Analysis of Effect of Tapped Heat from Exhaust Gases using Helical Coiled Heat Exchanger on Engine Performance

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Abstract

Objectives: Recycling the exhaust gas reduces the amount of oxygen after the combustion stroke, resulting in less nitrogen oxide in the exhaust. But the dilution effect of exhaust gas recirculation cannot be neglected as soot emissions increase to undesirable degree. The objective is to tap the heat from the exhaust gas thereby cooling the exhaust which would not only reduce nitrogen oxide content but at the same time pre-heat the intake charge which increases the efficiency of the engine.

Methods/Statistical Analysis: Tapping of exhaust heat using a suitable heat exchanger is done by making the exhaust gas pass through one inlet of the helical coiled heat exchanger and atmospheric air in the other such that the air flow is perpendicular to the exhaust flow as the heat exchange rate is better. The temperature gained by the atmospheric air should be regulated and controlled as it can have adverse effects if the atmospheric air exceeds the pre-ignition temperature of the fuel. For this purpose, the exact temperature is to be gained by the atmospheric air required for proper combustion of air fuel mixture is checked with help of C++ program. Design considerations vital for the heat exchanger like effectiveness, area of spiral coil, overall heat transfer coefficient, are also checked with the help of C++ program. Findings: To ensure proper calculations of amount of heat exchanged between exhaust air and fresh inlet air, the properties of metals used for heat exchanger like its thermal conductivity, melting point etc. and dimensional specifications are incorporated in the program. Spirally wound tapered helical coil is compared with helical coil which results in 56% increase in overall heat transfer.

Application/Improvements: It is found that there is an increase in the efficiency of the engine by 2.5% and its thermal efficiency by 0.2%. Since the heat exchanger is designed for two-wheelers, the results of the finding were applied to two different models of two-wheeler i.e. Splender plus and Pulsar and efficiency compared for better understanding.

Keywords: Efficiency, Helical Coiled Heat Exchanger, Heat Transfer

1. Introduction

In order to increase the efficiency of the engine, the air is pre-heated by passing in a compact heat exchanger which can be used for two wheelers. The exhaust gas is made to pass through one inlet and the atmospheric air in another. The type of flow is perpendicular as the heat exchange rate is better. The temperature gained by the atmospheric air should be regulated and controlled as it can have adverse effects if the atmospheric air exceeds the pre-ignition temperature of the fuel. This would cause the combustion to occur even before the start of compression or at an early stage of compression stroke. For this purpose, the exact temperature is to be gained by the atmospheric air required for proper combustion of air fuel mixture is checked with the help of C++ program. This pre-heated air is sent to the carburetor for proper mixing and atomization after which it is fed to the engine during the suction stroke.

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2. Description

2.1 Heat Exchanger
The heat exchanger is the main component of the system. The heat exchanger used in this system is a compact heat exchanger which is portable and easy to fit into two wheelers. Since the spiral heat exchanger facilitates increase in heat transfer rate, the helical coil is wound spirally. It is wound in such a way that its diameter gradually increases along the entire length of the heat exchanger thus making it a spirally wound tapered helical coil. The casing is made of Aluminum which has a melting point of 660.3 degree Celsius. The spirally wound helical coil is made of Copper which has a good melting point as high as 1085 degree Celsius. Copper is used because of its high thermal conductivity and corrosive resistance properties. The amount of heat that should be transferred to fresh intake air is measured by a program in which the known values are substituted. The number of turns required to obtain in desired temperature of atmospheric air is decided after running the program for the heat exchanger shown in Figure 1.

2.2 Design of Heat Exchanger
The design of heat exchanger is of importance because it is the main component of the system. Compact heat exchanger is considered as they facilitate better heat transfer rate. At inlet, the shape of the heat exchanger is such that it can be easily fit into the exhaust of the two wheelers. The shape is divergent so that there is increase in pressure and drop in kinetic energy of the exhaust gas. This is done to prevent increase in back pressure of exhaust gas. At the outlet, the shape is convergent which increases the kinetic energy of the exhaust by reducing the pressure. The atmospheric air passes through the copper coil, the shape of which is tapered helical i.e. at entrance is small but gradually increases along the entire length of the heat exchanger. This increases the contact area between the exhaust gases and the atmospheric air passing through the copper coil thus ensuring proper heat exchange.

The design of the heat exchanger is shown in Figure 2. The dimensions are outer cover - diameter 84mm, entire length 216mm and thickness 2mm. The inner coil has 11 turns and the spiral coil diameter is 10 mm, the mean diameter ranges from 2.5 mm to 25 mm and the length of the coil copper winding is 150 mm.

