A review of Parabolic Trough Collector (PTC): Application and Performance Comparison

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Abstract: - In these circumstances, we must search forward to 'green energy' for power generation. Green energy means environment-friendly and non-polluting energy (inclusive of solar, biomass, wind, tidal, etc.). Concentrated Solar Power (CSP) generation is one of the maximum promising candidates for mitigating the destiny power crisis. The extracted energy from CSP technology may be very clean, dependable, and environmentally friendly. A review of the parabolic trough collector (PTC) which is one of the CSP technology with a focus on the components, the working principle, and thermal properties of the parabolic trough collector. Also, this study explains the parabolic trough power plants with tracking systems, from the other hand, evaluates the effects of using many types of reflectors and multi kinds of working fluids on the performance of the parabolic trough collector (PTC), in addition of that study presents the use of PTCs in many applications.

Key-Words: - Solar energy, Parabolic Trough Collector, Tracking system, Cavity receiver, Concentrated Solar Power, Heat transfer fluid

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1 Introduction

Industrial and commercial energy demand has risen sharply in current decades. Most energy is generated by using fossil fuel technologies. Which will increase pollutant emissions into the atmosphere, contributing to global warming and irritating human health, [1]. Solar energy is one of the inexperienced energy sources that can be used to lessen fossil fuel intake to satisfy commercial and commercial needs. In addition, the energy cost of solar photovoltaic (PV) and solar thermal energy has tended to lower with the development of electrical performance in current years, [1], [2], [3], [4]. Quantities of technology are utilized in industry to transform sun energy into warmness and electricity. These strategies are categorized and shown in Figure 1. Solar technology may be categorized as passive or active relying upon the sort of system, with active technology requiring external components consisting of pumps or digital controls to transform the energy. The sort of energy that enter the system is the energy generated immediately from the solar panel system utilized in industrial process and can be thermal or non-thermal. The sort of solar collector is determined with the aid of using evaluating the whole radiation added to the receiving region concentration is executed by the usage of mirrors or lenses to reflect or refract solar radiation from a massive area (collection) to a smaller area (receiver), [1], [5].

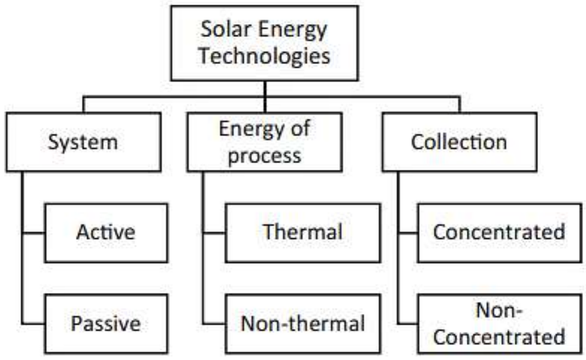

Figure 1. Classification of solar energy technologies [1].

Generating solar energy to generate electricity can be done through technologies. While the conversion of solar energy into electricity from PV cells depends on diffused and direct solar irradiance (DNI), CSP systems simply depend on DNI (which accounts for about 80% of total solar irradiance), [6]. CSP technologies are based on the following concentration technologies: compounded parabolic collector, linear Fresnel glass, solar dish, power tower, and parabolic trough collector. Among these technologies, the Parabolic Trough (PTC) is crucial from an isolation point of view and the profitable prospects (since they represent 85% of the total global capacity of the CSP factory). The functional principle of this concentration technology has been explained in detail in various literary works. Technological review of experimental inventions in PTC glass systems showed that optimization of all PTC factors can lead to design costs of 75-100$/m^2. PTC is generally used for high-temperature operation, hence its wide use in solar thermal energy systems [5,7].

