

# Thermal performance of Parabolic Trough Solar Collector

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**ABSTRACT:** The research progress of numerical simulation of parabolic trough solar collector was introduced. Especially the numerical simulation studies of the internal flow field in the collector tube and the external flow field of the concentrator were reviewed. In the study of the internal flow field in the collector tube, the type of heat transfer fluids and the characteristics of optical concentration have a significant effect on the heat collection performance and thermal stress distribution, especially in the water/steam medium heat collection loop. The unique gas-liquid two phase flow superposition of the non-uniform heat flux distribution outside the tube may lead to serious thermal stress bending deformation of the collector tube. In the study of the external flow field of the concentrator, due to the high actual wind speed and the low structural strength of the ultra-thin lens, the concentrator is subjected to wind load deformation, resulting in the loss of optical efficiency, and even leading to the failure of the parabolic trough collector structure, which directly affects the normal operation of the whole collector field.

**Keywords:** carbon neutrality, solar-thermal technology, parabolic trough collector



## 1. INTRODUCTION

In the context of carbon neutrality, countries around the world are making unremitting efforts to provide clean energy [1-2]. Solar energy resources are inexhaustible and inexhaustible, and it has always been a hot spot in the field of clean energy research. Solar thermal technology is one of the important forms of solar energy utilization technology [3], of which the parabolic trough (hereinafter referred to as "trough") solar thermal technology has the highest degree of commercialization [4] and is the most widely used. At present, in the research of trough solar thermal technology, the main goal is to further improve the photo thermal conversion efficiency of trough collectors, including the use of different types of heat transfer fluids (HTF) and the optimization of collector structures, etc. . With the rapid development of computer technology, numerical simulation has become a research method that keeps pace with experiment and theory, and has played an important role in the research of trough solar thermal technology. Cheng et al. [5] provided a new method for numerical simulation of trough solar collectors, in which the main innovation is to use a code based on Monte Carlo theory to ray trace the solar radiation and combine it with the flow in the collector tube. The results show that the obtained heat flow distribution outside the absorber tube is uniform, and most of the heat flow is distributed in the center of the left area of the absorber tube surface. Ray et al. [6] used computational fluid dynamics (CFD) simulation to study the effect of materials in the annular space between the absorber tube and the glass tube and the materials used. The results show that compared with the original air layer, the vacuum layer can make the collection Heater efficiency is increased by 4.82%; in addition, adding selective coating on the surface of the absorber tube can improve the overall performance of the collector tube by 34.95%. Teles et al. [7] pointed out that the geometric structure analysis of the trough collector plays an important role in determining its thermal efficiency, and proposed a new eccentric geometric structure, and the daily efficiency of the collector was obtained to be 42%~73%. Bellos et al. [8] optimized the intercept parameters of the trough collector, and obtained the optimal focal length and receiver diameter of 50 mm and 34 mm, respectively. Bellos et al. [9] conducted a parametric study on the nanofluid-based bare, vacuum and non-vacuum collectors, and the results showed that the maximum efficiencies of the above cermet-coated collectors were increased by 7.16%, 4.87% and 4.06%. The bending problem of collector tubes induced by thermal stress has always been the focus of research on trough collectors. Yilmaz et al. [10] studied the built-in coils

with different pitches in the absorption tube to solve this problem. Through the numerical simulation of the overall trough collector, it was found that the circumferential temperature of the absorption tube wall tends to be uniform, and the performance of the collector significantly enhanced, the overall heat transfer performance increased to 183%. Most of the above researches are based on the optimization and transformation of the structure of the collector itself. In this paper, the numerical simulation of the trough solar collector is taken as the research object., in order to provide reference for researchers in related fields.

## 2. Trough solar thermal technology

Solar thermal technology is a solar energy utilization method that converts solar energy into thermal energy. The heat generated by the heat collection circuit can be directly coupled to the traditional steam turbine unit. Compared with other renewable energy sources, this is one of the main advantages of solar thermal technology. one. In addition, the overall system of trough solar thermal power generation can fully demonstrate the advantages of heat storage through multi-energy complementation, and can effectively cope with the changing environment with the help of the thermal inertia of the heat transfer medium and the application of the corresponding heat storage technology, and maintain the relative temperature in the thermal cycle system. Stable, not only can continuously and stably output high-grade electric energy, but also achieve large-scale energy storage. The parabolic trough collector is mainly composed of a concentrator and a collector tube, as shown in Figure 1. The collector tubes include absorption tubes and glass tubes, as shown in Figure 2. In a typical conventional collector tube, the outer diameter of the absorber tube is 70 mm, and the outer diameter of the glass tube is 125 mm. The absorption coating attached to the outer surface of the absorption tube is used to complete the conversion of solar energy to thermal energy. Therefore, the coating needs to have a high absorption rate of sunlight, and at the same time, it needs to have a low thermal emissivity to maximize energy collection efficiency. Antonaia et al. [11] prepared a W-Al<sub>2</sub>O<sub>3</sub> multilayer absorber film, which maintained high solar absorptivity and low thermal emissivity at a temperature of 580 °C. Gao et al. [12] of the Chinese Academy of Sciences deposited a ZrC-ZrOx/Al<sub>2</sub>O<sub>3</sub> coating with a tandem layer structure on a stainless steel substrate by sputtering for selective solar light absorption. At 300 °C, the absorptivity of the coating reaches 0.92 and the thermal emissivity is only 0.12.

