Computational Analysis of a Relationship between Fan Blade Diameter and Depth of Radiator.

I.A. Lateef, M.Eng.[1]; B.A. Hassan, M.Ed.[1]; and A.E.A. Kareem, M.Sc.[2]

[1]Department of Mechanical Engineering,
[2]Department of Computer Science, Osun State College of Technology,
PMB 1011, Esa-Oke, Nigeria.

E-mail: baale_i@yahoo.com

ABSTRACT

Due to the enormous heat generated in the internal combustion engine of a motor vehicle, a cooling system must be included. In any cooling system of a motor vehicle, an increase in fan blade size leads to an increase in depth of radiator and vice versa. This paper examines the effect of fan blade diameter on the depth of radiator. Fortran computer code was developed for computation of fan blade diameter corresponding to the depth of the radiator. Aided by the developed software, the relationship between fan blade diameter and depth of radiator was investigated. Results obtained for case studies examined by varying the volumetric coefficient of compactness of a radiator, showed that depth of radiator increases with fan blade diameter. The numerical results were processed with the Microsoft Excel® package, which yield a relationship of the form, $D_{rad} = a(D_{bl})^{t}$, where (a) is a real characteristic value of a particular problem.

(Keywords: cooling water, fan blade diameter, depth of radiator, volumetric coefficient of compactness, radiator, motor vehicle cooling systems)

INTRODUCTION

Heat is a form of energy that has wide applications in engineering and technology. Motor vehicle engines are one of the more significant areas in which the application of heat is important. Globally, motor vehicle engines are mainly internal combustion engines which exploit petroleum products such as gasoline or diesel fuel (Abdrahim et al., 2003 and Salami, 2004). It is well established (Abdrahim et al., 2003) that about 3 million tons for diesel and 5 million tons of gasoline are consumed annually in Nigeria. The combustion process of petroleum products generates large amounts of heat that requires proper regulation for automobile internal combustion engine efficiency. It is estimated that out of the heat generated by internal combustion engines, thirty five percent (35%) passes through the wall of cylinder (Banga and Singh, 1987). This is rejected to the cooling system.

The cooling system is one of the major motor vehicle engine systems that helps ensure the temperature of the engine is kept within the limits imposed for safety and efficiency (Khovakh et al., 1977). The cooling agent customarily employed is air or liquid (thus they are air or liquid (water) cooling systems). For effective control of heat in a water cooling system, a “Heat Exchanger” is employed. It is a device that transfers heat from a region of higher temperature to lower temperature through fluid separated by a solid (Alamu et al., 2003; Banga and Singh, 1987; and Rogers and Mayhew, 1992). It’s labeled various names depending on the particular purpose it serves, thus the name boiler, evaporator, condenser, or radiator are often employed. Among the factors that determine the efficiency of water-cooling system is the fan blade diameter and depth of the radiator. The fan contains shrouds and blades, which drawn in air through the radiator thereby reducing the temperature of the water (Bent and Stephens, 1974 and Dolan, 1996). The fan increases air flow allowing the use of a smaller radiator, which can dissipate the required amount of heat (Lateef et al., 2004). The radiator on the other hand, is a vessel that receives and stores heated water from the engine and exposes it to the fan. The matrix of the radiator may be either tube-and-fin type (Figure 1) or film (cellular) type.