The concentration factor is parabolic trough systems, which use U-formed mirrors to concentrate the maximum of the thermal energy acquired from the solar onto a receiver; referred to as a heat sink or collector as shown in Figure 2. The letter is in the shape of the lengthy tube in the center at the focal line of the parabolic reflector. This is full of a thermally conductive fluid that keeps heat well, along with artificial oil or molten salt. The liquid absorbs the heat from the reflected rays of the sun and becomes superheated, achieving a temperature of approximately 390℃. It then is going through a heat exchanger to heat the water, which the water circulates, turning it into steam. The steam will extend right into a standard steam turbine, which spins the generator and generates electricity, [1], [2], [4].

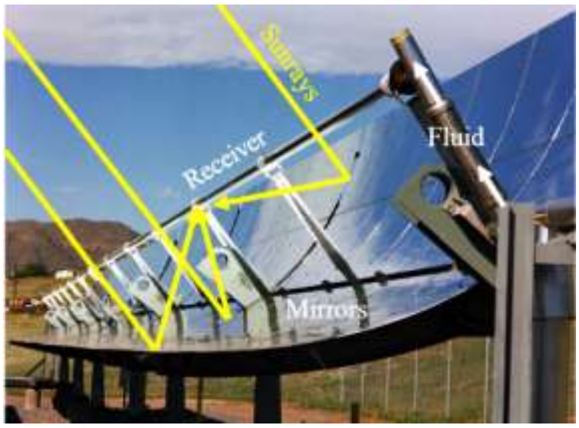

Figure 2: The main parts of the parabolic trough collector, [1].

After driving the turbine, the system is recovered and condensed, and recycled again and again in the power generation system. The same applies to the working medium, which is also recovered and reused after releasing heat into the water, [2]. A typical solar collector array consists of several parallel rows of parabolic troughs arranged and oriented along a north-south axis to track the east-west movement of the sun during the day. This positioning prolongs the exposure time of the solar reflector to solar radiation and ensures that the sun is continuously focused on the absorber tube. The coating on the latter allows maximum absorption of solar radiation and a vacuum glass envelope is used around the tube. This reduces heat loss to the environment, [2], [5].

1.1. Components of PTC

Parabolic trough solar collectors embody a parabolic reflector. This parabolic sheet can be made through the way of the method of bending a sheet to a parabolic shape. The sheet needs to be highly reflective and constructed as a lengthy parabolic reflecting mirror. In this type, the solar collector needs to be pointed straight away into the solar, and due to the fact, the solar radiation is parallel, all slight waves can reflect on focal from all components of the trough as established in Figure 3. This consequently motivates the pipe to warm the temperature up. The parabolic trough solar collectors consist of various parts; parabolic reflectors, receiver tube, guide structure, and tracking system, [6], [7].

Figure 3. General conceptual form of a parabolic trough collector (PTC), [6]. The receiver tube which is located on the focal line of the parabolic trough reflective surface Figure 4 can transfer the absorbed solar power to the fluid-flowing interior. The tube commonly consists of layers to make it more efficient, [6], [8]. An outer layer is created from glass this is apparent and antireflection to solar radiation and might lessen convection and radiation losses and hold electricity and transmittance below immoderate temperatures, further to an inner layer of copper or selective blackened nickel which, the interior of it, circulates the warm temperature transfer fluid, [9].

Figure 4. Details of parabolic trough solar collector, [6]. Coating of the internal layer makes it able to lower thermal radiation losses via way of means of soaking up the fast period sun radiation and additionally low emissivity for lengthy wave strength spectrum. The tool additionally consists of one-axis sun monitoring to align the trough with daylight and make certain the most quantity of radiation might be meditated at the focal line, [6], [7], [8], [9], [10]. Parabolic troughs are turned around to tune the Sun because of its actions throughout the sky every day from morning to night. This is one of the important sections that may grow the performance and maximize the sun's warmth gain. The essential phase of a parabolic trough sun collector is the warmth switch fluid flowing within the tube, which is often a combination of water or thermal oil and different components like nanofluids which beautify thermal conduction. The fluid is pumped thru the tube and absorbs the sun's warmth

achieving temperatures of over 200 °C. The warm water is then directed to a warmth exchanger which may warm a garage tank for distinct applications, [11], [12], [13]. As referred to above, PTC is utilized on big scales as sun-concentrating technology. Nanofluid-based concentrating parabolic sun collectors (NCPSC) offer higher strength absorption and conductive warmth switch in comparison with traditional parabolic trough concentrators. Recently, using nanofluids because the running fluid in parabolic trough sun collectors (PTC) is getting greater common, [11], [14].

