AN EXPERIMENTAL STUDY OF B- TYPE STIRLING ENGINE USING SOLAR RADIATION

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Abstract

Many attempts are being made all over the world in order to make power-generator engines with appropriate efficiency and with the capability of using waste heat recovery and renewable energy sources at the same level as the fossil fuels. Use of non-renewable energy sources of the earth including petroleum, gas and coal destroys the societies' public wealth and produces one-fourth of the total carbon dioxide of the world. The Stirling engine is an external combustion engine which operates on Stirling cycle. It operates on a closed cycle, so there is no need of using the fluid again and again as in case of other power plants. Due to this usage of non-renewable energy sources for production of power is not needed and also there is no problem of pollution because there are no emissions from the engine. The Stirling cycle efficiency is nearer to Carnot efficiency. But it was come into usage due to difficulties in design of regenerator up to last 19th century. But due to developments in material science, this problem has been overcome in 20th century. The cost of the engine is high, but due to its higher efficiency and no emissions, priority for this engine for production of power is increasing. The solar radiation can be focused on to the hot-end of the Stirling engine, thereby creating a solar-powered prime mover. The direct conversion of solar power into mechanical power reduces both the cost and complexity of the prime mover. In future, may be Stirling engine with solar energy as heat input will be a better power generation method.

Keywords: Stirling engine, Stirling cycle, Renewable energy, Solar radiation, Regenerator.

1. INTRODUCTION

To summarize, the Stirling engine uses the temperature difference between its hot end and cold end to establish a cycle of a fixed mass of gas, heated and expanded, ands cooled and compressed, thus converting thermal energy into mechanical energy. The greater the temperature differences between the hot and cold sources, the greater the thermal efficiency. The maximum theoretical efficiency is equivalent to the Carnot cycle; however the efficiency of real engines is only a fraction of this value, even in highly optimized engine. There are three important Stirling engine configurations, viz., Alpha Stirling, Beta Stirling and Gamma Stirling. A.Z.Hafezab [1] presented the modelling and simulation for a prototype of the solar-powered Stirling engine working at the low temperature range. A mathematical model for the thermal analysis of the solar-powered low temperature Stirling engine with heat transfer is developed using Matlab program. The model takes into consideration the effect of the absorber temperature on the thermal analysis like as radiation and convection heat transfer between the absorber and the working fluid's. Kongtragool and S. Wongwises [2] created a quasi-isothermal heat engine based on the Ericsson cycle and designed as rolling piston engine. We present in this paper two types of such engines: one-valve heat engine and valve-less heat engine. The theoretical analysis shows that for high temperature 600 K and low temperature 300 K the thermal efficiency can be obtained 0.46-0.49 for one-valve heat engine and 0.36-0.46 for valve-less heat engines for compression rate 1.2-1.05. To obtain acceptable power-two-weight ratio of the engine it is necessary to maintain the mean pressure of the cycle equal to 100-200 bar as it is made in some Stirling engines'. Abdullah [3] described design considerations to be taken in designing of a low temperature differential double-acting Stirling engine for solar application. During the preliminary design stage, the critical parameters of the engine design are determined according to the Schmidt analysis, while the third order analysis was used during the design optimisation stage in order to establish a complete analytical model for the engine. G. Walker [4] presented an investigation on finite time thermodynamic evaluation and analysis of a Solar-dish Stirling heat engine. Finite time thermodynamics has been applied to determine the net power output and thermal efficiency of the Stirling system with finite-rate heat transfer, regenerative heat loss, conductive thermal bridging loss and finite regeneration process time. L.C. Waldes [5] described and analysed a variable phase angle, α-type Stirling engine from kinematic and thermodynamics point of view. Kinematic relations were described for the calculation of hot and cold cylinder volumes.

2. Experimental Results

The specifications of the β-type Stirling engine are shown below

2.1 **Engine specifications**

Bore of the cylinder, D =20mm

Stroke length of the piston, L=35mm

Compression ratio, r =v1/v2=6

Mass flow rate, m=0.007kg/min =1.167×10^{-4} kg/s.

