5 Experimental Study Procedure

As expressed in the section above, the experimental setup consisted of three main sections as 2 independent main flow line and 1 data collection unit. The main elements that formed the experimental setup were centrifuge pump, centrifuge fan, fluid tank, automobile radiator, auxiliary piping elements and a thermostat resistance.

In these experiments, cooling fluid flow rate measurement was obtained with a buoy-type flow meter, temperature values were obtained with K-type thermocouples and airflow velocity was obtained with hotwire anemometer. Values obtained by the thermocouples were transferred to the datalogger and temperature values were detected by transferring this data to a laptop via datalogger. Additionally, resistance was switched on and off with a thermostat thus, the fluid temperature in the fluid tank was kept constant.

Water+ethylene glycol mixture with fixed temperature was pumped to the radiator inlet line with a centrifuge pump. There were 2 valves on the piping of this line. One of these valves was the main flow valve and the other one was the by-pass valve. The cooling fluid flow rate circulating the automobile radiator was adjusted with these valves. The inlet flow rate of the fluid to the radiator was controlled and measured by a buoy-type flow meter on this line.

The high-temperature water+ethylene glycol mixture circulating inside the automobile radiator was cooled to the air which sent to the air channel with a centrifugal fan. The centrifugal fan inlet voltage can be changed with a variac and this way, cooling airflow rate to the channel can be adjusted to the desired value. The air velocity inside the channel was assigned with a hotwire anemometer. Additionally, by using a multimeter connected to the fan, fan voltage and current values can be read on the system. After the experimental setup was started, the data obtained from the experimental setup was recorded when the entire system was at steady-state and system was stabilised. The experimental matrix in Table 4 was used to perform the experimental procedures.

Table 4
Experimental Parameter Matrix

Cooling Fluid Type	0% EG (0% Ethylene Glycol+100% Water) 25% EG (25% Ethylene Glycol+75% Water) 50% EG (50% Ethylene Glycol+50% Water) 75% EG (75% Ethylene Glycol+25% Water) 100% EG (100% Ethylene Glycol+0% Water)
Inlet Temperature	40, 50, 60, 70 and 80 °C
Inlet Flow Rate	10, 14, 18 and 22 l/min
Air Velocity	1, 2 and 4 m/s

Later air, water and ethylene glycol density, viscosity, thermal conductivity coefficient and specific heat values were determined with the bulk temperature approach by using thermophysical property tables. With the help of measurement results obtained from the experiments and equations given above, radiator cooling performance for the parameters considered in this study were analysed.

4. Findings and Discussion

In this study, cooling fluid type, flow rate and cooling air velocity in an automobile radiator was changed for experiments. The cooling fluid mixture was prepared by adding different ethylene glycol (EG) ratios to water selected as the main fluid. Within this scope, for 0% EG, 25% EG, 50% EG, 75% EG and 100% EG water+ethylene glycol mixture ratio, 300 experiments were conducted at fluid radiator inlet flow rate range of 10-22 l/min, the inlet temperature range of 40-80°C and cooling air velocity range of 1-4 m/s. In the light of the results obtained from these experiments, the heat transfer performance of an automobile radiator was analysed. Some of the obtained results from the experiments are presented below.

In Figure 4, the relationship between the fluid outlet flow rate and fluid average outlet temperature (T_{out}) was analysed together for different ethylene glycol (EG) mixture ratio at cooling air velocity of 4 m/s and fluid inlet temperature of 80°C. As can be seen from the figure, for all EG mixture ratios, average fluid outlet temperature increases with the increase of fluid radiator inlet flow rate. When the curves for different EG ratios were analysed together, it can be seen that the lowest T_{out} temperatures occurred for 0% EG (only water) condition. With the increasing EG ratio, Tout value increased as well and reached the highest level for 100% EG (only ethylene glycol). Therefore, it was determined that for constant inlet flow rate, increased EG ratio also increased T_{out} value.

