UNIT II

SOLAR RADIATION AND ITS MEASUREMENT

INTRODUCTION

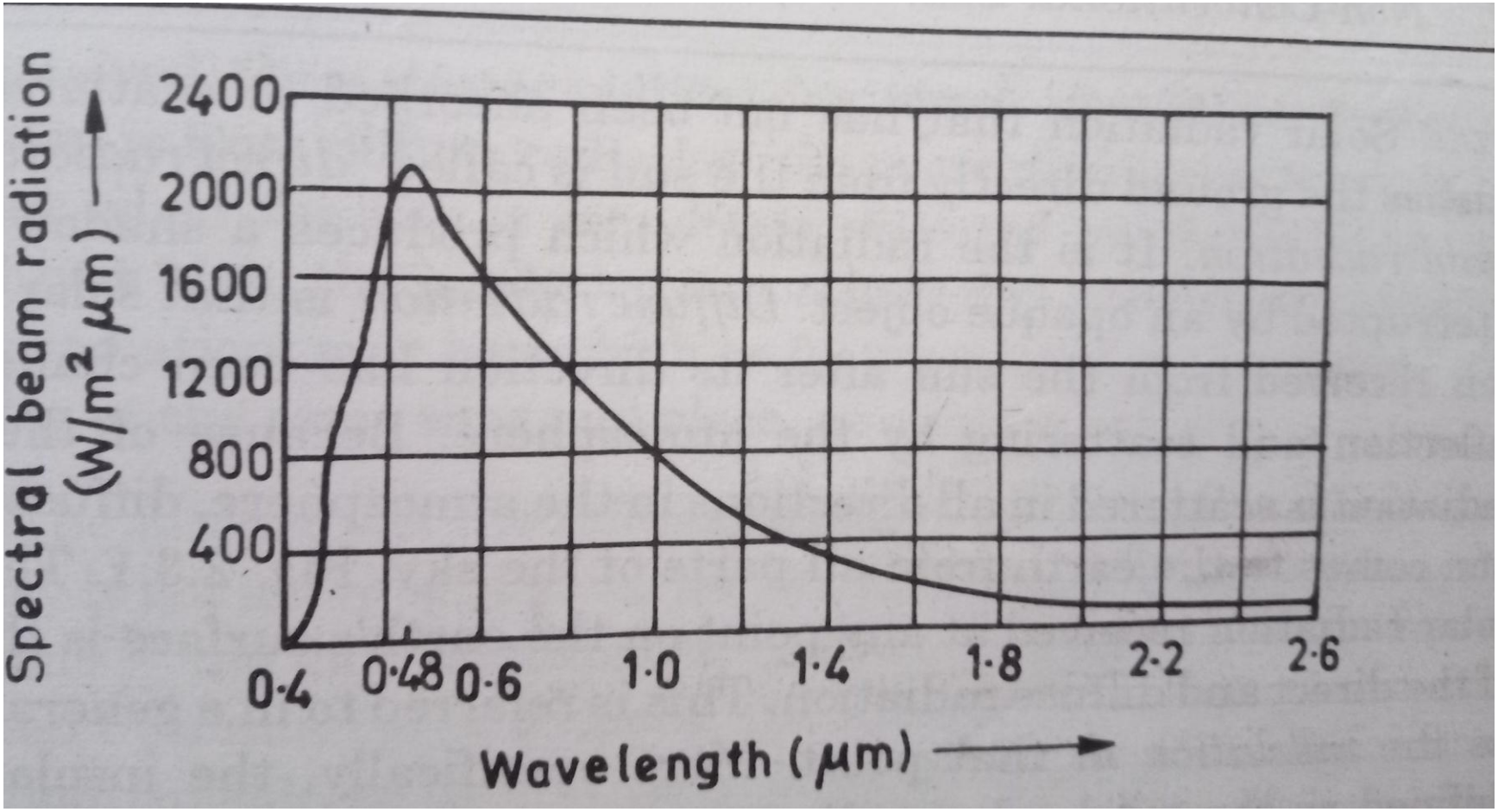
- *Solar energy*
- *Major drawbacks*

  - intermittent and variable manner of arrival to earth's surface

  - large area required to collect the energy

- *Solar constant*
  - *NASA : Standard value in three common units:*
    - *1.353 kilowatts per square metre*
    - *116.5 langleys (calories per sq.cm.)*
    - *429.2 Btu per sq.ft. per hour*

Spectral Distribution



Percentage of Radiation

Wavelength (MICRONS)	0 – 0.38	0.38 – 0.78	0.78 – 4.0
Approximate energy (W/m^2)	95	640	618
Approximate percentage of total energy	7	47.3	45.7

Beam and Diffuse Radiation

- *Beam radiation*
  - *Reaches ground directly*
  - *Also called as "direct radiation"*
- *Diffuse radiation*
  - *After reflection and scattering*

Beam and Diffuse Radiation

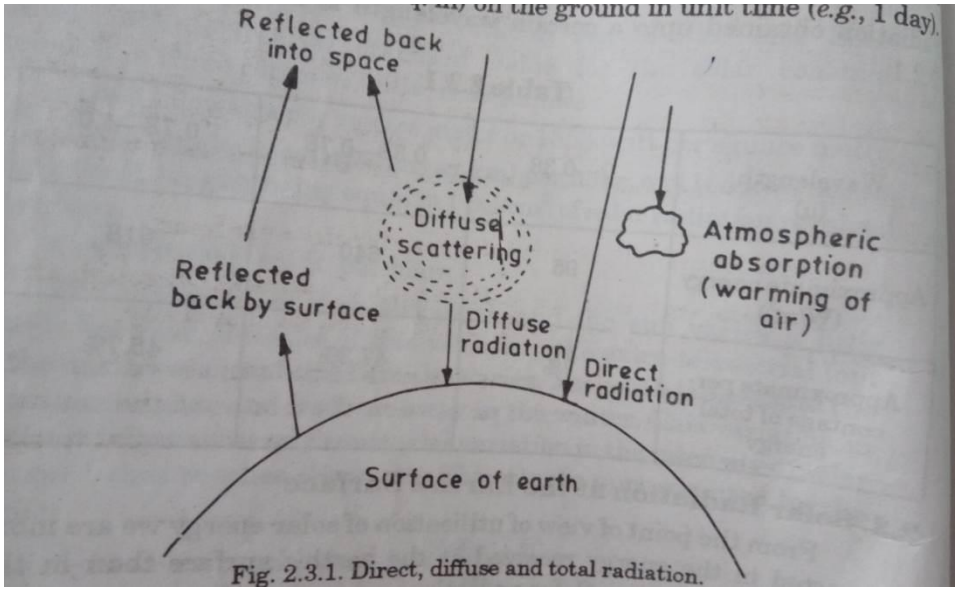


Fig. 2.3.1. Direct, diffuse and total radiation.

Beam and Diffuse Radiation

- *Part of radiation is reflected back into the space, by clouds*
- *Radiation entering the atmosphere is partly absorbed by molecules in the air*
- *Oxygen and ozone absorb nearly all the ultraviolet radiation*
- *Water vapour and carbon dioxide absorb some of the energy in the IR range*
- *Part of the radiation is scattered by atmospheric molecules and dust particles*

Attenuation of Beam Radiation

- *Absorption*
  - *Short wave UV rays are absorbed by the ozone in the atmosphere*
  - *Long wave IR rays are absorbed by carbon dioxide and moisture in the atmosphere*
  - *Solar energy lies within 0.29* μ to 2.5 μ range

Attenuation of Beam Radiation

- *Scattering*
  - *By water vapour and dust*
  - *Attenuates the radiation*
  - *Depends on atmospheric conditions*
  - *Ozone absorbs in UV band*
  - *Absorbs short wave radiation below 0.29* μm
  - *Transmittance is almost unity above 0.39* μm
  - *Water vapour absorbs in the IR band*

Solar spectrum at ground level

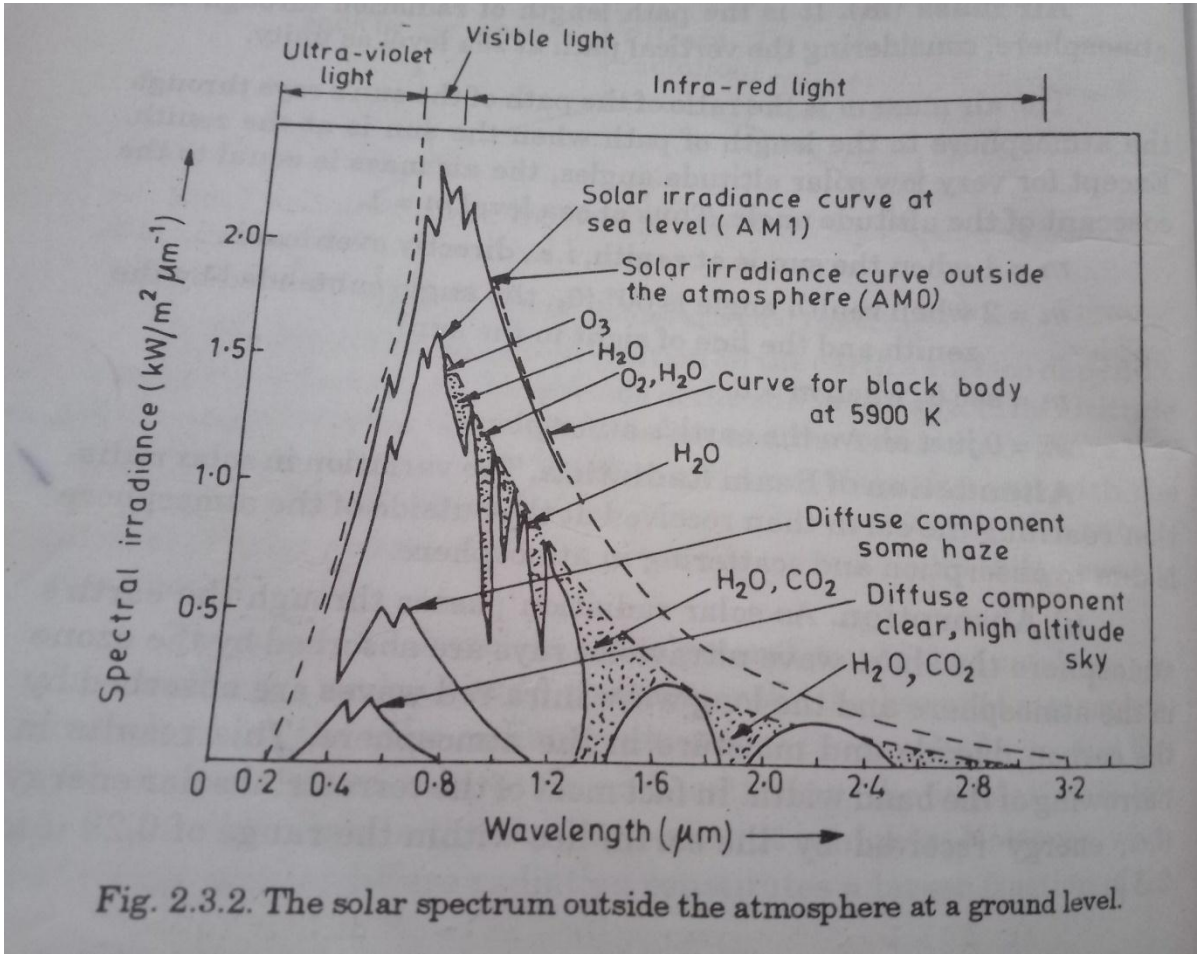


Fig. 2.3.2. The solar spectrum outside the atmosphere at a ground level.

Solar spectrum at ground level

- *Maximum intensity observed at noon at sea level is 1 kW/m^2*
- *At an altitude of 1000 metres, the value rises to about 1.05 kW/m^2*
- *Higher mountain values – slightly above 1.1 kW/m^2*
- *Dotted curve – black body radiation at 5900 °K*
- *Atmospheric transmission factor*

INSTRUMENTS FOR SOLAR RADIATION

Pyrheliometer

- collimates the radiation to determine beam intensity as a function of incident angle

Pyranometer

- measures the total hemispherical solar radiation

Angstrom Pyrheliometer

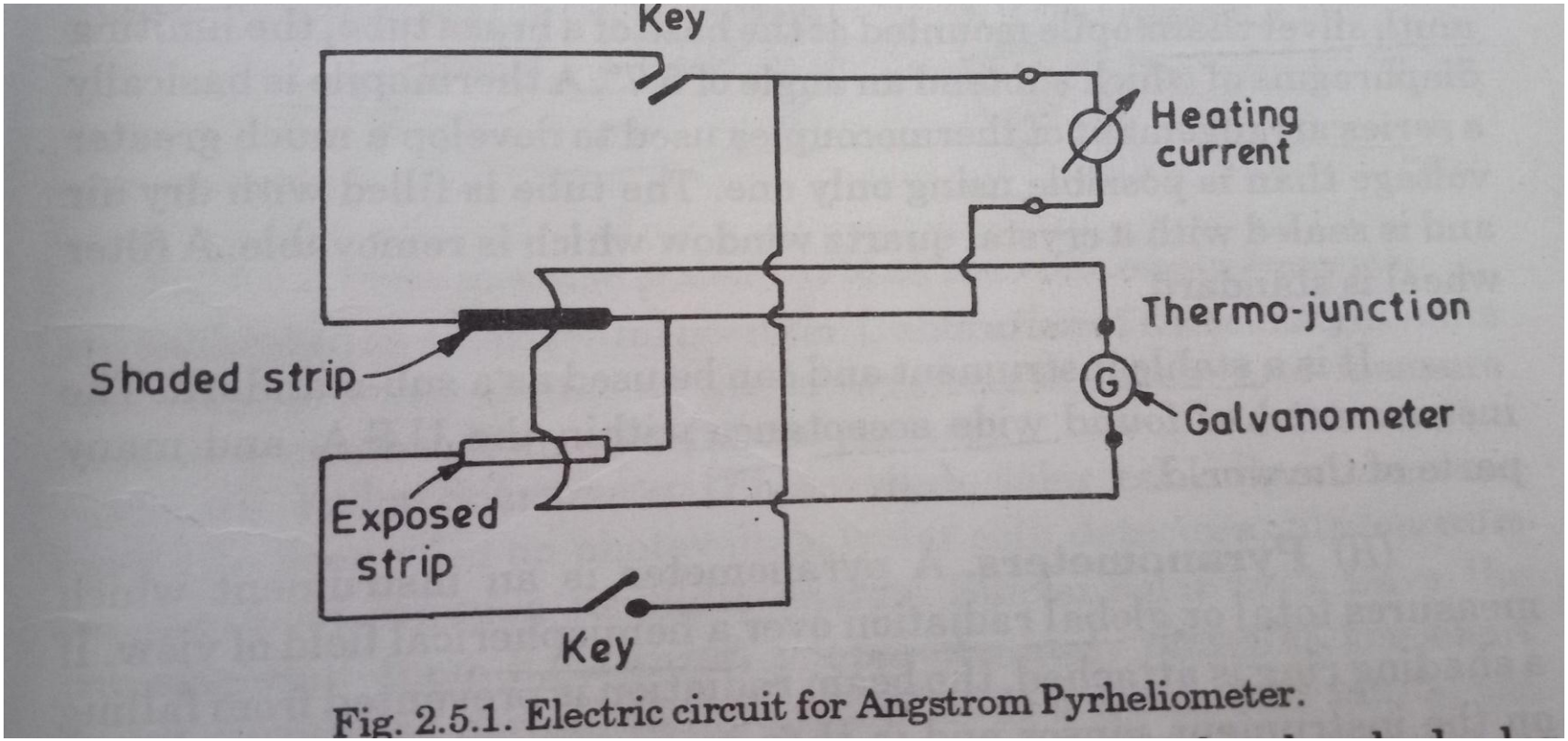


Fig. 2.5.1. Electric circuit for Angstrom Pyrheliometer.

Angstrom Pyrheliometer…

- *Manganin strip – 20 x 2 x 0.1 mm*
- *Energy used for heating is equal to the absorbed solar energy*
- *Thermocouples, through a sensitive galvanometer, used to test the equality of temperature*
- *Energy H is , $H_{DN} = K_i^2$*
- *K – dimension and instrument constant, = $R/W\alpha$*

ANGSTROM PYRHELIOMETER

Other Pyrheliometers…

Abbot silver disk Pyrheliometer

- blackened silver disk

- mercury in glass thermometer

- shutter made of three polished metal leaves

- good stability

- used for calibrating pyranometers

Other Pyrheliometers….

- *Eppley Pyrherliometer*
  - *Temperature compensated 15 junction bismuth silver thermopile*
  - *Series of arrangement of thermocouples*
  - *Tube is filled with dry air*
  - *Sealed with crystal quartz window*
  - *Stable instrument*

SILVER DISK PYRHELIOMETER

EPPLEY PYRHELIOMETER

PYRANOMETERS

- an instrument which measures total or global radiation over a hemispherical field of view

- sun's radiation is allowed to fall on a black surface

- hot junctions are attached to the black surface

- cold junctions do not receive solar radiation

- e.m.f. proportional to solar radiation is generated

TYPES OF PYRANOMETERS

-

- Eppley pyranometer
- Yellot solarimeter
- Moll-Gorchyheski solarimeter
- Bimetallic actionographs
- velochme pyranometer
- thermoelectric pyranometer

Pyranometer

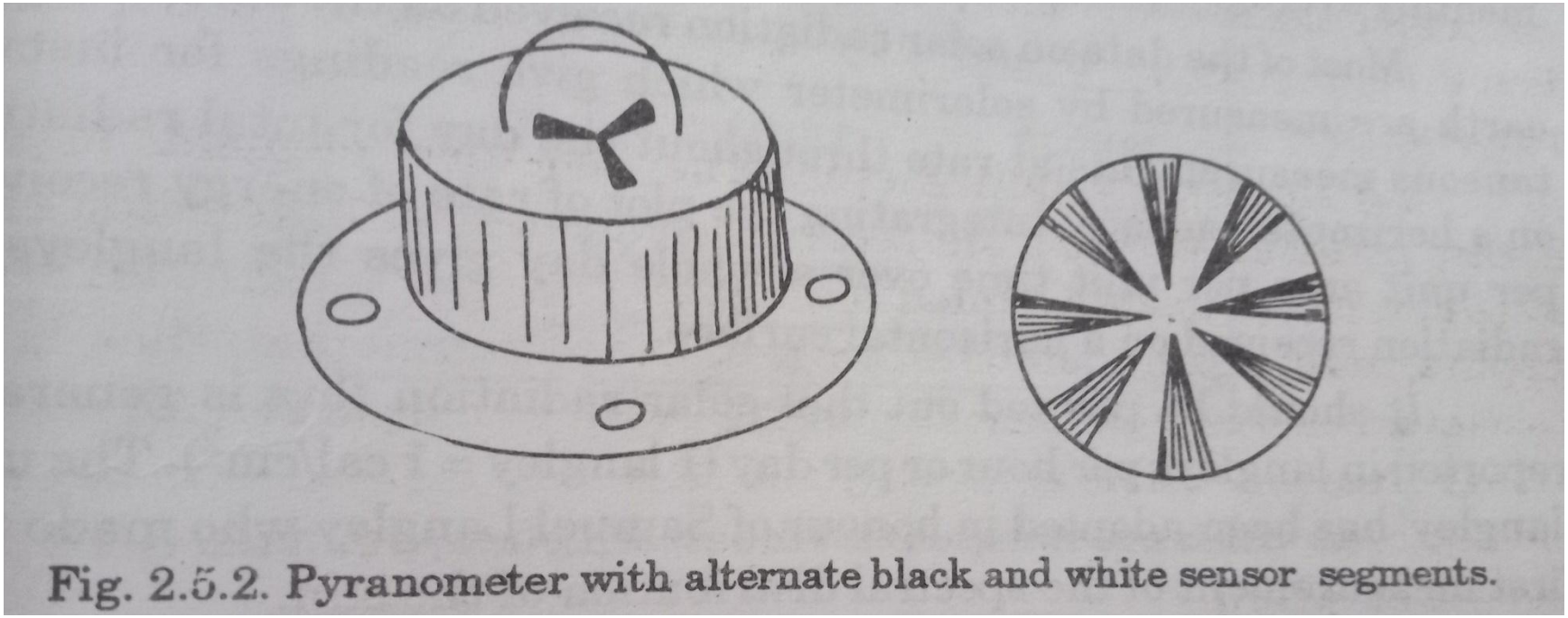


Fig. 2.5.2. Pyranometer with alternate black and white sensor segments.

PYRANOMETERS

- *Eppley Pyranometer*
  - *principle: there is a difference between the temperature of black surfaces and white surfaces*
  - *Temperature difference is achieved by thermopile*
  - *Concentric silver rings 0.25 mm thick with 10 or 50 thermocouple junctions*
  - *Disks are enclosed in a hemispherical glass cover*
  - *Calibrated in horizontal position*

PYRANOMETERS…

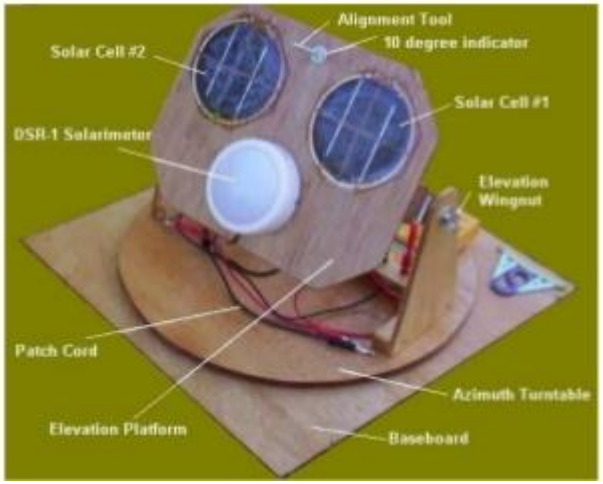
- *Yellot Solarimeter*
- *Photovoltaic solar cell*
- *Property – light current in a linear function of the incident solar radiation*
- *Disadvantage – spectral response is not linear*
- *Instrument calibration is a function of spectral distribution of the incident radiation*

EPPLEY PYRANOMETER

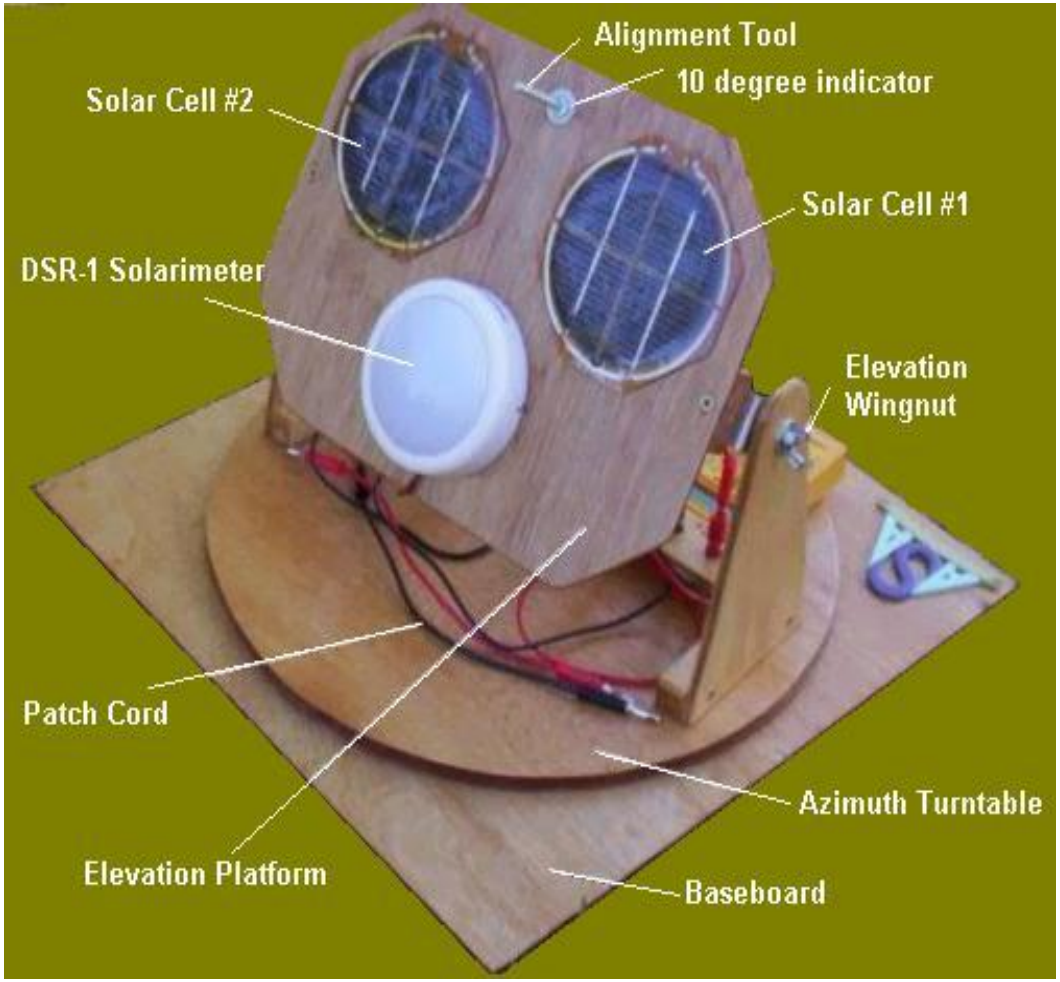
YELLOT SOLARIMETER

PHOTOVOLTAIC SOLARIMETER

- Typical pyranometer measure solar flux intensity
- Working principle PV cell
- Solar energy → Solar cell → Variable resistive load→ Current produced
- Moved in direction off sun
- Meter calibrated in watt per meter square



