Design Projects in Undergraduate Heat Transfer: Six Examples from the Fall 2007 Course at the University of Arkansas

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Introduction

One of the main objectives of engineering education is to effectively transfer subject information to the engineering students. A number of methods have been developed for enhancing this student learning including multimedia developments[1,2], active, problem-based learning[3], collaborative learning[4,5], and participation in cooperative education[6]. Several papers have specifically addressed methods for improving or supplementing the teaching of heat transfer including the use of spreadsheets to solve two-dimensional heat transfer problems[7], the use of a transport approach in teaching turbulent thermal convection[8], the use of computers to evaluate view factors in thermal radiation[9], implementation of a computational method for teaching free convection[10], and the use of an integrated experimental/analytical/numerical approach that brings the excitement of discovery to the classroom[11]. Supplemental heat transfer experiments for use in the laboratory or classroom have also been presented, including rather novel experiments such as the drying of a towel[12] and the cooking of French fry-shaped potatoes[13]. Suggestions for the integration of heat transfer course material into the laboratory and classroom were described by Penney and Clausen[14-18], who presented a number of simple hands on heat transfer experiments that can be constructed from materials present in most engineering departments. This cross-course integration of course material has been shown to be a very effective learning tool that causes students to think beyond the content of each individual course[19].

As part of the requirements for CHEG 3143, Heat Transport, groups of two junior level chemical engineering students at the University of Arkansas were required to execute design project assignments on a number of relatively common systems, including:

- The rating of a Jeep Grand Cherokee cooling system radiator
- The rating of a Jeep Grand Cherokee air conditioning system condenser
- The design of a capillary tube electric resistance heater for a dentist's drill cooling water heater
- The design of an electrical heater to supply hot air to a paint curing oven
- The design of an electrically heated reboiler for the U of A Senior Laboratory distillation column
- The design of a vertical shell-and-tube condenser for the U of A Senior Laboratory distillation column

For each of these assignments, the student group was required to write a fully documented TK (Tool Kit) computer program to perform the design calculations, and to write a formal report that fully details the design work. All of the required equipment was selected and specified from manufacturer's literature.

This paper describes the students' work in rating a Jeep Grand Cherokee cooling system radiator relative to the duty required to cool the engine. Photographs and dimensions of the radiator are presented, along with the model development and results from the analysis. Exercises such as this are effective in urging the students to apply the principles of heat transfer to actual physical systems, and thus to better visualize physical applications of classroom principles.

Rating a Jeep Grand Cherokee Cooling System Radiator

Objective

The purpose of this project was to rate a 2006 Jeep Grand Cherokee radiator relative to the duty required to cool the engine.

Equipment and Materials

Figure 1 shows a photograph of a section of the junk radiator that was used in calculating the rating. The photograph shows a cut-away of the tubes through which the ethylene glycol solution flowed, as well as the perforated fins over which the air flowed. Figure 2 shows a Microsoft Visio schematic of the radiator section that depicts the dimensions of the tubes and the air fins, as determined by direct measurement, using the help of the Chemical Engineering Department Machinist. Dimensions are shown in Table 1. Figure 3 shows both a photograph and a Microsoft Visio schematic of the side view of the radiator. The tubes through which the air flowed can be better seen in this side view.

