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Validation of Design Parameters of Radiator using Computational tool

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ABSTRACT - *Today's automobiles are getting equipped with high powered engines. The process of equipping such automobiles with hiss necessitated the need for improving the cooling efficiency of its radiators. The present work aims on studying the thermal behaviour of automobile radiators. Both LMTD and NTU methods are widely used for design and performance analysis. In recent years, software is used as a validating tool to generate results. This paper explains these methods along with software results. This paper also includes the case studies on two known examples from a text book. The validated results and comparisons are presented. This work provides a clear way for the easier verification of the thermal performance of radiators. The designers involving radiators could use this research as a base for improving their performance. The software used for the performance evaluation is HXcombine for analysing heat exchangers. The results obtained serve as good database for the future investigations.*

Keywords: *Automobile Radiator, Cooling Efficiency, Case study, LMTD, NTU, Software*

1. INTRODUCTION

The Radiator is a kind of heat exchanger which is used for cooling IC engines, especially in automobiles. The radiator system works by sending liquid coolant through passages in the engine block and heads, from where the coolant picks up heat from the engine block and heads.

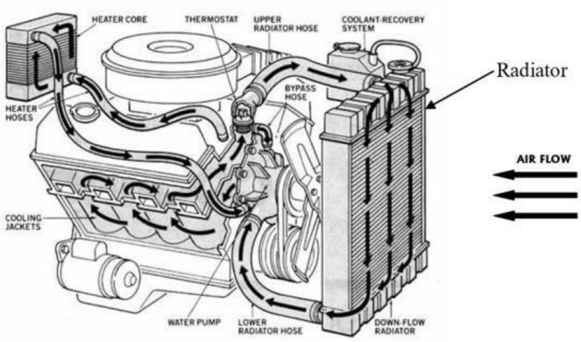

Fig - 1: Typical car radiator [1]

The heated fluid is then carried to the radiator through the rubber hose. Improving the cooling efficiency (only above the optimum temperature) of the radiator improves the performance of the engine. Most of the researches in this field are concentrating on improving the heat transfer rate by means of altering the properties of the coolant by adding some nanoparticles. A typical radiator used in automobiles is shown in figure 1. This paper discusses the comparative analysis of theoretical and software methods of designing radiators.

2. EXPERIMENTAL SCHEME

The outlet of the radiator is connected to the oil storage tank. The oil storage tank is connected to the heater. This in turn is connected to the inlet of the radiator. For the flow purpose the centrifugal pump is used and for connection purpose the rubber hoses are used. The research work involves the analysis of cooling performance of radiator by introducing different nanoparticles and also by altering their usual design. The proposed approach follows the following layout

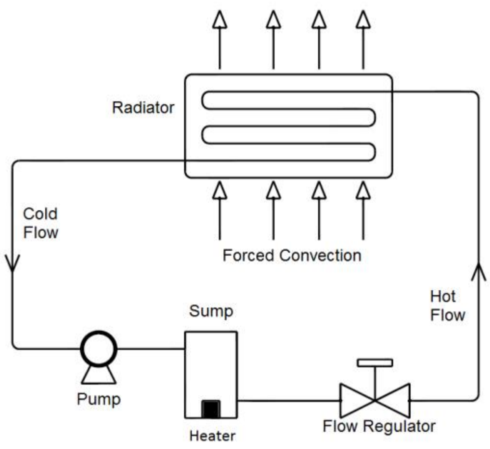

Fig - 2: CAD Drawn Experimental Layout

The coolant enters the radiator in hot condition. The radiator distributes the hot coolant into its branched tubes where the coolant transfers its heat to the surroundings through the fins. The coolant leaves the radiator at a temperature just above the optimum temperature. This coolant is stored in the oil storage tank. From the storage tank the oil is taken through the engine's coolant jackets (here the engine is replaced by heater coils). As a result the coolant carries away the excess heat from the engine. This coolant in hot condition is taken to the radiator and the cycle continues.