YELLOT SOLARIMETER…



SOLAR ENERGY

Energy from the Sun

- The Sun is a huge ball of nuclear power
- On average, every square meter of Earth's surface receives 164 watts of solar energy
- In other words, you could stand a really powerful (150 watt) table lamp on every square meter of Earth's surface and light up the whole planet with the Sun's energy!
- Solar panels can convert this power into a convenient supply of electricity

SOLAR ENERGY

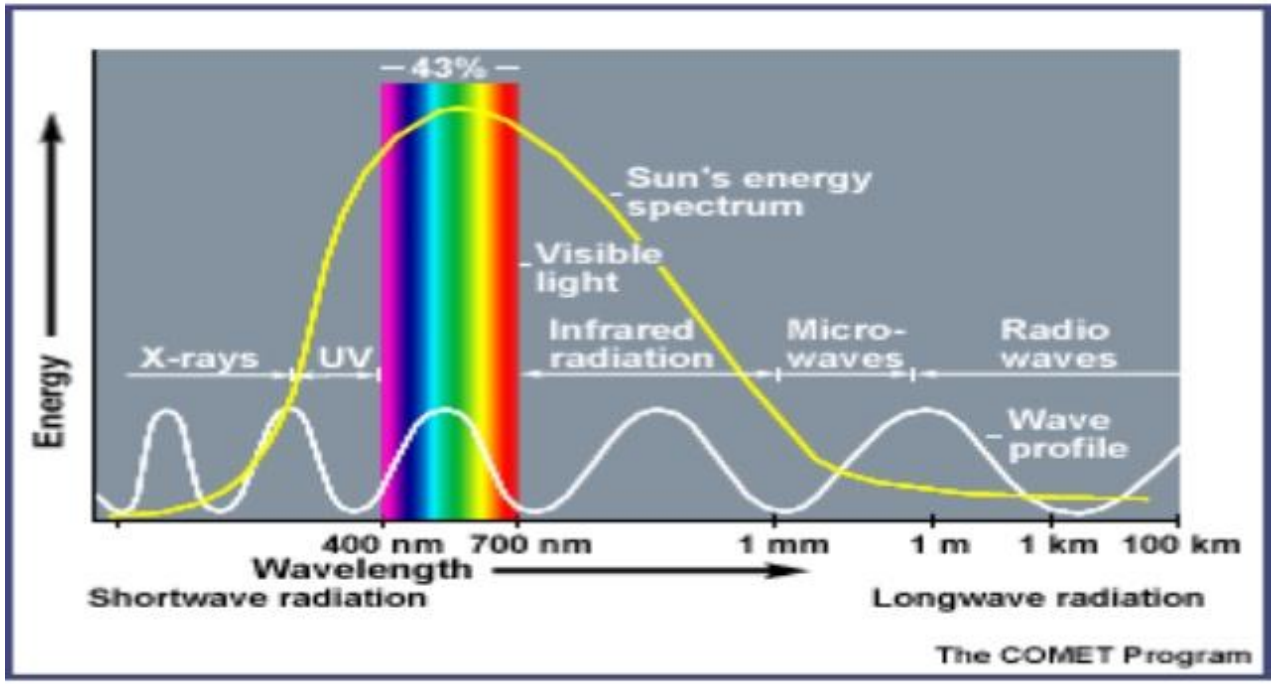
- Sun has produced energy for billion of years and it is the most important source of energy for all life - forms
- It is a renewable source of energy
- It is the cleanest form of energy
- It does not produce any pollutants

SOLAR ENERGY

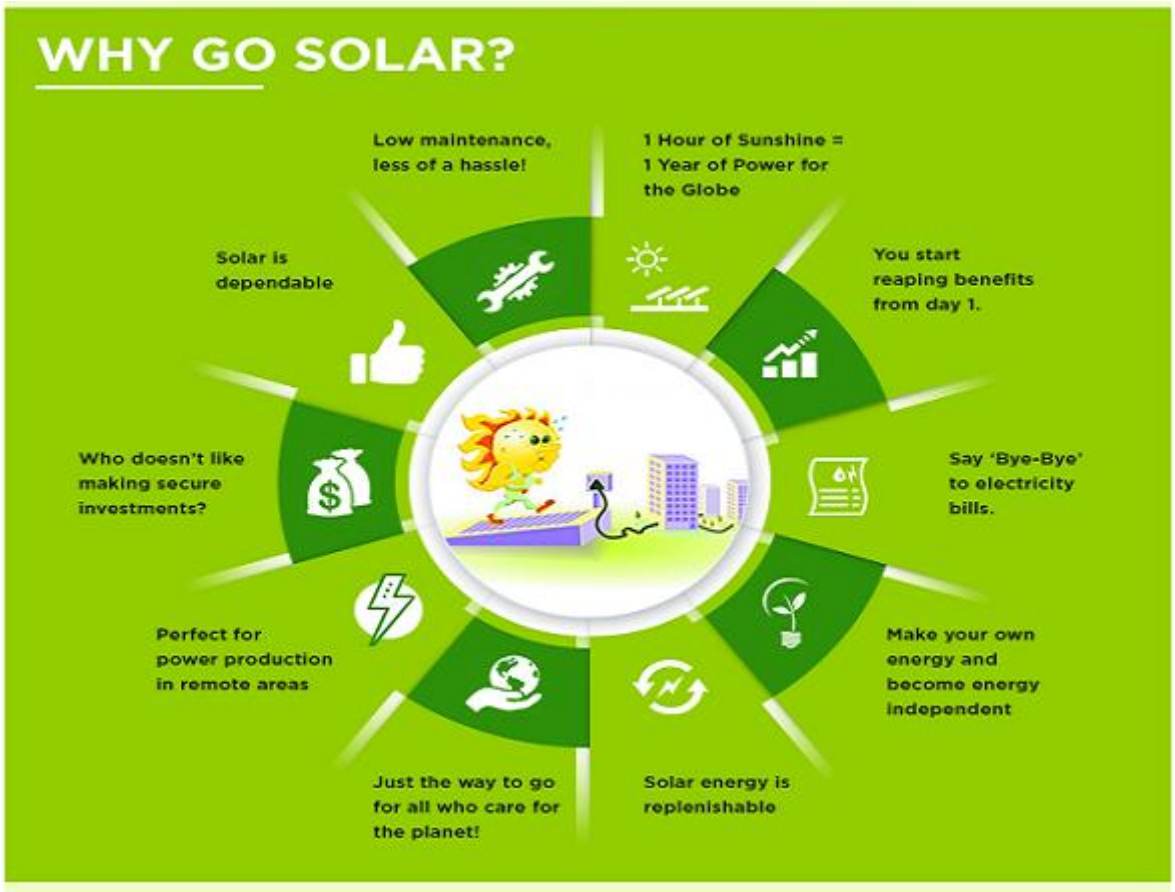
What's Solar Energy?

- Solar energy Originates with the thermonuclear fusion reactions occurring in the sun.
- Represents the entire electromagnetic radiation (visible light, infrared, ultraviolet, x-rays, and radio waves).
- This energy consists of radiant light and heat energy from the sun.
- Out of all energy emitted by sun only a small fraction of energy is absorbed by the earth.
- Just this tiny fraction of the sun's energy is enough to meet all our power needs.

SOLAR ENERGY



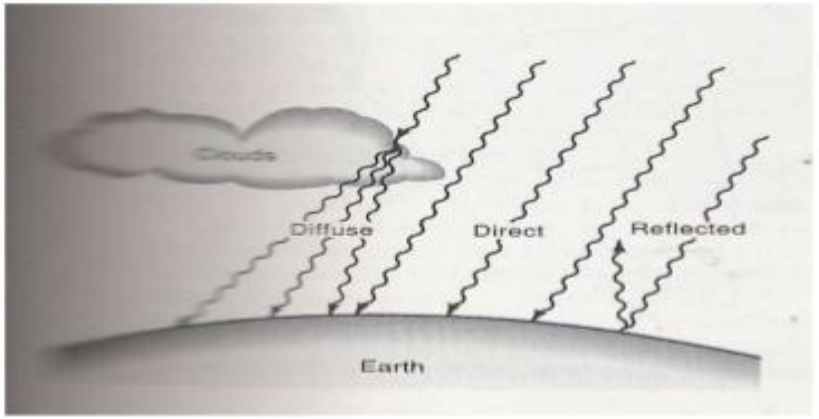
WHY GO SOLAR?


Low maintenance, less of a hassle!
1 Hour of Sunshine = 1 Year of Power for the Globe
Solar is dependable
You start reaping benefits from day 1.
Who doesn't like making secure investments?
Say 'Bye-Bye' to electricity bills.
Perfect for power production in remote areas
Make your own energy and become energy independent
Just the way to go for all who care for the planet!
Solar energy is replenishable

INSOLATION

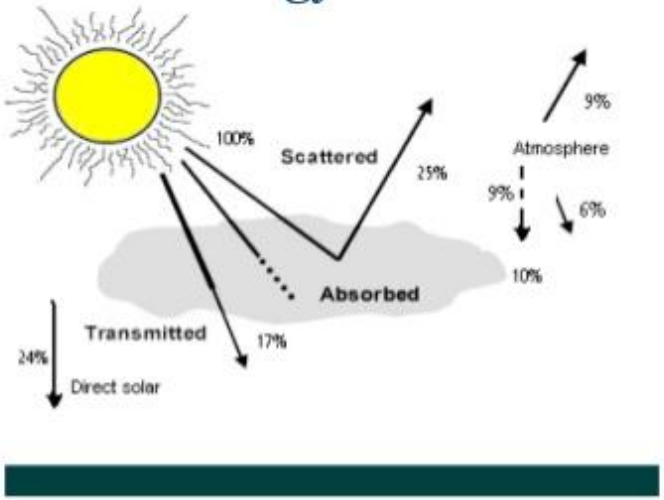
Insolation

- Insolation is the amount of solar radiation reaching the earth. Also called Incident Solar Radiation.
- Maximum value is 1000 kW/m^2.
- Components of Solar Radiation:
  - Direct radiation
  - Diffuse radiation
  - Reflect radiation



SOLAR ENERGY

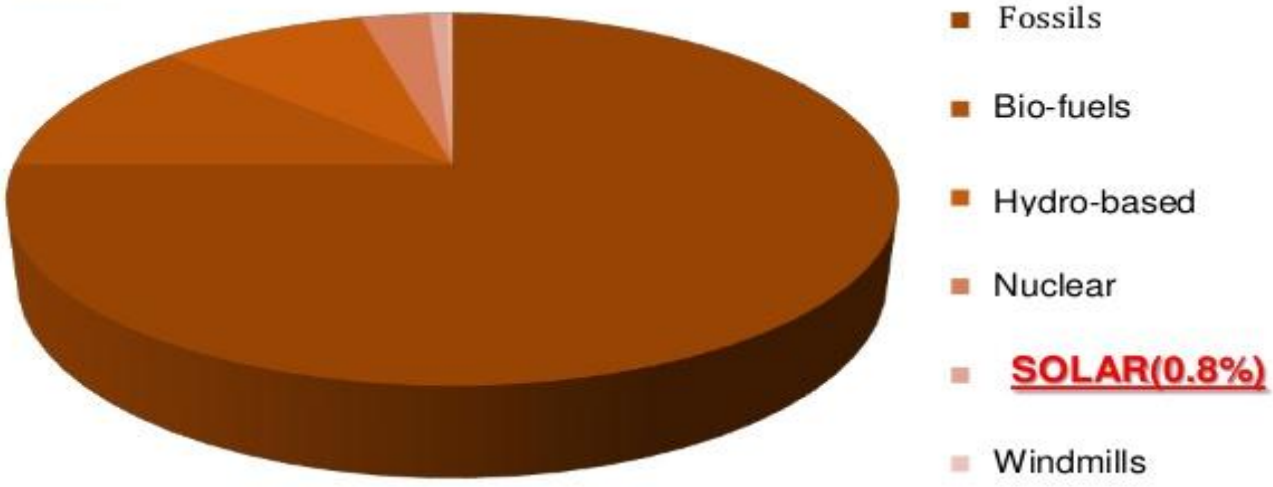
How much solar energy?



The surface receives about 47% of the total solar energy that reaches the Earth. Only this amount is usable.

SOLAR ENERGY

- Using present solar techniques some of the solar energy reaching the earth is utilized for generating heat, electricity etc....
- Even then the energy demand met by using solar energy is very less.



SOLAR ENERGY

Why Solar Energy?

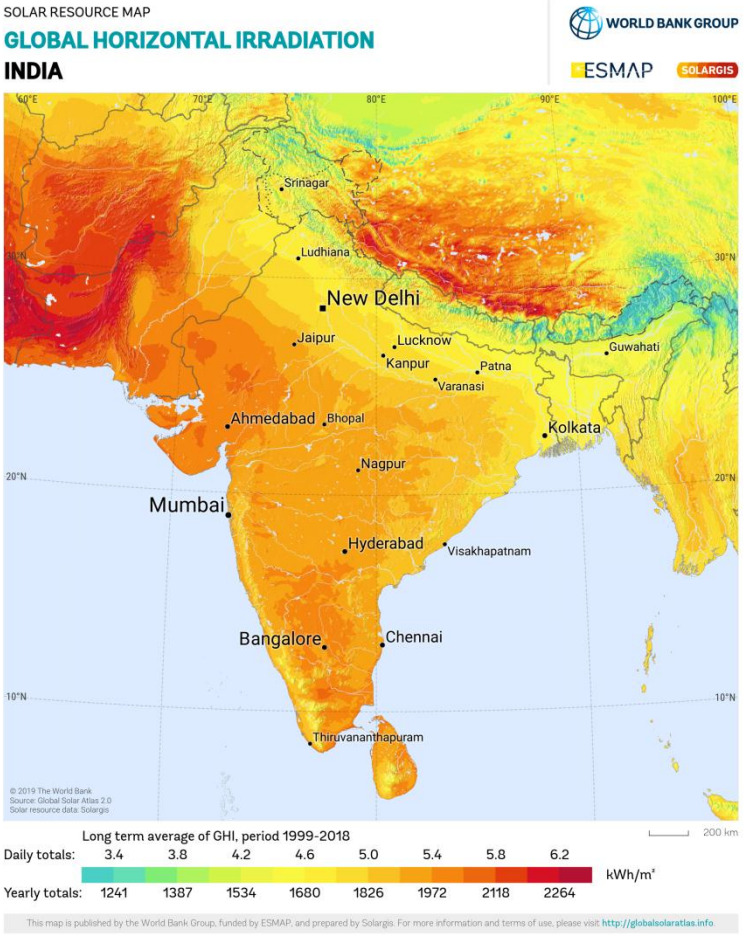
- The fossil fuels are non renewable sources so we can not depend on them forever.
- Though nuclear energy is a clean and green energy ,as said by Dr.A.P.J Abdul Kalam, there are always some problems associated with it.
- So the only option we have is solar energy because it is a nonpolluting and silent source of electricity and also low maintenance and long lasting energy.

SOLAR ENERGY

How solar energy is used

- Solar Thermal Energy
- Solar Heating
- – Solar Water Heating
- – Solar Space Heating
- – Solar Space Cooling
- Electricity Generation Using Solar Concentrators
- Photovoltaic Cells

SOLAR POTENTIAL OF INDIA



SOLAR POTENTIAL IN INDIA

- With about 300 clear and sunny days in a year, the calculated solar energy incidence on India's land area is about 5000 trillion kilowatt-hours (kWh) per year (or 5 EWh/yr).
- The daily average solar-power-plant generation capacity in India is 0.20 kWh per m^2 of used land area, equivalent to 1400–1800 peak (rated) capacity operating hours in a year with available, commercially-proven technology.

SOLAR ENERGY IN TAMILNADU

- Tamil Nadu has the 5th highest operating solar-power capacity in India in May 2018. The total operating capacity in Tamil Nadu is 1.8 GW. On 1 July 2017, Solar power tariff in Tamil Nadu has hit an all-time low of Rs 3.47 per unit when bidding for 1500 MW capacity was held.
- The 648-MW Kamuthi Solar Power Project is the biggest operating project in the state. On 1 January 2018, NLC India Limited (NLCIL) commissioned a new 130 MW solar power project in Neyveli.

Solar electricity generation

- Solar electricity generation from April 2019 to March 2020

- 50.1 TWh, or 3.6% of total generation (1,391 TWh).

Annual solar power generation

- YearSolar power generation (TWh)

2013–14	3.36
2014–15	4.60
2015–16	7.45
2016–17	12.09
2017–18	25.87
2018–19	39.27
2019–20	50.10

SOLAR CELL

Solar Cell

- An electronic device that converts sunlight directly into electricity
- It's about the size of an adult's palm, octagonal in shape, and coloured bluish black
- Solar cells -> Solar modules -> Solar panels
- Also called as photovoltaic (PV) cells
- Solar energy technologies use the sun's energy to light homes, produce hot water, heat homes and electricity.

பூவுலகின் தோழி ரேச்சல் கார்சன்!

சுற்றுச்சூழலைக் காக்க விழிப்புணர்வை ஏற்படுத்திய முன்னோடி விஞ்ஞானி ரேச்சல் கார்சன். அமெரிக்கா, பென்சில்வேனியா மாகாணத்தில், ஸ்பிரிங்டேல் என்ற சிற்றூரில், மே, 27, 1907ல் பிறந்தார்.

தந்தை ராபர்ட் கார்சன், கம்பெனி எழுத்தராக இருந்தார். அம்மா மரியா கார்சன்; ஆசிரியை பயிற்சி முடித்தவர். இயற்கை ஆர்வலராகவும் விளங்கினார். குழந்தை ரேச்சலுக்கும் அதே மனப்பான்மையை ஊட்டி வளர்த்தார்.

கூடு இழந்த ராபின் பறவைகளுக்கு, ரேச்சலின் வீடு சரணாலயமாக இருந்தது.

சிறுவயதிலேயே எழுத்தாளராகும் ஆர்வம் கொண்டிருந்தார் ரேச்சல். 10 வயதில் எழுதிய கதை, 'செயிண்ட் நிக்கோலஸ்' என்ற இதழில் பிரசுரமானது.

பென்சில்வேனியா மகளிர் கல்லூரியில் உயிரியல் படிப்பில் சேர்ந்தார். படிப்பு முடித்தது. வாங்கியிருந்த கல்விக்கடனை செலுத்தாததால், பட்டம் வழங்கப்படவில்லை. குடும்ப சொத்தை அடமானம் வைத்து கடனை செலுத்தி பட்டம் பெற்றார்.

பின், முதுகலை விலங்கியல் படிப்பில் சேர்ந்தார். அப்போது அமெரிக்காவில், பெண்கள் உயர்கல்வி கற்பது எளிதாகயில்லை. பல்கலைக்கழகத்தில் மாணவியருக்கு விடுதி வசதி எல்லாம் கிடையாது. பேராசிரியை மேரி என்பவருடன் தங்கி படிப்பை தொடர்ந்தார். உயரிய மதிப்பெண்ணுடன், முதுகலை பட்டம் பெற்றார்.

அமெரிக்க மீன்வளத்துறையில் பகுதி நேர வேலையில் சேர்ந்தார். வானொலி நிகழ்ச்சி மூலம் கடல்வாழ் உயிரினங்கள் குறித்த ஆர்வத்தை ஏற்படுத்தும் வேலை அது. பணியிலிருந்த போதே, 'அட்லாண்டிக்' என்ற இதழில், 'கடல் அடியில்' என்ற கட்டுரையை எழுதினார். பெண் என தெரிந்தால், முக்கியத்துவம் கிடைக்காது என அஞ்சி, ஆர்.எல்.கார்சன் என்ற புனைப்பெயரில் ஆய்வுக் கட்டுரைகள் எழுதினார்.

அவற்றை தொகுத்து, 'கடல் காற்றின் கீழே' என்ற நூலை, 1941ல் வெளியிட்டார். 'காட்டுயிர்களின் வாழிடம் தான் நமக்கு வீடு என்பதை உணராமல், அவற்றை அழித்துக்கொண்டே இருக்கிறோம்' என, நூலில் குறிப்பிட்டிருந்தார்.

இரண்டாம் உலகப்போரின் போது, அவரது ஆய்வு, பூச்சிகொல்லி விஷம் பக்கம் திரும்பியது. குறிப்பாக, 'டைக்குளோரோ டைபினைல் ட்ரைகுளோரோ ஈத்தேன்' என்ற பூச்சிகொல்லி விஷத்தால் ஏற்படும் அபாய விளைவுகளை ஆய்வு செய்தார். ஆய்வின் இடையே, 'நம்மைச் சுற்றியுள்ள கடல்' என்ற நூலை வெளியிட்டார். அது

பெரும் வெற்றி பெற்றது. வெளிவந்த நான்கு மாதங்களில், 1 லட்சம் பிரதிகள் விற்றுத் தீர்ந்தன.

எழுத்திலும், ஆய்விலும் முழு கவனம் செலுத்தினார். கடல்சார் அறிவியல் குறித்து, 'கடலின் விளிம்பில்' என்ற நூலை வெளியிட்டார். இதுவும் பெரும் வரவேற்பைப் பெற்றது.

மண்ணியல், தொல்லுயிரியல், உயிரியல், மானுட வரலாறு என பல துறைகளின் விவரங்களோடு கடல் குறித்து மூன்று நூல்களையும் எழுதியிருந்தார். எழுதியவர் பெண் என்பதை அமெரிக்கர்களால் நம்பமுடியவில்லை.

அமெரிக்க மக்களின் வாழ்வில், பாடும் பறவையான ராபினுக்கு முக்கிய

இடமுண்டு. அதன் எண்ணிக்கை வேகமாக குறைந்து வந்தது. அதற்கான காரணத்தை ஆராய்ந்து விளக்கினார்.

'ராபின்களின் முக்கிய உணவு மண்புழு; பூச்சிக்கொல்லி தெளிப்பால், மண்புழுக்கள் அழிகின்றன; அதனால் உணவு கிடைக்காத, ராபின் பறவைகளும் அழிகின்றன' என்பதை ஆதாரப்பூர்வமாக விளக்கினார்.

அணு ஆயுதச் சோதனையால், கதிரியக்கப் பொருளான, 'ஸ்ட்ரோண்டியம் – 90' என்ற நச்சு, வளிமண்டலத்தில் கலந்தது. அது, உணவு வழியாக தாய்ப்பாலில் சேகரமாகி, எலும்பு புற்றுநோய் மற்றும் ரத்தப் புற்றுநோயை உருவாக்கியது. இந்த விவரங்களை ஆராய்ந்து, அசைக்க முடியாத ஆதாரங்களுடன், 'மவுன வசந்தம்' என்ற நூலை, 1962ல் வெளியிட்டார்.

இந்த நூல், தமிழ் உட்பட, 20 மொழிகளில் பெயர்க்கப்பட்டுள்ளது. புத்தகத்தின் கடைசி வரி, 'பூச்சிகளை நோக்கி வீசப்படும் ஆயுதம், பூமியையே அழிக்கும் சாதனம்' என்று உள்ளது.