1.2. Working principle

Parabolic trough plants have massive arrays of solar collectors that function as a reflective face twisted in the form of a parabola (or trough) to concentrate sun onto a receiver pipe Figure 5. A heat transfer fluid (HTF), which is a regular artificial oil painting, flows via the receiver and is hotted through the absorber solar. This hot fluid is used to result in a brume that turns a conventional brume, [5], [11].

Wet, dry, or cold-blooded cooling may be used to cool and condense the spent brume; the choice will affect water consumption, cycle performance, and cost. A parabolic trough manufacturing unit consists of the subsequent subsystems solar collector field, receiver and related HTF system, power block, thermal storehouse (voluntary), reactionary-fired backup, and essential ancillary installations, [11] as shown in Figure 5.

Figure 5. Simplified sketch of using a parabolic trough in the power plant, [11]. The reflector is equipped with a 0.85mm silver coated mirror for the back and 4mm high transmittance glass on the top. You will receive High reflectivity around 93.5%. The diameter of a stainless-steel tube is 70mm with a high-temperature absorption liner surrounded by a 115mm diameter vacuum glass tube Anti-reflective coating covering the receiver tube, [14]. The tube contains HTF (synthetic oil) heated to 400°C by DNI from solar energy. Working diagram of a PTC power station in. During a sunny day, HTF in the tube is heated by DNI and goes to the steam power plant, then preheats water, and generates steam in the steam generator. It also superheats the vapor, then releases the heat and circulates back to the SCF to complete the cycle again, [15].

The system keeps running at nighttime or on cloudy days and is provided with the foremost standard storage system referred to as the "two-tank molten Salt Storage System". It consists of a hot tank, a chilly tank, and a heat exchanger. Throughout the day, a part of the heated HTF is distributed to the heat exchanger and pumps cold molten salt. Within the heat exchanger, the cold molten salt receives thermal energy from the HTF and is kept hot Armor. At nighttime or on cloudy days, the recent molten salt returns its thermal energy to the cold HTF that is employed to come up with steam. An annual capability utilization of 70% through the utilization of the thermal storage system. The solar thermal station will be hybridized with a fuel backup system to supply peak masses on sunny days or continue performing on cloudy days, [16].

1.3. Tracing system

Parabolic Trough Collectors (PTCs) track the position of the sun throughout the day. In order to collect ID efficiently, a drive motor is used. Two different methods are used to track the sun:
The first method uses photocell sensors on the PTC that can track the position of the sun.

Second method: involves astronomical algorithms. Using very precise mathematical algorithms, calculate every second of the day the altitude and azimuth of the sun and the angular position of the axis of rotation with electronic devices [14]. Figure 6 shows the East-West tracking of a parabolic trough collector’s plant. Figure 6. East-West tracking of a parabolic trough collector, [15].