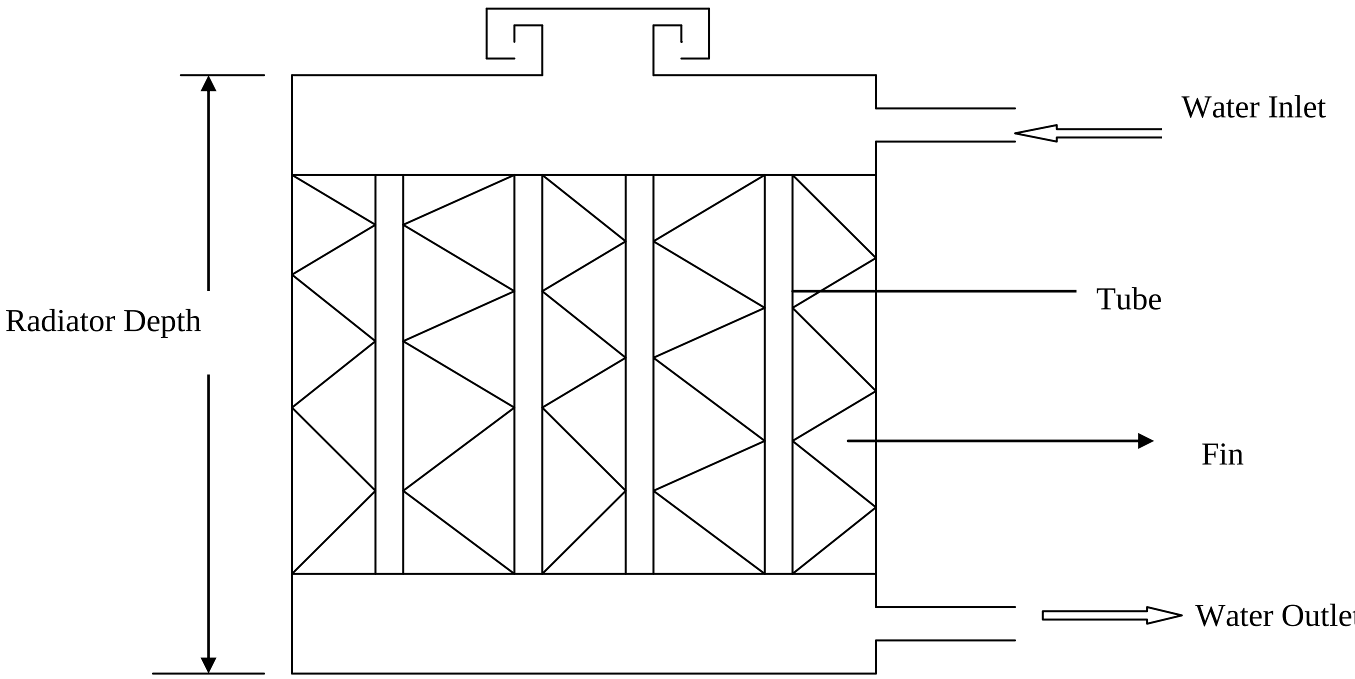

Figure1: Tube and Fin Radiator.

According to Abdrahim et al. (2003), Nigeria is now a dumping ground for used vehicles commonly called 'TOKUNBO' due to the poor economy and dejected conditions of auto-assembly plants in the country. It is established that Tokunbo vehicles are associated with several problems, most especially overheating and replacement of worn out parts. Considering the climatic conditions, there is a need to change radiators to suit the Nigeria environment. This is usually done without any consideration for fan blade diameters to match radiator dimensions, such as depth and heat dissipation surface area, therefore, leading to overheating of such an engine. The total dimensions of a radiator exposed to the fan determine the amount of air stream drawn in which also determines the quantities of heat removed from hot circulating water.

From the foregoing, the interaction between the radiator dimensions (depth) (Figure 1), heat dissipation area, and fan blade diameter gives the efficiency of the cooling system, hence the need for establishing the degree of their dependence. This will be a useful yardstick in generating the necessary information which could aid an informed choice of both radiators and fan blades.

This relationship is determined in this work by integrating general design equations for fan blade diameters into the volumetric coefficient of compactness (Khovakh et al., 1977). The resulting expression was developed into Fortran computer codes to generate precision values for fan blade diameter corresponding to series of depth of radiator values.

MATERIALS AND METHODS

The design equation for fan blade diameter is given (Khovakh et al., 1977) as:

$$D_{bl} = 2\sqrt{\frac{A_{frad}}{\pi}} ....(1)$$

where,

D_{bl} = Fan blade diameter (m)

A_{frad} = Face area of radiator (m^2)

The volume of radiator has been expressed (Champion and Arnold, 1970) as:

$$V_r = A_{frad} \cdot D_{rad} \text{.......}(2)$$

where,

$V_r =$ Volume of radiator (m^3)

$D_{rad} =$ Depth of radiator (m)

The general equation for volumetric coefficient of compactness of a radiator is given (Khovakh et al., 1977) as:

$$V_{rad} = \frac{A_{rad}}{V_r} \text{.......}(3)$$

where,

$V_{rad} =$ Volumetric coefficient of compactness (m^-)

$A_{rad} =$ Total heat dissipation area (m^2)

The relationship between the heat dissipation area of radiator and fan blade diameter is expressed (Lateef, 2004) as:

$$A_{hrad} = a\left(D_{bl}\right)^2 + b\,D_{bl} + c \text{.......}(4)$$

where, a, b, and c are real values characteristic of a particular cooling system.