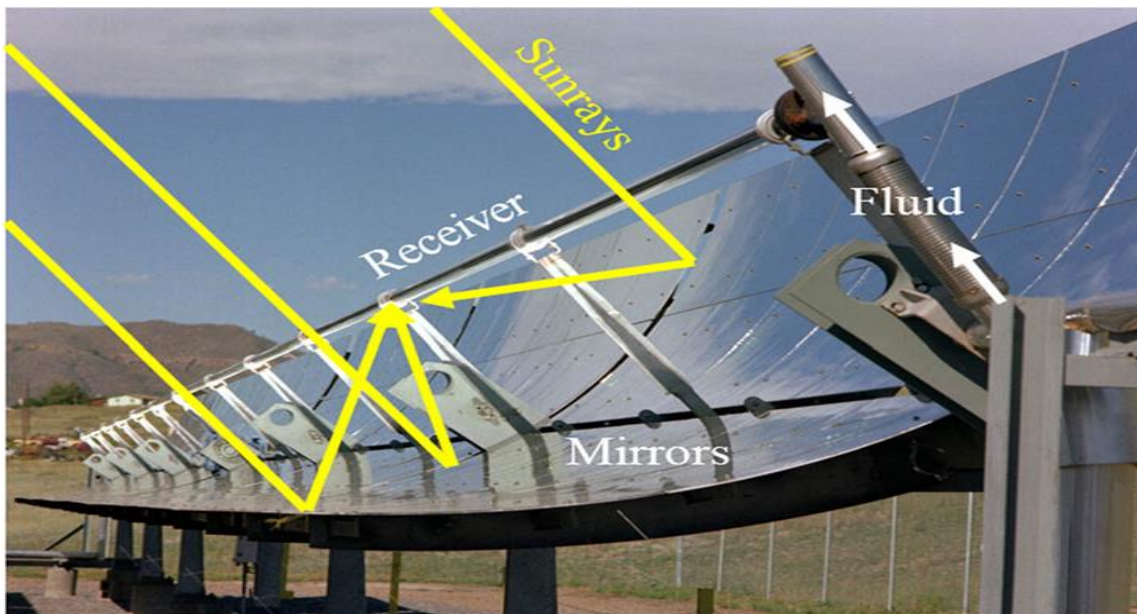
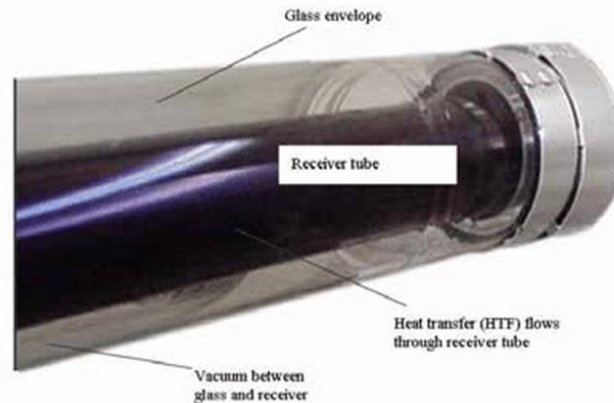


FIGURE 1. - Parabolic trough collector



**FIGURE 2. - Heat collecting element**

The annular vacuum layer between the absorption tube and the glass tube is used to reduce the heat loss, thereby improving the heat collection efficiency. The failure of the vacuum layer will greatly increase the heat loss of the collector. Liu et al. [13] of the China Academy of Aeronautics and Astronautics showed that hydrogen is the main residual gas in the annular vacuum layer. Compared with the collector tube with good vacuum degree, the residual hydrogen will increase the heat loss by more than 4 times. The research of Espinosa-Rueda et al. [14] in Spain showed that after 5 years of operation of the power station, 9% of the collector tubes had vacuum degradation, and the glass-metal seal failure caused by thermal stress was considered to be the main reason for the vacuum failure. Especially due to the comprehensive influence of meteorological conditions, concentrating method, concentrator tracking accuracy, heat transfer medium in the heat collecting tube and other factors, the problems of circumferential temperature difference and thermal stress deformation generated by the heat collecting tube are very serious. The bending deformation of the absorption tube may cause the absorption tube to deviate from the focal line, resulting in loss of optical efficiency, and in severe cases, the glass tube will be bent and broken, resulting in the failure of the vacuum insulation layer. In addition, the concentrator is often located in an open area, the actual wind speed around the mirror field is large, the structural strength of the ultra-thin lens is low, and the natural wind can significantly deform the collector, which may lead to structural failure. Therefore, the light-heat-flow-force coupling analysis of the flow field in the collector tube and the wind load analysis of the flow field outside the concentrator are of great significance for the safe and efficient operation of the trough collector.