This research work involves altering the property of the coolant by introducing the nanoparticles into the coolant and analysing the corresponding heat transfer rate. In addition this work also includes altering the design of the radiator.

3. LITERATURE REVIEW

Numerical methods are being studied to make the computerized analysis of components. Numerical investigation on the spiral radiator to study flow characteristics and thermal performance by means of local element by element analysis utilizing ε-NTU method has been carried out. Experiments were performed and the results after comparison with the theoretical values were found to be promising. From the experimental data, a correlation among the important dimensionless numbers has been obtained using GARCH tool [2]. A research work mentioned the radiator thermal analysis consist sizing and rating of heat exchanger. It is also showed that the radiator size mainly depends on heat rejection requirement. Further thermal analysis of radiator is shown theoretically using ε-NTU method and its validation by simulation approach [3]. The radiator is modelled by two methods, one is finite difference method and the other is thermal resistance concept. In the performance evaluation, a radiator is installed into a test setup and the various parameters including mass flow rate of coolant, inlet coolant temperature etc. are varied [4].

It is declared that the efficiency of the radiator has been increased through a variety of methods, out of which radiator fan is the most used one to improving the efficiency of radiator by modification of radiator fan and radiator tube [5]. The conventional radiator size is rectangular which is difficult for circular fan to cover whole surface area. It creates lower velocity zones at corners giving less heat transfer [6]. An experimental performance analysis found that the power consumed by fan is 2 to 5% of power produced by engine. It is proposed to have circular heat exchanger for car radiators for maximum efficiency [7]. A work investigated on parameters which influence radiator performance at high coolant temperature that is 105^0 C and its effect on the effectiveness at variable fan speed. A literature review has also been done and ways were identified how to enhance radiator performance [8].

A study dealt with enhancement of heat transfer for both laminar and turbulent flow conditions [9]. A work described use of nanofluid based coolant in engine cooling system and its effect on cooling capacity. It is found that nano-fluid having higher thermal conductivity than base coolant like 50%/50% water and ethylene glycol.

4. HEAT EXCHANGER DESIGN PARAMETERS

4.1 LMTD METHOD

It is a simple matter to use the Log Mean Temperature Difference (LMTD) method of heat exchanger analysis when the fluid inlet temperatures are known and the outlet temperatures are specified or readily determined from the energy balance expressions, as follows

$$q = \dot{m}_h c_{ph}(T_1 - T_2)$$
$$q = \dot{m}_c c_{pc}(t_2 - t_1)$$
$$=> \ t_2 = \frac{q}{\dot{m}_c c_{pc}} + t_1$$
$$q = UA\Delta T_{lm}$$

The value of ΔT_{lm} for the exchanger may then be determined.

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{ln[(T_1 - t_2)/(T_2 - t_1)]}$$

4.2 NTU METHOD

If only the inlet temperatures are known, use of the LMTD method requires a cumbersome iterative procedure. It is therefore preferable to use an alternative approach termed the effectiveness–NTU (or NTU) method.

$$NTU = \frac{UA}{C_{min}}$$
$$NTU = f\left(\varepsilon, \frac{C_{min}}{C_{max}}\right)$$

For cross flow with single pass and both fluids unmixed we have

$$\varepsilon = 1 - exp\left[\left(\frac{1}{C_r}\right)(NTU)^{0.22}\{exp[-C_r(NTU)^{0.78}] - 1\}\right]$$

Effectiveness of a single pass crossflow heat exchanger with both fluids unmixed
Generally,

$$C_h = \dot{m}_h c_{ph}$$
$$C_c = \dot{m}_c c_{pc}$$

To find C_{max} and C_{min} from c_h and c_c
$q_{max} = C_{min}(T_1 - t_1)$

$$\varepsilon = \frac{q}{q_{max}}$$
$$NTU = \frac{UA}{C_{min}}$$

Then the graph can be used to predict the value of 'U'

5. CASE STUDIES

The two case studies on automobile radiators have been taken from a standard text book [11] that is dealt as radiators of cross flow type. For both case studies, the calculations are done using ε – NTU method. Case study 1 deals with the design calculation while case study 2 deals with performance evaluation.

