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Optimization of tilting angle of parabolic solar dish for effective steam generation

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Abstract
This paper on Optimization of tilting angle of Solar parabolic dish is based on the experimental work done in Ahmednagar city. Sun is the source of enormous amount of energy. Solar rays after falling on surface of solar plate will create energy generation in form of electricity and other, like steam generation. It will depend on Sun's intensity of producing heat and will vary with the temperature. In this experimentation we have taken readings from 09.00 am to 05.00 pm, every day, to find out the maximum steam generation. We used solar concentrated solar parabolic collector/dish, instead of flat plate collectors to get more amount of power generation, steam generation. To find and decide the optimum tilting angle three methods has been used. After deciding the tilt angle, to give the rotation to parabolic dish and to set it at specific angle, small worm gear box is used. Our aim was, to find the Optimum tilt angle of Solar Parabolic Dish, for effective steam generation, and to reduce the cost of conventional fuel used, i.e. high speed diesel and also to increase the life of the plant.

Keywords: concentrated solar parabolic dish, tilt angle, latitude, steam generation 4-7 kg/hour

1. Introduction
Sunlight is a renewable energy source which can converted into usable energy by solar panels. There are two main types of solar energy. Solar photovoltaic panels, which directly convert solar energy into a usable form of energy using a PV cell containing a semiconductor material. Concentrating solar power concentrates energy from sun to a heat receiver which coverts energy from receiver into mechanical energy, and in turn, solar thermal electricity (Chang *et al*. 2010) [4].
At any moment, the sun emits about 3.86 x 10^{26} watts of energy. Most of that energy goes off into space, but about 1.74 x 10^{17} watts strikes the earth. The Earth receives 174,000 terawatts of incoming solar radiations at the upper surface atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. An increase in solar radiation of 28.76% results in the increase in power of 24. 78% (Pavlović *et al.*, 2010) [3].
The statistical data with which we have taken readings at every hour and evaluated maximum output energy at specific angle. In this Experiment we have studies variation and effect of tilting angle in Ahmednagar city which has, latitude 19.09^0 N, the optimum tilt angle for solar panels during winter will be $19.09 + 15 = 34.09^0$.
For maximum output energy we changed angle with respect to time and observe that steam produced which may be beneficial to cost consumption as well as time consumption. Solar radiations are dependent on geography of location. Since, Ahmednagar is closer to equator, we get greater amount of solar energy.
In this experiment we have used parabolic type dish collector. Basically there are four types of parabolic dish collector. They are Linear Fresnel, Parabolic Trough, Parabolic Dish, and Solar Tower respectively. In linear Fresnel, which has focusing type is line, which is having one tracking axis and concentration ratio is 10 to 40 %.
It gives temperature between 60 to 250 ^{0}C. Second type is parabolic trough, having one tracking axis, focusing line type, which gives concentration ratio of 10 to 85% and maximum temperature range is 60 to 400 ^{0}C (Danny *et al*., 2007).Third type is parabolic dish type in which focusing type is fixed which is point, at one point, we get all energy and tracking axis is two, which is generally used in various applications, with concentration ratio of 600 to 2000% and due to that temperature range is also high which is 100 to 1500 ^{0}C. Forth type is solar tower point type focus has two tracking axis with concentration ratio 300 to 1500% and gives temperatures of 150 to 2000 ^{0}C.

2. Objective and Investigation
Experiment we have conducted in Ahmednagar city it is found out tilt angle for getting maximum solar energy in month May and minimum in December because of winter season. The sun radiates about 3.8 x 10^{26} W of power in all the directions. Out of this about 1.7 x 10^{17} W is received by earth.
The average solar radiation outside the earth's atmosphere is 1.35 kW/m^2 varying from 1.43 kW/ m^2 (in January) to 1.33 kW/m^2 (in July).
We have carried out this work for Gajraj Drycleaners, whose present status of steam generation is as - Fuel used for 50 – 60 kg steam generation - HSD - 50 liter/day, maximum temperature of steam generated – 140^0 C, maximum pressure of steam discharged – 05 – 07 bar and maximum temperature of steam discharged – 120^0 C.
We has to change it to, maximum temperature of steam generated – 180^0C and maximum pressure of steam discharged – 07 – 10 bar.

