Solar powered stirling engine for domestic household and rural areas in Karachi, Pakistan

Motor Stirling con energía solar para áreas domésticas y rurales en Karachi, Pakistán

Motor Stirling, alimentado por energia solar para áreas domésticas e rurais domésticas em Karachi, Paquistão

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Recibido: 24/10/2023 Aceptado: 13/11/2023

Summary. - There is a critical need to use the abundantly available solar energy worldwide due to the global energy crisis. The goal of this study is to demonstrate the residential use of a stirling engine powered by solar energy in Karachi, Pakistan. The design was carried out to produce a power output of 5 kW in order to address the issues with household and rural area power generating. The design was simulated using MATLAB. The use of solar energy as the engine's heat input was one of the design's key components. This allowed the engine to be built for locations with a lot of solar radiation. In regions with abundant solar energy, solar cookers, sun air warmers, and other appliances may be used. For power generation, however, the Stirling engine was chosen. Calculations of the sun intensity showed that 5 kW of Stirling engine output could be generated from 12 kW of solar electricity. The concentrator for concentrating and reflecting the incoming radiations to the Stirling engine was selected as a solar parabolic dish. This process heated the engine's working fluid, which then expanded and contracted due to thermodynamic forces to produce the engine's power strokes.

Keywords: Solar energy; Stirling engine; Schmidt analysis; Beale number.

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Memoria Investigaciones en Ingeniería, núm. 25 (2023). pp. 266-283
https://doi.org/10.36561/ING.25.15
ISSN 2301-1092 • ISSN (en línea) 2301-1106

Resumen. - *Existe una necesidad crítica de usar la energía solar abundantemente disponible en todo el mundo debido a la crisis de energía global. El objetivo de este estudio es demostrar el uso residencial de un motor Stirling alimentado por energía solar en Karachi, Pakistán. El diseño se llevó a cabo para producir una potencia de salida de 5 kW para abordar los problemas con la generación de energía del hogar y el área rural. El diseño se simuló usando MATLAB. El uso de la energía solar como entrada de calor del motor fue uno de los componentes clave del diseño. Esto permitió construir el motor para ubicaciones con mucha radiación solar. En regiones con abundante energía solar, se pueden usar cocinas solares, calentadores de aire solar y otros electrodomésticos. Para la generación de energía, sin embargo, se eligió el motor Stirling. Los cálculos de la intensidad del sol mostraron que 5 kW de salida del motor Stirling podrían generarse a partir de 12 kW de electricidad solar. El concentrador para concentrar y reflejar las radiaciones entrantes al motor Stirling se seleccionó como un plato parabólico solar. Este proceso calentó el fluido de trabajo del motor, que luego se expandió y contrajo debido a las fuerzas termodinámicas para producir los golpes de energía del motor.*

Palabras clave: *Energía solar; Motor Stirling; Análisis de Schmidt; Número de Beale.*

Resumo*. - Há uma necessidade crítica de usar a energia solar abundantemente disponível em todo o mundo devido à crise energética global. O objetivo deste estudo é demonstrar o uso residencial de um motor Stirling alimentado pela energia solar em Karachi, Paquistão. O projeto foi realizado para produzir uma potência de 5 kW, a fim de abordar os problemas com a geração de energia da área doméstica e da área rural. O design foi simulado usando o MATLAB. O uso da energia solar como a entrada de calor do motor foi um dos principais componentes do design. Isso permitiu que o motor fosse construído para locais com muita radiação solar. Em regiões com abundante energia solar, fogões solares, aquecedores de ar solar e outros aparelhos podem ser usados. Para a geração de energia, no entanto, o motor Stirling foi escolhido. Os cálculos da intensidade do sol mostraram que 5 kW de saída do motor Stirling podem ser gerados a partir de 12 kW de eletricidade solar. O concentrador para se concentrar e refletir as radiações de entrada no motor Stirling foi selecionado como um prato parabólico solar. Esse processo aqueceu o fluido de funcionamento do motor, que então se expandiu e contraiu devido a forças termodinâmicas para produzir os golpes de energia do motor.*

Palavras-chave: *Energia solar; Motor Stirling; análise de Schmidt; Número de Beale*