அனைத்து உயிர்களையும் காக்கும் வகையில், சிந்திக்கத் தூண்டியவர் ரேச்சல் கார்சன். பூவுலகின் தோழியாக வாழ்ந்தார். புற்றுநோயால் பாதிக்கப்பட்டு, 1964ல் மரணமடைந்தார்.

– தேவிகாபுரம் சிவா

பாரம்பரிய காற்றாலை!

ஐரோப்பிய நாடான நெதர்லாந்தில் உள்ள மோலன்லாண்டன் நகராட்சிக்கு உட்பட்ட கிராமம், கின்டர்டிஜிக். இது, லூக் மற்றும் நூர்து ஆறுகள் சங்கமிக்கும் பகுதியில் உள்ளது. ஆற்றோட்டத்துக்கும் தாழ்வாக அமைந்துள்ளது கிராமம்.

இதனால் அடிக்கடி வெள்ளத்தால் பாதிக்கப்பட்டது. இதை தவிர்க்க, வடிகால்வாய்கள் வெட்டியும் பலன் இல்லை. இந்த நிலையில், 1740ல், நீர் இறைக்கும், 19 காற்றாலைகள் இங்கு நிறுவப்பட்டன. இவை, ஆற்றில் நீரோட்டம் அதிகமாகும் போது, அருகே உள்ள நீர்தேக்கத்துக்கு தண்ணீரை ஏற்றும்.

இவற்றில், பல காற்றாலைகள் இன்றும் முறையாக வேலை செய்கின்றன.

இந்த பகுதியில் மின் உற்பத்திக்காக, ஏராளமான காற்றாலைகள் இப்போது நிறுவப்பட்டுள்ளன.

மிக எளிய வழியில் சூழலை பாதுகாத்துவரும் இந்த கிராமத்தை, உலக பாரம்பரிய சின்னங்களில் ஒன்றாக, 1997ல் அறிவித்துள்ளது, யுனஸ்கோ அமைப்பு. பழைய காற்றாலைகள், சுற்றி சுழன்று நீர் இறைப்பதை இன்றும் பார்க்கலாம். நெதர்லாந்து நாட்டின் முக்கிய சுற்றுலா இடங்களில் இதுவும் ஒன்று!

– பட்டு

காற்றாலை மின்சாரம் கொள்முதலில் உச்சம்

சென்னை, ஆக. 9–

காற்றாலைகளில் இருந்து நேற்று முன்தினம், இதுவரை இல்லாத வகையில், 10.75 கோடி யூனிட் மின்சாரத்தை, மின் வாரியம் கொள்முதல் செய்துள்ளது.

தமிழகத்தில், தனியார் நிறுவனங்கள், 8,502 மெகா வாட் திறனில், காற்றாலை மின் நிலையங்கள் அமைத்துள்ளன. அவற்றில் உற்பத்தியாகும் மின்சாரத்தை, மின்சார ஒழுங்குமுறை ஆணையம் நிர்ணயித்துள்ள விலைக்கு, மின் வாரியம் கொள்முதல் செய்கிறது.

அதன்படி, ஒரு யூனிட் காற்றாலை மின்சார விலை சராசரியாக, 3.18 ரூபாய். மே முதல் செப்டம்பர் வரை காற்றாலை சீசன். 2018 ஜூலை, 19ல், காற்றாலைகளில் இருந்து, 10.73 கோடி யூனிட் மின்சாரம் கொள்முதல் செய்யப்பட்டது.

இதுவே, இதுவரை மின் வாரியம் வாங்கிய காற்றாலை மின்சாரத்தில் உச்ச அளவு. நடப்பு சீசனிலும், காற்றாலைகளில் இருந்து அதிக மின்சாரம் கிடைக்கிறது.

தினமும் சராசரியாக, 7 கோடி முதல், 8 கோடி

யூனிட் மின்சாரம் பெறப்பட்டது. சில தினங்களாக, காற்றின் வேகம் அதிகம் இருப்பதால், காற்றாலைகளில் இருந்தும், அதிக மின்சாரம் கிடைக்கிறது.

இதையடுத்து, நேற்று முன்தினம், காற்றாலைகளில் இருந்து, இதுவரை இல்லாத அளவாக, 10.75 கோடி யூனிட் மின்சாரம் கொள்முதல் செய்து, மின் வாரியம், புதிய சாதனை படைத்துள்ளது.

அன்றைய தினம், மின் நுகர்வு எனப்படும், தமிழகத்தில் உள்ள வீடுகள், தொழிற்சாலைகள் உட்பட, அனைத்து பிரிவினரும் பயன்படுத்திய மின்சார அளவு, 28.13 கோடி யூனிட்.

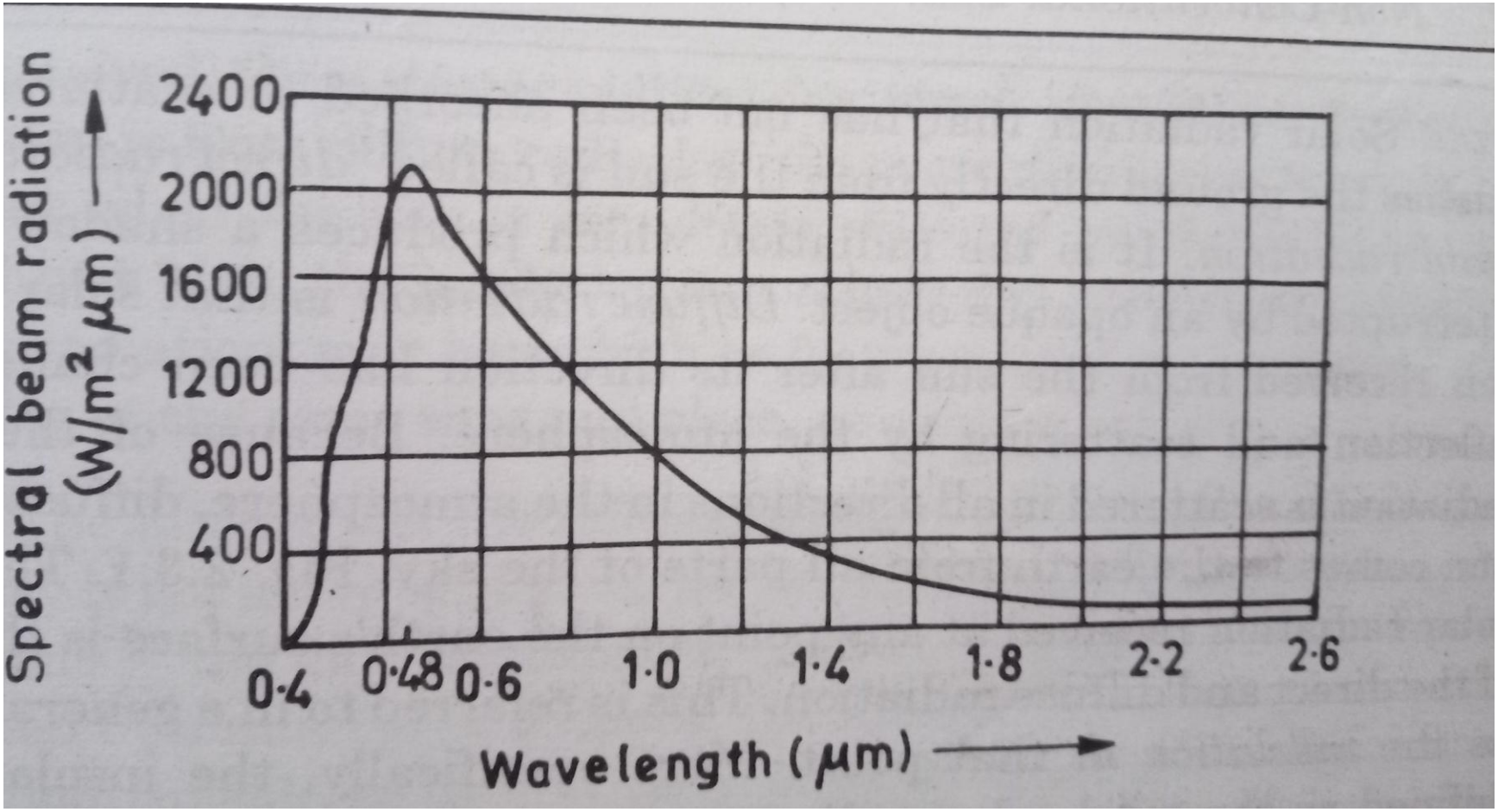
அதை பூர்த்தி செய்ததில், 10.75 கோடி யூனிட்களுடன் காற்றாலை மின்சாரம் முதலிடத்தில் உள்ளது.

INTRODUCTION

- Solar energy
- Major drawbacks

- Solar constant
  - NASA : Standard value in three common units:
    - 1.353 kilowatts per square metre
    - 116.5 langleys (calories per sq.cm.)
    - 429.2 Btu per sq.ft. per hour

Spectral Distribution



Percentage of Radiation

Wavelength	0 – 0.38	0.38 – 0.78	0.78 – 4.0
Approximate energy	95	640	618
Approximate percentage	7	47.3	45.7

Beam and Diffuse Radiation

- Beam radiation
  - Reaches ground directly
  - Also called as “direct radiation”
- Diffuse radiation
  - After reflection and scattering

Beam and Diffuse Radiation

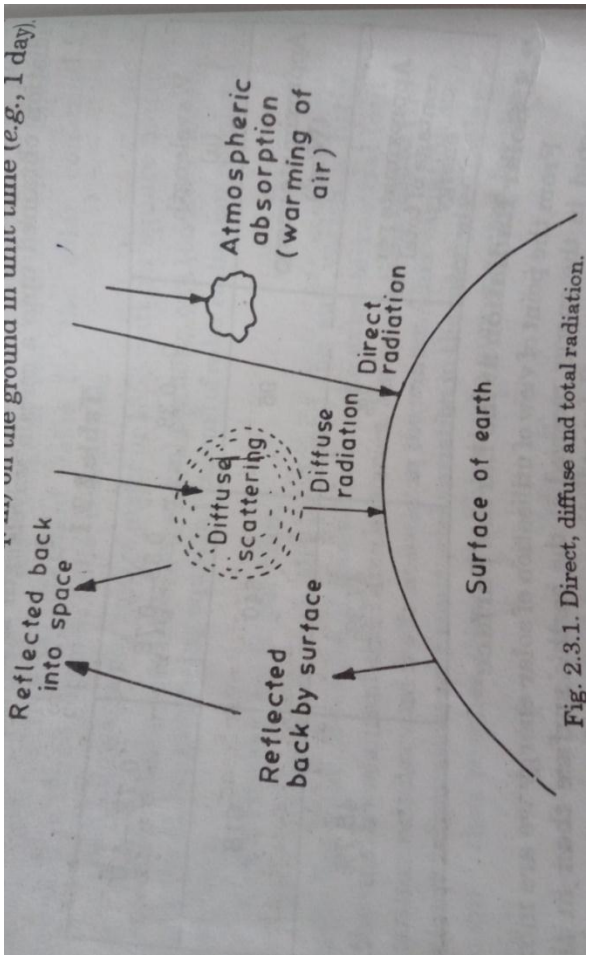


Fig. 2.3.1. Direct, diffuse and total radiation.

Attenuation of Beam Radiation

- Absorption
  - Short wave UV rays are absorbed by the ozone in the atmosphere
  - Long wave IR rays are absorbed by carbon dioxide and moisture in the atmosphere
- Scattering
  - water vapour and dust

Solar spectrum at ground level

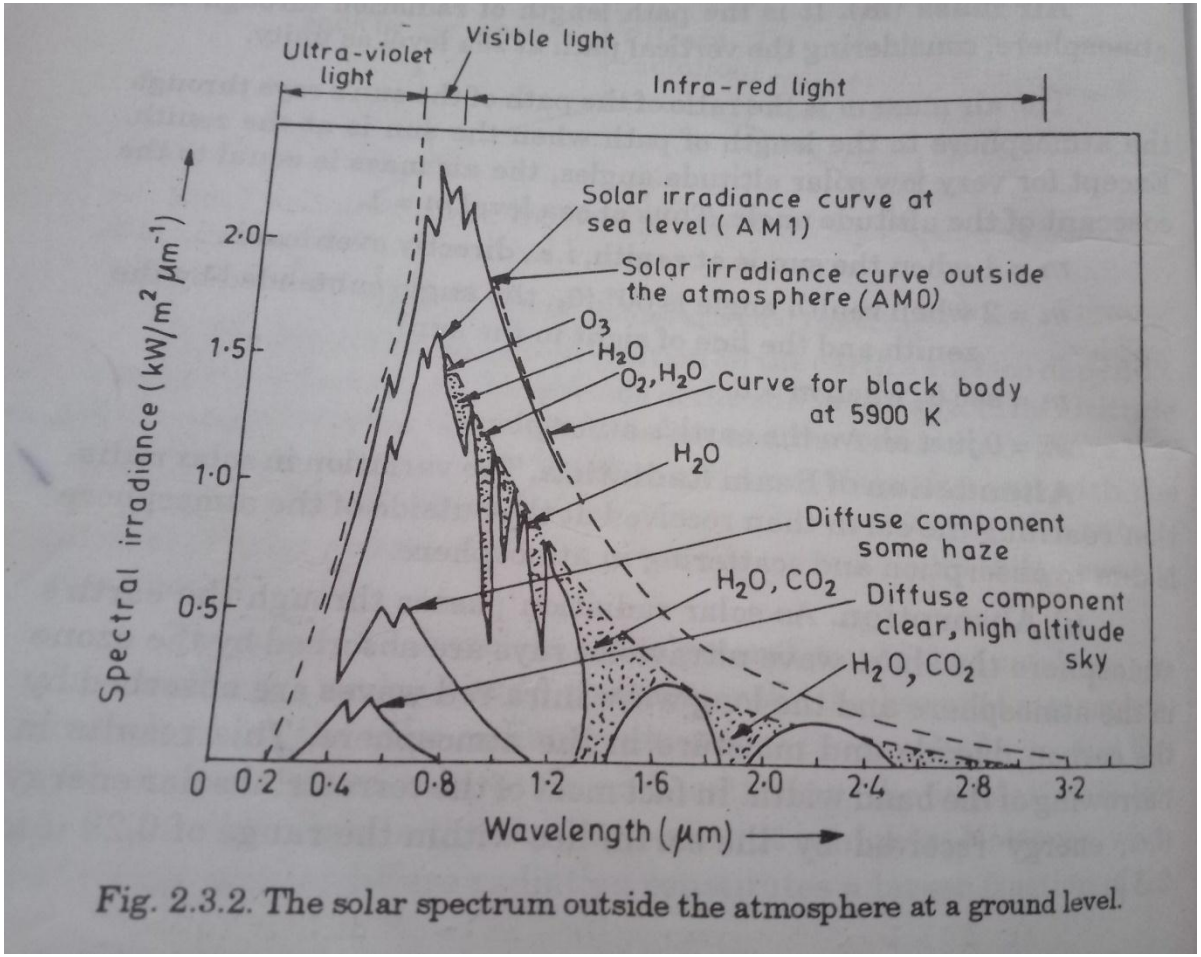


Fig. 2.3.2. The solar spectrum outside the atmosphere at a ground level.

Angstrom Pyrheliometer

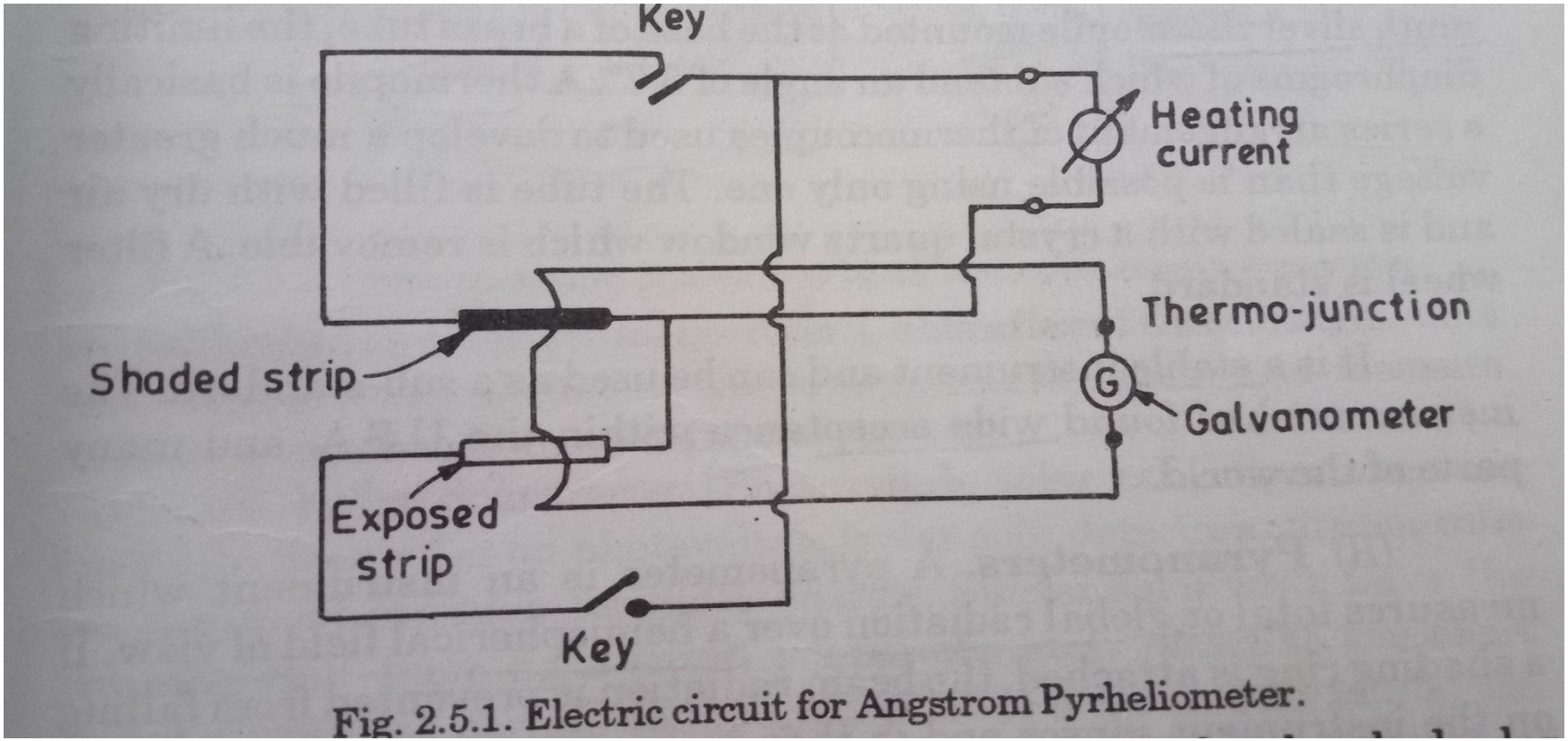


Fig. 2.5.1. Electric circuit for Angstrom Pyrheliometer.

Pyranometer

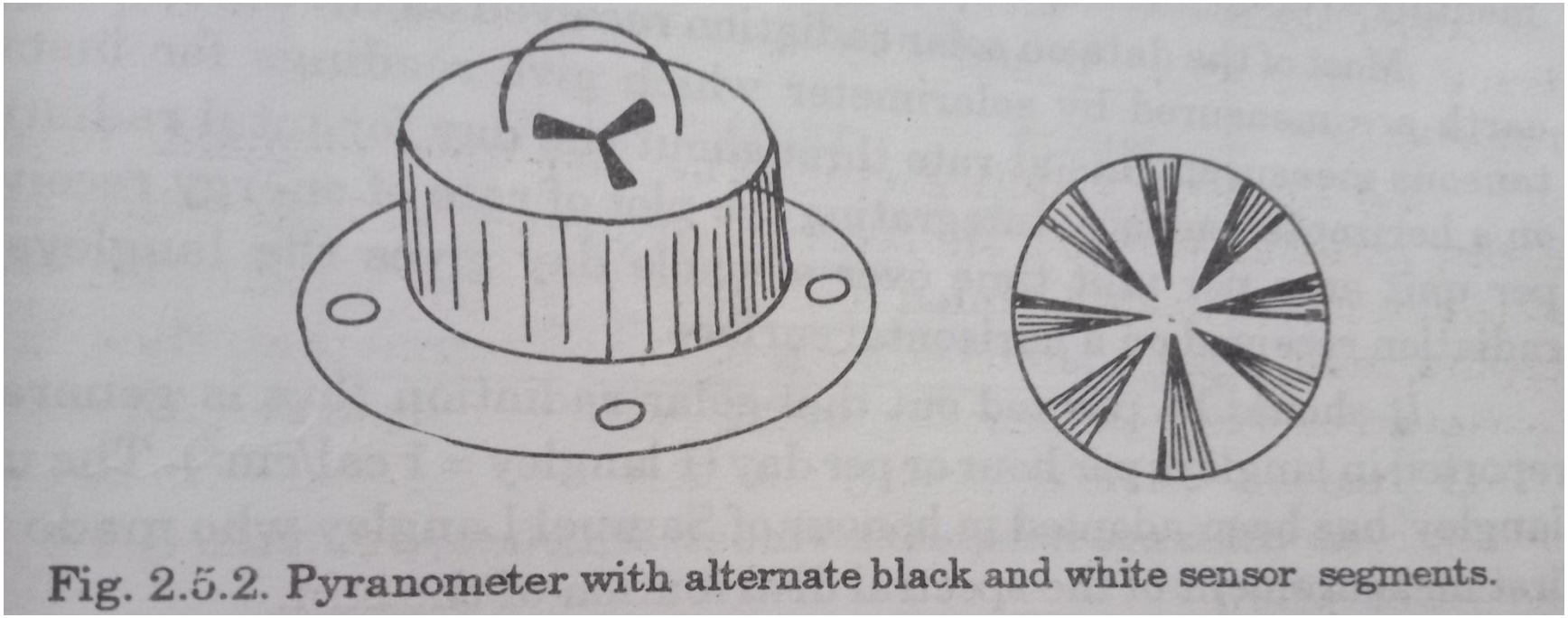


Fig. 2.5.2. Pyranometer with alternate black and white sensor segments.

Global and Diffuse radiation

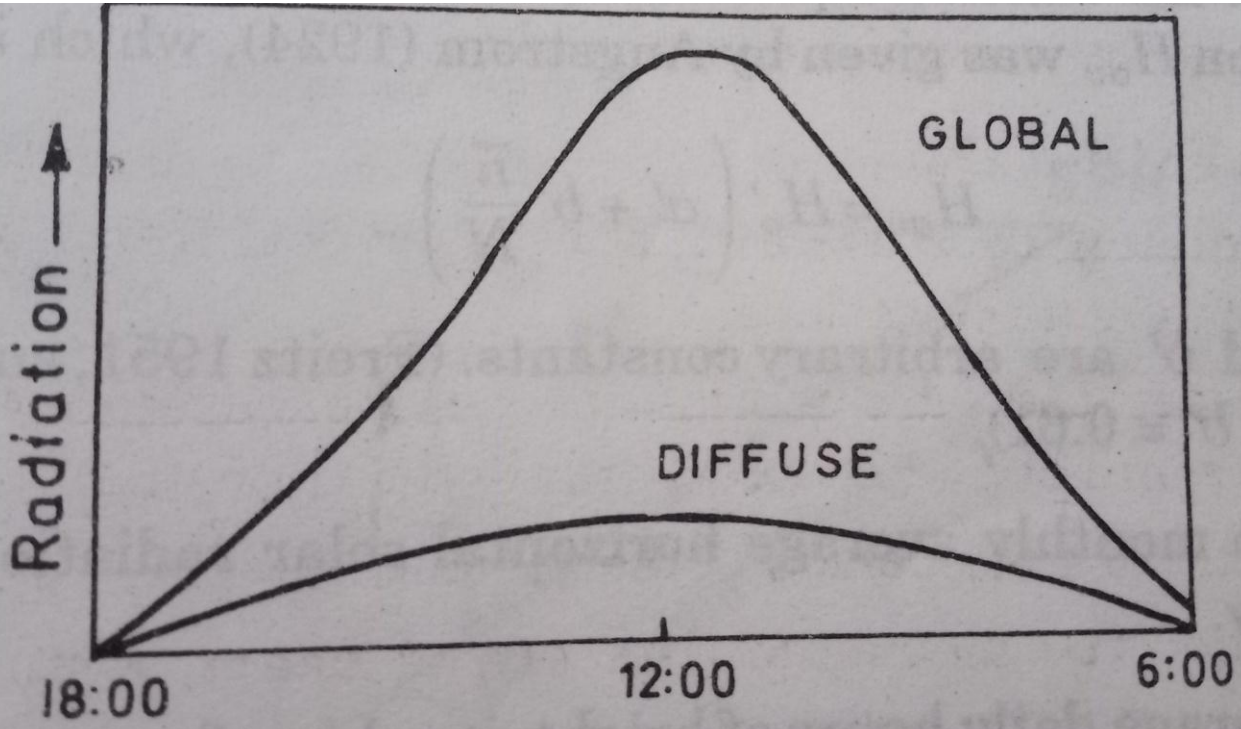


Fig. 2.6.1. A typical daily record of global and diffuse radiation.

