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Experimental Validation of Radiator Effectiveness

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III. ENGINEERING SCIENCE

EXPERIMENTAL VALIDATION OF RADIATOR EFFECTIVENESS

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Abstract

It is difficult to imagine modern vehicles without a cooling system. The cooling system is based on the radiator. Scientists have done various researches to improve radiator efficiency and these are still ongoing. This paper shows both theoretical and experimental methods for determining the effectiveness of radiator.

*Key words: Cooling system, vehicle, effectiveness, coolant, Arduino uno*ю

Introduction

Vehicle radiator efficiency is determined by examining components of the cooling system. It is mainly determined by studying the parameters of the cooling system (radiator, coolant etc.). This paper provides an alternative and experimental methods of effectiveness. By increasing the effectiveness of car radiator fuel consumption of cars is reduced as only one cooling system consumes more than 30% of all fuel.

Define effectiveness of the radiator by alternative way

From the laws of thermodynamics, we know that heat transfer increases as we increase the surface area of the radiator assembly. That said the demand for more powerful engines in smaller hood spaces has created a problem of insufficient rates of heat dissipation in automotive radiators. As a result, many radiators must be redesigned to be more compact while still hav-

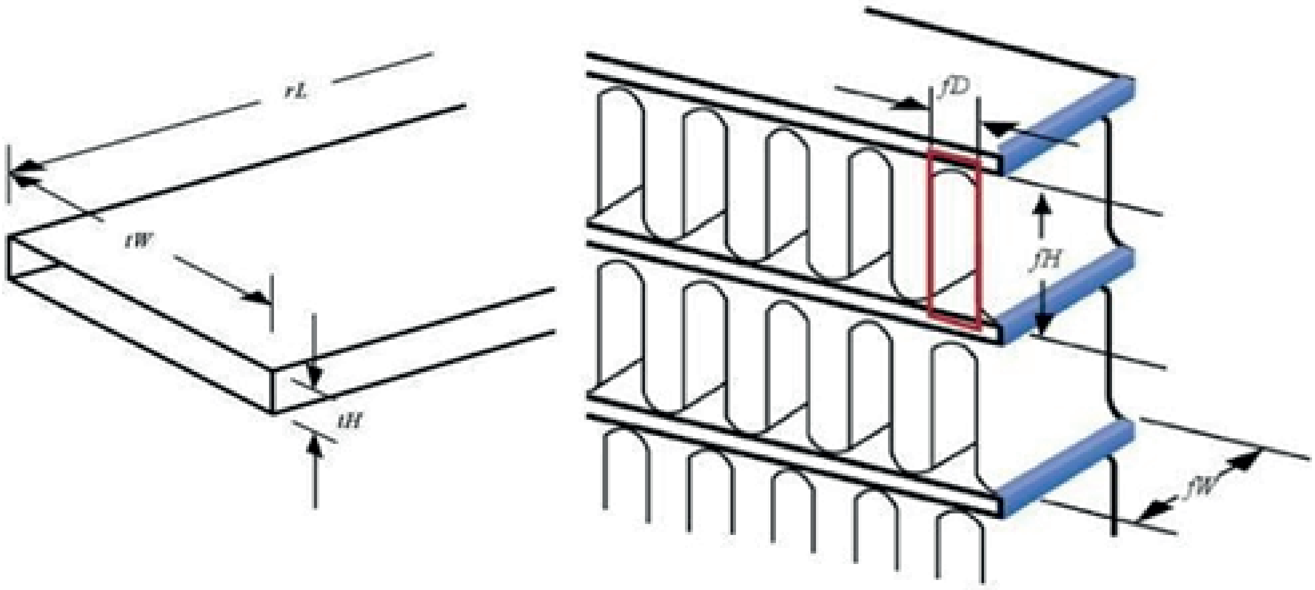

Figure 1 Schematic of single tube and fins of Radiator [3]

ing sufficient cooling power capabilities. This application proposes a new design for a smaller radiator assembly. The new design is capable of dissipating the same heat as the original, given a set of operating conditions [3]

Original Spark Radiator dimensions using by ruler in normal condition

All measurements were determined using the Chevrolet Spark car radiator in the center of Mechatronics in TTPU.