1. Introduction. – Energy plays a vital role in the economic development of a country. The source of energy should be cheap, environment friendly and highly available [1]. If the sources are not available in abundant, then the gap between the demand and supply of energy occur which can affect the whole mankind to run towards the development, this gap leads to energy crisis. Energy crisis is a significant congestion to the road of economy. It slows down the pace of economic activities as well as causing people unrest with shortage of electricity and gas [2]. Today, almost every country of the world is facing energy crisis. Such crisis includes oil & petroleum crisis, gas crisis, energy shortage and electricity crisis. The sources of energy like coal, oil and natural gas are very limited and we are mainly using these resources to fulfill our energy requirements. Meanwhile on the other side, the demand for energy supply is increasing by every passing year [3]. The main energy crises that the whole world is facing nowadays are high energy costs, depleting resources: monopoly control of supply and pricing of energy, irreversible environmental damages, lack of government support and funding for renewable energy [3]. Being situated in the sunbelt, Pakistan has a large solar irradiation area and receives a great amount of solar radiations, which can be used in different solar energy applications. In spite of having such advantages, Pakistan is facing energy crisis because of the less-utilization of renewable resources [4]. Pakistan's severe energy situation has become a roadblock to the economic potential in recent years. At the same time, the demand for energy is continuously increasing [5]. There are a number of devices on the market that enable the generation of electricity in home such as reciprocating engines, fuel cells, Stirling engines and thermocouples. Reciprocating engines provide the lowest price per unit of power, up to 10 kW. Most of the time electricity-producing devices are able to meet household needs, if not, and then electricity is taken from the grid. Similarly, the excess of electricity, produced by the device, can be sold to the grid. Power units available for use in the home do not usually exceed 1 kW. Low level of electrical power achievable from devices offered in the market is the result of analysis of the structure of electricity consumption by households [6]. The electricity demand in Pakistan has increased drastically within the last few years in which the main contribution is from the household sector [7].

Renewable energy is that kind of energy which is refined from those resources which are available in bulk amount, such as sunlight, wind, rain, waves and geothermal heat. Due to various issues with conventional or non-renewable resources, the researchers are paying their attention towards the renewable resources [1]. It is clear that the limited non-renewable resources are creating energy crisis, but on the other hand, a great potential for renewable resources is available. The entire energy crisis can be vanished if these renewable resources are utilized properly. Not only they are beneficial for energy side but are also environment friendly. Among these resources, the most important and highly available renewable resource is solar energy. Pakistan is blessed with a great potential of renewable energy resources such as solar energy, wind energy, hydropower energy, geothermal energy etc. As Pakistan covers a large solar radiation area, it is rich in sunlight and solar energy. Pakistan has a huge solar potential which is estimated to be 100,000 MW [7]. So, there is massive opportunity to use this renewable resource in many applications by using different solar conversion techniques.

Amongst all available techniques, solar thermal is a technique that captures the solar radiations striking the surface of collector and converts this solar energy into heat energy which then utilized for heating processes and electricity generation [8]. They are further classified into two types (Concentrating System and Non-Concentrating System) on the basis of different applications and design conditions. Concentrated solar power (CSP) systems is used to concentrate solar radiations onto the solar panel that converts it into heat energy [9].The aperture area of the concentrator or reflector is very large as compared to the area of receiver. Due to large aperture area, CSP systems cover a large sunlight area which results in the high achievable temperatures [8]. These systems are generally used for power generation. There are various types of solar concentrators available as parabolic trough (PT), linear Fresnel (LF), solar power tower (SPT) and parabolic dish (PD).

Amongst mentioned concentrators, parabolic dish concentrator is similar to a large satellite dish in appearance but has mirror-like reflecting surface and an absorber placed at the focus. It takes a large area of sunlight and converges them to a small heat exchanger due to which less heat exchange area is required which consequently reduces the cost. Parabolic concentrator is a heat exchanger that operates with highest efficiency of 29.4% in the power generation [10]. It uses a dual axis tracking system in order to capture maximum radiations [11,12]. Because of high optical efficiencies and good achievable temperatures at the receiver of the system, these systems are associated with wide range of applications. Small concentrators generate heat for small scale applications, like food processing and space heating, whereas, large concentrators can provide high temperature steam for large scale applications, like power generation and industrial processes.
The high temperature fluid can be utilized in following applications [13]:

- Electricity generation
- Food processing
- Space Heating
- Crop drying
- Water treatment and removal of toxic substances.
- Reprocessing of waste materials

The parabolic dish concentrators are just like a large satellite but have reflecting surfaces which helps in concentrating large area of sunlight to a small area of receiver efficiently. Stirling engine is located at the focus of parabolic dish which receives solar radiations, a tracking system used to direct the dish automatically towards the sun and a generator for power generation [11]. An efficient reflector must possess following characteristics:

- Reasonable weight according to the requirement
- Low cost
- Durability against moisture and weather changes

Such system has high optical efficiency and possesses a low operating loss. These factors make parabolic concentrator most efficient and cheap solar energy conversion technique. Furthermore, parabolic dish system is crucially designed for small and moderate scale applications of about 10 kW which is capable for fulfilling power requirements in rural areas of Pakistan where national electricity grid is far away [10]. A parabolic geometry contains the locus of points which is equally distanced from fixed line and point. This line and point are known as the directory and the focus respectively. The intersection point of its axis is known as vertex which is the middle point of directory focus [14]. The components of parabolic solar concentrator include base support, reflecting surface, dish frame, and a solar tracking system. The tracking system involved is two axis tracking system that has slew drivers. Main function of slew drivers is to ensure the dish rotation in both vertical and horizontal directions by all possible angles. There exist several ways to set the whole dish for the convergence of incoming radiations, the most efficient way is to adjust the base support at the center of gravity point of the whole dish so that the torque on the transmission system can be reduce easily. All these components should function properly so that the entire system can work efficiently [10]. Frames of the dish are of many kinds such as trusses, rectangular beams, H-beams, T-beams, etc. Among them, rectangular beam is the simplest one in manufacturing. The frame of the concentrator must be designed in such a way that it can easily support the weight of the sheets of reflecting material and forces of wind. A good dish must give minimum possible deflection due to applied forces on it because high deflection can influence the efficiency of the entire dish system. For the robust structure, ribs are joined to base rings through radius [10].

