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Assessment of Solar Energy Opportunity in a Bicycle Manufacturing Plant

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Abstract: Solar energy is a potential renewable source of energy in the present scenario. The main aim of the present work is to explore the options of using solar energy in a bicycle manufacturing plant and to identify the options for reducing the energy cost involved in the plant. The prime objective of this work is to identify the various energy consuming processes in the entire plant and to compute the overall energy cost involved. Pareto principle is used to identify the high energy consuming processes. Additionally, solar air heater with parabolic concentrator is designed, and reduction in energy cost and CO_2 emission is calculated theoretically.
Keywords: Renewable Energy, solar collector, phosphate coating, energy cost reduction.

Introduction

Renewable energy is the energy which is readily available on the surface of the earth. The sun rays which impacts on the earth, results in direct heating and photosynthesis. This direct heating from the sun results in temperature differences which creates wind, which in turn creates waves. The tides are originated due to moon's gravitation pull on the oceans. Geothermal energy originates from earth's crust, and this produces heat at the earth's surface. All this energy can be harnessed into useful energy using technology. This energy which can be harnessed from the nature is called the Renewable energy. Globally, it has been predicted that energy consumption shall increase by 56% by 2040. At present, fossil fuels are widely used to manage the global energy needs. But these fossil fuels will get depleted over a period of time and hence there is a requirement of alternate energy like renewable energy. The major advantages of renewable energy are its ready availability, price stability, eco friendly, non polluting nature etc.[1]

The different renewable energy technologies and their sources are shown in table 1. [2]

Table 1: Renewable energy technologies and their source

Source	Renewable energy
Sun	Solar Energy
Wind	Wind Energy
Rivers	Hydro Power Energy
Biomass	Biomass energy
Tides	Tidal Energy
Earth Crust	Geothermal Energy
Ocean	Ocean thermal Energy

Solar Energy

The total power of solar radiation reaching Earth is 1.73×10^{17} W. The total energy of solar radiation reaching earth per year is 5.46×10^{24} J or 5,460,000 EJ/year. When we compare the annual global energy consumption with that of total solar energy reaching earth is merely 0.01%. A mere 0.01% of the annual solar energy reaching Earth can satisfy the energy need of the entire world. Hence, solar energy has the greatest potential of all the sources of renewable energy. [2]

Solar Collectors

Solar collectors transform solar radiation into heat and transfer that heat to a medium (water, solar fluid, or air). Then solar heat can be used for heating water, to back up heating systems or for heating swimming pools. There are different types of Solar Collectors that are discussed briefly below. [3]

a) Flat Plate Collectors

A flat-plate collector consists of an absorber, a transparent cover, a frame, and insulation. Flat plate collectors absorb solar energy and convert it into heat and then transfer that heat to stream of liquid or gas. Flat-plate collectors are the most widely used kind of collectors in the world for domestic solar water heating and solar space heating applications. Flat-plate collectors are used typically for temperature requirements up to 75 ºC although higher temperatures can be obtained from high efficiency collectors [3]

b) Evacuated Tube Collectors

While flat-plate collectors are all essentially made the same way and perform the way from one brand to other, evacuated tube collectors vary widely in their construction and operation. Evacuated tube collectors are constructed of a number of glass tubes. Each tube is made of annealed glass and has an absorber plate within the tube, because tube is the natural configuration of an evacuated collector. During the manufacturing process in order to reduce heat losses through conduction and convection, a vacuum is created inside the glass tube. The only heat loss mechanism remaining is radiation. The absence of air in the tube creates excellent insulation, allowing higher temperatures to be achieved at the absorber plate. In order to improve an efficiency of evacuated tube collector there are several types of concentrators depending on its concave radius established. There are many possible designs of evacuated collectors, but in all of them selective coating as an absorber is used because with a non-selective absorber, radiation losses would dominate at high temperatures, and eliminating convection alone would not be very effective[3]

c) Concentrating Collectors

A concentrating collector utilizes a reflective parabolic-shaped surface to reflect and concentrate the sun’s energy to a focal point or focal line where the absorber is located. To work effectively, the reflectors must track the sun. These collectors can achieve very high temperatures because the diffuse solar resource is concentrated in a small area.