### 3. Numerical simulation of the flow field in the collector tube

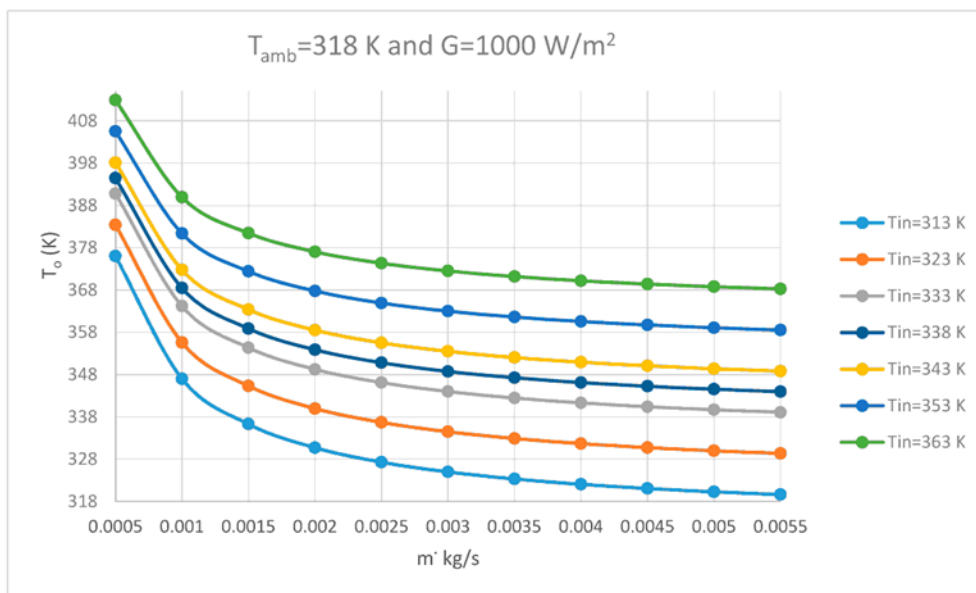
The heat transfer medium in the absorption tube is the key to the heat exchange of the solar thermal technology, and the selection of the heat transfer medium directly affects the heat collection efficiency. At present, the heat transfer media in trough solar thermal technology mainly include molten salt, heat transfer oil, water/steam, air, nanofluid, liquid metal, etc. In the trough type CSP technology, the non-uniform heat flow distribution of the collector tube wall causes the collector tube to present a huge temperature gradient, which is a major problem restricting the trough type CSP technology. In the trough concentrating technology of single-phase medium such as molten salt and heat transfer oil, the huge temperature gradient generated by the collector tube can easily lead to thermal stress deformation of the collector tube. In the water-medium two-phase heat collection loop, this problem is more prominent. In the commercialization process of the CSP technology, it will be urgent to pay more attention to the thermal stress deformation problem in the water-medium trough heat collection technology.

#### 3.1 Heat transfer oil medium

Heat transfer oil has high thermal conductivity and low viscosity, but is easily affected by the upper limit of the temperature of the heat transfer oil medium. When the temperature is high, the heat transfer oil generates hydrogen due to thermal decomposition, which penetrates into the annular vacuum layer through the absorption tube, thereby increasing the heat loss and affecting the heat collection performance. At the same time, the heat transfer oil is flammable, and once it leaks, it is prone to accidents. In addition, the environmental pollution of oil is also worthy of attention. Zhao Qing et al. [15] of Tianjin University used numerical simulation method to study the non-uniform heating characteristics of heat collector tubes under heat transfer oil medium. The results show that: as the fluid inlet temperature increases, the average convective heat transfer coefficient of the tube wall will also increase, and the average friction coefficient of the inner wall of the tube will also increase. decreases; the effect of increasing inlet velocity is consistent with that of increasing temperature. Variations in the loop inlet parameters will have a greater

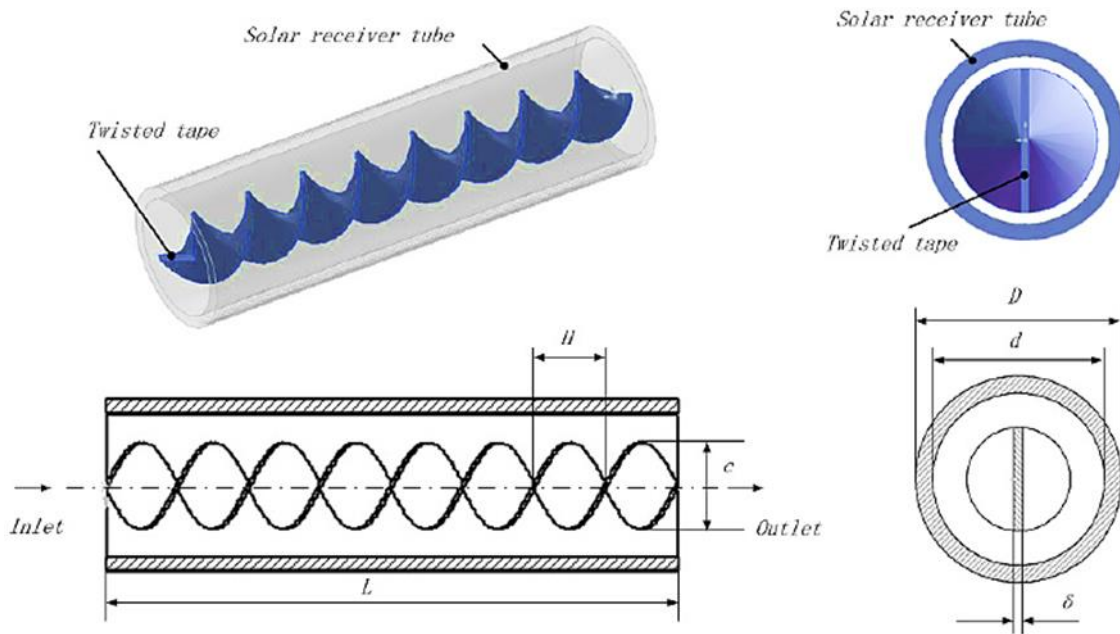
impact on non-uniform heating than uniform heat flow. Wang Jinping [16] of Southeast University conducted a systematic analysis of the trough solar thermal technology of heat transfer oil medium, and the research results showed that: The cosine loss of the incident angle is the main factor affecting the concentrating efficiency of the trough. Taking Qinghai as a typical area, the concentrating efficiency in summer is about 10% higher than that in winter; the thermal efficiency of the collector tube will decrease with the increase of temperature. The established temperature regulation model It can realize dynamic response to changes in the external environment, and the control error of the outlet temperature is  $\pm 1.5$  °C. Chinese Academy of Sciences Lei et al. [17] conducted a numerical simulation analysis on the thermal stress of the collector tube in the heat transfer oil medium, and studied the influence of solar radiation, fluid temperature and velocity on the temperature distribution and thermal stress distribution of the collector tube, including: using Monte Carlo Luo method is used to calculate the non-uniform heat flux density; computational fluid dynamics method is used to calculate the flow heat transfer problem in the heat collector; finite element method (FEM) is used to obtain the stress distribution of the heat collector.

