*Chapter 2*

## 2.1 DESIGN

### 2.1.1 Solar chimney power plant in Manzanares

A Solar Updraft Tower converts solar radiation (direct and diffuse) into electricity by combining three well-known principles: the greenhouse effect, the tower and wind turbines in a novel way. Hot air is produced by the sun under a large glass roof. This flows to a tower in the middle of the roof and is drawn upwards. This updraft drives turbines installed at the base of the tower and these produce electricity.

The prototype produced electricity for seven years, thus proving the efficiency and the reliability of this new kind of solar power generating system.
Tall Solar Updraft Towers could produce 100 or 200 MW each and power production cost may go down below 0.07 €/kWh. [7]

| | |
|---|---|
| Tower height | 194 m |
| Tower diameter | 10 m |
| Collector diameter | approx. 244 m |
| Collector area | 40,000 m² membrane, 6,000 m² glass |
| Collector height | approx. 1.80 m |
| Collector weight | 5.5 kg/m² (without glass) |
| Tower weight | 125t |

**Figure 2-1: Manzanares solar chimney power plant.**

## 2.1.2 Solar chimney power plant in Zanajn

A solar chimney power plant derives its mechanical power from the kinetic power of the hot air which rises through a tall chimney, the air being heated by solar energy through a transparent roof surrounding the chimney base. [8]

The performance evaluation of solar chimney power plant was done by FLUENT software by changing three parameters including collector slope, chimney diameter and entrance gap of collector. [8]

The results were validated with the solar chimney power plant which was constructed in Zanajn, Iran with 12 m height, 10 m collector radius and 10 degree Collector angle. By simulation and numerical optimization of many cases with dimensional variations, increasing 300 to 500 percent of chimney velocity and eventually increasing output power of system was observed in different cases. [8]

**Figure 2-2: Zanajn solar chimney power plant.**

For purpose of more studies regarding these kinds of power plants, an experimental sample was built in University of Zanjan, in 2010. [8]

The chimney height is 12 m and the collector has 10 m diameter. The collector angle must be designed in a way that the most possible heat could be absorbed, Zanjan city has the attitude of 36º, 68´ and longitude of 48º, 45´. [8]

So if we want to have the most absorbed heat by the collector, the collector output must have the height of 5 $\tan\pi/6$. The collector output was made with a height of 1m and the collector opening was 15 cm. The schematic and the dimensions of the built sample are shown in Figure 2 and Table 1. [8]

| Geometric parameter | Symbol | Amount (m) |
| --- | --- | --- |
| Collector opening height | $H_2$ | 0.15 |
| Collector output height | $H_c$-$H_2$ | 1 |
| Chimney diameter | $d_c$ | 0.25 |
| Collector diameter | $d_2$ | 10 |
| Chimney height | $H_c$ | 12 |

**Table 2-1: Dimensions of the built sample.**

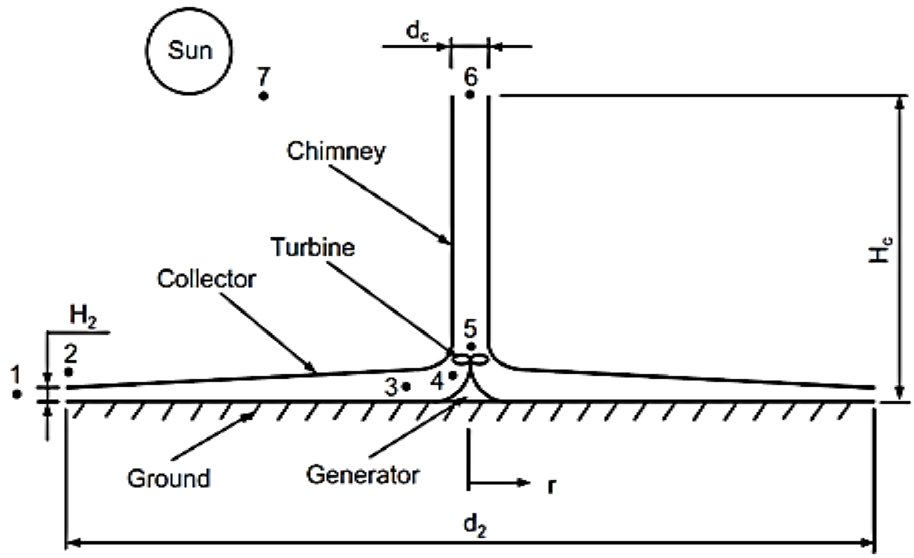


**Figure 2-3: Schematic of the solar chimney.**

## 2.1.2 Influence of main plant dimensions on power output

### 2.1.2.1 Collectors Parameters

| | |
| --- | --- |
| $Rc$ | Collector radius |
| $\hbar ci$ | Collector inlet height |
| $\hbar co$ | Collector outlet height |
| $\hbar c$ | Collector height at distance r from inlet |

