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(Research Article)

Heat flux performance of a pin-finned ice heat sink

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Abstract

The research was aimed at enhancing the thermal performance of a modified engine block of the ICE of motorcycle to increase heat flow to the ambience.

The internal combustion engine is a self-propelled system capable of converting chemical energy to huge amount of heat and mechanical energy, therefore to regulate this enormorse value of energy, design and development of a thermally effective and efficient component is critical to prolong the engine life and assures smooth functionality.

The design of the internal combustion motorcycle engine heat sinks generally direct effort to increase heat flux to the ambience – this was carried out by augmenting the surface area and geometry of the experimental sample of an identified engine block (Errand 125-CT) motorcycle engine block (lower block). Three samples of the lower block were used to accomplish the experiments objectives. The horizontal projecting straight rectangular fin were ground inward normal to the vertical cylindrical wall through a perimeter of 35.2cm each for a number of the rectangular fins less the topmost and bottommost fins. The grinding was carried out for samples B and C through a depth of 1.5 and 3.0mm except for samples A which is the original (control) sample. Drilling machine was used to create holes of diameter 4.01mm in a vertical orientation on the horizontally projecting rectangular fins.

A number of 0, 60 and 120 pin fins were pushed/hammered vertically into the drilled holes to manipulate both surface the surface area and fin geometry.

The sample A, B and C were placed for ten minutes each in an electric klin till the pyrometer (IR thermometer) indicates a temperature of 100 °C. The top and bottom cylinder core were covered with the aid of a wooden slab of diameter 5.18cm before placing them in the axial air flow facility at the air speed of 0 ,10 and 20m/s in turn. A digital stop watch and pyrometer were used to note the time for the samples to cool from 80 to 30^{0}C in an axial air pumping machine at varied velocity field. Sample A, B and C has a total of 0 ,60 and 120 number pin fins respectively each sample has mass of approximately 1160.02 grammes. From observation sample C, took a period of 529.9, 663 and 2308 seconds to cool from 80 to 30^{0}C in a velocity field of 20, 10 and 0m/s respectively. Sample B, took a period of 558.0, 680 and 2363 seconds to cool from 80 to 300 C respectively. Sample A (zero pin fins) took a period of 586, 703 and 2439.2 seconds to cool from 80 to 30^0 C respectively at an air velocity of 20 ,10 and 0m/s respectively. Two parameters, including thermal effectiveness and efficiency were applied to evaluate the fin performance as a ratio of the original fin (control sample) the effectiveness of modified pin fin samples at 20m/s for sample A, B and C indicated 1.000, 1.0322 and 1.0610 for effectiveness; 1.000, 1.087 and 1.1576 for efficiency ratio in the same order. Therefore, an increased pin number and air velocity clearly improve the thermal performance of air-cooled engines.

Keywords: Heat Flux; Thermal Performance; Ice Heat Sink; Pin-finned; Pyrometer

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1. Introduction

Internal Combustion Engines (ICE) are generally heat engines or heat generating devices designed to convert heat/themed energy to mechanical work. Various mechanical systems are propelled on this device following a repeated cycle. Common application of such cycles are; the steam engines and petrol engines. Heat engines as they are referred to have the ability to develop a huge amount of energy values or calories obtained by the stiometric combustion of fossil fuel that translates to a high energy out put is tapped by deliberately designed mechanism: calculations and careful evaluation depicts as 0.017x45.0J of energy per cycle agreeing that for a petrol engine, the calorific value equal 45KJ per kilogramme of fuel(petrol); this is also approximately true for the same mass of diesel as viewed by (Linstrom, Peter 2021).

In sum a stiometric amount of petrol/gasoline mixed with air is drawn into the cylinder of the internal combustion engine and compressed; the ignition spark plug at a high electrical potential sparks up and initiate the combustion process of the mixture (petrol and air); due to the increase of energy of the mixture particles (combusted product) work is done by these particles on the wall of the containing cylinder including the piston; the piston travels out ward/down ward to impart a measure of mechanical energy or work effecting a value of torque on the crank. This cause the automotive system to be displaced from its original position thereby causing useful motion/work to be done, as described in Encyclopedia Brtanica (2012), Meriam Webstar Dictionary 2024.