Figure 1. Horizontal Cut: Radiator Cross Section

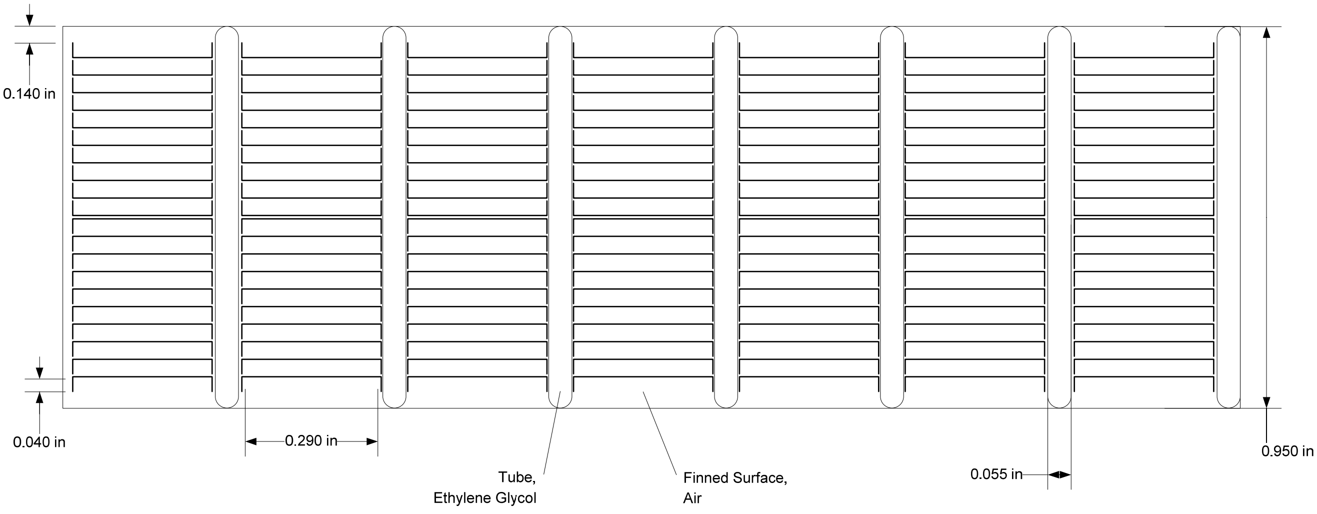

Figure 2. Radiator Cross Section

Table 1. Radiator Dimensions

DIMENSION	MEASUREMENT (in)	MEASUREMENT (m)
Ethylene Glycol Tubes		
Number of Tubes	59	59
Length	23.6	0.6 m
Width	0.950 in	0.024 m
Height	0.055 in	0.0014 m
Wall Thickness	0.033 in	0.00076 m
Aluminum Fins (Air Side)		
Length	1.054 in	0.027 m
Width	0.295 in	0.0074 m
Thickness	0.002 in	.000051 m
Unperforated Length	0.140 in	.0036 m
Number of Perforations Per Fin	20	20
Number of Fins Across	370	370
Number of Fins Down	61	61
Average Distance Between ins	0.064 in	.0016 m
Perforations		
Length	0.040 in	.0010 m
Width	0.290 in	.0074 m
Thickness	0.002 in	.000051 m

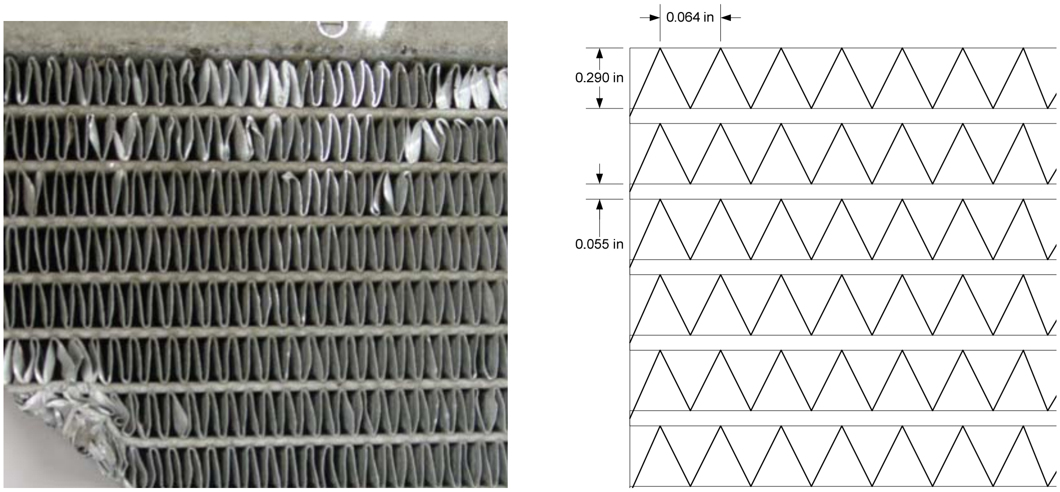

Figure 3. Radiator Side View

The required physical properties of ambient air (1 atm, 45°C) and a 50% water, 50% ethylene glycol antifreeze solution are shown in Table 2. Goering *et al.*[20] note that antifreeze enters the radiator at a temperature of 98°C and exits at a temperature of 90°C.