Radiator length (rL)	0.532 m
	1,74541 ft
Radiator width (rW)	0.411 m
	1,34843 ft
Radiator height (rH)	0.0148 m
	0,04593176 ft
Tube width (tW)	0.0148 m
	0,04593176 ft
Tube height (tH)	0.0017 m
	0,005577428 ft
Fin width (fW)	0.0148 m
	0,04593176 ft
Fin height (fH)	0.0065 m
	0,02132546 ft
Fin thickness (fT)	0.00005 m
	0,000164042 ft
Distance Between Fins (fD)	0.0015 m
	0,00492126 ft
Number of tubes (ntube)	42

Table 1: Measured dimensions of real Chevrolet Spark radiator, Mechatronics center at TTPU, 2018

Coolant volumetric flow(Vfc)	0.0008 m^3/s
Air volumetric flow(Vfa)	0.816 m^3/s
Air velocity(Va)	4.5 m/s
Heat transfer performance(q)	18600 J/s

Table 2: Radiator operating conditions

Thermal conductivity(kc)	0.634 $\frac{W}{m*K}$
Specific heat (Cc)	4179 $\frac{J}{kg*K}$
Dencity(pc)	996.5 $\frac{kg}{m^3}$
Dynamic viscosity(μc)	0.00068 Pa*s
Coolant temperature(Tc)	355 K

Table 3: Water properties as a coolant at 355 K

Thermal conductivity (ka)	0.0276 $\frac{W}{m*K}$

Specific heat (Ca)	1005 $\frac{J}{kg*K}$
Density (pa)	1.2 $\frac{kg}{m^3}$
Dynamic viscosity (μa)	0.0000185 Pa*s
Coolant temperature (Ta)	295 K

Table 4: Air properties at 295 K

Let us now determine the radiator's Effectiveness (ε) using all the available information.

Ac is coolant surface area: Ac =ntube * (2 * (tH * rL) +2 * (tW * rL)) = 0.737m² (1)

$$Ac = ntube * (2 * (tH * rL) + 2 * (tW * rL)) = 0.737 m^2 \quad (1)$$

Aa is air surface area: $Aa = TotNumAirPassages * (2*(fD*fH) + 2*(fH*fW)) = 3.0813 m^2$ (2)

TotNumAirPassages = NumRowsOfFin*$(\frac{rL}{fD})$ = 41*0.532/0.0015 = 145.4

$$Atot = Ac + Aa = 3.82 m^2 \quad (3)$$

Solve for hc:

$$Amin = tW * tH = 0.00002516 m^2 \quad (4)$$

WP = 2 * (tW + tH) = 2*(0.0148+0.0017) = 0.033 m

$$Dh = \frac{4*Amin}{WP} = 0.00304 m^2 \quad (5)$$

$$Vc = \frac{vf}{ntube*Amin} = 1.9 m/s \quad (6)$$

$$ReynoldsNum = \frac{p*Vc*Dh}{\mu} = 7926.93 \quad (7)$$

From the DittusBoelterEquation:

NusseltNum = 0.023*ReynoldsNum0.8 * PrandtlNum1/3

PrandtlEquation:

$$PrandtlNum = \frac{c\mu}{k} = 6.6 \quad (8)$$

NusseltEquation:

$$NusseltNum = \frac{hc*DHc}{k} \quad (9)$$

Nusselt number is known from DittusNoelter Equation an is equal to 45.34

$$hc = \frac{Nusseltnum*k}{DHc} \quad (10)$$

hc = 6190

Determine ***ReynoldsNuma***

We solve ha in a similar manner as I did for hc

$$Amina = fH*fD = 0.00000975 m^2 \quad (11)$$

$$WPa = 2*(fD + 8*fD) = 0.027 m^2 \quad (12)$$

$$DHa = \frac{4*Amina}{WPa} = 0.00144m \quad (13)$$

$$ReynoldsNuma = \frac{pa*va*DHa}{\mu a} = 384 \quad (14)$$

Calculate for Cratio

Ntu equation : $Ntu = \frac{UA}{Cmin}$

Thermal Capacity Rate: CR=C*mfr

MassFlowRate: mfr=FluidViscosityt*p

$$mfa = vfa * pa = 0.98 kg/s \quad (15)$$

$$mfc = vfc * pc = 2.03 kg/s \quad (16)$$

$$CRa = Ca*mfa = 985 J/s*K \quad (17)$$

$$CRc = Cc*mfc = 7474. J/s*K \quad (18)$$

CRc >CRa so, Cmin = CRa and Cmax = CRc

$$Cratio = \ = 0.1317 \quad (19)$$

Now, we need to calculate Number of Transfer Unit (Ntu), ITD and Effectiveness (ε)

ITDEquation:

ITD = CoolantTemperature – AirTemperature = 60 K 20)

εNtuEquation

0.314 or 31.4% $q = \varepsilon*Cmin*ITD \rightarrow \varepsilon = \frac{q}{Cmin*ITD}$ (21)

Experimental validation of radiator effectiveness

The main purpose of the experiment is determining inlet and outlet temperatures of coolant at different points.

First law of thermodynamics for the system:

$$Q^{\cdot} = Ca*(Ta,i - Tc,o) = Cc*(Tc,o - Tc,i) = \varepsilon*Cmin*(Ta,o - Tc,i); \quad (22)$$

Tc,i - coolant inlet temperature, Ta,i – air inlet temperature

Tc,o – coolant output temperature, Ta,o – air output temperature

By measuring inlet and outlet temperatures for both fluids, it is possible to see which side has higher difference. The one that has higher difference in temperature, has Cmin from above equation, since Cmin=min (Ca, Cc). If mass flow rate of engine coolant is also measurable (from pump speed), it is possible to find numerical value of Cmin, Cmax and consequently ε, using the first law of thermodynamics only.

$Cc*(Tc,o - Tc,i) = \varepsilon*Cmin*(Ta,o - Tc,i)$

Equipments for experiment: Arduino uno, breadboard, temperature sensors (Dallas 18 b 20), resistor (10kohm), automobile radiator with an electric fan, water pump, anemometer (TSI), coolant and metal wires. Temperature sensors are connected to Arduino uno board as follows and result should appear on the screen.

Cc is a coolant heat capacity; it can be calculated by the following formula:

Cc = mass flow rate * pecific heat capacity of the coolant; (23)

Cmin=min (Ca, Cc) = Ca is an air heat capacity; it would be following: (24)

Ca = mass flow rate of air * Specific heat capacity of the air; (25)

mass flow rate of coolant = 0.05 kg/s

mass flow rate of air = density of air (295K) * volume of air; (26)

volume of air = active surface of radiator * length; (27)

length = average velocity of air * time; (28)

In Table 8, there is average velocity is 4.3 m/s. By the calculation active surface of air has been obtained and it is equal to 0.532m * 0.411m = 0.22m^2

density of air = 1.2041 kg/m3 from these calculations volume was obtained

volumetric flow rate of air =

= 0.22m2 * 4.3 m/s = 0.82 m3/s (29)

mass flow rate of air =

= 0.82 m3/s * 1.2041 kg/m3 = 0.98 kg/s (30)

Figure 2 water pump [Technopark, Turin Polytechnic University, Tashkent 2018].