**Table 2-2: Collectors Parameters.**

In this section, the influence of overall SCPP plant dimensions on power output is investigated. In Figure 2.4, the power output is seen to increase from 25MW for a collector radius of 1000m to 115MW for a collector radius of 8000m. This increase is almost linear up to about 3000m radius, as increased collector size leads to increased heat input. It is interesting to note that the increase is almost linear with collector radius, but not with area (which increases with the collector radius squared). The power output then plateaus towards its maximum for larger collector radius above 5000m. This shows that when the other dimensions are fixed, increasing the collector size beyond a certain size brings diminishing returns. [9]

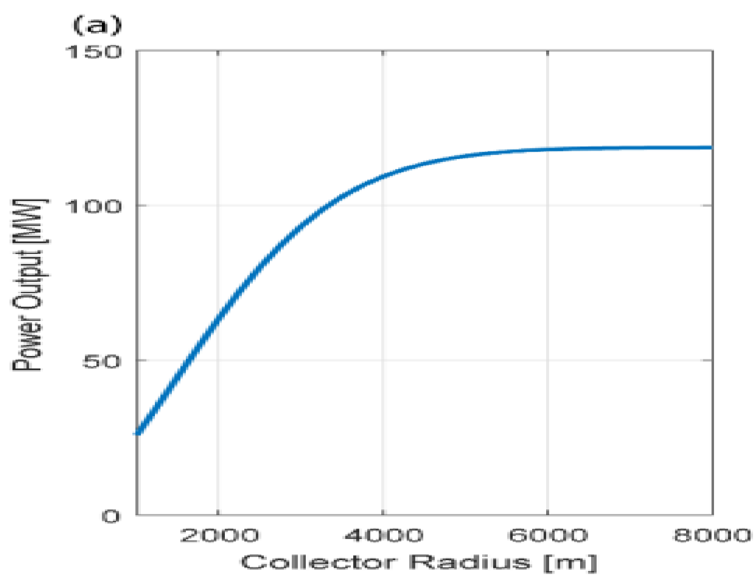


**Figure 2-4: Plant dimensions on power output.**

### 2.1.2.2 Chimney parameters

| | |
|---|---|
| $Rch$ | Chimney radius |
| $Hch$ | Chimney height |
| $\Delta pf$ | Pressure drop due to friction in the chimney |

| | |
|---|---|
| $P$ | Power generated |

**Table 2-3: Chimney parameters.**

In Figure 2.5 shows similarly, that the power output increases almost linearly from 20MW for low chimney radii (20m), as an increased chimney cross-section allows for increased air flow. It reaches a maximum of 145MW at a 165m radius and then marginally decreases for chimney radii up to 200 m. This maximum is relatively flat so that a power in excess of 140 MW would be obtained for any chimney radius within the 120m-200m range. [9]