From Equation (1):

$$A_{frad} = \frac{\pi\left(D_{bl}\right)^2}{4} \text{.......}(5)$$

From Equation (3):

$$A_{hrad} = V_{rad} \cdot V_r \text{.......}(6)$$

Combining Equation (2) and (6):

$$A_{hrad} = V_{frad} \cdot A_{frad} \cdot D_{rad} \text{.......}(7)$$

Equation (7) can be written as:

$$D_{rad} = \frac{A_{hrad}}{V_{rad} A_{frad}} \text{.......}(8)$$

Substituting Equation (4) into Equation (8):

$$D_{rad} = \frac{a\left(D_{bl}\right)^2 + b\,D_{bl} + c}{V_{rad} \cdot A_{frad}} \text{.......}(9)$$

using Equations (5) and (9):

$$D_{rad} = \frac{4(a\left(D_{bl}\right)^2 + b\,D_{bl} + c)}{V_{rad} \cdot \pi \cdot \left(D_{bl}\right)^2} \text{.......}(10)$$

The value of depth of radiator D_{rad}, Fan blade diameter D_{bl} and columetric coefficient of compactness V_{rad} are all features of design condition for determining the efficiency of water cooling system of a motor vehicle.

Therefore, if volumetric coefficient of compactness V_{rad} is held constant, the effect of the fan blade diameter on the depth of the radiator can be deduced from Equation (10). Computer simulation of Equation (10) was carried out. The program developed in Fortran was structured in interactive data input form. The software determines the relationship between the depth of the radiator and fan blade diameter of a cooling system of a motor vehicle engine. Data generated through the program was then processed with the Microsoft Excel® package to obtain mathematical expressions which describe the relationships between fan blade diameters and depths of radiators.

Case Study: A typical case study (A) with the following parameter was investigated, $V_{rad} = 900$ (m^-), π=22/7, a = 70.714, b = 0.0001, and D_{bl}=0.225 (m). Keeping all other parameters constant, the fan blade diameter varied from 0.225 (m) to 0.65 (m) resulting in different values of depth of radiator. Also, for B, C, D, and E cases, we used increments in volumetric coefficient of compactness at a rate of 10 (m^-) and variation of fan blade diameter between 0.25 to 0.65 (m) to generate different values for Depth of radiator.

RESULTS AND DISCUSSIONS

Tables 1-6 present the results obtained from the depth of radiator increases with increases in fan blade diameter. However, increases in volumetric coefficient of compactness at constant fan blade diameter leads to a decrease in the depth of radiator.

Table1: Program Output for Fan Blade Diameter Variation with Depth of Radiator at Volumetric Coefficient of Compactness = 900 (m^-).

S/N	BLADE DIAMETER (m)	DEPTH OF RADIATOR (m)
1	0.225	2.5316
2	0.250	3.8584
3	0.275	5.6491
4	0.300	8.0008
5	0.325	11.0201
6	0.350	14.8226
7	0.375	19.5333
8	0.400	25.2867
9	0.425	32.2261
10	0.450	40.5043
11	0.475	50.2835
12	0.500	61.7350
13	0.525	75.0392
14	0.550	90.3861
15	0.575	107.9748
16	0.600	128.0136
17	0.625	150.7200

Table 2: Program Output for Fan Blade Diameter Variation with Depth of Radiator at Volumetric Coefficient of Compactness = 910 (m^-)

S/N	BLADE DIAMETER (m)	DEPTH OF RADIATOR (m)
1	0.225	2.5037
2	0.250	3.8160
3	0.275	5.5870
4	0.300	7.9129
5	0.325	10.8990
6	0.350	14.6597
7	0.375	19.3187
8	0.400	25.0088
9	0.425	31.8719
10	0.450	40.0592
11	0.475	49.7310
12	0.500	61.0566
13	0.525	74.2146
14	0.550	89.3929
15	0.575	106.7883
16	0.600	126.6068
17	0.625	149.0638

Accordingly, the data of the output of the computer program (Tables 1-6) were further processed with Excel® package to develop a mathematical relationship between the depth of radiator and fan blade diameter in a water cooling engine.

