

Review Paper on Effect of Dust on the Solar Parabolic Trough and Applications

Khushaboo Singh
Mechanical Department, JNVU /
MBM Engineering College,
Jodhpur, India,

Krishna Purohit
Mechanical Department, JNVU /
MBM Engineering College,
Jodhpur, India,

Dr. P M Meena (PhD-IITB)
Associate Professor
Mechanical Department, JNVU /
MBM Engineering College,
Jodhpur, India,

ABSTRACT

In the present scenario, the huge demand of energy and economy create the necessity to give importance to all types of energy resources either it is conventional or nonconventional. Since the rapid consumption of fossil fuel over billions of people across the world are still unable to assess electricity. Furthermore, if the consumption of fossil fuel will be continued then our future generation will certainly have to face the shortage of it and the global warming potential and ozone layer depletion will also increase. Solar collectors (mirrors) suffer from the dust deposition which requires frequent cleaning to maintain their efficiency. Since hundred thousand square meters of solar mirror are required even for a relatively small solar power plant, the cleaning on such a large mirror surfaces involves a significant operation and maintenance (O&M) activities and cost in concentrating solar thermal power plants. Dust deposition on solar mirror surface is site specific and the dust characterization for each site is required in order to optimize the solar mirror cleaning activities.

Keywords

Solar Parabolic Trough, Concentrated Solar Thermal (CST).

1. INTRODUCTION

One main reason why the performance of a parabolic trough collector measured experimentally differs from the simulation results is inaccurate prediction of absorbed solar energy. The amount of absorbed energy of such systems mainly depends on optical properties of mirrors, absorber tube, and transmissivity of glass cover of absorber tube. One of the main challenges is to develop a reliable simulation tool to predict accurately the performance of solar thermal plants. Solar absorption and thermal power production are strongly related to the optical properties of the collectors (Yaghoubi et al. 2011 and Şahin, A.D., 2007). Such properties are the reflectivity of mirrors, solar transmissivity of cover glass and absorptivity of absorber tube (Sansoni et al.2011).

The reflectivity of mirrors and glass cover transmissivity of a collector are highly affected by the amount of dust deposited on these surfaces. This effect has been well understood and different power plants have considered various cleaning schedules to reduce dust effect on the performances of solar systems. Different studies have been performed to study dust effect on various solar systems; for example, Kaldellis et al. (2010) have studied dust deposition impact on photovoltaic-assisted water pumping systems. Several authors have studied the effect of dust deposition on flat plate collectors. Goossens and Van Kerschaever (1999) investigated the effect of wind velocity and airborne dust concentration on the drop of photovoltaic (PV) cell performance

caused by dust accumulation on such cells. Performance drop and I-V characteristics were investigated at four wind velocities and four dust concentrations. El-Shobokshy and Hussein (1993) investigated the effect of dust on the performance of photovoltaic cells. Garg (1974) investigated the effect of dust on the transmittance of solar radiation through various inclined glass plates and plastic film. Hegazy (2001) investigated dust accumulation on glass plates with different tilt angles and associated reductions in solar transmittance experimentally over a period of one year under the climate conditions of the Minia region, central Egypt. His results show that the fractional reduction in glass normal transmittance depends strongly on dust deposition in conjunction with plate tilt angle, as well as on the exposure period and site climate conditions. Sayigh et al. (1985) observed 64, 48, 38, 30 and 17% reduction in the transmittance of the glass plates after 38 days of exposure to the environment with tilt angles of 0, 15, 30, 45 and 60°, respectively. Mastekbayeva and Kumar (2000) and Nahar and Gupta (1990) also investigated the effects of dust on transmittance of different materials. El-Nashar (2009) studied the seasonal effect of dust deposition on a field of evacuated tube collectors of a solar desalination plant. The system is located near the city of Abu Dhabi, UAE, and the results are therefore relevant to this region. It was found that dust deposition can cause a monthly drop in glass tube transmittance of 10–18%. The drop in transmittance of the glass tubes due to dust deposition can cause a large drop in plant production. For example, the author states that for a transmittance decrease from an initial value of 0.98 (clean glass condition) to a low value of 0.6, corresponding to a very dusty glass condition, production drops from 100% to 40% of the clean collector production level. Although various studies have been performed to study dust effect on the performance of different solar systems, very limited published studies on dust effects are available for parabolic trough collectors (PTC) of solar thermal power plants.