Reflective surfaces are used to obtain a shiny and brighter dish surface so that it can concentrate a tremendous amount of solar radiations onto the receiver placed at focus of the dish. In order to increase the efficiency of the entire system, the material with high reflectivity must be selected. It may be aluminum sheets, glass mirrors, and sheets of stainless-steel. For settlement among efficiency and cost, sheets of stainless steel appear to be a suitable choice. Furthermore, sheets of stainless steel are easy to assemble, and provide high resistance against corrosion even in the severe weather conditions [10]. The parabolic dish concentrators are designed to collect as much solar energy as possible; it can be done only when the solar collector is following the sun path. For this purpose, good tracking system is needed. PDS uses a dual axis tracking system to capture maximum solar radiations in both vertical and horizontal directions [15]. The Stirling system proves to be one of the best methods of utilizing solar radiation heat as mechanical energy, with theoretical maximum efficiency. This engine runs on a closed reversible cycle, and it uses a renewable energy source, without the combustion of any fuel. Such a heat source can be solar radiation. Stirling Engines are of much interest due to requirements of low-temperature heat source at temperature differences between 150°C and 400°C and they can produce up to an astonishing 25 kW power [16]. The main benefit of using the Stirling engine is the possibility to utilize any heat source. This paper serves the purpose of analyzing and designing a Stirling engine that can successfully power a domestic household.

Pakistan is confronting serious energy issues since the past few years. The current energy situation has become a massive hurdle in the road of Pakistan’s economy. Many industries and organizations have shut off because of absence of electricity supply to fulfill their requirements. The gap between the supply and demand of energy is increasing day by day, and now it has reached to 5000 MW, further it is expected to rise extensively in the next coming years. Pakistan has tremendous potential in renewable energy resources to fill this gap, but we need to utilize it efficiently. Pakistan, being situated in the Sun Belt, enjoys an advantage of different solar energy techniques. This source of energy is widely distributed and available in abundance throughout the country. Pakistan covers a large area of sunlight, and receives global irradiation in bulk amount, ranges from 4.45 - 5.83 kWh/m2/day as an annual mean value. Most of the areas in Pakistan receive 5.30 kWh/m2/day of global irradiance. While the World's average solar irradiation is 3.61 kWh/m2/day. The lowest value of Pakistan's solar irradiation (4.45 kWh/m2/day) is even greater than the world's average, so it is clearly indicated that Pakistan stands in a great Sun Belt range [17].

The present study focuses at designing a solar powered Stirling engine powered by solar parabolic dish concentrator for the power generation to cater the serious energy crisis especially in rural areas of Pakistan. By limiting the cost, the entire weight of the plate is reduced. There is a compromising situation between efficiency and cost. The study will analyze the best suitable material to meet the requirement at low cost.

2. Methodology. - The design of the parabolic dish concentrator is influenced by various factors, which includes dish diameter, material used in the dish, aperture size, focal length, rim angle. The steps involved in the analyzing and designing a parabolic dish receiver system and detailed equations of model are given as:

The initial step in the designing of the parabolic concentrator is selection of diameter of parabolic dish (D_{conc}), since rest of the calculations depend on the diameter. Selection of diameter is based on the output power requirement.

Aperture area (A_{conc}): is the total area upon which all the incoming radiations from sun are incident. The aperture area is calculated by the following equation (1)

$$A_{conc} = \frac{\pi}{4} D_{conc}^{2} \tag{1}$$

Rim angle (ϕ_{rim}) can be described as an angular distance that is measured along the focal length to the edge of the solar parabolic truncated [18].

The parabolic dish converges the incident radiations to a point called the focus. The distance between the axis of the dish and the focus is defined as the focal length (f). It is found by using the equation (2)

$$f = \frac{D_{conc}}{4\tan\left(\frac{\phi_{rim}}{2}\right)} \tag{2}$$

The diameter of the focus ($\mathrm{D_{rec}}$) affects the size of the receiver, which accepts the reflected radiation of the concentrator. It can be found by equation (3)

$$D_{rec} = \frac{f * \vartheta}{cos\phi_{rim}(1+cos\phi_{rim})} \tag{3}$$

The solar radiations reflected by the concentrator are received by the cavity receiver and transfers the heat to the operating fluid. Area of aperture($\mathrm{A_{rec}}$): is found by equation (4)

