# CHAPTER II

# THEORETICAL AND RELATED LITERATURE

## Introduction of concentrated solar power technology

All solar technologies are used to radiating sunlight, but they differ in methods of preparation and use of solar energy to produce heat and electricity. One of the technologies is called concentrating solar power, when the sun's energy is concentrated by reflective devices such as parabolic troughs or mirror panels and then the resulting concentrated heat energy is transferred to a heat-transfer medium, which is used to powering a conventional turbine and producing electricity. Concentrating solar power consists of two parts. One part collects solar energy to convert heat, and another part converts the heat to electricity.

Concentrating solar power technology has four main types, can be identified: Parabolic trough, Central receiver (also called power tower or solar tower), Dish–Stirling systems, Fresnel trough technology (See Figure 2). Muller-Steinhagen, 2004[5], described the performance characteristics of all concentrating solar power concepts shown in Table 2.

**Table 2 Performance characteristics of various CSP technologies**

| Technology | Capacity range (MW) | Concentration factor | Peak solar efficiency (%) | Solar-electric efficiency (%) |
|---|---|---|---|---|
| Parabolic trough | 10-200 | 70-80 | 21 | 10-15 |
| Fresnel reflector | 10-200 | 25-100 | 20 | 9-11 |
| Power tower | 10-150 | 300-1000 | 20 | 8-10 |
| Dish-Stirling | 0.01-0.4 | 1000-3000 | 29 | 16-18 |

Thermal to electric cycle efficiencies in trough and power tower are often 35% to over 40% depending on the steam conditions and plant size. Concentration increases power density and leads to higher temperature. All CSP technologies require large area for collection solar irradiance to generate electricity on an industrial scale. For example, the area for CSP plant approximately is required 80000 $m^2$/MW for power tower, 40000 $m^2$/MW for parabolic trough and 25000 $m^2$/MW for Fresnel[6].

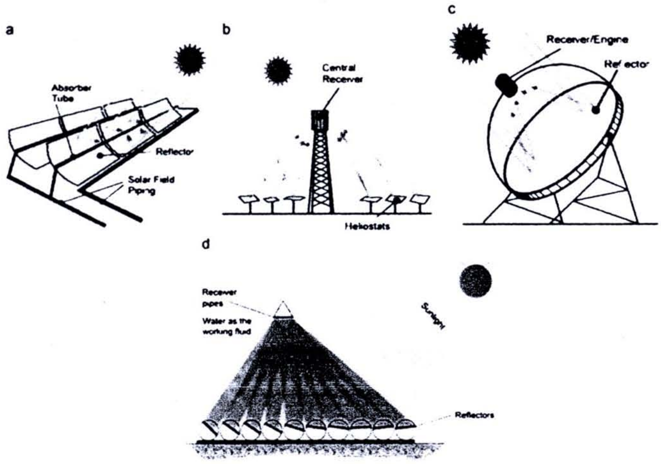

**Figure 2 Principle of a) parabolic trough, b) power tower,c) parabolic dish systems, and d) linear Fresnel reflector**

**Source:**I.Purohit, P.Purohit[13]

According to the report 2010–2011 [7], parabolic trough solar field technology is the most developed CSP technology with around 90% of total currently operating plants (more than 500 MW) in the world. This thesis in mainly is concentrated feasibility study solar power plant using parabolic trough technology. Parabolic trough solar power plant is electricity generated from mirrors to focus sunlight onto a receiver that captures the solar energy and converts it into heat that can run a steam turbine generator or engine. The main components of the systems are the solar collector assembly, the power generation system, the thermal storage, the cooling tower, and the fluid transfer piping. The solar collector assembly is self-tracking. The parabolic trough collector made of the metal support structure on which the parabolic reflectors (mirrors) are installed, with the receiver pipes and supports. The tracking system includes the drive, sensors and controller.

A parabolic trough solar field is composed of a large, module array of single-axis-tracking parabolic mirrors. Many parallel rows of these mirrors span across the solar field, usually arranged on a north south horizontal axis. Sunlight received by parabolic mirrors is redirected towards the parallel receiver (absorber) tube, which is filled with liquid (water, oil, molten salt), which in turn is transported to the power block, where the heat is used to produce high-steam to generate electricity. The basic principle of parabolic trough solar power plant is presented in Figure 3.