Specific heat capacity of air is 717 J/(kg*K) [TTPG84] Specific heat capacity of coolant (water) is 4180 J/(kg*K). The Arduino Uno board is dependent on MS Excel for real-time viewing and control to the result. As a result of experiment, effectiveness of the car radiator is determined by the temperature of coolant input and outputs from the radiator [Table 10].

Now, Calculate the effectiveness obtained the results from the experiment using the formula above:

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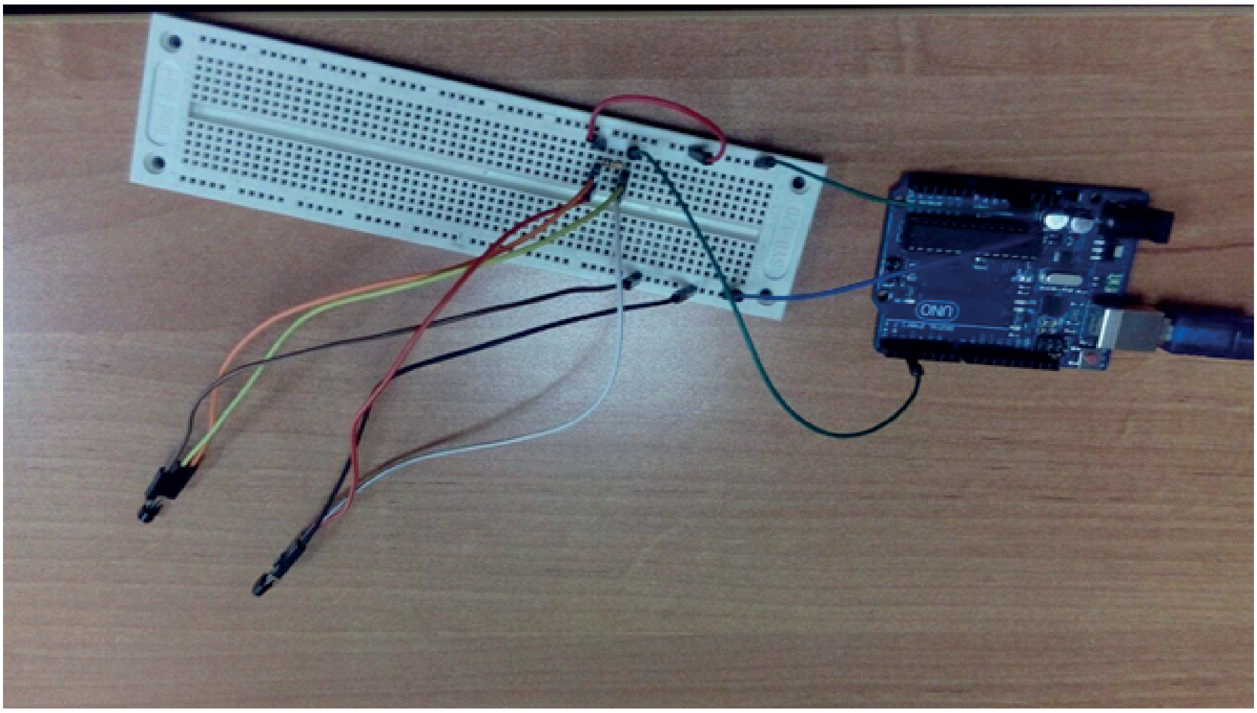

Figure 3 Temperature sensors (ds 18 b 20) connected to Arduino Uno.