$$A_{rec} = \frac{\pi}{4} D_{rec}^2 \tag{4}$$

Concentration ratio ($\mathbf{C}$) is the ratio of aperture areas of concentrator and receiver. The value of concentration ratio varies between 1 and 10,000. It can be given as equation 5;

$$C = \frac{A_{conc}}{A_{rec}} \tag{5}$$

The power output of the Stirling engine can be selected according to requirement and the available solar energy in the region. After the selection of the power, the best configuration of the engine is selected and the designing process is started. The design is based on Beale number technique and Schmidt concept [19]. Beale number technique is used to estimate the power output of a Stirling engine design. An approximate relation of the power output was given by the scientist William Beale which is correct for all types of gamma Stirling engine [13]:

$$P = 0.015p \times f \times V_{\circ} \tag{6}$$

Where;
P= Power output of a Stirling engine
Pm= Mean cycle pressure in bars
f= Speed of engine in Hz
Vo= Displacement volume of power piston in cm3

$$V_{\circ} = V_e + V_E = (1 + kr)V_E \tag{7}$$

By rearranging the equation (6) as:

$$P/(p \times f \times (1 + kr)V_E) = Constant \tag{8}$$

This constant is known as Beale number which is 0.015 for almost all type of Gamma Stirling engine. The combination of all above parameters is a dimensionless quantity which depends on the hot side temperature and cold side temperature.

Schmidt analysis [19] is based on isothermal analysis which assumes the sinusoidal volume variation in the expansion space as well as in the compression space. This theory assumes the ideal compression and ideal expansion processes in the isothermal system, in which temperature of fluid before work done and after work done remains constant. The regenerator which acts as a heat exchanger between cold side and hot side space is assumed to be an ideal. This method is considered to be real even though some idealization in the processes is included. Schmidt analysis is the useful technique in the designing of Stirling engine and the most important approximation for engines running at low rpms. The Schmidt technique allows finding the engine performance under P-V diagram. All the possible processes are being governed through perfect gas equation. To simplify the designing phase of the Stirling engine, there are some assumptions that are necessary for efficient Gamma engine. Below are listed some important assumptions [20]:

- Working gas is a perfect gas, i.e. it obeys general gas equation.
- Regenerator is assumed to be an ideal, i.e. the regenerative is perfect.
- Mass flow rate of a working fluid remains constant.
- The volume of working spaces varies sinusoidal.
- The expansion and compression are both isothermal.
- The regenerator temperature is logarithmic mean temperature of expansion side and compression side.
- The speed of engine remains constant.

The first stage in creating a Stirling engine is determining the power output that is needed for our application, and only then should the configuration be designed. There are three fundamental Stirling engine configurations: Alpha, Beta, and Gamma, as mentioned in the literature study. Given that they are used in practice, several relevant parameters must be assumed. The swept volumes of the compression and expansion cylinders are determined using the Beale number idea and Schmidt analysis theory, leading to the evaluation of a few constants. These constants are found by repeatedly applying iterations until the desired power output is obtained. Swept volumes are evaluated by calculating the phase angle. The parameters and nomenclature used in the Schmidt analysis are listed below:

- Tc= Compression side temperature
- TH= Expansion side temperature
- Vc= Live volume of compression side
- VE= Live volume of expansion side
- Vd= Total volume of regenerator and associated ducts and ports
- Qe= Amount of heat transferred in the expansion side
- $Tr = \frac{T_C}{T_H}$
- X= VD/VE, Dead volume ratio
- kr= Vc/VE, Swept volume ratio
- Ar= (Tr2 + 2 x Tr x k x cos(a) + k2) ½, A factor
- B= (Tr + k + (2 x S)), A factor
- N= Speed of engine
- Pm= Mean cycle pressure
- P= Power extracted from the cycle
- R= Gas constant
- $S = \frac{(2X\tau)}{T_R+1}$, Reduced dead volume

- $\delta_i = \frac{(T_r{}^2+k^2+2T_r k\cos\alpha)^{\frac{1}{2}}}{(T_r+k+2S)}$, A constant
- αi= Phase difference between expansion and compression space
- $\theta_i = \tan^{-1}\{(k\sin\alpha_i)/(T_r + k\cos\alpha_i)\}$
- $\emptyset_i = \alpha_i \times 180°$, Phase angle
- ϕ_i= Crank angle

Before starting calculations, some fixed parameters are assumed that are associated with the operation of Stirling engine, which are the Power (P), efficiency (η_{th}), the compression side temperature (TC) and the mean pressure (Pm) and Hot side temperature (Th).
By the Carnot thermal efficiency formula:

$$\eta_{th} = 1 - \frac{T_C}{T_H} \tag{9}$$

Calculation for volume by Beale number concept

$$f = \frac{N}{60} \tag{10}$$

Net Work done by the cycle is found by the formula:

$$Net\ work\ done = \frac{P}{f} \tag{11}$$

Heat input by the Beale number method is determined by:

$$Heat\ Input,\ \ Q_e = \frac{Net\ work\ done}{\eta_{th}} \tag{12}$$

By the equation (8),

$$0.03 = \frac{P}{(p_m \times f \times (1+k_r)V_E)} \tag{13}$$

From Schmidt cycle,
The heat transferred to the working space in the expansion space is given by:

$$Q_e = \frac{\pi\, p_m\, V_E\ \delta_i \sin\phi_i}{1 + \sqrt{1-\delta_i{}^2}} \tag{14}$$

