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Development and Testing of a Heat Dissipation System Using Fins for a Motorcycle Exhaust Pipe

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Abstract: The paper developed and investigate the use of fins as heat exchanger in dissipation of heat that arise from motorcycle exhaust pipe which can result in variety of degree of burns, affecting both users and passengers when in accidental contact with it. In this research work, copper pipe and aluminum fins were used because the heat transfer rate needs to be improved. The fabrication of the fins array was carried out with the use of 1mm aluminum material and 4mm copper pipe the base plate, the fins array are very potable and may be unfastened used on other exhaust pipes, since the fins are assembled with bolts and nuts. The analysis shows that the rate of heat transfer from the exhaust pipe (without fins) is1078W, while the heat transfer from the fins array was 2692.3W; which shows an increase in exhaust pipe heat transfer by factor of 2.5. Therefore, the risk of contacting serious burn when in accidental contact with the exhaust pipe has been reduced. It is hereby recommended that, the Semi rectangular fins profile can also be used for further research work because they are also effective, and the Copper fin may be considered for further work due to excellent thermal conductivity of the material.

Keywords: *Fins, Heat Transfer, Fins Calculations, Fins Fabrication, Testing*

INTRODUCTION

Mate and Kumbbbar (2017), stated that motorcycle use internal combustion engines, which have vast quantity of energy loss in the form of heat. The hot gases from the combustion chamber pass through the motorcycle exhaust pipe. The exhaust pipe also known as muffler is designed to remove burned gas from the internal combustion engine. These burned gases and fumes are produced as the result of combustion, and these by-products must be expelled from the engine combustion chamber (Suvro, 2022) . The temperature of these by product are high and dangerous to human skin.. Researchers (Loannis *et al*, 2005; Lai *et al*, 2002; Matzavakis *et al*, 2005; Jeff, 2011) have carried out researches on dangers and fatality caused by motorcycles exhaust pipe. It was noted that motorcycles exhaust pipes gives huge amount of heat causing severe burns to riders and populace on accidental contact. Therefore, there is need to subdue this dangerous phenomenon. Therefore, this research aimed to combat this phenominom.

Lai *et al,* (2002). carried out a research work on skin burns caused by motor cycles. The research was applied in seventy eight people and was documented. The results shown with bachelors having 75.7%, people less than 25 years have 70.5% and 69.3% been accredited to women who wear miniskirts. Observations made on exhaust pipes and its surroundings when in motion, shows that the degree of hotness are between the range of 170–250 and 40–60^{0}C.As a means of preventing these injuries, it was noted that a well designed external shield, having a sufficient separation from the exhaust pipe should be attached. This can be in form of fins or extended surface. Thereffore, this brought the concept of this preent research work. Other rsearchers (Dattatray et al, 2013; Obodeh and Ogbor. 2009; Kar et al, 2003;, Zidat, 2003) have worked on design and modification of the exhaust system and have proposed measures for reduction of hot spots in the system.

Zidat *et al*, (2003), carried out a research work on basic heat transfer analysis to review and position the comparative impact of thermal mass, outer heat lagging with inner gas current on the manifold outlet temperature, using a simple heat balance in the Exhaust manifold. It was noted that a rise in wall thickness can enhance the mass and therefore the outer heat transfer (through the rise of the outer diameter) without the modification of the interior heat transfer. A rise within the inner diameter will reduce the interior heat transfer that can conjointly enhance the mass and so the outer heat transfer. Lastly the air space case will cut back the outer heat transfer, which can enhance the mass of the manifold. The effect of changes in internal heat transfer is more than ten times the effect of mass or external insulation changes during the first 15 seconds of a cold start.

In line with Lai *et al,* (2002), suggestion and unlike the work done by Zidat *et al*, (2003); this present work tends to enhance heat removal through the application of fins or extended surface on the motor cycle exhaust pipe. These extended surface or protrusions known as fins primarily raise the extent for the process of convention and therefore a speed in heat transfer through conventional. When heat transfer takes place by convection from both internal and external surfaces of a plate, generally, fins are used on the surface where the heat transfer coefficient is low.

