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OPTIMIZATION OF EFFECTIVENESS IN RADIATOR STRAIGHT FIN TYPE WITH FLAT TUBE ANGLE VARIATION

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***Abstract*— this research explains about the effect of change of radiator cooling angle position to radiator capability in cooling water coolant. Heat is the result of combustion that occurs in the combustion chamber with a very high temperature above 80^{0}C. If this temperature is left it will cause the machine to be over heating so it can make damage to the engine components. In this case it needs a solution to keep the machine fixed in the temp work by way of equipping the engine with the cooling system. The cooling system serves to release engine heat to the environment through the radiator. Therefore, it is necessary to increase the effectiveness of the radiator optimally in order to maintain the working temperature of the machine under normal circumstances. The method used in this research is by using experimental method. Tests conducted on Toyota Kijang 5k radiator fin with a straight models to vary the angle of flat tube in the radiator. With this research, the best heat dissipation process is in the position of radiator with the angle of tube 5^0.**

***Keywords*— effectiveness: slope angle: flat tube**

INTRODUCTION

Cooling system is one of the main parts in an engine that serves to keep the engine condition to stay at a working temperature of 80^{0}C. The conditions required to maintain optimum working of the cooling system. One of the important cooling system components is the radiator. The radiator is a device that serves as a heat exchanger. This heat is obtained from the combustion of an engine which is transferred through the cooling fluid to the radiator. Then the heat in the radiator is moved to the environment (ambient) through the raditor fins.

Various studies have been conducted to improve the working effectiveness of the radiator. Reference [1] conducted a study by analyzing heat transfer on radiator coolant from otto motor on each engine cycle with NTU-effectiveness transfer method of heat and he concluded that the value of C_{min} / C_{max} of 0.5, NTU of 1.3 and the effectiveness of 0.65 and total heat transfer of 5,187 watts. Reference [2] conducted a study with cooling fan design optimization of radiator cooling using experimental method by varying the fan form (blade count: 5-7 pieces and blade angle: 300 and 600) and the distance of the blade attached to the radiator (1.5-2, 5 cm), and he concludes that the number of blades and fan distances to the radiator greatly affects the water cooling of the radiator.

Reference [3] conducted a study by analyzing fluid flow discharge on radiator effectiveness in mazda car engine using experimental method by varying holding time of 1-30 minutes interval 5 minutes and engine speed 1000-1400 rpm interval 100 rpm, he concluded that water flow discharge affect the value of radiator effectiveness 30 minutes detention time there is an increase in the value of a balanced effectiveness, in accordance with the increase of water flow discharge, this shows the stability of radiator effectiveness value. Reference [4] conducted an experimental experiment of optimization of heat transfer rate and pressure drop due to the effect of air flow rate on the flat tube radiation heat exchanger using experimental method by varying air flow rate (2-12 m / s with interval 1 m / s) with a constant flow of water flow (18.927x10-5 m^3 / s), and he concludes that the optimum flat tube radiator type performance occurs at an airflow rate of 8 m / s.

Reference [5] conducted a research on radiator volume analysis of temperature changes on a Chevrolet diesel motor using experimental method by varying the water volume of the radiator (2.5 to 4 liters with intervals of 0.25 liters), and he concluded that the reduced volume of radiator water engine temperature has increased significantly and radiator efficiency decreases. [6] Conducted an experimental study of the effect of radiator type changes on the performance of a Sinjai machine by varying the radiator geometry of radiator (straight fin radiator and fin louver radiator), and he concluded that using a fin louver radiator was able to increase waste heat by 34.2% finer strip radiator but decrease bhp by 4.49%, increase sfc by 50.343% and decrease thermal efficiency by 32.02%.

Reference [7] conducted a study on the effect of coolant temperature on the performance of heat transfer and decrease of automotive radiator pressure using experimental method by varying the coolant temperature entering the radiator (60^{0}C to 90^{0}C at 10^{0}C intervals) and flow discharge (30 to 45 lpm with interval 5 lpm), and he concluded that coolant temperatures entering 90^{0}C and 45 lpm discharge produce heat transfer rate and convection heat transfer coefficients on the largest coolant side of 23475 watts and 8263,75 W / m2 0C. And the smallest pressure drop value is 22405.9 Pa. Reference [8] conducted a modified water scoop and radiator distance study on gasoline fuel consumption using experimental method by varying the scoop water angle (0^0 and 30^0) and the radiator distance from the machine (10 cm and 20 cm), and he concluded that the slope of 300 and a distance of 10 cm can

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reduce fuel consumption at low and high speeds of 5.7% and 21.7%.