The calculation results show that: the surface of the absorber tube presents a high temperature gradient; low inlet fluid velocity, temperature and high solar radiation will significantly increase the temperature gradient and thermal stress of the absorber tube, which is a huge challenge to the safety of the heat collector tube. Figure 3 shows the effect of temperature and velocity on the maximum temperature difference of the absorber [17].



**FIGURE 3. - Influence of temperature and velocity on the maximum temperature difference of absorber tube**

Mwesigye et al. [18] of Tswane University of Technology in South Africa inserted helical ties with a twist ratio of 0.50~2.00 and a width ratio of 0.53~0.91 (see Figure 4) in the absorption tube for heat transfer enhancement research. The results show that: after inserting the spiral ties, the heat transfer performance of the absorber tube is improved by 169%, the circumferential temperature difference of the tube wall is reduced by 68%, and the thermal efficiency is improved by 10%.



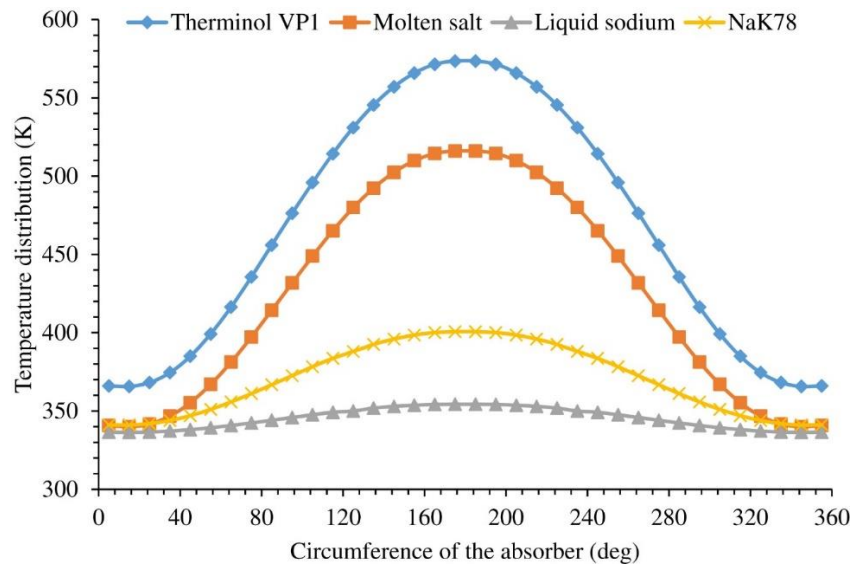
**FIGURE 4. - Schematic diagram of twisted tape inserted in absorber tube**

The National Technical University of Athens Bellos et al. [19] used numerical simulation method to study the enhancement effect of fins on the heat transfer performance of the absorber tube. The fin distribution inside the absorber tube is shown in Figure 5. The research results show that the heat transfer enhancement increases with the increase of the length and width of the fins, but it will also bring greater resistance; in the case of the length of the fins of 10 mm and the width of 2 mm, the absorption tube shows the best performance. Excellent performance improvement, i.e. thermal efficiency increased by 0.82% and Nusselt number increased by 65.8%.

### 3.2 Molten salt medium

Molten salt can operate at a higher temperature, and at the same time, molten salt can also be directly used for heat storage to generate electricity at night, thereby improving the stability of the solar thermal power generation system and reducing the impact on the power grid. However, because the CSP station is affected by the temperature difference between day and night, the molten salt medium will face the problem of freezing point. Necessary thermal protection measures must be taken at night or in winter to prevent the molten salt medium from solidifying in the collector tube. At the same time, the low-temperature solidification characteristics will also accelerate the wear, aging and even damage of the collector tubes, and the increase of thermal insulation and antifreeze equipment will increase the cost, such as greater pump power consumption and investment in auxiliary heating equipment. In addition, the corrosion problem of molten salt on pipelines also requires an effective solution. Wang et al. [20] of the Chinese Academy of Sciences established a three-dimensional model considering the processes of radiation, conduction, and convection coupled heat transfer for the molten salt trough heat collector system using numerical simulation methods, and focused on the analysis and comparison of the changes of key operating parameters on the system heat collection. performance impact.

The results show that under the conditions of inlet velocity of 4 m/s, inlet temperature of 825 K, and direct normal irradiance (DNI) of 1 250 W/m<sup>2</sup>, the maximum temperature difference of the absorption tube can reach 42 K. The temperature change curve of the absorption tube wall under different solar radiation conditions is shown in Figure 6 [20].



**FIGURE 5. - Temperature variation curve of absorber tube wall under different radiation conditions**

Wang Yanjuan [21] conducted a light-thermal-force multi-physics coupling study on trough solar thermal technology. The results show that under non-uniform heat flow, the maximum temperature difference of the absorption tube can reach 94 K, and the maximum stress can reach 110 MPa. At the same time, when one end of the absorption tube is constrained, the axial elongation of the absorption tube can reach 10 mm. By comparing the calculation results of different media, it can be seen that the temperature distribution of the heat transfer oil medium is more uneven than that of the molten salt medium, resulting in greater thermal stress deformation.