Fins are extended surface protruding on a surface to increase the heat transfer rate between the surface and the surrounding fluid. It has wide range of engineering applications. They are used in air cooled internal combustion engines, refrigeration condenser tubes, electric transformers, reciprocating air compressors, semiconductor devices, and automobile radiator. The selection of fin solely depends on different parameters like; fin spacing, geometrical shape, base thickness, fin height, kind of material, surface finish. Researchers (Debdatta, 2002; Rambabu *et al*, (2014); Bako *et al,*(2015); Putti *et al,* (2016); and Bako *et al*, (2018)), used fins to improve the strength and heat dissipation rate of an automobile brake drum. While Bako *et al,* (2021a) and Bako *et al,* [(2021b), worked on improvement of strength and heat dissipation of a two stroke spark ignition engine block using fins.

Unlike the work done by Bako et al (2021a & 2021b), this work tends to improve the heat dissipation of the exhaust of a two stroke spark ignition engine in order to reduce the huge amount of heat causing severe burns to riders and populace during accidental contact with the exhaust pipe.

MATERİALS AND METHOD

In this research work, copper pipe and aluminium fins were used where the heat transfer rate needed to be improved upon. Fabrication of the fins array was carried out with the use of 1mm aluminium material and 4mm copper pipe as the base plate. The fin array is very portable and may be easily unfastened and tried on other exhaust pipes, as parts were joined solely by bolt and nut. Copper and Aluminium materials were chosen for the manufacturing of the heat removal system, due to low weight, low cost and corrosion resistance The makeup includes a fin array, a copper pipe coupled to the exhaust pipe by means of bolt and nut.

2.1 Design Calculations

2.1.1 Fins Equation

$$Q_{conv} = hA(T_s - T_\infty) \quad (1)$$

Where Q_{conv}= Convective heat transfer

$$q_x = q_{x+dx} + q_{conv} = q_x + \frac{dq_x}{dx}dx + hA(T_s - T_\infty) \quad (2)$$

where $q_x = -kA_c\frac{dt}{dx}$,

$$q_x + d_x = q_x + \frac{dq_x}{dx}dx$$

Therefore the general solution is;

$$\theta\ (x) = C_1e^{mx} + C_2e^{-mx} \quad (3)$$

The fin heat transfer rate is

$$q_f = -A_c\frac{dT}{dx}(x = 0) = \sqrt{hPkA_c}\tanh mL = M\tanh mL \quad (4)$$

The Convective heat transfer is:

$$T(x) = T_\infty + (T_s - T_\infty)\frac{Cosh[m(L-x)] + \frac{h}{mk}\sinh[m(L-x)]}{Cosh(mL) + \frac{h}{mk}sinhmL} \quad (5)$$

$$\theta = T - T_\infty, \quad m^2 = \frac{hP}{kA_c}$$

2.1,2 Tube Heat Transfer (without Fin)

From Newton's law of cooling

$$A_{no\ fin} = \pi D_1 L \quad (6)$$

Where D = Diameter of the cylindrical pipe , L = Length of the cylindrical pipe

$$\dot{Q}_{no\ fin} = hA_{nofin}(T_s - T_\infty) \quad (7)$$

2.1.3 Single Fin Heat Transfer

The single fin heat transfer is determined by Newton's law of cooling as;

$A_{fin} = 2\pi(r_2^2 - r_1^2) + 2\pi r_2 t$ (8)

Where

$\pi = \frac{22}{7}$, r_2 = bigger radius , r_1 = smaller radius, t = thickness

$\dot{Q}_{fin} = \eta_{fin} \times hA_{fin}(T_s - T_\infty)$ (9)

2.1.4 Unfinned Portion Heat Transfer

The unfinned portion heat transfer is determined by,

$A_{unfinned} = \pi D_1 S$ (10)

$\dot{Q}_{unfin} = hA_{unfin}(T_s - T_\infty)$ (11)

The totality of heat transfer and number of fins is determined by,

$\dot{Q}_{total} = n\,(\dot{Q}_{fin} + \dot{Q}_{un\,fin})$ (12)

2.1.5 Exhaust Pipe Heat Transfer Enhancement

The exhaust pipe heat transfer enhancement is determined by,

$\dot{Q}_{Increase} = \dot{Q}_{total} - \dot{Q}_{no\,fin}$ (13)