From some research above can be concluded that the radiator serves as a heat exchanger that will affect the engine performance. So far, many studies have focused on setting radiator position distances, heat exhaust air velocity, radiator water volume, coolant temperature and flow rate and changes in the radiator fin geometry but have not achieved optimum effectiveness resulting in a decrease in engine thermal efficiency. Therefore researchers try to do research by changing the radiator geometry by providing a slope angle on the installation of flat tube in the radiator core in order to obtain optimum radiator effectiveness and overall efficiency.

THE MATERIAL AND METHOD

Heat Exchanger on Radiator

The heat exchanger on the radiator is a device used to transfer heat between two or more fluids having a temperature difference of high-temperature fluid to a low-temperature fluid. The heat transfer is either directly or indirectly. In most systems these two fluids do not experience direct contact. Direct contact of heat exchanger occurs as an example of a fluidized heat gas in a cold liquid to increase the temperature of the liquid or cool the gas.

Heat exchangers used in vehicles can be encountered on a radiator whose function is essentially as a heat exchanger. The function of the radiator is to release the heat, then in the making selected radiator that has a high thermal conductivity, which is able to deliver good heat such as copper and brass. The heat discharged by the coolant may be calculated using the following equation

$$q = \dot{m} c_p \Delta T \quad (1)$$

$$q = \dot{m} c_p T_2 - T_1 \quad (2)$$

Where:

q = heat transfer rate (kJ / sec or W)
m = Mass flow rate of coolant (kg / s)
c_p= the incoming heat capacity (J / kgK)
T_1= inlet temperature (K)
T_2= outlet temperature (K)

From these equations we can then analyze the heat transfer in a radiator as follows [9]:

The amount of heat released by water

$$q_a = \dot{m}_a c_p T_{a1} - T_{a2} \quad (3)$$

Where:

q_a = rate of heat transfer released by water (kJ / sec or W)
m_a = the mass flowing water rate (kg / s)
c_p= the incoming heat capacity (J / kgK)
T_1= inlet temperature (K)
T_2= outlet temperature (K)

As for calculating the mass of water that flows can use the equation

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

Where:

ρ_a = density of water (kg / m3)
V_a = water velocity of entry (m / s)
A = inlet cross-sectional area (m2)

The amount of heat by cooling air

$$q_u = \dot{m}_u c_p T_{u2} - T_{u1} \quad (5)$$

Where:

q_u = Heat transfer rate received by air cooler (Watt)
$\dot{m}_u$ = the mass flow rate of the flowing air (kg / s)
c_p = the incoming heat capacity (J / kgK)
T_{u1} = outlet temperature (K)
T_{u2} = inlet temperature (K)

As for calculating the air mass that flows can use the equation is

$$\dot{m}_u = \rho_u V_u A \quad (6)$$

Where:

ρ_u = density of air (kg / m3)
V_u = incoming air velocity (m / s)
A = the cross-sectional area of the air intake (m^2)

Effectiveness

The effectiveness of a heat exchanger is defined as the ratio between the actual heat transfer rate and the maximum possible heat transfer rate. Where the equation can be shown as follows (Holman, 1997):

$$\varepsilon = \frac{q}{q_{max}} \quad (7)$$

Where:

q = Real heat transfer (W)
q_{max}= possible maximum heat transfer (W)

For actual (actual) heat transfer can be calculated from energy released by hot fluid or energy received by a cold fluid for a counter-current heat exchanger.

$$q = \dot{m}_h c_h (T_{h,in} - T_{h,out}) = \dot{m}_c c_c (T_{c,out} - T_{c,in}) \quad (8)$$

Where:

$\dot{m}_h$ = hot fluid flow rate (kg / s)
$\dot{m}_c$ = cold fluid flow rate (kg / s)
c_h = hot fluid heat capacity (Kj / kg K)
c_c = cold fluid heat capacity (Kj / kg K)
$T_{h,in}$ = Inlet temperature of hot fluid (K)
$T_{h,out}$ = Temperature out of hot fluid (K)
$T_{c,in}$ = In cold fluid (K)
$T_{c,out}$ = Temperature out cold fluid (K)

The heat capacity of each fluid can be searched through the equation:

$$C = \dot{m} \ c_p \quad (9)$$

Where:

$\dot{m}$ = fluid flow rate (kg / s)
c_p = specific fluid heat (Kj / kg K)

To determine the maximum heat transfer for the heat exchanger it should be understood that the maximum value will be obtained if one of the fluids undergoes a temperature change of the maximum temperature difference contained in the heat exchanger, ie the difference between hot and cold fluid sign temperature. A fluid that may differ from this maximum temperature is the minimum cold fluid flow rate, the energy balance requirement that the energy received by one fluid must equal the energy released by the other fluid. If a fluid experiencing a greater value of fluid density is made,

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then the temperature will be greater than the maximum, and this is not possible. So the maximum heat transfer may be stated as follows

$$q_{max} = \dot{m}c_{min}(T_{h,in} - T_{c,in}) \quad (10)$$

Where, c_{min} is the smallest heat capacity between cold fluid and hot fluid. If $c_h = c_{min}$ then the value of effectiveness can be searched by the following equation:

$$\varepsilon = \frac{\dot{m}_h c_h (T_{h,in} - T_{h,out})}{\dot{m}c_{min}(T_{h,in} - T_{c,in})} \quad (11)$$

$$\varepsilon = \frac{(T_{h,in} - T_{h,out})}{(T_{h,in} - T_{c,in})} \quad (12)$$

As for $c_c = c_{min}$, the effectiveness value can be searched by the following equation:

$$\varepsilon = \frac{\dot{m}_c c_c (T_{c,out} - T_{c,in})}{\dot{m}c_{min}(T_{h,in} - T_{c,in})} \quad (13)$$

$$\varepsilon = \frac{(T_{c,out} - T_{c,in})}{(T_{h,in} - T_{c,in})} \quad (14)$$

Methodology

This research is done by using experimental method. The test was performed on a 5k Toyota Kijang Super radiator with a straight fin radiator model with a slope angle at the installation of flat tube area of 0^0. The treatment was done by changing the angle of the flat tube on the radiator. The change in the angle of the flat tube position is varied by 5^0, 10^0 and 15^0. The temperature measurement results are carried out at the inlet of the cooling water, the cooling outlet, the cooling air inlet and the cooling air outlet. The result of the measurement is done data processing, then analyzed by using the effectiveness equation (ε) on the heat exchanger by measuring the cooling water temperature and the cooling air Test Equipment

Test equipment to be used in this research include straight fin radiator, with specifications:

Machine: 5k kijang super

Model fin: straight fin

Type coolant: water coolant

Flow type: down flow

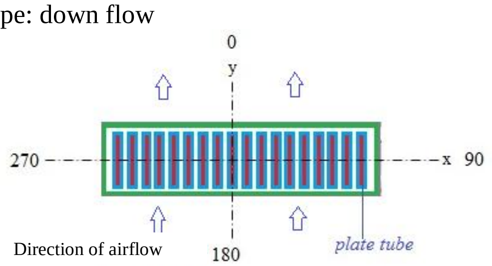


Figure 1 Schematic of a straight fin standard radiator at the top view.

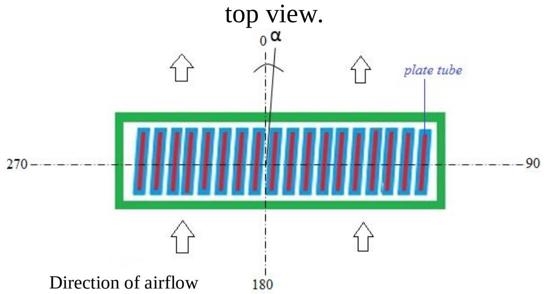


Figure 2 Schematic of a straight fin radiator with a flattened angle flat tube model at the top view