Dust is the dominant source for solar collectors deposition in CST power plants and regular cleaning is required to recover the reflectance lost caused by mirror deposition. The effective cleaning method has to address the significant characteristics of dust such as the size, distribution, density, shape, composition, chemistry and charge. Shao, et al. (2008) showed that the particle sizes range from 20 to 70 µm has short-term suspension and the long-term suspension particles must be less than 20 µm. This indicates that the particle size deposit on solar mirror should be less than 70 µm if the airborne dust is the main cause for mirror deposition according to this study. The significant characteristics of dust are site specific. The influence of dust on the reflectance of solar mirrors is a complex function of dust deposition behavior,

the accumulation rates and the exposure conditions. Effective mirror cleaning strategy is strongly dependent on dust composition, particulate size of the dust, relative humidity, rainfall, wind, temperature, and the materials of the mirrors used. Therefore, effective cleaning (method and frequency) is site specific: it depends on the dust load and the dust property at the specific site. The effect of dust particles on solar mirror surfaces is to deflect or scatter incident light rays. For concentrating solar thermal (CST) power plants, even a small deflection will cause the rays to miss the target (receiver) and not be collected (Bergeron and Freese, 1981). As a result, CST power plants will lose production. Therefore, regular mirror cleaning is essential and it forms an important part of the operation and maintenance (O&M) activities in solar thermal power plants to maintain high reflectivity of the mirrors. Effect of dust on the performance of various CST systems has been carried out by many researchers (Elminir, et al, 2006, El-Nashar, 2009 and Moharram, et al, 2013). Niknia, et al, (2012) reported that an amount of 1.5 g/m² dust could reduce the instantaneous performance of parabolic trough collectors (PTCs) up to 60% and the average performance during the dust deposition up to 37%. Experience from Spain showed that, in summer, the PTC reflectivity rapidly decreased at a rate of about 0.0025% per day during the first two weeks after washing the PTC system (Lovegrove and Stein, 2012). Strachan et al, (1993) studied the effect of dust on the degradation of heliostat efficiencies. On the average, soiling reduced mirror reflectivity of the heliostats by 6.3 and 8.8% respectively for the two types of heliostats in their study. Blackmon (1978) observed that the reflectance losses were about 7.2% and 11% for the glass and acrylic mirrors of the heliostat respectively after a storm.

Examples of the types of dust found in the work environment include:

- [1] **mineral dusts**, such as those containing free crystalline silica (e.g., as quartz), coal;
- [2] and cement dusts;
- [3] **metallic dusts**, such as lead, cadmium, nickel, and beryllium dusts;
- [4] **other chemical dusts**, e.g., many bulk chemicals and pesticides;
- [5] **organic and vegetable dusts**, such as flour, wood, cotton and tea dusts, pollens;
- [6] **biohazards**, such as viable particles, moulds and spores
- [7] Dusts are generated not only by work processes, but may also occur naturally, e.g., pollens, volcanic ashes, and sandstorms.

PARABOLIC TROUGH CONCENTRATOR

Parabolic trough solar collector usually consists of a parabolic solar energy concentrator, which reflects solar energy into an absorber. The absorber is a tube, painted with solar radiation absorbing material, located at the focal length of the concentrator, usually covered with a totally or partially vacuumed glass tube to minimize the heat losses. Typically, the concentration ratio ranges from 30 to 80, depending on the radius of the parabolic solar energy concentrator.

In general, solar collectors can be classified into three categories, Point collector (high temperature, order of 1000°C or more), line collector (intermediate temperature, order of 300°C or more) and plane collector (low temperature, order of 100°C or less). Point collectors usually consist of a parabolic mirror, which concentrates the solar radiation into a small area (point), or it