But since pm and VE are unknown here so equation (8) can be written as,

$$p_m V_E = \frac{P}{(1+k_r) \times f \times 0.03}$$

Substituting the above factor into the equation (14), so it becomes:

$$Q_e = \frac{\pi\, P\ \delta_i \sin\phi_i}{(1 + \sqrt{1-\delta_i{}^2}\,) \times (1+k_r) \times f \times 0.03} \tag{15}$$

After the determination of the heat transferred to the working fluid in the working space by applying iterations, the required volumes for expansion space, compression space can be easily found.

The volume of expansion space is given by equation (16)

$$Ve = \frac{1}{2} \times V_E(1 + cos\emptyset_i) \tag{16}$$

For this type of engine, the compression space volume is determined by the position of the working piston as well as by the position of the displacer. The formula for finding the volume is given in equation (17):

$$V_c = \frac{1}{2} V_C \left[1 + \cos(\phi_i - \alpha_i)\right] = \frac{1}{2}\ k_r V_E[1 + \cos(\phi_i - \emptyset_i)] \tag{17}$$

The crank angle a reaches the value of zero when the displacer is at the upper dead point.

Volume of dead space is a constant volume of the total working volume and is excluded from the volumes of expansion and compression.

$$V_D = XV_E \tag{18}$$

The total swept volume of the engine is given by

$$V_T = V_e + V_C + V_D \tag{19}$$

The volumes that will be obtained by the simulation of these equations will be helpful in the fabrication of the engine and will give an accurate estimation of the size of the engine. These volumes are dependent on the engine RPM, the variation of engine speed will provide us with different volumes for the same power output. Hence, we can then select an engine model according to our power requirements and area limitations. As discussed, the operation of the Stirling engine is largely dependent on the heat source. The engine can be designed keeping in view the source of heat input available. Since we are designing a Solar powered Stirling engine, we have to estimate the amount of solar radiations and to design a viable means to utilize this radiation as the heat source on the hot end of the engine.

2. Results and Discussion. - Both urban and rural areas can solve their power generating issues with the help of solar-powered Stirling engines. MATLAB was used to model the mathematical equations covered in the earlier chapters, ensuring accuracy in the results. For our purposes, the parabolic dish that reflects the incoming radiations is positioned with the Stirling engine at its center. Other uses for the parabolic dish include solar air heating and cooking, which are particularly helpful in remote locations without access to power or gas. This study focuses on the Stirling engine, which has the characteristics listed in Table 1.

LOCATION	KARACHI
SOLAR COLLECTOR	PARABOLIC DISH CONCENTRATOR
SOLAR APPLICATION	STIRLING ENGINE
ENGINE CONFIGURATION	GAMMA CONFIGURATION
REQUIRED POWER OUTPUT	5 KW

Table 1: Main characteristic requirement

The Stirling engine is designed to deliver a power output of 5 KW which is sufficient for our requirements. The engine configuration is chosen to be gamma type. The reasons for this are twofold.

- Gamma Stirling even works efficiently on small temperature difference that beta and alpha can’t operate on such small temp difference.
- Gamma type engines have a displacer and power piston, similar to Beta machines, however in different cylinders. This allows a convenient complete separation between the heat exchangers associated with the displacer cylinder and the compression and expansion workspace associated with the piston. Thus, it avoids the complications of the displacer piston passing through the power piston.

The practical working efficiency of the engine on the basis of experimental information in research papers was found to be 40 % [21]. Using this efficiency and power output the equations in chapter 5 are simulated on MATLAB. The different parameters are iterated to result in a power output of 5 KW. These values are shown below. Other than the engine power output and engine efficiency, some parameters have to be assumed on the basis of practical experimentation (TC= 293K; Pm= 1 bar). At first it is necessary to find the temperature of hot side before finding any other parameters of engine. By using the equation (9), the hot side temperature was found to be, TH= 488.33K. The performances of the constructed engine are shown in the Table 2 below, in which the speed of engine is varied from 1500 rpm to 3000rpm at a constant power output of 5000 Watts.

Engine speed (RPM)	Engine Frequency (Hz)	Net Work done (Joules)	Heat Input (Joules)
1500	25	200	500
2000	33.333	150	375
2500	41.667	120	300
3000	50	100	250

Table 2. Heat Input at different RPMS

In order to confirm the heat input values from the formulae, the iteration technique is applied to find the basic parameters that can be used in Schmidt analysis.