Global and Diffuse radiation – Cloudy Day

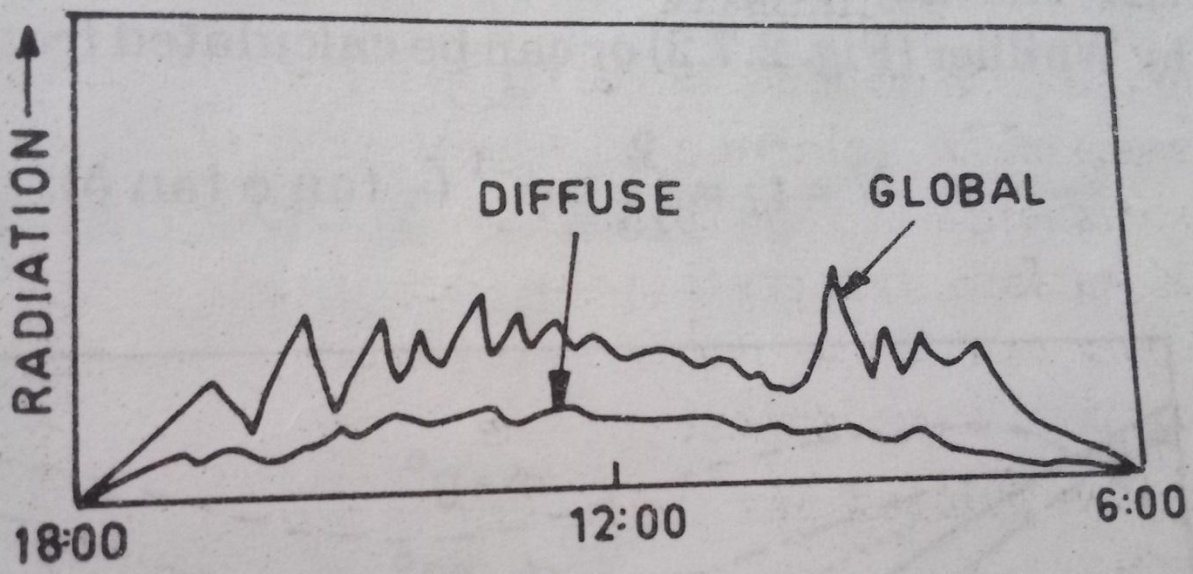


Fig. 2.6.2. A typical global and diffuse radiation on a cloudy day.

SUNSHINE RECORDER

- *A **sunshine recorder** is a device that records the amount of sunshine at a given location or region at any time.*
- *provides information about the weather and climate as well as the temperature of a geographical area.*
- *information is useful in meteorology, science, agriculture, tourism, and other fields. It has also been called a heliograph.*

Types of sunshine recorders

- *One type uses the sun itself as a time-scale for the sunshine readings*
- *The other type uses some form of clock for the time scale*
- *Older recorders required a human observer to interpret the results*
- *Recorded results might differ among observers*
- *Modern sunshine recorders use electronics and computers for precise data that do not depend on a human interpreter*

Campbell–Stokes recorder

Jordan sunshine recorder

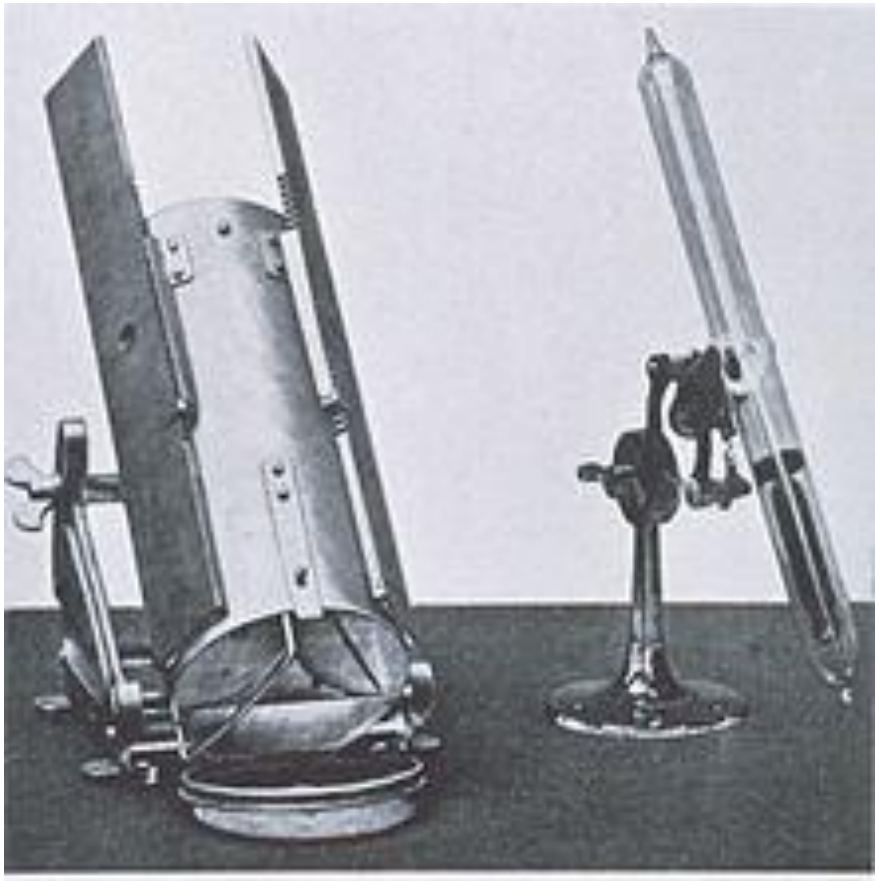


FIG. 1.—JORDAN'S SUNSHINE RECORDER.

MARVIN'S SUNSHINE RECORDER.

SOLAR RADIATION DATA

- *instantaneous measurement of values integrated over a period of time*
- *time or time period of measurements*
- *whether beam, diffuse or total radiation*
- *instrument used*
- *receiving surface orientation*
- *if averaged, period over which they are averaged*

Global and Diffuse radiation

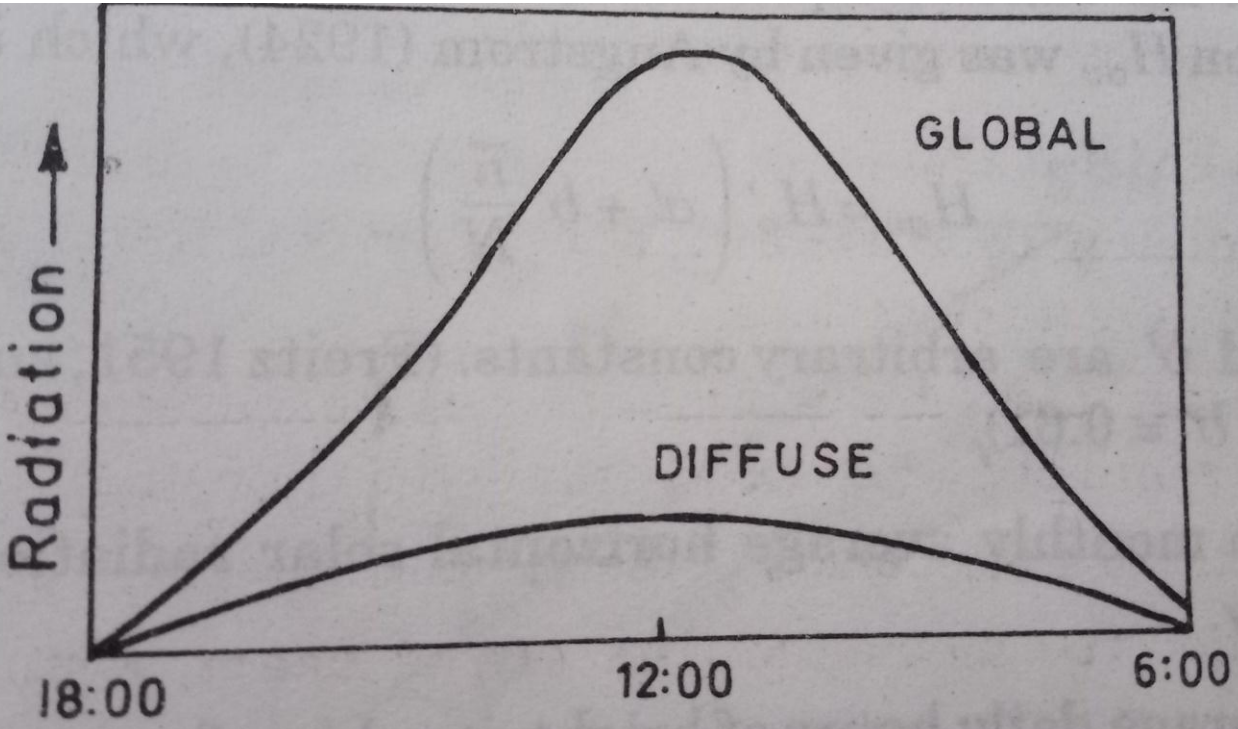


Fig. 2.6.1. A typical daily record of global and diffuse radiation.

Global and Diffuse radiation – Cloudy Day

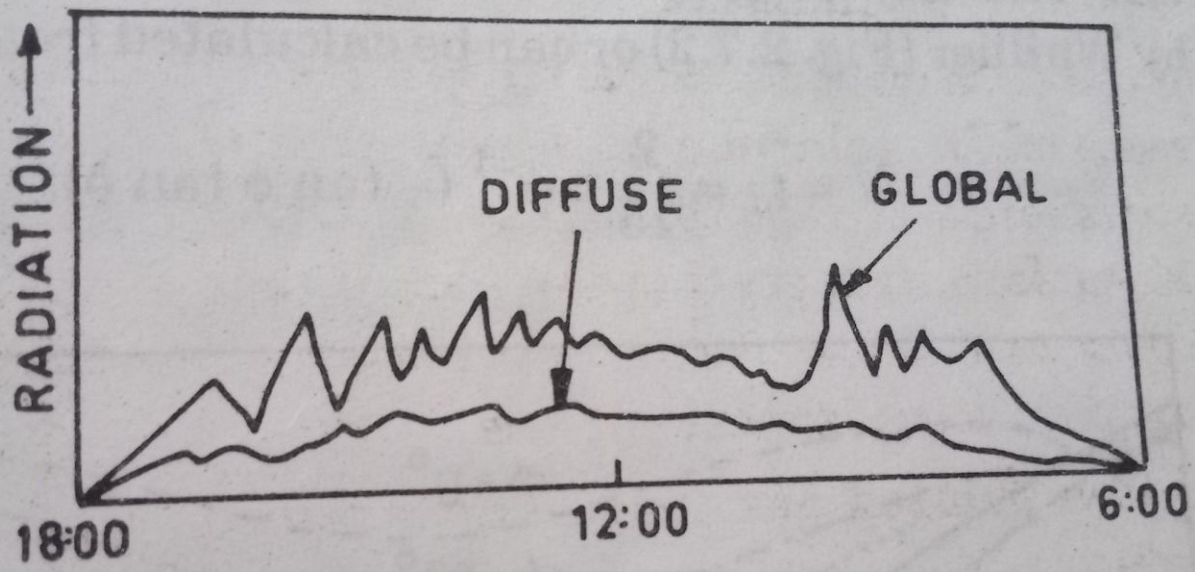


Fig. 2.6.2. A typical global and diffuse radiation on a cloudy day.

SOLAR RADIATION DATA…

- *India lies between latitude 7° and 37° N*
- *Receives an annual average intensity – 16700 to 29260 kJ/m^2/day*
- *Peak values are generally measured in April or May*
- *During Monsoon the daily solar radiation decreases to about 16700 kJ/m^2/day (400 cal/cm^2/day)*

SOLAR ENERGY COLLECTORS

- device for collecting solar radiation
- transfer the energy to a fluid passing in contact with it
- Two types:
  - Non concentrating or flat type solar collector
  - Concentrating (focusing) type solar collector

PHYSICAL PRINCIPLES

- *Fundamental process in use for conversion of solar radiation into heat – green house effect*
- *Energy from sun comes as light of shortwave radiation*
- *When this radiation strikes a solid or liquid, it is absorbed and transformed into heat energy*
- *Re radiation is a long wave radiation*

Green house effect

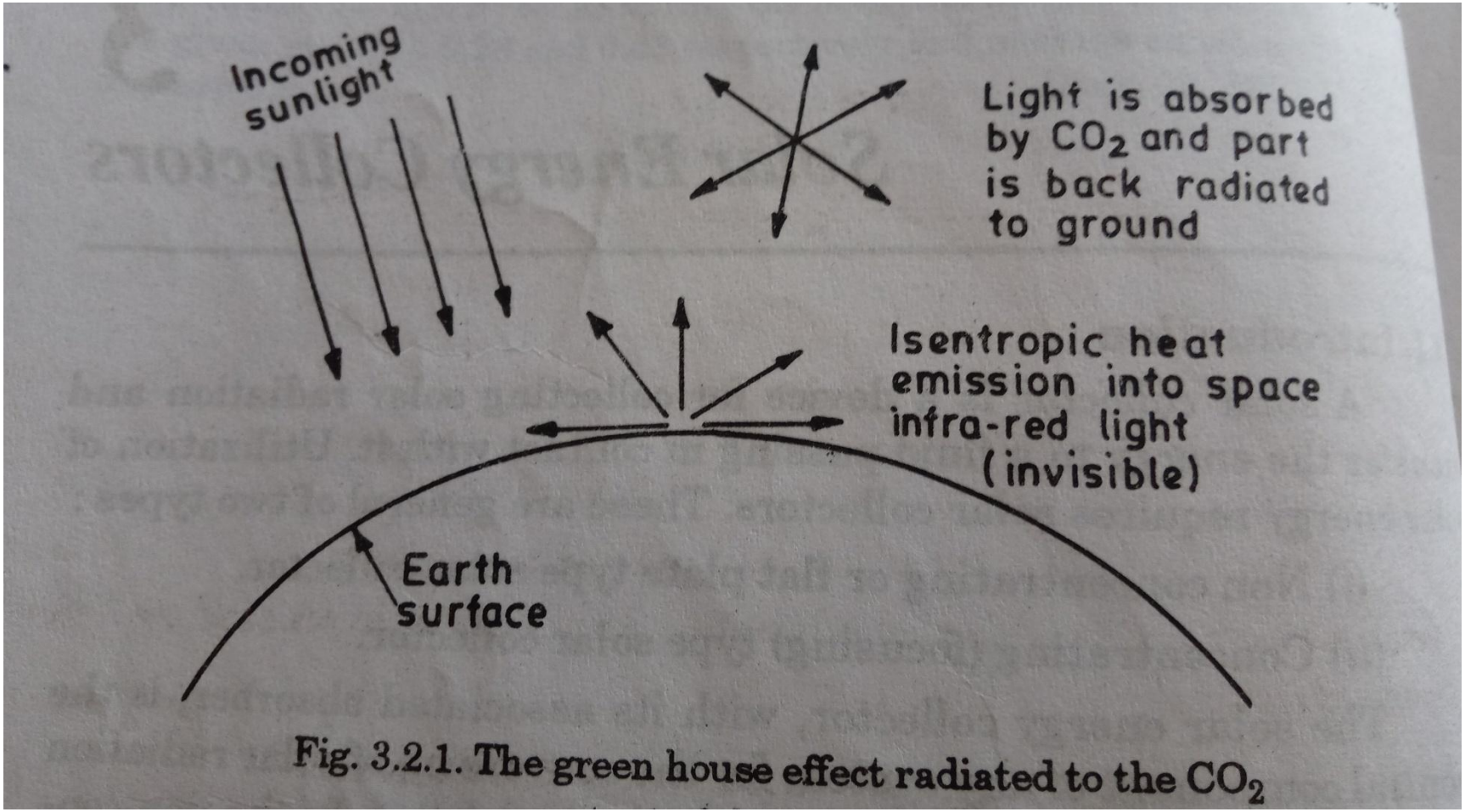
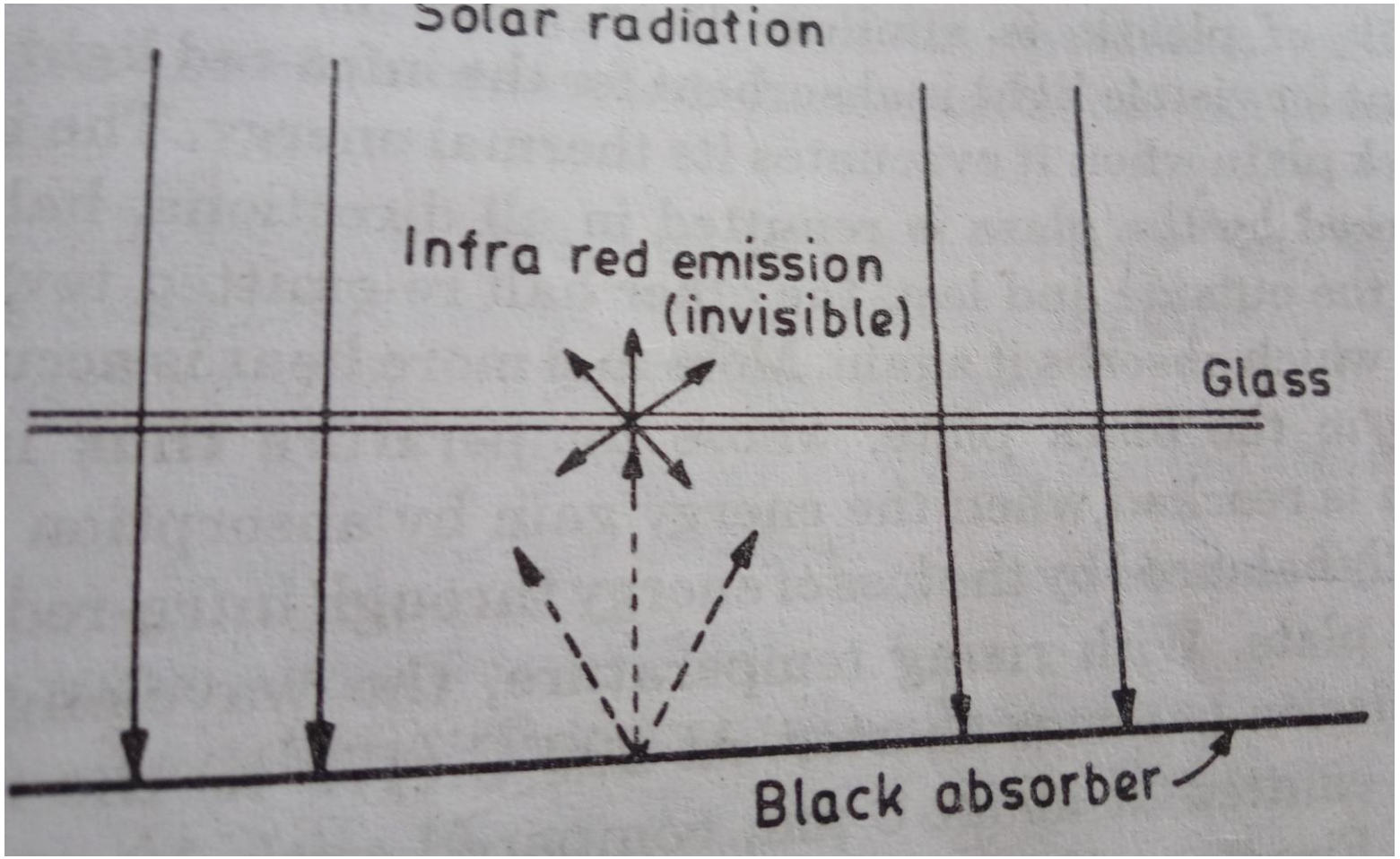


Fig. 3.2.1. The green house effect radiated to the CO_2

Green house effect …

- *Visible sunlight is absorbed on the ground, at a temperature of 20℃*
- *For example, emits infra-red light at a wavelength of about 10μm, but CO_2 in atmosphere absorbs light of that wavelength and back radiates part of it*
- *Green house effect brings an accumulation of energy to the ground*

PRINCIPLE OF GREEN HOUSE EFFECT



PRINCIPLE OF GREEN HOUSE EFFECT

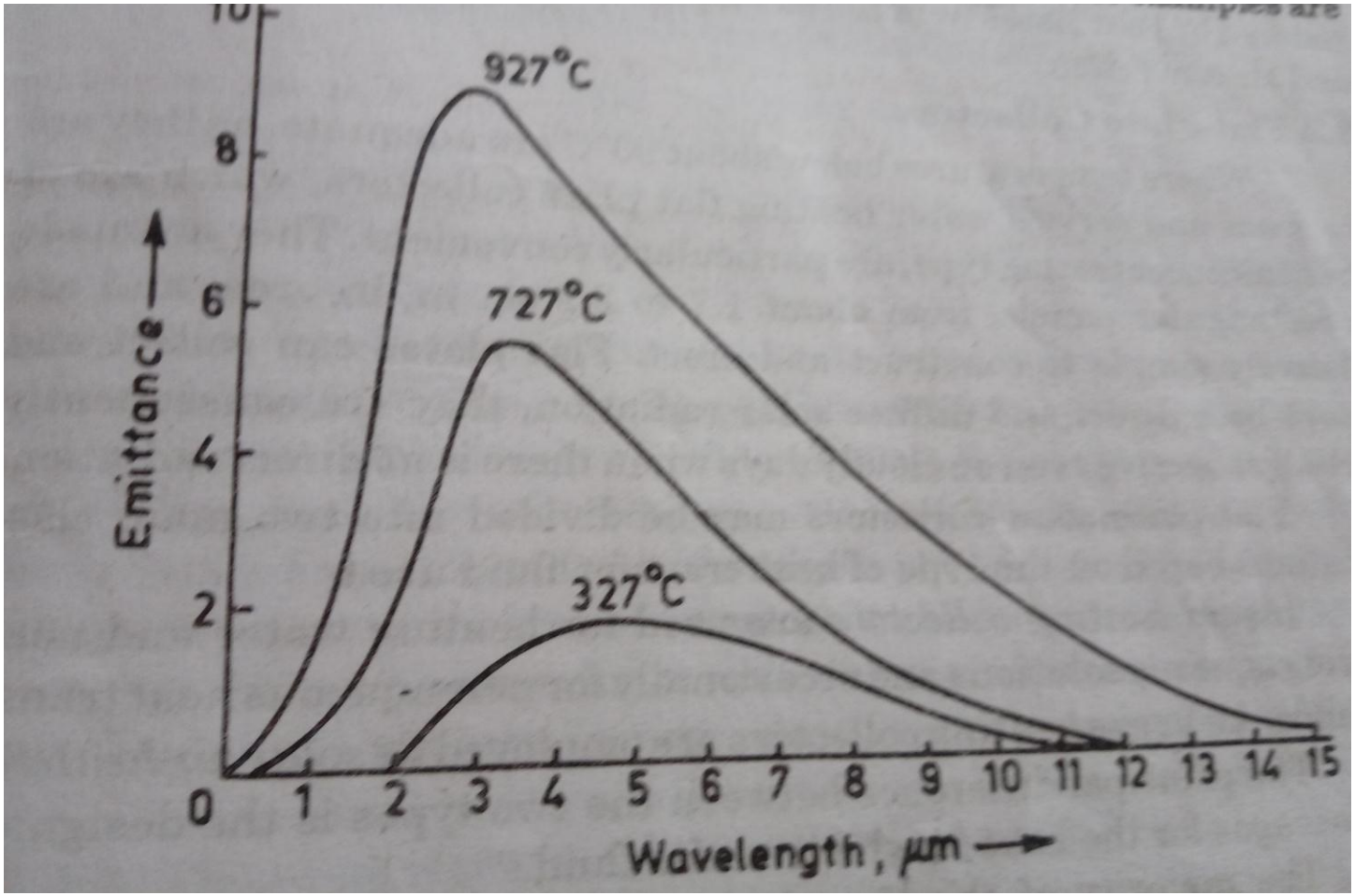
- Emission increases with temperature following T^4 law
- Wien's law :

$$\lambda_{max} . T = \text{constant} = 2989\ \mu m\ \text{Kelvin}$$

T – surface temperature of the black body

λ_{max} – wavelength at which light emission reaches a maximum

EMITTANCE OF A BLACK BODY



FLAT PLATE COLLECTORS

- convenient where temperatures below 90° C are adequate
- Made in rectangular panels, 1.7 to 2.9 sq.m. in area
- Simple to construct and erect
- Can collect and absorb both direct and diffuse radiation
- Partially effective even on cloudy days when there is no direct radiation