5.1 CASE STUDY 1

Problem statement

An automobile radiator may be viewed as a cross-flow heat exchanger with both fluids unmixed. Water, which has a flow rate of 0.05 kg/s, enters the radiator at 400 K and is to leave at 330 K. The water is cooled by air that enters at 0.75 kg/s and 300 K. If the overall heat transfer coefficient is 200 $W/m^2{\cdot}K$, what is the required heat transfer surface area?

Table - 1: Data for Case study 1

Hot fluid	Cold Fluid	Common Parameters
$T_1 = 400$ K $T_2 = 330$ K $\dot{m}_h = 0.05$ Kg/s	$t_1 = 300$ K $\dot{m}_C = 0.75$ Kg/s	$U = 200\ W/m^2{\cdot}K$ A = ? q = ? t_2 = ?

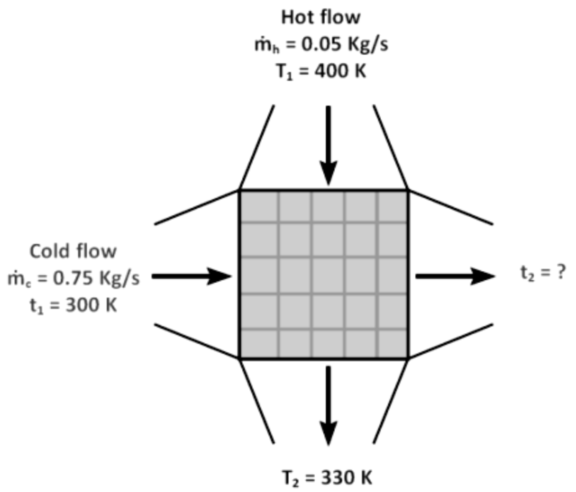

Fig - 3: Case 1 Statement

Design calculation

Heat capacity rates:

$T = (T_1 + T_2)/2$
$T = (400+330)/2 = 365$ K
Let us assume $t \approx 310$ K

From Thermophysical Properties of Saturated Water Table, for T = 365 K we have $c_p = 4.209$ KJ/Kg·K

From Thermophysical Properties of Gases at Atmospheric Pressure Table, for $t \approx 300$ K we have $c_p = 1.007$ KJ/Kg·K
$\dot{m}_C{\cdot}c_{pc} = 0.75 \text{ X } 1.007 = 0.75525$ KW/K (C_{max})
$\dot{m}_h{\cdot}c_{ph} = 0.05 \text{ X } 4.209 = 0.21045$ KW/K (C_{min})

Heat transfer rate:

$q_{max} = C_{min}{\cdot}(T_1 - t_1)$
$q_{max} = 0.21045 \text{ X } (400-300) = 21.045$ KW
$q = (\dot{m}_h{\cdot}c_{ph}) \cdot (\Delta T) = (\dot{m}_h{\cdot}c_{ph}) \cdot (T_1 - T_2)$
$q = (0.21045) \text{ X } (400-330) = 14.73$ KW

For t_2 determination:

$q = (\dot{m}_C{\cdot}c_{pc}) \cdot (\Delta t) = (\dot{m}_C{\cdot}c_{pc}) \cdot (t_2 - t_1)$
$14.7315 = (0.75525) \text{ X} (t_2 - 300)$
$t_2 = 319.51$ K

Since the problem has been solved using the assumed value of t_2 (i.e. t_2 = 320 K), the iterations should be carried out for the accurate value of t_2. On iterating, the solution converges within four iterations and the actual value of t_2 is found to be 319.4904 K which is almost same as the assumed value.