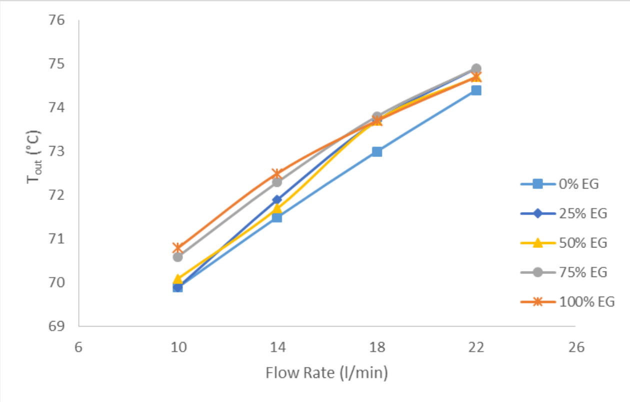

Figure 4. The Change Of Average Fluid Outlet Temperature With Fluid Flow Rate At An Air Velocity of 4 m/s And Fluid İnlet Temperature Of 80°C

Figure 5 shows the heat transferred from a fluid (Q_{out}) changed by the fluid inlet flow for different EG mixture rates at cooling air velocity of 4 m/s and fluid radiator inlet temperature of 80°C. When the figure was analysed, it can be seen that curves plotted for different EG ratios had a similar slope. In general, for all EG ratios, heat transferred from the radiator (Q_{out}) increased with increasing fluid inlet flow rate. However, while Q_{out} value increased linearly until the fluid flow rate of 18 l/min, there is no significant change after this value. Additionally, it was determined that maximum heat transfer occurred for 0% EG (only water) mixture. It was observed that increased EG ratio in the fluid decreased exchanged heat. Therefore, it was determined that ethylene glycol added in the cooling fluid had a negative effect on heat transfer.

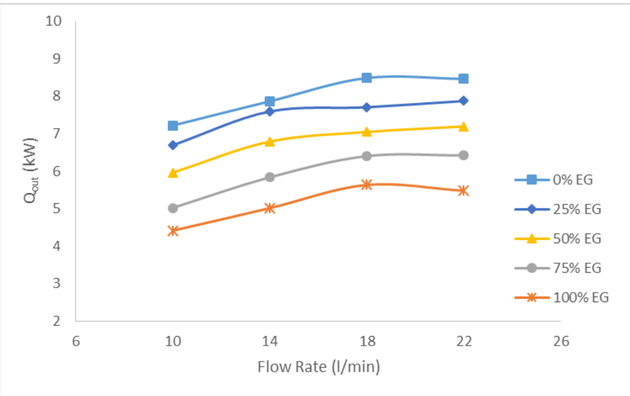

Figure 5. The Change Of Heat Transferred From The Heat With A Fluid Flow Rate At An Air Velocity of 4 m/s and Fluid İnlet Temperature of 80°C

Figure 6 shows the average heat transfer coefficient (h) changed by the fluid inlet flow for different EG mixture rates at cooling air velocity of 4 m/s and fluid radiator inlet temperature of 80°C. From the figure, it can be seen that for all EG mixture ratio, inlet flow increase has improved average heat exchange coefficient (h). As can be seen from the figure, the average heat exchange coefficient value increased as the fluid flow rate increased. Increased EG in the fluid decreased the flow rate. Therefore, it was seen that adding ethylene glycol inside the cooling fluid had a negative effect on heat exchange coefficient and decreased radiator heat exchange performance.

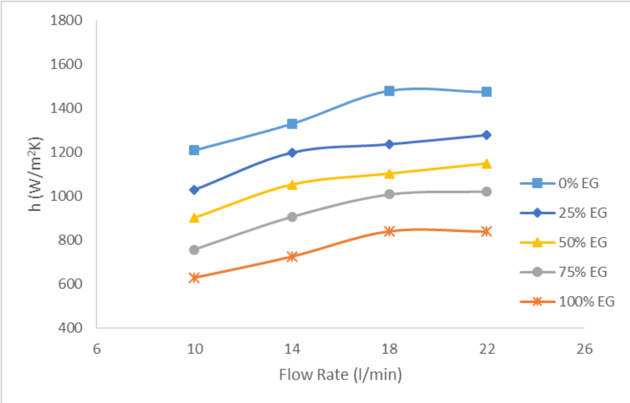

Figure 6. The Change of Average Heat Transfer Coefficient With Fluid Flow Rate At An Air Velocity of 4 m/s and Fluid İnlet Temperature Of 80°C.