As for the experimental apparatus scheme of research in figure 3 below:

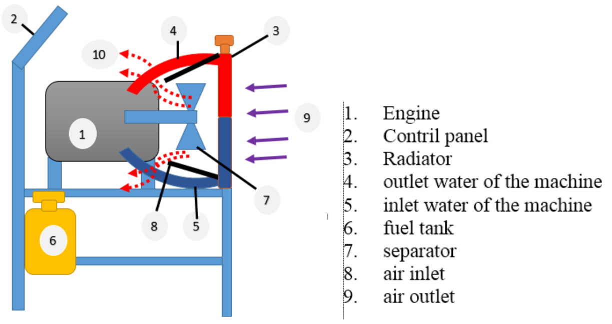


Figure 3. Experimental apparatus scheme

In this study there are some things that are considered constant including environmental temperature, humidity and air pressure environment.

RESULTS AND DISCUSSION

From the research that has been done in the laboratory of Motor combustion in Automotive Engineering Department, Faculty of Engineering University of Padang obtained experimental data as follows:

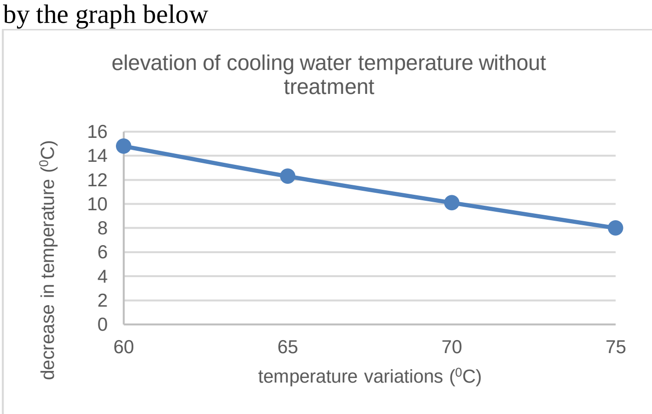
a. The position of the radiator without slope treatment or tube position (0^0) in the standard state

After the data is taken at the position of flat tube radiator in standard condition **(0^0)** then the data obtained in table 1 as follows:

Table 3. Decrease of temperature without slope (0^0)

No	Debit Flow (m^3/minute)	T water in (^{0}C)	T water out (^{0}C)	T air in (^{0}C)	T air out (^{0}C)	Eleva tion (^{0}C)
1	0.02	60.0	45.2	29.4	30.0	14.8
2	0.02	64.8	52.5	29.2	29.4	12.3
3	0.02	70.1	60.0	29.0	29.3	10.1
4	0.02	75.0	67.0	29.3	29.5	8.0

In table 1 above we can see the decrease of cooling water temperature on the radiator tends to be linear as shown by the graph below



Graph 1. Elevation of cooling water temperature without treatment

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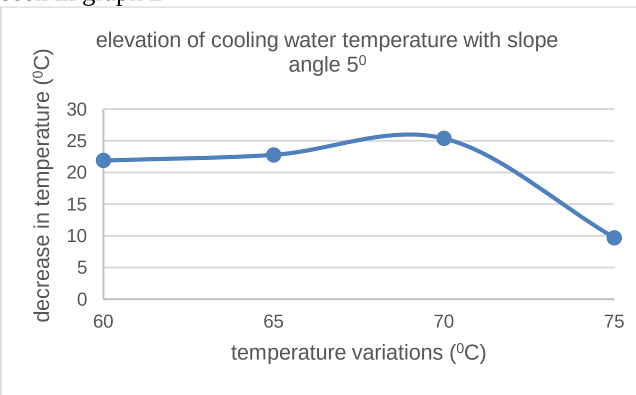
The tendency of temperature decrease that occurs is with increasing temperature of water entering the cooling capability of radiator also decrease

b. The position of the radiator with the slope tube radiator radiation position of 5^0 after the data is taken on the position of flat tube radiator by doing a slope of 5^0 then obtained the data in table 2 as follows:

Table 2. Decrease of temperature with slope 5^0.