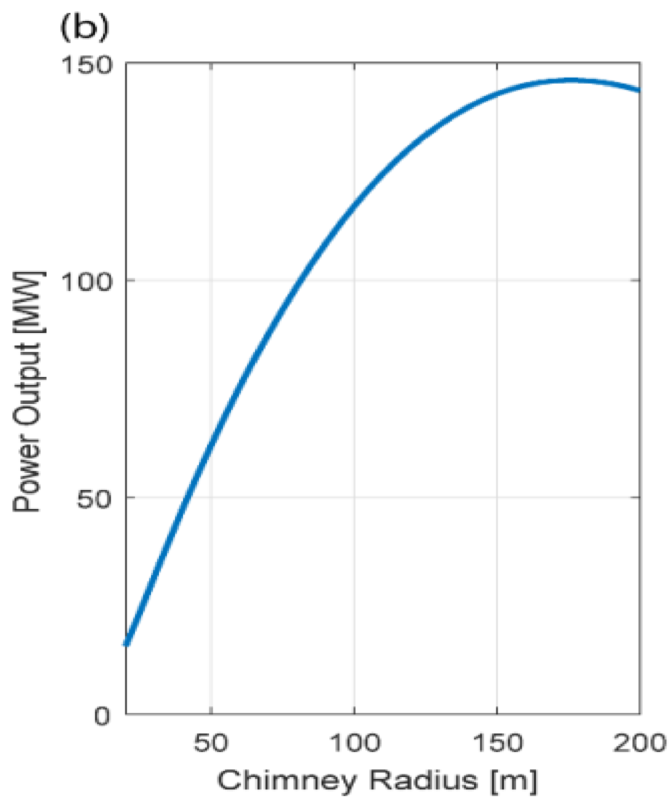


**Figure 2-5: Relation between chimney radius and power output.**

The power output increases significantly with chimney height (Figure 5c). The model predicts a power output of 8 MW for a 200m-high chimney, up to 130 MW for a chimney 1500m high. Within the range considered, the predicted power output (all other reference dimensions fixed) is well approximated by a quadratic variation with chimney height as can be found from fitting the curve in Figure 5c. Therefore, in terms of power output alone, the higher the chimney, the better the plant performance. [9]

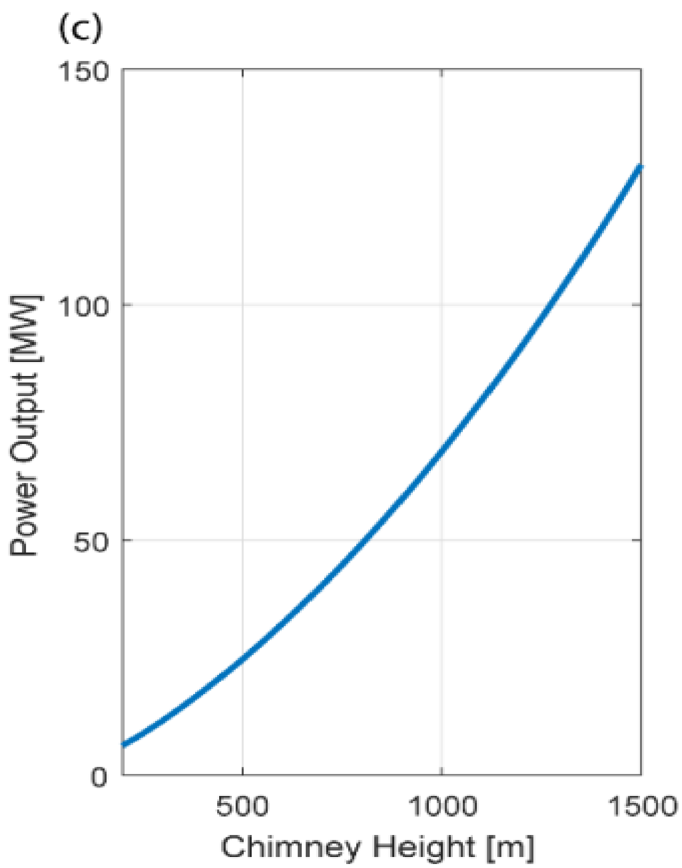


**Figure 2-5: Relation between chimney height and power output.**

| | |
|---|---|
| Optimum collector radius | 5000m |
| Optimum chimney radius | [120-200]m |
| Optimum chimney height | 1500m |

**Table 2-4: Optimum chimney dimensions.**

### 2.1.2.3 Turbine Parameters

| | |
|---|---|
| x | Turbine pressure drop ratio |
| $\eta t$ | Turbine efficiency |

| | |
|---|---|
| $\Delta pt$ | Pressure drop available to the turbine |

**Table 2-5: Turbine Parameters.**

The turbine pressure drop is a key parameter in power output prediction. Its optimum value and dependence on other parameters has been studied, but remains a matter of debate [14]. Therefore, in the first part of this investigation the relationships between turbine pressure drop, power output and other parameters was studied systematically.