Optimization of Tilt Angle for Solar Collector to Receive Maximum Radiation examined the theoretical aspects of choosing a tilt angle for the solar flat-plate collectors used at ten different stations in the world and makes recommends on how collected energy can increased by changing the tilt angle. (Ahmed *et al.*, 2009).

Average optimum tilt angle at New Delhi for the winter months is 47.5° (latitude + 19°) and for the summer months 13° (latitude -16°). They found, Monthly based optimum tilt is different for different stations (M. Jamil *et al.*, 2009) [2]. Season based optimum tilt is also different for different stations. Annual based optimum tilt is approximately equal to latitude of the location.

For achieving high efficiency, the collector is designed such as the angle of tilt can easily be changed on seasonal basis, not monthly (Navneet *et al.*, 2014).

Comparative approach for the optimization of tilt angle to receive maximum radiation showed that, the optimization tilt angle for other cities can be carried out for India and other location exterior of India and for optimization of tilt angle (Abhishek Agarwal *et al*. 2012) [5, 6] concluded that, the solar radiation output of solar collector is investigated at various tilt between angles 0° to 90° for south facing to calculate daily and monthly optimum tilt angles, seasonal optimum tilt angles and yearly optimum tilt angle for different locations in India.

3. Experimental setup and procedure

To get maximum power output from the solar collector system it is desirable to tilt the collector to that tilt angle at which the incident solar radiations are maximum. To find the Optimum tilt angle of Solar parabolic dish, we have used three methods, for optimization.

1. Method 1 - for calculating approximate solar panel angle according to latitude.

The optimum tilt angle is calculated by adding 15° to latitude during winter and subtracting 15° from latitude during summer. For Ahmednagar, latitude is 19.09° N

The optimum tilt angle for solar panels during winter will be = 34.09° (Srinivas *et al.*, 2012) [7].

The summer optimum tilt angle on the other hand will be = 4.09°.

2. Method 2 - This is an improvement over general method which gives better results.

The optimum tilt angle for solar panels during winter - = 46.18°.

In summer season, this angle is = 6.32°.

For required tilt angles during seasons-spring and fall, 2.5° is subtracted from the latitude.

3. Method 3 - Taguchi Method of Optimization - By considering the parameters, like, ambient temperature, theoretical angle, steam generation, by Taguchi method optimized tilt angle is found out, for Summer and Winter season.Which is, Summer angle 4.7^0 to 7.1^0 and winter angle $37^{0.}$

Table 1: Tilt angle for Solar parabolic dish in Ahmednagar

Summary - Solar Panel Angle Calculation for Ahmednagar				
Season	Angle / tilt calculation	Method 1	Angle / tilt calculation	Method 2
Winter	Latitude + 15^0	34.09°	(Latitude x 0.9) + 29^0	46.18°
Summer	Latitude - 15^0	4.09°	(Latitude x 0.9) - 23.5^0	6.32°
Spring and Fall	Latitude - 2.5^0	17.09^0	Latitude - 2.5^0	17.09^0

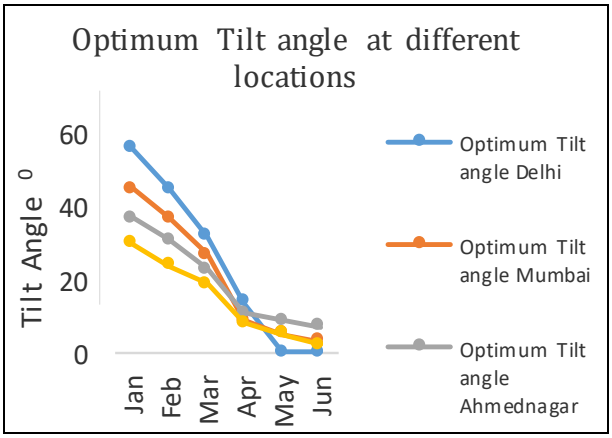

Fig 1: Theoretical Tilt angle values at different locations

4. Design Calculations

The assembly of the parabolic shaped dish solar steam generator is done, with following design specifications -

