THE THEORETICAL AND EXPERIMENTAL INVESTIGATION OF THE HEAT TRANSFER PROCESS OF AN AUTOMOBILE RADIATOR

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Abstract

This paper analyzes the heat transfer process involved in the operation of an automotive radiator. The paper is written as part of an undergraduate research activity. The analysis of a radiator encompasses nearly all of the fundamentals discussed in a heat transfer class, including the internal and external fluid flow through a heat exchanger and the design and analysis of heat sinks and exchangers. The theoretical heat exchanger investigation begins with analyzing the internal fluid flow through the radiator's noncircular tubes, yielding the convective heat transfer coefficient for water. The external fluid flowing across the radiator tubes and fins is then analyzed

$A_{external}$	Total external surface area
$A_{internal}$	Total internal surface area
NTU	Number of transfer units
C_{min}	Minimum heat capacity
C_{max}	Maxi

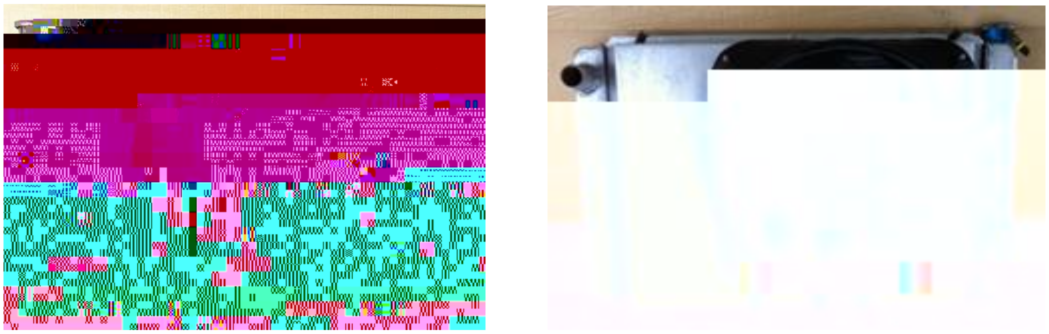

Figure 1: Universal aluminum radiator (left) and 3000 cfm fan (right)

Coolant Inlet

Air Flow

Coolant Outlet

Figure 2: Schematic of radiator

Cool air is then forced across the radiator's core, by

Internal Flow of Water

The hot water from the engine travels through the tubes of the radiator.

Area of Tubes

[illegible] (2)

The hydraulic diameter must be used because it is a non-circular cross section. The hydraulic diameter can then be used to estimate the Reynolds number. The equation for the hydraulic diameter calls for the wetted perimeter of the tubes. However, the difference in the outer and inner tube dimensions is so negligible that the outer perimeter is used for convenience.

Mean Temperature of Water

The average temperature of water must be calculated to find the fluid's material properties. The properties will be interpolated at this temperature. The properties that are needed are density, Prandtl number, thermal conductivity, dynamic viscosity, and specific heat. [1]

Velocity

[illegible] (3)

The velocity of the water through each tube must be found to calculate the Reynolds number. The number of tubes is given by the chosen radiator.

Reynolds Number

[illegible] (4)

Nusselt Number

The Nusselt number was found as a constant for a rectangular cross section from Table 8.1 for fully developed laminar flow.

Mean Temperature of Air

The average temperature of air must be calculated to find the correct material properties for later use. These properties are specific heat, thermal conductivity, kinematic viscosity, and Prandtl number.

Velocity

[illegible] (6)

Reynolds Number

[illegible]

Experiment

Setup
An aluminum stock radiator was tested with a 2.5 L Subaru engine at idle conditions. The coolant used in the radiator was pure water. The inlet and outlet temperatures for both the water and the air were measured using a thermocouple. For the water, a probe can be inserted in the tube right before the fluid enters the radiator and right after it exits. The inlet temperature of air will be assumed to equal the ambient. A probe was placed approximately five inches from the fan on the back side of the radiator to measure the outlet air temperature. In addition, the flow rate of the air across the radiator was measured using an air flow meter. Lastly, the flow rate through the radiator was measured by attaching a rotameter just before the coolant enters the radiator.

Procedure
The engine ran without the radiator fan until it reached 200 degrees Fahrenheit. Once the engine reached this temperature, the fan on the radiator was turned on to begin cooling the engine. The radiator, along with the fan, then cooled the engine until the temperatures reached steady state, which took approximately six minutes. The inlet and outlet temperatures and the flow rates for air and water were then recorded.

This experimental process was repeated four times in order to give a range of results to compare with one another. These experimental results were then compared with the inlet and outlet temperatures found in the theoretical analysis of the problem.

Results and Discussion

All of the dimensions for the radiator were carefully measured and are recorded below in Table 1. Certain material properties, given in Tables 2 and 3, were needed for water and air for the theoretical calculations. The values of these properties were found using the average temperature of the fluid. [1] An iteration process involving the inlet and outlet fluid temperatures was needed to calculate the final absolute value for the outlet temperatures. To complete this process the convective heat transfer coefficients, overall heat transfer coefficient, number of transfer units, effectiveness, and heat transfer rate for the radiator were needed.

$L_{radiator}$	$H_{radiator}$	$W_{radiator}$	W_{tube}	H_{tube}	L_{fin}	W_{fin}	H_{fin}	N_{tube}	N_{fin}
inches	inches	inches							

Table 4: Final Results for Radiator

h_{water}	h_{air}	UA	NTU	ε	$q_{predicted}$
W/m^2K	W/m^2K	M^2kg/Ks^3	unitless	%	W
609.27	45.13	836.34	0.59	40	23670

The final results, given in Table 4, for the theoretical calculations based on the given inlet temperature fo/1(o/1(o/1(o/1(o/1(o/1(o/1(o/1(o/1(o/1(o/1(o/1(o/1(o/1(o/1(o/1(o/1(o/16a6/1(o/1(o/1(o/1(o/16a6/1(o/1(o/1(o e