Elucidating these process based on first and second laws of thermodynamics the calorie of energy generated by the combusted fuel is a constant and cannot be destroyed rather it is at a potential where it can only be converted from one form to another. Possible energy transformation may comprise sound, light, electrical, sound, mechanical among others. From the angle of the second law of thermodynamics which can be simply construed as follows: when heat flows from the hotter region of heat reserviour to the colder region all the heat energy on transfer process can not be 100% rejected at the relatively cold reserviour (heat sink) with out some part of the heat being converted to work. The major points here; heat reserviour and rejection of heat to the hear sink .The second law is establishing that work must be done for the process to happen drawing from Classius statement.

Considering the huge amount of heat generated at a relatively high rate in the heat engine and steady rejection to the heat sink, there is a rising need to regulate this havalenge of heat energy as it becomes clear that at this clime and rate the engine (ICE) component is at the risk of experiencing various stresses; such as mechanical and thermal stresses: at this level the chemical, material and atomic status of the material components may be compromised especially if design limits are exceeded.

1.1. Associated Challenges/Problems Common to Inter Combustion Engine (ICE)

One of the widest applications of the air-cooled Internal combustion Engine (ICE) is the motorcycle engine; the motorcycle engine has a relatively high adoption in the design of F1, candidate race cars like; Westfield Megabus, magnum MKK5 and campagna T-Rex mentioning a few among the robust lists. Back in Nigeria, the National Agency for Science and Engineering Infrastructure (NASENI) revealed a 100% indigenous fully built unit of motorcycle for commercialization (Zakariyya, 2020) looking at the huge economic benefit of the motorbike industry: for instance, in (2016), J.D. power predicted that an all-high revenue of motor bike vehicle in U.S. dollars of 90 billion is accruable globally. Therefore, it is imperative to identify issues attendant to the automotive system (motorbike engine) and direct measurable effort toward combating them. The common ICE issues are centred on heat exchange of an air cooled Internal Combustion Engine (ICE) and may prompt the following setbacks; preignition/premature ignition, Detonation/knocking of engine, warping and component failure including crank, shaft and con – rod, leakages of lubricating oil, destruction of gasket due to overheating, charge leakage and general drop in performance (effectiveness and efficiency) including mechanical efficiency all these draw – backs can be limped to overheating effects of the Internal Combustion Engine (ICF) and possibly inconsistent fuel stiometrc mixing(Daniel Hall (2007).

1.2. The Air-Cooled Heat Sink of an Internal Combustion Engine

The air-cooled heat sink of an Internal Combustion Engine (ICE) is generally heating exchangers: heat exchangers are devices applied in the interface between two fluid media comprising hot and cold fluid masses with the objective of heat transfer between this media; designed to allow heat flow from hot to cold media or vis – a—vis.

Heat exchangers used are either active or passive; however, classification of heat exchangers can be considered on the basis of fluid flow orientation in a broader view including parallel flow, counter flow and cross flow heat exchangers. The counter flow heat exchanger has been proved to be most effective in heat transfer process.

1.3. Types of Heat Exchangers

Devices that their functional ability are based on the exchange of heat energy between hot and cold fluid media can be identified according to types; they are shell and tube, plate and air – cooled heat exchanges or air-cooled fins. Of the types stated, the motorcycle engine adopts the air-cooled heat exchangers/air-cooled fin as a feature for energy exchange from the cylinder core to the relatively cold ambience the air-cooled rectangular fin are incorporated on the motorcycle engine to help regulate the temperature of the engine block; to limit thermal stress and safe guard the component from possible failure. Theodor et al (2007) “Fundamental of Heat and Mass Transfer” (6th ed.)

1.4. The Errand 125 CT Motorcycle Engine Block Model

The air cooled straight rectangular fin are typically used in the design of the motorcycle air cooled heat exchanger. On average note, some important design specification considered on the air cooled rectangular straight fin design of a typical motorcycle engine include: the alumnium alloy base conductor material as the heat reserviour, a pitch of about 10mm between two successive rectangular fins, a fin length of approximately 2.7 to 3.3cm; an aspect ratio averaging (30 to ratio 2.4mm) on a proximate note. These are some notable features common among a host of others.