2 Properties of PTC

2.1 Thermal properties of the examined nanofluids

The trackers pay attention to the daylight efficaciously and transfer transformed warmness to a running fluid. This development is steady-state, and running fluid within the annular vicinity with excessive precise warmth is preferred. Standard Newtonian painting fluids represent water, melted salt, and air flowing through the collectors. These fluids have bad thermo physical right ties, hence; decreasing the performance of the collectors. The foremost parameter in growing PTSC performance is geometry modeling, running fluid selection, and receiver tube cloth. Molten salts had been used as a running fluid yielding terrific thermal con ductility, reduced corrosion, and preventative with inside the additives of the receiver tube. The charge of absorption factor is likewise terribly excessive within the UV-seen vicinity. Furthermore, length and completely different right ties can also be fine-tuned at the atomic stage backside to the maximum amount to get a much better conductive phase. The programs of Nanofluids have extended with the growth of their popularity, and their use in clinical devices, solar energy, fuel cells, and heat exchangers had been explored. Nanofluids have a high-notch capability in PTSCs as they could assist extensively discount within the fee of the device. Selective coatings of black chrome or black nickel are used for non-evacuated receivers due to their financial motives and ease of production. The foremost amount of the receiver tube is 5 m due to production constraints; therefore, the tubes are con nested in an assortment to achieve the favored amount of PTC. The performance of PTSCs is ill with the geometric parameters and also the materials. Semi-finite analytical formula become mentioned within the literature, which depicts that the semi-finite technique concerns distinctive integration, geometrical and optical traits aren't modified effortlessly via the approach of means of the usage of this system. These methods are used for figuring out the performance, hotness flux, and absorbent tube material in various research. In another study, an improvement of up to 4.3% within the PTC overall performance device the usage of oil/Al_2O_3 Nanofluid. The use of hybrid Nanofluids with twin traits is receiving a reputation over a previous couple of years. Hybrid Nanofluid is synthesized via a manner of means of splitting nanoparticles (NP) types within the host fluid. The exploitation of this generation in sun collector applications is scarce owing to several troubles in expressing the thermo bodily traits of hybrid, [17], [18].

The first step of the nanofluids research is to calculate the thermal houses of the tested Nanofluids. The Nanofluid density (ρ_{nf}) is calculated relying upon the classical shape of the heterogeneous combination. Whereas, the precise warmth capacity (Cp_{nf}) is derived from the thermal equilibrium among the stable debris and its surrounding base fluid. Nevertheless, numerous fashions are in use for figuring out the nanofluid viscosity and thermal conductivity. The version proposed through Ref. [50] is used for the dynamic viscosity (μ_{nf}) which has been derived primarily based totally on the experimental statistics wherein they measured the viscosity of Al_2O_3-water. For the thermal conductivity (k_{nf}). Table 2 shows the thermo-physical properties of fluid materials, [17], [19].

Table 2: The thermo-physical properties of fluid materials [17].

Properties	Water with Al_2O_3 (0.01% conc.)	Water with CuO (0.01% conc.)	Glass
Density (kg/m^3)	1029.7	1054	2200
Specific heat (kJ/kg-K)	4.05507	3.965	910
Thermal conductivity (W/m.k)	1.029	0.6870	1.75
Kinematic viscosity (m^2/s)	0.405 x 10^{-6}	0.396 x 10^{-6}	-
Dynamic Viscosity (kg/m.s)	4.169 x 10^{-4}	4.169 x 10^{-4}	-

There are several approaches via the method of means of the research relating to the utility of nanofluids in PTC is categorified: the primary class could also be performed on the kinds of nanoparticles used in research. The nanoparticle may be classified into principal sections:

1. Metallic nanoparticles consisting of iron, Copper, Zinc, and Aluminum.
2. Non-metal nanoparticles such as SiO_2, TiO_2, Fe_2O_3, ZnO, CeO_2, multiwall carbon nanotubes (MWCNT), and carbon nanotubes (CNT), [6].

2.2 Insulation and Absorption

In general, higher operational temperatures in solar collectors result in larger cycle efficiencies, however conjointly increase thermal losses that cut back the gathering efficiency. Such a state of affairs represents a good potential for the improvement of solar collectors via style optimization, [20].

PTC structures encompass an absorber, typically a metal tube, wherein the electricity is transferred to an operating fluid, a concentric glass envelope, an annular air hole or vacuum to lessen warmth losses, and a sun monitoring mechanism, [21]. PTCs can generate vapor for use at once in an electricity cycle and also, and they could warmth thermal oil or natural fluids to circuitously generate vapor in a warmth exchanger. Higher working temperatures and electricity technology capacities may be received through the use of CR collectors. Two varieties of receivers for sun tower structures are normally used: outside and hollow space receivers [22], [23]. The first kind includes a chain of panels of tubes organized in a cylindrical layout. Usually, darkened metallic tubes were used with steam and molten salt for high working temperatures that are viable for tubular receivers working with gas Figure 7 and Table 3 show a sketch of the evacuated receiver and some of the working fluids and the operation temperatures, respectively.