consists of many mirrors directing the solar energy into a small region. Those mirrors are usually monitored electronically. This type of collector needs a sophisticated solar tracking mechanism and usually applied in power generation, metal melting, hydrogen production, etc. The second type of the collector is the line collector, which usually consists of a parabolic cylinder that directs solar radiation into a tube (line), located at the focal length of the collector. The tube is coated with solar absorbing material and covered with a glass tube. The gap between the glass tube and tube is fully or partially evacuated from air to reduce the heat losses. Also, for better performance, the absorber is covered with selective materials and the glass tube coated with anti-reflective material. This type of collector can reach 300°C or more depending on the concentration ratio, flow rate and solar intensity. The tracking mechanism for this type of collectors is simpler than the tracking mechanism for the point collectors. It has been applied to power generation in many locations around the world. State of art reviews of the trough solar collector applications for power generation with history are given by Price et al, (2002); Fernandez-Garcia et al, (2010) and Garcia et al, (2010). Using natural convection heat tube integrated with solar trough collector experimentally investigated by Zhang et al, (2012). They claimed that their system achieved a thermal efficiency of about 38%. Application of a trough solar collector for water disinfection is given by Malato et al, (2007). Also, it is an ideal device for water desalinations, where the salted water can be flashed after passing through the collector. The evaporated water can be condensed and used as fresh water after certain processes. Flat plate type of solar collectors usually consists of a flat plate to absorb solar radiation with a glass cover. In general, the flat plate collector does not need the solar tracing mechanism. This type of collector usually operates at temperature of order of 100°C. However, for vacuumed glass tubes and if the solar intensity is high, the temperature may reach about 150°C. The more attractive feature of this type of collector is that it does not need the solar tracking mechanism. The main application of this type of collector is for domestic water and space heating. Different types of solar collectors and their applications were reviewed by Kalogirou et al, (2004).

2. PRINCIPLE OF PTC

Figure 1 shows a typical parabolic-trough collector (PTC), which is basically composed of a parabolic-trough-shaped concentrator that reflects direct solar radiation onto a receiver tube located in the focal line of the parabola (linear-focus concentration). Since the collector aperture area is bigger than the outer surface of the receiver tube, the direct solar radiation is concentrated. The concentrated radiation reaching the receiver tube heats the fluid that circulates through it, thus transforming the solar radiation into thermal energy in the form of sensible heat of the fluid. This fluid can be efficiently heated up to 400°C. The *concentration ratio* of a PTC is the ratio between the collector aperture area and the total area of the absorber tube. Usual values of the concentration ratio are about 20, although the maximum theoretical value is in the order of 70.

The heart of a PTC is its receiver tube, because the overall efficiency of the collector greatly depends on the optical and thermal properties of this element (e.g. solar absorptance, thermal emittance, thermal loss coefficient, etc.). The receiver tube of a typical PTC is composed of an inner steel pipe that is surrounded by a transparent glass pipe to reduce convective heat losses from the hot steel pipe. The steel pipe is provided with a selective coating, which has a high solar absorptivity (>90%) and low

emissivity in the infrared wavelength range (<30%), thus reducing thermal losses by radiation. Several types of coatings are commercially available for PTC. If the working temperature is below 290°C, a cheap electrically deposited black-chrome or black nickel coating can be used. For higher temperatures, sophisticated cermet coatings manufactured by physical vapour deposition (PVD) or sputtering are required to achieve a good thermal efficiency (~ 70%) of the PTC. Figure 2. shows a typical vacuum receiver pipe for PTCs.

The glass cover is connected to the steel pipe by means of metallic expansion bellows which compensate for the different thermal expansion of glass and steel when the receiver tube is working at nominal temperature. The glass-to-metal-welding used to connect the glass cover and the flexible bellows is a weak point in the receiver tube and it has to be protected from the concentrated solar radiation to avoid a high thermal and mechanical stress that could lead to the breakage of this welding. A aluminum shield is usually placed over the flexible bellows to protect the welding.

3. APPLICATION OF PTC

PTC applications can be divided into two main groups. The first and most important is Concentrated Solar Power (CSP) plants. Typical aperture widths are about 6 m, total lengths are from 100 to 150 m and geometrical concentrating ratios are between 20 and 30. Temperatures are from 300 to 400⁰ C (A. Ferna, et al. 2010). CSP plants with PTCs are connected to steam power cycles both directly and indirectly. Although the most famous example of CSP plants is the SEGS plants in the United States, a number of projects are currently under development or construction worldwide. The other group of applications requires temperatures between 100 and 250⁰ C. These applications are mainly industrial process heat (IPH), low-temperature heat demand with high consumption rates (domestic hot water), DHW, space heating and swimming pool heating) and heat-driven refrigeration and cooling. Typical aperture widths are between 1 and 3 m, total lengths vary between 2 and 10 m and geometrical concentrating ratios are between 15 and 20. Most of the facilities are located in the United States, although some have recently been built in other countries. There are also some projects and facilities for other applications such as pumping irrigation water, desalination and detoxification.