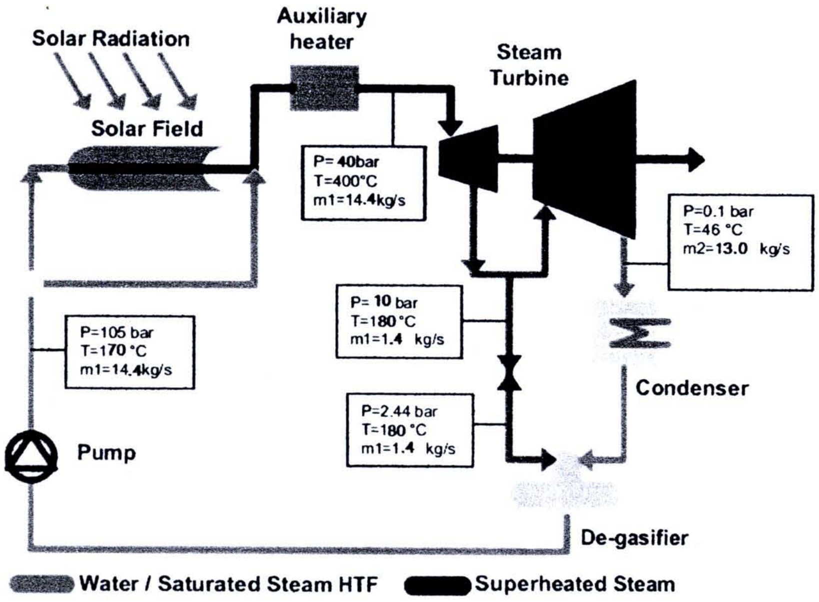

**Figure 3 Principle of 5MW parabolic trough solar power plants**

This technology requires around 40000 $m^2$/MW land; while approximate water requirement is 2.9–3.5 $m^3$/MWh. For example, Nevada Solar One from the United States (64 MW capacity) and ANDASOL-1 from Spain (50 MW capacity) are some recently commissioned parabolic trough solar power plants. The nine Solar Electric Generating Systems is the biggest application of this type of system, which has a total installed capacity of 354 MWe[8]. These have been designed, installed, and operated in the Mojave Desert, the first one since 1985 and last one since 1991. They generate peaking power, which is sold to the Southern California Edison utility. Today, California's parabolic trough plants have generated well over 15,000 GWh of utility-scale electricity with 12,000 GWh from alone, which is more than half of all solar electricity ever generated. This represents about US$2 billion worth of electricity sold over the last 20 years, and today they produce electricity at about US$0.10/kWh[9].

At the present, CSP projects of more than 12,000 MW capacities have been announced worldwide by various project developers/promoters; out of which are mainly based on parabolic trough technology followed by the power tower.

CSP technology is finding a solution to solve a problem of electric power and determine the factors to implement National renewable energy program to be increase share of renewable energy. CSP technology is seen as one of the major way to reduce the country's dependence on energy imports and demand, to increase currency reserve and domestic energy market.

**Policy development of CSP technology**

Britt C. S., et al., 2009 [30], and the world resources institute published "Juice from concentrate" report examines a renewable energy resource, concentrated solar thermal power, that presents policy-makers and investors with a significant potential for reducing carbon dioxide emissions from coal-fired power plants.

Policy options to accelerate deployment of CSP plant fall into two main categories. Some "push" the technology into the market through subsidies and by promoting cost reductions via R&D and technological advances, while others "pull" the technology into the market by increasing the cost of incumbent technology alternatives or mandating use of renewables, creating a guaranteed market for the power produced.

"Push" policy options such as feed-in tariff, investment tax credit, loan guarantees, concessionary finance, and lower import tariffs are available to support CSP plant deployment while the industry matures and costs come down. These policies can be structured to reduce the cost of renewable generation, or they may provide a subsidy to generators of renewable energy, allowing them to sell at below-cost prices.

"Pull" options such as carbon price, carbon offset mechanism, renewable portfolio standard and level playing field focus on market-creation policies that pull a new technology into commercial deployment. A stable market for CSP plant generation increases the likelihood of opportunities to contract plants using new technologies as well as a market for component parts once a new manufacturing facility starts producing them. Policies that could pull CSP plant into the market include mandating the use of renewable energy via portfolio standards, as well as policies (such as cap-and-trade or a carbon tax) that increase the cost of the incumbent technology by pricing in associated externalities.