Table 2. Physical Properties of Air and Ethylene Glycol

Property	Air (1 atm, 45°C)	50% Ethylene Glycol/Water
Density, kg/m^3	1.109[a]	1059[b]
Viscosity, kg/m·s	1.941×10^{-5} [a]	7.0×10^{-4} [c]
Thermal conductivity, W/m·K	0.02699[a]	0.41[b]
Specific heat, J/kg·K	1007[a]	3500[b]

[a] from Cengel, Y.A., 2007, *Heat and Mass Transfer: A Practical Approach*, 3rd ed.
[b] from Redline Water Wetter, Thermal Properties, http://www.racerpartswholesale.com/redtech3.htm, April 26, 2007.
[c] from Engineering Tool Box, Ethylene Glycol Heat Transfer Fluid, http://www.engineeringtoolbox.com/ethylene-glycol-d_146.html, April 12, 2007.

Model Development

It was assumed that the Jeep Grand Cherokee operated under moderate conditions, driving at 80 miles per hour on a summer day (a temperature of 30°C). The development of moderate conditions also included the use of perforations on the fins, which were assumed to double the shell-side heat transfer coefficient, thereby increasing the heat transfer. An engine efficiency of 40% was assumed. With this engine efficiency, it was possible to calculate the heat rejected from the engine as a fraction of the energy available from the engine:

$$Q_{hl} = \frac{1-\eta_e}{\eta_e} Q_e \qquad (1)$$

This calculation, as well as all of the subsequent calculations detailed below, is shown in the TK program that is appended.

Separate calculations were performed for the air on the finned side of the radiator and the ethylene glycol solution on the tube side of the radiator in order to calculate the respective heat transfer coefficients. The hydraulic diameters for both the finned side and the tube side were calculated from Equation (2), using the appropriate dimensions:

$$D_h = \frac{2 \cdot L \cdot W}{L + W} \tag{2}$$

In combining the hydraulic diameter with the flow velocity and stream physical properties, it was then possible to calculate a Reynolds number for each stream.

$$\mathrm{Re} = \frac{V \cdot \rho \cdot D_h}{\mu} \tag{3}$$

A Nusselt number was calculated for each stream using the Dittus-Boelter correlation:

$$Nu = 0.023 \cdot \mathrm{Re}^{0.8} \cdot \mathrm{Pr}^{n} \tag{4}$$

The exponent n has a value of 0.4 in heating the air, and a value of 0.3 in cooling the ethylene glycol solution. The Prandtl number for air was found in Table A-15 of Cengel[21]. The Prandtl number for the ethylene glycol solution was calculated by the equation:

$$\mathrm{Pr} = \frac{\mu \cdot C_p}{k} \tag{5}$$

The Nusselt numbers were used to calculate the finned air side and ethylene glycol solution tube side heat transfer coefficients by the equation:

$$Nu = \frac{h \cdot D_h}{k} \tag{6}$$

The areas for heat transfer were calculated from the dimensions of the radiator. The heat transfer area of the air side fins was calculated from the thickness of the radiator the corrected length of the fin and total number of fins by the equation:

$$A_{fin} = t_{radiator} \cdot L_c \cdot N_t \tag{7}$$

The unfinned area of the air side tubes was calculated from the average distance between fins, and the number of fins in the horizontal and vertical directions using the equation:

$$A_{unfin} = 2 \cdot S \cdot t_{radiator} \cdot N_{f,horizontal} \cdot N_{f,vertical} \tag{8}$$

The total heat transfer area on the air side was then calculated from the area of the fins, the unfinned area and the fin efficiency by the equation:

$$A_s = A_{unfin} + A_{fin} \cdot \eta \tag{9}$$

The heat transfer area on the ethylene glycol solution side of the tubes was calculated from the height, length and width of the tubes, using the equation:

$$A_{sol} = 2 \cdot \left(H_{tube} + 2\right) \cdot W_{tube} \cdot L_t \tag{10}$$

The tube wall temperature was required in order to determine the effect of the air side fins on heat transfer. The tube wall temperature was calculated from a heat balance on the outer surface of the ethylene glycol tubes:

$$Q_{in,tube} - Q_{out,tube} + Q_{gen,tube} = Q_{acc,tube} \tag{11}$$

There was no heat generated on the surface of the tubes, and the temperature of the tube wall is essentially constant, making the accumulated heat negligible. The heat into the tube wall is due to convection with the air, shown as:

$$Q_{in,tube} = h_{air} \cdot A_{unfin} \cdot (T_{base} - T_{air,avg}) \qquad (12)$$

