Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2015
(ICMERE2015) 26 – 29 November, 2015, Chittagong, Bangladesh

ICMERE2015-PI-207

DESIGN AND DEVELOPMENT OF A PARABOLIC DISH SOLAR COLLECTOR

Md Arafat Islam[1,*], Kh. Md. Faisal[2], Md Rejwanul Haque[3] and Maidul Islam[4]

[1-4]Military Institute of Science and Technology, Mirpur Cantonment, Dhaka-1216, Bangladesh
[1,*]aisadaf7@yahoo.com, [2]faisal@ae.mist.ac.bd, [3]rejwan.xy@gmail.com and [4]mislam.dipu@gmail.com

Abstract*- The main aim of this research is to develop a solar collector to provide lower temperature heat to LTD Stirling engine. A low thermal energy is transferred to the Stirling engine as a heat source. This collector is used as a solar tracker to regulate the position of the dish to optimize the power output of the engine. The tracker is automated by the fuzzy logic. Moreover, this research projects the modeling, fabrication and the thermal efficiency of the system in which the estimated thermal efficiency is 50.17 %.*

Keywords: Solar, Design, Stirling engine

1. INTRODUCTION

In past two decade there has been significant increase in the price and the demand of the conventional fossil fuel for power generation. Recently, alternative energy has become a demand of time to mitigate such problems and solar thermal energy could a best option in this regard. To demonstrate such problem a parabolic dish solar collector is designed to provide energy to the LTD Stirling Engine for small scale power generation. Approximately a 700 watt solar heat input is required to operate the engine which rated power output is 2 watt [1]. A parabolic solar water heater concept is used to design the collector and hence experimental analysis is carried out to investigate whether the designed collector is able to supply require heat input to the absorber to raise the temperature of water at expected level. Fuzzy logic is applied to optimize solar tracking throughout the day time to ensure best efficiency.

2. CALCULATION OF AREA UNDER PARABOLA

To design the parabolic dish solar collector the area under a parabola are to be determined. Consider a parabolic arc as shown in Fig. 1 with the width of its base B and height H. We want to find a suitable formula for the area under the arch [2].

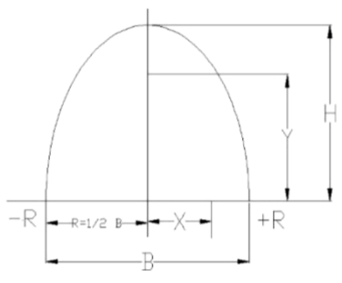

Fig.1: An arch having height H and base B

Let us consider,
Width = B
Height = H
R = ½ B one half of the base from the geometry
x = Variable change from –R to +R
y = Height of the arc above point on its base.
The general equation of parabola is

$$y= ax^2 + bx + c \qquad (1)$$

Here, (x, y) co-ordinates are (R, 0), (0, H), (-R, 0)
Now when x=R, y=0; x=0, y=H
The parabola must passes through the point (-R, 0), (0, H), (R, 0)
So,

$$0 = R^2a + Rb + c \; [R, 0] \qquad (i)$$

$$0 = Ra^2 - Rb + c \; [-R, 0] \qquad (ii)$$

$$H = c \; [0, H] \qquad (iii)$$

Solving (i), (ii), (iii) we get the value

$$a = \frac{-H}{R^2}, \qquad b = 0, \qquad c = H$$

Putting the value of a, b, c in Eq. (1) we get,

$$y = H - \left(\frac{H}{R^2}\right)x^2$$

$$\Rightarrow x^2 = \frac{R^2}{H}(H - y)$$

3. GEOMETRICAL PARAMETER CALCULATION

From the geometry,
Small elemental volume $= \pi x^2 dy$

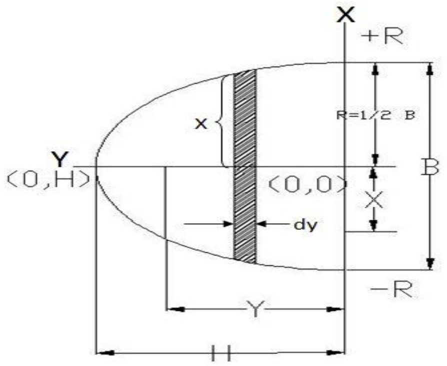

Fig.2: Geometrical parameter calculation

Total Volume,

$$V = \int_0^H \pi x^2 dy = \frac{\pi R^2 H}{2}$$

Area,

$$A = \frac{\frac{\pi R^2 H}{2}}{H} = \frac{\pi R^2}{2}$$

From the equation of parabola,

$$y = H - \left(\frac{H}{R^2}\right) x^2$$

The equation of vertex

$$X^2 = 4fY$$

Let us consider,
$H - y = Y, x = X$
So,

$$X^2 = \frac{R^2}{H} Y$$

Compare with $X^2 = 4fY$ [where $Y = (H - y), x = X$]

$$4f = \frac{R^2}{H}$$

Focal point,

$$f = \frac{R^2}{4H}$$

4. DESIGN OF THE COLLECTOR

The solar collector is designed to collect heat by absorbing sunlight. It is a device for converting the energy in sunlight, or solar radiation, into a more usable or storable form. The quantity of solar energy striking the Earth's surface averages about 1,000 watts per square meter under clear skies, depending upon weather conditions, location, and orientation of the surface [3, 4]. Basically this collector is designed based on giving adequate heat energy to a locally fabricated LTD Stirling Engine, as shown in Figure 3. This engine usually runs by recovering the waste heat from the heated water and the performance of the engine depends on the temperature difference between the top and the bottom plate of the engine (only based on rpm here) as shown in Table 1. A constant heat input is maintained by Fuzzy controlling unit to get best possible output from the engine throughout the day time. i.e. by applying a simple Fuzzy Logic.