For the plant with reference dimensions and environmental conditions, the turbine pressure drop $x$, was varied from 0.6 to 0.95 and the power output calculated. The results shown in Figure 3 indicate that within the range of pressure drops investigated, the power output peaks for $x$ around 0.8 and the power output only decreases by up to 8% for $x$ within [0.7-0.9]. [9]

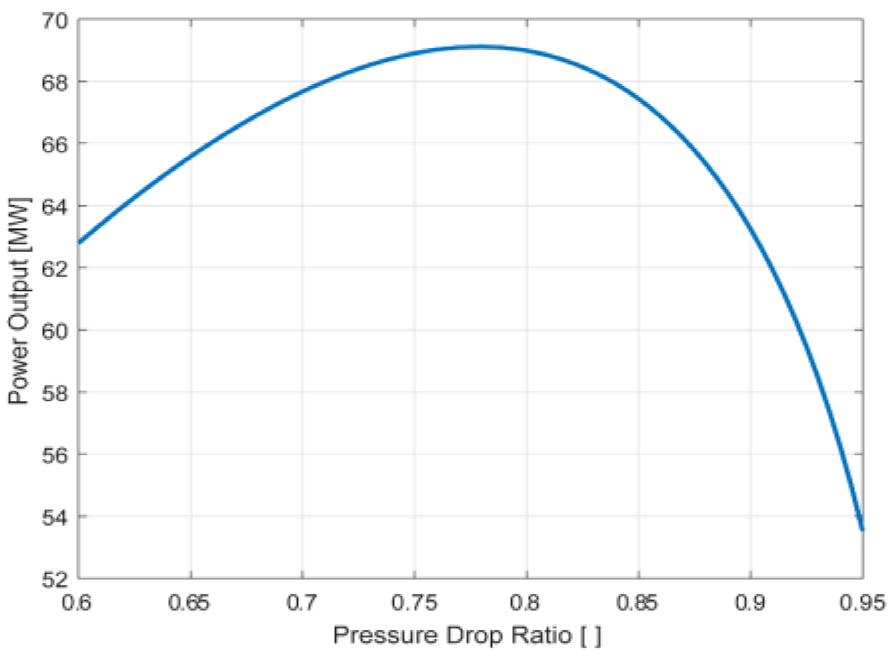


**Figure 2-6: Relation between power output and pressure drop ratio.**

### 2.1.2.4 Power Output Relation

$P_{out} = v\ A_c\ \Delta P_t\ \eta_{tg}$. [10]

$A_c$= cross sectional area of chimney.

V= velocity of air, m/s.

$\Delta P_t$= pressure difference across the turbine, kPa.

$\eta_{tg}$= efficiency of the turbine generator system.

### 2.1.2.5 Conclusion

- Electricity generation initially increases linearly with collector radius and chimney radius, before plateauing off or reaching a maximum. [9]
- Power output increases quadratically with chimney height confirming the need to design plants with tall chimneys. [9]
- For a given chimney height, the collector size must be carefully matched with the chimney radius. [9]
- The collector radius must be large enough for the air temperature to reach equilibrium with the canopy and ground. However, increasing the radius beyond this point brings no additional benefit. [9]
- Narrow chimneys constrict the flow and consequently limit power output. Chimney radii of up to 200 m are necessary to reach power output of 900 MW. [9]

## 2.2 MATRIEAL SELECTION

### 2.2.1 Glass Solar panel of solar chimney

Photo-voltaic (PV) module, PV panel or solar panel is an assembly of photovoltaic cells mounted in a framework for generating energy. Solar panels use sunlight as a source of energy to generate direct current electricity. A collection of solar cells is called a PV panel, and a system of PV panels is called an array. Arrays of a photovoltaic system supply solar electricity to electrical equipment. [11]

Each module is rated by its DC output power under standard test conditions (STC) and hence the on field output power might vary. Power typically ranges from 100 to 365 Watts (W). The efficiency of a module determines the area of a module given the same rated output – an 8% efficient 230 W module will have twice the area of a 16% efficient 230 W module. Some commercially available solar modules exceed 24% efficiency. Currently, [needs update] the best achieved sunlight conversion rate (solar module efficiency) is around 21.5% in new commercial products typically lower than the efficiencies of their cells in isolation. The most efficient mass-produced solar module has power density values of up to 175 W/m2 (16.22 W/ft2). [11]

#### 2.2.1.1 Solar Panel Cost

His is probably the first factor people consider when comparing solar panels. The solar panel cost is determined by different variables: the size (in Watts), the physical size, the brand, the quality of the materials, the durability and any certifications the solar panel might have. [11]