Table 3: Program Output for Fan Blade Diameter Variation with Depth of Radiator at Volumetric Coefficient of Compactness = 920 (m^-).

S/N	BLADE DIAMETER (m)	DEPTH OF RADIATOR (m)
1	0.225	2.4765
2	0.250	3.7746
3	0.275	5.5263
4	0.300	7.8269
5	0.325	10.7805
6	0.350	14.5003
7	0.375	19.1087
8	0.400	24.7369
9	0.425	31.5255
10	0.450	39.6238
11	0.475	49.1904
12	0.500	60.3929
13	0.525	73.4079
14	0.550	88.4212
15	0.575	105.6275
16	0.600	125.2306
17	0.625	147.4435

Table 4: Program Output for Fan Blade Diameter Variation with Depth of Radiator at Volumetric Coefficient of Compactness = 930 (m^-).

S/N	BLADE DIAMETER (m)	DEPTH OF RADIATOR (m)
1	0.225	2.4498
2	0.250	3.7340
3	0.275	5.4669
4	0.300	7.7428
5	0.325	10.6647
6	0.350	14.3444
7	0.375	18.9032
8	0.400	24.4710
9	0.425	31.1865
10	0.450	39.1977
11	0.475	48.6615
12	0.500	59.7435
13	0.525	72.6186
14	0.550	87.4705
15	0.575	104.4917
16	0.600	123.8841
17	0.625	145.8581

Table 5: Program Output for Fan Blade Diameter Variation with Depth of Radiator at Volumetric Coefficient of Compactness = 940 (m⁻).

S/N	BLADE DIAMETER (m)	DEPTH OF RADIATOR (m)
1	0.225	2.4238
2	0.250	3.6942
3	0.275	5.4087
4	0.300	7.6604
5	0.325	10.5511
6	0.350	14.1918
7	0.375	18.7021
8	0.400	24.2106
9	0.425	30.8547
10	0.450	38.7807
11	0.475	48.1438
12	0.500	59.1079
13	0.525	71.8461
14	0.550	86.5340
15	0.575	103.3801
16	0.600	122.5662
17	0.625	144.3064

Table 6: Program Output for Fan Blade Diameter Variation with Depth of Radiator at Volumetric Coefficient of Compactness = 950 (m⁻).

S/N	BLADE DIAMETER (m)	DEPTH OF RADIATOR (m)
1	0.225	2.3983
2	0.250	3.6553
3	0.275	5.3518
4	0.300	7.5797
5	0.325	10.4401
6	0.350	14.0424
7	0.375	18.5053
8	0.400	23.9558
9	0.425	30.5299
10	0.450	38.3725
11	0.475	47.6370
12	0.500	58.4858
13	0.525	71.0900
14	0.550	85.6290
15	0.575	102.2919
16	0.600	121.2760
17	0.625	142.7874

As evident from Figures 2 and 3, the case considered (A-F) gave quantitative expression irrespective order as presented below:

$$D_{RAD} = 0.6926\left(D_{bl}\right)^2 - 3.7559\ D_{bl} + 9.7631$$

$$D_{RAD} = 0.685\left(D_{bl}\right)^2 - 3.7145\ D_{bl} + 9.6546$$

$$D_{RAD} = 0.66775\left(D_{bl}\right)^2 - 3.6741\ D_{bl} + 9.5496$$

$$D_{RAD} = 0.6702\left(D_{bl}\right)^2 - 3.6349\ D_{bl} + 9.4479$$

$$D_{RAD} = 0.6631\left(D_{bl}\right)^2 - 3.596\ D_{bl} + 9.3464$$

$$D_{RAD} = 0.6562\left(D_{bl}\right)^2 - 3.5589\ D_{bl} + 9.2498$$

With each having R^2 value of 0.9972. Generally, these relationship are non–linear (quadratic) and of form: $D_{rad} = a\left(D_{bl}\right)^2 - b\,D_{bl} + c$ where a, b, and c are real characteristic values of the particular problem of cooling system of automobiles.