- Diameter of the sun - 1.39 x 10^6 km
- Average distance of the sun from the earth-1.5 x 10^8 km
- Radius of the earth (r_e) - 6400 km
- Effective temperature of the surface of the sun - 5762^0K
- The sun's central interior region temperature (estimation) - 8 x 10^6 K to 40 x 10^6 K
- Density of the sun - 80 to 100 times that of water
- Solar constant (Isc) - 1353 w/m^2
- Extra-terrestrial radiation (Io) -1398 w/m^2 (maximum), 1310 w/m^2 (minimum)
- Geographical location of Ahmednagar - - Latitude = 19.09°N - Longitude = 74.75°E
- On average yearly total solar energy incident on a horizontal surface in Ahmednagar : 2300 kwh/$m^{2.}$

Solar Parabolic Dish dimensions –

Surface area of Collector – $16m^{2.}$

Diameter -2.25 meter (7.52 feet), 02 mm thick mirror.

Focal Point - 180 cm (1800 mm)

Steam generation capacity - 7 kg/hour

Nominal Temp - 180^0 at 7 bar pressure

Reflectivity - more than 90 %.

Solar radiations received by parabolic solar dish, concentrates it and concentrated radiations are allowed to fall on receiver, where temperature reaches to 170 to 180 ^{0} C.

Water passing through container is converted in to steam, because of this high temperature obtained.

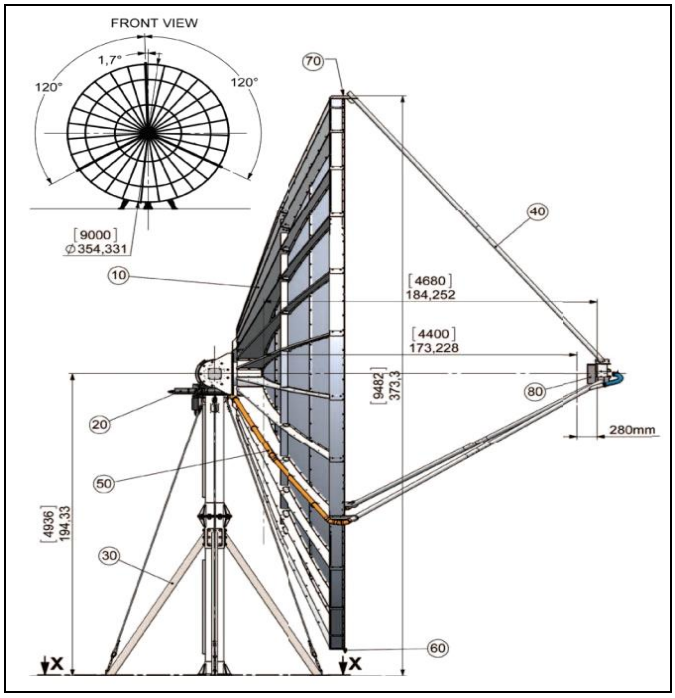

Fig 2: Solar parabolic dish

Table 2

Sr.	Name of part	Dimension
10	Dish Support	100 x 5 mm
20	Tracking Stem	Reduction Gear
30	Parabolic Dish Support	50 x 10 mm
40	Focal Point Support Arm	180 x 5 mm
50	Seasonal Adjustment	100 x 5 mm
60	Clearance	200 mm
70	Top face - 16 m^2 area	1500 mm
80	Focal point / Aperture	1800 mm

Fig 3: Installed Solar Parabolic Type Dish.

Fig 4: Tilting angle arrangement

Tilting arrangement for Solar Parabolic Dish – Small speed reducer gearbox is used to change the angle of solar parabolic dish, daily, monthly, etc.