FLAT PLATE COLLECTORS

- *Flat plate collectors :*

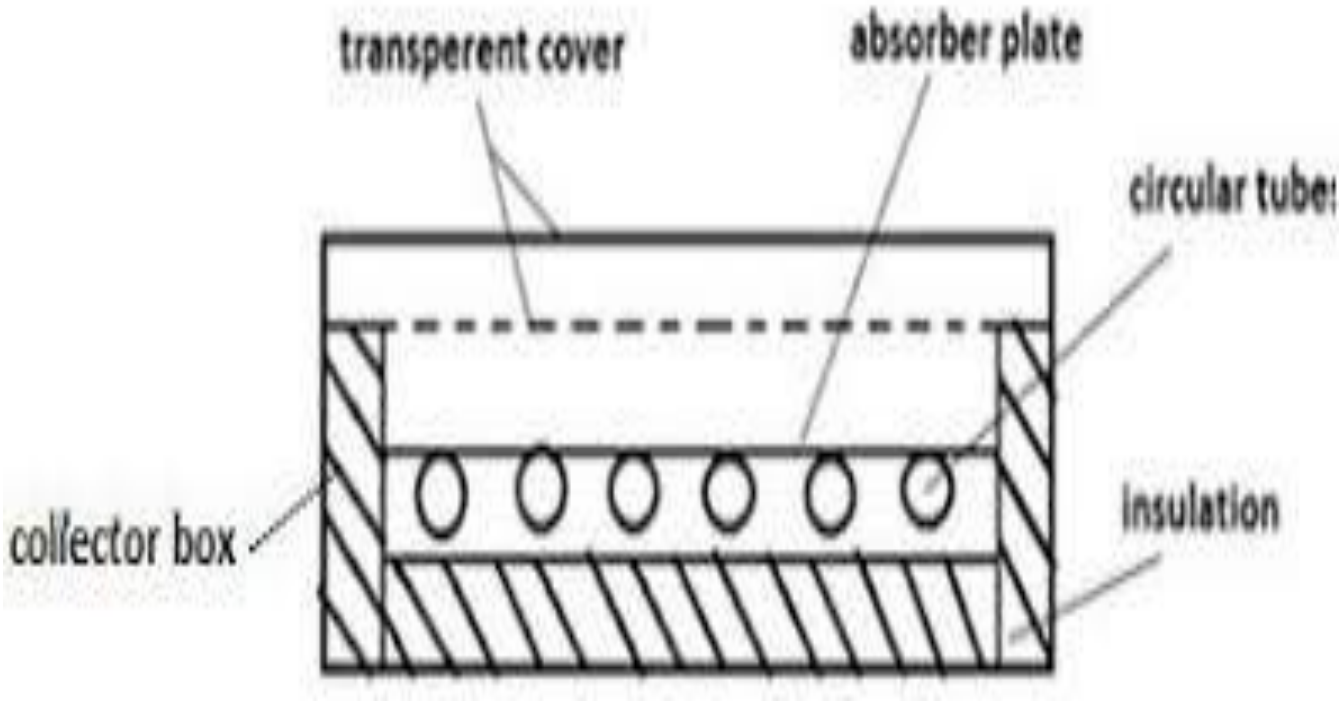
- *Liquid heating collectors*
- *Solar air heaters*

Principle difference – design of the passages for heat for the transfer fluid

COMPONENTS

- *Transparent cover – glass or plastic film*
- *Tubes, fins, passages, channels – carry water, air*
- *Absorber plate – metallic or with black surface*
- *Insulation – to minimise heat losses – fibre glass or styro – foam*
- *Casing or container – to protect from weather*

FLAT PLATE COLLECTOR



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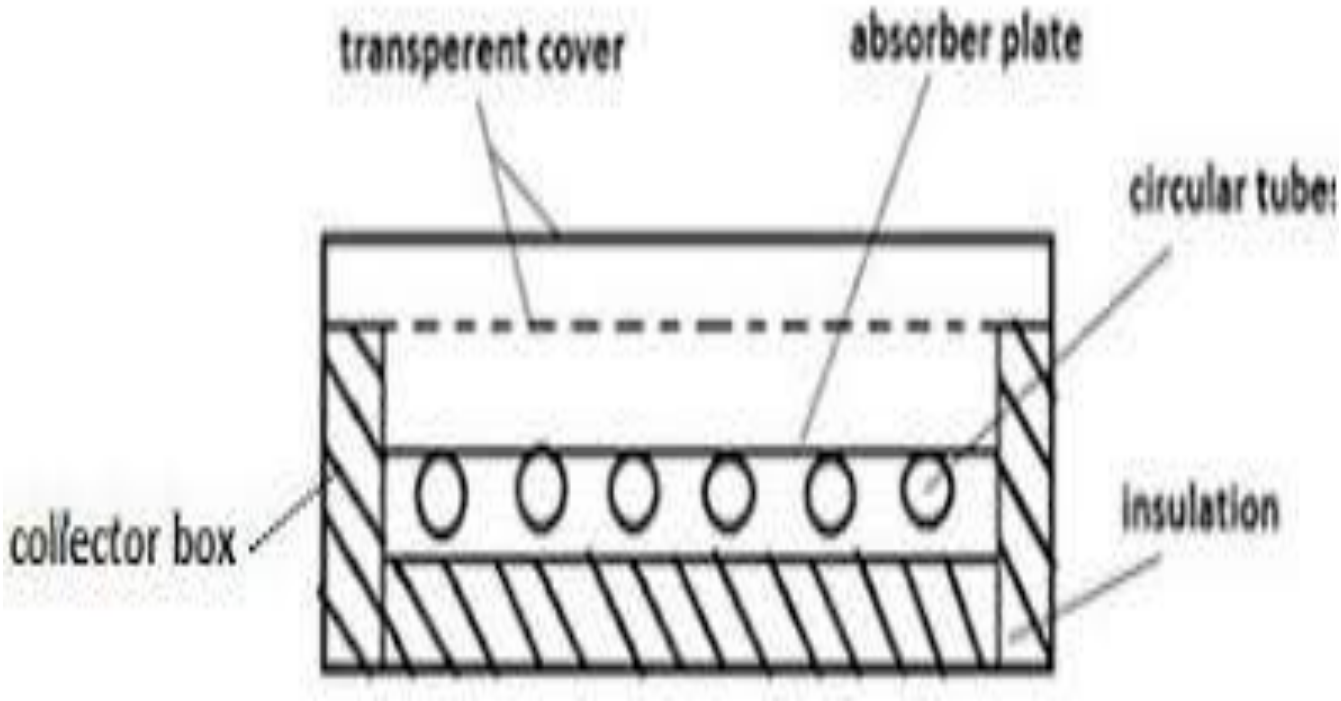
FLAT PLATE COLLECTOR



TYPICAL LIQUID COLLECTOR

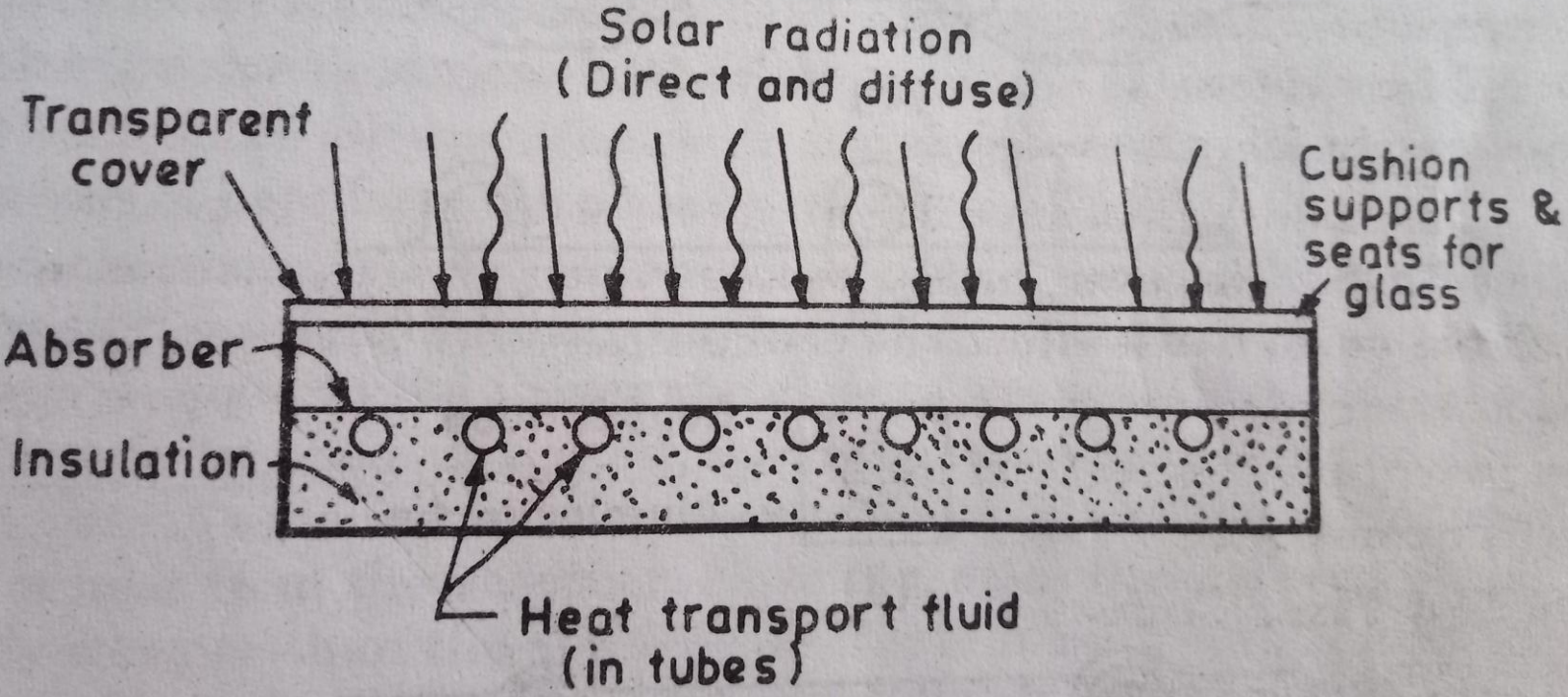


Fig. 3.3.1. Selection through typical flat-plate collector.

TYPICAL LIQUID COLLECTOR

- *Plate and tube type collector*
- *Flat surface with high absorptivity – absorbing surface*
- *Metal plate – Cu, steel or Al*
- *Absorber plate – metal sheet – 1 to 2 mm in thickness, dia – 1 to 1.5 cm*
- *Tubes – soldered, brazed or clamped*
- *Corrugated galvanized sheet – absorber plate*

CROSS SECTION OF COLLECTOR PLATES

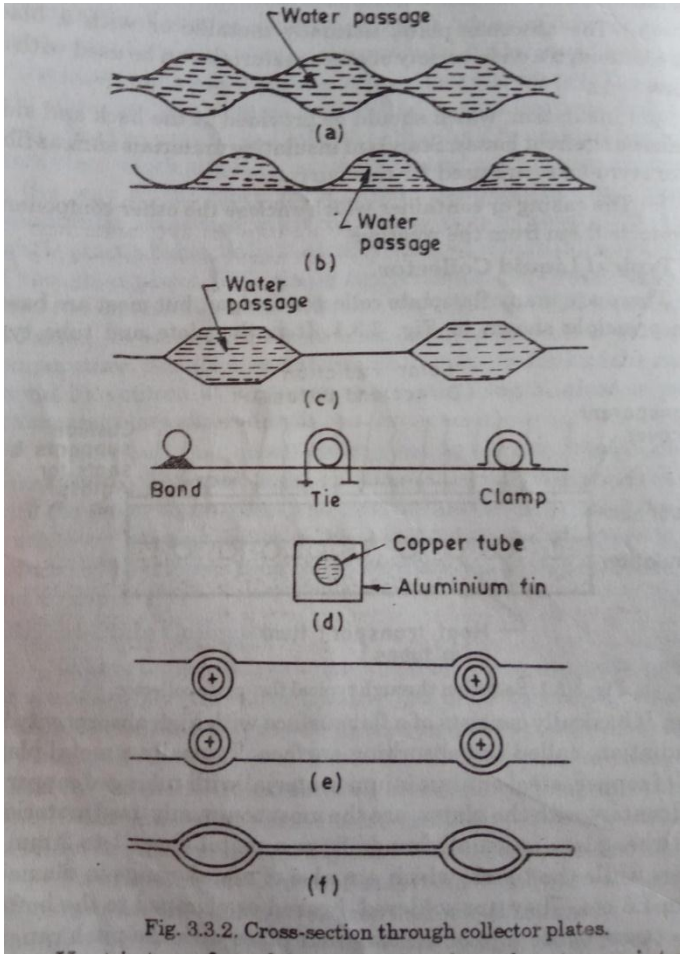


Fig. 3.3.2. Cross-section through collector plates.

TYPICAL LIQUID COLLECTOR

- *Heat is transferred from the absorber plate by circulation of fluid*
- *Thermal insulation – 5 to 10 cm thickness*
- *Front covers – glass – transparent to solar radiation and opaque to IR re-radiation*
- *Glass – thickness – 3 to 4 mm*

TYPICAL LIQUID COLLECTOR

- *Advantages of second glass: reduced losses due to air convection*
- *Radiation losses in the IR spectrum – reduced by further 25%*
- *Loss can be kept small – glass with low iron*
- *Larger loss – partial reflection*
- *Reflection – reduced by coating with thin films (eg. Magnesium fluoride) or etching with HF*

TYPICAL LIQUID COLLECTOR

- *Transparent plastics – drawbacks – greater loss of heat*
- *Decrease in transparency due to heating*
- *Primer coat – thin and self etching type*
- *Black painted absorbers – cheaper*
- *Coatings – selective coatings eg. Black chrome*
- *Typical dimension – 2m x 1m x 1.5 m*

HEAT TRANSPORT SYSTEM

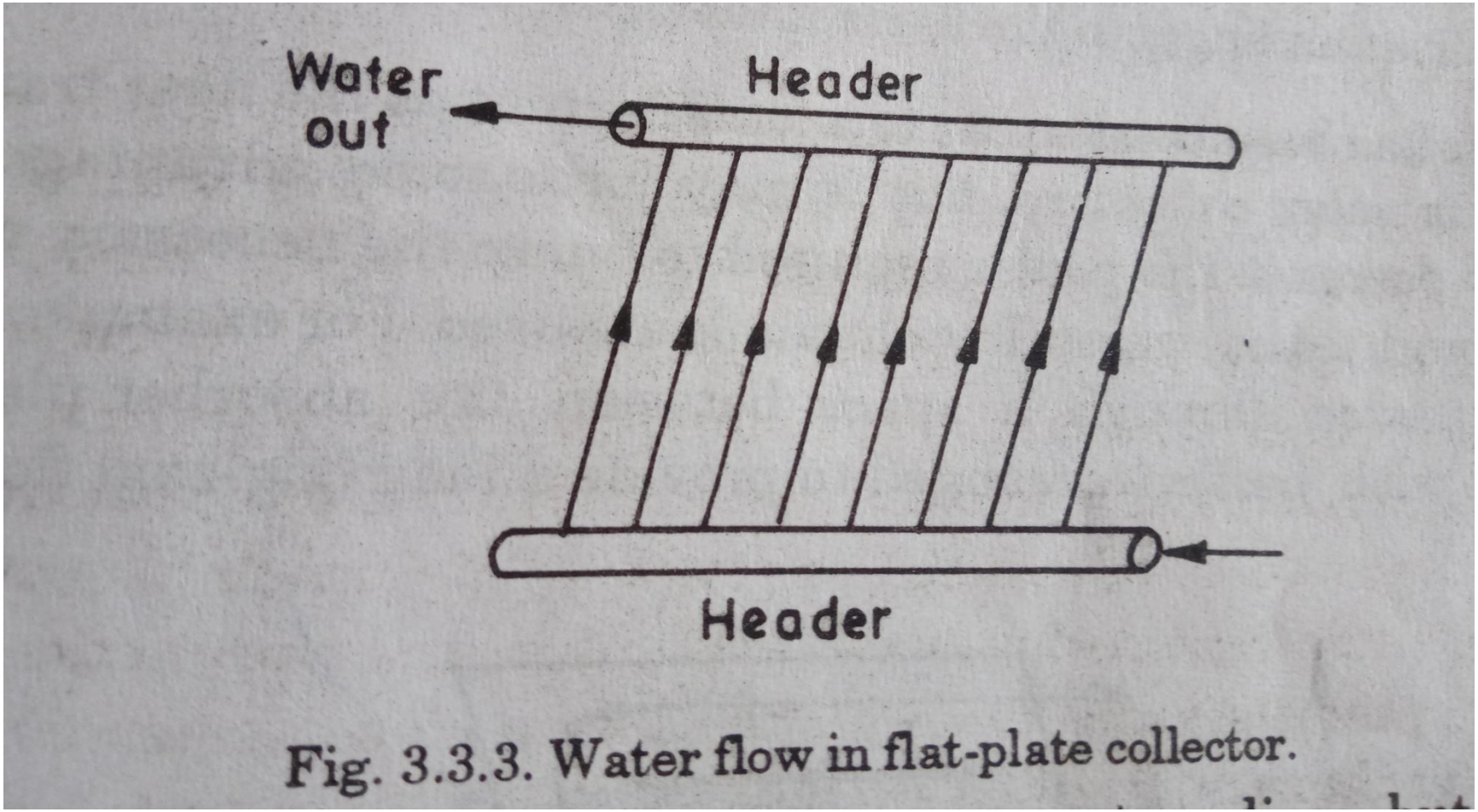


Fig. 3.3.3. Water flow in flat-plate collector.

HEAT TRANSPORT SYSTEM

- *Heat generated in the absorber – removed either by water or air*
- *To maximize exposure- collectors are sloped*
- *Water – effective heat transport medium*
- *Ethylene glycol – to prevent freezing*
- *Water is drained if freezing is expected*
- *Corrosion of metal tubes by water*
- *Oxygen in air increases the rate of corrosion – minimized by copper tubing*

SOLAR AIR HEATER

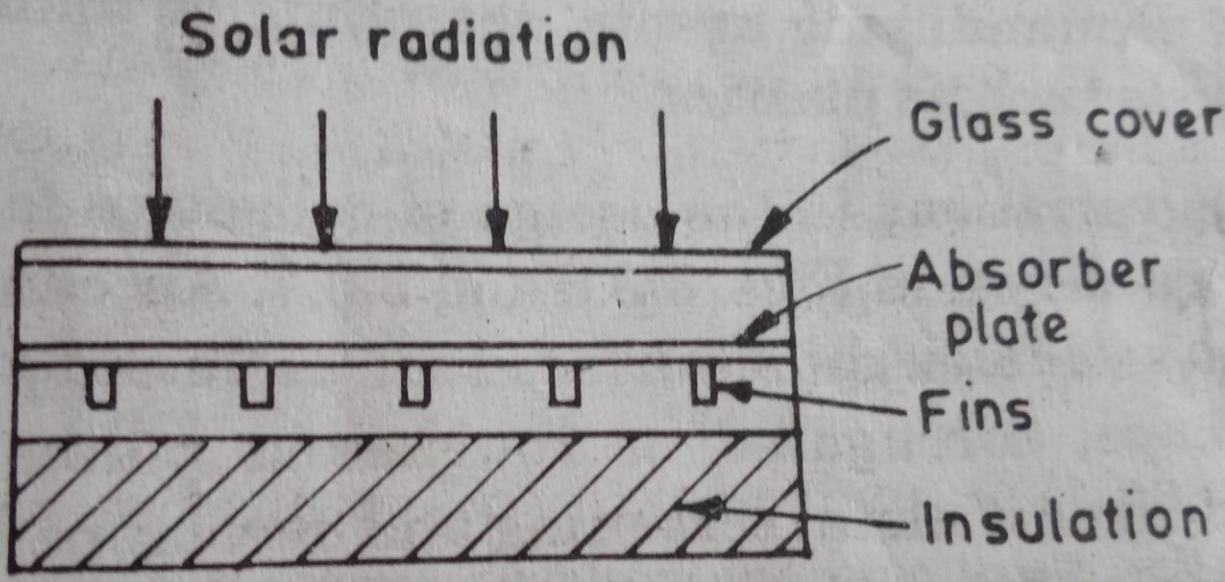


Fig. 3.3.4. Typical Solar Air Collector.

SOLAR AIR HEATER

- *Air stream is heated back side of the collector plate*
- *Fins attached to the plate increase the contact surface*
- *Back side is heavily insulated with mineral wool*
- *Most favourable orientation, is facing due south at an inclination angle equal to the latitude plus 15°*

AIR FLOW

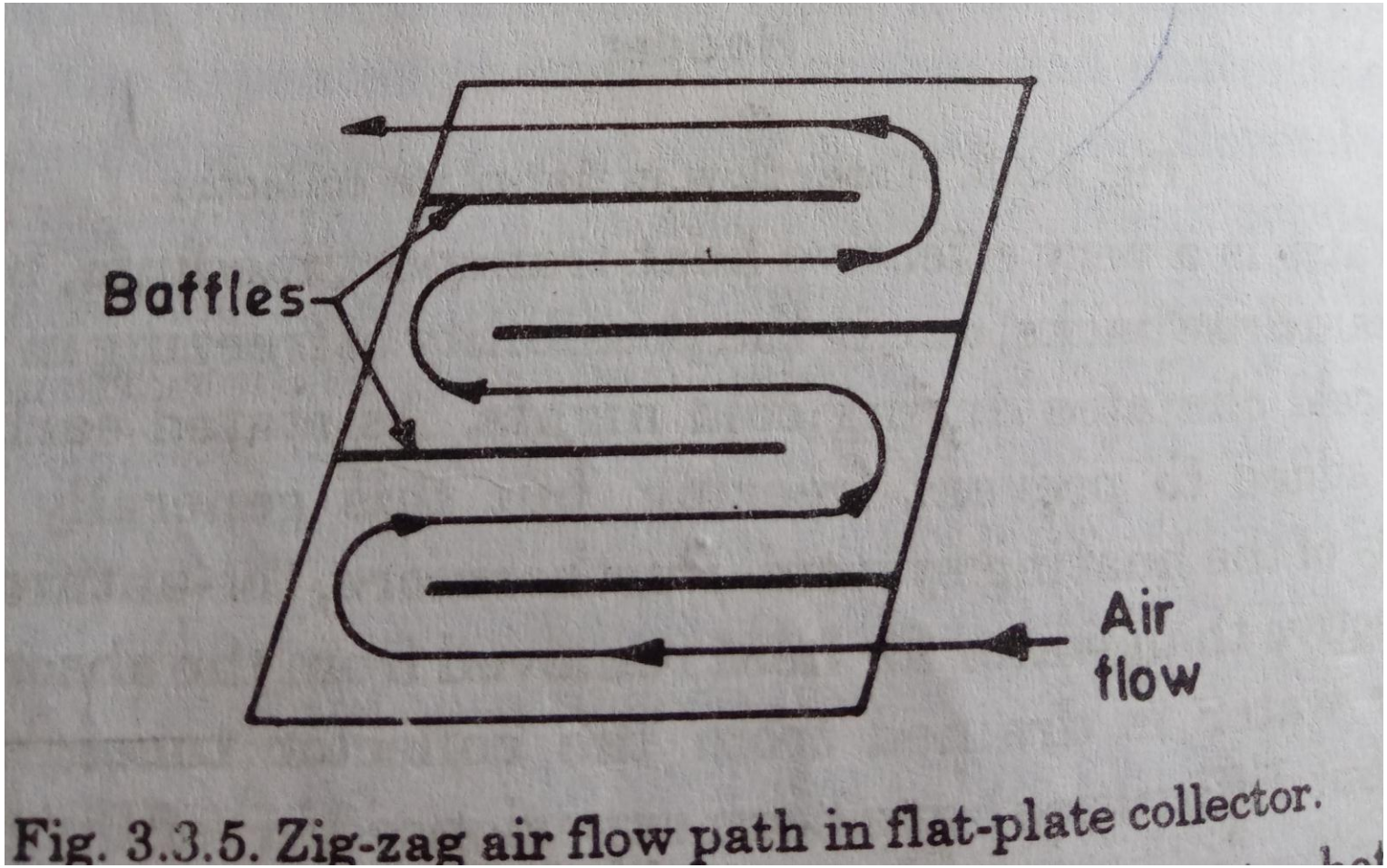


Fig. 3.3.5. Zig-zag air flow path in flat-plate collector.

