TiMER

Trends in Mechanical Engineering Research

THE EFFECT OF TEMPERATURE AND FLYWHEEL ON PERFORMANCE OF STIRLING ENGINE GAMMA TYPE

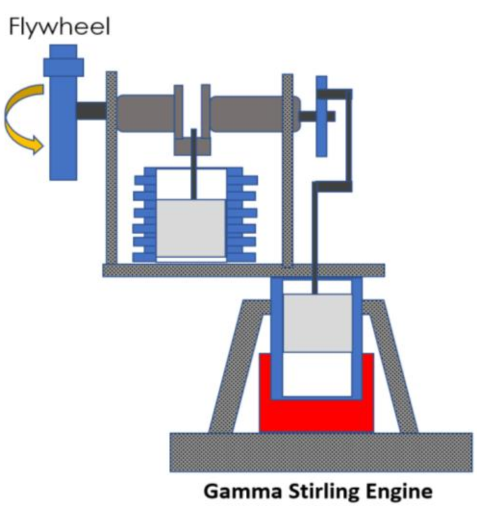
Imron Rosyadi [a]*, Agung Sudrajad [a], Dhimas Satria[a], Setyo Margo Utomo[b], Agus Mulyana[a]

[a] Department of Mechanical Engineering, Faculty of Engineering, Universitas Sultan Ageng Tirtayasa, Cilegon, Banten, Indonesia

[b] Process and Manufacturing Industry Technology Research Center, Indonesia

*Corresponding author: imron_jtm@untirta.ac.id

Graphical abstract



Abstract

This is the Stirling engine is one of the alternative power generators that can be implemented at this time. The power generated by the Stirling engine can be used as a generator of electrical energy or for automotive applications. This study aims to determine the optimum performance of the stirling engine in power and torque by providing variations in temperature. The test temperature was carried out by providing energy from LPG fuel with varying temperatures, namely 200˚C, 300˚C, 400˚C, 500˚C, 600˚C and 700˚C. The data taken is RPM, power and torque. From the test results, for 200˚C is 16 W, for 300˚C is 30.66 W, for 400˚C is 45.72 W, for 500˚C is 67.5 W, for 600˚C is 81.06 W, for 700˚C is 105.27 W. In this study, a variant of changing the weight of the flywheel was also carried out. The test results show that an increase in flywheel weight of 1 kg causes an increase in RPM of 22.7% and power of 22.7%.

Keywords: Stirling, temperatur, flywheel

Abstrak

Mesin stirling adalah salah satu alternatif pembangkit daya yang dapat di implementasikan saat ini. Daya yang dihasilkan mesin stirling bisa digunakan sebagai pembangkit energi listrik atau untuk aplikasi automotif. Penelitian Ini Bertujuan untuk mengetahui performa optimum mesin stirling pada daya dan torsi dengan memberikan variasi pada temperatur. Temperatur pengujian dilakukan dengan memberikan energi dari bahan bakar LPG yang divariasikan temperaturnya yaitu 200˚C, 300˚C, 400˚C, 500˚C, 600˚C dan 700˚C. Data yang diambil adalah RPM, daya dan torsi. Dari hasil pengujian, untuk 200˚C adalah 16 W, untuk 300˚C adalah 30,66 W, untuk 400˚C adalah 45,72 W, untuk 500˚C adalah 67,5 W, untuk 600˚C adalah 81,06 W, untuk 700˚C adalah 105,27 W. Dalam penelitian ini dilakukan juga varian perubahan berat flywheel. Hasil pengujian menunjukkan peningkatan berat flywheel 1 kg menyebabkan peningkatan RPM sebesar 22,7 % dan daya sebesar 22,7 %..

Kata kunci: Stirling, temperatur, flywheel

Article history
Received
13 June 2023
Received in revised form
19 June 2023
Accepted
23 June 2023
Published
30 June 2023

Doi: http://dx.doi.org/10.62870/timer.v1i1.20456

1.0 INTRODUCTION

The Stirling engine is a theoretically working closed-cycle mechanical device with combustion in the Stirling cycle, or a modification thereof. This machine utilizes a compressed working fluid such as water, hydrogen, helium, nitrogen, or steam. This Stirling engine has higher efficiency with lower exhaust emissions than gasoline or diesel engines (1), (2), (3), .