Figure 7 shows the Nusselt number (Nu) changed by the fluid inlet flow for different EG mixture rates at cooling air velocity of 4 m/s and fluid radiator inlet temperature of 80°C. For all EG mixture ratios, it was determined that increased fluid inlet flow rate increased Nusselt number. Similarly, as EG ratio added to water increased, Nusselt number increased as well. However, this was contradicted to increased EG mixture ratio in the fluid causing decreased fluid average heat exchange coefficient (h) in Figure 6. The reason for this contradiction was related to Equation 14 used for calculating Nusselt number. When the equation is considered, it is expected to have a direct ratio between Nusselt number (Nu) and average heat exchange coefficient (h). However, when the related formula was considered, the thermal conductivity coefficient (k) is a dividend. In this study, 5 different cooling fluid type was determined by adding different ethylene glycol ratios inside water. Therefore, the thermal conductivity coefficient (k) values for these 5 different fluid types are different. The thermal conductivity coefficient (k) of ethylene glycol is lower than water. Therefore, increased EG ratio in the fluid leads to decreased k value for the fluid. In Equation 14, Nusselt number increases as the k value decrease. Therefore, as EG ratio increases, the Nusselt number value increases but the heat exchange coefficient (h) value decreases. Since heat transfer in the radiator is considered was considered in this study, it is believed that Nusselt number will not be a healthy approach for analysing the results and heat exchange coefficient (h) value was considered for the remaining graphics.

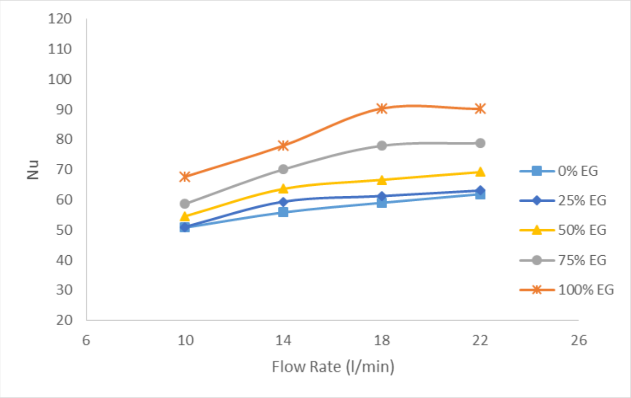

Figure 7. The Change Of Average Nusselt Number With Fluid Flow Rate At An Air Velocity of 4 m/s and Fluid İnlet Temperature of 80°C

For fluid radiator inlet flow rate of 14 l/min and inlet temperature of 70°C, the change of average fluid outlet temperature (T_{out}) with cooling air velocity is given in Figure 8. As can be seen, the curves plotted for 5 different EG mixture ratios have a similar structure. It can be seen that for cooling air velocity of 1 m/s, Tout value was at the maximum level and the change of EG ratio has no significant effect. As air velocity increased, T_{out} value decreased and curves plotted for different EG ratios become further from each other. Especially for high air velocity, it was determined that increased EG mixture ratio also increased average fluid outlet temperature (T_{out}) values.

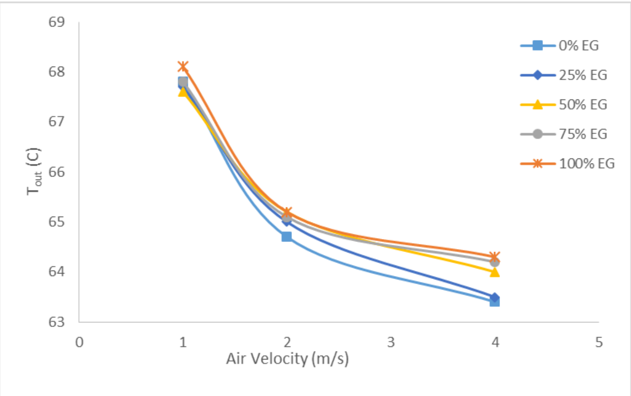

Figure 8. The Change Of Average Fluid Outlet Temperature With Air Velocity At An İnlet Flow Rate of 14 l/min and Fluid İnlet Temperature of 70°C

Figure 9 shows the effect for 14 l/min constant fluid flow rate and 70°C inlet condition on fan velocity change Q_{out} for different EG ratios. When the figure is considered, it can be seen that Q_{out} value increased with increasing cooling air velocity. Therefore, it is possible to state that cooling air velocity had a positive effect on heat transfer. This is related to increased forced convection with increased air velocity. Additionally, for constant air velocity, it can be seen that Q_{out} value decreased with increasing EG ratio inside the fluid.