Cavity receivers, on the other hand, have the absorbing floor or extent interior of an insulated compartment to supply some stage of insulation with the surroundings. Each sort of receiver could also be designed to collect sun electricity on a floor or extent via the method of means of the employment of porous substances resistant to excessive temperatures. Usually, outside receivers operate at higher temperatures, and also the heliostat discipline may be accommodated across the tower. On the opposite hand, the insulation in hollow receivers will cause better efficiencies due to decrease heat losses; however, its geometry restricts the lodging of the heliostats during a part of azimuthal angles, [20], [21], [22].

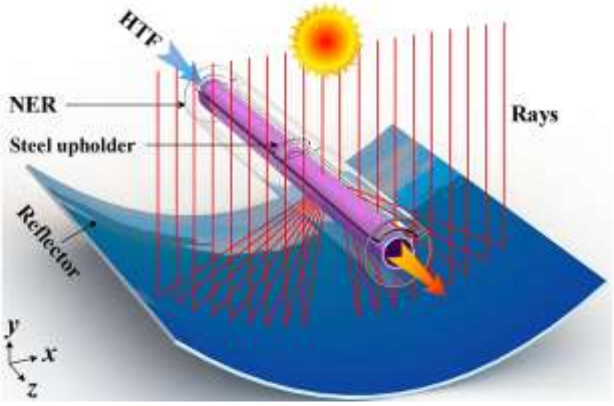

Figure 7. A sketch of the evacuated receiver [22].

Table 3: Some of the working fluids and operating temperatures.

Working fluid	Operation temperature
Water, oil and natural compounds	100°C-400°C
Molten salts	500°C-600°C
Gasses	900°C

2.3 Reflector

The main function of mirrors is to reflect solar radiation and concentrate it on the receiver. Mirrors are made from high-reflective material -aluminum or silver-with substrates and superstrates that protect the reflective layer from corrosion or abrasion simply so long life is achieved. Table 4 represents the primary varieties of mirrors applied in applications. Silvered glass mirrors, anodized sheet aluminum (sometimes covered with a polymer film), aluminized polymers, and silvered polymer films are the most normally used materials for production, [1]. Figure 8 illustrates the relationships between the reflectance of the reflectors and the cost.

Table 4: Types of mirrors with coatings, [1].

Type	Description	Typical Hemispherical reflectance	Cost ($/m^2)	Properties
Silvered glass reflector	-A copper guide (recently, it was replaced by a water–insulation layer). -Protected by paint coatings in the back, with a silvered–based coating. - High transmittance low reflective glass as cover (superstrate, a low–iron glass).	Up to 0.96	20-30	-high corrosion resistance -commercially -heavy and brittle
Aluminized reflectors	Polished aluminium layer with an aluminium-based reflective layer and oxide enhancing layer.	Up to 0.9	< 20	-lightweight and flexible -cheap -High variability and durability -more applicable for low-enthalpy concentrators -low durability in polluted locations
Silvered polymer reflectors	Silvered reflective layer coated with a flexible polymer and a very thin UV-screening film superstrate.	0.9-0.95	20-30	-under development -less expensive -high reflectance and lightweight -higher flexibility -long term performance needs to be proven

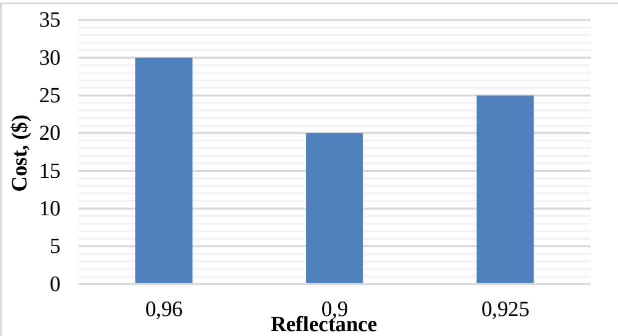

Figure 8. Reflectance vs. cost.