AIR FLOW

- *Air – used to a lesser extent as the heat – transport medium*
- *Air – have some advantages over water*
- *Wider flow channels – used to decrease the power required to pump*
- *Air – passed through space between absorber plate and insulator with baffles arranged in zig-zag flow path*

AIR FLOW

- *Air – eliminates both freezing and corrosion problems*
- *Heated air can be directly used for space heating*
- *Larger duct sizes and higher flow rates – required for air than water*
- *Transfer of heat from air to water in a hot water supply system is inefficient*

APPLICATIONS OF SOLAR AIR HEATERS

- *Drying or curing of agricultural products*
- *Space heating for comfort*
- *Seasoning of timbre*
- *Curing of industrial products*
- *Regeneration of humidifying agents*

CLASSIFICATION OF AIR HEATERS

- *NON – POROUS ABSORBER : air stream does not flow through the absorber plate*
- *Air may flow above and or behind the absorber plate*
- *POROUS ABSORBER : Includes slit and expanded metal, transpired honey comb and over-lapped glass plate absorber*

NON – POROUS AIR HEATERS

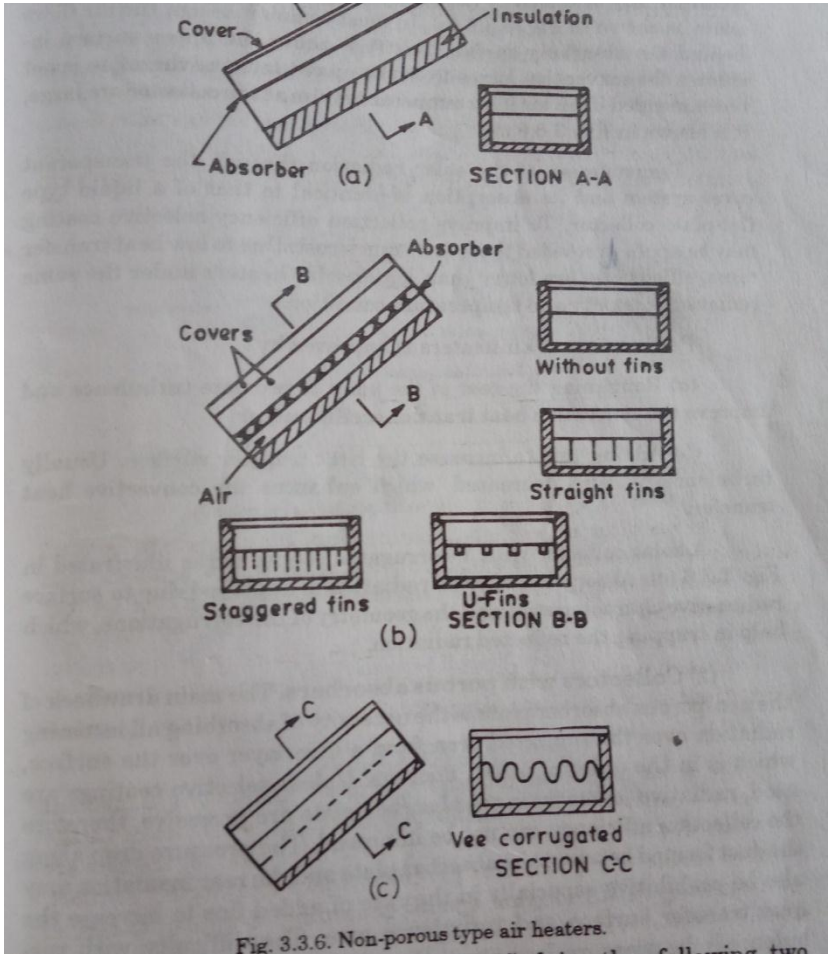


Fig. 3.3.6. Non-porous type air heaters.

NON – POROUS AIR HEATERS

- Cooled by the air stream flowing over both sides of the plate
- Air flow above the upper surface increases the convection losses from the cover plate
- Transmission of solar radiation through the transparent cover system ; absorption is identical to liquid type flat – plate collector
- Selective coating may be applied

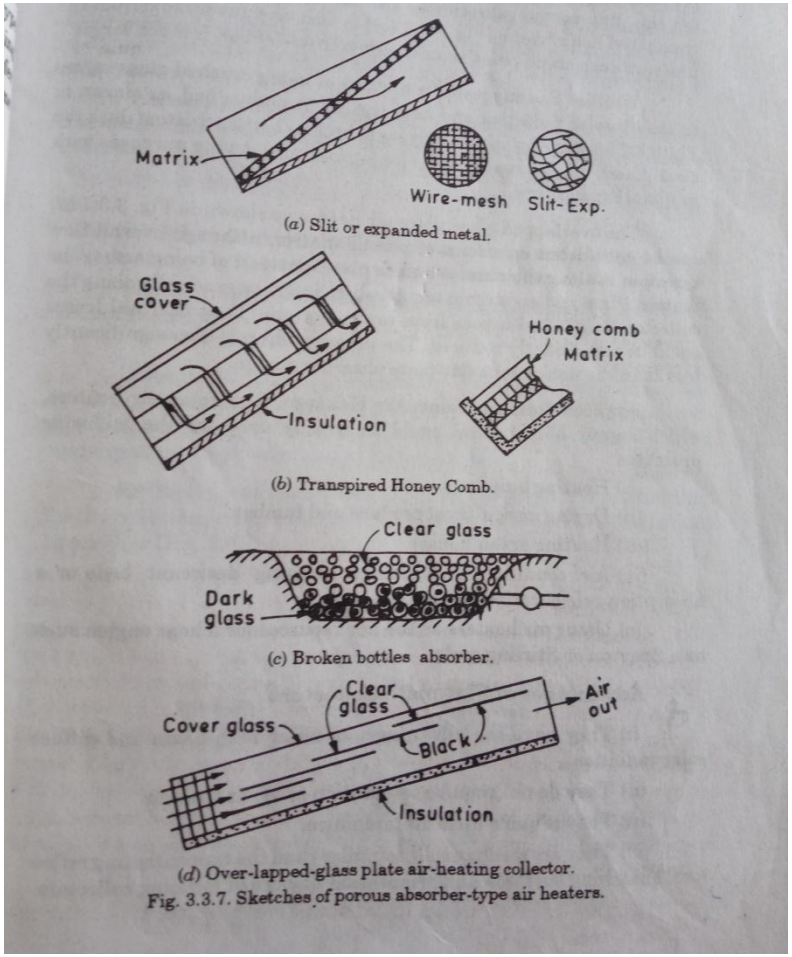
NON – POROUS AIR HEATERS

- *Performance of air heaters is improved by:*
  - *i) roughening the rear of the plate to promote turbulence and improve the connective heat transfer coefficient*
  - *ii) adding fins to increase the heat transfer surface*
- *A solar collector with V-corrugated copper foil:*
- *Absorption of solar radiation is improved due to surface radioactive characteristics and the geometry of the corrugations*

COLLECTORS WITH POROUS ABSORBERS

- *Defects due to non-porous absorbers are eliminated by two ways:*
- *Solar radiation penetrates to greater depths*
- *It is absorbed gradually depending on the matrix density*
- *Pressure drop is usually lower with flow behind the plate since cross section is much lower*

POROUS AIR HEATERS



(a) Slit or expanded metal.

(b) Transpired Honey Comb.

(c) Broken bottles absorber.

(d) Over-lapped-glass plate air-heating collector.

Fig. 3.3.7. Sketches of porous absorber-type air heaters.

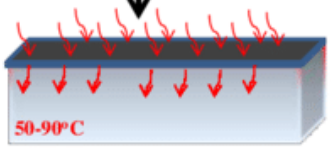
APPLICATIONS OF SOLAR HEATERS

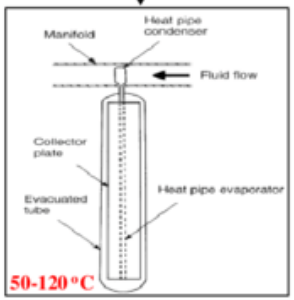
- *Heating buildings*
- *Drying agricultural produce and lumber*
- *Heating green houses*
- *Air conditioning buildings utilizing dessicant beds*
- *Used as the heat sources for a heat engine*

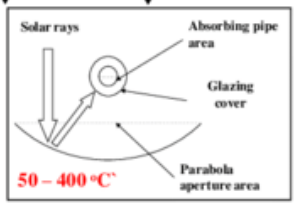
ADVANTAGES OF FLAT PLATE COLLECTORS

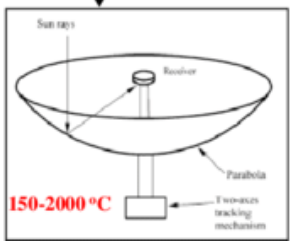
- *Uses both bean and diffuse solar radiation*
- *Do not require orientation towards the sun*
- *Require little maintenance*
- *Mechanically simpler*

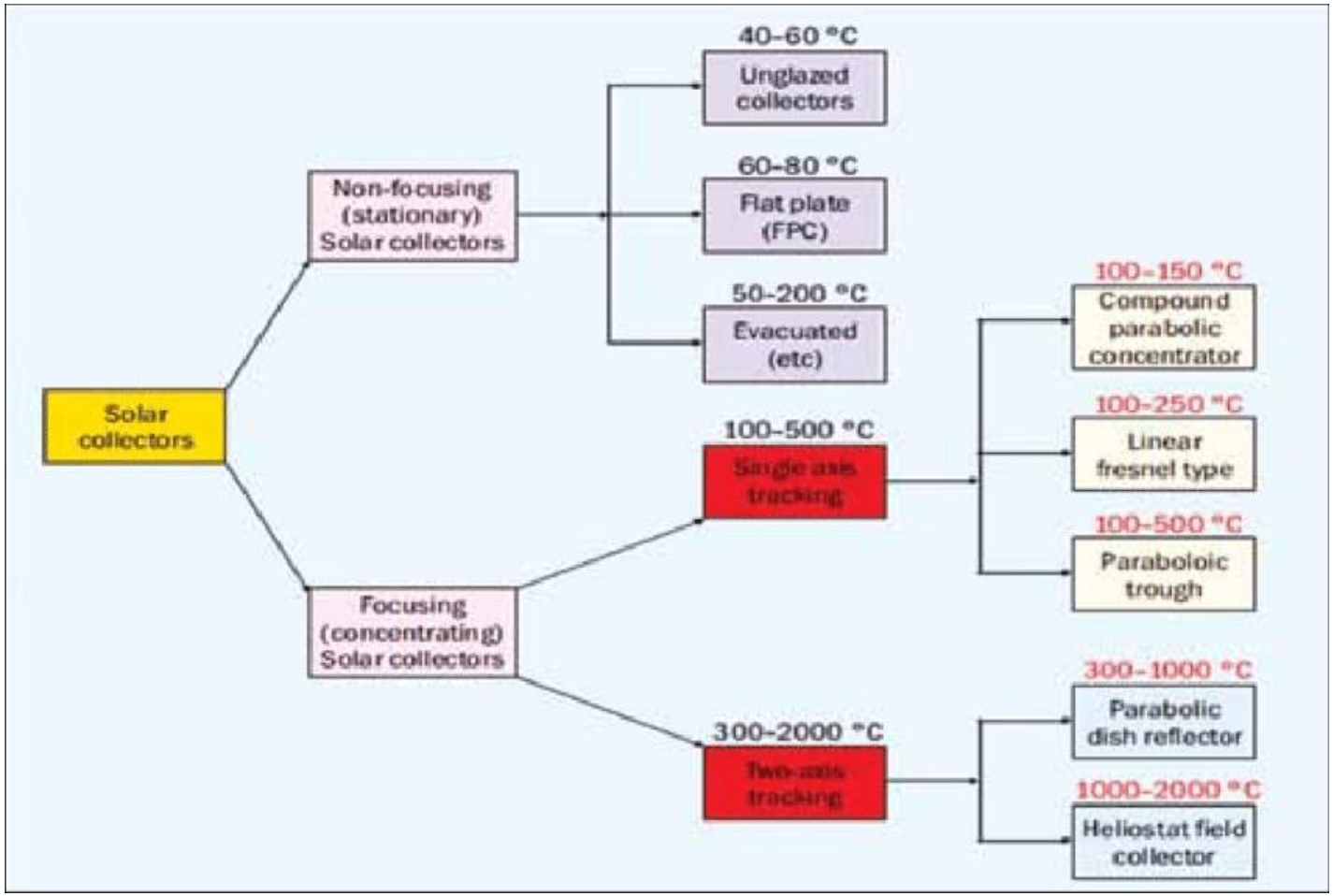
Solar Thermal Collectors

- Non- Concentrating Collector
  - Flat Plate Collector
    - C.R. 1
    - 

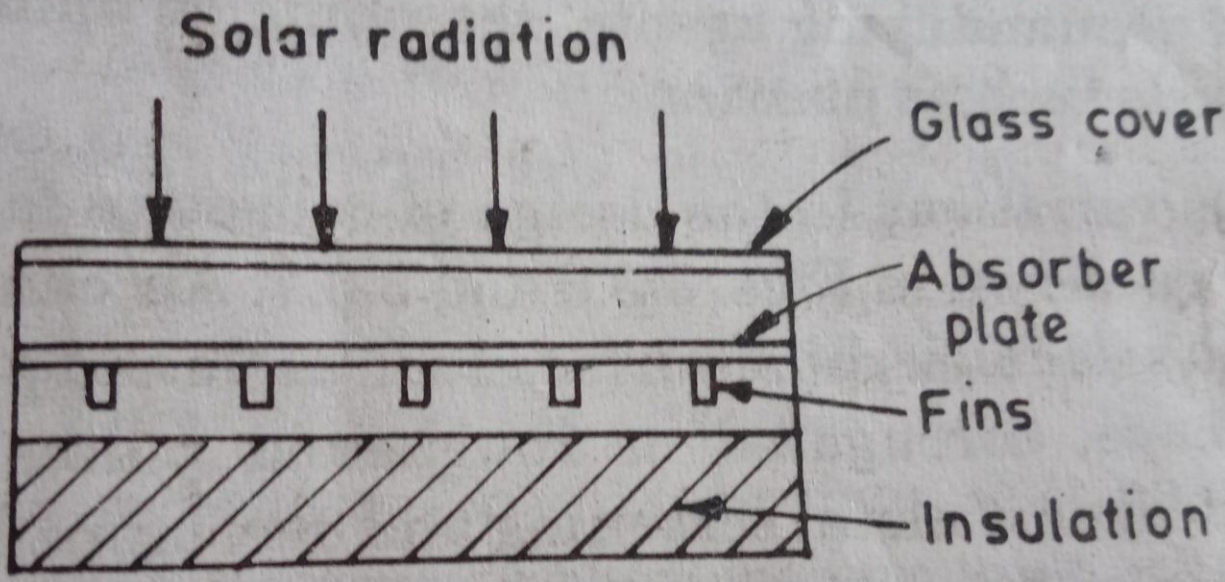
  - Evacuated Tube Collector
    - C.R. 1
    - 

- Concentrating Collector
  - Line Focussed
    - Max. C.R. 212
    - Linear Fresnel Reflector
    - Parabolic Trough Collector
    - 

  - Point Focussed
    - Max. C.R. 300 to 1500
    - Parabolic Dish Reflector
    - Power Tower
    - 


Solar collectors
Non-focusing (stationary) Solar collectors
Focusing (concentrating) Solar collectors
40-60 °C
Unglazed collectors
60-80 °C
Flat plate (FPC)
50-200 °C
Evacuated (etc)
100-500 °C
Single axis tracking
300-2000 °C
Two-axis tracking
100-150 °C
Compound parabolic concentrator
100-250 °C
Linear fresnel type
100-500 °C
Paraboloic trough
300-1000 °C
Parabolic dish reflector
1000-2000 °C
Heliostat field collector

SOLAR AIR HEATER



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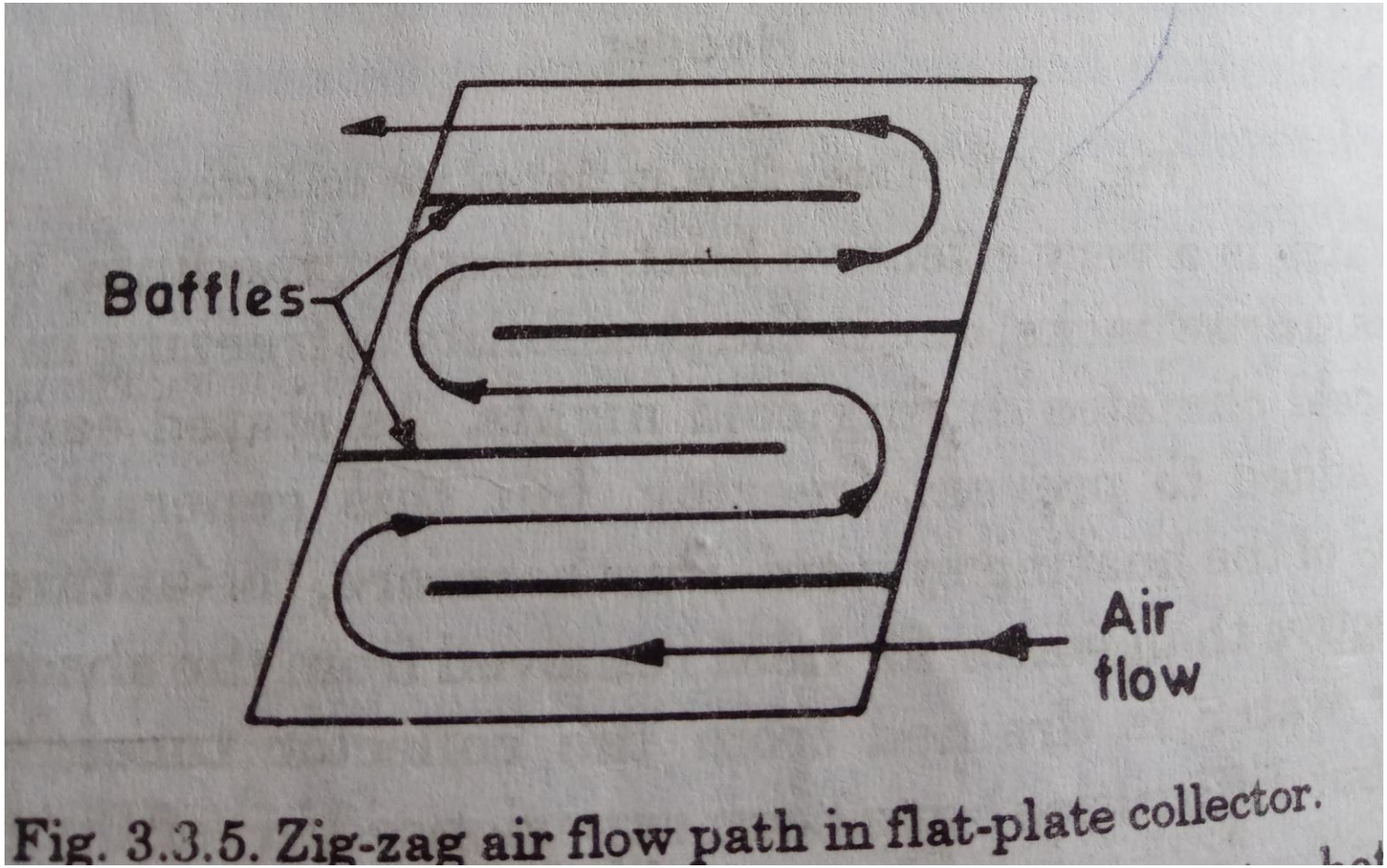

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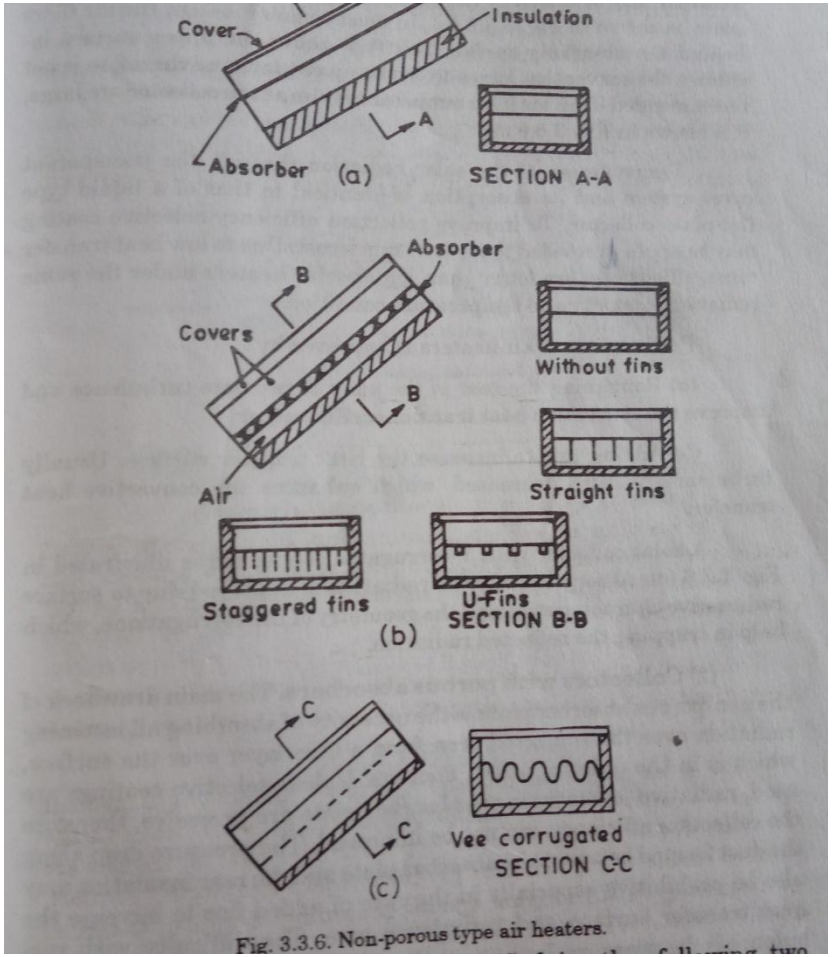

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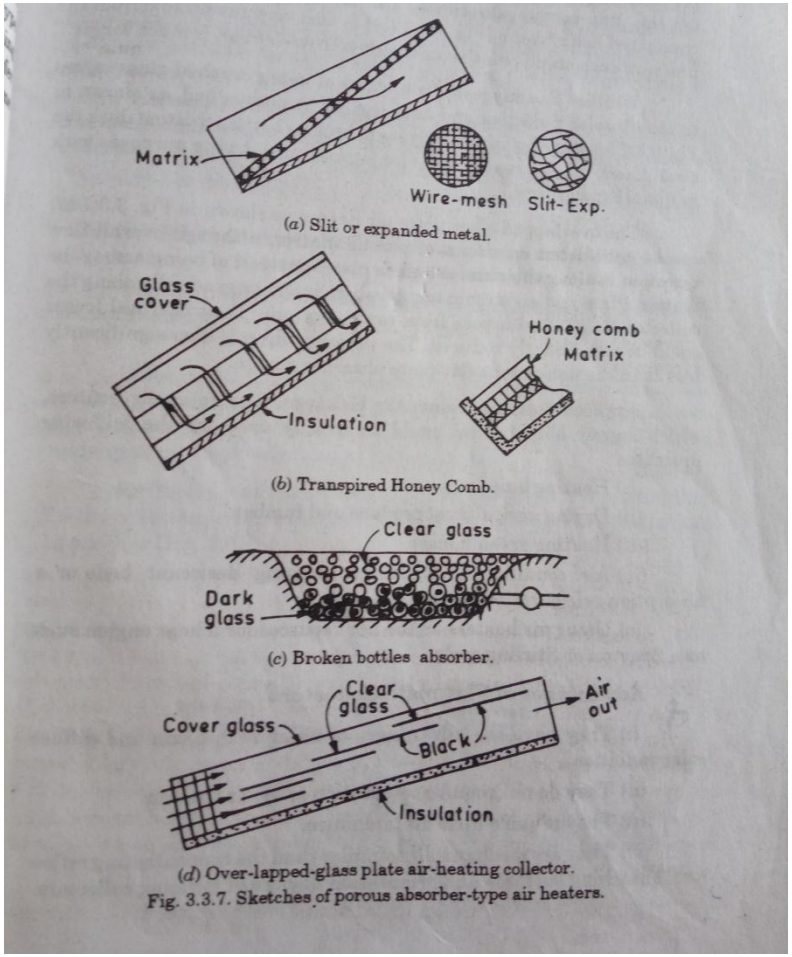