2.1.6 Cone Frustum Surface Area

The cone frustum surface area is given as,

$A_{nofin} = \pi(R + r)\sqrt{(R - r)^2 + h^2}$ (14)

Where 'h' is the height, "R" is the bigger radius "r" is the smaller radius

DESIGN PARAMETERS

3.1 Parameters Obtained from Bajaj Motorcycle

Diameter of bigger part of the exhaust pipe (frustum)	100mm
Diameter of smaller part of the exhaust pipe (frustum)	80mm
Length of bigger part of the exhaust pipe for the (frustum)	500mm
Bent exhaust cylindrical pipe (smaller) diameter	30mm
Length of bent exhaust cylindrical exhaust pipe	300mm
Exhaust pipe temperature	180˚C
Fin material thermal conductivity	186 W/m°C
Diameter of aluminum fin (outer)	120mm
Diameter of aluminium fin (inner)	38mm
Thickness of aluminuim fin	1mm
Diameter of copper pipe (outer)	38mm
Diameter of copper pipe (inner)	30mm
Thickness of copper pipe	4mm
Copper pipe length	140mm
Fin spacing (S)	7mm
Fin number	19
T_∞	25^0C
Coefficient of heat transfer	40W/m^2.˚C

3.2 Determination of Area of the Copper Pipe

Diameter of the copper pipe (outer)	38mm
Diameter of the copper pipe (inner)	30mm
Thickness of the copper pipe	4mm

From equation 3.8 area of the copper pipe is given as

$$A_{cop} = 2\pi(r_2^2 - r_1^2) + 2\pi r_2 t \quad (15)$$

3.3 Determination of Area of the Aluminium Fin

Diameter of circular aluminium fin (outer)	120mm
Diameter of circular aluminium fin (inner)	38mm
Thickness of circular aluminium fin	1mm

$$A_{fin} = 2\pi(r_2^2 - r_1^2) + 2\pi r_2 t \quad (16)$$

3.4 Determination of Area of the Bigger Exhaust Pipe (Frustum)

Length (height) of the bigger exhaust pipe (frustum)	500mm
Diameter of the bigger exhaust pipe (top)	100mm
Diameter of the bigger exhaust pipe (bottom)	80mm

From equation 3.14 area of the bigger exhaust pipe (frustum) is given as

$$A_{nofin} = \pi(R + r)\sqrt{(R - r)^2 + h^2} \quad (17)$$

3.5 Determination of Area of the Smaller Exhaust Pipe (Frustum)

Length of the smaller exhaust pipe (frustum)	10mm
Diameter of the smaller exhaust pipe (top)	80mm
Diameter of the smaller exhaust pipe (bottom)	30mm

$$A_{nofin} = \pi(R + r)\sqrt{(R - r)^2 + h^2} \quad (18)$$

3.6 Determination of Area of the Cylindrical Bend (Most injurious Part)

Length of the cylindrical pipe	300mm
Diameter of the cylindrical pipe	30mm

From equation 3.6 area of the cylindrical exhaust pipe is given as

$$A_{no\ fin} = \pi DL \quad (19)$$

Exhaust pipe total surface area = Bigger exhaust pipe area + Smaller exhaust pipe are + The cylindrical pipe area.

3.7 Determination of Heat Transfer from the Exhaust Pipe (without Fins)

From Newton's law of cooling is calculated as,

$$\dot{Q}_{no\ fin} = hA_{nofin}(T_s - T_\infty) \quad (20)$$

The Efficiency of the circular aluminum fins coupled to the neck of exhaust pipe is calculated as follows:

$$L = \frac{1}{2}(D_2 - D_1) \quad (21)$$

$$\eta_{fin} = L + \frac{1}{2}t\sqrt{\frac{h}{kt}} \quad (22)$$

3.8 Determination of Single Fin Heat Transfer Rate

$$A_{fin} = 2\pi(r_2^2 - r_1^2) + 2\pi r_2 t \quad (23)$$

Area of the circular copper pipe;

$A_{cop}= 2\pi(r_2^2 - r_1^2) + 2\pi r_2 t$ (24)

Total area for fin = area of aluminum circular fin + area of circular copper pipe.