Table 1 Data Observed from Experimental Engine Block

S/N	Features	Magnitude/cm	Description
1	Thickness	0.24	Constant for each sample
2	Pitch	1.00	Constant for each sample
3	Length or depth of grinding inward on each samples	1.0 ,1.5, 1.0, 2.5 and 3.0mm	Constant for each of sample A ,B ,C , D ,E and F through the horizontally projecting fins respectively.
4	Perimeter or length grinded on each sample	35.20	Constant for each of samples A,B.C,D,E and F across all horizontally projecting fins respectively
5	Core diameter	5.18	Constant for each sample
6	Material	Aluminum alloy (600 series)	Constant for each sample

1.5. Design Information of The Air Cooled Pinflnned Heat Sink of The Motorcycle Interal Combustion Engine (ICE)

The pitch specification of the straight constant area rectangular fin which logically translates to the distance of separation between two successive lines measured from the cente rs of the rectangular (inline) pin fins is 10mm and 6.1 to 11.9mm for straight rectangular fins and inline cylindrical pin fin as optismal spacing respectively (Yuncu & Amber 2024).

For an enhanced performance of pinfins space to diameter ratio of (1.0 approx.) was recommended to designers by (Wirtz et al, 1997). Such pin element, may be of the following shape; rectangular, annular parabolic, trapezoidal and cylindrical pin fins etc. the pin fin array may be of staggered or inline - fin orientation may be in stream wise or span wise arrangement.

The height to diameter ratio of pin fins are optimally recommended as (2.0) by Schlichting (1979) and (Menking et al, 2009).

1.6. The Modified Motorcycle Engine Block

The air-cooled motorcycle heat sink/engine block was modified for an enhanced heat dissipation power – This is thus meant to an further enhance the performance of the engine block for an augmented and improved thermal performance. The original (control) sample is the (ERRAND – 125 – CT) motorcycle engine block model.

1.7. Design Consideration on Errand 125 -CT

The following consideration follow while modifying the motorcycle engine block afore – stated:

- The pitch of the original sample (unmodified) was kept at approximately (10mm) which was the manufactures specification.
- A number of pin fins were arrayed in-line at a minimum spacing of 8.0mm measured centre to centre across successive cylindrical pin fins; thereby space to diameter ratio rates (2.0) or mor
- The design modification however registered (1.5) with height to diameter ratio though lower by a sight measure than the optimal recommendation made by (Menking et al, 2009); the pin fin material however maintained original sample's ahiminium alloy.

The conceptual frame work of the study work investigated the rate at which heat flow would occur from an existing motorcycle engine block with (ERRAND 125 CT) as the sample typically investigated. Research work had varied the numbers of cylindrical pin fins hammened into the drilled holes created on the horizontally projecting constant area straight rectangular air-cooled motorcycle engine block across identified sample (A, B and C.) sample A, is the original engine block with zero number of cylindrical pin fins. Sample B and C h as 60 and 120 number vertical cylindrical pin fin hammened vertically into the corresponding drilled holes respectively ; both the engine block and the cylindrical pin fins are all made of ahiminium material – The (sample A,B and C) l are all of equal masses of both block and pins altogether – The constant mass was achieved by grinding inward sample B and C such that a depth of 1.5mm and 3.0mm were cut inward from the external perimeter of the horizontally projecting straight constant area straight rectangular fins. The cylindrical pin fin of the same material was used to compensate the cut off chips to maintain a constant mass of all sample. The samples were placed in turn in a kiln at 80-degree Celsius measuring with an IR pynometer the samples were subsequently removed and placed in an axial air flow pump at a selected velocity field. The time taken for the sample to cool from 80^{o}C to 30^{o}C was noted. The time interval was taken using a digital stop watch and temperature observed with the aid of the IR pyrometer – A wooden slab of diameter 5.18cm was used to cover the top and bottom cylindrical cores of the engine block samples before placing each in the axial air pump at an air velocity field prescribed by design. Time interval of temperature fall for each 5.0 degree Celsius was critically noted.