3.1. CSP plants

Appropriate site locations for CSP plants in the world include the North African Desert, the Arabian Peninsula, major portions of India, central and western Australia, the high plateaus of the Andean states, north eastern Brazil, northern Mexico and, of course, the United States Southwest. Promising site locations in Europe are found in southern Spain and several Mediterranean islands (Navap, et al.1996). All commercial CSP plants are north-south oriented, because this maximizes the amount of power produced along the year. The higher the latitude, the more necessary this becomes. There are two ways to integrate a PTC solar field in a steam turbine power plant, directly, that is, generating steam in the solar field (DSG technology), or indirectly, by heating thermal oil in the solar field and using it to generate steam in a heat exchanger (HTF technology). In both cases, solar fields can drive all types of steam turbine power plant

cycles. Another interesting option is incorporation of a solar system in a combined cycle (CC), called Integrated Solar Combined-Cycle System (ISCCS), in which two different thermodynamic cycles, a steam-turbine Rankine cycle and gas-turbine Brayton cycle, are combined in a single system through a Heat Recovery Steam Generator (HRSG). The general concept is an oversized steam turbine, using solar heat for steam generation and gas turbine waste heat for preheating and superheating steam (Price H, et al.2003).

3.2 Industrial process heat (IHP)

The key sectors are food and beverages including wine, textile, transport equipment, metal and plastic treatment, and chemicals. And the most suitable processes are cleaning, drying, evaporation and distillation, blanching, pasteurisation, sterilisation, cooking, melting, painting, and surface treatment (Vannoni C, et al.2008). Of the total energy used by industry, a major portion, approx.45–65%, is used for direct application of industrial process heat in the preparation and treatment of goods. The thermal energy demand for IPH is below 300⁰C, and 37.2% of the total IPH demand is in the range of 92–204⁰C (Thomas A,1992).According to the ECOHEATCOOL study done in 32 countries, 27% of the thermal energy demand for IPH is between 100–400⁰C (Werner S, et al.2006). For that reason, one of the most important applications of a small-sized PTC is IPH.

3.3 Domestic hot water and space heating

One of the most widespread applications of solar thermal energy is hot water production. According to an IEA report for 2006, solar thermal collector capacity in operation worldwide was about 127.8 GWth (182.5 million m²), most of it domestic, both for DHW (kitchen, shower, laundry and sanitation facilities) and space heating (Werner S, et al.2007). The temperatures at which energy is required by these applications are below100⁰C. Therefore, conventional solar collectors with suitable efficiencies (FPC, CPC or evacuated tube collectors) could be employed. However, when a large amount of hot water is demanded, a large collection area, which sometimes becomes excessive, must be installed. In this case, PTCs might be of interest, because they supply thermal energy at higher temperatures than those required by the load and, therefore, higher demands can be covered by mixing the hot solar fluid with another cooler. Examples of applications with high hot water consumption rates are large swimming-pool heating systems, and DHW and space heating for large buildings, such as industrial buildings, factories, hospitals, educational centres, sport facilities, government buildings, prisons, airports, bus and train stations, etc. In most situations, a minimum hot water consumption of about 1900 l/day would be needed to make a PTC system, which is more effective for large, 7-day-a-week hot water users, to be feasible (Collins T, et al.2000).

The advantages of PTCs over the solar collectors traditionally used in water heating facilities are their lower thermal losses and, therefore, higher efficiency at the higher working temperatures reached, smaller collecting surface for a given power requirement, and no risk of reaching dangerous stagnation temperatures, since in that case, a control system sends the collectors into off-focus position. The disadvantages of PTCs are that its solar tracking system increases installation and maintenance costs, and the need to clean their components also increases maintenance costs.