By inserting these values in equation (15), Table 3 shows the obtained heat inputs running on different engine speeds using iterations:

Engine Speed (RPM)	**Heat Input (Joules) 1st iteration**	**Heat Input (Joules) 2nd iteration**	**Heat Input (Joules) 3rd iteration**
	α = 0.3, φ= 54°, X= 1.5, k= 1	α = 0.2, φ= 36°, X= 2, k= 1.3	α = 0.15, φ= 27° X= 2.5, k= 1.5
1500	1141.52	736.35	503.62
2000	856.14	552.26	377.71
2500	684.91	441.81	302.17
3000	570.76	368.17	251.81

Table 3: First Iteration of Heat Input at Different RPMS

Since by the third iteration, the heat input to the working fluid was found to be near to one that was calculated above. So, these parameters were further used to find the required volumes of expansion space, compression space and the dead region.

After determining the heat input from the iteration techniques, we are able to successfully find out the expansion space volume, the compression space volume and the total volume of the engine. By using equations (13,16,17,18), Table 4 shows the results obtained by running on different engine speeds.

Engine Speed (RPM)	Expansion space volume (cm^3)	Compression space volume (cm^3)	Total Maximum Volume (cm^3)
1500	643.97	965.95	3198.48
2000	482.97	724.46	2398.86
2500	386.38	579.57	1919.09
3000	321.98	482.97	1599.24

Table 4: Engine Volumes for Different RPMS

Since Schmidt analysis assumes the harmonic variation of expansion and compression, therefore Figures 1-4 shows the graphs if crank angle V/S expansion and compression volumes running on different engine speeds that support assumption.