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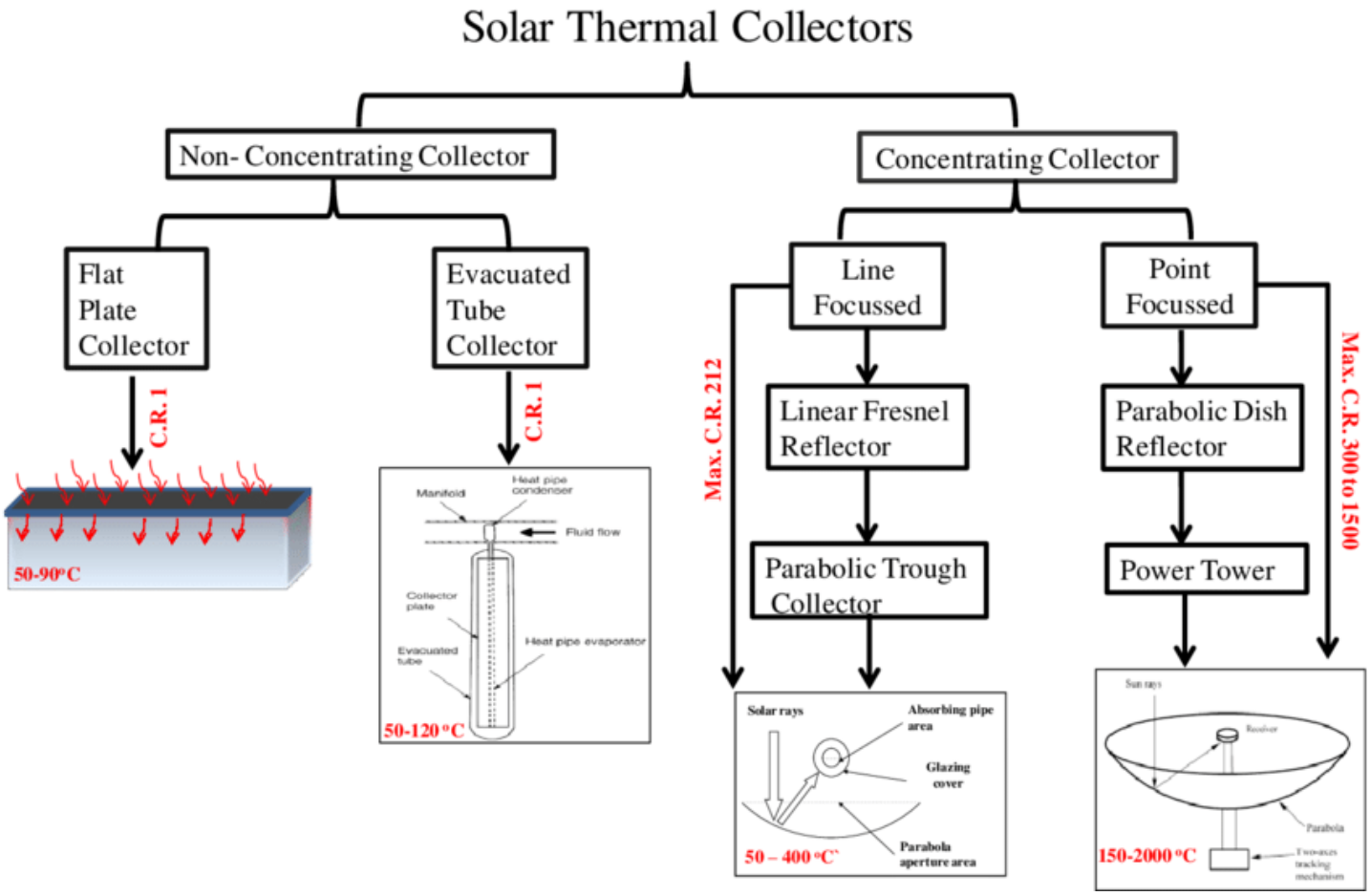
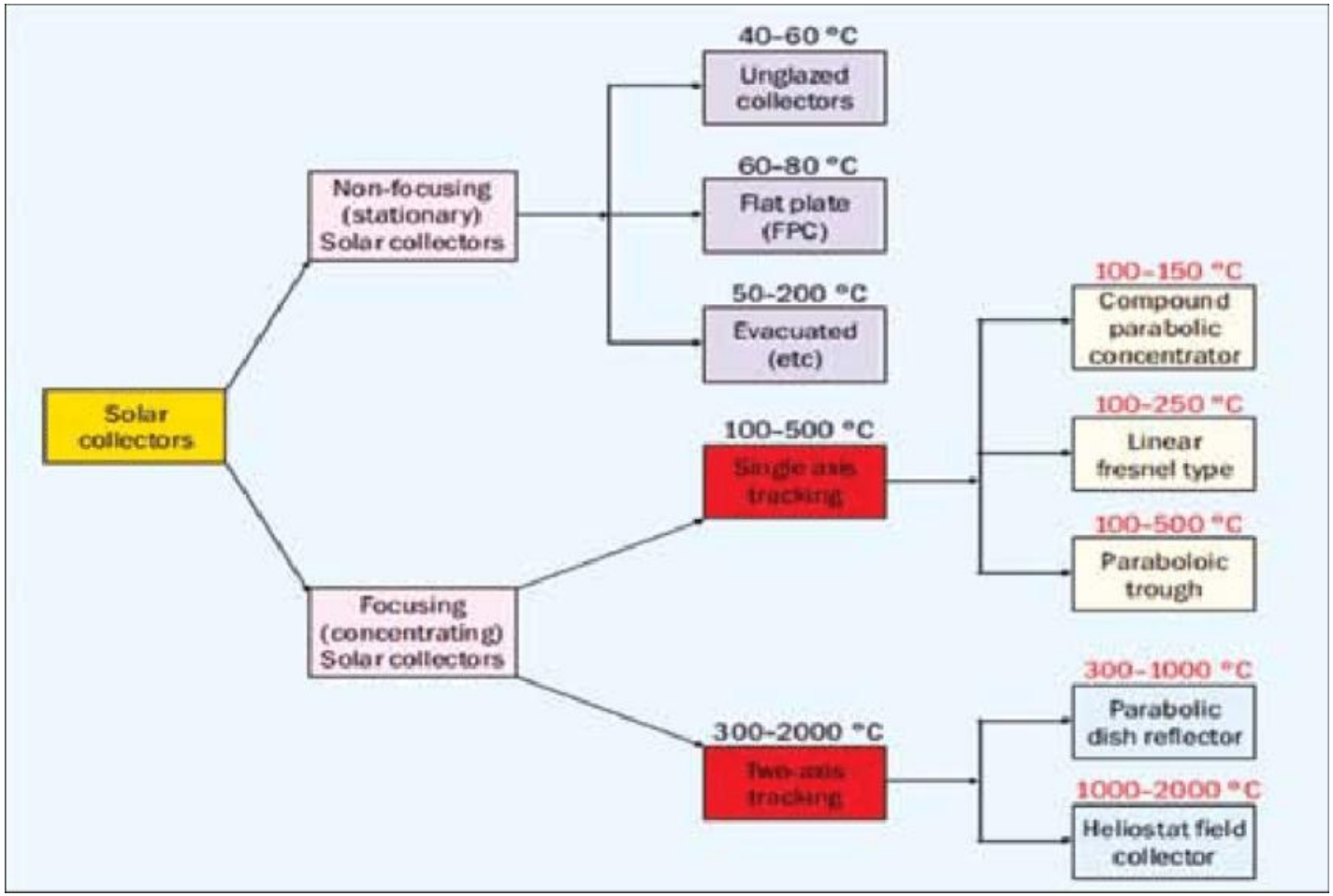
CLASSIFICATION



CLASSIFICATION



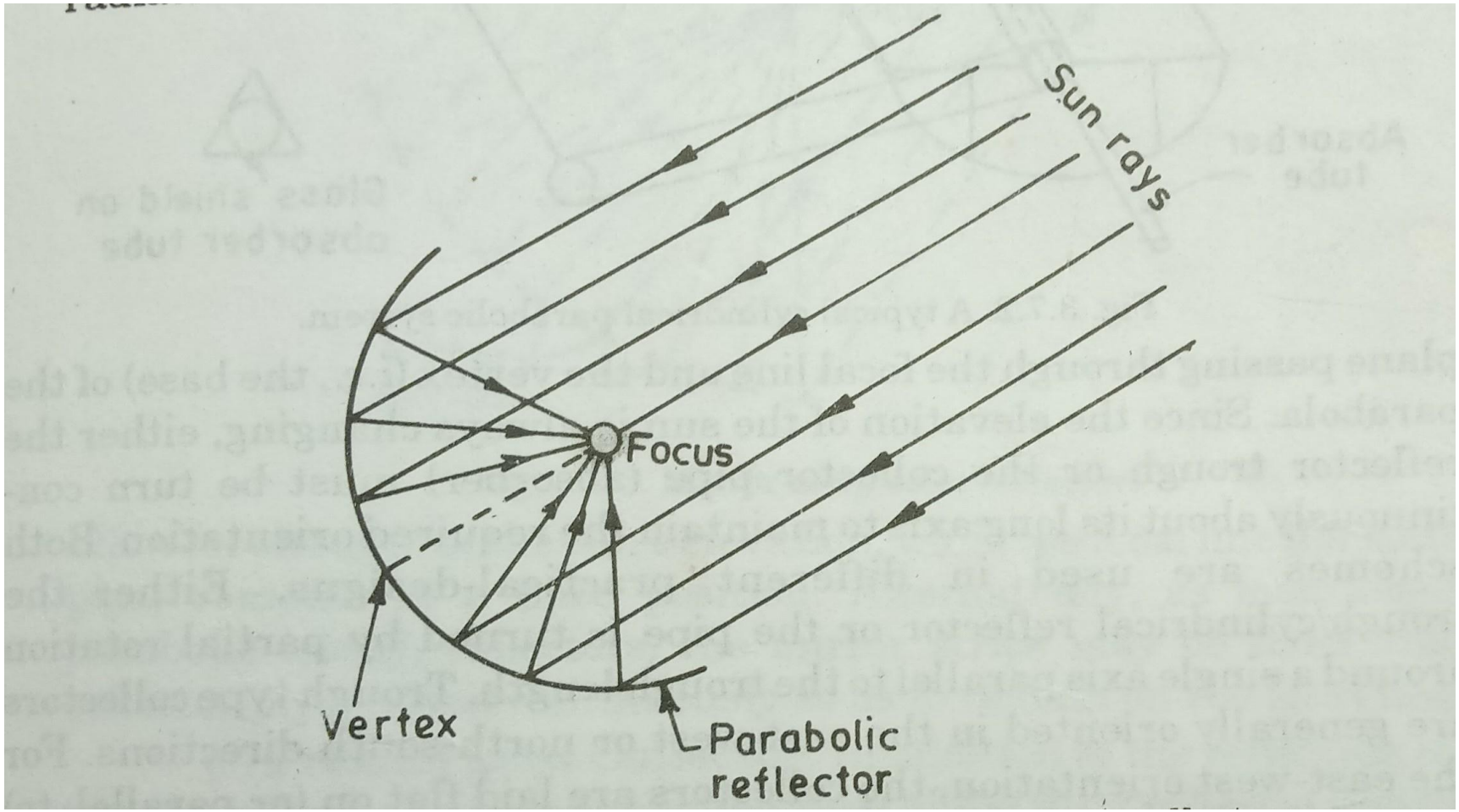
CONCENTRATING COLLECTOR

- *FOCUSING TYPE*
- *Focusing collector – device – collect solar energy with high intensity solar radiation on the energy absorbing surface*
- *Uses optical system – reflectors and refractors*
- *Special form of flat-plate collector*
- *Modified by reflecting (or refracting) surface between the solar radiation and absorber*

TYPES OF CONCENTRATING COLLECTORS

- ***GENERAL CATEGORIES:***
  - *Line focusing – line is a collector pipe*
  - *Point focusing – point is a small volume through which the heat transport fluid flows*
- ***MAIN TYPES:***
- *Parabolic trough collector*
- *Mirror strip collector*
- *Fresnel lens collector*
- *Flat plate collector with adjustable mirrors*
- *Compound parabolic concentrator (CPC)*

PARABOLIC TROUGH REFLECTOR



PARABOLIC TROUGH REFLECTOR…

- *Solar radiation – particular direction - collected – area of reflecting surface and concentrated at the focus of parabola*
- *Reflector – form of a trough – with parabolic cross section – radiation is focused alone a line*
- *Cylindrical parabolic concentrators – used*
- *Collector pipe – with selective absorber coating – used as an absorber*

PARABOLIC TROUGH REFLECTOR…

- *Dimension – length : 3 to 5 m*
- *Width : 1.5 to 2.4 m*
- *Ten or more units – connected end to end in row*
- *Several rows – connected in parallel*
- *Made of highly polished aluminium, silvered glass or aluminized plastic on a firm base*

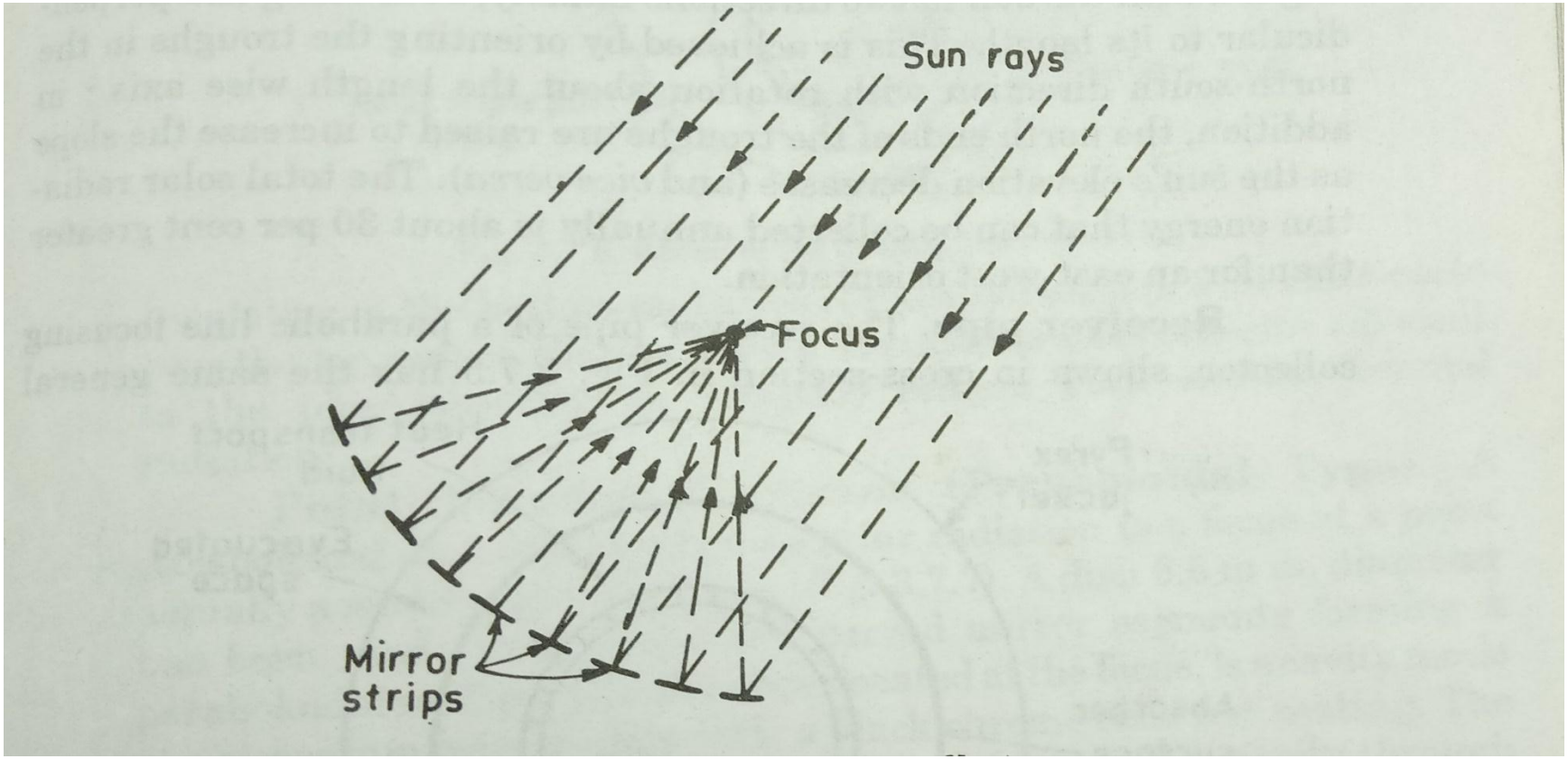
PARABOLIC TROUGH REFLECTOR…

- *To bring the focus, sun must be in a direction that lies on plane passing through the focal line and the vertex of the parabola*
- *Elevation of sun – changes – reflector trough or the collector pipe (absorber) – turn to maintain required orientation*
- *Generally oriented in the east – west or north – south directions*

PARABOLIC TROUGH REFLECTOR…

- *For east – west orientation, collector is laid flat on the ground*
- *For north – south orientation, north end is raised and collectors are sloped facing south – just like flat plate collectors*
- *Slope angle – to be changed periodically*
- *Simpler, but less efficient – to use a fixed angle design*

MIRROR STRIP REFLECTOR



MIRROR STRIP REFLECTOR…

- *Another kind of focusing collector*
- *Number of plane or concave mirror strips are mounted on a flat base*
- *Angles of the individual mirrors – reflect solar radiation from a specific direction on to the same focal line*
- *Angles of mirrors – adjusted – changes in the sun's elevation*
- *Focal line remains in a fixed position*

FRESNEL LENS COLLECTOR

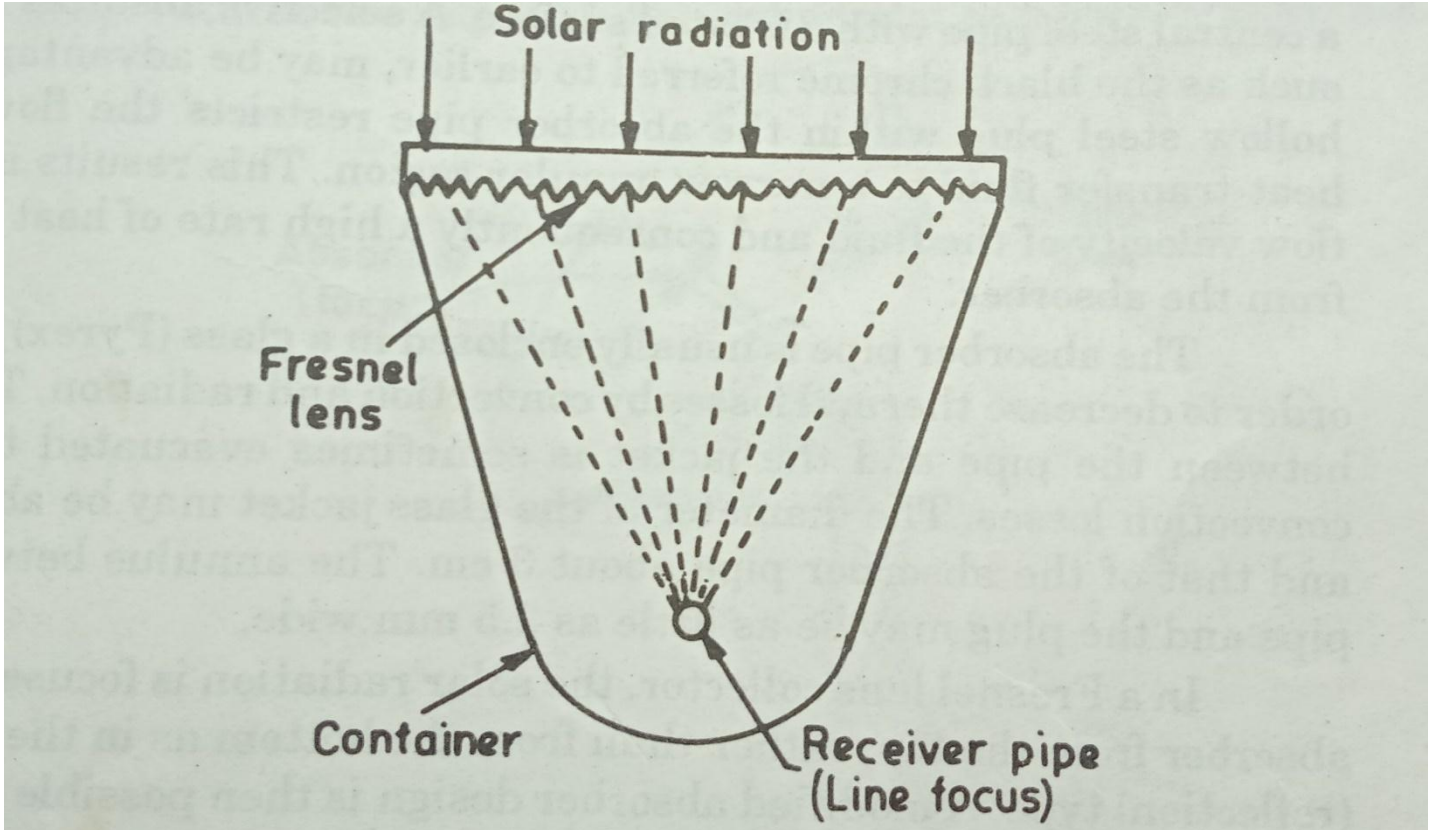
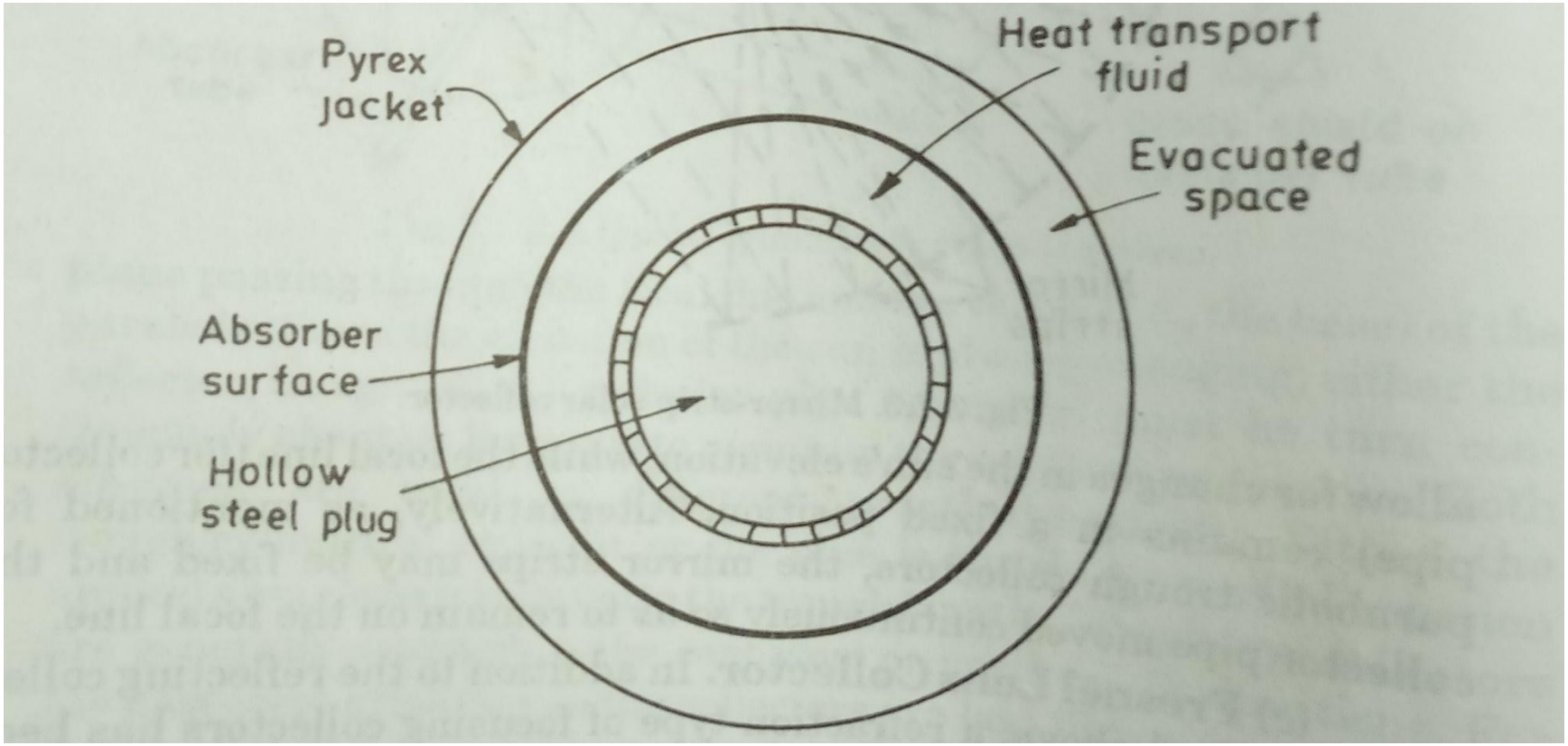


Fig. 3.7.4. Cross-section of Fresnel lens through collector.