Fig.3: LTD Stirling Engine

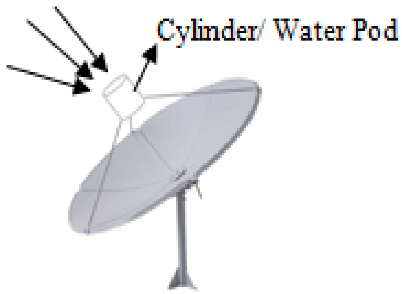

Fig.4: Solar Dish Collector

Table 1: Performance of LTD Stirling Depending on Temperature Difference

Observation No.	Temperature (°C)			R.P.M.
	Hot Plate	Cold plate	Difference	
1	80	7	73	69
2	84	7	77	74
3	89	7	82	87
4	93	7	86	94
5	98	7	91	107

For providing adequate heat input (up to maximum 100˚C) to the water in order to run LTD Stirling Engine, the absorber of the heater is selected as cylinder. The following parameters/ dimension are considered to design the collector. High reflected mirror is used to reflect solar ray and the absorber is made of aluminum sheet metal.
Volume of water inside the tank = Volume of absorber
So, the effective surface of heating area is,

$$A_{abs} = \frac{\pi D_{abs}^2}{4} + \pi D_{abs} \times L = 0.219 m^2$$

To reduce the frequency of tracking
Take the value, c=10. [5], the aperture area $(A_a) = c\, X$ 0.219. The aperture diameter is

$$\frac{\pi D_a^2}{2 \times 4} = 2.19$$
$$\Rightarrow D_a = 2.36\, m$$

We take the height $H = 30\ cm$

The focus length,

$$f = \frac{\pi D_a^2}{2 \times 4} = 2.19\ cm$$

Volume of the collector,

$$V = \frac{\pi R^2 H}{2} = 656153.4\ cm^3$$

The incident surface area of the collector,

$$A = \frac{\pi R^2}{2} = \frac{\pi (236)^2 H}{2} = 43743.54\ cm^2$$

$$\frac{f}{D}\ \text{ratio} = 0.49$$

Linear Diameter = $245.77\ cm$

In order to get the parabolic shape of the collector the following co-ordinates as mentioned in Table 2 is used from the formula mentioned above.

Table 2: x, y Coordinate

X (cm)	Y (cm)
-118	30
-103.25	22.97
-88.50	16.88
-73.74	11.72
-59.00	7.50
-44.25	4.22
-29.50	1.88
-14.75	0.47
0.00	0.00
14.75	0.47
29.50	1.88
44.25	4.22
59.00	7.50
73.74	11.72
88.50	16.88
103.25	22.97
118	30

5. THERMAL PERFORMANCE ANALYSIS

The mass flow rate of heated water, $\dot{m} = 2.4982\ x\ 10^{-3}\ kg/s$

Water inlet Temperature, $T_1 = 25°C$

Water outlet Temperature, $T_2 = 100°C$

Heat absorbed by water,

$$Q = mC_p \Delta T = 787.44W$$

Energy Incident**,**

$$I_b A_a = 716.6\ \frac{W}{m^2} \times 2.19\ m^2 = 1569.354\ W$$

Thermal Efficiency,

$$\eta = \frac{Energy\ Absorbed}{Energy\ Incident} \times 100\% = 50.01\%$$

6. FUZZY BASED CONTROLLING UNIT

Fuzzy theory is a science closely related to our lives. It describes things with language. A solar panel receives the most sunlight when it is perpendicular to the sun's rays. But the sunlight direction changes regularly with changing seasons and weathers.

Table 3: Daily average bright sunshine hours in Dhaka

Month	Daily Mean	Maximum	Minimum
January	8.7	9.9	7.5
February	9.1	10.7	7.7
March	8.8	10.1	7.5
April	8.9	10.2	7.8
May	8.2	9.7	5.7
June	4.9	7.3	3.8
July	5.1	6.7	2.6
August	5.8	7.1	4.1
September	6.0	8.5	4.8
October	7.6	9.2	6.5
November	8.6	9.9	7.0
December	8.9	10.2	7.4
Average	7.55	9.13	6.03

To increase the unit area illumination of sunlight on solar panel, we have proposed a fuzzy logic based two axes controlled solar tracker. With the help of this fuzzy theory we have designed the fuzzy logic controller, which is described in Section 6.1 Implementation of this system is discussed in Section 6.6.