3.4 Air-conditioning and refrigeration

PTC facilities connected to high-consumption water-heating systems The Coefficient of Performance (COP) is higher for a LiBr – H₂O double-effect than for a single-effect absorption chiller, but it requires thermal energy at temperatures of 140-160⁰C (HENNING HM. 2007), at which performance of conventional collectors is not good enough. As PTCs are highly efficient at these temperatures, the combination of these two systems is of great interest. Connection of NH₃– H₂O absorption chillers to a solar system requires solar collectors able to work efficiently at temperatures above 950 C, such as the PTCs or high-efficiency stationary collectors. Air-conditioning and refrigeration facilities driven by a PTC solar field are still infrequent. However, several test facilities using this technology have appeared in the literature during the last 50 years.

3.5 Irrigation water

To make use of PTCs for pumping irrigation water, the thermal energy Although pumping irrigation water is not the most frequent application of PTCs, there are several examples of this kind of facility produced by the solar field must be converted into mechanical energy for driving the water pump. This application is of special interest in isolated zones and rural areas, where the grid is far away and fuel transport is economically restrictive. On an experimental level, a 1-kW water pump was installed and assessed at the UNAM in 1976. The pump was driven by a 12-m² PTC field with DSG in the absorber tube. Unfortunately, solar system global efficiency was found to be only 2%. This poor result led to a new project, without satisfactory improvement. A feasibility study conducted by the University of Arizona (United States) in 1975–1976 found that lower cost, improved solar devices, improved energy use management and availability of modestly priced capital were the key engineering and economic factors preventing successful marketing and use of solar-powered pumping plants.

3.6 Desalination

The problem of an adequate potable water supply may well become one of the most serious challenges facing the world in this century. Solar desalination is one of the most promising technologies for confronting this problem. The PTC's suitability for solar desalination has been studied in several different types of desalination, such as Reverse Osmosis (RO), Multi-Effect Distillation (MED) and Multi-Stage Flash (MSF). A few commercial or pilot plants were implemented. The widespread presence of hazardous organic chemical compounds, mainly in water but also in air, has motivated interest in finding alternative environmentally friendly solutions for the treatment and/or removal of these compounds. Concentrated solar energy augments the detoxification process, because more high-energy photons are projected directly into the stream of water or air. Consequently, there are several examples of solar detoxification using a solar concentrating system. When the solar concentrating system selected is a PTC, a transparent tube (usually glass) is placed in the focal line of the reflector instead of the metal absorber tube, as photo-reactor.

4. STATUS OF PARABOLIC DISH SOLAR CONCENTRATORS IN INDIA

In India, Dish Technology to harness solar energy for generating electricity is yet to get established. However, pioneering work on use of Scheffler Dish for SOLAR COOKING was done by Shree

Deepak Gadhia of Gadhia Solar, Valsad, Gujarat to overcome the shortcomings of box type solar cooker (could only boil and roast the food) and mini concentrating dish type solar cookers (cumbersome outdoor usage). It was introduced for community cooking about two decades back and was successfully used for other applications like desalination, food processing, Gadhia Solar supplied and installed several Solar steam cooking systems of different sizes ranging to cook from 500 to 40,000 people and for different user groups starting with temples and ashrams and Army, Hospitals, Industrial Canteens, Hostels etc. (Deepak Gadhia, 2009)

Parabolic collectors using thermic fluid as working medium were developed and are successfully working for cooking at Muni Seva Ashram, Goraj, Gujarat to overcome the limitations of steam as working medium – better thermal storage, transfer and control .

Prototype design of solar parabolic dish collector with truncated cone shaped helical coiled receiver made up of copper, coated with nickel chrome at focal point. Instantaneous efficiency of 63.9% has been achieved in this system, which can be used for heating boiler feed water, laundry applications and other steam generation applications. (Atul Sagade, et al.2012).

Development of ARUN brand of SCS for pasteurization of milk at Mahanand Dairy in Latur, Maharashtra.