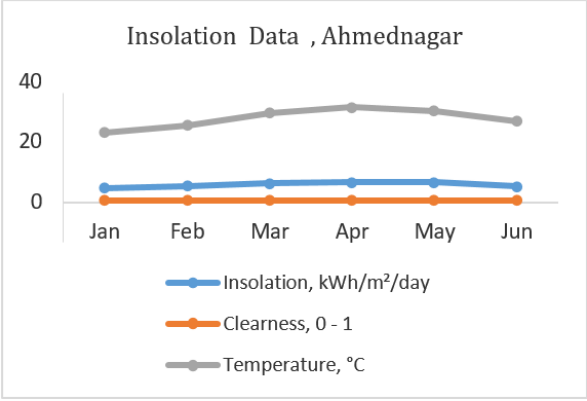

Fig 5: Solar insolation data with average temperature at Ahmednagar.

Experimentation - In this experiment we have taken readings of ambient temperature, focal point temperature, steam generated, by tilting angle setting for solar parabolic dish, in the month of March, April and May2017. They are given as below

Table 2: Solar Steam generation for March 2017

MARCH Date /Time	09.00 am				10.00 am			
	Tilt Angle (^{0})	Ambient Temp. (^{0} C)	Focal Pt. Temp (^{0} C)	Steam Generation (kg/hr)	Tilt Angle	Ambient Temp.	Focal Pt. Temp	Steam Generation
1	5	26	75	4	5	27	85	4
2	5	26	80	4	5	28	95	4
3	5	27	90	4	5	27	95	4
4	5	27	90	5	5	28	100	5
5	5	27	95	4	5	27	95	4
6	7	28	100	5	7	28	100	5
7	7	28	105	4	7	28	100	5
8	7	27	100	4	7	27	95	6
9	7	28	90	5	7	28	95	5
10	7	28	85	4	7	29	90	5

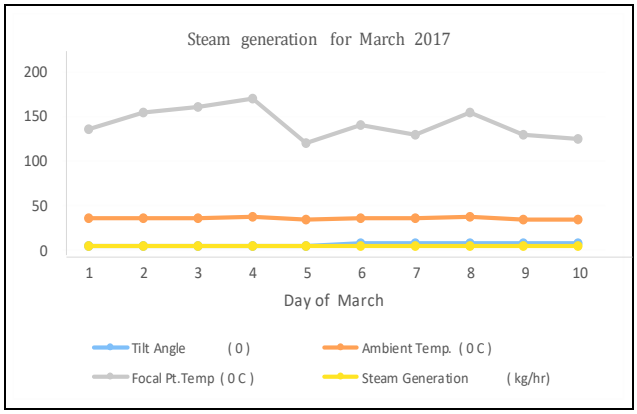

Fig 6: Steam generation for March 2017

These readings and results are compared with the diesel engine steam generation, which is already in use from last 05 years. After comparison we found that the steam generation with the help of solar parabolic dish is more cost effective and electrical energy is saved.

Table 3: Comparison of Steam generation by Diesel generator and Solar Parabolic dish in Ahmednagar.

Sr.	System	Diesel Steam Generation	Solar Steam Generation	Remark
1	Fuel Required	HSD – High Speed Diesel	Solar Radiation / Energy	Solar Radiation or Solar Energy is Pollution free, radially available and free of cost
2	Fuel Consumption	10 Litre / Hour	Nil	
3	Temperature	130 – 140^0 C	170 – 180^0 C	
4	Steam Generation	7 – 8 kg / hour	7 – 10 kg / hour	
5	Cost of fuel	55 Rs / hour	Nil	
6	Cost / day	275 Rs / day	Nil	
7	Cost / month	275 x 25 = 6875	Nil	
8	Yearly cost	6875 x 12 = 82500	Initial Installation cost is high	
9	Pay back period	Life 05 years & requires lubrication and maintenance	300000 - 03.63 Years ~ 04 Years	Life 25 Years

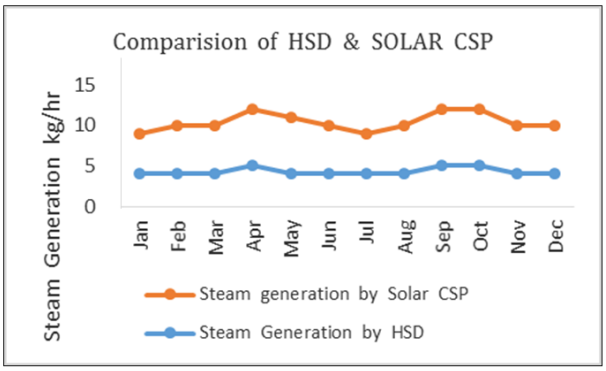

Fig 7: Comparison of HSD and Solar Steam Generation.