The Stirling engine can be implemented and can be used as a distributed electric energy generator which is currently being looked at as renewable energy in overcoming global energy security and environmental impact (4). Solar thermal energy can be used to drive the piston in the stirling engine.

The Stirling engine works due to gas expansion when heated and followed by gas compression when cooled. The machine contains a quantity of gas that is moved between the cold and hot sides continuously. This gas transfer is possible due to the displacement piston which transfers the gas between the two sides and the power piston changes the internal volume due to the expansion and contraction of the gas. The moving piston is referred to as a regenerator which can regenerate air (5). The stirling engine is coupled to the generator shaft, the generator shaft will move when the engine piston moves, thus producing electricity. By utilizing solar heat to produce a temperature difference between the hot and cold parts of the stirling engine, we have obtained the mechanical energy from the stirling engine which is used to rotate the generator. The Stirling engine can be used to generate electricity that is environmentally friendly and of course cheaper because it does not require fuel (6).

In a thermodynamic review, it is known that the efficiency of the Stirling engine will increase as the operating temperature increases in the exoansion area. However, at the design level, this is limited by the ability of materials with high strength and thermal conductivity, as well as having a minimum coefficient of thermal expansion (7), (8).

This strling machine will become the object of further observation or research in order to obtain useful results for the future in terms of application, construction and efficiency. In this research, stirling engine design is designed with optimum stirling engine performance. The purpose of this study was to determine the optimum performance of the stirling engine in terms of power and torque by varying temperature. In this study, the Stirling engine was given a load at the Top Dead Point (TDC) of the piston power and saw the effect of this loading.

2.0 METHODOLOGY

2.1. Material

The designed stringing machine is a machine gamma (γ) type, with the following specifications :

Table 1. . Stirling engine specifications

No	Type	Information
1	Engine Type	Gamma (γ)
2	Phasa Angle	90 °
3	Working Gas	Air
4	Cooling	Water
5	Heater	Solar Collector

The heat source comes from the stove. This variation aims to test the performance of the Stirling engine to the maximum and minimum levels.

2.2. Testing Procedures

Before conducting the test, the stove must be heated first, because the Stirling motor works with external combustion (9), in this case the stove used is a gas LPG as simulator to replace solar energy (10). In another study, burning spirit was used as a substitute for a source of heat energy (11). After the stove has been burning steadily, the fire is focused on the displacer cylinder (the hot part of the Stirling engine) to a predetermined temperature.

The use of the stove as a heat source is intended so that the input temperature can be regulated and stable.

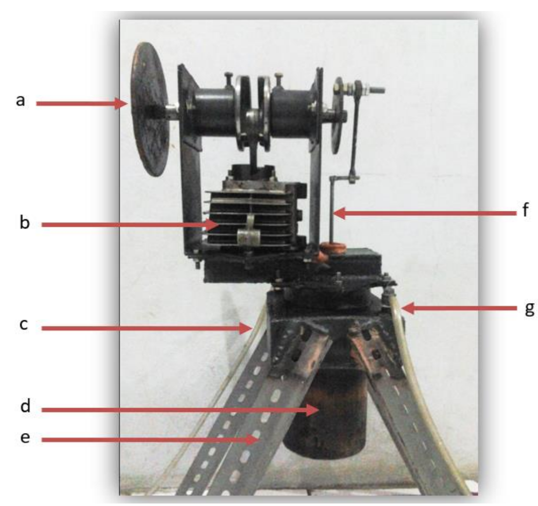


Figure 1. Stirling Engine Parts

Caption :

a. Flywheel
b. Cold cylinder (Tc)
c. Cooling water inlet
d. Silinder piston displacer (TE)
e. Bracket

f. Lingkage piston displacer
g. Cooling water outlet

The next procedure is to give the flywheel an initial rotation. After the stirling engine rotates, the parameters needed for performance analysis are recorded, namely, the air temperature in the hot cylinder (TE), the air temperature in the cold cylinder (TC) and the stirling engine speed (rpm). Then measure the engine speed using a tachometer. After all the data is obtained, the test is carried out five times in each specified temperature variation. In this variation the temperature maintained is 200^{O}C, 300 ^{O}C, 400 ^{O}C, 500 ^{O}C, 600 ^{O}C and 700^{O}C.