Thailand wishes to diversify its energy mix and to promote the use of Renewable Energy within its energy mix. The Renewable Development Plan is accompanied by several support measures for promotion of all kinds of renewable energy technologies both financial and non-financial supports. For example, Technical assistance, Investment grant for biogas, municipal waste, and solar, "Adder" (or Feed-in Premium), provision of tax credit, privilege, and subsidies from the Energy Conservation Fund and the possible co-investment with the ESCO (Energy Service Company) Fund.

Adder cost is the supplement of normal purchasing tariff of electricity from national grid that different depending on the type of Renewable energy technology, electricity production capacity.

## Related research papers

This research is focused on the parabolic trough solar power technologies. Vallentin and Viebahn, 2010 [11], noted at present, the international discourse on CSP focuses on two technology options: parabolic trough technologies and solar tower technologies. Other concepts are researched as well, but so far no commercial plant has been realized. Parabolic trough technology is the most mature and economic solar thermal power generation technology today. The thesis is purposed to emphasize on suitability condition to install parabolic though CSP technology in Gobi Desert.

Peter Viebahn, et al., 2010 [12], describe study in the year 2009, 604 $MW_{el}$of CSP plant capacities which were operated globally. The 761 $MW_{el}$ were in construction and 5780 $MW_{el}$ were in the planning phase. From these figures, parabolic trough CSP technologies dominate with a share of 75% planned and nearly 100% in operation and construction.

The methodology of solar resources assessment plays important role in the technical evaluation for CSP plant. IshanPurohit, et al., 2010 [13] has been made the technical and economic assessment of CSP technologies in India. In this study he analyzed the techno-economic feasibility of CSP technologies in Indian conditions, used two projects such as PS-10 and ANDASOL-1. These two different projects have been simulated at the several Indian locations. For annual direct normal radiation more than 1800 kWh/m$^2$ was evaluated for all locations and analyzed financial feasibility study of CSP technologies. The impact of emissions trading on the financial figures of merit of CSP systems had also been studied.

The direct normal radiation for specific locations from 1900 to 2100 kWh/m$^2$/year is a bottom threshold for CSP development. The direct normal radiation can be measured directly or indirectly. The direct measuring equipment is pyrheliometer. The indirect measuring equipments are pyranometer and pyranometer with fixed shadow ring.

VasilisFthenakis, et al., 2008 [14], used 45 years hourly solar irradiation data from the southwest region of the US, to simulate capacity of the CSP, under worst weather conditions.

Y. Azoumah, et al., 2010 [15], made site guidelines for CSP plants in the Sahel. This paper provided technical guidelines for the selection of site in constructing a CSP plants in Sahelian countries. Six important parameters namely the solar radiation, the energy demand, the water resources, the availability of land, the nature of soils, and the topography were highlighted as crucial factors for the selection of best site for CSP projects.

Al-Soud and Hrayshat, 2009 [16], studied the techno and economic feasibility of CSP plant for Jordan. For this study use a prototype of a 50MW CSP plant. Moreover, a calculation model – using the concept design of proposed CSP plant, and the solar irradiation data – was developed to estimate the energy yield of the plant.

Literature reviews give an idea to determine the key factors for parabolic trough solar thermal power plant assessment such as the solar radiation, the energy demand, the water resources, the availability of land and the topography.

### Solar geometry and beam radiation

The solar radiation reaching on the earth's surface corresponds to an energy amount of 1 x $10^{18}$ kWh per year. This amount of solar energy is approximately 10000 times more than the current global energy demand.

Solar radiation can be converted into heat and electricity by using various technologies such as CSP. The technical feasibility CSP technologies at a specific location depends on the availability if solar radiation or solar resource. The most influential factor is the solar resource, as the electricity output of a CSP plant is almost proportional to the solar irradiation at the site. There is a direct and a diffuse portion of the solar radiation and the sum of both portions is called global irradiation. The diffuse solar radiation is called as sunlight passes through the atmosphere, some of it will be absorbed, scattered, and reflected by air molecules, water vapor, clouds, dust and pollutants from power plants, forest fires and volcanoes.

The direct radiation is typically measured on a plane normal to the beam as Direct Normal Irradiation (DNI). The relation between direct, diffuse and global solar irradiation, as well as the normal and the horizontal plane is shown in the Figure 4 below. As CSP plants concentrate sun-beams, the DNI is the parameter that is relevant.