But,

$\dot{Q}_{fin} = \eta_{fin} \times hA_{fin}(T_s - T_\infty)$ (25)

3.9 Determination of the Single Unfinned Heat Transfer

$A_{unfin} = \pi DS$ (26)

$Q_{unfin} = hA_{unfin} (T_s - T_\infty)$ (27)

19 numbers of fins were used due to the distance of the neck of the motorcycle exhaust pipe and the heat transfer totality is

$\dot{Q}_{total}= n (\dot{Q}_{fin} + \dot{Q}_{un\ fin})$ (28)

The exhaust pipe heat transfer enhancement is

$\dot{Q}_{increase} = \dot{Q}_{total} - \dot{Q}_{no\ fin}$ (29)

The overall effectiveness $=\frac{Qtotal}{Qunfin}$ (30)

The exhaust pipe heat transfer rate enhances by a factor of 2.5 due to fins addition.

3.10 Temperature Distribution

$$T(x) = T_\infty + (T_s - T_\infty)\frac{Cosh[m(L-x)] + \frac{h}{mk}\sinh[m(L-x)]}{Cosh(mL) + \frac{h}{mk}sinhmL} \quad (31)$$

When $x = 0$

$P = 2(w + t)$

$A_c = w \times t$

$$m^2 = \frac{hP}{kA_c}$$

3.11 Thermal Resistance

Ohm's law is acknowledged mathematically as

$$Current\ (I) = \frac{potentialdifference\ (V)}{electrical\ resistance\ (R)} \quad (32)$$

By similarity, heat flow equation (Fourier's equation) can be expressed as

$$Heat\ Flow\ Rate(\dot{Q}) = \frac{Temperaturedifference\ (dt)}{\frac{dx}{KA}} \quad (33)$$

V is similar to dt and R is similar to the quantity $(\frac{dx}{KA})$, that is known as thermal conduction resistance R_{th} ,$R_{th}= \frac{dx}{KA}$

FABRICATION

Copper and aluminum materials possess ease of fabrication (machining and welding) although that of aluminum is much easier compared to that of copper materials. It is important that it is made up of good hardness quality for machinability operations like drilling, welding and bolting operations. Although there is difficulty in welding aluminum material of smaller millimeter (mm) as it flecks after welding, but now it can be welded safely by special welding technique.

4.1 Method of Fabrication

The fabrication method involved the production of an array of fins and other operations like marking out operation, welding, drilling and bolting of the parts together. After the aluminum fins was marked out from the aluminum sheet, then guillotine shear cutter, chisel, scriber and hammer was used for the operation and the following dimension were cut out; the circular fin (into two semi-circle). The copper pipe was marked out and machined to the actual diameter and length (into two semi-circle). Aluminum fin seated on the copper pipe and both clamped to the neck part of the exhaust pipe (most injurious part) by means of bolt and nut. Fig.1 shows the fabricated fins and the experimental set-up for this experiment.