It can thus be deduced that larger depth of radiator requires a corresponding larger fan blade diameter in agreement with a non-linear relationships that boost cooling efficiency of automobile engines.

The correlations above are for the specific cases considered. An attempt to obtain a single correlation to generalize the results for the relationship between depth of radiator and fan blade diameter using line of best fit (Figure 4) generated an approximated power function: $D_{rad} = 966.29\left(D_{bl}\right)^4$, with R^2 value equal to unity (1).

CONCLUSION

This paper discusses the relationship between the fan blade diameter and the depth of the radiator for an effective cooling system of motor vehicle engines. A computer program was developed to evaluate the relationship and conclusion is made. The results confirm that increase in the fan blade diameter leads to increase in depth of radiator.

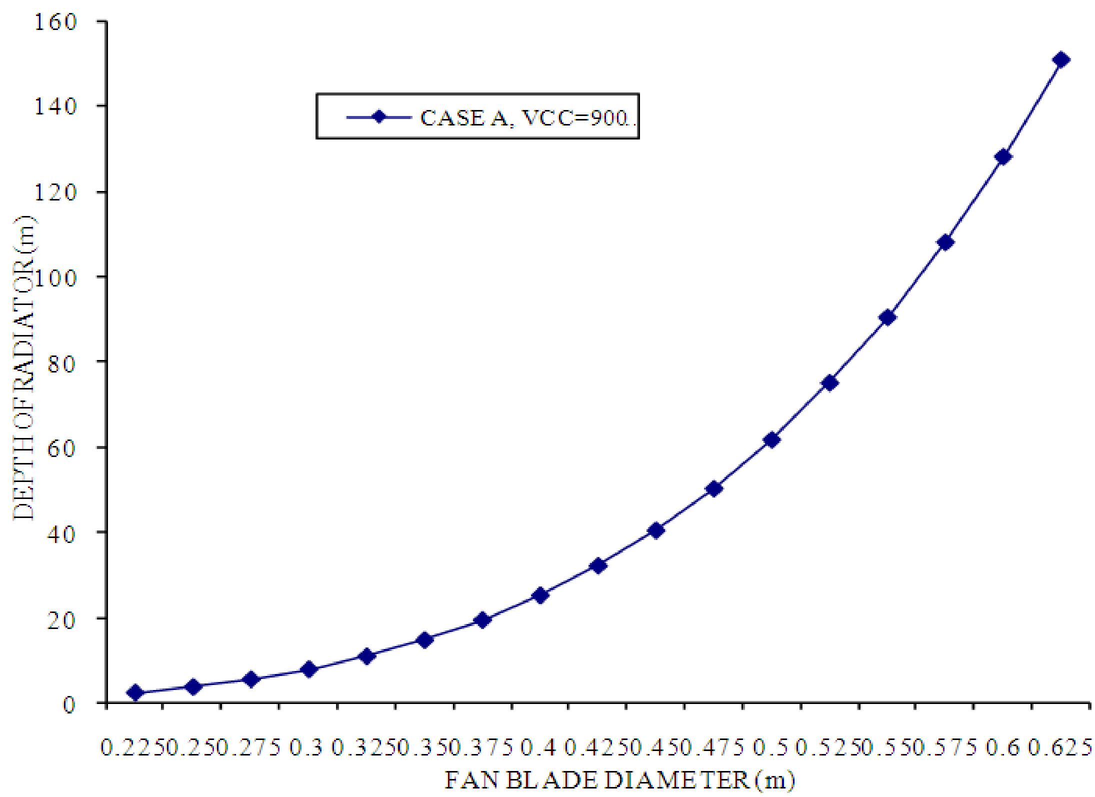

Figure 2: Fan Blade Diameter Variation with Depth of Radiator at VCC=900 (m-).