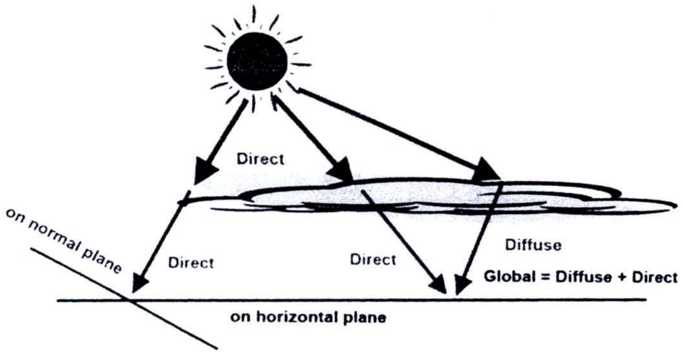

**Figure 4 Solar irradiation**

**Source:** its own drawing

The amount of DNI that reaches any area on the earth's surface varies depending on atmospheric and meteorological conditions, the latitude and longitude of the area.

### Solar geometry

The geometric relationships between a plane of any particular orientation to the earth at any time and the incoming beam solar radiation can be said as; the position of the sun relative to plane can be described in terms of several angles [17]. Some of the angles are described in Figure 5. The geometric angles are as follows.

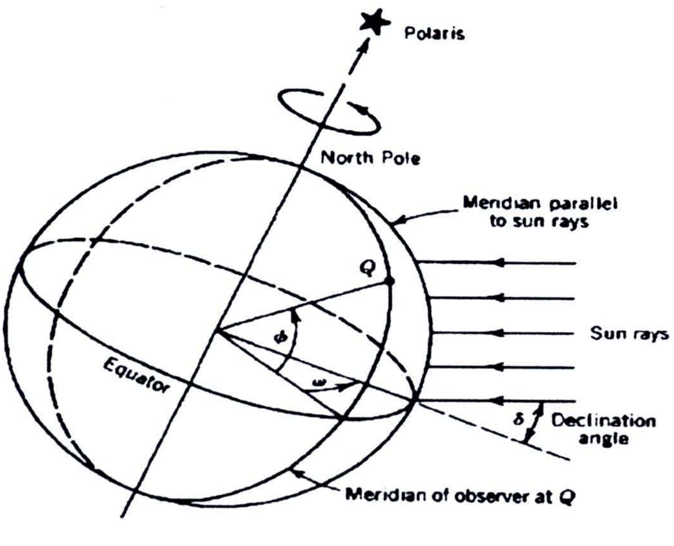

**Figure 5 Definition of latitude, hour angle, and solar declination**

$-90^\circ \leq \emptyset \leq 90^\circ$: **latitude** ($\emptyset$) is the angular location north or south of the equator;

$-23.45^\circ \leq \delta \leq 23.45^\circ$: **declination**($\delta$) is the angular position of the sun at solar noon with respect to the plane of the equator;

$0^\circ \leq \beta \leq 180^\circ$: **slope**($\beta$) is angle between the planes of the surface in question and the horizontal;

$-180^\circ \leq \gamma \leq 180^\circ$: **surface azimuth angle**($\gamma$) is the deviation of the projection on a horizontal plane normal to the surface from the local meridian;

($\omega$): **hour angle** is the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at $15^\circ$ per hour;

($\theta$): **angle of incidence** is the angle between the beam radiation on a surface and the normal to that surface.

Additional angles define the position of the sun in the sky.

($\theta_z$): **zenith angle** is the angle between the vertical and the line sun, that is, the angle of incidence of beam radiation on a horizontal surface.

($\alpha_s$): **solar altitude angle** is the angle between the horizontal and the line to the sun, that is, the complement of the zenith angle.

($\gamma_s$): **solar azimuth angle** is the angular displacement from south of the projection of beam radiation on the horizontal plane, shown in Figure 6. Displacement east of south is negative and west of south is positive.