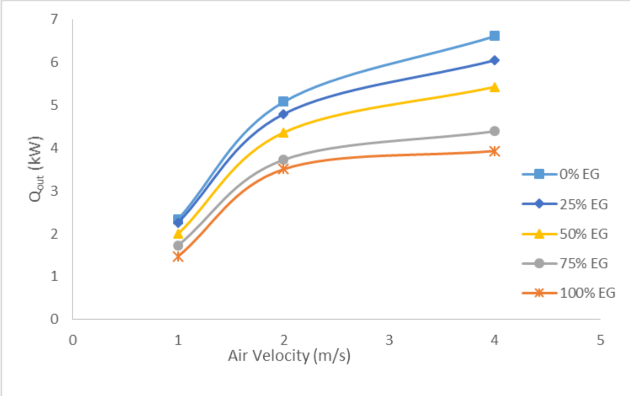

Figure 9. The change of heat transferred from fluid with air velocity at the inlet flow rate of 14 l/min and fluid inlet temperature of 70°C

In Figure 10, the change of average heat transfer coefficient (h) value with air velocity at the inlet flow rate of 14 l/min and fluid inlet temperature of 70°C can be seen. Curves plotted for different EG ratios have a similar tendency with Figure 9. While the heat transfer coefficient value increased with increasing air velocity, this coefficient decreased with increasing EG ratio.

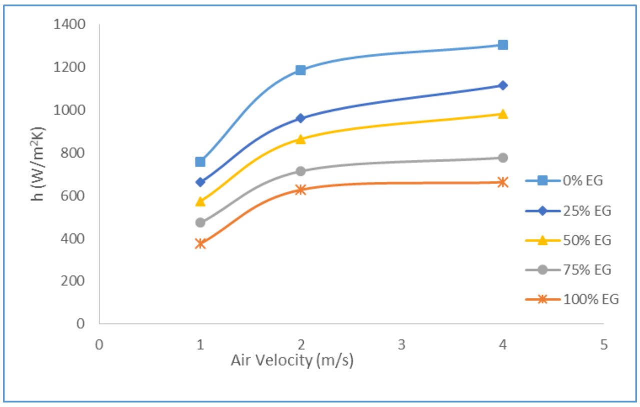

Figure 10. The Change of Average Heat Transfer Coefficient With Air Velocity At The İnlet Flow Rate of 14 l/min and Fluid İnlet Temperature of 70°C

When Figure 11 is analysed, the effect of fluid inlet temperature on outlet temperature can be seen for different EG ratios at 10 l/min inlet flow rate and 4 m/s constant fan velocity. It can be observed that the increase in fluid inlet temperature increased the outlet temperature (T_{out}) linearly. Additionally, it was seen that curves plotted for different EG mixture ratios were similar.

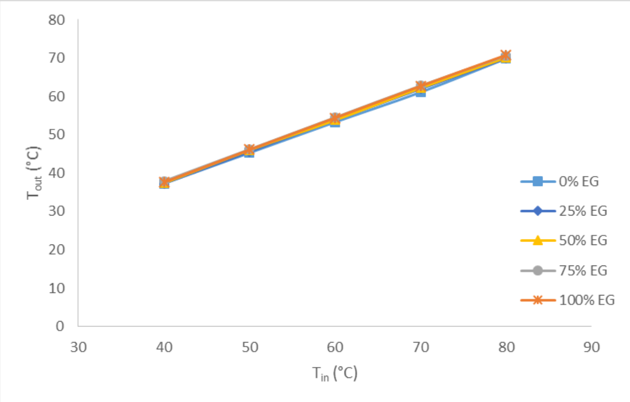

Figure 11. The Change Of Average Fluid Outlet Temperature With Fluid İnlet Temperature At The İnlet Flow Rate of 10 l/min and Air Velocity of 4 m/s

In Figure 12, the change of Qout value with fluid inlet temperature was evaluated for different EG mixture ratios at 10 l/min fluid flow rate and 4 m/s air velocity. Based on the obtained findings, it was determined that the increase in fluid radiator inlet temperature increased the transferred heat value for all EG mixture ratios. The curve was at the top level for 0% EG and the bottom level for 100% EG. In Figure 13, the change of average heat transfer coefficient (h) value with fluid inlet temperature is given for the same operating parameters. Curves plotted for different EG ratios have a similar tendency with the previous figure. While the air inlet velocity increased, h value increased and while the EG ratio inside the mixture increased, h value decreased.