Solar concentrator may be classified as tracking type and non-tracking type. Tracking may be continuous or intermittent and may be by one-axis or two-axis. As the sun may be followed by moving either the focusing part or the receiver or both; concentrators can be classified accordingly. Further, the system may have distributed receiver or central receiver. The concentrators may also be classified on the basis of optical components. They may be reflecting or refracting type, imaging or non-imaging type, and line focusing or point focusing type. The reflecting of refracting surface may be one piece or a composite surface; it may be a single or two stage type systems and may be symmetric or asymmetric. In practice, however, hybrid and multistage systems, incorporating various levels of the features, occur frequently. [3]

TI Cycles of India

TI Cycles was established by the Murugappa Group in the year 1949, in collaboration with Tube Investments, UK. The first Hercules bicycle rolled out in 1951. Three more brands were added to the portfolio - Phillips in 1959, BSA in 1964 and Montra in 2011.Today, TI Cycles is the leader in the ‘specials’ segment. The energy of the company can be felt nationwide, thanks to a network of around 1,500 primary dealers and 10,000 secondary dealers.TI Cycles has the capacity to manufacture 4 million cycles a year at 3 plants across India - Chennai in the South, Nasik in the West and Noida in the North. This is supported by 4 zonal offices and 4 warehouses across the country.

Identification of Energy Consuming Locations at TI Cycles

Following are the energy consuming locations in TI Cycle

- Phosphate coating plant
- Painting Plant
- Finishing
- Kitting
- Effluent treatment plan
- Admin Block

Data Collection methodology for Energy Cost

- Power consumption readings are taken from energy meter at various energy consuming locations.
- Fuel consumptions are taken from flow meter
- Daily monitoring of fuel consumption and power consumption.
- Power consumption is calculated
- Fuel Consumption is calculated

Principle adopted to Identify High Energy Cost Locations

High energy location was identified using Pareto principle as shown in Figure 1

"The Pareto principle (also known as the 80–20 rule, the law of the vital few, and the principle of factor sparsity) states that, for many events, roughly 80% of the effects come from 20% of the causes.

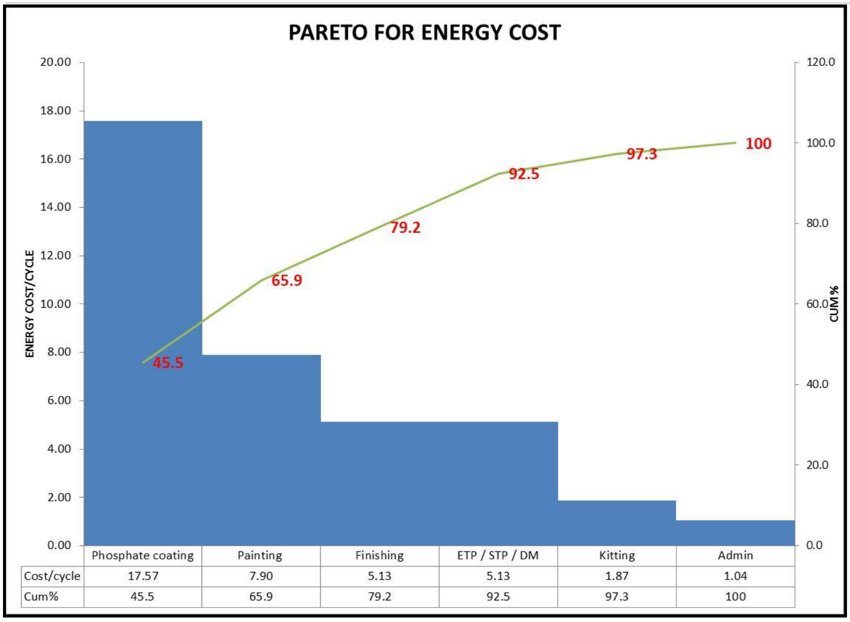


Figure 1: Pareto for Energy cost

Phosphate coating process

Phosphate coating is the most widely used metal pre-treatment process for the surface treatment and finishing of ferrous and nonferrous metals. Due to its economy, speed of operation and ability to afford excellent corrosion resistance, wear resistance, adhesion and lubricative properties, phosphating plays a significant role in the automobile, process and appliance industries

Identification of Process

Total energy cost for phosphate coating process is Rs.17.57/cycle

As per the Figure 2 and Figure 3 which was created from daily consumption data, it clearly shows that fuel cost contributes about 67% of the overall Energy cost of Phosphate coating process,