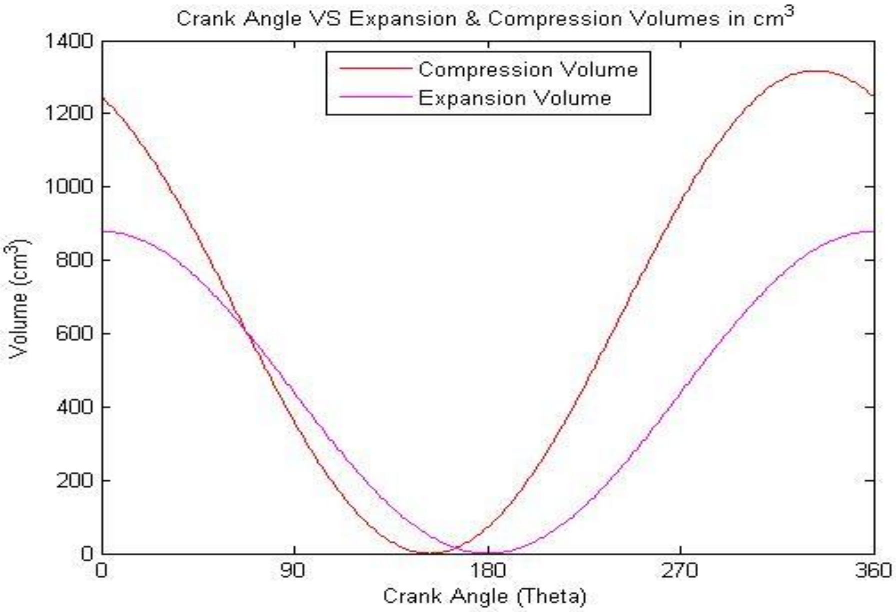

Figure 1: Crank Angle VS Expansion and Compression volumes at 1500 rpm

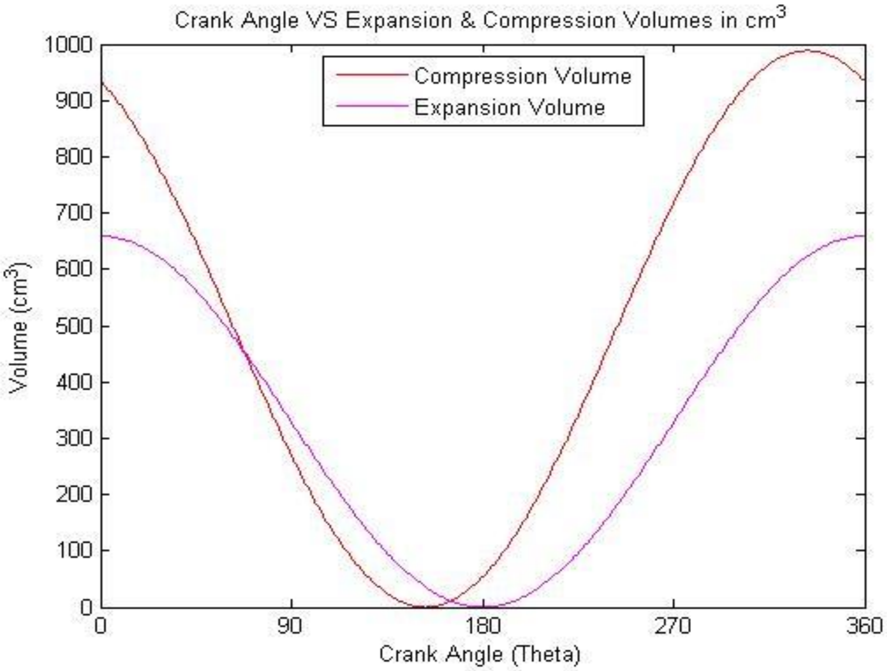

Figure 2: Crank Angle VS Expansion and Compression volumes at 2000 rpm

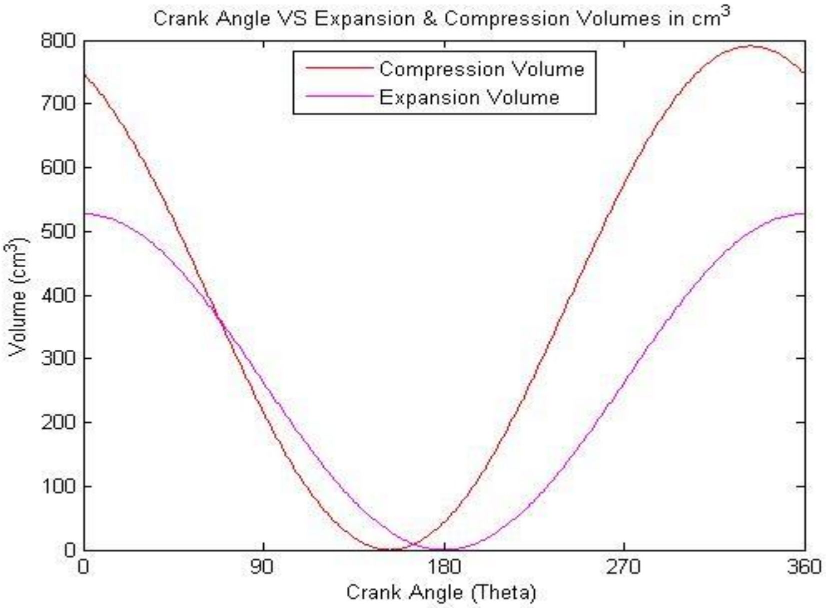

Figure 3: Crank Angle VS Expansion and Compression volumes at 2500 rpm

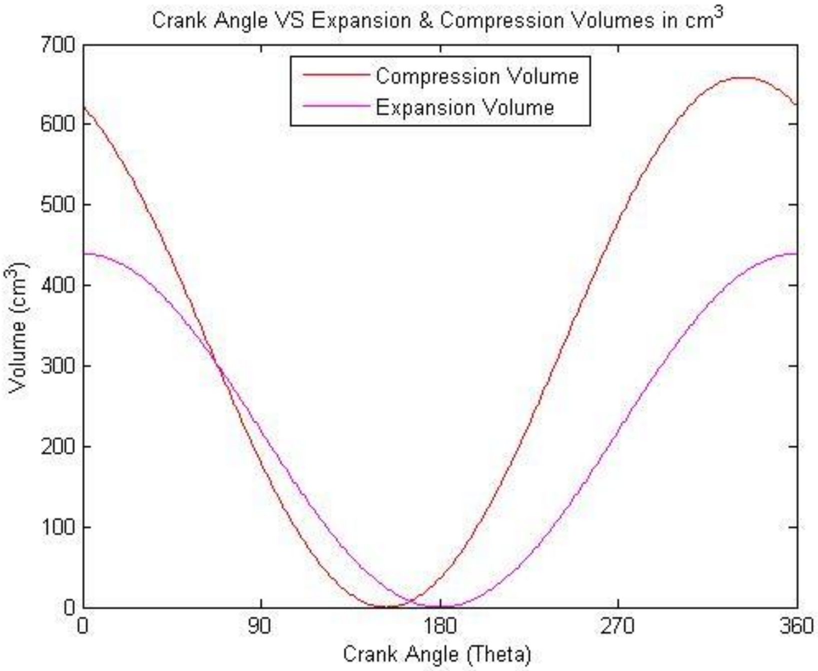

Figure 4: Crank Angle VS Expansion and Compression volumes at 3000 rpm

It can be seen from the figures 1-4 that as the engine speed goes on increasing, the maximum volumes of compression region and expansion regions decreases. Therefore, it is important to select the optimum engine speed in the designing phase to make the engine performance better. The engine having an efficiency of 40% needs more power (=12kW) to generate 5kW. The parabolic dish concentrator has to reflect greater power in order for the Stirling engine to operate. Based on the solar radiation information obtained, there is a need to find a suitable dish diameter in accordance to power requirement of 12 KW. The dish diameter is the most important factor in designing the dish. The other parameters will be calculated on the basis of dish diameter for the complete design of dish. In the graph of Figure 5, the diameter of the dish is plotted against the power generated by average DNI radiations. As per requirement of 12kW, the required diameter of dish was 6.6m. based on the diameter, the focal length was found to be 2m with rim angle of 80°.