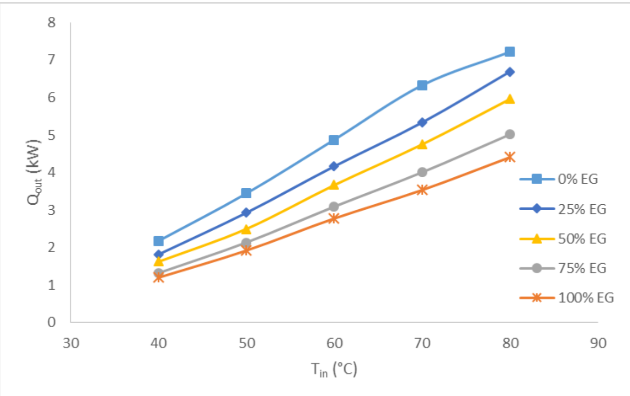

Figure 12. The Change Of Heat Transferred From Fluid With Fluid İnlet Temperature At The İnlet Flow Rate of 10 l/min and Air Velocity of 4 m/s

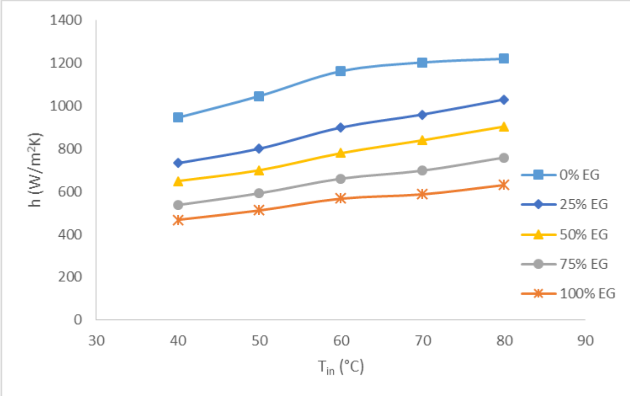

Figure 13. The Change Of Heat Transfer Coefficient With Fluid İnlet Temperature At The İnlet Flow Rate of 10 l/min and Air Velocity of 4 m/s

In Figure 14, 15 and 16, the change of average heat transfer coefficient (h) with ethylene glycol (EG) ratio added inside the cooling fluid was given for different fluid flow rate, different air velocity and different inlet temperature respectively. When three figures are considered, it can be seen that as the ethylene glycol ratio inside the fluid increased, heat transfer coefficient (h) value increased linearly. This was similar for all fluid inlet flow rate, temperature and air velocity in this study. Therefore, for all analysed parameters, it is possible to state that ethylene glycol addition inside the cooling fluid had a negative effect on heat transfer. As can be seen from the same figures, when all parameters are constant, increased fluid inlet flow rate, inlet temperature or air velocity increased heat transfer coefficient (h). Therefore, it is possible to state that increased fluid inlet flow rate, inlet temperature and air velocity had a positive effect on heat transfer in the radiator and increased radiator thermal performance.

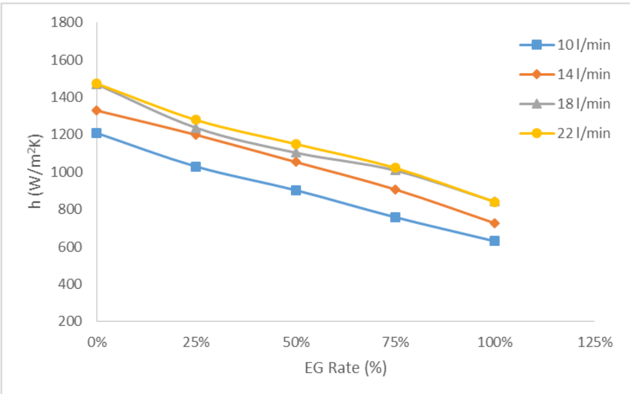

Figure 14. Average Heat Transfer Coefficient Change With Ethylene Glycol (EG) Mixture Rate At Fluid İnlet Temperature of 80 °C and Air Velocity of 4 m/s for Different Fluid İnlet Flow Rates