The other important equipment used in the system is carburetor and its type is selected based on requirements of the entire set-up. The carburetor type selected for this system is vertical or up-draught carburetor. This is chosen over other types of carburetor for its air fuel mixture flow (upward flow) and area of space consumed. This carburetor allows gravity flow of fuel which depends on the height making it suitable for this set-up.

3. Measurement of Temperature of Inlet Air after Heat Exchange
The temperature at the outlet of the heat exchanger is calculated using C++ program. The fuel used generally in two wheelers is gasoline which is known as petrol; the outlet temperature of the heat exchanger is regulated and controlled so that it is maintained at less than its auto-ignition temperature. Petrol has an auto-ignition temperature of range 247-280 degree Celsius. A very important factor that needs attention is the auto ignition temperature decreases when the molecular weight of the petrol increases. The other important factor to decide...
upon the outlet temperature of the heat exchanger is air fuel mixture rate. The general air fuel mixture ratio is 15:1 i.e. one gram of fuel needs 15 grams of air for good combustion$. But the standard ratio of air fuel mixture is 14.7:1.

**Terminologies Used:**

- T1 = Inlet of Hot fluid
- T2 = Outlet of Hot fluid
- t1 = Inlet of Cold fluid
- t2 = Outlet of Cold fluid
- $t_{12}$ = outlet of the cold fluid for spirally wounded tapered helical coil heat exchanger.
- $t_{02}$ = outlet of the cold fluid for helical coil heat exchanger.
- $T_{12}$ = inlet of the cold fluid for tapered spirally wounded helical coil heat exchanger.
- $T_{02}$ = inlet of the cold fluid for helical coil heat exchanger.
- $A_1$ = area of the spirally wounded tapered helical coil heat exchanger.
- $A_2$ = area of the helical coil heat exchanger.
- $m_h$ = mass flow rate of hot fluid
- $C_{ph}$ = Specific heat of hot fluid
- $m_c$ = Mass flow rate of Cold fluid
- $C_{pc}$ = Mass flow rate of Cold fluid
- $n$ = No of turns
- $b$ = breadth of copper spiral or the inner diameter of spiral
- $w$ = Wall thickness of copper spiral
- $Q$ = Heat Transfer
- $r$ = radius of the tube
- $h$ =length of the tube

**Formula Used:**

For tapered helical coil:

\[ t_2 = \frac{2Q - mhC_{ph}(T_1 - T_2) + mcC_{pc}t_1}{mcC_{pc}} \]

\[ T_2 = T_1 - \text{effectiveness} \ (T_1 - t_1) \]

\[ U = \frac{1}{(1/((0.3983^2)*b))(1/K_{hot}) + (1/K_{cold}) + (W/K_s))} \]

\[ A = 15.0565b^2 + 1.05316(e^{0.34657} - 1) \]

\[ \text{effectiveness} = \left(1 - e^{-N(1-C)}\right) \]

\[ N = \frac{(UA)}{(mhC_{ph})} \]

Area of helical heat exchanger = $2\pi r^2 + 2\pi rh$

**Programs:**

a) **Calculation of effectiveness:**

```c
#include<stdio.h>
#include<math.h>
#include<conio.h>
void main()
{
    float A,B,C,D,E,F,N,Mh,Cph,Mc,Cpc,Flong;
    clrscr();
    printf("n N=");
    scanf("%f",&N);
    printf("n Mh=");
    scanf("%f",&Mh);
    printf("n Cph=");
    scanf("%f",&Cph);
    printf("n Mc=");
    scanf("%f",&Mc);
    printf("n Cpc=");
    scanf("%f",&Cpc);
    C=((Mh*Cph)/(Mc*Cpc));
    A=(1-C);
    B=exp ((-N)*(A));
    D=(C*B);
    E=(1-B);
    F=(1-D);
    Flong=(E/F);
    printf("n Flong=%f",Flong);
    getch();
}
```

b) **Calculation of outlet temperature of exhaust gas:**

```c
#include<stdio.h>
#include<conio.h>
#include<math.h>
void main()
{
    float A,T1,T2,t1,Flong;
    clrscr();
    printf("T1=");
    scanf("%f",&T1);
    printf("n Flong=");
    scanf("%f",&Flong);
    printf("n t1=");
    scanf("%f",&t1);
    A=((Flong)*(T1-t1));
    T2=(T1-A);
    printf("n T2=%f",T2);
    getch();
}
```