Performance testing is based on how much the rpm, power and torque that can be produced by the stirling engine with the parameters used are how big the temperature difference is between the hot and cold parts of the stirling engine.

3.0 RESULTS AND DISCUSSION

a. Stroke power piston, radius Crank power piston multiplied by two
   - 0,025m x 2 = 0,05 m
b. Stroke displacer piston, radius *Crank* displacer dikali dua
   - 0,04m x 2 = 0,08 m
c. Piston displeasure dimension
   - r = 0,05 m
   - t = 0,1405 m
d. Fluid chamber volume
   - Volme silinder power piston (VPP)

   VPP = π . r^2 . t
   = 1,14 x 10^{-4} m^3
   - Volume siku penghubung (VSP)

   VSP = P . L . T
   = 3,5 x 10^{-4} m^3
   - Volume silinder displacer (VSD)

   VSD = π . r^2 . t
   = 21,37 x 10^{-4}m^3

3.1. Calculation of test results data before flywheel modification

Calculation of test results data before flywheel modification.

Table 1. test results data before flywheel modification

No	T_{AND} (˚C)	Tc (˚C)	RPM
1	200	50	144
2	300	50	232
3	400	50	319
4	500	50	393
5	600	50	437
6	700	50	529

1. Calculation of the results of data collection

T_E = 200 ˚C = 473 K
RPM = 144
Tc = 50 ˚C = 323 K

- The stroke volume when the piston is compressed (Vsc) and (Vs_{AND}) :
- ❖ Vsc = π r^2 x S = 3,14 x (0,026)^2 m x 0,054 m = 1,14 x 10^{-4} m^3
- ❖ Vs_{AND} = π r^2 x S = 3,14 x (0,055 m)^2 m x 0,08 m = 7,59 x 10^{-4} m^3
- Compression ratio (r) :
- ❖ $r = \frac{Vsc + VtVsc + Vt}{Vt \quad Vt}$ = = 5,38
- Temperature regenerator (T_R)
- ❖ $T_R = \frac{TE+TcTE+Tc}{2 \quad 2} = \frac{473\ K+323\ K\ 473\ K+323\ K}{2 \qquad 2}$ = 398 K
- Temperature Ratio (t)
- ❖ $t = \frac{TcTc}{TETE} = \frac{323\ K\ 323\ K}{473\ K 473\ K}$ = 0,68 K
- Step volume ratio (v)
- ❖ $V = \frac{VscVsc}{VsEVsE} = \frac{1,14 \times 10^{-4}\ m^3\ 1,14 \times 10^{-4}\ m^3}{7,59 \times 10^{-4}\ m^3\ 7,59 \times 10^{-4}\ m^3}$ = 0,15 m^3
- Remaining volume ratio in cold cylinder (X_{DC})
- ❖ $X_{DC} = \frac{VDCVDC}{VSEVSE} = \frac{1,14 \times 10^{-4}\ m^3\ 1,14 \times 10^{-4}\ m^3}{7,59 \times 10^{-4}\ m^3\ 7,59 \times 10^{-4}\ m^3}$ = 0,15 m^3
- ❖ $X_{OF} = \frac{VDEVDE}{VSEVSE} = \frac{3,79 \times 10^{-4}\ m3\ 3,79 \times 10^{-4}\ m3}{7,59 \times 10^{-4}\ m^3\ 7,59 \times 10^{-4}\ m^3}$ = 0,499 m^3
- ❖ $X_R = \frac{VR\ \ VR}{VSEVSE} = \frac{1,31 \times 10^{-4} 1,31 \times 10^{-4}}{7,59 \times 10^{-4} 7,59 \times 10^{-4}}$ = 0,17 m^3