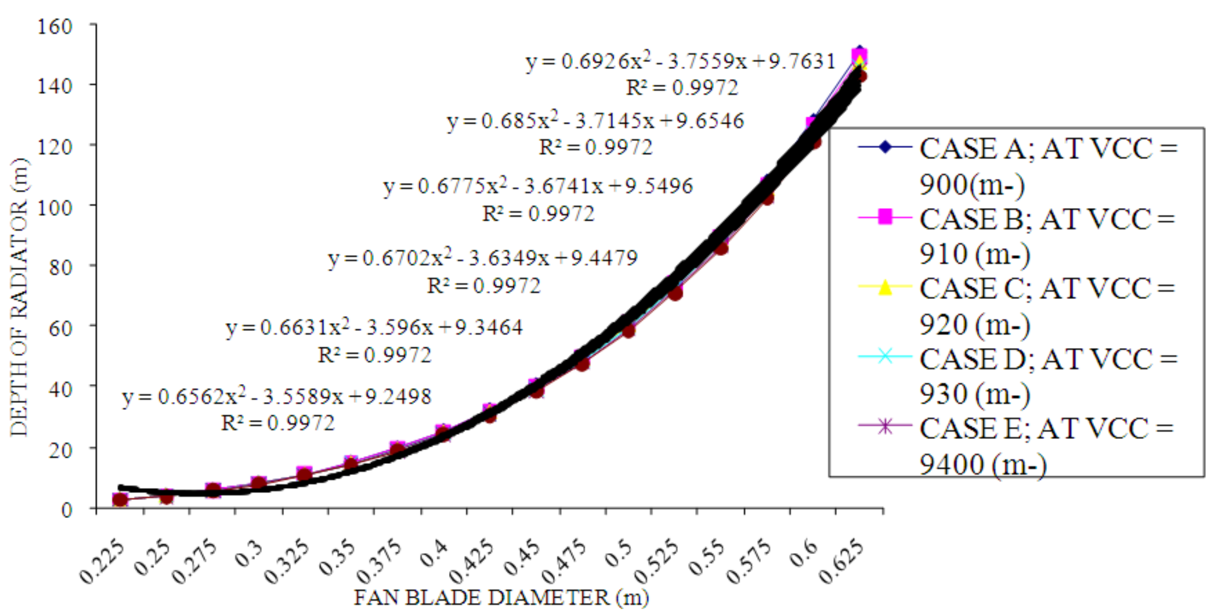

Figure 3: Relationship between Fan Blade Diameter and Depth of Radiator at Varying VCC.

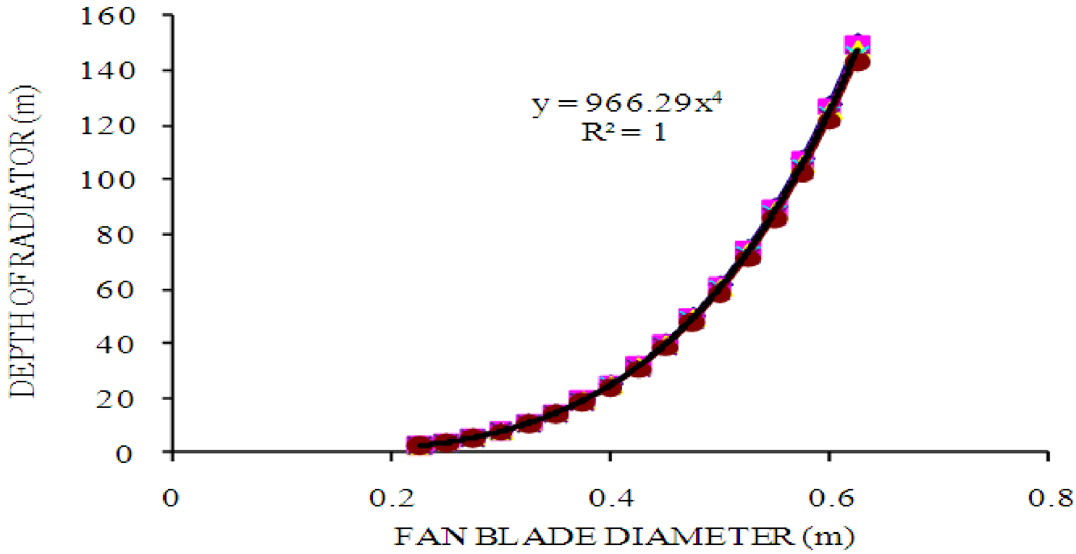

Figure 4: Variation of Fan Blade Diameter with Depth of Radiator at Different VCC.