c) **Calculation of area of spirally wound tapered helical coil:**

```c
#include<stdio.h>
#include<conio.h>
```


```c
#include<conio.h>
#include<math.h>

void main()
{
    float A,B,C,D,E,b,n;
    clrscr();
    printf("b=");
    scanf("%f ",&b);
    printf("n=");
    scanf("%f ",&n);
    B=((15.0565)*(b*b));
    C=exp (n*0.3465);
    D=(C-1);
    E=(1.05316*D);
    A=(B+E);
    printf("A=%f ",A);
    getch();
}

d) Calculation of area of helical coil heat exchanger:
#include<stdio.h>
#include<conio.h>
#include<math.h>

void main()
{
    float r,h,a;
    clrscr();
    printf("r=");
    scanf("%f ",&r);
    printf("h=");
    scanf("%f ",&h);
    a=((6.28*r*r)+(6.28*r*h));
    printf("area=%f ",a);
    getch();
}

e) Calculation of overall heat transfer coefficient:
#include<stdio.h>
#include<conio.h>
#include<math.h>

void main()
{
    float A,B,C,D,E,U,b,Khot,Kcold,W ,Ks;
    clrscr();
    printf("b=");
    scanf("%f",&b);
    printf("Khot= ");
    scanf("%f",&Khot);
    printf("Kcold= ");
    scanf("%f",&Kcold);
    printf("W=");
    scanf("%f",&W);
    printf("Ks=");
    scanf("%f",&Ks);
    A=(0.3983*b);
    B=((1/Khot)+(1/Kcold));
    C=(A*B);
    D=(W/Ks);
    E=(C+D);
    U=(1/E);
    printf("U=%f ",U);
    getch();
}

f) Calculation of NTU:
#include<stdio.h>
#include<conio.h>
#include<math.h>

void main()
{
    float A,B,C,U,Mh,Cph,N;
    clrscr();
    printf("A=");
    scanf("%f ",&A);
    printf("U=");
    scanf("%f ",&U);
    printf("Mh=");
    scanf("%f ",&Mh);
    printf("Cph=");
    scanf("%f",&Cph);
    B=(U*A);
    C=(Mh*Cph);
    N=(B/C);
    printf("N=%f ",N);
    getch();
}

g) Calculation Of Efficiency:
#include<stdio.h>
#include<conio.h>
#include<math.h>

void main()
{
    float N1,N2,BE,AF ,FC,Increase;
    clrscr();
    printf("BE=");
    scanf("%f ",&BE);
    printf("AF=");
    scanf("%f",&AF);
    N2=(N1*N2);
    printf("N1=%f ",N1);
    printf("N2=%f ",N2);
    printf("BE=%f ",BE);
    printf("BE+%f ",BE);
    printf("AF+%f ",AF);
    Increase=(BE-%f);
    printf("Increase=%f ",Increase);
    getch();
}
```

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scanf("%f",&AF);
printf("\n FC=");
scanf("%f",&FC);
N1=(BE/FC);
N2=(AF/FC);
Increase=((N2-N1)/(100));
printf("\n N1=%f\n ",N1);
printf("\n N2=%f\n ",N2);
printf("\n Increase=%f\n ",Increase);
getch();
}

h) Comparison between spirally wound tapered helical coil heat exchanger and helical coil heat exchanger in terms of overall heat transfer