- **Working Fluids in Stirling Engines**

The working fluid used in this stirling engine is air with a total air mass (m) which is entered into the stirling engine when room temperature and ambient (atmospheric) pressure. The following are the values for room temperature and air pressure used:
Room temperature (T_{like}) = 25^{O} C = 302 K
Air pressure (p_{air}) = 1 atm
To calculate the total mass, the volume position must be in the maximum position. The maximum position of the gamma type stirling engine when the power piston is in the TDC position (Top Dead Point). Then the volume of the hot cylinder can be calculated as follows

IN_{AND} = (Volume silinder displacer) – (Volume piston Displacer)
= 21,37 x 10^{-4}m^3 – 11,02 x 10^{-4}m^3
= 10,35 x 10^{-4}m^3

Vc = Cylinder Volume at TDC
= p r^2 t
= 3,14 . (0,026 m)^2 . 0,054 m
= 1,14 x 10^{-4} m^3

Vsp = P . L . T

= 0,24 m . 0,074 m . 0,02 m
= 3,5 x 10^{-4} m^3
= 10,35 x 10^{-4} m^3 + 1,14 x 10^{-4} m^3 + 3,5 x 10^{-4}
= 14,99 x 10^{-4} m^3 ≈ 0,001499 m^3

For,

$$m = \frac{1{,}01325 \ x\ 10\text{^}5\ Pa\ x\ 0{,}001499\ m3}{286\ \frac{J}{Kg}K\ x\ 302\ K}$$

$$m = \frac{101325\ N/m\text{^}2\ x\ 0{,}001499\ m3}{286\ \frac{Nm}{Kg}K\ x\ 302\ K}$$

m = 0,00175 Kg

- **Average pressure (P_{mean})**

  Inside the Stirling engine cylinder there is a pressure that must be calculated both in compression and expansion conditions. To calculate the average pressureis used as follows:

$$P_{mean} = \frac{2mRTc}{VsE\sqrt{S^2-B^2}}\frac{2mRTc}{VsE\sqrt{S^2-B^2}}$$

Where the values of the coefficients a, S and B

- $\alpha\alpha = tan^{-1}\frac{v\sin dx}{t+\cos dx-1}\frac{v\sin dx}{t+\cos dx-1} = tan^{-1}\frac{0{,}15\sin 90^o}{0{,}68+\cos 90^o-1}\frac{0{,}15\sin 90^o}{0{,}68+\cos 90^o-1} = 25{,}07^O$
- $S = t + 2t\,X_{OF} + \frac{4t\,Vr}{1+t}\frac{4t\,Vr}{1+t} + v + 2X_{DC} + 1$

  = 4,42
- $B = \sqrt{t^2 + 2(t-1)v\cos dx + v^2 + 2t + 1}$

  = 1,68

for,

- $P_{mean} = \frac{2\ x\ 0{,}00175kg \times 286\frac{J}{kg.K} \times 323\ K}{7{,}59\ x\ 10^{-4}\ m^3\sqrt{(4{,}42)^2-(1{,}68)^2}}$

  $P_{mean} = 104230{,}49\ \frac{N}{m^2} = 104230.49$ Pa

- **Cycle Extreme Pressure**

  In the stirling engine there is also an extreme pressure that must be calculated. Extreme pressure is the maximum and minimum pressure that occurs in the Stirling cycle which is used as the driving energy of the Stirling engine.
  Calculation of extreme pressure where the value of the coefficient c is as follows:

$$C = \frac{BB}{SS} = \frac{1{,}681{,}68}{4{,}424{,}42} = 0{,}38.$$

- **Maximum Pressure (P_{max})**

  The maximum pressure is the largest pressure value that occurs in the stirling engine which can be calculated as follows:

$$\frac{Pmax}{Pmean} = \sqrt{\frac{1+c\,Pmax}{1-cPmean}} = \sqrt{\frac{1+c}{1-c}}$$

for,

$$Pmax = \sqrt{\frac{1+0{,}38}{1-0{,}38}}\sqrt{\frac{1+0{,}38}{1-0{,}38}}\ x\ 104230{,}49\ Pa$$