R=2077 J/kg.k for Helium gas

2.2 Solar collector specifications

Diameter of the parabolic dish=1m

Focal length of the parabolic collector = 30cm

Temperature range = 50 - 150^0C

2.3 Experimental observations

The heat input temperature at hot junction=collector temperature= T_3=T_4=120^OC=393^OK

The heat rejection temperature at cold junction= T_1=T_2 =37^0C=310^0K

Speed= 850 RPM

2.3.1 Experimental results

Heat added during constant temperature process (3-4) =170.68 J/s or Watts

Heat rejected during constant temperature process (1-2) =134.63J/s or Watt

Work output (P)=36.05 W

Work done/ cycle (W) =5.089 J/cycle

Efficiency (η) =21.12 %

(Assuming regenerator efficiency as 100%)

Area of the cylinder (A) =3.14×10^{-4} m^2

Stroke volume (Vs) =1.232×10^{-5} m^3

2.4 Performance plots

2.4.1 Efficiency Vs Hot junction temperature (T_H)

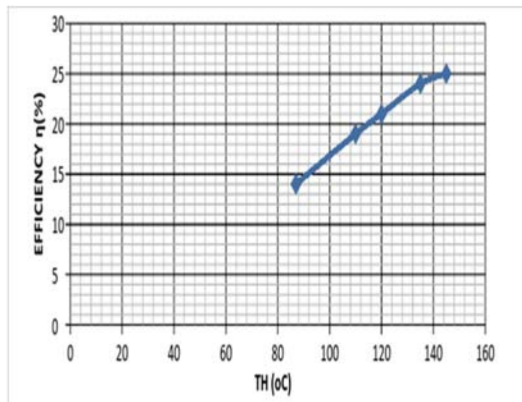

Fig.2.1 Efficiency η (%) vs. Hot junction temperature T_H (^{o}C)

As the hot junction temperature increases by keeping the cold junction temperature constant at 37^oC.The efficiency is increasing as shown in the Fig 5.2.

2.4.2 Efficiency (η) Vs Cold junction temperature (T_L)

As the cold junction temperature increases by keeping the hot junction temperature constant at 120^oc, the efficiency is decreasing as shown.

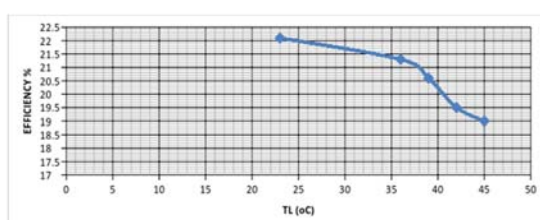

Fig 2.2 Efficiency η (%) Vs. cold junction temperature T_L (^{o} C)

2.4.3 Indicated Power (I.P) Vs Hot junction temperature (T_H)

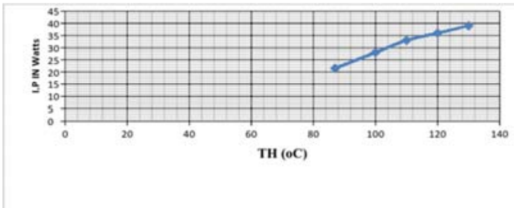

Fig 2.3 Indicated power P (Watts) vs. hot junction temperature T_H (^oC)

As the hot junction temperature increases by keeping the cold junction temperature constant at 37^oC the indicated power is increasing as shown in the Fig 5.4.

2.4.4 Indicated Power (I.P) Vs Cold junction temperature (T_L)

As the cold junction temperature increases by keeping the hot junction temperature constant

At 120^oC the indicated power is decreasing as shown in the Fig 5.5.

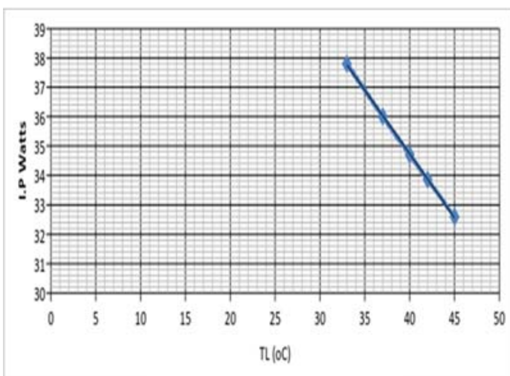

Fig 2.4 Indicated power P (Watts) Vs. cold junction temperature T_L (^oC)

2.4.5 Efficiency (η) Vs Indicated Power (I.P)

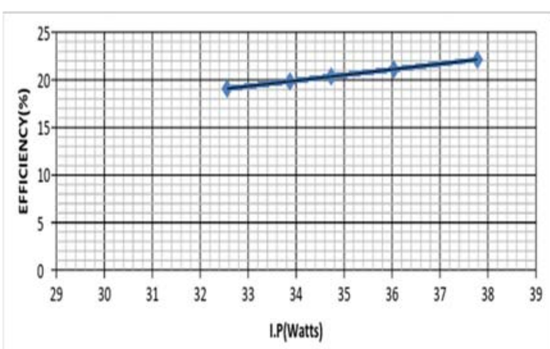

Fig 2.5 Efficiency η (%) vs. Indicated power P (Watts)