#include<stdio.h>
#include<conio.h>
#include<math.h>

void main()
{
    float A,B,C1,C2,D1,D2,T1,T02,t1,t02,T12,t12,mh,cp,
    h,mc,cpc,
    ef1,ef2,Q1,Q2,U,q,LMTD1,LMTD2,a1,a2,overall;
    clrscr();
    printf("\n T1= ");
    scanf("%f",&T1);
    printf("t1= ");
    scanf("%f",&t1);
    printf(" mh= ");
    scanf("%f",&mh);
    printf(" cph= ");
    scanf("%f",&cph);
    printf(" mc= ");
    scanf("%f",&mc);
    printf(" cpc= ");
    scanf("%f",&cpc);
    printf(" ef1= ");
    scanf("%f",&ef1);
    printf(" ef2= ");
    scanf("%f",&ef2);
    printf(" q= ");
    scanf("%f",&q);
    printf(" a1= ");
    scanf("%f",&a1);
    printf(" a2= ");
    scanf("%f",&a2);
    printf(" U= ");
    scanf("%f",&U);
    A=(mh*cph);
    B=(mc*cpc);
    T02=((T1-(ef1*(T1-t1)));
    T12=((T1-(ef2*(T1-t1)));
    t02=((2*q)-(A*(T1-T02))+(B*t1)/(B));
    t12=((2*q)-(A*(T1-T12))+(B*t1)/(B));
    C1=((T02-t1)-(T1-t02));
    C2=((T12-t1)-(T1-t12));
    D1=(log(T02-t1)/(T1-t02));
    D2=(log(T12-t1)/(T1-t12));
    LMTD1=(C1/D1);
    LMTD2=(C2/D2);
    Q1=(U*a1*LMTD1);
    Q2=(U*a2*LMTD2);
    overall=((Q2-Q1)/(Q2)*(100));
    printf("\n T02=%f\n ",T02);
    printf("\n T12=%f\n ",T12);
    printf("\n t02=%f\n ",t02);
    printf("\n t12=%f\n ",t12);
    printf("\n LMTD1=%f\n ",LMTD1);
    printf("\n LMTD2=%f\n ",LMTD2);
    printf("\n heat transfer helical coil=%f\n ",Q1);
    printf("\n heat transfer spirally wound tapered helical coil=%f\n ",Q2);
    printf("\n overall heat transfer=%f\n ",overall);
    getch();
}

Thermal Efficiency calculation:

Formulae used:

1-Tc/Th

Where, Tc: The ambient temperature

Tth: The temperature after compression

Considering the ambient temperature 30°C and the temperature after compression is 500°C the thermal efficiency derived is 94%. After using the heat exchanger the initial temperature is 47°C and the temperature after compression is assumed as 820°C for which the thermal efficiency increases to 94.26%.

4. Results and Conclusion

The design of heat exchanger with its dimensional specification is included in the program along with properties of copper like its thermal conductivity etc. to ensure proper calculations with respect to amount of heat exchanged between exhaust air and fresh inlet air. The standard values of thermal conductivity of exhaust gases and inlet air, copper, heat transfer rate of air, specific heats of air and
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exhaust are taken for calculations. Spirally wound tapered helical coil results in 56% increase in overall heat transfer when compared with helical coil which is depicted in Table 1. It is also found that there is an increase in the efficiency of engine by 2.5% and its thermal efficiency by 0.2%. For better understanding of this improvement in efficiencies, the results of the finding is applied to two different models of two wheeler i.e. Splender plus and Pulsar which is depicted in Table 2.

Table 1. Evaluated values for both heat exchanger

Result for spirally wound tapered helical coil heat exchanger:

| b | W | \(K_{hot}\) | \(K_{cold}\) | \(K_s\) | \(T_1\) | \(T_{12}\) | \(t_1\) | \(\text{Area}_{1}\) | q | \(M_h\) | \(C_{ph}\) | \(M_c\) | \(C_{pc}\) | n | Q | \(t_{12}\) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | 0.0584 | 0.0264 | 399 | 400 | 33.699 | 30 | 422.98 | 40 | 1 | 0.2375 | 1 | 1.005 | 11 | 15277320 | 23.036 |

Log Mean Temperature Difference =144.37

Result for helical coil heat exchanger:

| b | W | \(K_{hot}\) | \(K_{cold}\) | \(K_s\) | \(T_1\) | \(T_{02}\) | \(t_1\) | \(\text{Area}_{2}\) | q | \(M_h\) | \(C_{ph}\) | \(M_c\) | \(C_{pc}\) | n | Q | \(t_{02}\) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | 0.0584 | 0.0264 | 399 | 400 | 67 | 30 | 1727.83 | 40 | 1 | 0.2375 | 1 | 1.005 | 11 | 6688972 | 30.907 |

Log Mean Temperature Difference =80.72

Over all heat transfer= tapered helical coil is 56% greater than normal helical coil heat exchanger

Table 2. Comparative efficiency in mileage

| Efficiency 1 (Splendor Plus) | Efficiency 2 (Pulsar) |
|---|---|
| Before heat exchanger | 80.6 | 65 |
| After heat exchanger | 82 | 67 |

5. Scope

The desired temperature can be regulated by changing the dimensions of the design without changing the number of turns and over all shape of the heat exchanger. The other option for doing the same is to incorporate a cooling unit at exit of the heat exchanger. The cooling unit can be designed for desired temperature based on the output or exit temperature of air. Recommended cooling unit for this setup is "liquid to air inter cooler".

6. References

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