### 3.3 Water/steam medium

The use of an aqueous medium means that the collector loop will directly generate high-temperature steam, which uses the same fluid as the downstream steam-Rankine cycle, eliminating the need for investment in intermediate heat exchange equipment, thus reducing the cost and complexity of solar thermal power plants. Although the water medium has many advantages, the gas-liquid two-phase flow problem caused by the water medium cannot be ignored either. The complex flow pattern transitions in the heat collection circuit, including bubble flow, slug flow, stratified flow and annular flow, will affect the heat transfer characteristics of the absorber. The difference of gas-liquid heat transfer coefficient superimposes the variation of non-uniform heat flow density caused by the deflection of the concentrator outside the tube, which leads to uneven heating of the heat collector tube wall, resulting in a huge temperature gradient and thermal stress deformation. Therefore, it is of great significance to study the water-medium trough heat collector circuit to ensure better controllability of the technology and to enhance heat exchange to reduce the circumferential temperature difference of the collector tubes. In addition, the lack of suitable energy storage for CSP plants using solar direct steam generation (DSG) technology is also a potential obstacle to their commercialization. Spain Roldán et al. [22] carried out numerical simulation analysis on the heat transfer performance of the absorber tube in superheated steam medium. In this study, a 4.06 m long absorber tube model was established by using the real non-uniform heat flux density boundary using Fluent software, and the calculation results were calculated. Compared with the experimental results. The results show that the simulation results are in good agreement with the experimental results, and the numerical model can be used to analyze the temperature field distribution under different working conditions and collector tube parameters. Li et al. [23] of Xi'an Jiaotong University first used the two-dimensional finite volume method to calculate the temperature distribution of the absorber tube, and then used the three-dimensional finite element method to obtain the thermal stress deformation data of the absorber tube. The research results show that the superheating section bears high thermal load, and the two-phase section will produce large thermal stress deformation due to the appearance of stratified flow. Under the pressure of 4 MPa, the deflection of the absorption tube can reach 2.05 cm. Different deflection angles of the concentrator under stratified flow lead to different temperature distributions in the heat collection circuit, as shown in Figure 7 [23].

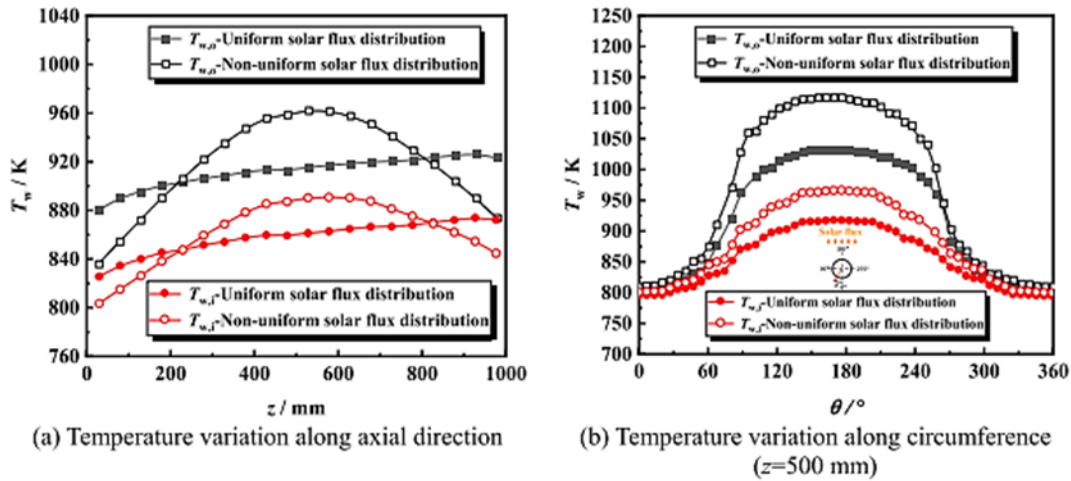


FIGURE 6. - Temperature distribution of heat collecting loop under stratified flow

Hachicha et al. [24] conducted thermodynamic analysis and numerical simulation of the water-medium trough collector circuit, and the established optical model and thermodynamic model will be used to predict the steam generation process under real working conditions. At the same time, the heat collection efficiency of the loop under different working conditions can be evaluated. The research results show that the temperature distribution trend is consistent with the distribution trend of concentrated non-uniform heat flux density; the collector tube in the superheating section presents a high temperature gradient, which has the risk of thermal bending damage. In addition, the increase of the inlet pressure will increase the proportion of the preheating section and reduce the proportion of the two-phase section; the increase of the inlet temperature will increase the thermal gradient of the collector tube in the superheating section. Wang et al. [25] of Xi'an Jiaotong University established a cross-dimensional multi-physics coupling analysis method for the water-medium heat collector loop to analyze the non-uniform temperature field distribution and thermal stress deformation of the collector tube. The results of typical operating conditions show that the temperature field distribution of the absorption tube varies greatly under different flow patterns. As shown in Figure 8 [25], the heat load in the superheated section is the highest, and the temperature at the top of the absorption tube is higher than that at the bottom under stratified flow, resulting in the absorption tube in the separation. The bending in the opposite direction occurs under laminar flow.