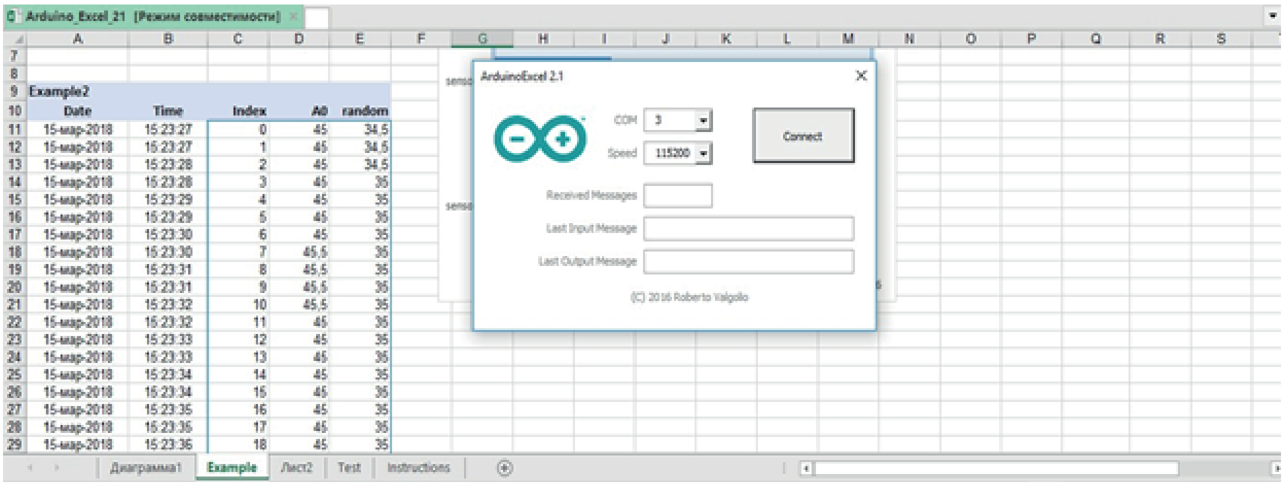

Figure 4 Real time analyzing of temperature of the coolant.

a) $T_{c,i} = 45°C = 318K$, $T_{c,o} = 35.5°C = 308.5K$

$$\varepsilon = \frac{C_c(T_{c,o} - T_{c,i})}{C_{\min} * (T_{a,o} - T_{c,i})} = \frac{C_{coolant} * M_{coolant}(T_{c,o} - T_{c,i})}{C_{air} * M_{air}(T_{a,o} - T_{c,i})} = \frac{4180\frac{J}{kg*K} * 0.05\frac{kg}{s} * (308.5K - 318K)}{717\frac{J}{kg*K} * 0.98\frac{kg}{s} * (307K - 318K)} =$$

$$\frac{1985.5\frac{J}{s}}{7729\frac{J}{s}} = 0.265 \text{ or } 26.5\%$$

b) $T_{c,i} = 46°C = 319K$, $T_{c,o} = 37°C = 310K$

$$\varepsilon = \frac{C_c(T_{c,o} - T_{c,i})}{C_{\min} * (T_{a,o} - T_{c,i})} = \varepsilon = \frac{1881\frac{J}{s}}{6950\frac{J}{s}} = 0.2706$$