= 154261.12 Pa

- **Minimum Pressure (P_{min})**

  the minimum pressure on the stirling engine can also be calculated as follows:

$$\frac{Pmin}{Pmean} = \sqrt{\frac{1-c\ Pmin}{1+cPmean}} = \sqrt{\frac{1-c}{1+c}}$$

for,

$$Pmin = \sqrt{\frac{1-0{,}38}{1+0{,}38}}\sqrt{\frac{1-0{,}38}{1+0{,}38}}\ x\ 104230{,}49\ Pa$$

= 73586.72 Pa

- **Stirling Engine Work Generated in One Cycle (Wi)**

  The work of one cycle is the difference between the incoming and outgoing calorific values or the sum of the work when the piston expands and compresses is.
  $W_e = W_{AND} + W_C$
  Where are the values of Wc and W_{AND}will be equal to the number of calories so Qc = Wc, so does $W_{AND} = Q_{AND}$

- **Expansion Work (W_{AND})**

  Expansion work is the work produced in process 3-4 in the ideal Stirling cycle. Expansion work (W_{AND}) is obtained as follows:

$$IN_{AND} = \frac{Pmean.VSE.\pi.c.\sin\alpha}{1+\sqrt{1-c^2}}\frac{Pmean.VSE.\pi.c.\sin\alpha}{1+\sqrt{1-c^2}} = 20{,}83\ J$$

- **Compression Work (W_C)**

  The compression work is the work given to process 1-2 in the ideal stirling cycle. The negative sign in the equation indicates that work is directed into the system.

$$IN_C = -\frac{Pmean.VSE.\pi.c.t.\sin\alpha}{1+\sqrt{1-c^2}}$$

IN_C = - 14,16 J

- **Stirling Engine Work (Wi)**

  So the stirling engine work per cycle is:
  Wi = 20,83 J – 14,16 J = 6,67 J

$$Which = \frac{Wi\ .n}{60}\frac{Wi\ .n}{60}$$

$$Which = \frac{6{,}67\ J\ x\ 144}{60}\frac{6{,}67\ J\ x\ 144}{60} = 16{,}008\ \ Watt$$

- **Torque (T)**

$$Li = \frac{2\pi n T}{60000}$$

$$0{,}016 = \frac{2(3{,}14) \times 144\ \times T}{60000}$$

$$T = 1{,}0615\ Nm$$

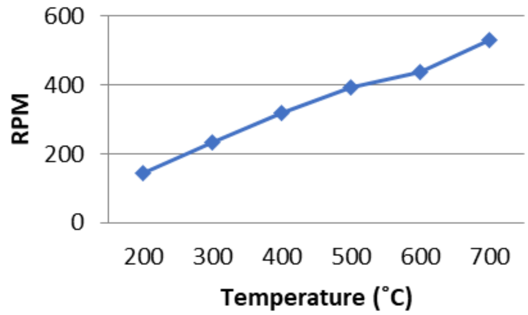


Figure 2. Graph of the Relationship between Temperature and RPM before modification

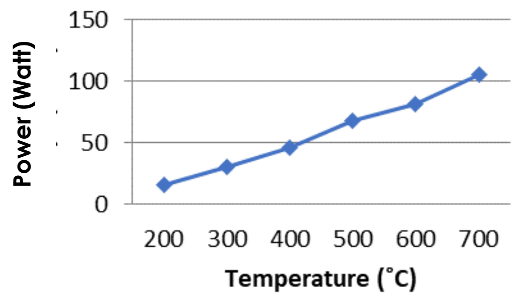


Figure 3. Graph of Relationship between Temperature and Power before modification