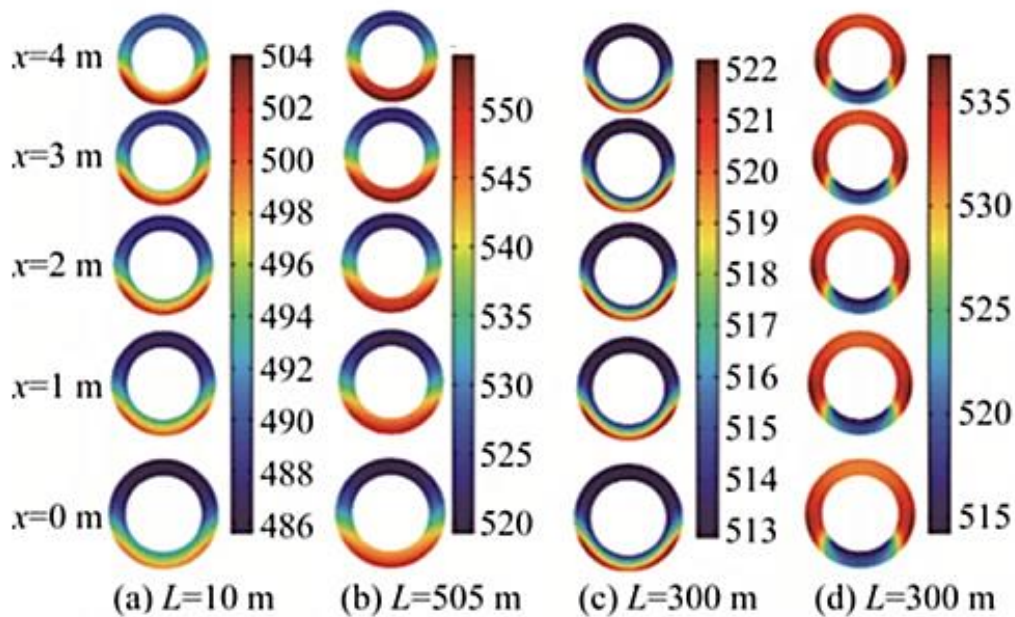


FIGURE 7. - Temperature distribution of absorber tube under different flow patterns

### 3.4 Nanofluidic media

The research of nanofluids focuses on the improvement of heat transfer performance. The usual practice is to add nanoparticles with high thermal conductivity into the base fluid, so as to obtain higher heat transfer efficiency. However, the addition of high-concentration nanoparticles will increase the viscosity of the medium, thereby increasing the cost of pump power consumption, and also facing the problem of nanoparticle deposition. In addition, the particle size of nanoparticles and the effect of additives on performance are also the focus of research. Mwesigye et al. [26] of Tswane University of Technology in South Africa studied the heat transfer performance when Al<sub>2</sub>O<sub>3</sub> particles were added to heat transfer oil by numerical simulation method. The volume fraction of nanoparticles studied was 0~8%. It can improve the heat transfer performance by 76%. The thermal efficiency formula obtained by balancing the heat transfer performance improvement and the pump power consumption shows that the thermal efficiency can be improved by 7.6% at the lowest temperature and lowest flow rate. Hachicha et al. [27] of the University of Sharjah in the United Arab Emirates studied the effect of suspended industrial-grade multi-walled carbon nanotubes in aqueous medium on the heat collection performance by establishing a one-dimensional numerical simulation model. The results show that the nanotubes enhance the turbulent mixing intensity, and the heat collection efficiency increases with the increase of the volume flow rate. When the mass fraction of nanoparticles is 0.05%, 0.1% and 0.3%, the Nusselt number of the suspension can be increased correspondingly. 12%, 16% and 21%. At higher flow rates, the nanofluid concentration should be increased for better heat transfer, but also inevitably increases the pressure drop. Allouhi et al. [28] proposed a one-dimensional mathematical model to study the effect of nanoparticles on the thermal performance of medium and high temperature trough collector technology. The results show that the high temperature circuit is more suitable for using nanofluids and produces higher relative gains in energy transfer; under the research conditions, when heat transfer oil is used as the base fluid, the addition of CuO, TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> can increase the thermal efficiency by 1.06% and 1.14%, respectively. % and 1.17%.

Minea et al. [29] studied the effect of mixed nanoparticles in the trough heat collector system, and the results showed that compared with the base liquid, the Al<sub>2</sub>O<sub>3</sub>-Cu mixed nanofluid decreased the thermal conductivity due to the excessive increase of the dynamic viscosity. Thermal properties; the average Nusselt number increased by 14% at a volume fraction of 2% for the Cu-MgO mixture.

### 3.5 Other heat transfer media

Gaseous media (such as CO<sub>2</sub>, air, etc.) can work at higher temperatures while bringing lower operating costs. However, the heat capacity of the gas medium is poor, and it is often necessary to increase the thermal efficiency through pressurization and larger flow rate, which undoubtedly further increases the operating cost. At the same time, the higher pressure puts forward higher requirements on the structural performance of the heat collector. Good et al. [30] of the Swiss Federal Institute of Technology in Zurich established a 1.2 MW trough collector system with air as the heat transfer medium.

The collector loop is 212 m long and is used to produce heat transfer fluid at 500 °C. The experimental results show that the corresponding numerical simulation results are in good agreement with the experimental results, and the average absolute deviation of the temperature is 7.3 °C. Finally, with an annual solar radiation of 2 400 kW.h/m<sup>2</sup>, the power plant can provide 1 810 MW.h of thermal energy.

Using the supercritical CO<sub>2</sub> cycle to improve the performance of the line focusing solar thermal system through multi-stage compression, the fluid heat capacity is significantly increased at the critical point, which greatly improves the cycle efficiency. If air is directly used as the heat transfer medium, the fluid cost is directly reduced.

Qiu et al. [31] of Xi'an Jiaotong University studied the thermal performance of supercritical CO<sub>2</sub> in a trough collector, and the results showed that the circumferential temperature difference decreases with the increase of the inlet velocity or the decrease of the inlet temperature, and the maximum temperature difference can reach 60 K. Under typical operating conditions, the Brayton cycle efficiency with supercritical CO<sub>2</sub> as the medium is 18.75%-84.17%, and the Rankine cycle efficiency is 81.93%-84.17%.

The research results provide a reference for the design of trough power plants using supercritical CO<sub>2</sub> as the heat transfer medium. The high performance of liquid metal (including high thermal conductivity, low air pressure, relatively low viscosity and high working temperature) has also received widespread attention, but liquid metal is expensive, and the cost problem cannot be ignored. Efficiency improvement when fluid.

Wu Minqiang from the University of Science and Technology of China [32] designed a new type of heat collector tube structure with liquid lead-bismuth alloy as the heat transfer medium, and studied the influence of key parameters such as environmental conditions and outlet temperature on the heat collector performance.