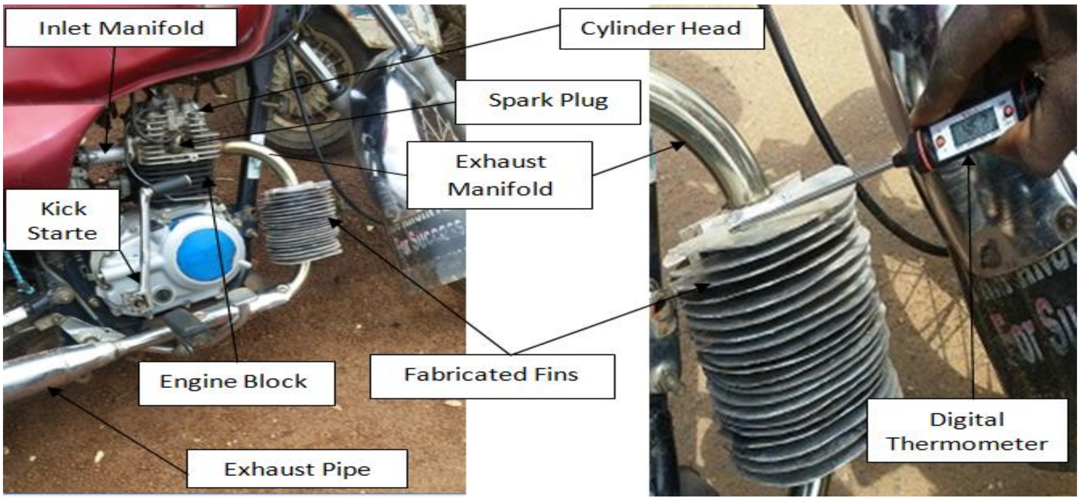


Fig. 1: Experimental Set-up and Testing

RESULTS AND DISCUSSION

The grouped fins that was developed on a Bajaj bike (boxer motorcycle) and Digital Thermometer was used: The temperature of the Bajaj motorcycle exhaust pipe was first taken before starting up the engine and it was 30^{0}C. The engine was started, and the temperature of the motorcycle exhaust pipe was obtained after 340sec. The temperature at the neck of the exhaust pipe was 118^{0}C (without fin). Then the copper pipe (frame) and aluminum fins array were coupled at the neck of the motorcycle exhaust pipe and the temperature was measured after 180sec,. The temperature of the aluminum fins was measured to be 31.4^{0}C, and that of the copper pipe (frame) was 49.9^{0}C, while the motorcycle exhaust pipe was 52.5^{0}C. With the attachment of the copper pipe and aluminum fin array, the motorcycle engine was allowed to run for the period of 340sec. then the temperature of the aluminum fin array measured 36.1^{0}C, the temperature of the copper pipe (frame) measured 70.1^{0}C and the temperature of the motorcycle exhaust pipe measured 74^{0}C.

All this was taken when the motorcycle was at idle i.e. Motorcycle did not take a trip from the testing point. As soon as the Motorcycle finally moved for 5minutes with no fins, the temperature of the motorcycle exhaust pipe neck (most injurious part) measured 125˚C and the motorcycle was allowed to move for 8minutes with no fins the temperature of the motorcycle exhaust pipe neck was 150^{0}C. When the copper pipe (frame) and the aluminum fins is attached to the motorcycle exhaust pipe neck for the duration of 5minutes movement, the temperature of the motorcycle exhaust pipe neck read 66^{0}C. And the motorcycle was allowed to take a trip for another 10minutes with the attachment, the temperature of the motorcycle exhaust pipe neck measured 48^{0}C. Better changes were observed when compared with the idle work of the motorcycle, because of fluid motion round the exhaust pipe. With additional number of fins the heat transfer rate would improve and the temperature obtained would far more reduce compared with the case of the motorcycle exhaust wrap by Jeff (2011). This suggested that the wrap of motorcycle exhaust pipe is a solution in reducing exhaust burns but will not put off all burns.

Copper and aluminum materials come to mind due to their high thermal conductivity rate for the fabrication of fins. On the other hand, the most excellent material is the one that give out the required intention at the least amount of cost. Therefore, the preference of materials for this work were governed by some factors like availability of material, melting point, corrosion resistance, cost and durability.

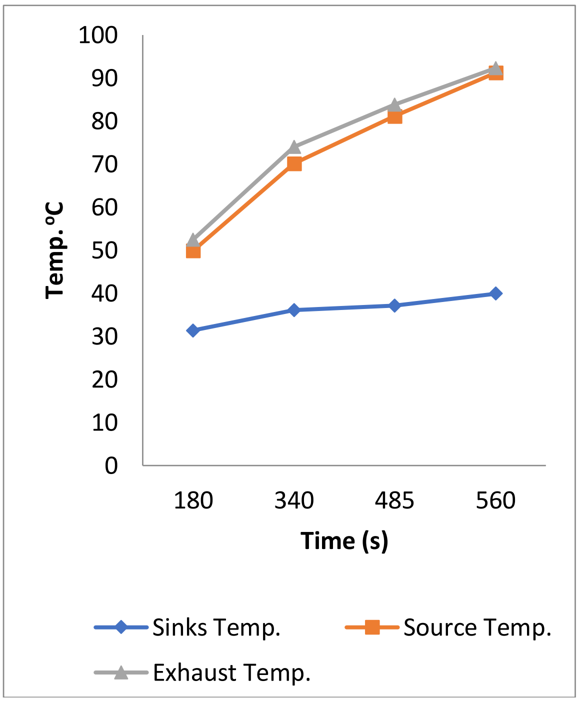
As a result of high thermal conductivity and good melting point of copper materials made it easier to be welded or coupled at the neck of exhaust pipe that can easily convey heat to the aluminum fins. As a result of this, copper pipe was used as the heat source at the neck of the exhaust pipe. The copper pipe has a smoother surface, two semicircle copper pipe with length 140mm, inner diameter of 30mm with thickness of 4mm were used as the heat source. While due to the good thermal conductivity; aluminum heat sink were used in the study. The aluminum heat sink temperature is between 25^{0}C to 30^{0}C. 19 aluminum heat sink fins with outer diameter 120mm, inner diameter 38mm and thickness of 1.0mm were used for this study.