Table 2 Sample A, zero Pin Fin, Control Engine Block

S/n	Air speed (m/s)	Temp. ^{o}C	Cooling time/sec	NAT. Conv. m/s
1	0	80	0.0	0
2	0	75	300.0	
3	0	70	990	
4	0	65	710	
5	0	60	960	
6	0	55	1170	
7	0	50	1380	
8	0	45	1660	
9	0	40	1870	
10	0	35	2100	
11	0	30	2439.2	

Table 3 Sample A, Control Engine Block, Zero Pin Fin

S/N	Air speed (m/s)	Temp. ^{o}C	Cooling time/sec	V=10m/s
1	10.0	80	0.0	
2	10.0	75	85.0	
3	10.0	70	150.0	
4	10.0	65	225.0	
5	10.0	60	295.0	
6	10.0	55	367.0	

7	10.0	50	440.0	
8	10.0	45	502.0	
9	10.0	40	575.0	
10	10.0	35	645	
11	10.0	30	703.0	

Table 4 Sample A. Control Engine Block, Zero Pin Fin

S/n	Air speed /m/s	Temp. oC	Cooling time/sec	V=20m/s
1	20.0	80	0.0	
2	20.0	75	60.0	
3	20.0	70	123.0	
4	20.0	65	180.0	
5	20.0	60	240.0	
6	20.0	55	295.0	
7	20.0	50	345.0	
8	20.0	45	405.0	
9	20.0	40	460.0	
10	20.0	35	520.0	
11	20.0	30	586.0	

Table 5 Sample B, 60 Pins

S/N	Air speed(m/s)	Temp. ^oC	Cooling time/sec	Nat convection
1	0	80	0.0	
2	0	75	190.0	
3	0	70	380	
4	0	65	555	
5	0	60	738	
6	0	55	922	
7	0	50s	1160	
8	0	45	1360	
9	0	40	1561	
10	0	35	1800	
11	0	30	2363	

Table 6 Sample B, 60 Pin Fins

S/n	Air speed (m/s)	Temp. ^oC	Cooling time/sec	V=10m/s
1	10.0	80	0.0	
2	10.0	75	70.0	
3	10.0	70	139.0	

4	10.0	65	210.0	
5	10.0	60	278.0	
6	10.0	55	334.0	
7	10.0	50	400.0	
8	10.0	45	475.0	
9	10.0	40	540.0	
10	10.0	35	605.0	
11	10.0	30	680.0	

Table 7 Sample C, 60 Pins

S/n	Air speed /m/s	Temp. ^{o}C	Cooling time/sec	V=20m/s
1	20.0	80	0.0	
2	20.0	75	35.0	
3	20.0	70	69.0	
4	20.0	65	105.0	
5	20.0	60	145.0	
6	20.0	55	190.0	
7	20.0	50	240.0	
8	20.0	45	294.0	
9	20.0	40	320.0	
10	20.0	35	445.0	
11	20.0	30	558.0	

Table 8 Sample C, 120 pin

S/N	Air speed (m/s)	Temp. ^{o}C	Cooling time/sec	Nat conv.
1	0	80	0.0	
2	0	75	80	
3	0	70	150	
4	0	65	240	
5	0	60	360	
6	0	55	520	
7	0	50	790	
8	0	45	1090	
9	0	40	1450	
10	0	35	1800	
11	0	30	2300	

Table 9 Sample C, 120 pin fins

S/N	Air speed (m/s)	Temp. °C	Cooling time/sec	V=10m/s
1	10.0	80	0.0	
2	10.0	75	50.0	
3	10.0	70	101.0	
4	10.0	65	150.0	
5	10.0	60	210.0	
6	10.0	55	284.0	
7	10.0	50	355.0	
8	10.0	45	420.0	
9	10.0	40	500.0	
10	10.0	35	580.0	
11	10.0	30	663.0	

Table 10 Sample D, 120 pin fins

S/N	Air speed (m/s)	Temp. oC	Cooling time/sec	V=20m/s
1	20.0	80	0.0	
2	20.0	75	30.0	
3	20.0	70	59.0	
4	20.0	65	85.0	
5	20.0	60	110.0	
6	20.0	55	150.0	
7	20.0	50	190.0	
8	20.0	45	270.0	
9	20.0	40	350.0	
10	20.0	35	440	
11	20.0	30	529.9	