Solar panel is to consider the cost. However, it shouldn’t be the one and only factor to be considered, since the least expensive panel might not be the most efficient and probably not the best option if you consider the long term. How to choose solar panels can be risky but, they have a long lifespan (more than 30 years), so it is more important to ensure a good quality system than choosing the cheapest option. [11]

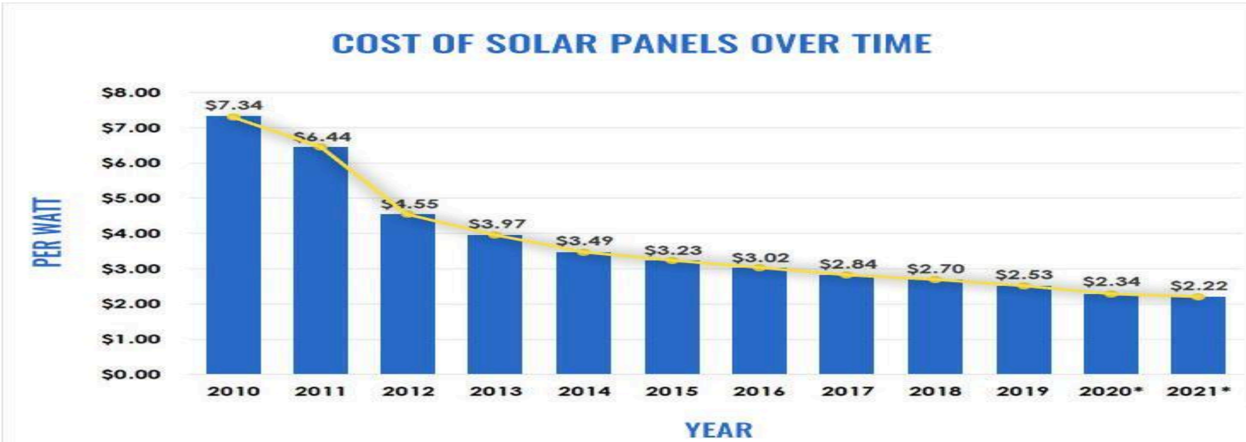


**Figure 2-7: Cost of solar panels over time.**

### 2.2.1.2 Solar Panel Quality

This takes into account how the panel is manufactured and the quality of the materials used to build the solar panel. There are different types of manufacturers producing panels that differ in quality, price, and efficiency. There are vertically integrated solar panel manufacturers which control each stage of the production process. They put a strong eye on quality and invest a lot into research and development (R&D). There are other manufacturers that only assemble panels, but usually don't manufacture their own cells and don’t invest in R&D. They use more human production than robotic, but produce the most affordable panels. [12]

### 2.2.1.3 Energy Efficiency

The efficiency of solar panels has improved dramatically in recent years, from an average of around 15% conversion of sunlight to usable energy to around 20%. High-efficiency solar panels can reach as much as nearly 23%. [12]

| | |
|---|---|
| Paly | 18% efficiency |
| Mono | 19% efficiency |
| HJT N-Type | 22% efficiency |

| | |
|---|---|
| IBC | 22.5% efficiency |

**Table 2-6: Energy Efficiency.**

### 2.2.1.4 Temperature Coefficient

The impact that heat has on a solar panel's operational efficiency after installation, Since solar panel overheating accelerates their ageing, the lower the percentage per degree Celsius, the better. The semiconductors in solar panels are sensitive to high temperatures. According to the manufacturing standards, 25 °C or 77 °F temperature is the optimum temperature range of photovoltaic solar panels. [13]