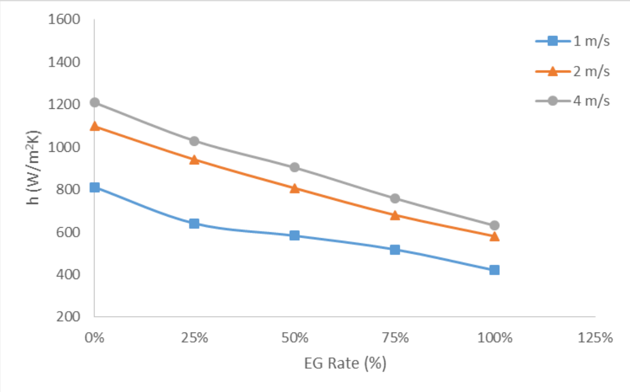

Figure 15. Average Heat Transfer Coefficient Change With Ethylene Glycol (EG) Mixture Rate At Fluid İnlet Temperature of 80 °C and Fluid İnlet Flow Rate of 10 l/min For Different Air Velocities

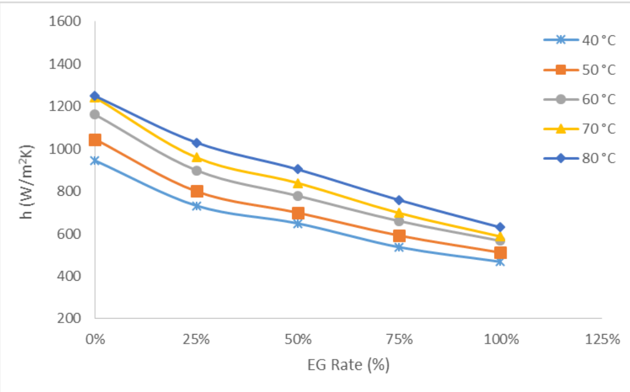

Figure 16 Average Heat Transfer Coefficient Change With Ethylene Glycol (EG) Mixture Rate At Air Velocity 4 m/s Fluid İnlet Flow Rate of 10 l/min For Different Fluid İnlet Temperatures

5. Results

Within the scope of this study, an experimental setup was formed to represent an automobile radiator operation. With this experiment setup, experiments were repeated for automobile radiator cooling fluid inlet flow rate range of 10-22 l/min, inlet temperature range of 40-80 °C and air velocity range of 1-4 m/s. For this purpose, 5 different cooling fluid types were created by adding different ethylene glycol mixture ratios inside the water which was selected as the main fluid. Within this scope, water+ethylene glycol prepared as 0% EG, 25% EG, 50% EG, 75% EG and 100% EG mixture ratios were considered as cooling fluid. In light of the data obtained from the experimental setup, the operating performance of an automobile radiator was experimentally analysed. After these experiments, when all other parameters were kept constant, increased automobile radiator cooling fluid temperature, cooling fluid inlet flow rate or air velocity have increased Qout and h value, therefore, lead to an increased heat transfer in the automobile radiator. Within the range of parameters analysed in this study, it was observed that when ethylene glycol was added inside the cooling water, radiator heat transfer performance decreased. Although ethylene glycol addition had positive properties such as decreasing cooling water freezing temperature, increasing boiling point and preventing corrosion, it was found that it had a negative effect on heat transfer. As a result, optimum cooling performance for the automobile radiator was determined at 0% EG mixture (only water), fluid inlet temperature of 80°C, the flow rate of 22 l/min and air velocity of 4 m/s.

Nomeclature

A	area(m^2)
c_p	specific heaat (J/kgK)
D_h	hydraulic diameter (m)
F	logarithmic temperature correction factor
h	mean heat transfer coefficient (W/m^2K)
k	thermal conductivity (W/m^2K)
$\dot{m}$	mass flow (kg/s)
Nu	nusselt number
$\dot{Q}$	heat transfer (kW)
Re	reynolds number
T	temperature (°C, K)
V	velocity (m/s)
$\dot{V}$	volumetric flow (m^3/s)
w	angular velocity (rad/s), uncertainty
ΔT_{lm}	logarithmic mean temperature difference
μ	Dynamic viscosity (Pas) or (kg/ms)
ρ	Density (kg/m^3)

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Author Contributions

Bahadır GEMİCİOĞLU contributed to investigation, data curation, writing-original draft, visualization, Tolga DEMİRCAN contributed to conceptualization, methodology, writing-review editing, supervision, project administration, funding acquisition.

Conflict of Interest

There is no conflict of interest.

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