No	Debit Flow (m^3/minute)	T water in (^{0}C)	T water out (^{0}C)	T air in (^{0}C)	T air out (^{0}C)	Elevation (^{0}C)
1	0.02	60.0	38.1	29.4	30.5	21.9
2	0.02	65.0	42.2	29.3	30.4	22.8
3	0.02	70.2	44.8	29.3	30.4	25.4
4	0.02	75.0	65.3	29.2	30.3	9.7

For more clearly the cooling temperature drop can be seen in graph 2



Graph 2. Elevation of cooling water temperature with slope angle 5^0

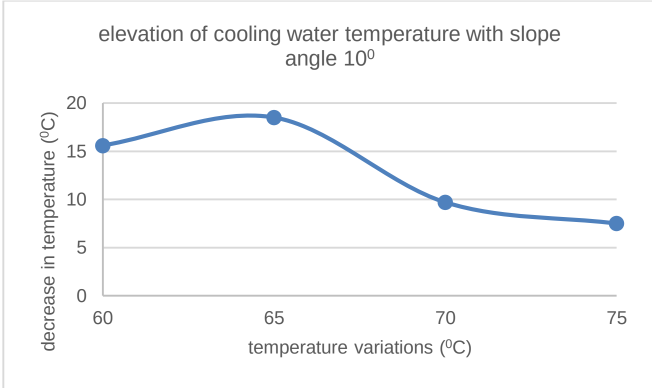
From the graph 2 in general can be seen decrease temperature significantly when compared with the position of the radiator without this treatment occurs because the position of the tilted radiator will expand the touch of cooling on the flat tube.

c. Position of radiator with slope tube radiator radiation position of 10^0 after the data is taken at the position of flat tube radiator by doing a slope of 10^0 then obtained data in table 3 as follows:

Table 3. Decrease of temperature with slope 10^0

No	Debit Flow (m^3/minute)	T water in (^{0}C)	T water out (^{0}C)	T air in (^{0}C)	T air out (^{0}C)	Elevation (^{0}C)
1	0.02	60.0	44.4	29.8	30.8	15.6
2	0.02	65.1	46.6	29.8	30.8	18.5
3	0.02	70.0	60.3	29.9	30.9	9.7
4	0.02	75.0	67.5	29.9	30.9	7.5

based on table 3 can be seen that the ability of the radiator began to decline compared with position 5^0, the condition is influenced by the position of the tilted flat tube, it is suspected to affect the speed of the coolant fluid flow in other words increase pressure drop.



Graph 3. Elevation of cooling water temperature with slope angle 10^0

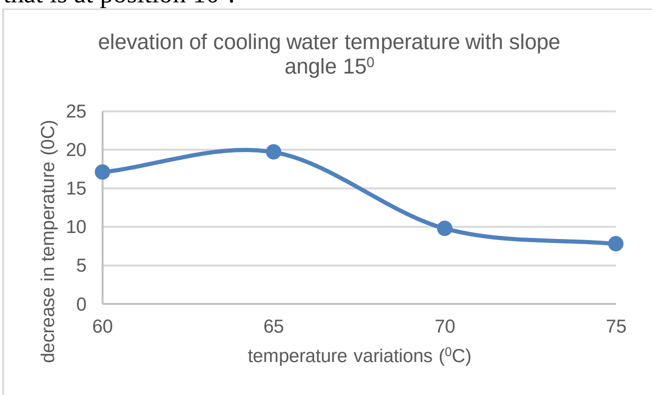
In graph 3 it can be seen that the cooling capability of the radiator decreases

d. The position of the radiator by treatment with the slope of the flat tube radiator is 15^0 after the data is taken on the position of flat tube radiator with a slope of 15^0 then obtained data in table 4 as follows:

Table 4. Decrease of temperature with slope 15^0

No	Debit Flow (m^3/minute)	T water in (^{0}C)	T water out (^{0}C)	T air in (^{0}C)	T air out (^{0}C)	Elevation (^{0}C)
1	0.02	60.0	42.9	30.3	31.3	17.1
2	0.02	64.9	45.2	30.4	31.4	19.7
3	0.02	69.9	60.1	31.0	32.0	9.8
4	0.02	75.0	67.2	30.5	31.4	7.8

In table 4 it can be seen that the flow characteristics are almost the same so that the temperature decrease in the radiator is not much different from the previous treatment that is at position 10^0.