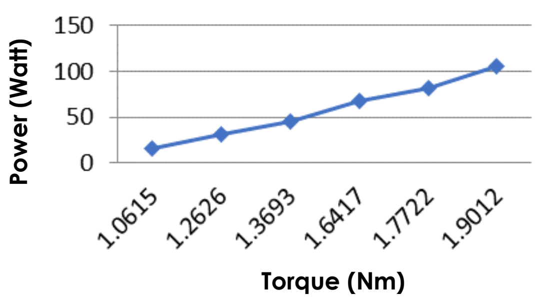


Figure 4. Graph of the Relationship between Torque and Power before modification

3.2. Calculation of test results data after flywheel modification

On the flywheel, the Stirling engine is slightly modified to get optimal results. The modification made to the flywheel is to apply a load of 1 kg to the top dead center (TDC) of the power piston.

Figure 5. modification of the flywheel on the stirling engine

after doing the calculations from the data from the test results, the results obtained are as follows.

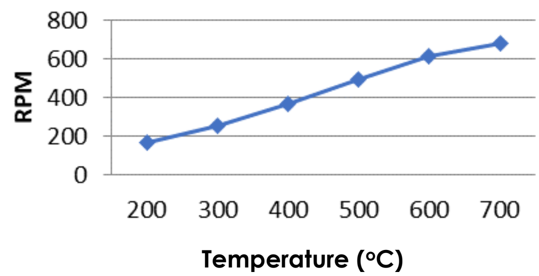


Figure 6. Graph of the Relationship between Temperature and RPM after modification

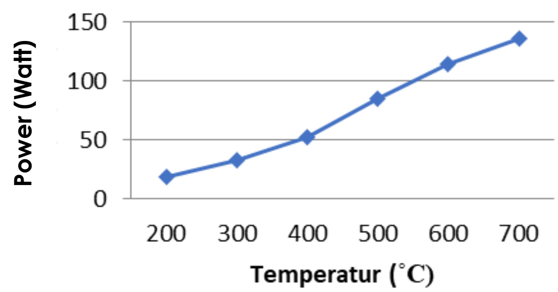


Figure 7. Graph of Relationship between Temperature and Power after modification

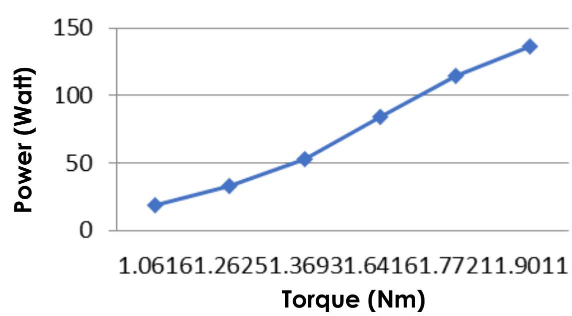


Figure 8. Graph of the Relationship between Torque and Power after modification

- Comparison before and after modification of the stirling engine flywheel

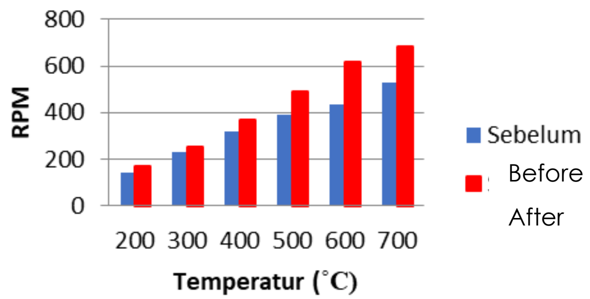


Figure 9. Comparison of RPM before and after modification

From the graph above, it can be seen that changes in the flywheel on the stirling engine affect the RPM. Changes to the flywheel help the stirling engine spin so that it gets bigger RPM results. Because the energy absorbed in the flywheel is flowed back to increase the flywheel rotation speed at the same input.