5. Test Results

By changing the tilt angle of parabolic dish and the observations in months March, April and May, we summarize the temperature of output and evaluated best angle for every month in Ahmednagar.

Table 4: Average Tilt Angle, Ambient Temperature, focal point temperature and Steam generation in Ahmednagar, Maharashtra (India)

Month	Tilt Angle ^{0}	Ambient Tempera- ture ^{0}C	Focal Point Tempera- ture ^{0}C	Steam Generation Kg/hr
Jan	7	29.9	135	4
Feb	7	31.9	150	4
Mar	5	35.4	165	5
Apr	5	39.7	180	6
May	3	40.5	185	7
Jun	1	32.7	150	5
Jul	1	28.4	135	4
Aug	15	27.4	125	4
Sept	20	29.4	120	5
Oct	30	31.4	120	5
Nov	35	30.1	115	4
Dec	37	28.9	110	4

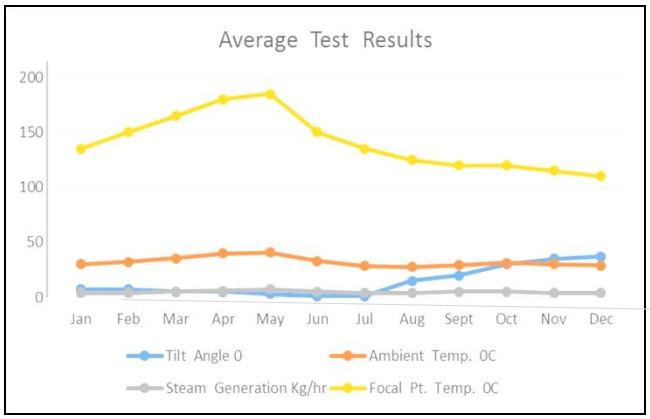

Fig 8: Average Test Results for solar steam generation in Ahmednagar

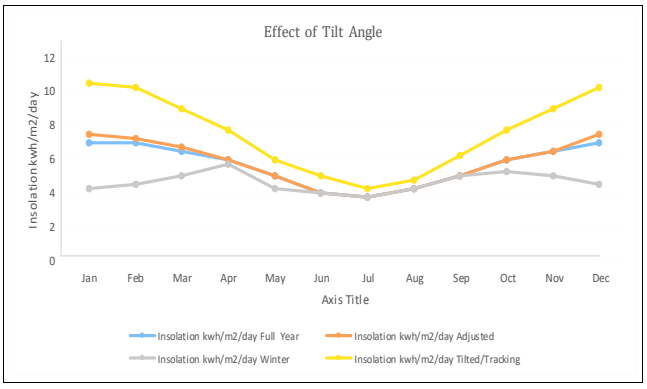

Fig 9: Effect of Tilting angle for steam Generation

6. Result and Discussion

The optimum tilt angle is different for each month of the year. The Collected solar energy will be greater if we choose the optimum panel tilt for each month. Also, we found that the yearly average of optimum tilt is equal to the latitude of the site. The results show that the average optimum tilt angle at Ahmednagar for the winter months is 37^0 and for the summer months is 07^0. So, the yearly average tilt panel is 17^0, which nearly corresponding to the latitude of Ahmednagar location (19.05^0).

7. Conclusion

Based on Experimental observation following conclusion can be established:

1. Tilting angle for Solar Parabolic dish in Ahmednagar for summer season is 7^0 to 5^0 and for winter season 35^0 to 37^0.
2. Parabolic dish with $16m^2$ gives output steam generation of 50 kg/day, at 4 to 6 kg/hr.
3. By using solar parabolic dish for steam generation, running cost of plant is reduced with payback period of 04 Years.
4. Steam generation by Solar parabolic dish depends on solar insolation received by the dish.

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