Simultaneous solution of Equation (12) with an equation describing heat transfer into the tube wall due to conduction allows for calculation of the fin base temperature:

$$Q_{out,tube} = \frac{T_{sol,avg} - T_{base}}{\dfrac{\Delta x_{tube}}{k_{alum} \cdot A_{sol}} + \dfrac{1}{h_{sol} \cdot A_{sol}}} \qquad (13)$$

The fin efficiency was also required to calculate the radiator duty. The calculation of fin efficiency requires a corrected length and a corrected area of the fins. These parameters were determined from measured dimensions using the following equations:

$$L_c = L + t/2 \qquad (14)$$

$$A_P = L_c \cdot t \qquad (15)$$

Using these corrected parameters, the fin efficiency was calculated from Cengel[21] using the following parameter:

$$\xi = L_c^{3/2} \cdot \left(\frac{h_{air}}{k_{alum} \cdot A_p} \right)^{1/2} \qquad (16)$$

The heat flow due to the fins and the heat flow due to the unfinned area were calculated from the equations:

$$Q_{fin} = \eta \cdot h_{air} \cdot A_{fin} \cdot (T_{base} - T_{air,avg}) \qquad (17)$$

$$Q_{nofin} = h_{air} \cdot A_{nofin} \cdot (T_{base} - T_{air,avg}) \qquad (18)$$

The total duty of the radiator is then the sum of these two heat flows:

$$Q_{rad} = Q_{fin} + Q_{nofin} \qquad (19)$$

Finally, the rating of the radiator can be calculated as the ratio of the radiator duty to the heat loss from the engine:

$$Rating = \frac{Q_{rad}}{Q_{hl}} \qquad (20)$$

Results and Discussion

Table 3 shows results from the study including the calculated heat transfer coefficients, the fin and engine efficiencies, the heat flows and the radiator rating. In operating the jeep under moderate conditions, the air velocity across the fins was 56 m/s. The air side heat transfer coefficient was 404 W/m^2·K, and the ethylene glycol solution side coefficient was 6500 W/m^2·K. The maximum energy output from the engine was 112 kW, an energy output that is quite close to the 148 kW obtained when operating a vehicle at 80 mi/hr and achieving 18 mpg (miles per gallon) of gasoline. The heat loss from the engine was 168 kW, and the radiator duty was 85 kW. The radiator rating was 50.7%.

Table 3. Results from the Study

Flow Rates

Ethylene Glycol Solution Velocity	1.5 m/s

Velocity of Air Across the Fins	56 m/s
Jeep Velocity	80 mph

Temperatures

Entering Air	30 C
Exiting Air	45 C
Entering Ethylene Glycol Solution	98 C
Exiting Ethylene Glycol Solution	90 C

Heat Transfer Coefficients

Air Side	404 $W/m^2 \cdot K$
Ethylene Glycol Solution Side	6506 $W/m^2 \cdot K$

Efficiencies

Engine Efficiency	40%
Fin Efficiency	48%

Heat Flows

Engine Horsepower	112 kW
Heat Loss from Engine	168 kW
Radiator Duty	85 kW

Rating

Radiator Rating	50.7%

There were multiple factors in the design method that led to uncertainty in the determination of the radiator duty. The outlet temperatures of the ethylene glycol and air were estimated, and could be different due to a number of environmental factors. Perforations on the fins created turbulence in the air side stream. Since a direct correlation accounting for the effect of these perforations could not be found, a reasonable assumption was made that their presence doubled the heat transfer coefficient. Surface roughness is another consideration. Kandlikar *et al.*[22] note that surface roughness has a large impact on heat transfer characteristics of small diameter tubes. Surface roughness was ignored in this study. The calculated rating was 50.7% and, although this rating seems low, there are other methods for removing heat losses from the engine. When the car is stationary, the engine is cooled by natural convection. During periods of movement, air flows over the engine and cools it by forced convection. The Jeep's exhaust system will also remove a portion of the engine heat loss.