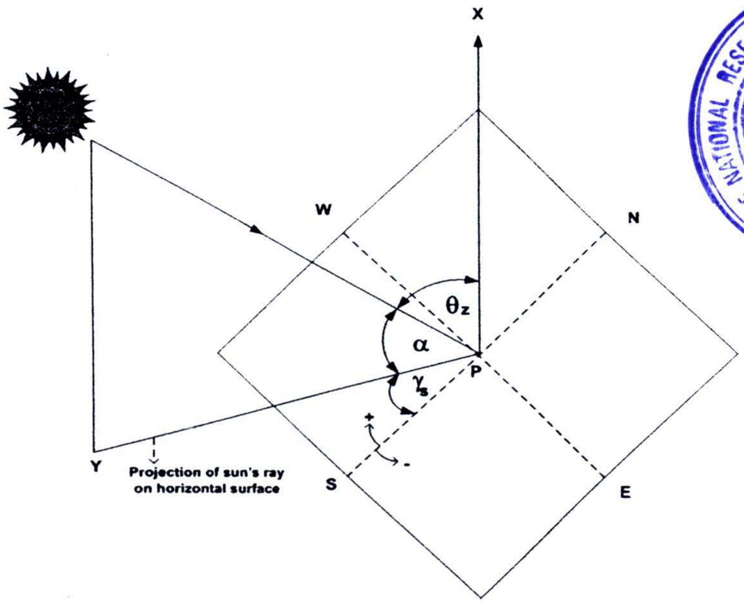

Figure 6 Derived angle: Incident, Zenith, Altitude and Azimuth angle

## Estimation of clear sky radiation

Hottel H.C., 1979 [18] has presented method for estimating the beam radiation transmitted through clear atmospheres which takes into account zenith angle and altitude for a standard atmosphere and for four climate types.

The atmosphere transmittance for beam radiation is given in the equation (1.a),

$$\tau_b = a_0 + a_1 exp\left(\frac{-k}{\cos\theta_z}\right) \qquad (1.a)$$

For horizontal surfaces, the angle of incidence is the zenith angle of the sun. Its value must be between 0° and 90° when the sun is above the horizon. For this situation, $\beta=0$,

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \qquad (1.b)$$

Where:

$\tau_b$– the atmospheric transmittance for beam radiation.

The constants $a_0$, $a_1$ an k are for the standard atmosphere with 23 km visibility and they can be found from $a^*_0$, $a^*_1$, and $k^*$, which are given for altitudes less than 2.5 km by

$$a_o^* = 0.4237 - 0.0821^*(6 - A)^2 \qquad (1.c)$$

$$a_1^* = 0.5055 + 0.00595^*(6.5 - A)^2 \qquad (1.d)$$

$$k^* = 0.2711 - 0.01858^*(2.5 - A)^2 \qquad (1.e)$$

Where: A – the altitude of the observer in kilometers.

Correction factors are applied to $a^*_o$, $a^*_1$ and $k^*$ to allow for changes in climate types. The correction factor such as $r_o= a_o/ a^*_o$' $r_1=a_1/ a^*_1$, and $r_k= k/k^*$ are given in Table 3.

**Table 3 Correction factors for climate types**

| Climate type | $r_o$ | $r_1$ | $r_k$ |
|---|---|---|---|
| Tropical | 0.95 | 0.98 | 1.02 |
| Midlatitude summer | 0.97 | 0.99 | 1.02 |
| Subarctic summer | 0.99 | 0.99 | 1.01 |
| Midlatitude winter | 1.03 | 1.01 | 1.00 |

**Source:**Hottel, H.C., 1976 [18]

Thus, the transmittance of this standard atmosphere for beam radiation can be determined for any zenith angle and any altitude up to 2.5 km [17]. The clear sky beam normal radiation is then estimated by equation (2.a).

$$G_{cb} = G_{on}\tau_b \tag{2.a}$$

$$G_{on} = G_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right) \tag{2.b}$$

Where: $G_{on}$ – the extraterrestrial radiation incident on the plane normal to the radiation on the n-th day of the year, W/m$^2$

n – the day of the year

The clear-sky horizontal beam radiation is

$$G_{cb} = G_{on}\tau_b\cos\theta_z \tag{3.a}$$

For periods of an hour, the clear sky horizontal beam radiation is

$$I_{cb} = I_{on}\tau_b\cos\theta_z \tag{3.b}$$

**Estimation of direct normal solar radiation**

Solanki C.S., et al., 2008 [19], estimated monthly average direct normal solar radiation using new method, called elevation angle constant method. The estimated values have been compared with values obtained using the model-based approach. The direct normal solar radiation estimated by model-based approach method, which is used following steps:

1. Calculate the monthly average daily extra-terrestrial solar radiation on horizontal surface, $H_o$ (J/m$^2$), using following equations,

$$H_o = \frac{(24)(3600)G_{sc}}{\pi}\left(1 + 0.033\cos\frac{360n}{365}\right)\left(\cos\emptyset\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\emptyset\sin\delta\right) \tag{4.a}$$

where, $G_{sc}$= 1367 W/ m$^2$ – the solar constant

$n$ – the day of the year

$\omega_s$is sunset hour angle,

$$\omega_s = \cos^{-1}(-tan\emptyset \times \tan\delta) \tag{4.b}$$

$$\delta = 23.45\sin\left(360\frac{284 + n}{365}\right) \tag{4.c}$$

2. Estimate the monthly average daily global radiation on the horizontal surface on the earth, $G_{daily}$, using the following equation [20]:

$$\frac{G_{daily}}{H_o} = a + b\frac{\acute{n}}{N} \tag{5.a}$$

where, $a$ and $b$ are empirical constants, $\acute{n}$ is monthly averaged daily hours of bright sunshine, $N$ is monthly averaged daily maximum possible hours of sunshine. The constants $a$ and $b$ are evaluated as

$$a = 0.409 + 0.5016\sin(\omega_s - 60) \tag{5.b}$$

$$b = 0.6609 - 0.4767\sin(\omega_s - 60) \tag{5.c}$$

3. Estimate the monthly average daily diffuse radiation on the horizontal surface, $D_{daily}$, using following relationship [21]:

For $\omega_s \leq 81.4^\circ$ *and* $0.3 \leq K_T \leq 0.8$

$$\frac{D_{daily}}{G_{daily}} = 1.391 - 3.56K_T + 4.189K_T^2 - 2.137K_T^3 \tag{6.a}$$

And for $\omega_s > 81.4^\circ$ *and* $0.3 \leq K_T \leq 0.8$

$$\frac{D_{daily}}{G_{daily}} = 1.311 - 3.022K_T + 3.427K_T^2 - 1.821K_T^3 \tag{6.b}$$

where, $K_T$ is monthly average clearness index.

4. Estimate the hourly global radiation, $G_{hourly}$, from daily data using the following relationship [22]:

$$G_{hourly} = r_t G_{daily} \tag{7.a}$$

$$r_t = \frac{\pi}{24}(a + b\cos\omega)\left(\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \frac{\pi\omega_s}{180}\cos\omega_s}\right) \tag{7.b}$$

5. Estimate the hourly diffuse radiation, $D_{hourly}$, from daily data using the following relationship [23]:

$$D_{hourly} = r_d D_{daily} \tag{8.a}$$

$$r_d = \frac{\pi}{24}\left(\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \frac{\pi\omega_s}{180}\cos\omega_s}\right) \tag{8.b}$$

where, $\omega$ – hour angle / $15^0$ per hour from noon/.

6. Estimate the daily value of $I_N$ using the following equation:

$$I_N = \sum_{sunrise}^{sunset} \left( \frac{G_{hourly} - D_{hourly}}{\sin(\alpha)} \right) \qquad (9.a)$$

where, sin(α) is calculated using the following equation:

$$\sin(\alpha) = \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\cos(\omega) \qquad (9.b)$$

**Design steps for parabolic trough solar thermal plant**

Study of the design for parabolic trough solar thermal power plant is recommended by theory of calculation considered by following steps:

1. Consider DNI on site
2. Check the electricity demand, also check possibility grid connection
3. Set up the target of electricity supply
4. Select turbine and generator
5. Find out the input power that will be supplied to the turbine
6. Calculate for the optical efficiency
7. Set up the thermal efficiency of parabolic trough
8. Calculate for "Overall Heat loss coefficient", $U_L$
9. Calculate for the concentration ratio
10. Calculate for the parabola aperture
11. Calculate for the size of parabolic trough
12. Calculate the length of parabolic trough

Basic design of the solar thermal power plant is started to determine thermal efficiency concentrating collector, DNI, and useful heat. In this chapter DNI is calculated for both sites, it is order to find the useful heat. Thermal efficiency is determined by following two equations:

$$\eta_{thermal} = \frac{Q_u}{A_c I_t} = F_R\left(\eta_o G_b A_a - A_r U_L\left(T_{fi} - T_a\right)\right) \tag{10}$$

Or for parabolic trough:

$$\eta_{thermal} = \eta_o - \frac{U_L(T_r - T_a)}{I_t C} \tag{11}$$

Where:

$\eta_{themal}$– the thermal efficiency

$Q_u$ – useful power to turbine, kJ/s

$A_c$ – collector area

$I_t$ – direct normal radiation, kWh/m$^2$/a

$\eta_o$– the optical efficiency

$G_b$ – beam irradiance (W/m$^2$)

$A_a$– aperture area (m$^2$)

$A_r$– receiver area (m$^2$)

$U_L$– overall heat loss coefficient (W/m$^2$ °C)

$T_{fi}$ – temperature inlet collector (°C)

$T_r$ – average temperature of inlet and outlet collector (°C)