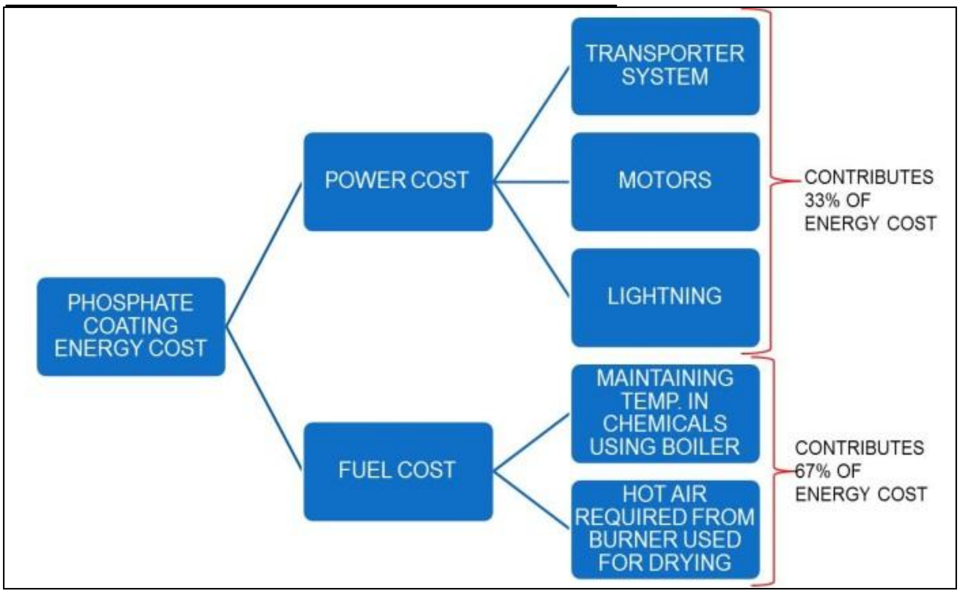
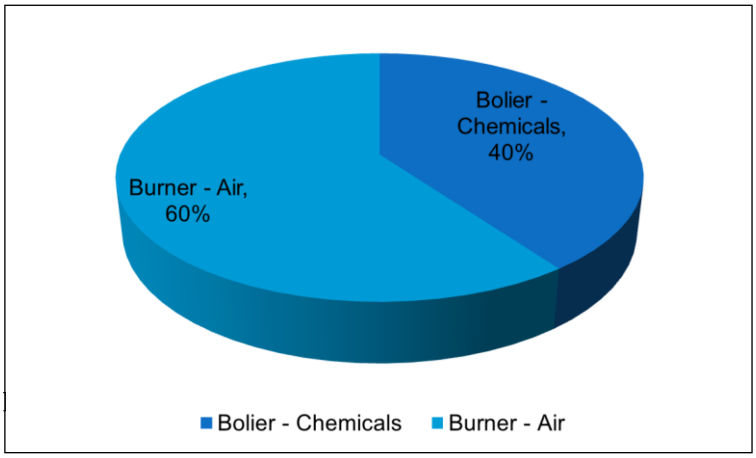


Figure 2: Phosphate coat energy cost contribution



Based on the above analysis, we observe that there is opportunity for using renewable energy source in producing hot air at oven. The renewable source that can be used is solar energy which can be used to heat the air, instead of using the burner. Hence, there is opportunity for implementation of solar air heater for producing hot air instead of using burner in phosphate coating process.

Solar air heating is a renewable energy heating technology used to heat or condition air for buildings or process heat applications. It is typically the most cost-effective out of all the solar technologies, especially in commercial and industrial applications, and it addresses the largest usage of building energy in heating climates, which is space heating and industrial process heating.

Design of Solar Air Heater in Drying Process of Phosphate Coating Process

Design Basis

To design a Solar Air heater for phosphate coating plant, to reduce the utilisation of the burner for heating the air used for drying the components in oven during the day time

Average Temperature required: 140 ° C

Selection of Solar Collectors for Solar Air Heater

In Solar conversion technology, three important parameters are used to select the right kind of solar collector.

1. Temperature level
2. Amount of energy to be converted or concentration degree
3. Efficiency required [4]

Table 2: Solar Collector [4]

Category	Type of collector	Temperature Range ◦C	Efficiency %
Less Concentration	Flat Tube Evacuated Tube	< 75 <200	30 - 50
Medium Concentration	Parabolic	150-500	50-70
High Concentration	Parabodial	>1500	60-75

Table 2 clearly shows the parabolic concentrated solar collectors are the right kind of collectors to be used for Solar Air Heater.