Conclusions/Observations

- The radiator was found to accomplish its job with a rating of 50.7%. The radiator carries enough of the heat loss for the engine to be cooled by the combined effects of the radiator, forced convection, and the exhaust system.
- The radiator rating could be improved by putting less stress on the radiator. Stress could be decreased in several ways:

  - When less engine horsepower is being used, less heat must be removed. Driving slower or carrying less weight would require less engine horsepower.
  - The simulation was carried out at summer temperatures. Driving in lower temperatures will also increase the radiator rating by increasing the radiator duty.
- The radiator is only required to carry a portion of the heat lost from the engine. The simulation shows that the radiator is able to perform even when the situation is extreme. In cases where the radiator does not need to remove this amount of heat, the pressure cap will reduce the flow to accommodate the heat transfer that must occur.
- Educationally, the students were presented with a real application of heat transfer correlations presented in class, and they obtained a reasonable estimate (within 15-20% of manufacturer's specification) of the radiator duty.
- Student performance in this class was the best in recent history, although it would be difficult to correlate performance with this performance without appropriate controls.

Nomenclature

A_s	total heat transfer area on the air side, m^2
A_{fin}	heat transfer area of the air side fins, m^2
A_{nofin}	heat transfer area of the air side if no fins were present, m^2
A_p	corrected fin area, m^2
A_{sol}	heat transfer area on the ethylene glycol solution side of the tubes, m^2
A_{unfin}	unfinned area of the air side tubes, m^2
C_p	specific heat, J/kg·K
D_h	hydraulic diameter, m
h_{air}	heat transfer coefficient on the finned air side, W/m^2·K
h_{sol}	heat transfer coefficient on the ethylene glycol solution side, W/m^2·K
H_{tube}	height of an ethylene glycol solution tube, m
k	thermal conductivity, W/m·K
k_{alum}	thermal conductivity of Aluminum, W/m·K
L	length, m
L_c	corrected length of the fin, m
L_t	length of ethylene glycol solution tube, m
$N_{f,horizontal}$	number of fins in the horizontal direction
$N_{f,vertical}$	number of fins in the vertical direction
N_t	total number of fins
Nu	Nusselt number
Pr	Prandtl number
$Q_{acc,tube}$	heat accumulated on the ethylene glycol tube surface, W
Q_e	energy available from engine, W
Q_{fin}	heat transfer due to fins, W
$Q_{gen,\ tube}$	heat generated on the ethylene glycol tube surface, W
Q_{hl}	heat lost from engine, W
$Q_{in,tube}$	heat into the ethylene glycol tube surface, W
Q_{nofin}	heat transfer due to the unfinned area, W
$Q_{out,tube}$	heat out of the ethylene glycol tube surface, W
Q_{rad}	radiator duty, W

Re	Reynolds number
S	average distance between fins, m
$T_{air,avg}$	average temperature of the air flowing through the radiator, °C
T_{base}	temperature at the base of the fins, °C
t_{fin}	thickness of fin, m
$t_{radiator}$	thickness of radiator, m
$T_{sol,avg}$	average temperature of the ethylene glycol solution, °C
V	stream velocity, m/s
W	width, m
W_{tube}	width of an ethylene glycol solution tube, m
Δx_{tube}	thickness of the ethylene glycol solution tube walls, m
η	fin efficiency
η_e	engine efficiency
μ	liquid viscosity, kg/m·s
ξ	value from Cengal[21], used to find efficiency
ρ	liquid density, kg/m^3

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W. ROY PENNEY
Dr. Penney currently serves as Professor of Chemical Engineering at the University of Arkansas. His research interests include fluid mixing and process design. Professor Penney is a registered professional engineer in the state of Arkansas.

RACHEL M. LEE, MEAGAN E. MAGIE
Ms. Lee and Ms. Magie are junior level chemical engineering students at the University of Arkansas. They participated with their classmates (in groups of two) in performing design exercises as part of the requirements for CHEG 3143, Heat Transport.

EDGAR C. CLAUSEN
Dr. Clausen currently serves as Professor and the Ray C. Adam Endowed Chair in Chemical Engineering at the University of Arkansas. His research interests include bioprocess engineering (fermentations, kinetics, reactor design, bioseparations, process scale-up and design), gas phase fermentations, and the production of energy and chemicals from biomass and waste. Dr. Clausen is a registered professional engineer in the state of Arkansas.