$T_a$ – ambient temperature (°C)

The concentration ratio (C) is defined as the ratio of aperture area to the receiver area.

$$C = \frac{A_a}{A_r} \tag{12}$$

The efficiency turbine and generator equal around 10 to 15 percent for thermal energy convert to electricity. The efficiency turbine and generator define using following equation:

$$P_{elec.} = \eta_{T\&G} \times Q_u \tag{13}$$

where: $P_{elec.}$ – is the power output from generator,

$\eta_{T\&G}$ – is an efficiency of the turbine and generator,

Mass flow of heat transfer fluid through the turbine is determined by equation:

$$\dot{m} = \frac{Q_u}{\Delta h} \tag{14}$$

where: $\dot{m}$ - mass flow

$\Delta h$ – variation enthalpy

The optical efficiency is defined as the ratio of the energy absorbed by the receiver to the energy incident on the collector's aperture.

$$\eta_o = \rho\tau\alpha\gamma\left(1 - A_f \tan\theta_c \cos\theta_c\right) \tag{15.b}$$

Where:

$\rho$ – reflectance (for parabolic = 0.88)

$\tau$ – transmittance (for parabolic = 0.77)

$\alpha$ – absorptance (for parabolic = 0.90)

$\theta_c$ – incident angle

$A_f$ – geometric factor which is a measure of the effective reduction of the aperture area due to abnormal incidence effects.

For parabolic trough:

$$A_f = \frac{2}{3}W_a h_p + fW_a\left[1 + \frac{W_a^2}{48f^2}\right] \tag{15.a}$$

Where:

$W_a$ – collector aperture (m)

$H_p$ – height of parabola (m)

f – focal distance (m)

The term of $(1 - A_f \tan\theta_c \cos\theta_c)$ that is found is approximate to be 1.

"Overall Heat loss coefficient", $U_L$, is calculated by using following relationship:

$$U_L = \left[\frac{D_a}{\left(h_w + h_{r,c-a}\right)D_c} + \frac{1}{h_{r,r-c}}\right]^{-1} \tag{16.a}$$

$$h_{r,r-c} = \left[\frac{\sigma\left({T_a}^2 - {T_{avc}}^2\right) \times \left(T_a - T_{ave}\right)}{\left(\frac{1-\mathrm{E}_a}{\mathrm{E}_a} + 1\right) + \left(\frac{1-\mathrm{E}_c}{\mathrm{E}_c} \times \frac{D_a}{D_c}\right)}\right] \tag{16.b}$$

$$h_{r,c-a} = E_c \sigma 4 T_{ave}^3 \tag{16.c}$$

$$h_w = N_u \frac{k}{D_c} \tag{16.d}$$

$$N_u = 0.30(R_e^{0.6})$$

$$the\ R_e = 1{,}000 - 50{,}000 \tag{16.e}$$

Recommended by McAdams (1954) [17]

$$R_e = \frac{\rho V D_c}{\mu} \tag{16.f}$$

Where:

$h_w$ – convection heat transfer coefficient, W/m$^{2o}$C

$h_{r,c-a}$ – radiation heat transfer coefficient from cover to ambient

$h_{r,r-c}$ – radiation heat transfer coefficient from receiver to cover tube

$D_a$ – absorber pipe diameter, m

$D_c$ – cover pipe diameter, m

$E_a$ – emissivity of absorber

$E_c$ – emissivity glass cover

σ – Stefan Boltzmann constant, $5.66 \times 10^{-8}$ W/m$^2$K$^4$

$T_a$ – surface temperature of absorber pipe

$T_{ave}$ – an average temperature of cover and ambient

$N_u$ – Nusselt number

$R_e$ – Reynolds number

k – thermal conductivity coefficient of air

ρ – air density

μ – air viscosity

To calculate area of parabolic trough collector field using below relationship:

$$A_c = \frac{P}{\left(G_b \rho \gamma \alpha \cos\phi\, \eta_p - \frac{U_L T_a}{C}\right)} \tag{17}$$

Where:

P – power output for turbine

$\eta_p$ – pipe system efficiency

γ – interception coefficient

**Economic analysis**

The economic analysis of this study is focused the levelized cost of energy (LCOE). If annual electricity production is estimated, then cost of kWh electricity defined in [26]:

$$LCOE = \frac{f_{cf} C_{invest} + C_{OM} + C_{fuel}}{E_{net}} \tag{18}$$

Where: $f_{cr}$ – the annuity factor =9.88%

$C_{invest}$ – total investment of the plant

$C_{OM}$ – annual operation and maintenance costs

$C_{fuel}$ annual fuel costs

$E_{net}$ – annual net electricity production

Montes M.J., et al. 2009 [26], analyzed an economic optimization of the solar multiple for a solar-only parabolic trough plant. In this study, economic analysis is considered between five parabolic trough solar thermal plants similar capacity approximately 50MW. Data for economic analysis are shown in Table 4. These data are used to calculate the investment cost for this research.