Two heat sinks were used in the investigation. The initial temperature of the exhaust pipe was 30^{o}C, and the temperature at the neck of the exhaust pipe without fin was 118^{o}C after 340 sec. Table 1 and Figure 1 presents the results obtained after measuring the temperature of the exhaust pipe with fin after the maximum of 560 sec while the engine is operating at 4000rpm. The results obtained (Table 1) shows that the maximum temperature of the exhaust pipe is 92.3^{o}C at 560sec which is less than the temperature of the exhaust pipe without fin incorporation.

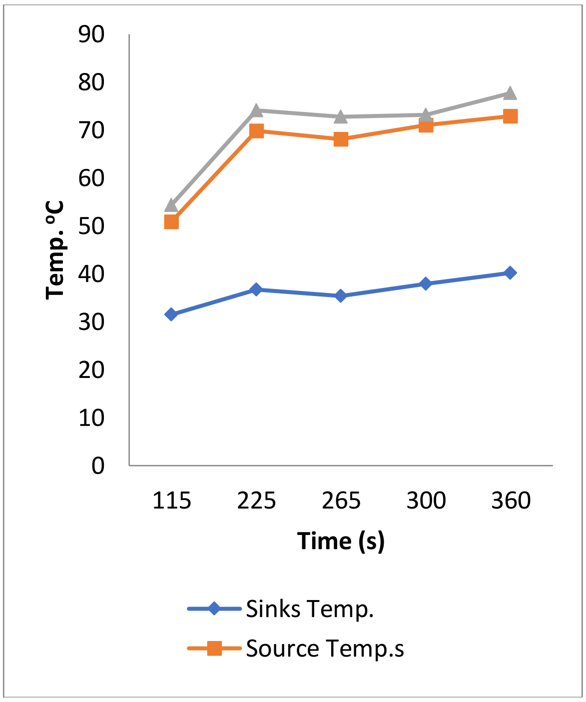
To ascertain the effectiveness of the new model of the exhaust pipe at different environment, the exhaust pipe was tested at two different locations. The results at the different locations are shown in Table 2 and Fig. 2 below. Even at different location, the temperature of the exhaust pipe with is far less than the exhaust pipe without fins. This shows that the modified design has improved heat dissipation than the exhaust pipe without fins. Table 3 and Figure 4 also how the rate at which heat is dissipated from the exhaust pipe with fins incorporation. The result shows that the temperature drops from180^{o}C to 25,3^{o}C in 1500 sec after the engine has been off. This shows the temperature difference within this period of time is 151,64^{o}C. This implied that the fins have improved the rate of heat dissipation of the exhaust pipe.

Table 1: Temperature Profile of Motorcycle Exhaust Pipe at Idle Mode with Fin

Speed (rpm)	Time (sec)	Alum Temp (T_1)^{0}C	Copper Temp (T_2) ^{0}C	Exhaust Temp (T_3 ^{0}C
2000	180	31.4	49.9	52.5
	340	36.1	70.1	74.0
	485	37.2	81.1	83.9
	560	39.9	91.2	92.3
4000	115	31.5	50.9	54.4
	225	36.7	69.8	74.1
	265	35.4	68.1	72.7
	300	37.9	71.0	73.1
6000	100	32.5	58.3	60.8
	130	36.2	68.1	71.9
	146	37.8	78.5	82.7
	170	39.2	80.5	87.3



(a)