Curved glass reflection with the silver coating is normally used as a reflector and that is the most critical and highly-priced component of the PTC system. Higher the reflectivity of the reflector makes it more costly. To lessen the cost of the PTC system few alternatives are also under development and are in the applications also. Aluminum foil, anodized aluminum sheets, and silver-covered PVC sheets, [24], [25], [26], [27], [28], [29].

Many researchers worked on fiberglass-strengthened plastic protected with aluminium foil as a trough and performed a reflectivity of 0.86. Reflectors fabricated from black proxy material and protected mild steel performance with and without glass cover respectively. They performed at 81.70°C with the resource of the use of using 10-micron thick aluminium foil as a reflector and copper absorber [29,30]. They have superior FRP parabolic trough collectors with SLARFLEX foil having an easy 90° rim angle and 0.974 reflectance. Significant optical parameters like the reflectivity of the mirror, the absorptivity of the receiver, and the transmissivity of the glass cover are crucial to achieving the maintained overall performance of the system, [30], [31], [32]. Figure 9 indicates the Structure of the single-layer monolithic glass mirror.

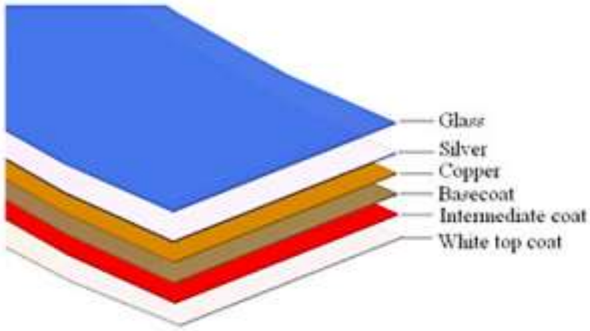

Figure 9. Structure of the single-layer monolithic glass mirror [28].

2.4. Thermic fluids and nanoparticles

Solar heat is required to be transferred from receiver to quit using, caloric fluids are best medium and wide being used in PTC. Artificial oils, water, or liquefied salt have been usually used to enhance the performance and movement of heat. Nanofluid trash had been applicable effectively via the manner of means of researchers worldwide. Figure 10 shows a schematic illustration of molten salt completely totally thermic fluid device utilized in a sun tower device, cold salt at 290°C is circulated in the device and het up to 565°C in the receiver via way of means of solar mirrored rays from heliostat also it is utilized in PTCs, [33].

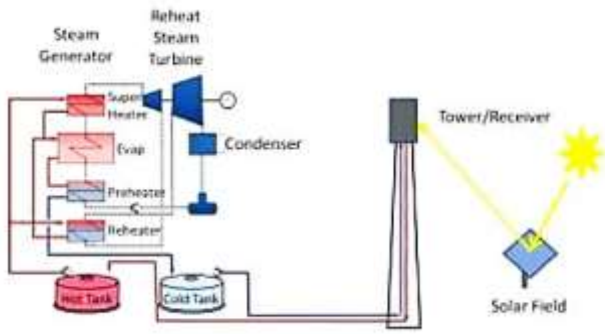

Figure 10. Flow diagram of Molten Salt as Thermal fluid [27].

Six one-of-a-kind Nanoparticles: Copper, Copper oxide, Ferric oxide), Titanium dioxide, Aluminum oxide, and Silicon dioxide) brought with oil, and advised that 6% Copper-Cu answer offers the most thermal performance of 74%. An extensive variety of materials on Silicon Dioxide and Water, Aluminum Oxide or artificial oil, MWCNT Multi-walled carbon nanotubes or mineral oil, and fuel line-based Nanofluids. Mineral oil answer can enhance performance by as much as 5% as compared to natural oil as Thermic fluid. Molten salt as warmth transfer fluid and done at most 520 °C, [28].