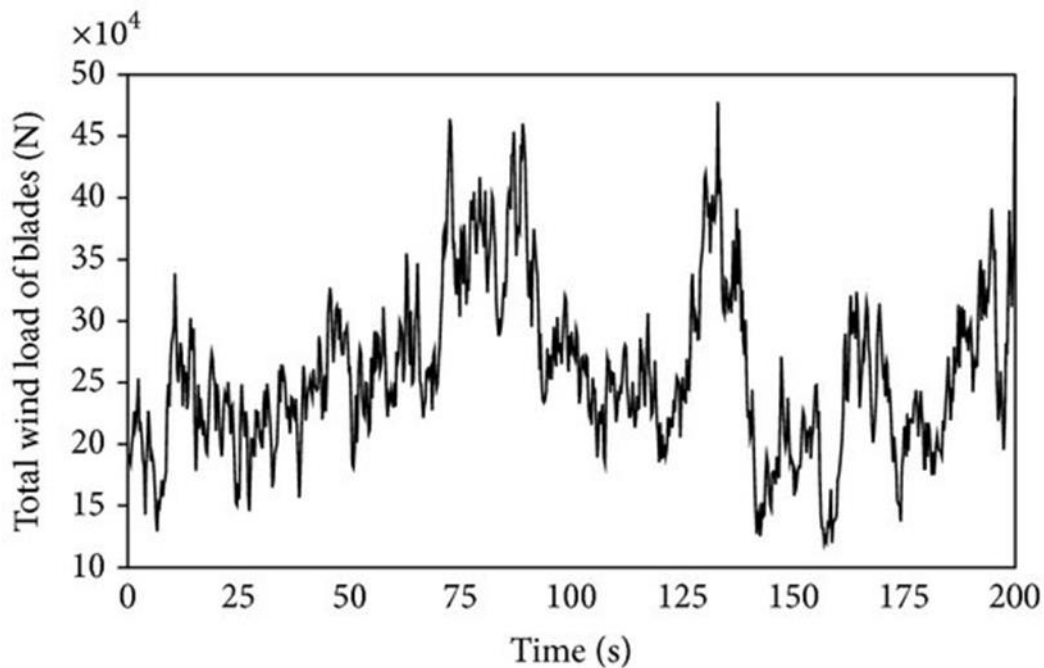
The research results show that compared with molten salt and heat transfer oil medium, the heat collection efficiency of liquid lead-bismuth alloy medium is increased by 4.24% and 6.03% respectively; The energy loss difference reaches 448.25 W/m. Compared with the molten salt medium, the annual power generation efficiency of the 50 MW trough CSP system designed based on the liquid lead-bismuth alloy medium is increased by 2.21%.



## 4. Numerical simulation of the outer flow field of the concentrator

### 4.1 Influence of concentrator wind load

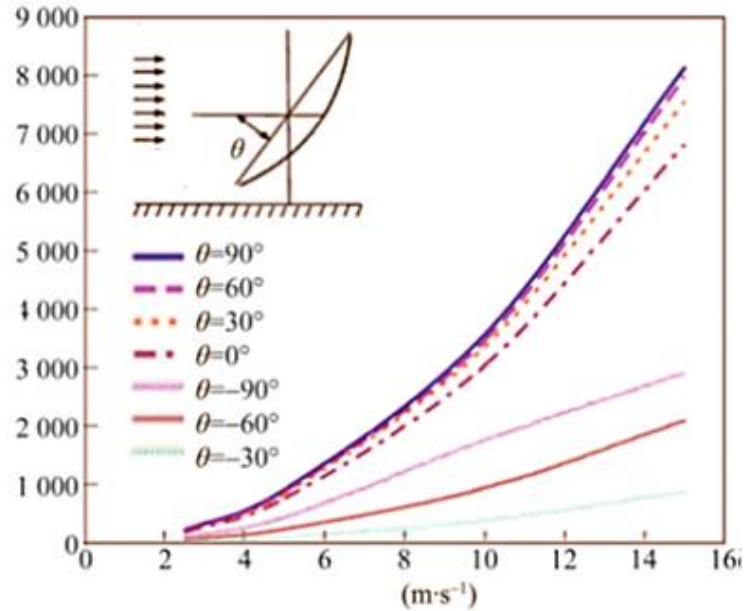
In actual operation, the trough condenser is affected by natural conditions such as natural wind, dust accumulation, cloudy weather, etc., especially the natural wind. Since the mirror field of the trough condenser is generally installed in an open area, the natural wind speed is relatively large, while the condenser itself uses ultra-thin lenses, and the structural strength is not high, so it is very sensitive to natural wind. According to the variation curve of the mirror field wind speed measured by the Institute of Electrical Engineering of the Chinese Academy of Sciences (see Figure 9)[33], the natural wind speed of the mirror field is mainly concentrated in 6~14 m/s, and the fluctuation is violent, which will cause deformation and oscillation of the mirror due to wind load. Under the action of a specific strong wind, the trough collector structure may even fail, which directly affects the normal operation of the entire CSP station. Although the safe wind speed range of the current trough collector design is 0~14 m/s, the violently fluctuating wind load still has a serious impact in actual operation. The deformation of the lens will affect the optical path of sunlight, and the deviation of the light during the concentrating process will directly lead to the loss of optical efficiency. Therefore, this paper will focus on the study of the wind-borne deformation of the concentrator in the research of the outer flow field of the concentrator.