Sta	Input	Name	Output	Un	Comment
					HEAT-S07-SPECIAL PROJECT-MAGIE AND LEE
					PROPERTIES
	1059	ρe			Density of Ethylene Glycol Solution, kg/m^3
	.41	ke			Thermal Conductivity of Ethylene Glycol Solution, W/m*K
	3500	Cpe			Specific Heat of Ethylene Glycol Solution, J/kg*K
	.0007	μe			Viscosity of Ethylene Glycol Solution, kg/m*s
		Pre	5.97560976		Prandtl Number Ethylene Glycol Solution, W/m*K
	237	kr			Thermal Conductivity of Aluminum, W/m*K
	1.109	ρa			Density of Air, kg/m^3
	.02699	ka			Thermal Conductivity of Air, W/m*K
	.00001941	μa			Viscosity of Air, kg/m*s
	.7241	Pra			Prandtl Number of Air
					DIMENSIONS
	.6	Lg			Length of Ethylene Glycol Tube, m
	59	N			Number of Ethylene Glycol Tubes
		Lt	35.4		Total Length of Tubes, m
	.02413	Wg			Width of Ethylene Glycol Tubes, m
	.001397	Hg			Height Ethylene Glycol Tubes, m
		Lc	.0075184		Corrected Length of Fins, m
	.0267716	L			Length of Fin, m
	.007493	W			Width of Fin, m
		Dh	.002641095		Hydralic Diameter Ethlyene Glycol Tubes, m
		Dha	.014801158		Hydralic Diameter Air Side, m
	360	Nfd			Number of Fins Down
	60	Nfa			Number of Fins Across
		Nt	21600		Total Number of Fins
	.001629833	S			Average Distance Between Fins, m
	.0000508	t			Thickness of Fin, m
		Thg	.0008255		Thickness of Ethylene Glycol Tube, m
					AREAS
		Ap	3.81935E-7		Corrected Area of Fin, m^2
		Af	4.3476393		Heat Transfer Area of fins, m^2
		Auf	1.88495623		Heat Transfer Area of Tube when fins are present, m^2
		As	3.9718231		Air Heat Transfer Area, m^2
		Ai	1.8073116		Ethylene Glycol Heat Transfer Area, m^2
					FLOW RATES
	1.524	Ve			Velocity Ethylene Glycol, m/s
		Va	35.7622222		Velocity Air, m/s
	80	Vjeep			Velocity of Jeep, mph
		V	55.7622222		Velocity of Air Across Fins, including effect of a fan, m/s
					TEMPERATURES
	98	Tei			Entering Temperature of Ethylene Glycol, C
	90	Tef			Exiting Temperature of Ethylene Gylcol, C
	30	Tai			Entering Temperature of Air, C
	45	Taf			Exiting Temperature of Air, C
		Tb	90.4899364		Average Temperature of Tube Walls, C
		Taav	37.5		Average Air Temperature, C
		Teav	94		Average Ethylene Glycol Temperature, C
		Te	90.1650288		Temperature of Fin End, C

Sta	Input	Name	Output	Un	Comment
					HEAT TRANSFER COEFFICIENTS
		hi	6505.7277		Tubeside Heat Transfer Coefficient (Ethylene Glycol), W/m^2*K
		h	404.033952		Heat Transfer Coefficient (Air), W/m^2*K
		hu	202.016976		Heat Transfer Coefficient w/o Perforations (Air), W/m^2*K
					RESISTANCES
		Rf	.000007272		Resistance Due to Conduction Through Fin, K/W
	.0004	Rfo			Fouling Factor, Air Side m^2*C/W
	.0004	Rfi			Fouling Factor, Ethylene Glycol Side m^2*C/W
					HEAT FLOWS
		Qe	111855		Maximum Output of 6 cyl. engine, W
	150	Qehp			Maximum Output of 6 cyl. engine, BHP
		Qhl	167782.5		Heat Loss From Engine, W
		E	279637.5		Engery Available, W
		Qf	44679.2633		Heat Transfer due to Fins, W
		Quf	40356.4104		Heat Transfer due to Unfinned Area, W
		Qtotal	85035.6738		Total Heat Transfer, W
		Qif	44679.2633		Heat Transfer Into Fin, W
		Qof	44679.2633		Heat Transfer Out of Fin, W
	0	Qgf			Heat Generated, Fin, W
	0	Qaf			Heat Accumulated, Fin, W
		Qit	40356.4104		Heat Transfer Into Ethylene Glycol Tube, W
		Qot	40356.4104		Heat Transfer Out of Ethylene Glycol Tube, W
	0	Qgt			Heat Generated, Ethylene Glycol Tube, W
	0	Qat			Heat Accumulated, Ethylene Glycol Tube, W
					DIMENSIONLESS PARAMETERS
		Re	6089.29245		Reynolds Number Tubeside, Ethylene Glycol
		Nu	41.9079069		Tubeside Nusselt Number
		Rea	47156.5239		Reynolds Number Air
		Nua	110.784929		Nusselt Number Air
					EFFICIENCY TERMS
		ξ	1.37729931		X-axis value of Fig 3-42, used to find efficiency, p.167
	.48	η			Efficiency of Fins, determined from Fig 3-42 using ξ
					RATING
		Ra	.506820877		Amount of Heat Loss Carried By Radiator