Theoretical background for Parabolic Solar Air Heater

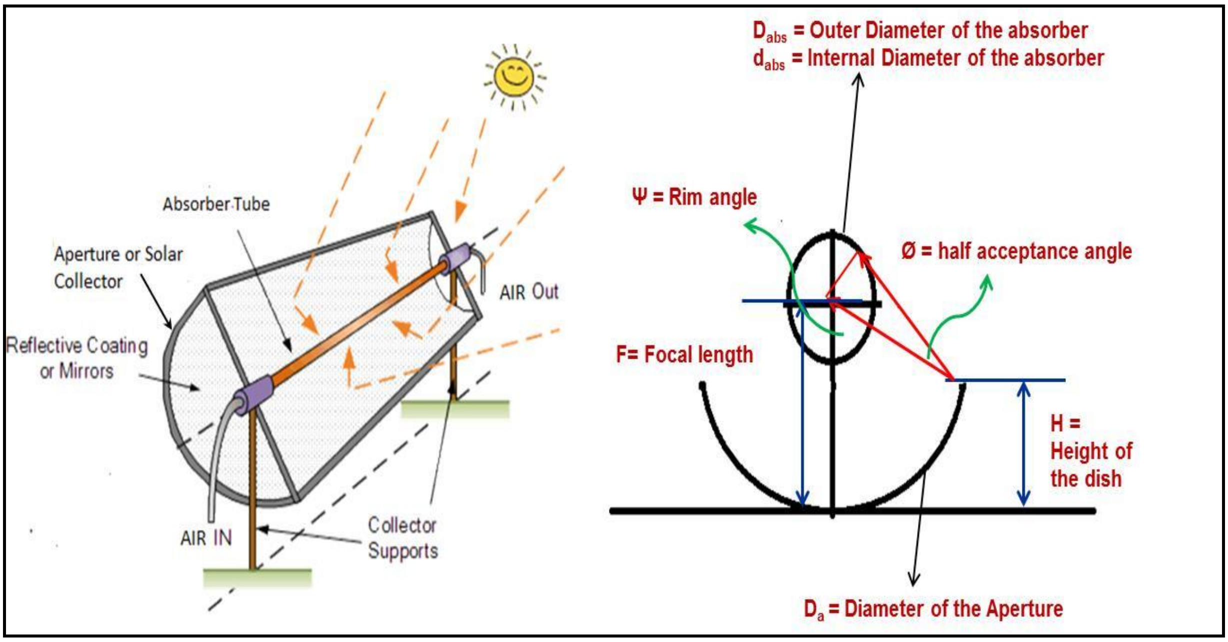


Figure 4, Nomenclature for Parabolic collector

Figurer 4, briefly describes the parameters used in the Solar Concentrating collectors, Aperture area (A_a) is the area of the collector that intercepts Solar radiation. [5]

Acceptance angle (ø) is defined as the angle through which a source of light can be moved and still converge at the receiver. A concentrator with small acceptance angle is required to track the sun continuously while a concentrator with large acceptance angle needs only seasonal adjustment. [5]

The Absorber area A_{abs} is the Total area of the absorber surface that receives the concentrated solar radiation. It is also the area from where useful energy can be extracted. [5]

Concentration Ratio = A_a/A_{abs} [5]

The optical efficiency (η_o) [1] is defined as the ratio of the energy absorbed (P_{abs}) by the absorber to the energy incident (I_D) on the concentrator aperture. It includes the effect of mirror / lens surface, shape and reflection/transmission losses, tracking accuracy, shading, receiver-cover transmittance, absorbance of the absorber and solar beam incidence effects. [5]

The optical efficiency (η_o) = $P_{abs}/ A_a \times I_D$ [5]

The optical efficiency of most solar concentration lies between 0.6 & 0.7.