Graph 4. Elevation of cooling water temperature with slope angle 15^0

On the 4th graph the trend of decreasing the temperature is almost the same because it gives a larger 5 change does not give a significant impact on the performance of the radiator in reducing the temperature of the cooling water

From the data already obtained then to calculate the effectiveness of the radiator using the equation as follows:

$$\varepsilon = \frac{\Delta T(fluida\ minimum)}{(beda\ suhu\ maksimum\ di\ dalam\ penukar\ kalor)} \quad (15)$$

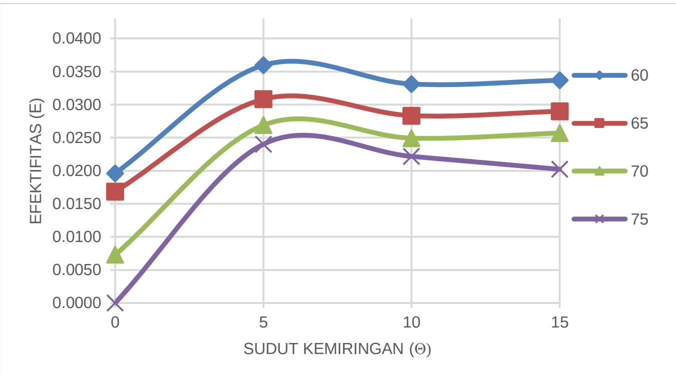
$$\varepsilon = \frac{(T_{c,out} - T_{c,in})}{(T_{h,in} - T_{c,in})} \quad (16)$$

After analyzing data by using effectiveness equation then obtained graph of influence of angle of slope to effectively of radiator on as follows:

Table 5 radiator effectiveness value

heat variations (^{0}C)	**effectiveness**			
	posisi 0^0	**posisi 5^0**	**posisi 10^0**	**posisi 15^0**
60	0.020	0.036	0.033	0.034
65	0.017	0.031	0.028	0.029
70	0.007	0.027	0.025	0.026
75	0.004	0.024	0.022	0.020
average	**0.011**	**0.029**	**0.027**	**0.027**

In table 5 when compared to all variations with the position without treatment then the value of effectiveness is better with the treatment. This condition is caused by making the position of the tilt flat tube will expand the region of heat absorption on the radiator, this will accelerate the process of heat release on the radiator. Of the best variations of position for effectiveness are 5^0 positions, whereas at positions 10^0 and 15^0 have decreased effectiveness because the position of the overly oblique flat tube blocks the cooling air so that the cooling air decreases the flow velocity.



Graph 5. Effect of slope of flat tube radiator angle to radiator effectiveness

From graph 5 above, it is seen that the increase of engine inlet temperature causes a decrease in the heat effectively of the radiator, where the greatest effectiveness is obtained at 60^0C temperatures at all test variations performed on the radiator flow and the same airspeed. This is because the increase in maximum temperature difference in the radiator is greater, causing a decrease in heat effectiveness at higher temperatures.

From graph 5 it is also seen that the increase in effectiveness of the maximum radiator occurs at a slope angle of 5^0 at all temperature variations with the highest effectiveness value obtained at 0.0359 at 60^0C temperatures at the same radiator flow rate and airspeed. This proves that the greater the extent of the touch of air on the flat tube radiator thus causing the greater heat transferred to the environment through the air fluid which causes an increase in temperature of the exit air (T_{out}) resulting in an increase in minimum fluid changes resulting in an increase in heat effectiveness.

Further variation of the angle of the flat tube radiator angle is obtained that the optimal angle occurs at the slope 5^0 whereas with the slope of the flute tube angle that is too large there is a decrease in heat effectiveness. This is caused by the increasing air resistance so that the air velocity in transferring heat from the flat tube becomes decreased causing the temperature of the air out to be reduced consequently there is a decrease in the value of fluid minimum changes resulting in decreased effectiveness of heat.

Conclusion

From the research that has been done with the optimization of the slope angle of the flat tube radiator, it is found that on the slope of flat tube 5^0 there is an increase of greater heat affectivity by 0,0359 at water temperature entering to radiator equal to 60^0C.

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