6.1 Fuzzy Logic Controller Structure

The basic fuzzy based switching controller is shown in Fig. 5

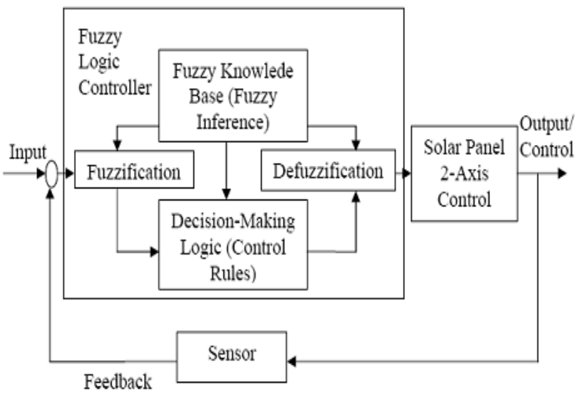

Fig. 5: Fuzzy based controller

6.2 Fuzzification Interface

The input of a common controller is a specific numeric value, but the knowledge base for fuzzy control is expressed with language. The system must turn numeric values into language and corresponding domains to allow the fuzzy interface engine to interface. This transformation is called fuzzification.

6.3 Knowledge Base

Knowledge base is the inference basis for fuzzy control. It defines all relevant language control rules and parameters. The knowledge base (including the database and rules base) is the core of a fuzzy control system.

6.4 Fuzzy Interface Engine

As the most important part of fuzzy control, the fuzzy inference engine performs the actual decision-making process. The basic theory of the fuzzy inference engine is an approximate inference. The engine has two key inference methods: Generalized Modus Pones (GMP) and Generalized Modus Tollens (GMT). GMT is object-oriented inverse fuzzy theory, but GMP is forwarding linking inference modus. In GMP, when data is input, the output can be inferred according to rules; GMP is applicable for a fuzzy control inference mechanism. Its operation includes the following three calculations: Perform an AND operation for all propositions of an antecedent of the triggered rule to obtain the antecedent fit.

Perform an AND operation for all of the propositions of the consequent corresponding to the antecedent fit of the triggered rule to determine how strongly true the rule is. Perform an OR operation for all consequents of all triggered rules.

6.5 Defuzzification

The reverse of fuzzification, defuzzification transforms the fuzzy inference engine's output values into equivalent assured values, making the assured value comply with the input signals of the controlled system. This process gives output control signals to the controlled system.

6.6 Implementation

Our controller design takes the measured value of the light strength received by the sensor as the feedback and implements control using many rounds of modifications.

7. CONCLUSION

The optimum extraction of solar thermal energy for LTD Stirling engine can be developed by fuzzy logic based parabolic shaped solar taker, which can maintain a rated power output by adjusting its position according to the concentrated solar ray needed to generate specific temperature on the bottom plate. The designed parabolic dish solar collector produces 787.44 watt heat input for the LTD Stirling engine which is more than expected for the rated power output. The thermal efficiency is about 50.17% is very much significant. Large size collector could be used to produce large amount of electric power generation by the LTD Stirling engine for mitigate present energy demand.

9. ACKNOWLEDGEMENT

A Low Temperature Differential (LTD) Stirling engine has been constructed to use alternative heat sources for small scale power generation like low grade fuel, wood, coal, waste heat etc. This work is a continuation to operate the LTD Stirling engine by solar thermal power.

10. REFERENCES

[1] M. A. Islam, W. M. Abdullah and D. M. Abdullah, "Fuzzy logic based LTD solar thermal stirling engines for power generation", Proceedings of the *7th International Conference on Electrical and Computer Engineering*, Dhaka, Bangladesh, pp. 619-621, 2012.

[2] G. D. Rai, "Solar Energy Utilization", 5th edition, Khanna Publishers, Delhi, India. 2005.

[3] B. S. Magal, "Solar Power Engineering", Tata McGraw Hill Publishing Company Limited, New Delhi, 1993.

[4] J. S. Hsieh, "Solar Energy Engineering." Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1986.

[5] J. Folaranmi, "Design, Construction and Testing of a Parabolic Solar Steam Generator", *Leonardo Electronic Journal of Practices and Technologies*, issue 14, pp. 115-133, 2009.

8. NOMENCLATURE

Symbol	Meaning	Unit
A_a	Aperture area	(m^2)
A_{abs}	Absorber area	(cm^2)
C	Concentrator ratio	Dimentionless
C_p	Specific heat of water	kJ/kgK
D_a	Aperture Diameter	(cm)
D_{abs}	Absorber outside diameter	(cm)
d_{abs}	Absorber internal diameter	(cm)
I_b	Beam radiation	(Ci)
$\dot{m}$	Mass flow rate	(kg/s)
Q	Heat absorbed by water	(J)
η	Thermal efficiency	Dimentionless
T_1	Inlet temperature of water	(K)
T_2	Outlet temperature of water	(K)
t_x	Thickness of the rod	(cm)
V_w	Volume of water inside rod	(cm^3)
H	Height of the dish	(cm)
f	Focus length	(cm)