or 27%

c) $T_{c,i} = 45.5°C = 318.5K$, $T_{c,o} = 35.5°C = 308.5K$

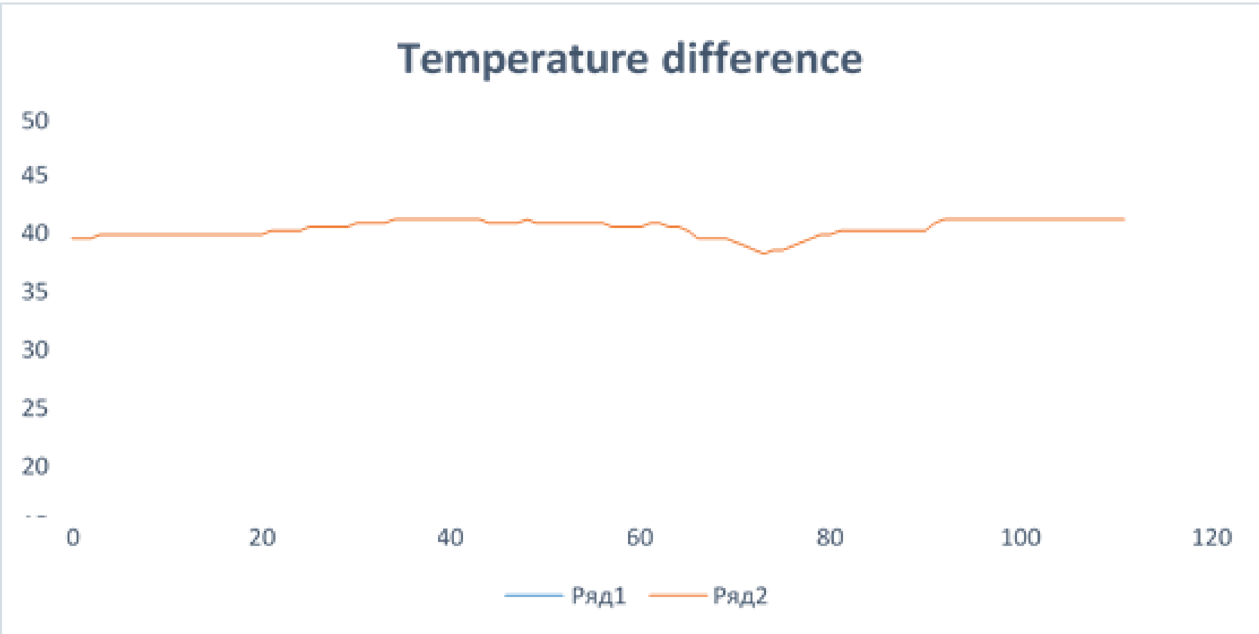

Figure 5 Temperature difference of the coolant

$$\varepsilon = \frac{C_c(T_{c,o} - T_{c,i})}{C_{\min} * (T_{a,o} - T_{c,i})} = \varepsilon = \frac{4179\frac{J}{kg * K} * 0.05\frac{kg}{s} * (308.5K - 318.5K)}{717\frac{J}{kg * K} * 0.98\frac{kg}{s} * (307K - 318.5K)} = \frac{2089.5\frac{J}{s}}{8080.6\frac{J}{s}} = 0.259 \text{ or } 26\%$$

Results and discussion

All of the dimensions for the radiator are carefully measured and recorded in Table 2. Properties coolant and air given in Tables 7 and 8. Average fluid temperature is used to determining their properties.

Lradiator	Hradiator	Wradiator	Wtube	Htube	Lfin	Wfin	Hfin	Ntube	Nfin
mm	mm	mm	mm	mm	mm	mm	mm		
532	14.8	411	14.8	1.7	3.4	14.8	6.5	42	780

Table 5: Basic Radiator Dimensions.

ρwater	Cp,water	kwater	µwater
kg/m3	J/kgK	W/mK	kg/sm
998.8	4180	0.58	0.00076

Table 6: Properties of Water at Average Temperature

ρair	Cv,air	kair	νwater
kg/m3	J/kgK	W/mK	m2/s
1.16	717	0.025	0.000022

Table 7: Properties of Air at Average Temperature.

Trial	Twater,in	Twater,out	Tair,in	Tair,out	Mwater	Vair	ε
	K	K	K	K	kg/s	m/s	%
1	318	308	296	306.2	0.05	4.28	26.5
2	318.5	308.5	296	307.1	0.05	4.32	27
3	318	308	296	307.2	0.05	4.25	26
4	319	308.5	296	307.5	0.05	4.35	27
Average	318.4	308.3	296	307	0.05	4.3	27

Table 8: Experimental Temperatures and Flow rates through Radiator

Conclusion

As you can see, the effectiveness found in alternative methods is different from the one found experimental way in the laboratory condition.

This can be explained by the following:

Problems connecting the hoses

Insufficient accuracy in measuring radiator sizes

The sensitivity level of the sensor used for temperature measurement is ±0.5 °C

- Coolant parameters are not explicitly accounted and so on

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