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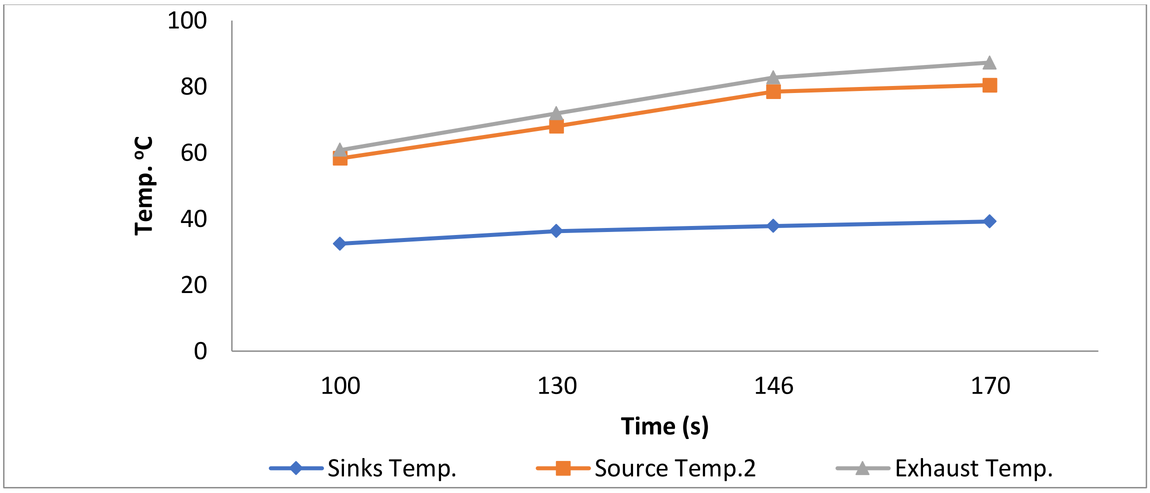

(c)

Fig. 2: (a) Temperature against Time for 2000rpm Speed (b) Temperature against Time for 4000rpm Speed (c) Temperature against Time for 6000rpm Speed.

Table 2: Temperature Profile of Motorcycle Exhaust Pipe at Running Mode with Fin
Observation of temperature of exhaust system at two different locations

Speed (rpm)	Time (sec)	Exhaust Temp (T_1)⁰C	Exhaust Temp (T_2)⁰C
2000	200	60	59
	300	65.1	66
	360	67	68
	500	70	69
	560	70	71
4000	160	58	57
	230	50	51
	290	42	43
	340	42	41
	380	41	42

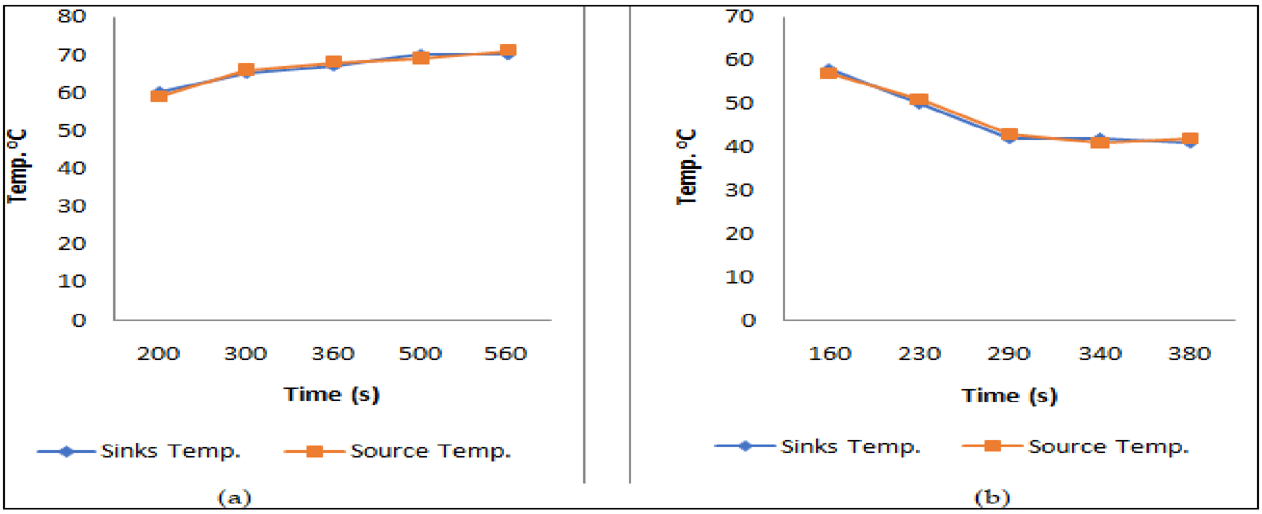

Fig. 3: (a) Temperature against Time for 2000rpm Speed (b) Temperature against Time for 4000rpm Speed