A parabolic dish collector is developed from low cost technology and tested outdoors. The absorber, made of aluminium alloys and coated with black paint, is placed on the focal receiver. The calculated overall heat transfer co-efficient varies from 130 to 180 W/m²K for actual climate conditions at Tiruchirappalli, India. The thermal efficiency of collector is found to be 60% and the cost is minimized to half the cost of a collector that is available in the market with same specifications. (M.Eswaramoorthy 2012) The Megawatt System (MWS Solar Dish Concentrator) - A High Efficiency 2-Axis Tracking Concentrator: Megawatt is a Co. in Delhi, which has developed indigenous parabolic dish type collector of 90m² area. Prototype has been built and is being tested at Solar Energy Centre of Ministry of New and Renewable Energy (MNRE). Now, it is proposed that this technology undergoes field testing under R & D support of MNRE for industrial heating applications.

Universal Medicap Ltd. (UML) is an industry having 6 x 106 kCal biomass heated thermic fluid heating boiler. It uses thermic fluid heat at 195⁰C in its process, which returns back to the boiler at 185⁰C. 16 MWS dishes of 90m² will be installed to produce heat during day time using solar concentrators and the existing boiler will be used as back-up.

The dish concentrator has an effective area of 90m², has two-axes tracking and is a solid paraboloid concentrator that always faces the Sun with cavity absorber at point focus having thermal output capacity ranging up to 63 kWth and an operating temperature up to 500 with various working fluids including hot water, pressurized water, low pressure steam, thermic fluid. This is integrated with user-end thermal circuit for saving existing fuel. Components with ISI mark or reputed suppliers will be used wherever applicable and available.

System life: The Concentrating Solar Collector system, M90 is designed for 30 years life under standard operating conditions and regular maintenance as per the manufacturer's instructions.

System De-rating: System performance derating is expected up to 1% per annum for initial 2 to 3 years and then, about 0.5% to 1% per annum depending on the site specific conditions. The author had visited UML to study the system there and to see the

progress of the work. The MWS Solar Dish systems are under installation.

ACKNOWLEDGMENTS

The authors would like to acknowledge the efforts and contributions of the many individuals, corporations, universities, laboratories, or others who have directly or indirectly contributed to this article.

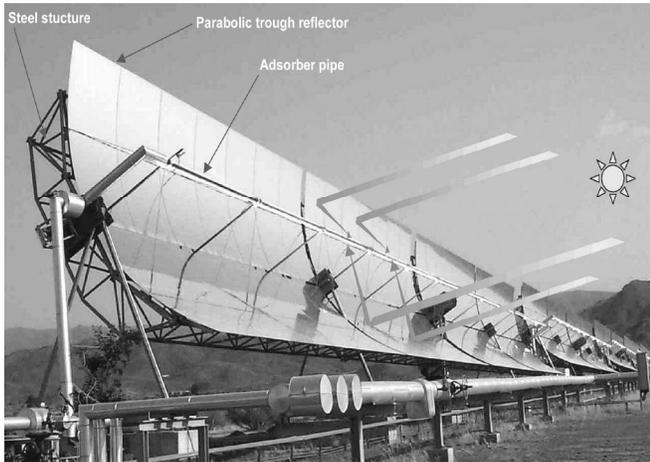


Fig. 1 Parabolic trough source: PSA. Collector.

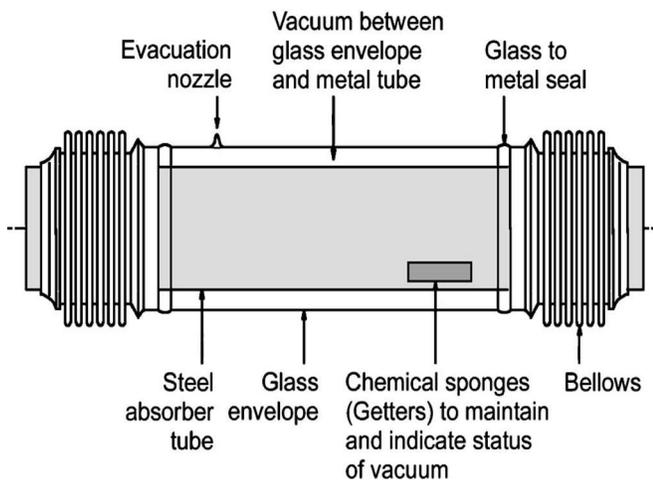


Fig. 2 Heat collection element (HCE) (source: Flabeg Solar International)

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