Fin performance can be rated using several expression ratio including effectiveness and efficiency. Applying the formular for fin effectiveness as a performance rating for samples A, B and C; sample's thermal performance is expressed as the ratio of time rate of heat energy dissipated from finned to unfinneed surface of each sample. From table below:

Table 11 Sample Speed and Rate of Heat Flow

S/No	Air Sample speed (metre per sec)	Rate of Heat Flow (rW)	Effectiveness
	(A)		
1	20 Zero pin	89.7	1.000
2	10	82.8	1.000
3	0	21.4	1.000

	(B)		
2	20 60 pins	92.58	1.033
	10	85.50	1.032
	0	22.00	1.030
	(C)		
3	20 120 pins	100.0	1.115
	10	87.7	1.060
	0	22.6	1.058

Figure 1 Control Model: ERRAND 125 CT (Original motorcycle Engine block or Heat sink (Rectangular Engine Block, Original Sample)

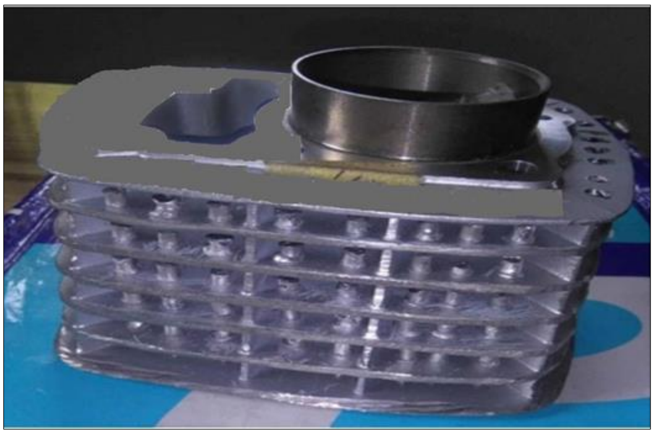

Figure 2 Pin Finned Engine Block (MODIFIED ERRAND 125 CT) /Experimental Sample/Model)

2. Results and Discussions

From observation sample A (control), experiment showed that it took the longest time interval for the temperature to fall from 80^{o}Cto 30^{o}C; followed by sample (B) with 60 number pin fins. Sample C, (120 pin fins) showed the shortest time internal to cool from 80^{0}C to 30^{0}C meaning it has the highest heat flux dissipation power in watts amongst all the three samples under investigation. Therefore, under the same design and air flow condition, sample, A of zero pin fins reflected the least power or heat flux from the cylinder core. Sample C- 120 pin fin has the largest dissipation rate/power followed by (sample B – 60 pin fins) this agrees with Newton's Law of Cooling that an increased surface area can impart on heat flux of a body's heat transfer apart from temperature difference which also plays an important role on the rate of heat flows from an object to the surrounding; The manipulation of the object's surface geometry could also have affected the rate of heat loss. Fin geometry implemented on the pin fins placed on the object's surface has the ability to influence air flow regime from laminar to turbulence thus affecting heat flow rate increasingly at turbulence flow regime. Altogether this can cause a heat dissipation increase in the pin finned motorcycle engine block of the (ERRAND 125 – CT) motorcycle heat sink/engine block. In addition, convective heat flow rate across temperature gradient is observed to be affected by geometry, fluid flow regime(speed) and spartial cover of a body as observed in the preceding heading.

3. Conclusion

Based on observation and findings; it is inferable that heat dissipation rate from (Errand 125 CT) motorcycle engine block can be designed to further its heat flux rate to the ambience: By including pin fins on its external surface and may occur for other heat sink designs.

- Inclusion of a number of pin fins on a heat exchanger's surface may affect the air flow regime from laminar to turbulence following some attendant recommended design specification carefully.
- For a good heat exchange design, findings have shown that heat flux tends to increase as the number of pin fins inclusion, air speed and fin geometry sand surface area by implication following the specified optimal recommendation on ground from foremost studies.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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