Al_2O_3 with water and carried out 28% increase in warmness transfer, all this be simulated mathematically for compelled convection heat transfer, eddy cutting-edge glide is used with Nanofluid in the PTC receiver. Furthermore, the addition of 3% nanoparticles of CuO to water led to a 35% development in heat transfer, [30], [34], [35]. Figure 11 illustrates the efficiency of addition nanoparticles.

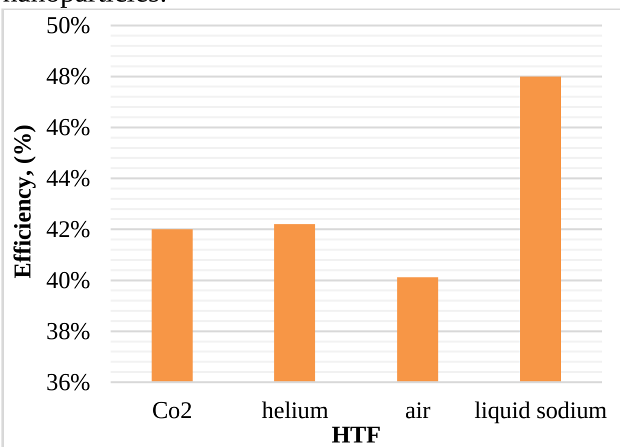

Figure 11. The efficiency of different HTF (Co_2, helium, air, and liquid sodium).

3 Improve the performance of PTC

There are numerous strategies to enhance the overall performance and the performance of the PTC as the usage of geometrical adjustments and Nanofluids in PTC. As compared to the usage of inner fins and Nanofluids. The 0.76% thermal performance improvement by using syltherm 800/CuO, 1.10% whilst using inner fins. The mixture of these methods is that the nice need with 1.54% thermal performance enhancements. regarding the pumping paintings increase, the Nanofluids lead to 25% better pumping work, the inner fins to 100%, even as the mixture to 150%. However, the pumping paintings take low values in all instances so it isn't continuously an important difficulty of the utility of the thermal enhancement strategies in PTC. As compared to the usage of inner fins, connection branching tube, and twisted tape inserts with natural oil and oil/Al_2O_3. The usage of the converging-diverging tube is a nice approach that enhances the exergy overall performance of 0.65% with pure oil and 0.73% with the Nanofluid as shown in Figure 12, [31].

The combination of Nanofluids with geometrical changes appears to be an exceptional technique. The pressure drop with Nanofluids is usually reduced compared to the other techniques. In the closing years, several methods were tested for enhancing the thermal overall performance of PTCs. the elemental aim of these strategies is to enhance the warmth switch situations among absorbent and fluid, growing the physical phenomenon internal the waft in specific ways. Moreover, the boom in the thermal performance results in a decrease in receiver temperature and to decrease in temperature gradients on it, a reality that reduces the viable deformation problems. There is much research that is targeted at the investigation of different operational fluids, such as Nanofluids for enhancing the thermal overall performance of PTCs, [29], [31].

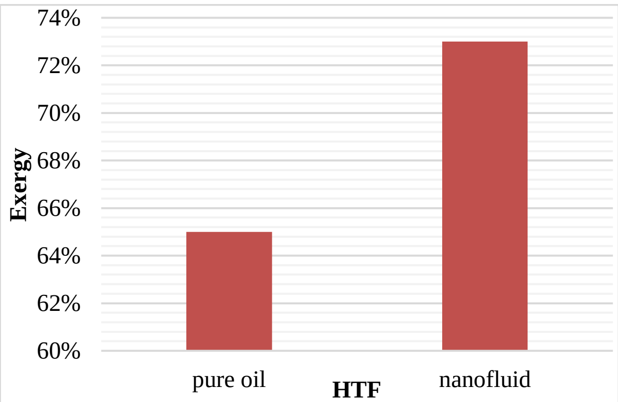

Figure 12. The exergy performance using pure oil and nanofluid.