In a thermal conversion system a working fluid is used to extract energy from the absorber. The thermal performance of the solar concentrator is determined by their thermal efficiency. The thermal efficiency (η_{th})is defined as the ratio of the useful energy delivered to the energy incident at the concentrator aperture. [5]

$\eta_{th} = \rho V C_p (T_2 - T_1) / I_b A_a$ [5]

The incident solar radiation consists of beam (direct) and diffuses radiation. However the majority of concentrating collectors can utilize only beam radiation.The instantaneous thermal efficiency of a solar concentrator may be calculated from an energy balance on the absorber. The useful thermal energy delivered by a concentrator is given by[5]

$Q_u = \eta_o I_b A_a - U_L (T_{abs} - T_a) A_{abs}$ [5]

(Q_u = Useful energy / U_L = Surface loss coefficient / T_{abs} = temp at the absorber / T_a = ambient temp)

Sizing of the Parabolic Solar Air Heater

The heat demand load of the heater is such that it will heat V = 0.04 m^3 of air in an hour, from T_a ambient temperature to outlet temperature T_f = 140°C.

Absorber Design

Assuming length (L) = 2 times the Internal Dia.
Assuming thickness (t) = 2 mm
Volume of the cylinder is equal to the volume of the air to be heated.
$V = \pi \times d_{abs}^2 \times L/4$
$D_{abs} = 0.298$ m
Effective surface area of the absorber
$A_{abs} = \pi \times D_{abs}^2/4 + \pi \times D_{abs} \times L$
$A_{abs} = 0.62\ m^2$
Concentration Ratio C
$C = A_a / A_{abs}$
Efficiency is maximum at the Concentration Ratio C = 10 [6]
$A_a = 10 \times A_{abs}$
Dia. of the Aperture D_a = 2.81 m
The half acceptance angle is given by the formula [7]
$C = 1 / \sin^2 \phi$
$\phi = 18.43°$
The optimum Rim angle ψ
$\Psi = 90 - \phi$
= 71°57
Focal Length of the dish is obtained by [8]
$F/D_a = (1+\cos\psi) / 4\sin\psi$
Focal Length F = 0.976 m
Height of the Dish (h) [8]
h = Da2/16F
h = 0.50 m

Design Verification

Useful energy Q_u = $\eta I_b A_a$
Efficiency of Solar Concentrator is 50% - 70%
η Minimum efficiency = 50%
A_a Area of the aperture = 6.2 m^2
I_b = Incident Beam radiation on the collector in Chennai = 700W/m^2, as per the Solar Radiation Book
Q_u = 0.5 x 6.2 x 700 = 2170 W
In Chennai, sun available 9 am to 6 pm, Totally 9 cycles will occur in a day.
Total useful energy = 9 Q_u
= 19530 W
Useful Energy is also given by Q_u = $MC_p (T_f - T_a)$
M – Mass flow rate of air
C_p – Specific Heat Capacity at 30 °C
According to Solar Radiation book, Ambient Temperature (T_a) at Chennai is 30 °C
$M = Q_u / C_p (T_f - T_a)$

Mass Flow rate =0.280 x 10 $^{-3}$Kg/s
Actual flow rate measured at the plant using mass flow sensor =0.256 x 10 $^{-3}$Kg/s

Hence, theoretical mass flow rate is approximately equal to actual flow rate of the burner system used.

Design Output

Figure 5 and Table 3, gives the summary of the Design output parameters of the Parabolic Solar Air Heater

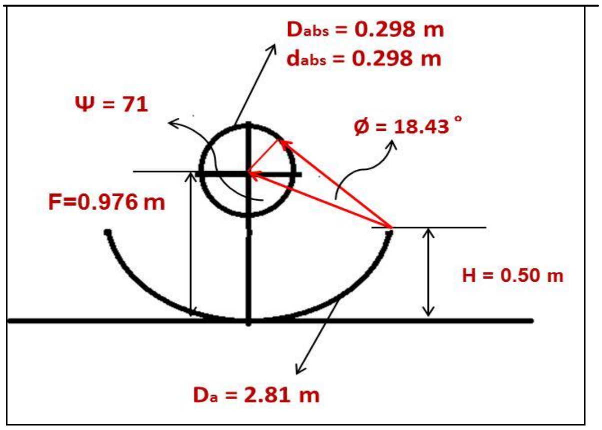


Figure 5, Design output parameters

Table 3: Design Output

Sl.No	Characteristics	UOM	Value
1	Outer Diameter of the absorber (D_{abs})	m	0.294
2	Internal Diameter of the absorber(d_{abs})	m	0.298
3	Half Acceptance angle (ø)	°	18.43
4	Rim angle(ψ)	°	71
5	Focal Length(F)	m	0.976
6	Height of the Dish (H)	m	0.50
7	Diameter of the Aperture (Da)	m	2.81