$t_2 = 319.49$ K

For NTU determination

$$\frac{C_{min}}{C_{max}} = \frac{0.21045}{0.75525} = 0.27865$$

$$\varepsilon = \frac{q}{q_{max}}$$

$$\varepsilon = \frac{14.7315}{21.045} = 0.7$$

From Effectiveness of a single pass, cross-flow heat exchanger with both fluids unmixed graph, for (C_{min}/C_{max}) = 0.27865 and ε = 0.7, we have NTU ≈ 1.5

But,

$$NTU = \frac{UA}{C_{min}}$$

Thus,

$$1.5 = \frac{0.200 \text{ X } A}{0.21045}$$

$A = 1.58\ m^2$

Result

$t_2 = 319.5$ K
$q = 14.73$ KW
$A = 1.58\ m^2$

Results from software (Case study 1)

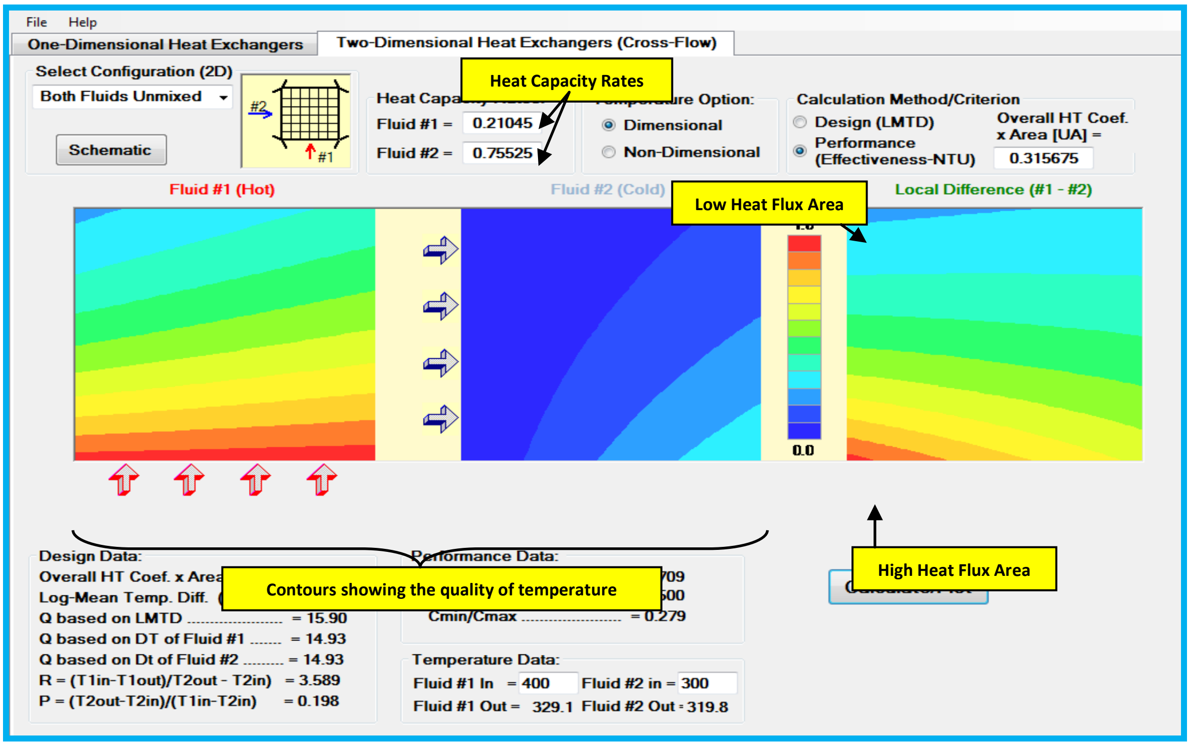

Fig - 4: Software Result for Case 1 [HX Combine]