Further analysis showed that fan blade diameter increases non-linearly with depth of radiator, and conclusively, for a perfect mathematical relationship and also for part replacement between fan blade diameter and depth of radiator with respect to volumetric coefficient of compactness, a power equation resulted:

$$D_{rad} = a\left(D_{bl}\right)^4$$

with (a) being a real value characteristic dependent of specific volumetric coefficient of compactness.

REFERENCES

1. Abdrahim, A.T., Usman, M.L., and Fagbile, R.O. 2003. "Atmospheric Pollution: Contribution from Automobile in a Nigeria City, Ibadan", *Journal of Life and Environmental Science*. 5(1):299-307.

2. Abdrahim, A.T., Usman, M.L., and Olalere, R.K. 2003. "A Review of Automobile Emission Control Measures in Nigeria". *Journal of Life and Environmental Science*. 5(1):273-281.

3. Alamu, O.J., Akintaro, A.O., and Adigun O. J. 2003. Effect of Regional Temperature Variation on Optimum Cooling Water Condenser". *Journal of Science and Technology Research*. 2(4):65-70.

4. Alamu, O.J. 2003. "Determination of Optimum Cooling Water Flow Rate in Condenser". *Ann. Engin. Anal*. 2(1):19-24.

5. Banga, T.R. and Singh, N. 1987. *A Textbook on Automobile Engineering. 2nd Edition*. Khanna Publishers: Delhi, India. 473 - 480.

6. Bent, R.W. and Stephens, D.L. 1974. *Motor Vehicle Technology, Part 1. 5th Edition*. Pitman Education Ltd.: London, UK. 50 – 56.

7. Champion, R.C. and Arnold, E.C. 1970. *Motor Vehicle Calculations and Science. 3rd Edition.* Edward Arnold Publishers, Ltd.: London, UK. 147.

8. Dolan, J.A. 1996. *Motor Vehicle Technology and Practical Work. Part 1 & 2. 1st Edition.* Heinemann Education Book: London, UK. 486 - 497.

9. Khovakh, M. et al. 1977. *Motor Vehicle Engines*. Mir Publishers: Moscow, USSR. 561 -575.

10. Lateef, I. A., Akintaro, A. O., Alamu, K. O. and Alamu, O. J. 2004. "Effect of Fan Blade Diameter on Heat Dissipation Area of a Radiator''. *Journal of Science and Technology Research*. No. JSTR-2004-056.

11. Rogers, G. and Mayhew, Y. 1992. *Engineering Thermodynamics Work and Heat Transfer. 4th Edition.* Pearson Education, Ltd. Singapore. 620.

12. Salam, K.A. 1996. *Auto-Technology Fundamentals. Series II*. Lagos Inland Printing: Lagos, Nigeria.

13. Kareem, A.E.A. 2008. F*undamental Concepts in Computer Programming*. Divine Publishers: Esa-Oke, Nigeria.

ABOUT THE AUTHORS

I.A Lateef, is a member of the Nigeria Institute of Mechanical Engineer (nimechE). He holds a B.Tech. and an M.Sc. in automobile technology from the Federal University of Technology, Minna, Nigeria and the University of Ado-Ekiti, Nigeria, respectively. His research areas are in automotive engineering, thermodynamics, information technology, and material science.

B.A. Hassan, holds a B.Tech. and an M.Ed. in metal technology and mechanical technology from the Federal University of Technology, Minna and the University of Benin, Nigeria, respectively. He is member of Nigeria Institute of Mechanical Engineer (nimechE). His research interests lie in thermodynamics, information technology, and material science.

A.E.A. Kareem is a Chartered member of Computer Professionals (Registration Council) of Nigeria. He holds a B.Tech. and an M.Sc. in computer science from the Federal University of Technology, Akure, Nigeria and the University of Ibadan, Nigeria, respectively. He is a member of the Nigeria Computer Society. He is an Associate Member of Nigerian Institute of Management (Chartered). His research interests are in software engineering, computer communication and networks and management of ICT infrastructures.

SUGGESTED CITATION

Lateef, I.A., B.A. Hassan, and A.E.A. Kareem 2010. "Computational Analysis of a Relationship between Fan Blade Diameter and Depth of Radiator". *Pacific Journal of Science and Technology*. 11(2):83-90.

Pacific Journal of Science and Technology