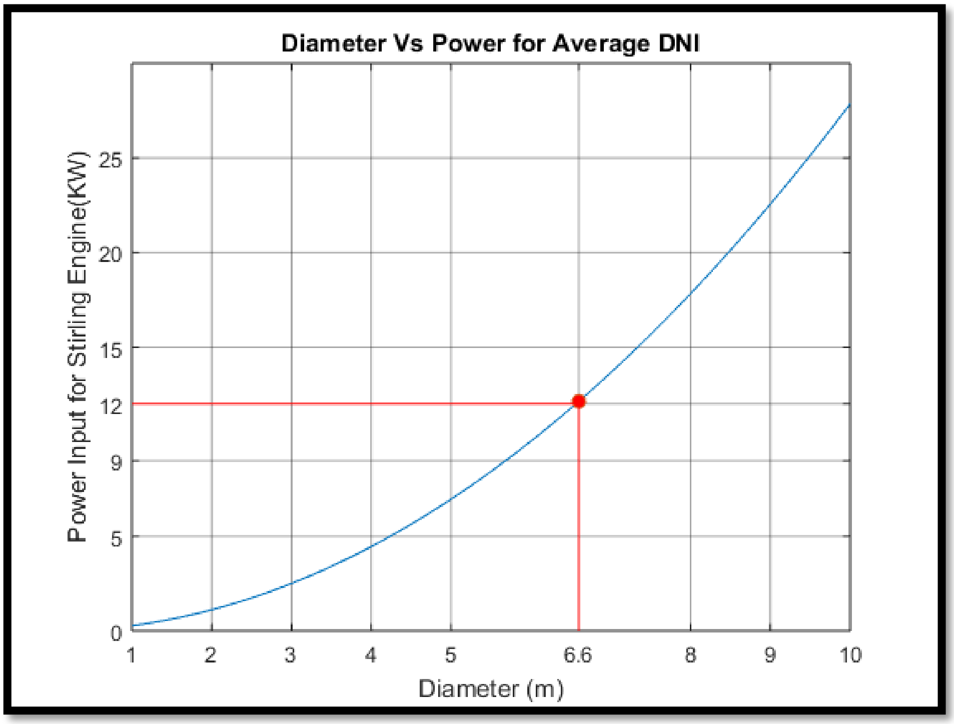

Figure 5: Diameter vs Stirling Power Input Graph

3. Conclusion. - To address the problems associated with power generation in rural and residential locations, the design was carried out to produce a power output of 5 kW. MATLAB was used to simulate the design. The outcomes turned out to be encouraging. One of the primary features of the design was the engine's heat input being provided by a solar energy source. This made it possible to design the engine for areas with strong solar radiation. Numerous uses, such as solar air warmers and cookers, are possible in an area where sun energy is plentiful. However, the Stirling engine was chosen for power generation. Five kW of Stirling engine output might be produced with 12 kW of solar electricity, according to calculations of solar intensity. The concentrator for converging and reflecting the incoming radiations to the Stirling engine was chosen to be a solar parabolic dish. Through thermodynamic processes, the engine's working fluid expanded and compressed, gaining heat that caused the engine to produce power strokes. While very helpful, the method of producing power with a Stirling engine and solar concentrator is not perfect. There is more room for improvement in the system's overall efficiency. We must address the real-world issue of energy losses, which can be mitigated by first choosing the best spot to install the dish. Our findings are quite helpful in this regard. Our model provides a user-friendly way to present the average daily, monthly, and annual values of the solar radiation striking a location at any given time of day. Secondly, by choosing a dish reflecting surface material with a high absorptivity, which allows it to absorb the majority of the radiations landing on it, the efficiency can be increased, without losing much to heat transfer losses. If the temperature at the engine's hot end is raised, the efficiency of the Stirling engine can be greatly enhanced. However, this requires that the radiations reflected by the dish reach the engine with little loss. It is possible to optimize the engine's working fluid to absorb more thermal energy. A major factor in reducing losses is the engine's configuration. The chosen gamma configuration's design minimizes issues brought on by seal and piston overheating. The system still has a lot of problems that need to be resolved, but as technology advances gradually and solar energy replaces fossil fuels as the primary energy source, research into solar energy and its applications appears to be both an encouraging field and a viable answer to many of the world's current issues. Our project's goal was to develop simple, user-friendly models for calculating solar energy and power generation solutions in the hopes that our efforts will assist others who face the same modern technological difficulties.

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Nota contribución de los autores:

1. Concepción y diseño del estudio
2. Adquisición de datos
3. Análisis de datos
4. Discusión de los resultados
5. Redacción del manuscrito
6. Aprobación de la versión final del manuscrito

MU ha contribuido en: 1, 2, 3, 4, 5 y 6.

IY ha contribuido en: 1, 2, 3, 4, 5 y 6.

SAJ ha contribuido en: 1, 2, 3, 4, 5 y 6.

BF ha contribuido en: 1, 2, 3, 4, 5 y 6.

MF ha contribuido en: 1, 2, 3, 4, 5 y 6.

Nota de aceptación: Este artículo fue aprobado por los editores de la revista Dr. Rafael Sotelo y Mag. Ing. Fernando A. Hernández Gobertti.