Table 3: Temperature Profile of Motorcycle Exhaust Pipe (after the engine is stopped)

Time (sec)	Temperature (T)^{0}C
Initial temp	180$^{0.}$C
50sec	153^{0}C
200sec	98^{0}C
400sec	60^{0}C
700sec	39^{0}C
1120sec	32^{0}C
1500sec	28.36^{0}C

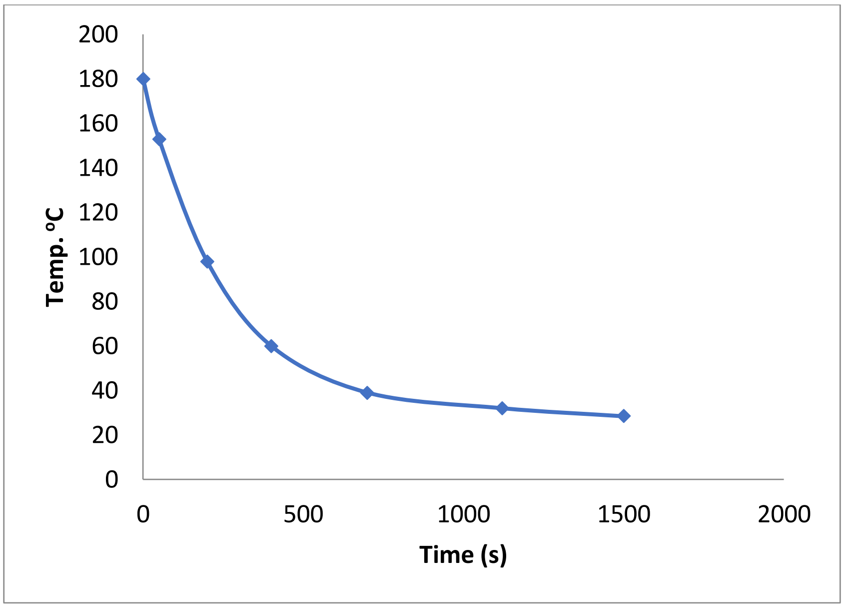

Fig. 4: Plot of temperature against time

CONCLUSIONS

The investigation on a heat removal system by using fin for motorcycle exhaust pipe, to get better heat transfer rate from Motorcycle exhaust pipe in order to put off burns on accidental contact with it, had been accomplished to a sensible degree, by designing a fin system that lower the temperature of motorcycle exhaust pipe. Special attention was given to factors that greatly affect the performance evaluation test of the fin, like the thermal contact resistance and optimum fin diameter, to ensure desired result. For the production of a fins array, to be coupled to the exhaust pipe, the most efficient and cheap option of material were taken into consideration the thermal conductivity, the weight, cost and resistance to corrosion. Conclusively, the analysis carried out to know the rate of heat transfer from the motorcycle exhaust pipe without fin was 1078W and when the exhaust pipe had a fins, the heat transfer rate was 2692.3W. With respect to this research, recommendations for further study include;

(i) Stronger aluminum alloy of 0.5mm may be use because it is advantageous when the fin is thin as possible.

(ii) Semi rectangular fins profile can also be used for further work because they are also effective

(iii) Copper fin may be considered for further work due to excellent thermal conductivity of copper

Abbreviation of Symbols

Q	Heat flow rate	A_c	Cross-sectional area
H	Coefficient of heat transfer	T_s	Temperature of the exhaust pipe
T_∞	Temperature of the fin	K	Thermal conductivity
D	Diameter of the circular fin	S	Spacing of fin
n	Number of fin	R	Big radius of fin
r	Small radius fin	P	Parameter of fin
t	Thickness of fin		

CONFLICT OF INTEREST

This research work has not been published or considered for publication elsewhere. There is no any conflict of interest.

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