Material Selection for the Parabolic Solar Air Heater

- Material of the body of the dish selected was polished aluminium due to ease of fabrication, light weight, low cost. Weight contributes important factor in Solar Air Heater, hence use of Aluminium will reduce the weight to considerable level.
- Material for the reflecting surface selected was Glass mirror of 2mm thickness to have light weight and high reflectivity of 95% and ease of maintenance.
- Material for the absorber selected was Copper pipe with 2 mm thickness for higher conductivity.
- Material for the absorber surface coating selected was Black chrome electro plated with high absorptance and low emittance.
- Automatic tracking system with solar energy radiation sensors for adjusting the dish was selected for better efficiency in tracking of solar light. [9,10]

Comparative Study of Energy Cost Using Solar Energy and Fuel Energy

Overall Phosphate Coating Energy Cost = Rs.17.57/cycle
Energy cost = Fuel Cost + Power Cost = 11.80 + 5.77 = 17.57
Fuel Cost used for burning the burner
to produce hot air = 60 %(based on the previous data)
Fuel cost = Rs.7.80 / Cycle
Burner working hours = 18 h
Solar power can be used = 9 h

Hence 50% reduction in the Fuel cost

Potential Saving on fuel cost = Rs.5.9/cycle Potential Energy cost after implementation of Solar Air heater = 11.67
Cost saving of Energy cost % = 35 %

Comparative Study of Co_2 Emission using Solar Energy and Fuel Energy

According to IEA Statistics, CO_2 from fuel combustion highlights 2014; combustion of 1 litre of diesel emits 2.64 kg of CO_2.
Average Diesel consumption for burning
Burner for creating Hot air = 33320 litres of diesel.
Hence CO_2 emission = 33320 X 2.64
= 87,964.8 kg of CO_2 emitted.

Potential CO_2 reduction after implementation of Solar Heater

Solar Air Heater runs 50% of the total working hours; hence diesel consumption will reduce to 50%.
Average diesel consumption will get
Reduced to 50% = 26389.44
Therefore Carbon emission =26389.44x2.64 = 69668.12

Hence Potential CO_2 reduction will be 20 %.

Conclusion

The solar air heater with parabolic concentrator was successfully designed for phosphate coating plant in a bicycle manufacturing plant .This is done by identifying the various energy consuming processes in bicycle manufacturing plant and computing the overall energy cost. Then pareto principle was used to identify the high energy consuming process. From the data collected, it was observed that phosphate coating process contributed towards high energy cost. Further drilling down on the energy cost, it was observed that fuel cost used to burn the burner to produce hot air of temperature 145 °C consumes 60% of the fuel cost of the phosphate coating process. Then air heating for phosphate coating process was assessed for possibilities of solar air heater, instead of burner heater. This Solar Air Heater can yield an energy cost reduction of 35% and reduction in CO_2 emission by 20%.

References

1. Chauhan.D.S, Srivastava. S.K, Non-Conventional Energy Resources – New Age International Publishers, 2010 – pp. 1-100.
2. Yogi Goswami D, Kreith F, Kreider J.F. Principles of Solar Engineering. – New York: Taylor & Francis Group, 2000. – pp. 694.
3. Julian Chen.C,Physics of Solar Energy,John Wiley & Sons, Inc,New Jersey,2011,pp1-5
4. Rabl A. Active Solar Collectors and Their Applications. Oxford University Press,New York 1985. – pp. 503.
5. Stine W.B and Harrigan R.W"Solar Energy Fundamentals and Design", John Wiley and Sons Inc., New York, 1985,pp 1 -200
6. Magal.B.S, Solar Power Engineering, Tata McGraw-Hill Publishing Company Limited, 1990, pp. 123.
7. Garg & Prakash- Solar Energy – Fundamentals & applications, Tata McGraw-Hill Education, 2000,pp 20-200
8. Rai G.D. – Solar Energy Utilisation, Fifth Edition, Khanna Publications, New Delhi, 2000, pp 1-200
9. Tiwari GN – Solar Energy, Fundamentals, Design, Modelling and application, Narosha Publishing Pvt.Limited, 2005. pp 50 – 150
10. Sukhatme. S.P. Solar Energy: Principles of Thermal Collection and Storage, 2nd ed., New Delhi: Tata Mc Graw-Hill Publishing Company Limited, 1996.pp 10 – 200.

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