**Table 4 Investment cost data for economic analysis of parabolic trough thermal plants**

| No | Item | Cost | Unit |
|---|---|---|---|
| 1 | Solar field | 206.00 | €/m$^2$ |
| 2 | Power block | 700.00 | €/kWe |
| 3 | Preheater | 1.54 | €/kWe |
| 4 | Evaporator | 10.45 | €/kWe |
| 5 | Superheater | 1.625 | €/kWe |
| 6 | Reheater | 4.221 | €/kWe |
| 7 | Land cost | 2.00 | €/m$^2$ |
| 8 | Surcharge for construction, engineering and contingencies | 20.00 | (%) |

The economic efficiency of the CSP plant is used a method of the cost benefit-analysis. The cost benefit-analysis is a tool for resource distribution /policy determination/ criteria of the government for the most efficient resource use.

Government evaluates the cost and benefit of the project from the standpoint of social welfare. The project evaluation for cost and benefit is done for public resources without reference of market price [27].

There are four factors present as the criteria for Cost – Benefit Analysis:

1. Net Present Value (NPV)
2. Benefit to Cost Ratio (BCR)
3. Internal Rate of Return (IRR)
4. Payback period (PBP)

**Net present value**

Net Present Value method for evaluating the desirability of investments can be defined as follows:

$$\textbf{NPV}=\sum_{n=0}^{N}\frac{B_n}{(1+i)^n}-\sum_{n=0}^{N}\frac{C_n}{(1+i)^n} = \textbf{PVB - PVC} \tag{19}$$

Where,

$B_n$ = Expected benefit at the end of year n

$C_n$ = Expected cost at the end of year n

i = Discount rate, i.e., the required minimum annual rate on new investment

n = Project's duration in years

N = Project's period

PVB = Present Value Benefit

PVC = Present Value Cost

**Benefit to cost ratio**

Benefit Cost Ratio is identified by the relationship between the benefits and costs of any recommended projects.

$$BCR = \frac{PVB}{PVC} \tag{20}$$

**Internal rate of return**

Internal Rate of Return is another time – discounted measure of investment worth. The IRR is defined as that rate of discount which equates the present value of the stream of net receipt with the initial investment outlay:

$$\text{NPV} = \sum_{n=0}^{N}\frac{B_n}{(1+i)^n}-\sum_{n=0}^{N}\frac{C_n}{(1+i)^n} = \text{PVB - PVC}$$

Where, "r" denotes IRR. An alternative and equivalent definition of the IRR is the rate of discount which equates the NPV of the cash flow to zero :

$$\mathrm{NPV} = \sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = 0 \qquad (21)$$

**Payback period**

Payback Period refers to the period of time required for the return on an investment to "repay" the sum of the original investment.
In general, the payback time N is defined by equation:

$$\sum_{n=1}^{N} (B_n - C_n) = 0 \qquad (22)$$

If the cost stream $C_n$ is broken down into an investment (TIC) that is made at one point in time, and variable costs ($VC_n$) covering, for instance fuel.

Operation and maintenance cost in the case of a power plant, the above equation can be written in the following form:

$$\mathrm{TIC} = \sum_{n=1}^{N} (B_n - VC_n)$$

In this form, time N clearly appears as the time required for net operational revenues to pay back the capital investment.

Al-Soud and Hrayshat studied the technical and economic feasibility of a 50MW CSP plant for Jordan. From this study report will be useful for evaluated design characteristics of the future perspectives of CSP plant in Mongolia.

IshanPurohit, et al., 2010 [13] had studied the clean development mechanism (CDM) which is an instrument under the Kyoto Protocol for promoting technology transfer and investment from industrialized (Annex-I) countries to the developing (non-Annex-I) countries for projects focused on mitigating emissions of greenhouse gases. It provides for Annex-I countries to invest in emission-reducing projects in non-

Annex-I countries and to use the resulting Certified Emissions Reductions (CER) credits towards their own compliance with the emission limitation targets set forth by the Kyoto Protocol.