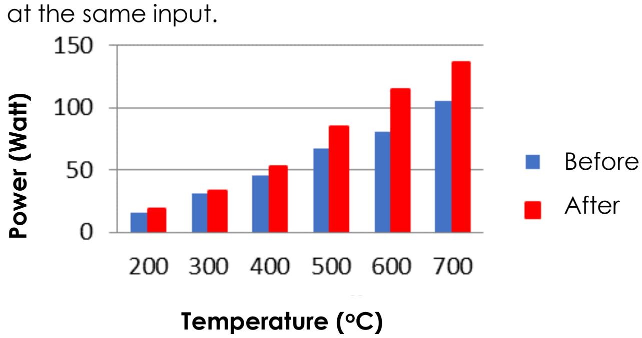


Figure 10. Comparison of Power before and after modification

From the results of the modification of the flywheel on the stirling engine, it can be seen that there is an increase in the power produced. This is because the RPM on the stirling engine has increased.

4.0 CONCLUSION

From the implementation of the research and analysis of the data obtained, several conclusions can be drawn, namely:

1. At a test temperature of 200˚C it produces a power of 16 Watts and a torque of 1.065 while at a test temperature of 700˚C it produces a power of 105.27 Watts and a torque of 1.9012 Nm. So, the greater the temperature, the greater the power generated.
2. The increase in RPM due to flywheel modification on the Stirling engine is an average of 22.7%. The increase in RPM is due to the energy absorbed in the flywheel being flowed back to increase the rotational speed of the flywheel at the same input.
3. The increase in power due to flywheel modification on the Stirling engine is an average of 22.7%.

Acknowledgement

I would like to thank those who have contributed to the implementation of this research. Hopefully what we have done can benefit those who read this article.

References

[1] Kongtragool B, Wongwises S. 2003. A review of solar-powered Stirling engines and low temperature differential Stirling engines. Renew Sustain Energy Rev.7(2):131–54.

[2] Chen J, Yan Z, Chen L, Andresen B. 1998. Efficiency bound of a solar-driven Stirling heat engine system. Int J Energy Res. 22(9):805–12.

[3] Topgül T, Okur M, Şahin F, Çınar C. Experimental investigation of the effects of hot-end and cold-end connection on the performance of a gamma type Stirling engine. Eng Sci Technol an Int J. 2022;36.

[4] Raghavendra H, Suryanarayana Raju P, Hemachandra Reddy K. Effect of Geometric and Operational Parameters on the Performance of a Beta-Type Stirling Engine: A Numerical Study. Iran J Sci Technol - Trans Mech Eng [Internet]. 2022;46(1). Available from: https://doi.org/10.1007/s40997-020-00406-0

[5] Zare S, Tavakolpour-Saleh AR. Free piston Stirling engines: A review. Int J Energy Res. 2020;44(7):5039–70.

[6] Singh UR, Kumar A. Review on solar Stirling engine: Development and performance. Therm Sci Eng Prog [Internet]. 2018;8(August):244–56. Available from: https://doi.org/10.1016/j.tsep.2018.08.016

[7] Shendage DJ, Kedare SB, Bapat SL. Numerical investigations on the Dish–Stirling engine system. Int J Ambient Energy. 2019;40(3):274–84.

[8] Asnaghi A, Ladjevardi SM, Saleh Izadkhast P, Kashani AH. Thermodynamics Performance Analysis of Solar Stirling Engines. ISRN Renew Energy. 2012;2012:1–14.

[9] Sarkar J, Bhattacharyya S. Application of graphene and graphene-based materials in clean energy-related devices Minghui. Arch Thermodyn. 2012;33(4):23–40.

[10] Khanjanpour MH, Rahnama M, Javadi AA, Akrami M, Tavakolpour-Saleh AR, Iranmanesh M. An experimental study of a gamma-type MTD stirling engine. Case Stud Therm Eng [Internet]. 2021;24(February):100871. Available from: https://doi.org/10.1016/j.csite.2021.100871

[11] Joseph J, Mathew Louis E, Thomas B, Anurag K, Sankar V, Pullan TT. Fabrication and testing of a gamma type stirling engine. Mater Today Proc [Internet]. 2019;46:9641–5. Available from: https://doi.org/10.1016/j.matpr.2020.07.152