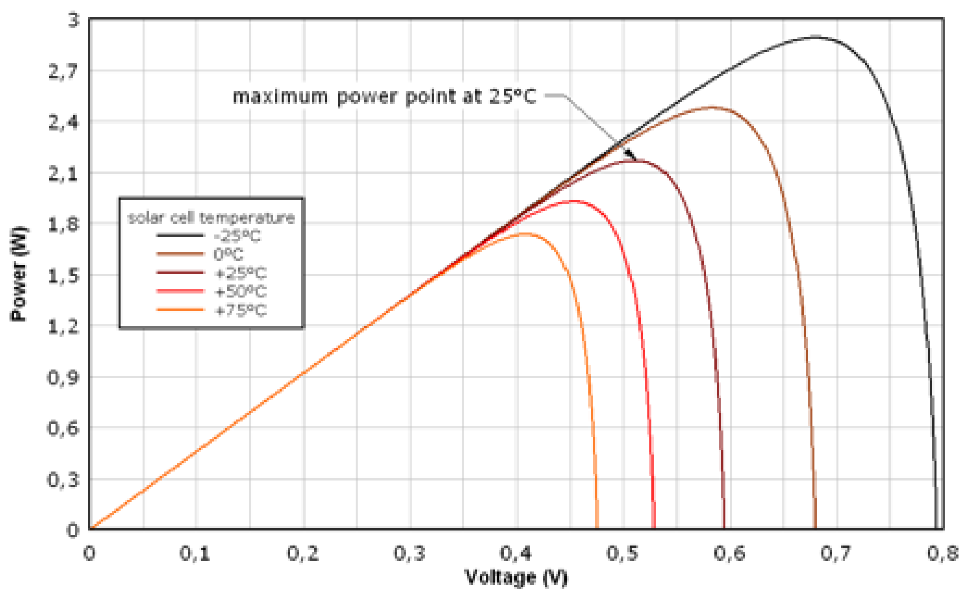


**Figure 2-7: Relation between Power and Voltage.**

The solar panel's power loss can be calculated as follows: [13]

65degC – 25degC = 40degC

40degC x -0.5% = 20%

Therefore panel power loss = 20% x 250W = 50W

Therefore panel power = 200W

### 2.2.1.5 Types of Solar Cells

Monocrystalline silicon offers high efficiency and good heat tolerance characteristics with a small footprint. Polycrystalline (or multi-crystalline) silicon cell based solar panels are now the most popular choice in residential installs. There are also Amorphous (or thin-film) silicon cells, which use the least amount of silicon and are not very efficient. For an equivalent wattage, a crystalline panel will be smaller than an amorphous panel. [13]

#### 2.2.1.5.1 Monocrystalline

Monocrystalline solar cells are made from single crystalline silicon. They are very distinctive in their appearance as they are often coloured, and the cells hold a cylindrical shape. In order to keep the costs low and performance at optimal levels, manufacturers cut out the four sides of the monocrystalline cells. This gives them their recognisable appearance. [13]

#### Advantages

They have the highest level of efficiency at 15-20%. [13]

They require less space compared to other types due to their high efficiency. [13]

Manufacturers state that this form of solar cell lasts the longest, with most giving them a 25-year warranty. [13]

They perform better in low levels of sunlight, making them ideal for cloudy areas. [13]

#### Disadvantages

Here are some of the disadvantages to monocrystalline solar cells: [13]

They are the most expensive solar cells on the market, and so not in everyone’s price range

The performance levels tend to suffer from an increase in temperature. However, it is a small loss when compared to other forms of solar cell. [13]

There is a lot of waste material when the silicon is cut during manufacture. [13]

### 2.2.1.5.2 Polycrystalline Solar Cells

The polycrystalline solar panels were first introduced to the public in 1981. Unlike the monocrystalline cells, polycrystalline ones do not require each of the four sides to be cut. Instead, the silicon is melted and poured into square moulds. These then form perfectly shaped square cells. [13]

#### Advantages

The manufacturing process is cheaper and easier than the monocrystalline cells [13]

It avoids silicon waste [13]

High temperatures have less negative effects on efficiency compared with monocrystalline cells. This makes the polycrystalline cells more attractive to people in warmer areas as the price is lower. [13]

#### Disadvantages

Efficiency is only around 13-16% due to low levels of silicon purity. So they are not the most efficient on the market. [13]

They have lower output rates which make them less space efficient. So more roof space is needed for installation. [13]

### 2.2.1.5.3 Thin Film Solar Cells

Depending on the technology that has been used, the efficiency rates for thin film solar cells tends to vary from 7% to 13%. Since 2002, the knowledge levels and popularity for thin film solar cells has risen dramatically, which also means that research and development have been increased. Due to this, we can expect future models to hold efficiency rates of 10-16%. [13]

## Advantages

They can be manufactured to be flexible, making them widely applicable to a range of situations and building types. [13]

Mass production is easy to achieve, making them potentially cheaper to produce than crystalline solar cells. [13]

## Disadvantages

They are not ideal for domestic use as thy take up a lot of space. [13]

Low space efficiency means that they will cause further expenses in the form of enhancers, like cables of support structures. [13]

They have a shorter lifespan and so shorter warranty periods. [13]