**FIGURE 8. - Measured wind speed variation curve**

### 4.2 Wind load of traditional trough collector

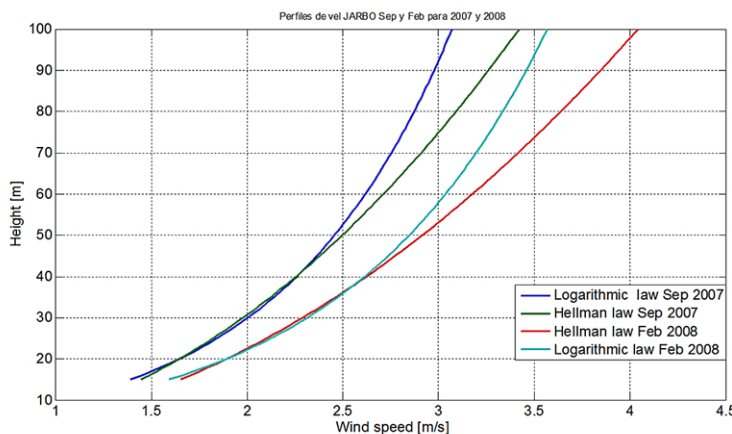
The earliest wind load research originated from the wind tunnel test of Sandia National Laboratory in the United States in 1980. These early wind tunnel tests and field measurements have provided valuable guidance for the construction of mirror fields and are of great significance. However, these methods inevitably have limitations. The test cycle is long and the cost is high. When the geometric conditions, terrain, wind speed, etc. change, a large number of repeated tests must be carried out, so the test is very complicated and cumbersome. Since the beginning of the 21st century, the simulation computing technology has developed rapidly. Because the simulation method can easily impose the same Reynolds number as the actual mirror field, and save a lot of time and cost, it has become a new method for many scholars to study the wind load problem. Naeeni et al. [34] simulated the two-dimensional flow field of the trough collector under different tracking orientations, and obtained the wind load variation curves under different wind speeds and orientations, as shown in Figure 10.



**FIGURE 9. - Variation curve of wind speed and wind load at different orientations**

Zemler et al. [35] conducted two-dimensional turbulence calculations for a single trough collector unit, and studied the effects of wind speed, opening width, and collector tracking orientation on wind load. Paerzold et al. [36] conducted a three-dimensional simulation of the trough collector based on ANSYS under different Nusselt numbers, and obtained the lift and drag coefficients under different tracking azimuths.

The above studies are based on the Reynolds-averaged Navier-Stokes (RANS) model, which is more computationally efficient than large eddy simulation (LES), but LES can evaluate the peak value of the trough collector. Load and Aeroelastic Response [37]. Hachicha et al. [38] established an aeroelasticity and heat transfer model based on LES for the first time, and verified the correctness of the model by calculating a flow around a cylinder. The aeroelastic coefficient calculated by LES was consistent with the wind tunnel test results. Mier-Torrecilla et al. [39] carried out a comparative study between wind tunnel test and CFD, and found that the average relative error of the two was about 10%, which verified the correctness of CFD calculation. Andre et al. [40] used the Lattice-Boltzmann method (LBM) and the finite element method to evaluate the wind load of the trough collector, and found that the two simulation methods obtained similar lift and drag forces. The results show that the simulation calculation has nothing to do with the selected simulation method, and the results of the wind tunnel test can be repeated. Zhang et al. [41] of Xi'an Jiaotong University established a three-dimensional transient model of fluid mechanics-elasticity-geometric optics for the first time by using the multi-physics coupling analysis method to study the effect of wind-loaded deformation on the optical efficiency of trough collectors. The results show that the opening orientation of the concentrator obviously affects the flow field and deformation, and the maximum displacement increases with the increase of wind speed. At 38° opening, the effect of wind speed on deformation and loss of optical efficiency is shown in Fig. 11 [41].



**FIGURE 10. - Influence of wind speed on deformation and optical efficiency loss at 38°**

### 4.3 Wind load of large opening trough collector

Although the large opening trough collector is the most promising new generation trough collector, it is also worthy of attention on the wind load problem. The wind load problem is exacerbated by the enlarged opening width. The large opening trough collector is a new type of collector, and the related wind load research is rarely reported. In the design stage of the large opening slot, in order to reduce the wind load, a large number of wind tunnel tests were carried out. It was found that compared with the torque tube structure, the torque box design structure can reduce the torque load by 5% and the horizontal wind load by 10%. In addition, the staggered gap between the inner and outer mirrors can reduce the wind load by more than 30% [42]. Winkelmann et al. [43] conducted a series of wind tunnel tests on a trough collector with an opening width of 10 m, and obtained the pressure and wind load coefficients at different tracking azimuths and different wind directions. The current wind load research mainly focuses on the traditional trough collector, however, the wind load analysis is of great significance to its safe operation. Therefore, the wind load research on the large opening trough collector is very important.

## 5. Conclusion

In the field of flow field research in the collector tube, in the heat transfer oil and molten salt circuits dominated by single-phase medium, the focus of numerical simulation research is still on the uneven temperature field distribution of the collector tube wall and the corresponding thermal stress deformation analysis. In the two-phase heat collecting circuit with water/steam as the medium, the change of gas-liquid flow pattern and the difference of heat transfer coefficient aggravate the circumferential temperature difference of the heat collecting tube wall, the risk of thermal stress bending deformation is greater, and the control of the circuit is increased. difficulty. In other heat transfer medium heat collection circuits, the heat collection tubes should have higher structural strength to meet the safety requirements of the pressurized air circuit. In addition, there should be an effective balance between the increase in heat collection efficiency and the increase in cost brought about by the addition of nanoparticles.

In the research field of the outer flow field of the concentrator, the loss of optical efficiency caused by the wind-borne deformation of the concentrator cannot be ignored. The wind load research of traditional trough collectors only focuses on the characteristics of the flow field, and the structural parameters are unreasonable, and the loss of optical efficiency is not included in the research scope. The wind load analysis of the new generation of large opening trough collectors is less. In the future, through more abundant wind-load deformation research, it is a more scientific evaluation index to evaluate the wind resistance performance of the trough collector by the reduction of the loss of concentrating efficiency caused by the wind-load deformation.

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## CONFLICTS OF INTEREST

The authors declare no conflict of interest

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