The indicated power increases with the efficiency as the hot junction temperature remaining constant at 120^OC. (Fig 5.6)

2.4.6 Hot junction Temperature (T_H) Vs Speed (N)

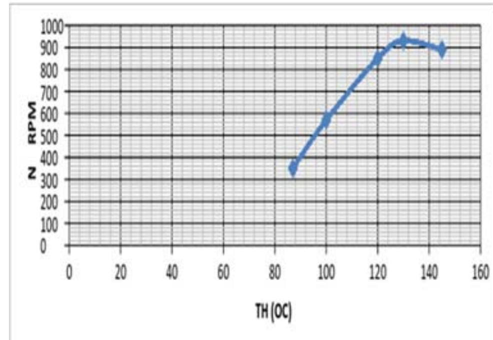

Fig 2.6 T_H (^OC) VS SPEED (RPM)

As shown in the Fig 5.8 at constant temperature of cold junction as the hot junction temperature increases the rpm of the engine increases up to 920 rpm. Later as the temperature increases further beyond 132^OC the rpm of the engine takes slightly downfall in its value.

3. RESULTS AND DISCUSSIONS

3.1 COMPARISION OF OTTO AND STIRLING CYCLES FOR THE SAME TEMPERATURE DIFFERENCE:

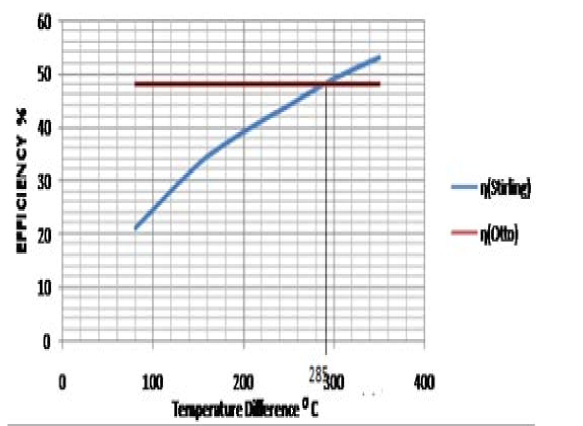

Fig 3.1 Efficiency Vs Temperature Difference

It is observed from the Fig 2.2 that, as the temperature difference is increasing the efficiency of the Stirling cycle will increase and the efficiency of Otto cycle is not dependent on the temperature difference. It only depends on the compression ratio. So it is constant at **47.8**%.At the low temperature difference levels the efficiency of Stirling cycle is less than that of the Otto cycle. It is equal to Otto cycle efficiency at a temperature difference of **285^OC.**After that the Stirling efficiency is greater than that of the Otto cycle efficiency.

3.2 COMPARISION OF DIESEL AND STIRLING CYCLES FOR THE SAME TEMPERATURE DIFFERENCE:

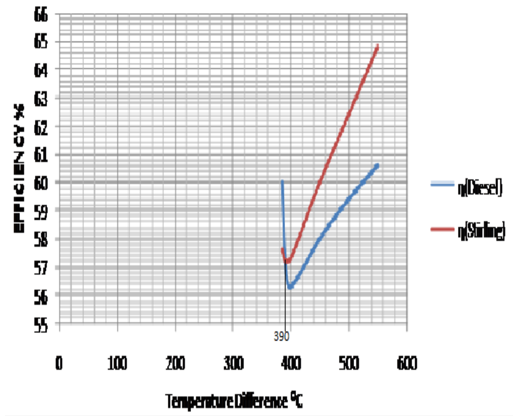

Fig 3.2 Efficiency Vs Temperature Difference

It is observed from the Fig 6.4 that, as the temperature difference is increasing the efficiency of the Stirling cycle will increase and the efficiency of diesel cycle is also increasing with the temperature difference. At low temperature differences the efficiency of the diesel cycle is greater than that of the Stirling cycle. The efficiencies of these two cycles are equal at a temperature difference of **390**^{O}C.

4. CONCLUSIONS

It is observed that, the efficiency of Stirling engine is greater than that of Otto cycle for temperature differences greater than 285^{O}C.Also the efficiency of Stirling engine is greater than that of Diesel cycle for temperature differences greater than 390^{O}C.The main disadvantage of this engine is the manufacturing of regenerator. Now a day due to the developments in material science, manufacturing of the regenerator has become easier. Thus we can expect that the Solar Stirling engine will play an important role in satisfying the power production requirements in future.

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