5.2 CASE STUDY 2

Problem statement

Hot air for a large-scale drying operation is to be produced by routing the air over a tube bank (unmixed), while products of combustion are routed through the tubes. The surface area of the cross flow heat exchanger is A = 25 m², and for the proposed operating conditions, the manufacturer specifies an overall heat transfer coefficient of U = 35 W/m²·K. The air and the combustion gases may each be assumed to have a specific heat of c_p = 1040 J/Kg·K. Consider conditions for which combustion gases flowing at 1 Kg/s enter the heat exchanger at 800 K, while air at 5 Kg/s has an inlet temperature of 300 K. What are the air and gas outlet temperatures?

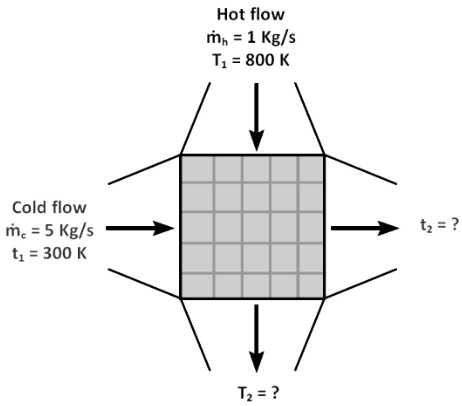

Fig - 5: Case 2 Statement

Table - 2: Data for Case study 2

Hot fluid	Cold Fluid	Common Parameters
T_1 = 800 K $\dot{m}_h$ = 1 Kg/s c_{ph} = 1040 J/Kg·K	t_1 = 300 K $\dot{m}_C$ = 5 Kg/s c_{pc} = 1040 J/Kg·K	U = 35 W/m²·K A = 25 m² q = ? T_2 = ? t_2 = ?

Design Calculation

Heat capacity rates:

$\dot{m}_C \cdot c_{pc}$ = 5 X 1040 = 5200 W/K (C_{max})
$\dot{m}_h \cdot c_{ph}$ = 1 X 1040 = 1040 W/K (C_{min})
For NTU determination:

C_{min}/C_{max} = 1040/5200=0.2
NTU =UA/C_{min}

NTU = (35 X 25)/1040 =0.841

Heat transfer rate:

q_{max} = C_{min}·($T_1 - t_1$)

q_{max} = 1040 X (800 – 300) = 520 KW

From the Effectiveness of a single pass, cross-flow heat exchanger with both fluids unmixed graph ε ≈ 0.57

q = ε X C_{min} X (T_1-t_1)

q = 0.57 X 1040 X (800-300) = 296.4 KW

For t_2 determination:

q = ($\dot{m}_C \cdot c_{pc}$) · (Δt) = ($\dot{m}_C \cdot c_{pc}$) · (t_2-t_1)

296400 = (5200) · (t_2 – 300)

t_2 = 357 K

For T_2 determination:

q = ($\dot{m}_h \cdot c_{ph}$) · (ΔT) = ($\dot{m}_h \cdot c_{ph}$) · (T_1-T_2)

296400 = (1040)·(800 – T_2)

T_2 = 515K

Result

q = 296.4 KW

t_2 = 357 K

T_2 = 515K

Results from software (Case study 2)