Many strategies had been tested, inclusive of using inserts in the flow and the change of the absorber floor with fins or dimples which act as passive vortexes in the float. Many types of item inserts had been tested in PTCs, [27], [32], which are illustrated in Figure 13.

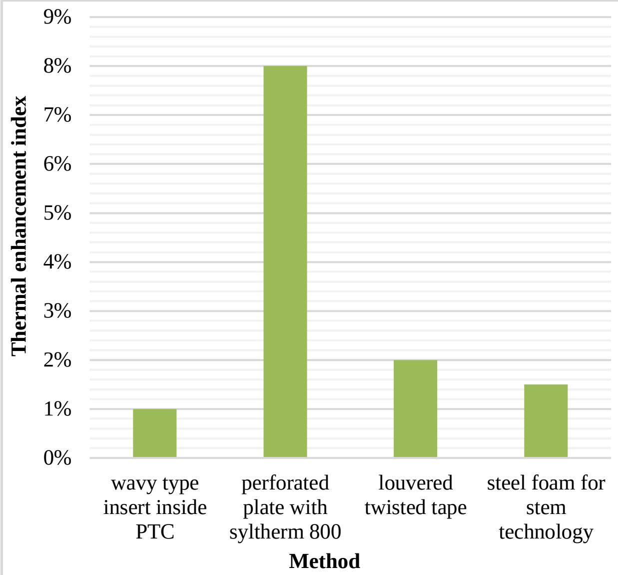

Figure 13. Thermal enhancement index by using most popular methods.

The use of louvered twisted-tape inserts with thermal oil and they found the thermal enhancement index to be 2.67 for Reynolds number equal to 5000 and to be close to 1.4 for Reynolds number equal to 25,000. The use of twisted tape inserts has been investigated by many researchers [26]. More specifically, they said using those items in low float rates and for twist ratio near, performed a comparative evaluation among these ways:

1- Helical coil-wire inserts
2- Twisted tape inserts
3- Dimpled tube.
4- Porous foam interior a PTC for operation with air, carbon dioxide, and helium.

They sooner or later observed that the dimpled absorber is the satisfactory answer to many of the tested, [26], [27], [28], [29], [30].

4. Applications of PTC

Uses of PTC include domestic heating, desalination, refrigeration systems, industrial heat, power plants, pumping irrigation water, the PV system, and solar chemistry. When used for water desalination, a thermal energy storage device must be used for non-stop operation. A water tank may be used for the very best and most inexpensive SHS medium. The size of the tank will depend on the working temperature and the capability of production, [23], [31]. Figure 14 shows the use of PTC in the solar cell.

Figure 14. A parabolic trough with solar cells [33].

5. Conclusion

The current reputation of PTC technology is supplied in this review. The design and structure of (PTC), the substances used, thermal properties, applicable facts approximately the reliability of every component, and the design factors of collectors are mentioned. Applications, common techniques utilized in energy conversion, and information on the application of parabolic trough collectors (PTCs) also are supplied. An exposition of techniques to assess the overall performance of PTC systems, describing the experimental techniques for trying out thermal and optical overall performance also are supplied.

The main ideas stand out in our present study. First, it is essential to mention the relevance and ability of this technology in the energy marketplace and the industry because the PTC is generally used for high-temperature operations, hence, its wide operation in solar thermal power systems. The main highlights are the effect that the PTC structures and components (design of reflector and the working fluids used inside the receiver) have on energy technology the use of sun resources, and their applicability in general-reason thermal applications. It is likewise essential to mention the importance of using solar systems and thermal systems instead of conventional power to mitigate GHG emissions. Second, it's essential to mention approximately the effect of substances on cost and performance. Finally, some of the methods used to improve the efficiency and performance of the system are mentioned in this study.

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