FRESNEL LENS COLLECTOR…

- *Refraction type of focusing collector*
- *Utilizes the focusing effect of a Fresnel lens*
- *Lens dimension – length: 4.7 m, width: 0.95 m*
- *Made in sections from acrylic plastic*
- *Must be continuously aligned with the sun in two directions , along and perpendicular to length*
- *Troughs – oriented in north-south direction*

RECEIVER PIPE – cross section



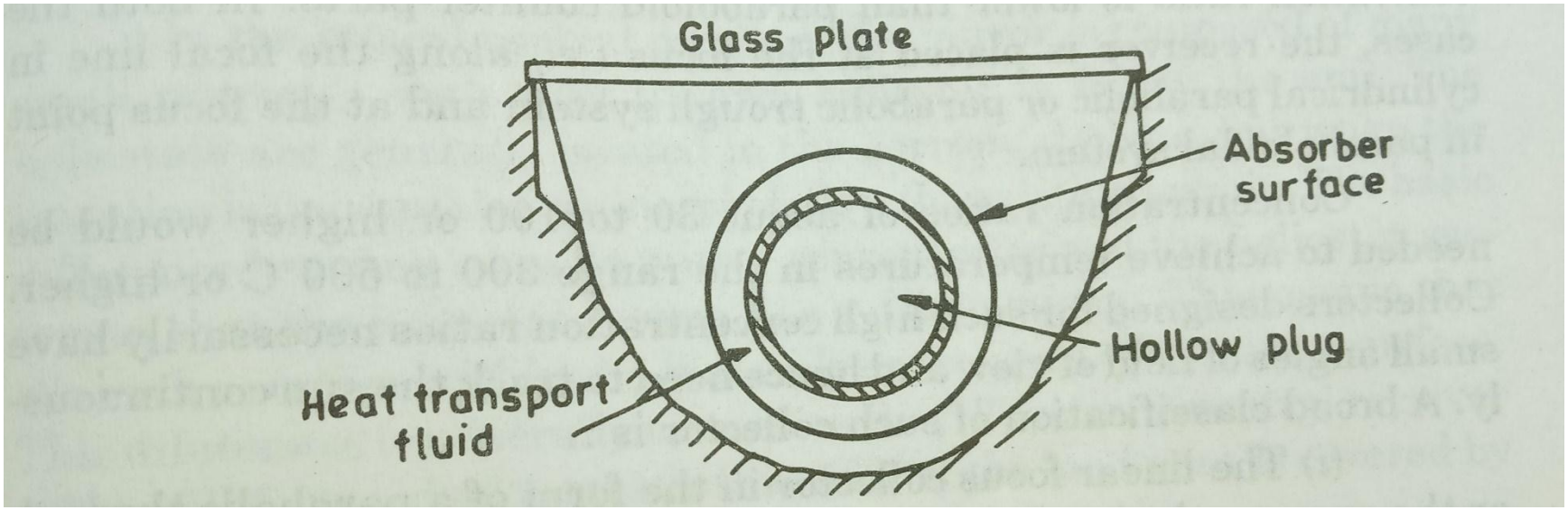
RECEIVER PIPE – cross section

- *Same general characteristics as a flat plate collector*
- *Absorber – central steel pipe with a treated surface*
- *Selective absorber surface – black chrome-advantageous*
- *Hollow steel plug within the absorber pipe restricts the flow of the heat transfer fluid*
- *High velocity of the liquid – high rate of heat transfer from the absorber*

RECEIVER PIPE – cross section

- *Absorber pipe – enclosed in a glass (pyrex) jacket – to decrease thermal losses by convection and radiation*
- *Space between pipe and jacket – evacuated to reduce convection losses*
- *Diameter – glass jacket - 5 cm ; absorber pipe – 3 cm*
- *Annulus between pipe and plug – 2.5 mm wide*

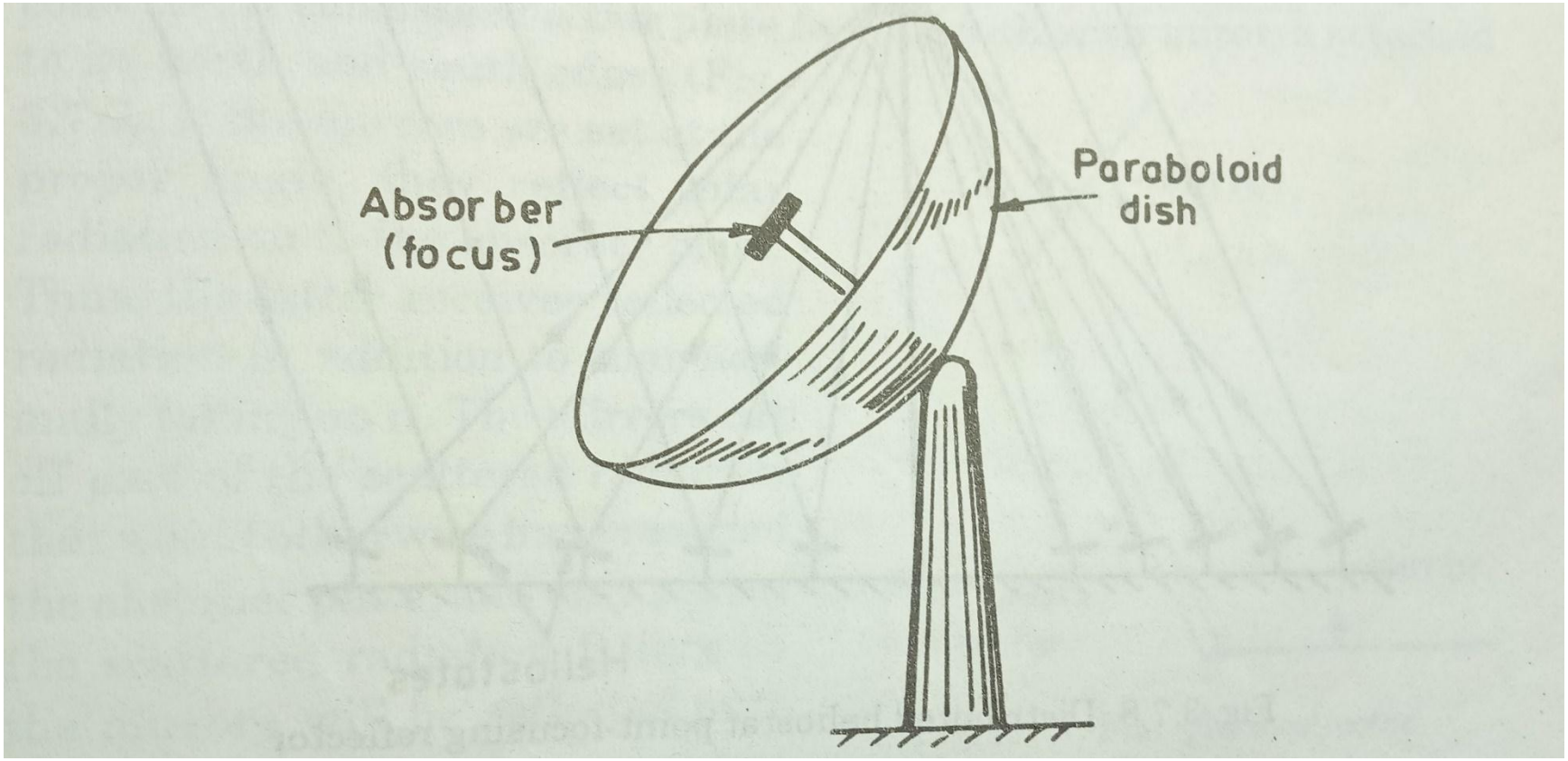
RECEIVER for FRESNEL LENS COLLECTOR



RECEIVER for FRESNEL LENS COLLECTOR…

- *Solar radiation is focused into the absorber from the top, rather from bottom as in parabolic reflection type*
- *Modified design – insulation at the bottom and sides – to reduce losses*
- *Stainless steel reflector adjacent to the pipe – reflects back emitted thermal radiation*

POINT FOCUS SOLAR COLLECTOR



POINT FOCUS SOLAR COLLECTOR…

- *Paraboloidal dish collector – solar radiation to a focus at a point – small central volume*
- *Dish – 6.6 m dia – made from 200 curved mirror segments – form a parabolodial surface*
- *Cavity made of zirconium – copper alloy with black chrome*
- *Heat transport fluid flows in and out of the absorber cavity*

POINT FOCUS SOLAR COLLECTOR…

- *Dish can be turned automatically about two axes*
- *Sun is always kept in line with the focus and the base*
- *Sun can be tracked fully at all times*
- *Concentration ratio – ratio of the area of the concetrator aperture to the energy absorbing area of the receiver*
- *Concentration ratio – very high in parabolic system – used where high temperatures are required*

HELIOSTAT POINT-FOCUSING REFLECTOR

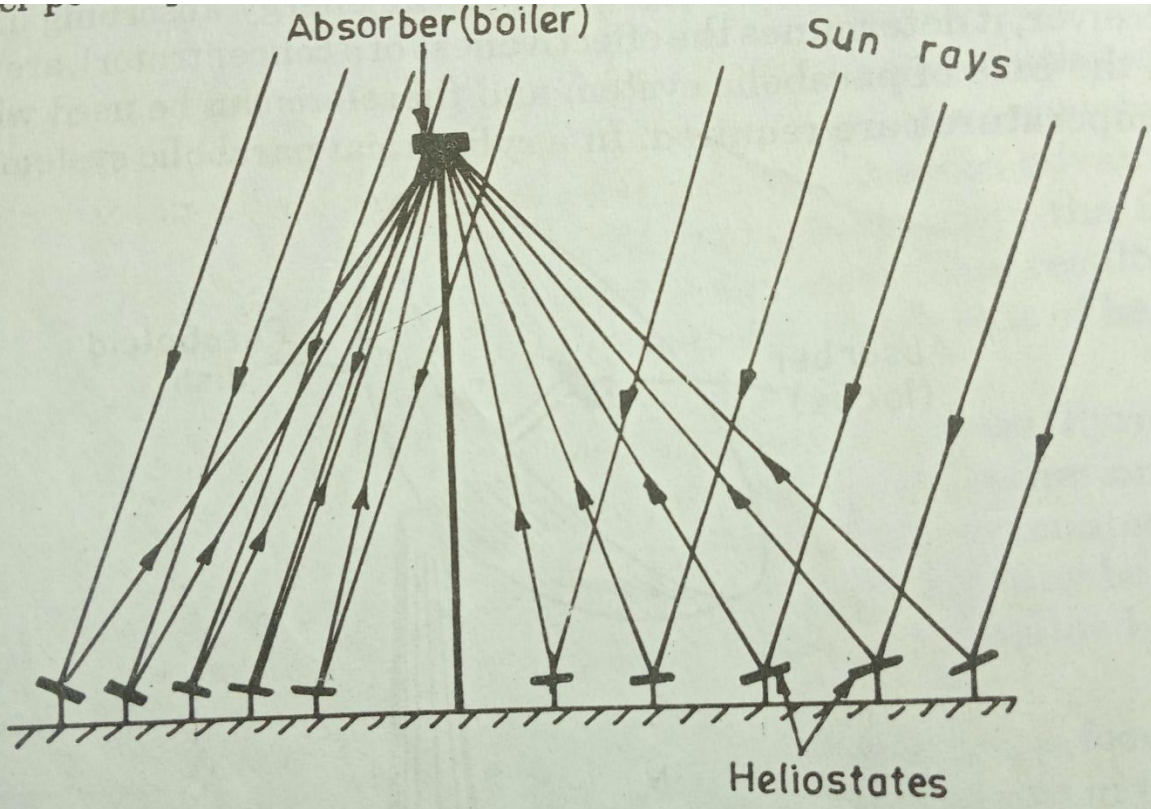


Fig. 3.7.8. Distributed heliostat point-focusing reflector (Central-Receiver).

HELIOSTAT POINT-FOCUSING REFLECTOR…

- *System equivalent to a very large paraboloidal reflector – considerable number of mirrors*
- *Mirror – heliostat – steered independently about two axes*
- *Central receiver collector – mostly used in tower plants for generation of electrical energy*
- *Mirror – composed for many small mirrors – each with its heliostat to follow the sun*

HELIOSTAT POINT-FOCUSING REFLECTOR…

- *Basic difference between single mirror concentrator and the heliostat system – latter has a dilute mirror*
- *Entire surface within the system is not covered with mirror surface – fill factor*
- *Central receiver with fill factor 40% - 40% of the land area is covered by the mirrors*
- *Basic problem – heliostat mirrors require non-linear driver rate in two coordinates*

HELIOSTAT POINT-FOCUSING REFLECTOR…

- *Highest efficiency in terms of utilization of the reflector area – fully steerable paraboloid – no losses due to aperture effects*
- *Small radiation losses – smaller area of the absorber at the focus*
- *Most difficult to fabricate and operate*
- *Practical size for aperture area – 50 m^2*
- *15 to 20 kW of useful energy – extracted by thermal conversion processes*

CONCENTRATING COLLECTOR – NON FOCUSING TYPE

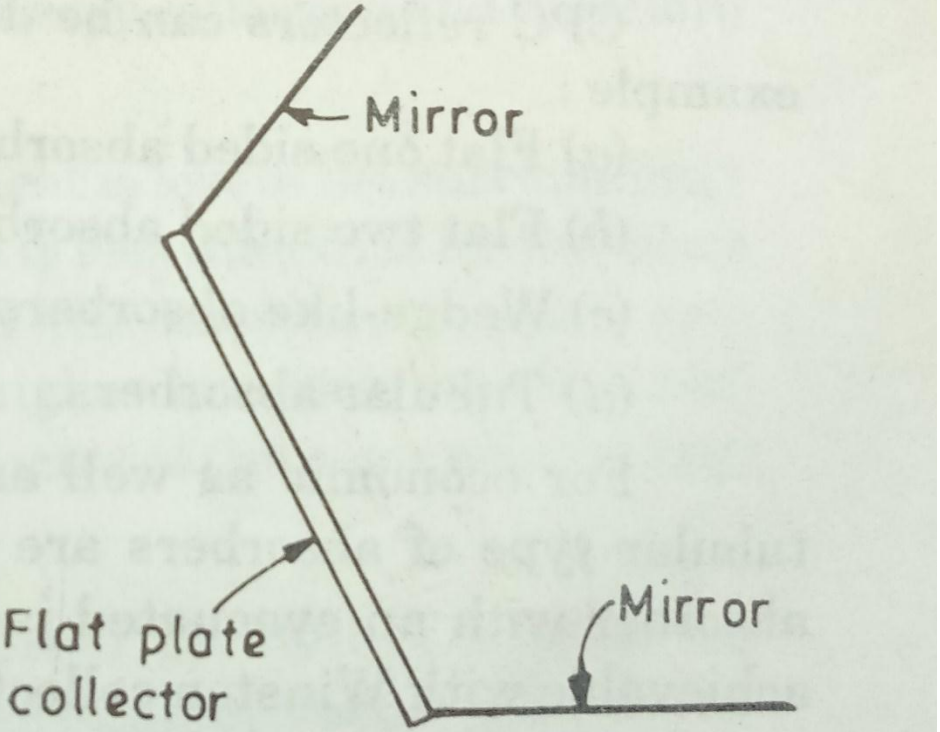


Fig. 3.7.9. Flat-plate collector augmented with mirrors.

CONCENTRATING COLLECTOR – NON FOCUSING TYPE…

- *Simplest type of concentrating collector – mirror boosted, flat plate collector*
- *Flat plate facing south with mirrors attached to its north and south edges*
- *Mirrors – proper angle – reflect solar radiation on to the absorber plate*
- *Only part of the scattered radiation falling on the mirrors will be reflected onto the absorber*

CONCENTRATING COLLECTOR – NON FOCUSING TYPE…

- *Number of collectors – combined – two or more rows*
- *Additional sun shading – caused by the mirror extensions*
- *Angles of mirrors – adjusted continuously at the sun's attitude changes*
- *Flat plate collectors with mirrors are not widely used*

COMPOUND PARABOLIC CONCENTRATOR (CPC)

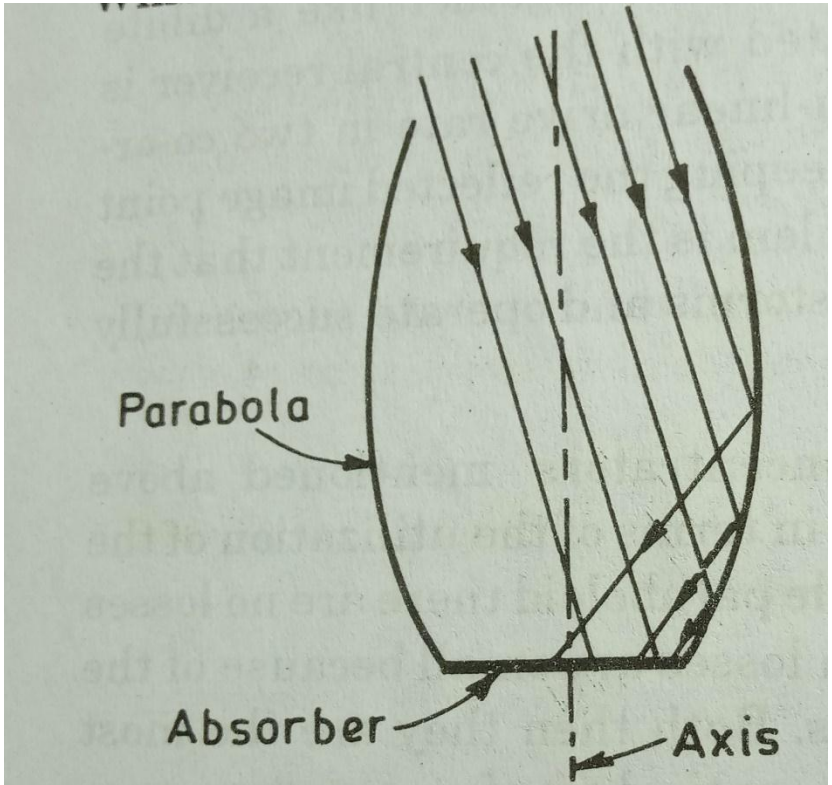


Fig. 3.7.10. Compound parabolic concentrator.

COMPOUND PARABOLIC CONCENTRATOR (CPC)…

- *Trough like arrangement – two facing parabolic mirrors*
- *Non – focusing – solar radiation from many directions – reflected towards the bottom*
- *Large proportion of the solar radiation, including diffuse (scattered) radiation, entering the trough is collected (and concentrated) on a small area*

COMPOUND PARABOLIC CONCENTRATOR (CPC)…

- *Provides moderately good concentration – in east and west direction without adjustment of sun tracking*
- *CPC reflectors : designed for any absorber plates*

    i) flat one – sided absorber

    ii) flat two – sided absorber

    iii) wedge – like absorbers

    iv) tubular absorbers

COMPOUND PARABOLIC CONCENTRATOR (CPC)…

- *With a concentric tubular absorber with an evacuated jacket, temperatures of about 200 ℃ are achievable with Winston collectors*
- *Suitable for temperature range of 100 - 150 ℃*
- *Capable of competitive performance at high temperatures of about 300 ℃ required for power generation*

ADVANTAGES

- *No need for tracking*
- *Has high acceptance angle*
- *Seasonal adjustments – required*
- *Efficiency for accepting diffuse radiation is much larger than conventional concentrators*
- *Concentration ratio is equal to the maximum value possible for a given acceptance angle*

ADVANTAGES OF CONCENTRATING COLLECTORS OVER FLAT – PLATE COLLECTORS

- *Reflecting surfaces required less material and structurally simpler*
- *Cost per unit area is potentially less*
- *Absorber area of a concentrator system is smaller for same solar energy collection – insolation intensity is greater*
- *Working fluid can attain higher temperature for the same solar energy collecting surface*

ADVANTAGES OF CONCENTRATING COLLECTORS OVER FLAT – PLATE COLLECTORS

- *Selective surface treatment and vacuum insulation to reduce heat losses are economically feasible*
- *Can be used for electric power generation when not used for heating or cooling*
- *Amount of heat stored per unit volume is larger ; heat storage costs are less*
- *Little of no anti-freeze is required to protect the absorber area*

DISADVANTAGES

- *Only beam component is collected*
- *Costly orienting systems to be used to track the sun*
- *Additional requirements of maintenance to retain the quality of reflecting surface against dirt, weather, oxidation, etc.*
- *Non- uniform flux on the absorber*
- *Additional optical losses*
- *High initial cost*

SELECTIVE ABSORBER COATING

- *An efficient way to reduce thermal losses from the absorber plate of a solar heating panel*
- *An ideal selective coating is one that is a perfect absorber of solar radiation while being a perfect reflector of thermal radiation*
- *Coating – make a surface, poor emitter of thermal radiation*
- *Increases the temperature of an absorbing surface*

SELECTIVE ABSORBER COATING…

- *Under steady state conditions,*
- *Solar flux absorbed = thermal flux emitted*
- *Absorbance and emittance of radiation at a given wavelength are equal*
- *At different wavelengths, they can vary from near zero to near unity*
- *A selective surface – has high absorptance for short wave radiation and a low emittance of long wave radiation*

SELECTIVE ABSORBER COATING…

- *Large number of coatings are available and are in wide spread use as flat plate collector coatings*
- *Primarily organic coatings – flat black paints*
- *Most of these coatings have absorptances exceeding 0.95 and emittances of 0.90 – 0.95*
- *Most surfaces are good absorber for solar radiation; good radiators of heat*

SELECTIVE ABSORBER COATING…

COATING	TYPE	ABSORPTANCE	EMITTANCE
BLACK CHROME	ELECTROPLATED	0.90	0.10
BLACK NICKEL	ELECTROPLATED	0.90	0.10
BLACK COPPER	COPPER OXIDE	0.87 – 0.92	0.07 – 0.35
NEXTEL	PAINT	0.98	0.89

SELECTIVE ABSORBER COATING…

- *Most selective surfaces are composed of very thin black metallic oxide on a bright metal base*
- *Black oxide coating is thick enough to act as a good solar absorber, with an absorptivity as high as 0.96*
- *Essentially transparent to long thermal radiation emitted by an object at a temperature of several hundred degrees*

CHARACTERISTICS

- *Properties should not change with use*
- *Should be able to withstand the temperature levels of the absorber plate over a long period of time*
- *Should be able to withstand atmospheric corrosion and oxidation*
- *Should be of reasonable cost*