Sta	Rule
C	;HEAT-S07-SPECIAL PROJECT-MAGIE AND LEE
C	;*****AIR CALCULATIONS*****
* U	Va=Vjeep*1609.3/60^2
* U	V=Va+20
C	;CALCULATE HYDRALIC DIAMETER
* U	Dha=(2*Lg*W)/(Lg+W)
C	;CALCULATE REYNOLDS NUMBER
* U	Rea=V*Dha*ρa/μa
C	;CALCULATE NUSSELT NUMBER
* U	Nua=0.023*Rea^.8*Pra^0.4
C	;CALCULATE HEAT TRANSFER COEFFICIENT INSIDE
* U	Nua=hu*Dha/ka
* U	h=2*hu
C	;CALCULATE NUMBER OF FOLDS
* U	Nt=Nfa*Nfd
C	;CALCULATE HEAT TRANSFER AREA
* U	As=(Auf+η*Af)
C	;*****ETHYLENE GLYCOL CALCULATIONS*****
C	;CALCULATE HYDRALIC DIAMETER
* U	Dh=(2*Hg*Wg)/(Hg+Wg)
C	;CALCULATE REYNOLDS NUMBER
* U	Re=Ve*Dh*ρe/μe
C	;CALCULATE PRANDTL NUMBER
* U	Pre=μe*Cpe/ke
C	;CALCULATE NUSSELT NUMBER
* U	Nu=0.023*Re^.8*Pre^0.3
C	;CALCULATE HEAT TRANSFER COEFFICIENT INSIDE
* U	Nu=hi*Dh/ke
C	;CALCULATLE HEAT TRANSFER AREA
* U	Ai=(2*Hg+2*Wg)*Lt
C	;CALCULATE TUBE THICKNESS
* U	Thg=0.0254*(.36-.295)/2
C	;CALCULATE TOTAL TUBE LENGTH
* U	Lt=Lg*N

Sta	Rule
C	;*****FIN EFFICIENCY CALCULATIONS*****
C	;;;CALCULATE AREAS
* U	Ap=Lc*t
* U	Af=L*Lc*Nt
* U	Auf=(S*Nfd)*L*Nfa*2
C	;;;CALCULATE EFFICIENCY (using Fig 3-43, p.167)
* U	Lc=W+(t/2)
* U	ξ=Lc^(3/2)*(h/(kr*Ap))^(1/2)
C	;;;CALCULATE HEAT FLOWS
C	;eq.1-24,p.26
* U	Qf=η*h*Af*(Tb-Taav)
* U	Quf=h*Auf*(Tb-Taav)
* U	Qtotal=(Qf+Quf)
C	;;;HEAT BALANCE OVER OUTER FIN SURFACE
C	;eq1-13, p.12
* U	Qif-Qof+Qgf=Qaf
* U	Qof=Qf
C	;eq.3-30, p.147
* U	Qif=(Tb-Te)/Rf
C	;eq.3-34, p.147
* U	Rf=W/(kr*Af)
C	;*****RATING CALCULATIONS*****
* U	Qe=Qehp*745.7
* U	Qe=.40*E
* U	Qhl=.60*E
* U	Ra = Qtotal/Qhl
C	;****TUBE WALL TEMPERATURE*****
* U	Taav=(Tai+Taf)/2
* U	Teav=(Tei+Tef)/2
C	;HEAT BALANCE ON OUTER SURFACE OF TUBE
* U	Qit-Qot+Qgt=Qat
* U	Qot=h*Auf*(Tb-Taav)
* U	Qit=(Teav-Tb)/((Thg/(kr*Ai))+(1/(hi*Ai)))

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