## 2.3 TURBINE SELECTION

### 2.3.1 Solar power plant turbines

It generates electricity by using thermal energy from solar radiation. Using solar arrays, solar radiation is focused on a small area (receiver) where solar energy is converted to heat. Heat is then collected by a working fluid which then drives a gas or steam engine cycle for electricity generation. [14]

#### 2.3.1.1 Turbine Design of the SCPP

Solar chimney literature has little to say about factors affecting efficiency of the turbines, but merely assumes various fixed values of efficiency in the range 40-80%, according to Backström & Gannon and Mullett. [14]

In this study, a new approach is present for redesign of the solar chimney turbine. The Matrix Throughflow Method (MTFM) usually design the axial flow turbine and fan, The MTFM is a two dimensional analysis tool. [14]

#### 2.3.1.2 Simulation Model

A solar chimney power plant has physics principles. The heating collector is work as air heater by solar energy, where terms of heat transfer are applied to predict performance. To analysis of chimney, the heat transfer is neglected but buoyancy force (fluid mechanics) is taken into account. The turbo machine theories should be applied to design and analyses the turbine. [14]

| | |
|---|---|
| Rotational speed (Ω) | 100 rpm |
| Air velocity | 9 m/s |

| | |
|---|---|
| Inlet total pressure | 92930 pa |
| Inlet total temperature | 291.5 k |
| Total head rise | 90 pa |
| Outer diameter | 5 m |
| Numbers of blades | 4 |

**Table 2-7: Simulation Model.**

### 2.3.2 Axial flow turbine

#### 2.3.2.1 Advantages

Turn vacant, unproductive land into productive land:

Massive arrays of PV panels are required for solar turbines to produce enough power. The arrays need a large amount of land with unobstructed sunlight. This is usually in barren areas such as deserts. [15]

Provide clean energy:

No fuels need to be burned for solar turbines to work. The only energy is sunlight, which leaves no carbon footprint. [15]

No cost to fuel:

Sunlight is free of charge. This helps to lower the cost of solar-powered plants and negate the influence of fluctuating conventional fuel costs. [15]

Improve efficacy of conventional power plants:

Solar turbines or CSP can be used to boost the performance of power plants that conventionally run on fossil fuels. Solar thermal energy can aid in increasing the temperature of the working fluid in these plants. [15]

#### 2.3.2.2 Disadvantages

Dependent on weather: The nature of solar radiation is intermittent. As such, solar turbines must carry out regular starts and re-heat options for maximum performance. [15]

Lower heating point: The transmission fluids of current solar turbines cannot be heated above 752°F. This can be overcome by placing the turbine on a high tower with the mirrors focusing sunlight directly on the steam boiler instead of using transmission fluid in the pipes. [15]

## 2.4 PHASE CHANGE IN SOLAR CHIMENY.

### 2.4.1 Paraffin

The effect of latent heat storage (LHS) on a solar chimney pilot was studied experimentally. Two kinds of experiments including with and without phase change material (PCM) were carried out, and the parameters including temperature and velocity were measured to investigate the solar chimney (SC) performance. [16]

Paraffin wax was used as a PCM in the constructed SC with 3 m chimney height and 3 m collector diameter in the campus of University of Tehran. The results show that the maximum absorber surface temperature for the SC with PCM and the conventional solar chimney (CSC) are 72 °C and 69 °C, respectively. Also, the maximum air velocity for the CSC is 1.9 m/s, while it is 2 m/s for the system equipped with PCM thermal storage. [16]

So, the LHS system causes increasing the average mass flow rate of the pilot around 8.33%. As a result, using LHS system in SC leads to improve the solar chimney performance. [16]

Paraffin (min 98% pure, industrial grade) was purchased from Shanghai YiYang Instrument Co., Ltd. (Shanghai, China) and its thermophysical properties are shown in Table 2.8. Paraffin offers the advantages of a high storage heat capacity, good chemical stability, low corrosion, and low cost. [16]

Table 1

Thermophysical properties of paraffin.

| Material | Melting Point (°C) | Density of Liquid Phase ($g/cm^3$) | Density of Solid Phase ($g/cm^3$) | Specific Heat ($kJ/m^3{\cdot}K$) | Thermal Conductivity ($W/m{\cdot}K$) |
|---|---|---|---|---|---|
| Paraffin | 60–64 | 0.768 | 0.900 | 1635 | 0.405 |

**Table 2-8: Thermophysical properties of paraffin.**