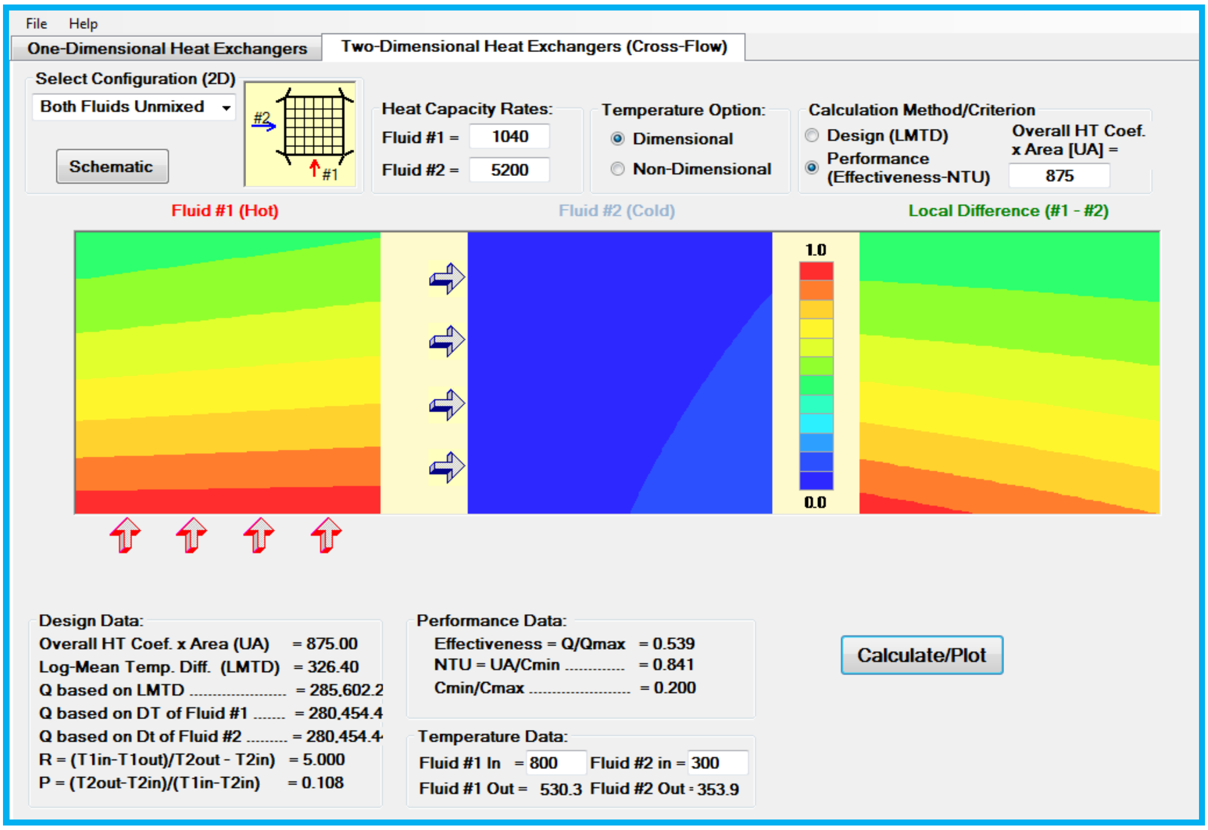

Fig - 6: Software Result for Case 2 [HX Combine]

6. RESULT

Table - 2: Comparison of results

Case Studies	Parameters	Design Calculation Result	Software Result
1	q (KW)	14.73	15.90
	A (m^2)	1.58	1.6
	t_2 (K)	319.51	319.8
	ε	0.7	0.71
2	q (KW)	296.40	285.60
	T_2 (K)	515	530.3
	t_2 (K)	357	353.9
	ε	0.57	0.54

It has been seen that the software results are almost same as that of the manually calculated results. On comparing software results with that of design calculation results it is obvious that the errors in software method is negligible and the software method can be used to design a radiator with considerable accuracy.

7. DISCUSSIONS

Thus this work has made a study and analysis of the thermal behavior of the automobile radiators using the LMTD and ε – NTU methods of designing radiators for various parameters of mass flow rates of coolant and air with its specific geometrical parameters. The performance enhancement of automobile radiators is found to be accomplished mainly by altering the convective heat transfer coefficient. The presence of case studies and comparing their results with the software generated results has proved an easier way of designing radiators which saves the time of the designer. In addition the case studies reveal that ε – NTU method is the most reliable method of designing radiators which are of cross flow type heat exchangers.

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